The Southeastern Drought and Wildfires of 2016

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http://www.sercc.com/NIDISDroughtAssessmentFINAL.pdf

EXECUTIVE SUMMARY

The exceptional drought and associated wildfires across the interior Southeast United States in 2016 greatly impacted the sectors of agriculture, water resources, public health, and tourism. In the first chapter of this report, we examine the history of droughts across the region and describe how the 2016 drought developed and evolved over the course of the year. In chapters 2 and 3, we describe the impacts of the drought in the sectors of agriculture and water resources, respectively. In chapter 4, we examine the wildfires that developed and the multiple factors that contributed to their extremeness with a focus on the Gatlinburg, Tennessee inferno. In chapters 5 and 6, we examine the impacts of the drought in public health and tourism, respectively. In each chapter of the report, we offer a background section that provides a foundation and context for understanding both the direct and indirect impacts of the drought.

The findings of our report are summarized below:

Chapter 1: Drought Evolution and Historical Context

- The drought began in March 2016, reached its maximum intensity and spatial coverage in late November of 2016, and ended in March 2017.

- The drought contributed to an increasing trend in drought occurrence that has been observed over the last 30–40 years (1980 to present). Longer droughts (e.g., much of the 1950's) and more severe droughts (e.g., 1927), however, occurred across the Southeast earlier in the 20th century.

- The core of the drought region covered northern Georgia and Alabama, western North Carolina, eastern Tennessee, and northwestern South Carolina.

- While high precipitation deficits caused the drought, increased evaporation rates driven by warmer than normal temperatures increased its intensity. This was especially the case during the fall when widespread record dryness and warmth was observed.

- The drought stood out relative to other droughts in terms of its duration (only 12 months) and the presence of exceptionally wet conditions immediately before the drought (winter 2015–2016) and after the drought (winter–spring 2016–2017).

Chapter 2: Agricultural Impacts

- Agriculture, a primary, multi-billion dollar industry in every Southeastern state, was significantly impacted by the drought. Yields on many crops were reduced, sometimes to the point of being of no net value after inputs like fuel and agricultural chemicals were factored in.

- Corn production was especially affected in the core region of eastern Tennessee, northwestern Georgia and northeastern Alabama during the spring phase of the drought.

- Animal feed, including forage and pasture, was reduced significantly across the core region of the drought during the spring and fall phases of the drought.

- Small grains (e.g., oats, rye, and wheat) were either planted late or not all during the exceptionally dry, fall phase of the drought.

- There were two benefits of the drought on agriculture:

    - Some crops experienced less pressure from fungal diseases and insect pests than normal, reducing the need for the application of agricultural chemicals such as fungicides and pesticides.

    - The exceptionally dry conditions during the fall phase of the drought provided favorable conditions for the harvest of many crops such as cotton and peanuts.

- Various lessons were learned from the agricultural impacts of the drought, including the following:

    - Because every crop responds uniquely to dry conditions at different stages of crop development, feedback from a more diverse group of agricultural producers and extension agents would benefit drought impact reporting.

    - Better communication of worsening drought conditions could help alert producers to impending impacts.

Chapter 3: Water Resources

- Stream discharges were severely impacted by the drought, with various streams (e.g., Chattahoochee River basin in Georgia) reaching record low levels in October and November 2016.

- Reservoir levels dropped more slowly due both to the storage of heavy rainfall that occurred prior to the drought and effective management by reservoir operators. Impacts on water supplies were therefore relatively limited, especially in the bigger reservoirs.

- Because of restricted releases of water from the reservoirs, the amount of water available for hydropower production was greatly reduced. Hydroelectric power generation from Buford Dam on Lake Lanier north of Atlanta, Georgia, for example, was less than 35% of the ten year average from January through May 2017.

- Groundwater levels dropped the slowest, and consequently impacts were minimal (e.g., there were only scattered reports of wells drying up in the core of the drought region).

Chapter 4: Wildfires

- Exceptionally dry and warm conditions during the fall set the stage for numerous large wildfires in the southern Appalachian Mountains (SAM) in late October through November 2016 that required an extraordinary amount of time and resources to contain.

- Extremely dry and aerated leaf litter from the fall leaf fall provided ample fuel for the fires, which was supplemented in many places by extra fuel in the underlying duff layer.

- Besides the extreme dryness, various factors conspired to make the wildfire outbreak extraordinary, including the following:

    - Frequent ignitions by arsonists.

    - Difficulties in containing the wildfires due, among other things, to their occurrence in difficult to reach areas of the SAM (e.g., steep terrain, remote locations).

- Most of the wildfires spread slowly as the winds on most days were relatively light. Consequently, they did not present an imminent threat to life and property.

- The Gatlinburg, Tennessee wind-driven wildfire, in contrast, killed 14 people, injured another 134, and destroyed over 2,400 structures. It provides a vivid illustration of what can happen in communities on the wildland-urban interface when high winds occur in the presence of extreme drought.

Chapter 5: Public Health

- The public health impacts of the 2016 Southeast U.S. drought identified in this assessment were attributed solely to the drought-induced wildfires in the southern Appalachian Mountains.

- All of the deaths and injuries from the wildfires were associated with the Gatlinburg inferno, except for one firefighting death in Kentucky and one death in a chain-reaction vehicular collision in Kentucky, which was attributed to dense wildfire smoke.

- High wildfire smoke concentrations occurred in areas tens to more than hundred miles downwind of the fires. Media reports suggest that the wildfire smoke was responsible for emergency room visits for respiratory issues, especially asthma, though a pilot research study failed to identify a significant relationship between wildfire smoke and emergency room visits in several counties across North Carolina.

- Public officials, in some cases, had difficulty translating information from the air quality alerts (from wildfire smoke) into decisions on whether or not to curtail or cancel outdoor events and activities.

Chapter 6: Tourism

- Wildfire damage to tourist venues was limited to Gatlinburg, Tennessee, where (e.g., 2,400 structures were destroyed with more than a billion dollars in damages). A wildfire next to the tourist hamlet of Lake Lure, North Carolina during the height of the tourist season did not burn any building structures but led to the evacuation of more than 1,000 residents.

- Tourism losses in Gatlinburg and Lake Lure were tied partially to significant reductions in visitation in the months following the fires due to exaggerated negative perceptions of the magnitude and extent wildfire damage.

- The occurrence of numerous warm and sunny days during the drought encouraged people to travel and contributed, along with other factors, to record-setting tourism revenues across the region.

Chapter 1. Evolution of the 2016 Drought and Its Historical Context

1.1. Introduction

Droughts in their most basic state are a restriction in the availability of water necessary for public supplies, businesses, agriculture, and maintenance of ecosystem health. The limited water that is available in a drought can cause disruptions in commerce, restrict use by businesses and municipalities, and cause health impacts which can harm humans and animals as well as the natural world. Droughts can also have secondary effects such as wildfires that cause additional damage to timber, properties, and the health of residents in affected areas. While droughts cause negative impacts on society as well as ecosystems, they are a natural part of the water cycle in many parts of the world. In fact, droughts also have positive impacts on many aspects of life, including an abundance of sunny, dry days which allow outdoor activities to occur, including construction and tourism. In the Southeast, many natural systems depend on the regular occurrence of drought to allow some plant species to reproduce and move through their natural life cycles. Droughts also reduce the number of pests and invasive species by depriving them of water.

The 2016 drought in the Southeast was a relatively brief event lasting only a year, which is shorter than many previous droughts that have occurred in the region. But it significantly impacted several economic sectors of importance in the Southeast, including agriculture, tourism, and human health. Water supplies were also restricted in some areas and led to low levels of reservoirs and streamflows; this affected the ability of municipalities and federal agencies to provide water and hydropower energy for their citizens.

In section 1.2, the climatology of recent Southeastern droughts will place the 2016 drought in historical context, showing the nature and impact of those droughts in the region. Section 1.3 will describe the development and evolution of the 2016 drought in terms of its portrayal in the National Drought Monitor. Four seasons of the drought are identified, each with distinctive characteristics. Section 1.4 will describe the nature and timing of precipitation across the region and how it contributed to the dry conditions that accelerated the drought's growth, and section 1.5 will incorporate the impacts of the extremely warm temperatures that further reduced the availability of water and dryness that set the stage for the wildfires that scorched parts of the region during the fall. Section 1.6 will discuss the larger-scale causes of the drought and section 1.7 will conclude this chapter by describing how the 2016 drought was unique compared to other historical droughts that have occurred in the Southeast.

1.2. Historical Drought in the Region

The frequency of droughts in the Southeast has increased after a relatively moist period with few droughts in the 1960s and 1970s, when temperatures were also cooler and year to year variability of rainfall was lower than in other periods. The most extreme drought in the Southeast occurred in 1927[1], though there have been several droughts over the years with comparable intensities, including the 2007 drought (Fig. 1.1). The 1950's were also noteworthy for being in near continuous drought. More recent droughts, since approximately 1998, have reached lower Palmer Drought Severity Index values than all but the 1927 drought[2].

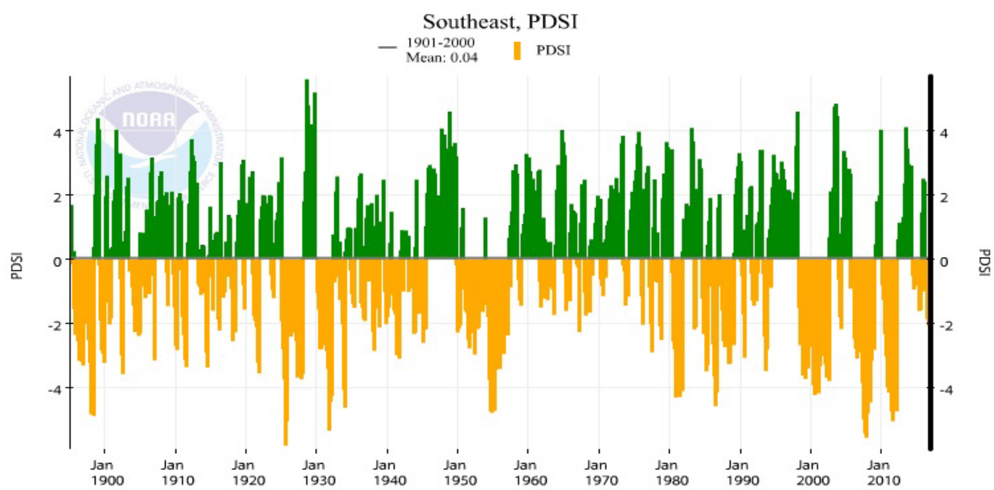

Figure 1.1. Monthly Palmer Drought Severity Index values for the Southeast from 1895 to the present. Green (positive) periods are relatively wet and drought-free, while yellow (negative) values indicate periods of drought, with lower values representing more extreme drought conditions[3].

Over the last two decades, drought has waxed and waned across the Southeast, ranging from no drought at all to over 80% covered by drought in fall 2007 (Figure 1.2)[4]. Each drought had a unique pattern of development and maximum intensity and a different area of maximum impact. Three exceptional droughts occurred during that time period prior to the 2016 drought:

- The 1998–2002 drought was exceptionally long; it began in southern Georgia with a core region of extreme drought that expanded into southern Alabama, Florida, western North Carolina and South Carolina in 2000, nearly disappeared in the summer of 2001 but returned to the Carolinas in winter 2001–2002 before ending in December 2002.

- The 2007–2009 drought covered most of the same area as the 2016 drought. It began in spring 2007 in northern Alabama and spread rapidly in summer 2007 to cover most of the Southeast and was accompanied by record-setting high temperatures. It re-strengthened in summer 2008, reaching exceptional drought status in western North and South Carolina before finally ending in spring 2009[5].

- The 2011–2013 drought, which impacted central and southern Georgia and Alabama and the Florida Panhandle beginning in spring 2011. This drought had little impact on the areas hit hardest by the 2016 drought, which may have allowed vegetation and leaf litter to accumulate in areas later hit by wildfires in 2016[6].

While each Southeastern drought had unique aspects of location, areal coverage and timing, the Southeast as a whole is a favored region in the United States for drought, with the core area, as represented by the PHDI, clustered in a region that extends from interior Alabama, Georgia, and western South Carolina[7]. This may be related to the general atmospheric patterns that lead to drought in the Southeast, especially the position of the Bermuda high which causes subsidence over the region when it expands westward across the region in summer[8].

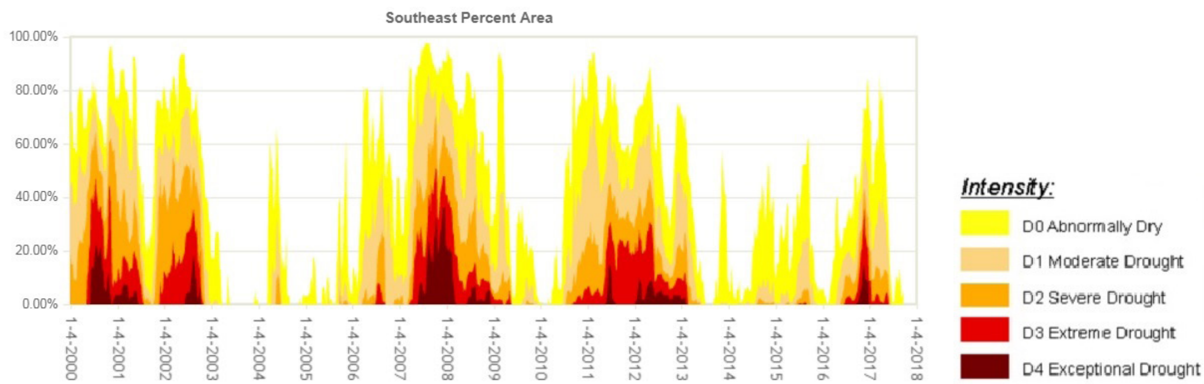

Figure 1.2. Timeline of drought in the Southeast by intensity from 2000 to present[9].

1.3. Evolution of the 2016 Drought

The 2016 drought began in mid-March 2016 as an area of abnormally dry conditions, stretching from the northeast Georgia Mountains to central North Carolina (Figure 1.3) and gradually intensified over the next few months[10]. The area of drought continued to expand through the summer as the driest area shifted to northwest Georgia and northeast Alabama. The driest conditions of the drought were observed in October and November and set the stage for the ignition of numerous wildfires in the area. The drought began to ebb at the end of November as heavy precipitation fell across the northern portions of the drought-stricken area. However, above normal temperatures and lower than normal precipitation over the core part of the drought-stricken region lead to the continuation of hydrological drought into spring 2017. The final removal of drought in the main target area did not occur until late spring 2017, while a new area of drought developed in southern Georgia.

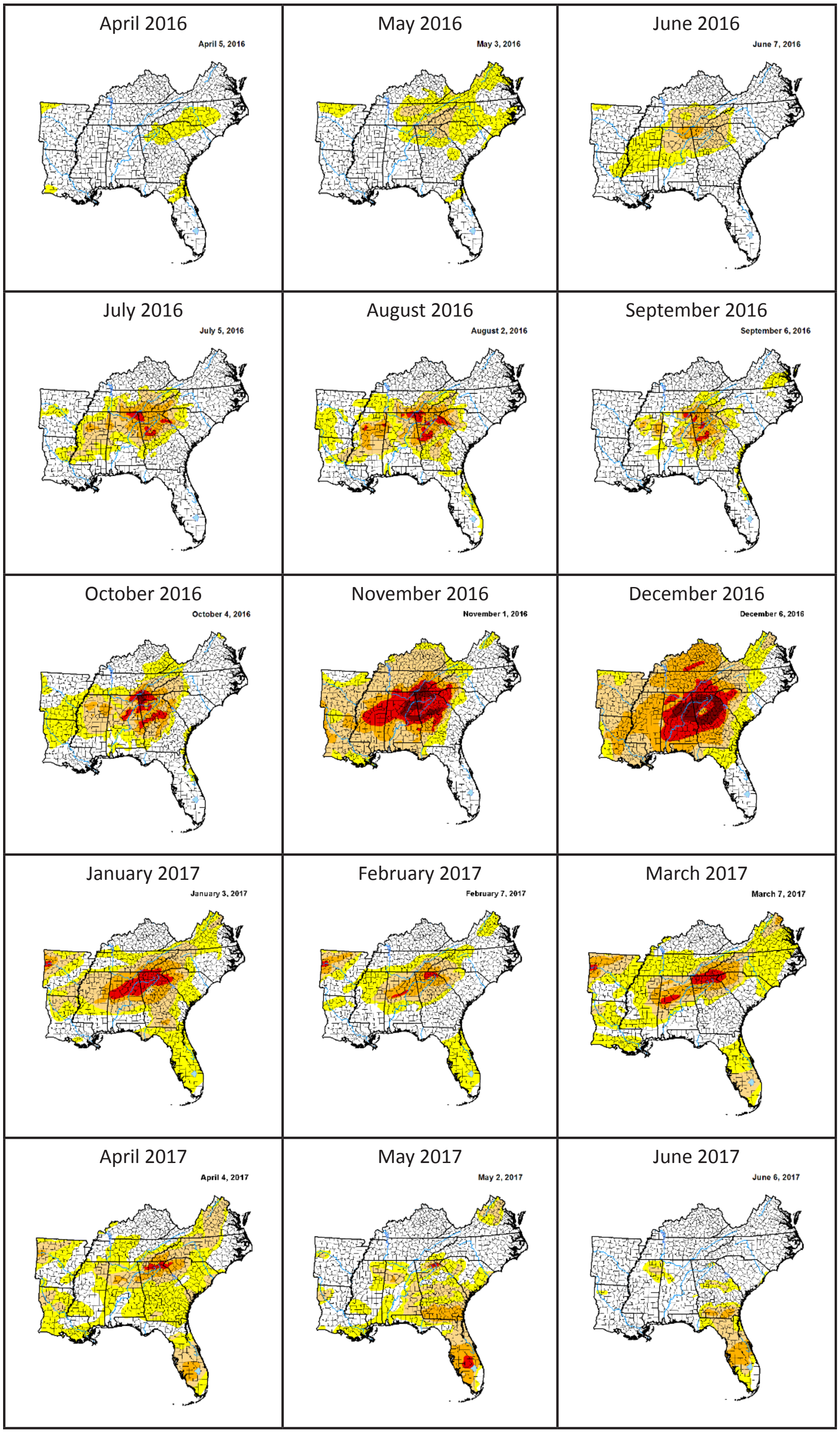

Figure 1.3. Time evolution of drought as revealed by early month Drought Monitor maps across the Southeast. The color intensity key is the same as in Figure 1.2.

The 2016 drought lasted roughly one year and can be broken into four phases that correspond roughly with the seasons (Fig. 1.4). Each seasonal phase (spring, summer, fall, winter) displayed a distinct character and unique impacts across different economic sectors (Table 1.1). The winter or last phase of the drought included a protracted period of recovery that stretched through the spring of 2017 (Fig. 1.3). Note that a new drought began in Florida in February 2017 and expanded into southern Georgia; it was responsible for most of the drought coverage shown in February 2017 in Figure 1.4.

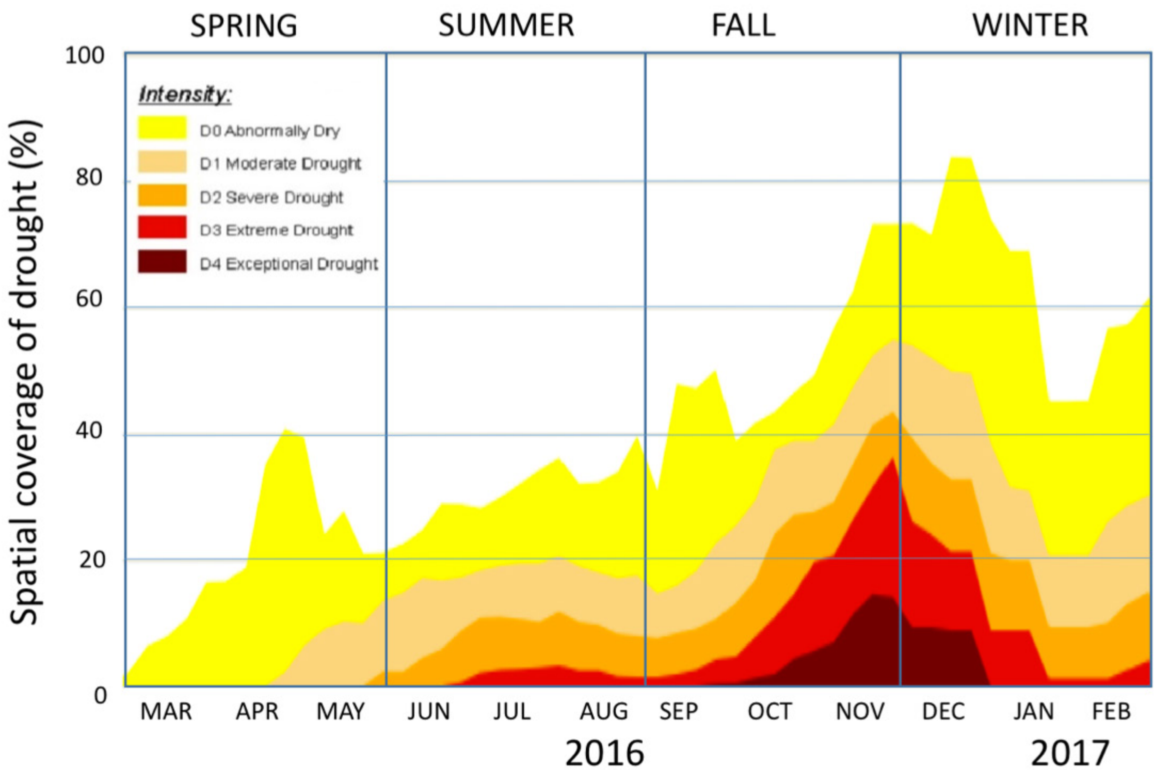

Figure 1.4. Time evolution of the spatial coverage of drought (percent area) in the Southeast, as defined by the Drought Monitor[11].

Phase	Time period	Drought intensity coverage from National Drought Monitor	Locations of highest drought category from the Drought Monitor	Major impacts during this phase
Spring	March-early June 2016	Moderate to severe	Northeast AL, northern GA, west and central TN, western NC and SC	Pastures and corn production in northwest GA and northeast AL
Summer	June through August 2016	Mostly severe drought with isolated pockets of extreme drought	Northern GA and northeast AL	Stream flows and reservoir levels across drought region, isolated groundwater levels, agricultural impacts mostly positive in irrigated fields but continuing problems with dryland farms and pastures, low disease pressure on crops
Fall	September through November 2016	Drought rapidly expanded to exceptional conditions across a wide area	Exceptional conditions in northern GA and northeast AL with extreme conditions extending into eastern TN and western NC and SC and southern AL	Wildfires and poor air quality, agricultural impacts mostly positive as dry conditions aided harvest
Winter	December 2016 through March 2017	Continuing extreme drought until rains brought improvement in late winter	Extreme drought in northern GA and extensive area of severe drought from AL to western NC	Extremely low stream flows and reservoir levels

Table 1.1. Four phases of the 2016 drought[12]. The color intensity key is the same as in Figure 1.2.

1.4. Precipitation Patterns Associated with the 2016 Drought

A large swath of the region received less than 80% of their normal precipitation during the one-year drought (March 1, 2016 through February 28, 2017, Figure 1.5)[13]. The driest areas included most of northern Georgia plus parts of northeast Alabama, western South Carolina, southeast Tennessee and southwestern North Carolina. Parts of eastern Florida also experienced extremely dry conditions during this period, but this dryness was associated with a new drought that developed as the Georgia-Alabama-Tennessee drought was waning.

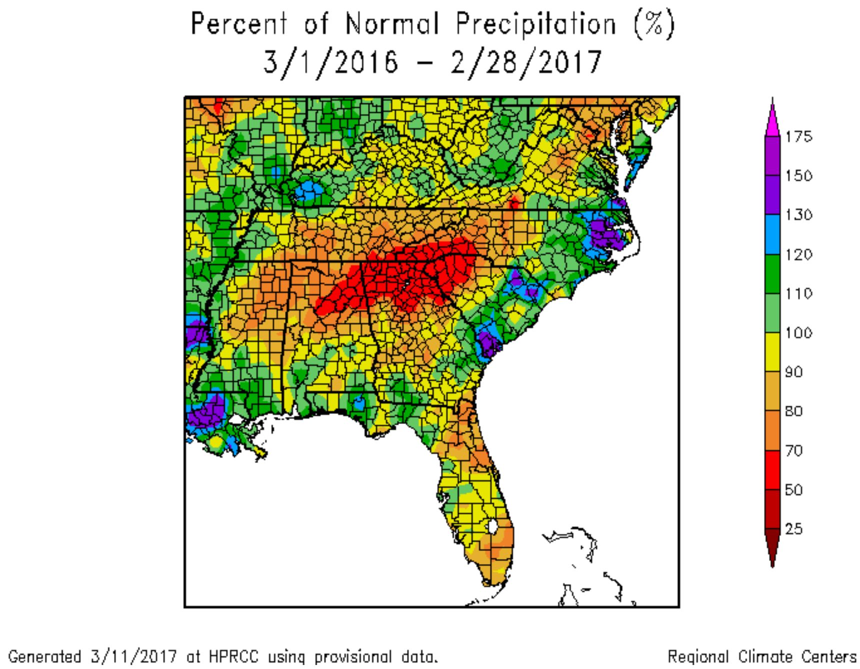

Figure 1.5. Percent of normal precipitation for March 1, 2016 to February 28, 2017[14].

The areas displaying the greatest precipitation deficits moved around the region as the drought evolved. Monthly precipitation maps for percentage of normal rainfall (Figure 1.6) show widespread rainfall deficits in the spring 2016 phase of drought with the greatest deficits in northern Georgia, northeast Alabama, and western North and South Carolina. For a number of stations in northeast Alabama and northwest Georgia, it was the second driest April-May period on record, surpassed only by the drought of 1934. In the summer 2016 phase of the drought, pockets of exceptional dryness were scattered through the area, and separated by small areas in which thunderstorms provided significant rainfall. This resulted in a dappled rainfall deficit pattern.

The greatest precipitation deficits occurred during the fall 2016 phase of the drought, and this was felt across most of the region, especially in October and November (e.g., in Lafayette GA, Figure 1.7). Many long-term stations in the area received less than 50% of their normal rainfall during these months, in contrast to areas along the East Coast where several tropical systems produced precipitation that exceeded 150% of normal (Figure 1.8). A number of stations in the drought region received less than 15% of their normal rainfall in the September through November period, including Weiss Dam AL (10.5% of normal), Wetumpka AL (12.5% of normal), Rome GA (14.2% of normal), and Greenville Downtown Airport SC (15.6% of normal)[15].

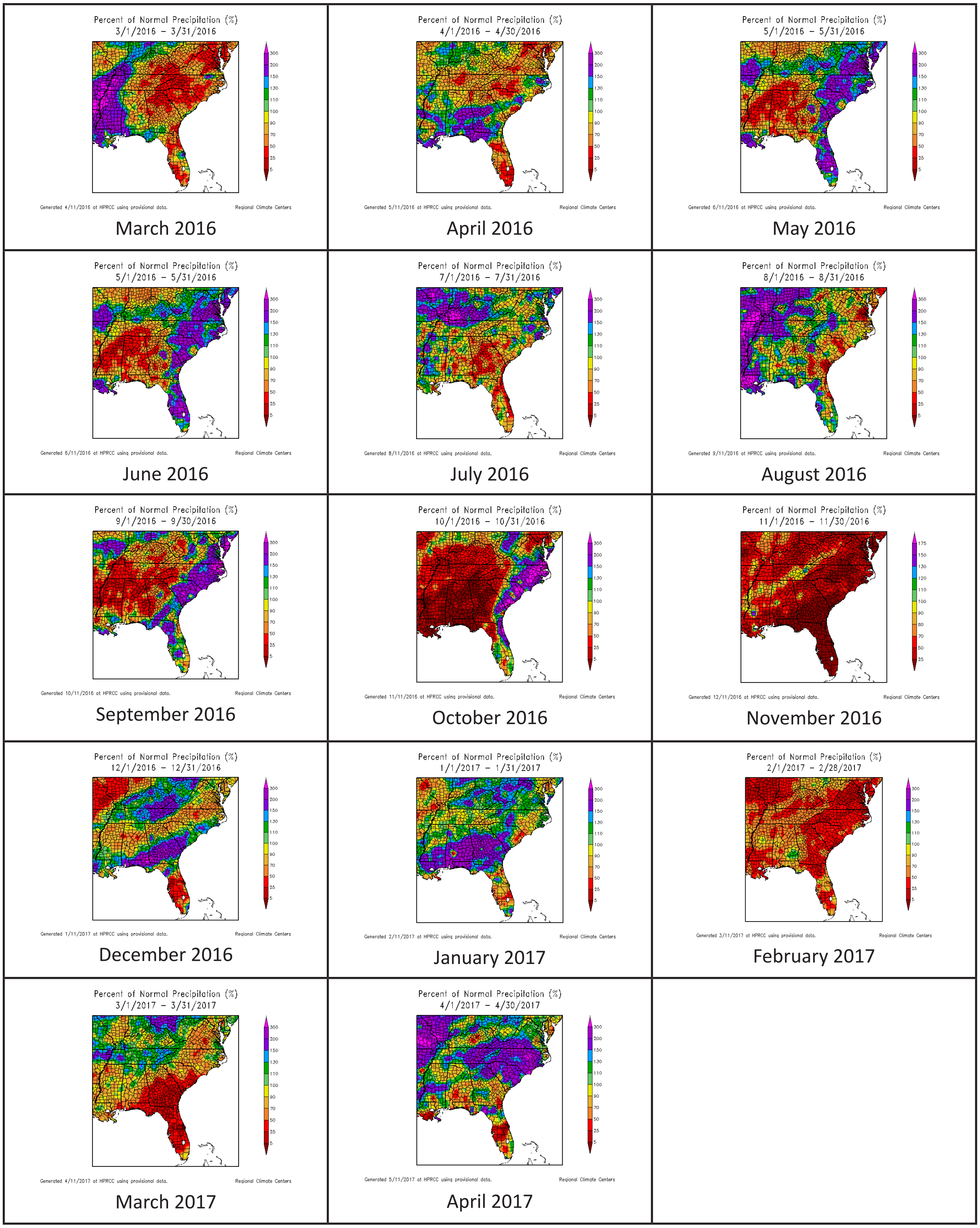

Figure 1.6. Percent of normal precipitation by month for March 2016 through April 2017[16]. Note that the scales on these images are auto-generated and may change from one month to the next.

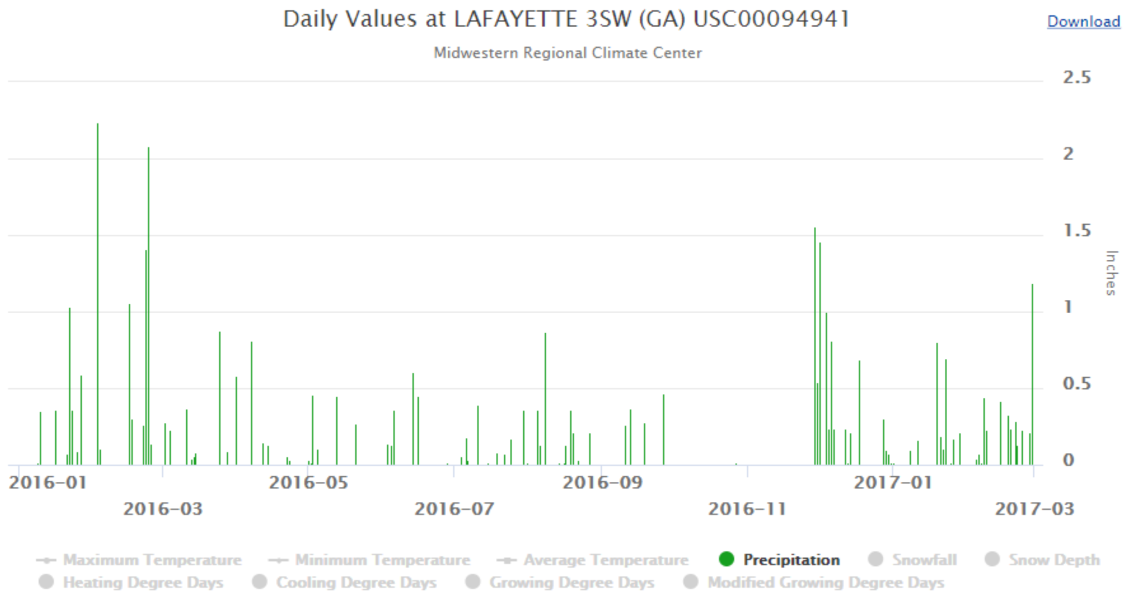

Figure 1.7. Daily rainfall observations from Lafayette, GA in northwest Georgia from January 1, 2017 through February 28, 2017[17].

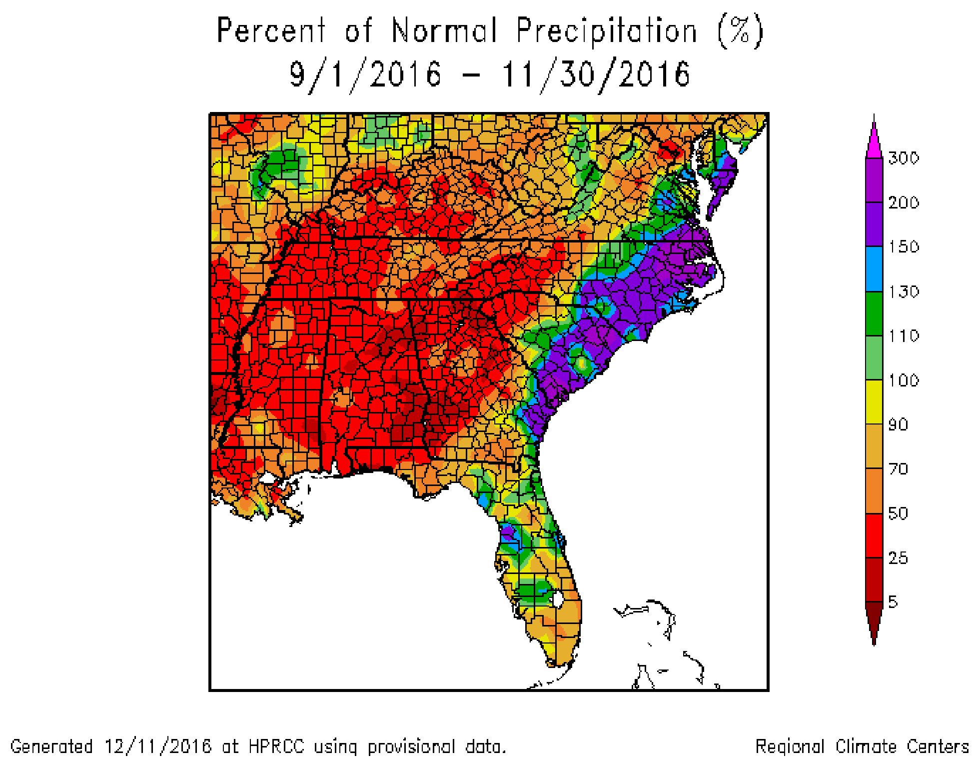

Figure 1.8. Percent of normal precipitation for September 1, 2016 through November 30, 2016[18].

1.5. Temperature Patterns Associated with the 2016 Drought

In addition to reduced precipitation, above normal temperatures can contribute to drought by increasing soil temperatures, evaporating water from surface sources, and stressing vegetation, humans and livestock. In the 2016 drought, mean temperatures in the region at stations in the worst-hit areas were the second warmest on record for the September through November time period (i.e., meteorological autumn), surpassed only by those in 1931 (Figure 1.9)[19]. This is especially unusual considering many of the stations with the longest observational records experienced their highest-ever maximum and mean temperatures for autumn. Almost every day from September through November witnessed maximum and minimum temperatures that were above average (Figure 1.10), and average temperatures during autumn were several degrees Fahrenheit above normal across the entire region (Figure 1.11). Most of the region was at least 6˚F above normal, and some locations were more than 8˚F above normal. The record lack of rainfall coupled with the high temperatures brought dryland agriculture to a standstill and caused vegetation in forested areas to become tinderbox-dry.

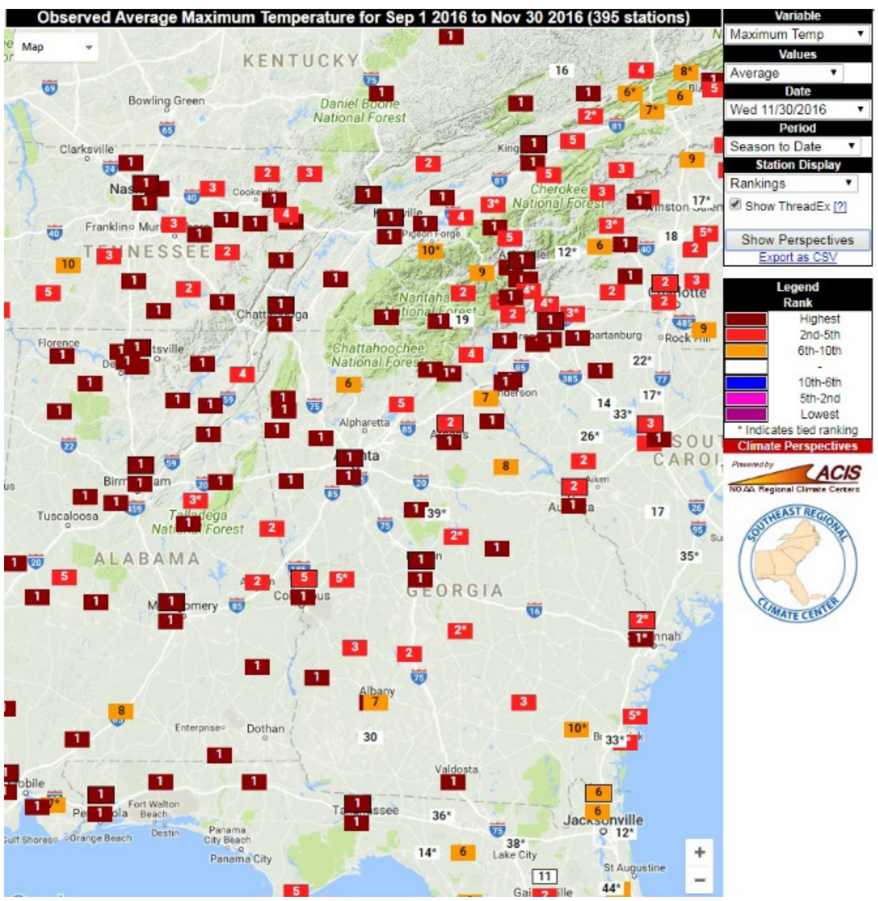

Figure 1.9. Historical ranking of mean temperature for September 1 through November 30, 2016, for individual stations in the 2016 drought region[20].

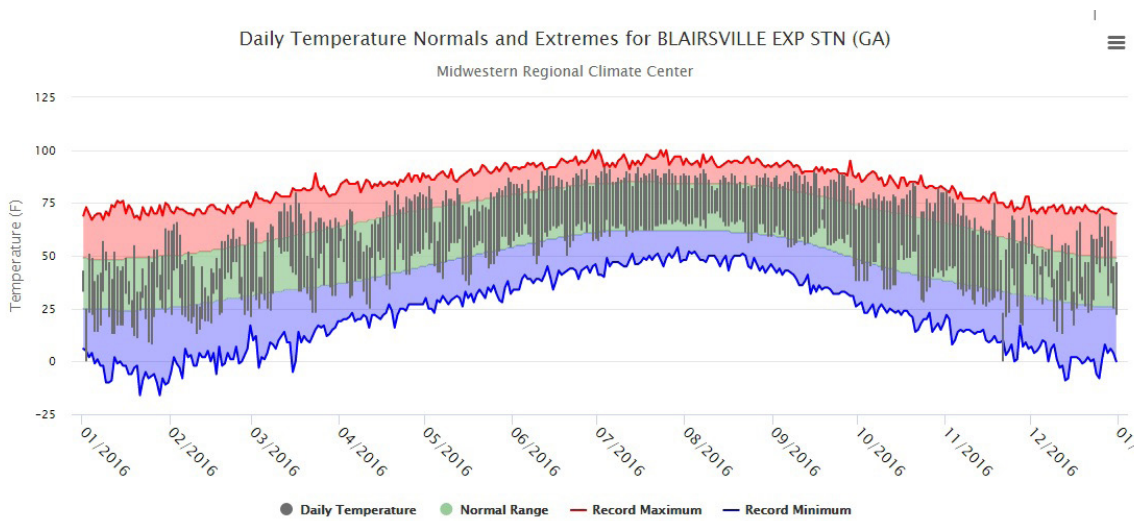

Figure 1.10. Daily temperature observations from Blairsville, GA for 2016[21].

Several of the stations that observed record high temperatures during the fall phase of the drought had combined city and airport records (called "threaded" records[22]) that were well over 100 years old. This indicates just how rare the fall temperatures were. Stations with Rank 1 fall temperatures include Huntsville AL and Knoxville TN (both with 107 years of record), Atlanta GA and Chattanooga TN (both with 138 years of record) and Montgomery AL with 145 years of record[23].

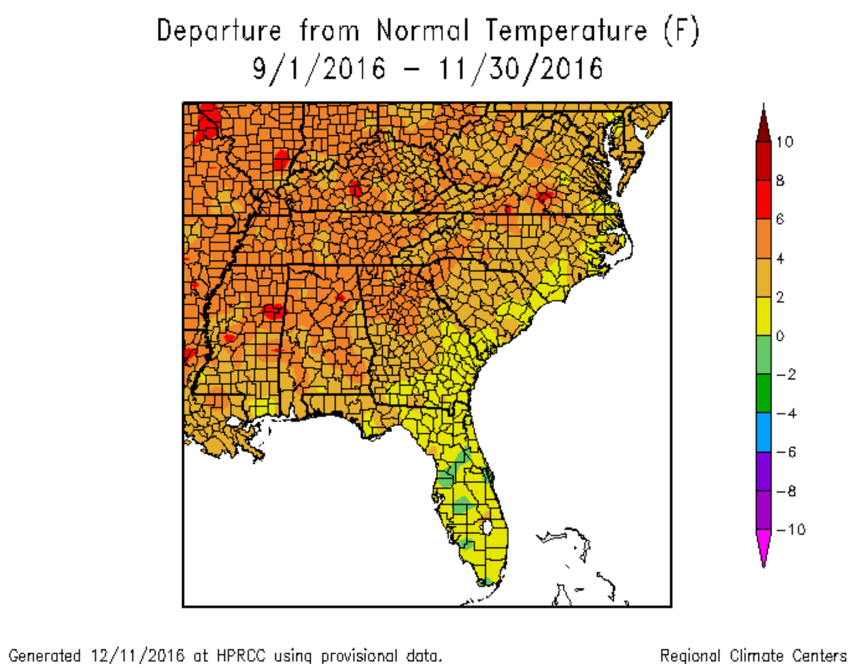

Figure 1.11. Departure from normal mean temperature for September 1, 2016 to November 30, 2016[24].

On the last three days of November 2016, significant rains across the region began to lead to a reduction of drought in those areas in the winter 2016-17 phase of the drought. However, complete recovery from the drought was delayed by the dry month of February 2017, which paused the return to normal conditions and contributed to record-setting low stream flows in the region as surface water and groundwater struggled to recover from the drought conditions (Figure 1.5).

1.6. Causes of the 2016 Drought

The physical factors that drove the 2016 drought in the Southeast were similar to those of previous droughts. However, the evolution of the one-year drought and its accompanying disastrous wildfires were unusual. The 2016 drought was driven primarily by low precipitation amounts as well as the record-setting maximum temperature values that occurred during the fall 2016 phase of the drought[25]. The high temperatures and attendant sunny skies drove increases in evaporative demand that led to stress on plants and contributed to low streamflows and reservoir levels. This was especially true during the fall phase when the drought was approaching its most extreme state. Comparisons of gridded estimates of soil moisture for this drought to previous drought episodes indicate that the 2016 drought was likely the second-most severe in the region since at least 1895, second only to the exceptional drought of the late 1920s[26].

Many droughts in the Southeast can be linked to the presence of a La Niña in the eastern Pacific Ocean, especially in the winter before the drought occurs. La Niña conditions generally contribute to Southeastern droughts by shifting the subtropical jet to the north of the region. Storm systems that normally travel along the jet stream carrying rain across the area bypass the region and instead increase precipitation in the Ohio River Valley. The lack of moisture-carrying storms leaves the Southeast drier than normal in the November through March period[27]. The drier conditions and lack of storm systems also reduces the winter cloud cover, resulting in warmer and sunnier conditions in those months. In this case, however, an El Niño was occurring, although it was moving towards neutral conditions. Because of this, it had little impact on the development of drought later in the year[28].

1.7. What Made the 2016 Drought Unique?

The 2016 drought in the Southeast was unique in several ways. First, it lasted only twelve months, about half as long as most droughts in the region. The drought developed slowly in the spring, when the only real impacts were seen in agriculture in northwestern Georgia, northeastern Alabama and eastern Tennessee. During summer 2016, the drought slowly expanded and intensified, and water resources were increasingly affected by the precipitation deficits. However, localized heavy showers and thunderstorms provided temporary relief to some areas, resulting in a mottled (i.e. spotted) spatial pattern in the drought depiction by the Drought Monitor. Entering the fall phase of the drought, extremely high temperatures coupled with extremely low rainfall values and the nearly complete absence of precipitation

in October and November, rapidly expanded the area covered by all categories of drought and provided optimal conditions for the ignition of numerous wildfires across the southern Appalachian Mountains in eastern Tennessee, eastern Kentucky, northern Georgia and western North Carolina. These wildfires emitted high quantities of smoke that affected the health of area residents (see Chapter 5); the fires burned large swaths of the forest and, in a few areas, threatened homes and businesses (see Chapter 4). Rain returned to the area at the end of November, dousing the remaining wildfires, but it was not sufficient to return streamflows and reservoir levels to normal. Dry conditions in February 2017 temporarily worsened conditions again until another wet spell in spring 2017 brought a conclusive end to the drought.
A second notable aspect of the 2016 drought was its position bookended by two very wet spells. A strong El Niño in the winter of 2015–2016 contributed to the extremely wet conditions. When the driest conditions of the drought occurred, especially in fall 2016, abundant plant material helped fuel the wildfires in some areas. The drought was ended by another very wet spell in spring 2017 after the slow recovery from drought conditions that occurred across the region in phase 4.

A third unique aspect of the drought was the spatial distribution of tropical cyclone-derived rainfall in the area during the drought period. The absence of this rainfall can be one of the precursors of worsening drought conditions in summertime droughts, although tropical storms only pass through this region about once every three years[29]. In 2016, Hurricane Hermine skirted the region in early September, passing through northern Florida and along the East Coast but providing little rainfall to the driest areas. Tropical Storm Julia provided additional rainfall along the Atlantic coast in mid-September but dropped little moisture inland. And then Hurricane Matthew moved north along the East Coast and briefly came ashore in South Carolina, bringing record-setting rainfall to eastern portions of Florida, Georgia and South and North Carolina. The extraordinary amount of rain that fell in eastern North Carolina in particular caused massive flooding and tremendous devastation to that region. The copious rain from all three storms, especially Matthew prevented the eastward spread of the drought into the eastern Carolinas as well as southeast Georgia. Otherwise the drought might have become much more extensive.

Endnotes and References

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[10] National Drought Monitor. http://www.droughtmonitor.unl.edu.

[11] Developed using the time series tool at the National Drought Monitor at http://droughtmonitor.unl.edu/Data/Timeseries.aspx.

[12] Developed using the time series tool at the National Drought Monitor at http://droughtmonitor.unl.edu/Data/Timeseries.aspx.

[13] High Plains Regional Climate Center cli-MATE. https://hprcc.unl.edu/maps.php?map=ACISClimateMaps.

[14] Developed using the High Plains Regional Climate Center (HPRCC) tool found at https://hprcc.unl.edu/maps.php?map=ACISClimateMaps.

[15] Midwestern Regional Climate Center. http://mrcc.isws.illinois.edu/CLIMATE/.

[16] Developed using the High Plains Regional Climate Center (HPRCC) tool found at https://hprcc.unl.edu/maps.php?map=ACISClimateMaps.

[17] Developed using the Midwestern Regional Climate Center's cli-MATE online climate analysis tool at http://mrcc.isws.illinois.edu/CLIMATE/.

[18] From the High Plains Regional Climate Center (HPRCC) tool found at https://hprcc.unl.edu/maps.php?map=ACISClimateMaps.

[19] Southeast Regional Climate Center. http://www.sercc.com/perspectives.

[20] Developed using the Southeast Regional Climate Center's Perspectives tool at http://www.sercc.com/perspectives.

[21] Developed using the Midwestern Regional Climate Center's cli-MATE online climate analysis tool at http://mrcc.isws.illinois.edu/CLIMATE/.

[22] Threaded records combine historical city and airport records into one continuous string. These are commonly used to look at long time periods for users such as media, but do not attempt to adjust the values to account for station discontinuities. They just use the actual observed values as reported at each site.

[23] Southeast Regional Climate Center. http://www.sercc.com/perspectives.

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Chapter 2. Agriculture

2.1. Introduction

Agriculture in the Southeast was significantly affected by the 2016 drought. The first impacts came as the drought was just beginning in spring 2016, but the precipitation deficits through the summer, combined with the near-absence of rainfall and record-setting high temperatures in the fall, resulted in reduced yields in many crops in the area. This caused extreme hardship for farmers as they struggled with dry, dusty fields, many insect pests, and dry farm ponds, which made it difficult to water their livestock.

In this chapter, section 2.2 will describe the agriculture of the Southeast and how it was impacted by the dry conditions. Sections 2.3 through 2.5 will discuss impacts of the 2016 drought on the production of corn (2.3), forage and livestock (2.4), and small grains (2.5) that were the most highly impacted in this drought. Agricultural losses due to the impact of pests, poor field conditions (especially during harvest) and reduced yields from lack of moisture are highlighted in section 2.6. Beneficial aspects of the drought to agriculture will be discussed in section 2.7. Finally, section 2.8 will discuss lessons learned from the 2016 drought for future Drought Early Warning Systems (DEWS) planning that may help farmers prepare for future drought conditions.

2.2. Background

The Southeast as a whole is a highly productive agricultural region, garnering many crops both for local use and for export. Products include livestock such as poultry, dairy and beef; row crops such as cotton and peanuts; nuts and fruit crops, such as pecans, blueberries and peaches; vegetables and ornamental plants; and wood products including timber and wood pellets. Droughts have a variety of direct impacts on agriculture, including moisture stress to crops, lack of water for livestock and irrigation, desiccation of pastures and dryland fields, water quality issues for the water that remains, and heat stress to livestock, plants and outdoor workers in the above-normal temperatures that often accompany the drought. Indirect impacts include higher costs for irrigation due to competition for water and increased need for fuel for irrigation pumps and transportation costs to bring feed to livestock[1].

Agriculture is the primary industry in every Southeastern state, bringing in billions to state and local economies and providing a significant fraction of the jobs in the region. In Georgia, agriculture generates almost $75 billion of the state's $917.6 billion economy[2]. Agriculture and related industries make up 42% of the economy of Alabama and employ 22% of the workforce[3]. In Tennessee, agriculture and forestry accounted for 14.7 percent of the state's economy in 2009[4]. Similarly, in North Carolina[5] and South Carolina[6], agriculture contributes a significant fraction of the total Gross Domestic Product of each state. The agricultural season stretches from March to November across the region affected by the 2016 drought, with the longest growing season in the south and a shorter growing season to the north, especially at higher elevations.

Water demands by the great variety of crops grown in the Southeast vary from one type to another, but all of them require adequate soil moisture to initiate seed germination, frequent rain to nurture the growing plants and fill the pods or grains of the crops, and dry conditions to harvest the yield. Water requirements of particular varieties change based on the growing stage of the plant, with highest needs during pollination (for corn) and development of fruit or grains in row crops and nut and fruit production.[7]

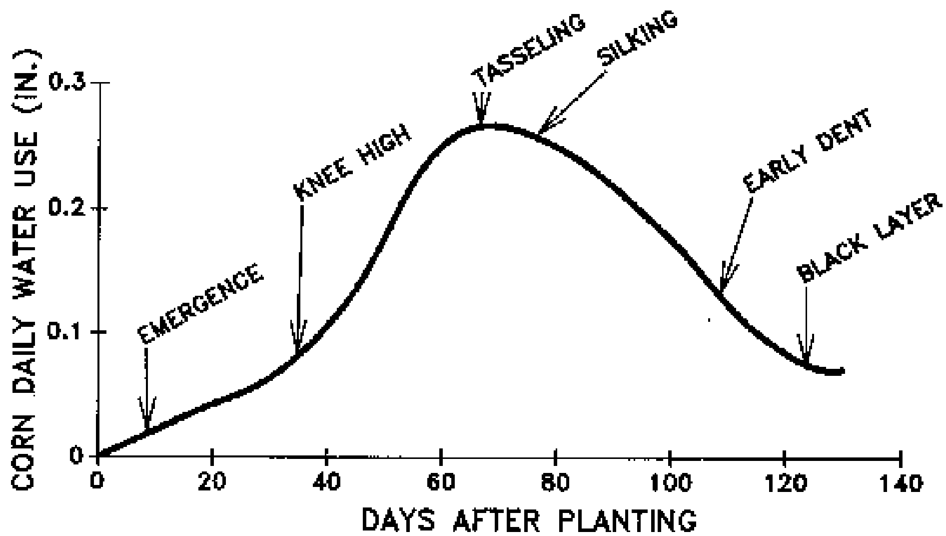

Figure 2.1. Corn susceptibility to drought stress as influenced by stage of development. The higher the susceptibility, the more yield reduction will result from a unit of dry stress[8].

Dry conditions may also increase pressure from some pests like army worms, requiring treatment that adds expenses to production. Conversely, the low humidity often associated with drought can reduce the need for treatment of fungal diseases, which are more susceptible to moist conditions.

For livestock, drought affects both the direct water requirements of the animals and the ability of producers to provide feed through pasture, forage, and grain production. Low water levels in farm ponds or the presence of high levels of toxic algae can force farmers to search for alternative quality water sources for their animals by pumping from subsurface aquifers or surface water or even municipal water supplies if available and allowed. Drought conditions can suppress normal growth of forage in pastures, requiring producers to find alternate feed sources such as hay or silage. In the worst cases, ranchers may have to cull the herds to cut the costs of carrying less-productive animals through the drought.

In the Southeast, production of trees for timber and wood pellets is a significant source of agricultural income[9]. Drought affects the health of trees and forests in a variety of ways. Dry conditions turn underbrush into a source of fuel for wildfires that may accompany the drought (this will be discussed in more detail in Chapter 4). Exposure to below-normal rainfalls over long time periods, especially when combined with above-normal temperatures, can cause stress to the trees and result in increased tree deaths for several years following the end of the drought[10]. This may result in an economic loss to the woodlot owners in reduced volume of wood products and increased maintenance costs to care for affected forests.

In addition to regional effects of droughts, the agricultural markets are intimately linked to weather impacts and competing markets in other regions of the country and the world, so agricultural producers must deal with changing values of commodities and the inputs they need to grow a successful crop. In years with high market value, even crops with significant yield reductions due to drought may still provide good value to farmers, while in other years with lower value, farmers may just choose to plow under the crops to eliminate the costs of harvest such as labor and diesel fuel. Producers must factor all of these competing expenditures into their crop or livestock management plans.

2.3. Drought Impacts on Corn

In the 2016 drought, agricultural producers were the first group to feel the adverse effects of the developing dry conditions. Corn production in eastern Tennessee, northwest Georgia, and northeast Alabama was particularly hard hit due to the timing of the driest conditions at pollination. Wet conditions early in the year allowed corn to be planted earlier than normal in Tennessee, for example. Conditions in Tennessee at that time were so wet and cool that some fields had issues with emergence and had to be replanted[11]. Farther south in Georgia, soil temperatures did not delay planting[12]. However, extremely dry conditions in northern Georgia, Tennessee and Alabama hit at a critical time in agricultural production by mid-May, near the end of the spring drought phase (March–May 2016). The corn that had been planted earlier in the season reached the pollination stage during a period when rainfall was very scarce. The weather station at Lafayette in the northwest part of Georgia received only two days with measurable rain between May 15 and 31, the most critical period for corn germination. This is half the usual number of rainy days during that period. The total rainfall during that period was just 0.28 inches compared to a normal of 2.51 inches.

Irrigated fields performed well even in the dry conditions, but those represent only about 20% of the fields in the region[13]. By comparison, the effect on dryland fields during pollination was poor kernel set and drastic reductions in yield[14]. Many producers cut up their corn for silage or animal feed or plowed it under because of the poor conditions of the ears. In Alabama, testing of new varieties of corn, which is normally undertaken each year by state Extension specialists on non-irrigated corn, was halted due to poor stands and drought conditions in central Alabama[15].

Figure 2.2. Poor kernel set in corn from non-irrigated trials at Milan. Cobs on the far right and far left are from irrigated plots for comparison. Picture was taken Aug. 3rd, 2016[16].

In contrast to the negative impacts on corn early in the growing season, the dry conditions later in the growing season (e.g., the summer and early fall phases of the drought) were mainly positive, especially in irrigated fields. Dry conditions reduced the occurrence of fungal diseases and insect pests, improving corn health. Very dry conditions during the fall harvest allowed producers to harvest in a timely way for the first time in several years[17].

The timing of the dry conditions during corn pollination resulted in significant reductions in the amount of corn produced. In Gordon County GA in the northwest part of the state, for example, the total number of bushels of corn harvested in 2016 was 129,000, compared to the five-year average of 434,000 bushels produced from 2011 to 2015. This is a reduction of 71% from the average yield. Because of falling corn prices in recent years due to heavy production in other parts of the United States, the value of the corn that was produced was only $501,000 compared to the five-year average production of $2,525,000, just 19.8% of the average[18]. Many farmers in that county did not even bother to harvest the crop, instead chopping it up for sorely-needed animal feed[19]. Similar economic losses were experienced in nearby counties in the region.

2.4. Drought Impacts on Pasture, Forage, and Livestock

The second major agricultural product impacted by the 2016 drought was animal feed, including both forage and pasture. This was especially true in northwest Georgia, northeast Alabama, and eastern Tennessee because of the timing of dry conditions. As the drought began to develop in March 2016, farmers were reaching the end of their normal hay-feeding season with the expectation of feeding the cattle in newly green pastures. However, the dry conditions in the spring phase of the drought left pastures dry and unproductive, forcing farmers to continue feeding their herds from their dwindling hay supplies. Hay was trucked into the area of driest conditions from out of state, reportedly from as far away as Missouri[20]. Farmers in the worst-hit areas only obtained one cutting of hay in the 2016 growing season instead of the three or more usually produced[21]. Even in areas away from the center of the drought, yields were lower than normal[22]. Dry conditions also increased pest pressure from insects such as bermudagrass stem maggots and army worms[23], further reducing the quality and quantity of available feed. Because of the increased costs of maintaining livestock during the drought, many agricultural producers were forced to cull their herds to decrease the number of animals that needed to be fed. Beef prices in the United States were already low, so farmers did not realize significant amounts of income from selling the cattle[24]. However, they did realize cost savings in not having to feed, water, and otherwise maintain older or less healthy cows over the period of the drought.

Additional hay was imported into these regions from Southeast Georgia in late summer and fall where precipitation from Hurricanes Frances, Julia and Matthew had caused pastures to produce excellent stands. In addition, peanut hay in southern Georgia was harvested once the peanuts were dug, and the hay was also shipped to the driest areas. While the peanut plants had been treated with agricultural chemicals not listed as acceptable for use in animal feed, the need was so great that many farmers took the risk of using the peanut hay because little else was available for their cattle[25].

Poultry production is the single biggest single category of agricultural production in the Southeast[26]. But since most poultry in the Southeast are produced in confined areas where pasture condition is not an issue, there were few impacts from the drought on the production of broilers or other poultry in the area, since water supplies in the main production areas were not significantly affected and feed was readily available for import into the region.

2.5. Drought Impacts on Small Grains

Small grains such as oats, rye, and wheat are normally planted in fall in the Southeast for harvest in the subsequent spring. They help stabilize the soil from erosion in winter precipitation events and provide a second crop in rotation with summer cotton or peanuts. They also provide a supplementary source of feed for livestock in the region. Successful growth of small grains requires moist soils in fall to ensure that the seeds will germinate in a timely fashion, and the plants will develop strong enough roots to survive winter conditions before resuming growth in spring.

The extremely dry conditions the fall phase of the drought caused many farmers to delay or avoid planting small grains in 2016 because of the problems with germination in the dry soil[27]. In some cases, farmers had to replant a second time after the first round of seeds failed to germinate[28]. However, the soil remained so dry in some locations that farmers had to completely abandon planting small grains, resulting in a loss of acreage and yield. The small grains that were successfully planted in fall 2016 were also affected by the unusually warm winter of 2016–2017. The warm temperatures caused problems with the process of “vernalization” of some crop varieties; “vernalization” is the need of some seeds to experience a period of cold temperatures to maximize production of the final crop. The lack of cold temperatures caused reduced yields and lack of heading in the small grains[29]. The frost in mid-March 2017 also damaged plants, leading to reduced heading and bleached crops which further reduced yields[30].

While county by county statistics for small grain production are not readily available, the statewide statistics for production show that yields of small grains were significantly affected by the 2016 drought. The number of bushels of wheat harvested in Tennessee in spring 2017 was 19.3 million bushels, compared to the 2012–2016 average of 28.9 million bushels. Similarly, in Alabama 7.7 million bushels were harvested compared to the five-year average of 14.6 million bushels. In Georgia only 3.2 million bushels were harvested compared to a five-year average of 11.1 million bushels[31]. Since this is a significant reduction in yield for the states as a whole, which includes areas that received near normal precipitation, the yield losses in the worst-hit drought areas were undoubtedly much worse.

2.6. Agricultural Losses from Pests, Poor Field Conditions and Reduced Yields

During the summer phase of the drought, few impacts of the dry conditions were reported in the Drought Impact Reporter (DIR)[32]. However, the true effects of the regional drought on crops became clear once producers started reporting their field conditions and crop yields in fall as harvest progressed and the poor yields became clear. The number of reports in the DIR surged in November 2016 as producers became aware of the ability to report their conditions to Drought Monitor authors[33]. Between November 11 and 17, 61 drought impact reports were submitted in Georgia alone after being encouraged to provide their stories by extension agents[34].

Based on the anecdotal evidence from DIR reports[35], yields of many crops were reduced, sometimes to the point of being of no net value after inputs like fuel and agricultural chemicals were factored in. Many producers indicated losses of 50% or more in dryland corn, cotton, and peanuts. Peanuts were especially hard to dig because the pods could not be extracted from the dry ground, resulting in additional losses due to poor harvest conditions[36]. Pecan farmers indicated that nuts were very small and reduced in value because of their size and poor quality. Christmas tree growers indicated that there was almost no tree growth in 2016. Irrigated crops also experienced reductions in yield of 15–30% in some areas, although they were much better than yields from unirrigated fields.

The dry conditions also caused problems for field work. Pests like army worms and whiteflies spread dramatically because sprays were not effective in the dry conditions, and the stressed plants were less able to stave them off. Dry soils made it difficult to plant tree seedlings[37] and fall crops but also made it difficult to do even basic farm work like clearing corn stubble because of concerns about fires and potential damage to the soil from heavy equipment.

Some agricultural losses were covered by crop insurance, although exact values were not available for this report. Other farmers became eligible for low-cost loans and payments after the USDA declared drought conditions in many of the counties in the region in fall 2016. The true cost of the 2016 drought may ultimately be almost impossible to determine due to the wide variety of crops in the region and the diverse impacts the drought had on different sectors of the agricultural economy.

2.7. Beneficial Impacts of the Drought on Agriculture

In spite of the exceptionally dry conditions and poor crop yields in the worst-hit areas, there were some beneficial aspects to the drought. Some crops experienced less pressure from fungal diseases and insect pests than normal, reducing the need for the application of agricultural chemicals such as fungicides and pesticides. This represented a cost savings to the producers due to fewer required purchases of chemicals as well as a savings in the fuel and labor needed to spray. This was particularly true for crops that were grown using irrigation, since the plants' water needs were met by the water supplied through pumping to the roots while the plants remained relatively moisture-free. The dry conditions also helped grapes grown for wine because the dry conditions allowed sugar to concentrate in the grape berries, resulting in a more flavorful product[38].

The exceptionally dry conditions during the fall phase of the drought also provided favorable conditions for the harvest of many crops such as cotton and peanuts. Many extension agents commented in the Weekly Weather and Crop Reports that this was the first year in several to have no problems due to rain when the crops were harvested. In previous years, rainfall, particularly from tropical systems but also from mid-latitude storms, caused problems with wet soils that were difficult to drive harvest equipment through. In previous years, rain also caused decreases in the quality of cotton due to sprouting of seeds in the cotton bolls while they were still on the plants[39]. Harvest of timber was also possible in areas where it was normally too wet to use heavy equipment[40].

2.8. Lessons Learned from Agricultural Impacts for the Drought Early Warning System (DEWS)

The most severe agricultural impacts in the 2016 Southeast drought occurred as a result of precipitation deficits in the spring phase of the drought (March through May 2016). As the drought intensified and expanded in areal coverage, a mixture of negative and positive impacts was identified. A secondary set of severe impacts occurred in fall as harvest was occurring and winter crops were being planted. Based on observations of how agriculture was affected, several key points should be considered to help improve identification of early drought occurrence and potential impacts in future droughts.

1. Every crop responds uniquely to dry conditions at different stages of crop development. Because of this, it is important to include a diverse group of agricultural producers and extension agents in the process of identifying and characterizing drought. Currently each state uses a separate system of monitoring drought, and the role of those with particular knowledge of agricultural impacts is unclear. As more agricultural experts are included in the monitoring process, impacts on agriculture, particularly those that are specific to

the stages of crop development that are most sensitive to water shortages, will improve the early recognition of developing drought and warn producers that impacts may be imminent and give them time to react in a timely way to the worsening conditions.

2. A number of extension agents indicated that the Drought Monitor (DM) map did not reflect local conditions adequately and that the strength of the drought shown in the DM was not as intense as they were seeing. To remedy this, agricultural producers and extension agents should be encouraged to frequently and consistently report their local conditions via both the weekly National Agricultural Statistics Survey report and online through the Drought Impact Reporter (DIR) and the CoCoRaHS Condition Monitoring form[41], if they are observers. That will provide additional information that will help DM authors generate the best depiction of current drought conditions. The lack of reports in the DIR during the summer phase of the drought may have led drought conditions in the DM to be underestimated. The increased number of reports received in early November, once producers became aware of the DIR and its importance to the DM authors, shows that producers are eager to share their experiences.

3. Livestock producers would have benefited from earlier identification of the drought so that they could have procured additional sources of hay before lack of pastures became critical. In the 2016 drought, the combination of almost no rain during the critical "green up" period in spring 2016 coupled with the normal end of winter hay-feeding escalated the need for alternate sources of hay beyond normal demand. This highlights the importance of regular monitoring of conditions as they are developing, even before an "official" drought is shown on the DM. The process of identifying drought conditions for the Drought Monitor may also have been hampered by the small number of individuals who help create the weekly DM that were located in the region where drought was developing, especially those with specific knowledge about agricultural impacts.

4. Better communication of the increasing drought through state extension newsletters, the USDA National Agricultural Statistics Survey, social media posts, and other methods could help alert producers to impending impacts. For example, if small grains farmers had known that severely dry conditions would last through fall 2016, they might have been able to identify alternative crops or varieties to plant to take advantage of the lower soil moisture conditions. Instead, by the time rain returned in late November, it was too close to the first fall frost to allow most grains time to develop strong enough root systems to survive the winter cold. Since each state has a different method for monitoring drought conditions, it would be useful to identify a regional drought coordinator who could watch conditions across state boundaries and develop a more holistic picture of drought across the region that could be shared with others in the area through a variety of methods, including webinars, social media outlets, and newsletters.

5. Irrigated crops did not suffer as many ill effects as dryland crops. In fact, many crops benefited from the drier conditions, resulting in less need to apply fungicides and herbicides. Irrigation, even when applied judiciously just in the driest periods, provides "insurance" to get through critical growth stages. While the absence or presence of

irrigation does not help in the early identification of developing drought, it does provide agricultural producers with a buffer to help mitigate the impacts of a dry spell or burgeoning drought. Preparation for the next drought should include a consideration of the costs versus benefits of providing irrigation to fields, including the possibility of using small local water sources such as on-farm ponds[42]. While this approach will not work in the most intense droughts, it may provide enough water for crops to survive and yield a profitable harvest in seasons where rainfall alone is not enough. Even when yields are reduced, as they were in the 2016 drought, larger and more consistent harvest may offset the costs of providing the irrigation.

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Chapter 3. Water Resources

3.1. Introduction

The Southeast as a whole receives more rainfall than any other major region of the United States, and water resources are plentiful in most years. Water is available in the form of rainfall averaging 50 inches or more over much of the region, flowing streams and reservoirs, and groundwater aquifers that lie beneath much of the region. Residents expect to have sufficient water to meet their needs without shortages, so when drought occurs, they are often caught short and have a difficult time dealing with the lack of freely available water. Longer droughts usually have the most significant impacts on water resources, but shorter intense droughts can also affect the availability of water, especially if local communities' water supplies are procured from streamflow and surface water in lakes and reservoirs rather than groundwater, which takes longer to respond to drought conditions. Droughts can affect both the quantity of water that is available through reduced input of precipitation and the quality of water due to concentration of toxic chemicals in the reduced water levels.

Section 3.2 in this chapter provides a context for understanding the 2016 drought with a brief background on water resources of the Southeast and how it supports the economy of the region, including agriculture, tourism, and power production. Section 3.3 highlights how drought affects water supplies in the region and how different states manage water resources, especially in times of low water levels. Reductions in streamflow due to the 2016 drought will be covered in section 3.4, and the impacts of the drought on reservoirs will be discussed in section 3.5. Groundwater impacts of the drought are briefly described in section 3.6. A summary of impacts from the 2016 drought on water supplies overall is provided in section 3.7 and lessons the drought taught water managers which could apply to a Drought Early Warning System are listed in section 3.8.

3.2. Background

The Southeast benefits from an abundance of water transported from the Gulf of Mexico and the Atlantic Ocean, with some additional input from the Pacific Ocean and local irrigation in the form of land-recycled moisture[1]. Overall, mean annual precipitation totals of 50 inches or more covers much of the region, although there is considerable variation. The wettest areas include the immediate coastlines and the windward slopes of the Southern Appalachian Mountains (SAM). The driest areas include inland areas away from coastal circulations, northern locations, which experience lower temperatures and reduced thunderstorm activity, and downwind of mountainous areas.

The wide availability of water in the Southeast helps to make it one of the most productive agricultural regions in the country. It is also widely used for hydroelectric power and consumption by a rapidly growing population. Both the Gulf of Mexico and the Atlantic Ocean serve as source regions for this moisture, which is lifted to produce precipitation by a wide variety of mechanisms, including tropical systems, fronts, orographic lift, and convection (i.e., thunderstorms). Precipitation is generally distributed evenly across the seasons, though there is often a dry period during the fall. Snow is occasionally observed in winter in more northern locations as well as in higher elevations. However, it seldom lasts for more than a day or two. Consequently, snowpack is not a significant source of water for streamflow.

Water supplies for agriculture and for populated areas vary depending on the physiographic region they are located in. In the coastal plains, many cities and agricultural producers use groundwater, often from sandy aquifers, pumping large amounts of water from the ground daily, particularly when rainfall has been scarce. In the Piedmont and mountainous areas of the Southeast, groundwater stored in crystalline aquifers (mostly fractured igneous and metamorphic rocks) are limited sources of ground water, and most water supplies are obtained from surface water, including rivers and on- and off-stream reservoirs[2]. Smaller shallow wells are also used in those areas to obtain water locally but draw water at much lower volumes than the large wells in the coastal plain.

3.3. Management of Water and Drought in the Southeast

Water is managed by a number of different agencies in the region, including the U. S. Army Corps of Engineers, the Tennessee Valley Authority, and the individual states and local water authorities. Each agency has their own methods dealing with monitoring water supplies and declaring drought. Since rivers flow between states and from one state to another, interstate compacts help guide the usage of water as it is transferred from one region to another. However, there have been major disagreements of how much water should be transferred from one state to another, leading to legal battles such as the recent case pitting Florida against Georgia over control of water in the Apalachicola-Chattahoochee-Flint (ACF) River basin in the U. S. Supreme Court. In years with adequate rain, water supply disagreements are rare, but in years with drought the battles can become heated as each agency strives to provide water for its users.

While drought can be identified quantitatively using indices such as the Standardized Precipitation Index, the Palmer Drought Severity Index, the 7Q10 stream flow, and other related indices, agencies and states each have their own methods for officially identifying and declaring drought and managing stressed water supplies that vary from one entity to the next:

- The US Army Corps of Engineers and Tennessee Valley Authority use water control manuals for each project that identifies stages of flood and drought conditions in their reservoirs and determines the appropriate management strategy for each stage of drought. Stages vary over the course of the year as water needs and potential hazards change with the season. If water supply is reduced, dam managers may reduce flow out of the reservoirs to the minimum required to meet the needs of downstream users such as power plants. The latest manual for the ACF basin, for example, was redone in 2015–2016 and is now operating under new rules[3].

- Alabama's primary authority for monitoring drought and providing statewide guidance is located in the state's Office of Water Resources. Drought declarations are aided by a planning committee that includes the State Climatologist[4]. The committee helps provide input into appropriate statewide actions[5].

- Georgia's Environmental Protection Division identifies appropriate Drought Response Levels for specified counties within the state based on their monitoring of the Drought Monitor, precipitation, streamflow, groundwater, reservoir levels, short-term climate prediction, soil moisture, and water supply conditions[6]. Individual water supply users, such as city water systems, can request exceptions to strengthen restrictions locally if they experience severe impacts from a drought that affect their ability to supply water. Water for agricultural use is not considered, only municipal supplies[7].

- Tennessee's Department of Environment and Conservation's (TDEC) Drought Management Plan identifies a Water Resources Technical Advisor Committee to monitor drought and provide advice to TDEC in declaring drought and identifying appropriate restrictions[8].

- North and South Carolina both have state-wide committees that work cooperatively to identify current drought severity and determine appropriate actions to be taken by state and local agencies in restriction of water use[9]. In North Carolina, the statewide committee provides their consensus drought determination to the National Drought Monitor. Local agencies use the DM status to determine appropriate action in their areas, but statewide responses are only activated once the drought reaches extreme drought (D3)[10]. In South Carolina, the statewide committee goes through multiple steps before mandatory water restrictions are imposed for the parts of the state impacted by drought[11].

In addition to state declarations of drought tied to state-level responses, there are also drought declarations tied to the availability of U. S. Department of Agriculture low-interest loans for farmers impacted by drought conditions. Normally the counties identified in these drought declarations are tied to the National Drought Monitor status in each county and a ring of contiguous counties around the official drought-affected counties is included. These drought declarations are independent of state drought declarations and linked specifically to the loan program that can help agricultural producers recover from a devastating drought (or flood). In addition, drought identification for crop insurance claims may be based on different criteria depending on when in the crop cycle the dry conditions occurred[12].

3.4. Reduction in Southeastern Streamflow in the 2016 Drought

Stream discharges were severely impacted by the 2016 Southeast drought. The first streams affected were in northern Georgia, northeast Alabama, eastern Tennessee, and western North and South Carolina, where a significant dry spell occurred in late April through mid-May (i.e., the spring phase of the drought). Streamflow in creeks and rivers continued to drop through the summer and fall phases of the drought, bottoming out in those areas during October and

November with the extremely dry conditions that developed during that period (Figure 3.1). During the winter phase of the drought, stream discharges in northwestern Georgia, eastern Tennessee and northeastern Alabama slowly rebounded, as rainfall events became more frequent.

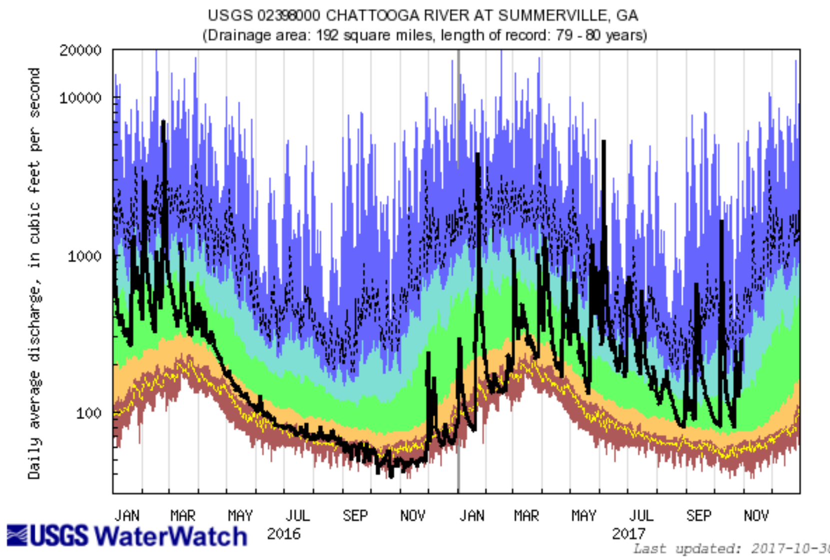

Figure 3.1. Daily average discharge from the U. S. Geological Survey gauge on the Chattooga River at Summerville, Georgia in northwest Georgia for 2016 through 2017.

In the Chattahoochee River basin above Lake Lanier in northeast Georgia, a steady decline in streamflow and daily discharge occurred from March 2016 nearly continuously through June 2017. Then it slowed temporarily in wetter conditions in July and early August (Figure 3.2). In the latter part of August, discharge fell rapidly as rainfall nearly stopped and continued at near-record low amounts until the end of November, when heavy rains brought a temporary increase in discharge. However, the continuing dry conditions in that region caused record low discharges for most of the time period from mid-December 2016 through March 2017 before finally returning to normal in late April 2017.

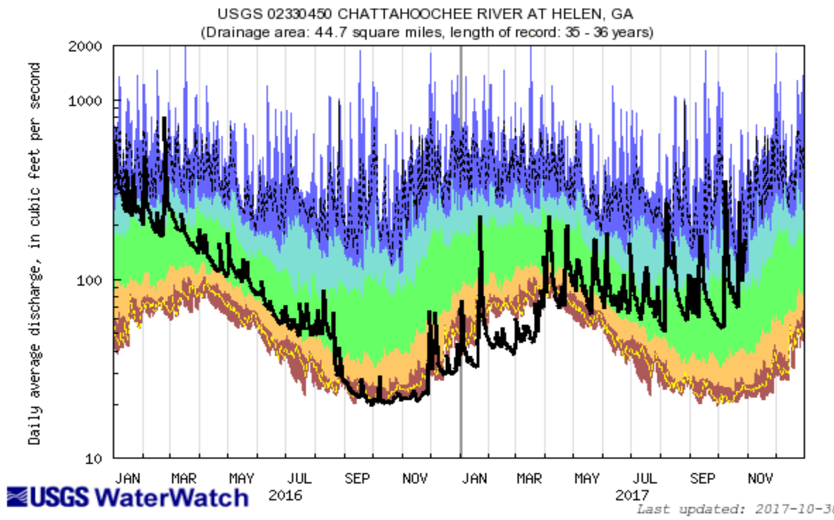

Figure 3.2. Daily average discharge from the U. S. Geological Survey gauge on the Chattahoochee River at Helen, Georgia, in northeast Georgia for 2016 through 2017.

In streams farther south in Georgia and Alabama, discharges also decreased beginning in April 2016, which is typical for that time of year as seen in the discharge curves in Figures 3.1, 3.2 and 3.3. By June 2016, however, the lack of rainfall caused these discharges to drop below average. Going into the fall phase of the drought, discharges decreased and reached record-setting levels in November (Figure 3.3). Discharges remained below average until mid-May 2017 except for temporary spikes caused by individual precipitation events in the winter of 2016–2017.

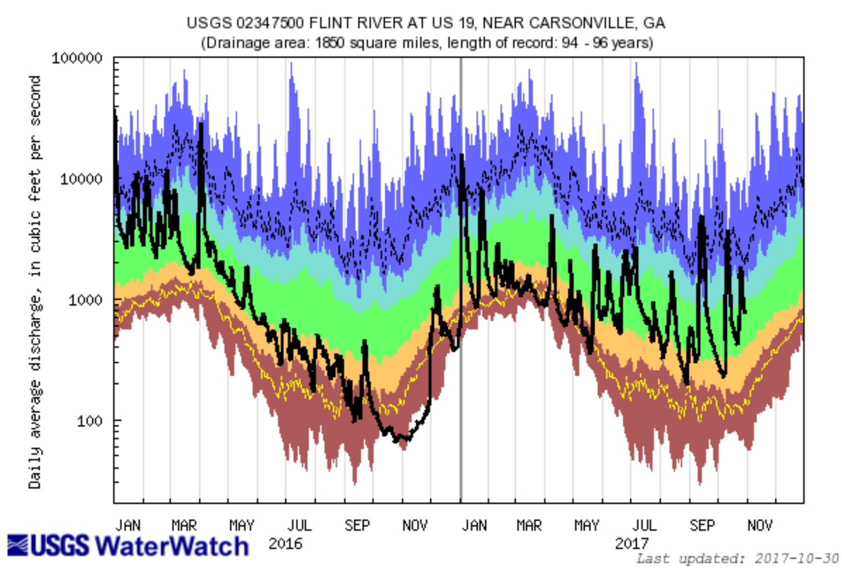

Figure 3.3. Daily average discharge from the U. S. Geological Survey gauge on the Flint River near Carsonville, Georgia, in southwest Georgia for 2016 through 2017. The Flint River is an unregulated stream, which means that there are no dams to alter the natural flow of the river and affect its response to rainfall.

In general, the flows of the streams in the region clearly reflected the rainfall patterns discussed in Chapter 1. They show the high initial values associated with the wet winter of 2015–2016, the gradual drying through the spring and summer phases of the drought, and the rapid drying associated with the almost complete lack of rainfall in the fall phase of the drought. They also show the slow recovery that occurred over the final winter phase of the drought, as dry conditions and well above-normal temperatures continued to keep streamflow low across the region until rain in the spring of 2017 finally helped return stream discharges back to normal.

3.5. Effects of 2016 Drought on Reservoir Levels

The low streamflow resulted in greatly reduced inflow in watersheds that feed into reservoirs around the region. Major reservoirs are operated primarily by the U. S. Army Corps of Engineers (COE) and the Tennessee Valley Authority, although some smaller reservoirs are operated by local water authorities. Lake levels in each reservoir gradually decreased due to the low inflows into the reservoirs, although levels were also determined by the operating guide curves for each dam. For example, Lake Lanier, a COE reservoir that serves as a water supply to Atlanta, started at an extremely high elevation in early 2016 due to the heavy winter rains that occurred in the 2015–2016 cold season. This high initial elevation helped keep the reservoirs at normal levels even after inflow from precipitation dropped during periods of low precipitation in the spring phase of the drought. Lake Lanier's elevation was gradually lowered from May through December 2016 as inflow from northeast Georgia was drastically reduced (Figure 3.4); it reached its lowest level at the end of December 2016. In 2017, the lake elevation hovered near the lowest level until the end of March 2017, when water levels began to rise again (Figure 3.5). Reservoirs in TVA also dropped significantly during the drought, although the deviations depended on how each reservoir was managed. In Lake Guntersville in northeast Alabama, operators were able to keep the reservoir in its normal operating zone by careful management, although the lake level in mid-May dropped to almost the bottom of its official summer operating zone[13]. Lake Wheeler dropped briefly below its normal operating curve in mid-May[14].

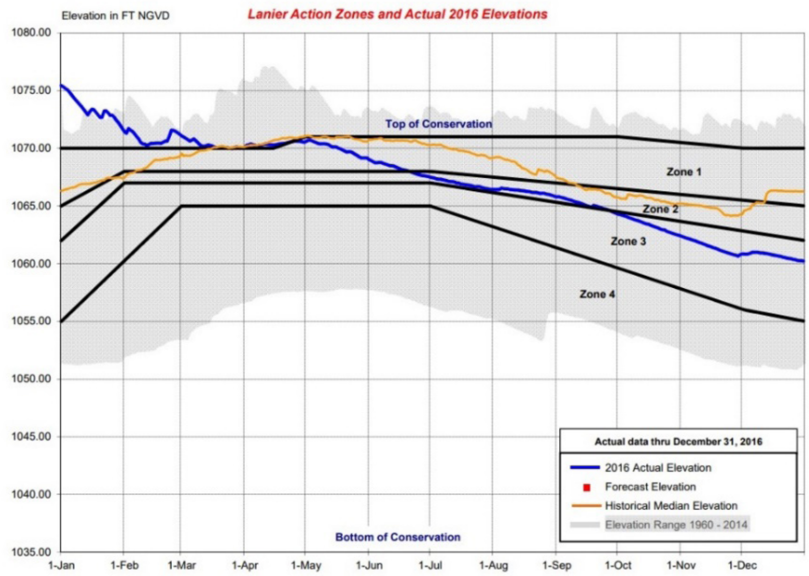

Figure 3.4. Elevation of Lake Lanier in 2016 (in blue) plotted on management guide curves from the U. S. Army Corps of Engineers.

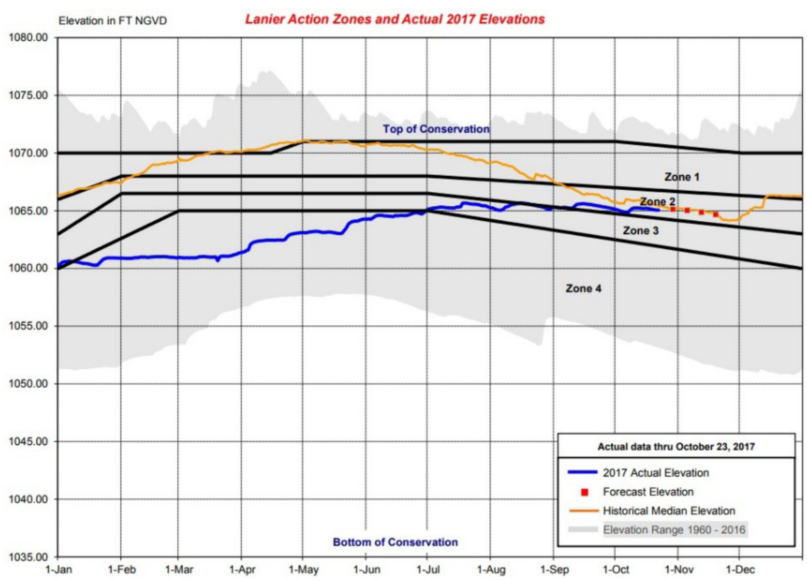

Figure 3.5. Same as Figure 3.1 except for 2017. Note that the guide curves in 2017 have been updated to reflect the new management design that was developed in 2015 and 2016.

In some local reservoirs, low streamflow and high evaporation rates dropped lake levels so low that water intakes nearly ran dry. In east Polk County, TN, the manager of Campbell Cove Lake opted to lower their intake to make sure the communities did not run out of water[15]. Other communities requested variances to draw water from local rivers or lakes to supplement their supplies.

3.6. Effects of the 2016 Drought on Groundwater

Groundwater resources across the region of the 2016 drought vary greatly. In the coastal plain, a variety of aquifers provide plentiful high quality water across most of the region. In northern Alabama and Georgia as well as eastern Tennessee and western North and South Carolina, availability of water from underground aquifers is more limited.[16] Most communities in those areas rely on surface water for the majority of their water supplies, as well as local small-scale wells for individual use. In the 2016 drought, groundwater levels were reduced across the region, but in the deepest aquifers only a limited reduction was observed during the drought period.

In the 2016 drought, shallow wells showed the most impact from the drought, as expected. The lack of rainfall infiltrating through the soil into the aquifer caused groundwater levels to decrease first gradually through the summer, and then more rapidly during the fall when there was almost no precipitation. Some of these wells dropped more than 20 feet over the course of the summer and fall. But the heavy rains that occurred near the end of November rapidly returned the shallower wells to near normal levels (Figure 3.6).

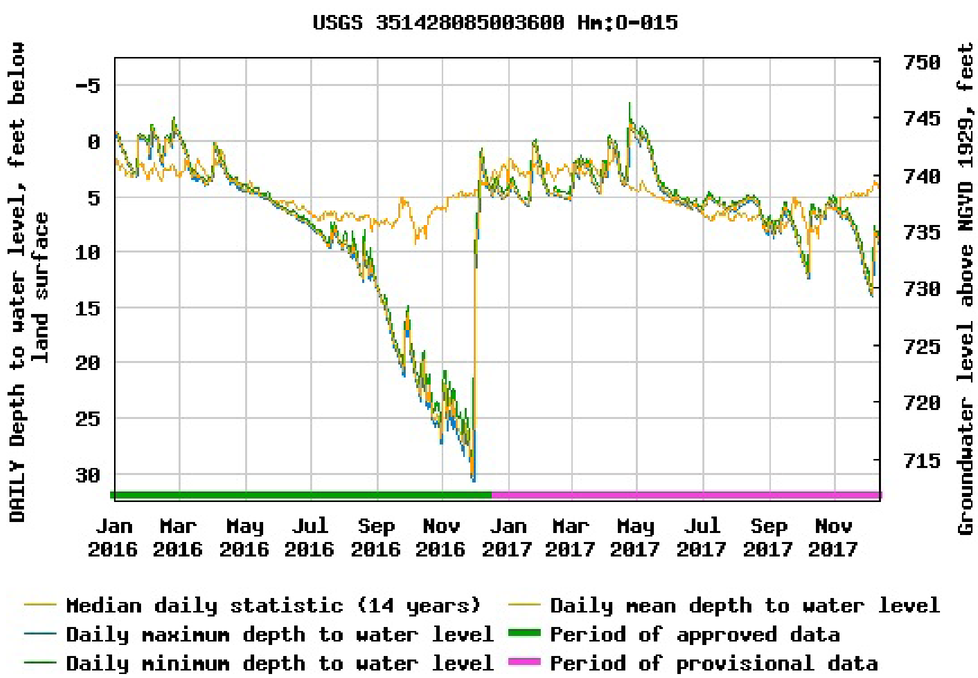

Figure 3.6. Daily depth to water level for USGS Well 351428085003600 located in Hamilton County in east Tennessee[17].

By contrast, some deeper wells responded more slowly to the precipitation deficits in the region of the drought. While they showed water levels below normal starting as early as April 2016, the levels declined more gradually over the summer and early fall, but failed to recover as the fall phase of the drought ended and the winter phase began. Some groundwater observations did not return to normal levels until the summer of 2017, well after the surface drought had ended (Figure 3.7).

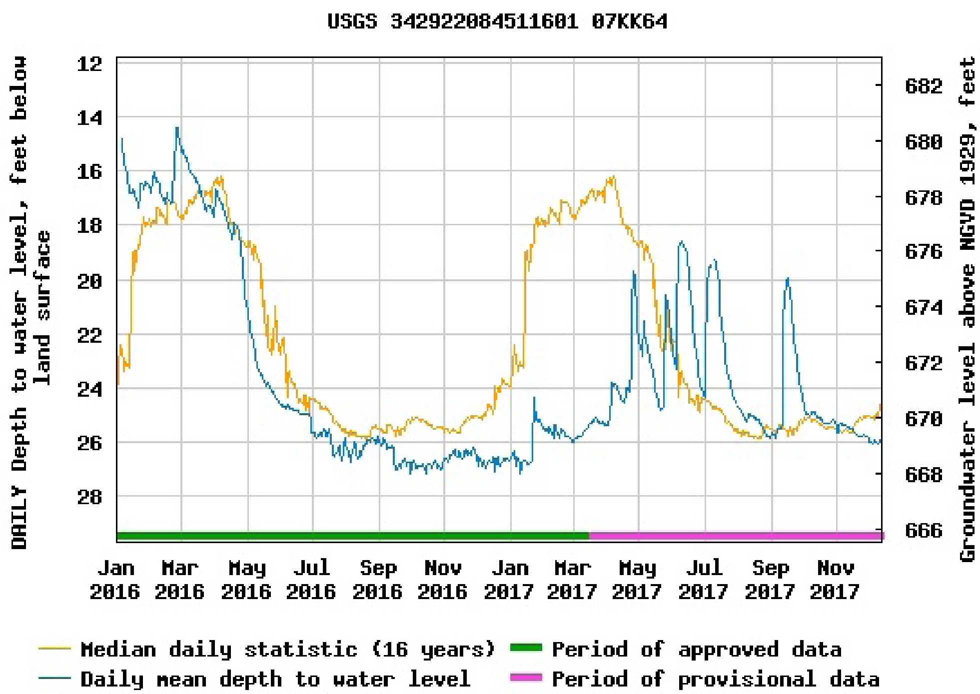

Figure 3.7 Depth to water level for USGS well 342922084511601 located in Gordon County in northwest Georgia[18].

While groundwater responded to the dry conditions, the natural delay linking low precipitation amounts to aquifer level reduced the impacts of the drought for water supplies from groundwater. This was especially apparent in northern parts of the region where aquifers are small and hard to obtain water from. In the coastal plains where sandy aquifers react more quickly to precipitation deficits, some water tables were reduced but there was still plenty of water available for agriculture and human consumption.

3.7. Impacts of Reduced Water Availability on Regional Water Supplies

In the heart of the drought region, including northern areas of Alabama and Georgia as well as eastern Tennessee, municipalities rely primarily on surface water as a source of water supplies for drinking and industrial use. Aquifers in that region do not provide easily accessible water supplies large enough to meet local demands due to their crystalline nature[19]. Due to the rapid decrease in streamflow in the latter phases of the drought, a number of counties and municipalities in Georgia west of Atlanta were unable to meet water supply needs under the Georgia drought response level they were in and were granted variances by the Georgia Environmental Protection Division to use alternative sources of water[20]. Birmingham (AL) Water Works charged a 400% drought surcharge for excessive water use beginning in November 2016 due to the Stage IV drought in Alabama after charging a 200% surcharge in October when the state was in Stage III drought. The surcharge was lifted in January 2017 when heavy rainfall eased water deficits[21]. The counties in southeastern Tennessee were requested to conserve water on October 28, 2016 by the Tennessee Department of Environment and Conservation and expedited applications for surface water withdrawals and stream impoundments October 28 through November 14, 2016[22]. Water shortages due to low stream levels were also noted in western North Carolina, where citizens in Maggie Valley NC were asked to voluntarily reduce consumption by 10%[23]. A number of farmers also reported that their local farm ponds were drying up[24].

Direct impacts on water supplies due to low reservoir levels were limited, especially in the bigger reservoirs such as the TVA lakes and the ACF reservoirs. Those reservoirs have a large enough capacity that even with reservoir levels considerably below their normal operating curves, they can be managed through their operating plans to conserve water resources during extreme droughts. So while some boat ramps were closed due to the low lake levels and some degradation of water quality was seen, overall there were only modest impacts from the drought on reservoir water supplies. The impacts on the reservoirs were due in some measure to the exceptionally heavy rain to the area associated with the 2015–16 El Niño event. That rain was captured in the reservoirs, leading to very high water levels in the months prior to the onset of the drought. The high levels in the beginning of 2016 served as a buffer for reservoir levels when the drought became more severe in summer and fall.

The drought-driven operation of the reservoirs did have a secondary consequence; the restricted releases from the reservoirs reduced the amount of water available for hydropower production. For example, at Buford Dam on Lake Lanier north of Atlanta, Georgia, production of hydropower during the period from January through May 2017, the period during which the reservoir was in Zone 4 on their operating curve, a total of 24,760 kilowatts was produced. This is less than 35% of a ten year average of 70,988 megawatts from 2007 to 2016, which includes two previous drought events[25]. In Zone 4, hydropower is generated only when water is released for other needs such as maintaining minimum flow downstream[26]. When drought operations are not in effect, hydropower production depends primarily on demand due to availability and comparative costs of other energy sources. The TVA also reported a 50% reduction in power production due to the drought[27].

Impacts from low groundwater levels were limited. Some local agricultural producers with private well systems noted problems with wells drying up in the region[28], but those reports were scattered and no widespread drilling of deeper wells was observed, in comparison to the 2007–2009 drought[29]. In the sandy aquifers of the Coastal Plains, water levels were also reduced but no issues with groundwater supply for agriculture and human consumption were reported.

3.8. Lessons Learned from Water Supply Impacts for the Drought Early Warning System

Because of the relatively short length of the 2016 drought compared to other recent droughts in the region, hydrologic impacts to the region were more restricted. Streamflow in some areas did reach new record lows, especially near the end of the drought. Consequently, a few communities in western Georgia and northeast Alabama had to apply for variances from the state water management rules to ensure they had enough water for their citizens. If the beginning stages of the drought had been identified earlier in the drought cycle, the water managers of the affected communities might have been able to apply for variances and get approval more quickly. However, once the application process was started, the procedures already in place in those states allowed managers to do what they needed to ensure that water supplies for their communities were available. Since it was difficult to find reports of impending water shortages from local water authorities, in the future it might be useful to garner more input to the Drought Monitor from local water managers to help the DM authors accurately depict drought as it is developing.

Most of the large reservoirs are well-managed, with operating plans that include procedures to be used in drought, and none of these large water supplies was significantly threatened by the drought. The plans worked as they were designed, and an earlier warning of an impending drought would not have been likely to change their operations other than to follow the guide curves already in place. And fortunately, the drought was only a year in length, limiting the worst impacts of the drought compared to multi-year droughts, such as the 2007-2009 drought. In this drought, there were dire predictions of the City of Atlanta running out of water in six weeks[30] (although it is unlikely that would have occurred).

Groundwater supplies in the 2016 drought were not significantly impacted by the precipitation deficits, given the short duration of the drought. Since groundwater responds on a much slower time scale to drought than streamflow and reservoir levels, it is unlikely that impacts from low groundwater levels would occur without impacts in the other water sources occurring first and sounding the alarm.

The 2016 drought was severe in many aspects, especially on its early impacts on agriculture and the significant impacts from wildfire that occurred in fall. But water resources in the region were not severely impaired by the dry conditions. Wet conditions before the drought began helped reduce the reduction in streamflow and reservoir levels through the spring and summer, and another wet spell at the end of November helped quickly reduce the impact of dry conditions on streams and wells, limiting the consequences to water supply. A longer drought would likely have had more significant effects on the availability of water.

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Chapter 4. Wildfires

4.1. Introduction

Extremely dry conditions during the fall phase of the 2016 Southeast drought set the stage for the ignition of numerous wildfires across the region, especially in the Southern Appalachian Mountains (SAM) (Fig. 4.1). The vast majority of these fires occurred in November and were fed by extremely dry leaf litter that had recently fallen from the tree canopy. Moreover, the underlying duff layer was present in parts of the forest and added greatly to the fire's fuel load[2]. The National Interagency Fire Center (NIFC) led more than five thousand firefighters in the effort to extinguish the fires[3]. State and local firefighters handled many additional smaller wildfires. Several of the wildfires were very large in size and required an extraordinary amount of time and resources to contain. The Pinnacle Mountain Fire in extreme northern South Carolina, for example, burned over 10,000 acres in a 26 day period and cost more than 5 million dollars to contain[4].

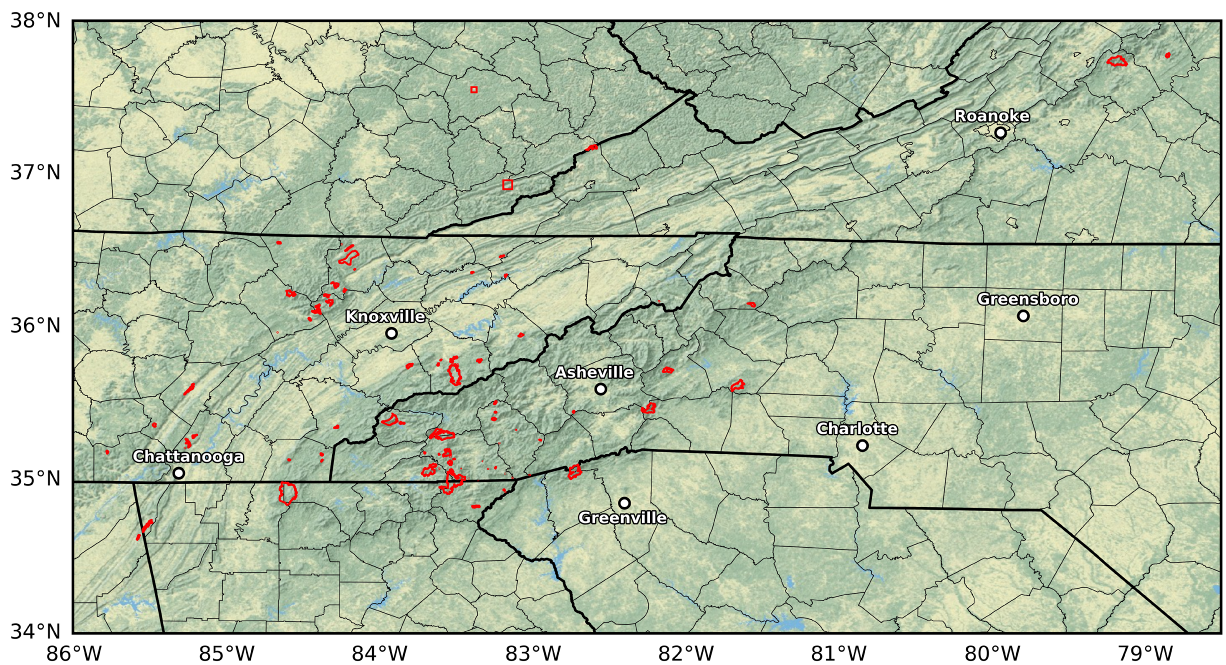

Figure 4.1. Areas burned by larger wildfires (1,000 acres and greater) in the 2016 drought across the Southern Appalachian Mountains[1].

Many of the SAM fires spread slowly due to the persistence of fair weather and weak winds, conditions that are common in the Southeast during the fall season under drought conditions. However, there were brief episodes of strong winds following the approach or passage of cold frontal systems that resulted in rapid and unpredictable fire movements. Most noteworthy was the Gatlinburg, Tennessee wildfire that killed 14 people, injured another 134, and destroyed over 2,400 structures[5]. A number of other communities, including Chimney Rock-Lake Lure, North Carolina, were threatened at times by rapidly spreading wildfires that were fanned by strong winds.

The fall season is a period in which many people hike, hunt, and camp in the SAM. With numerous warm and sunny days, record numbers of people recreated in the region - see Chapter 6 for details. While officials instituted a variety of burning and firework bans to prevent the accidental ignition of fires, many of the wildfires were intentionally ignited by arsonists[6, 7].

Section 4.2 of this chapter provides a background on wildfires in the SAM and context for understanding why the 2016 wildfire outbreak was extraordinary. In section 4.3, the exceptionally dry conditions observed during the fall phase of the 2016 drought are tied to the character of the SAM wildfires. In section 4.4, unique aspects of the SAM wildfires are spelled out and related to the distinctive character of Appalachian forests and the challenges of containing fires in its complex terrain. Section 4.5 summarizes the deadly Gatlinburg fire and highlights several lessons learned from the wildfire outbreak.

4.2. Background on Wildfires in the Southern Appalachian Mountains (SAM).

A wildfire requires fuel and an ignition source. The fuel is provided by organic material that has been dried out by drought conditions. These organics include vegetation (e.g. trees, shrubs, and grasses), leaf litter and an underlying duff layer, which contains decomposing organic material. Because of its wet climate, SAM forests are quite lush and provide copious amounts of leaf litter and woody debris, except at the highest elevations. Consequently the leaf litter layer is relatively thick, and the underlying duff layer quite deep, at least in parts of the forest where the woody vegetation supports its development[8, 9]. When a drought develops, these layers gradually dry out and become increasingly flammable starting with the leaf litter on top. When conditions remain dry for long periods, the duff layer may dry out and add greatly to the fuel load (e.g., up to 12 tons per acre per inch of duff[10]. While drought conditions set the stage for wildfire occurrence, low relative humidity and strong winds assist in spreading the fire.

Because of its moist climate and a lack of a dry season, the natural return period for fires in the SAM is longer than other parts of country, ranging from 7 years in the lower elevations to more than 35 years at the highest elevations (e.g., 5000' and higher)[11]. However, because of fire suppression efforts in the last >80 years, many forested areas in the SAM have not burned at all during that time[12]. Consequently, the upper layers of the soil (e.g., duff) have more organic material, which provide wildfires much more fuel to burn when they are ignited[13].

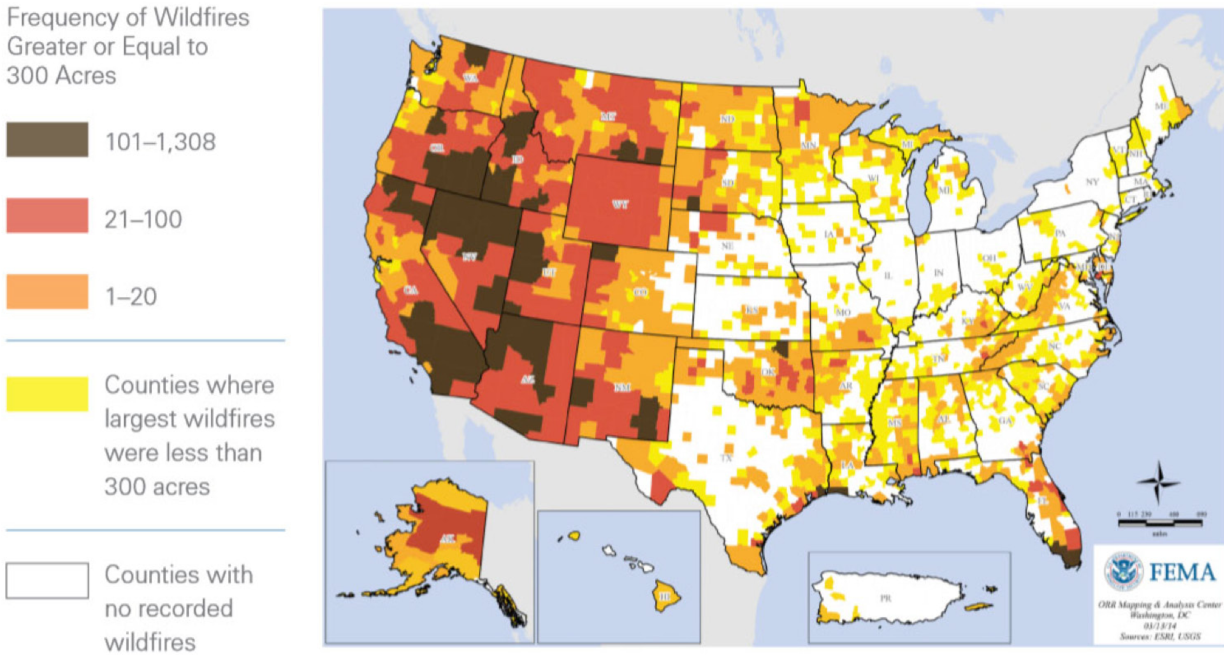

Figure 4.2. Wildfire activity by county: 1994–2013[14].

While the SAM has a longer fire return period, the region experiences a relatively higher number of large fires as compared to other areas in the interior Southeast (Fig. 4.2). This is due to the challenge of containing fires in remote areas and areas where the terrain is rugged. Significant time is required for firefighters to reach these areas, where they are forced to use hand tools to construct fire lines. Unfortunately, bulldozers cannot be transported in nor can they be used near roads in many places, because of the dangers of operating them on steep slopes. Without bulldozers, the construction of fire lines is a primitive, labor-intensive task[15, 16].

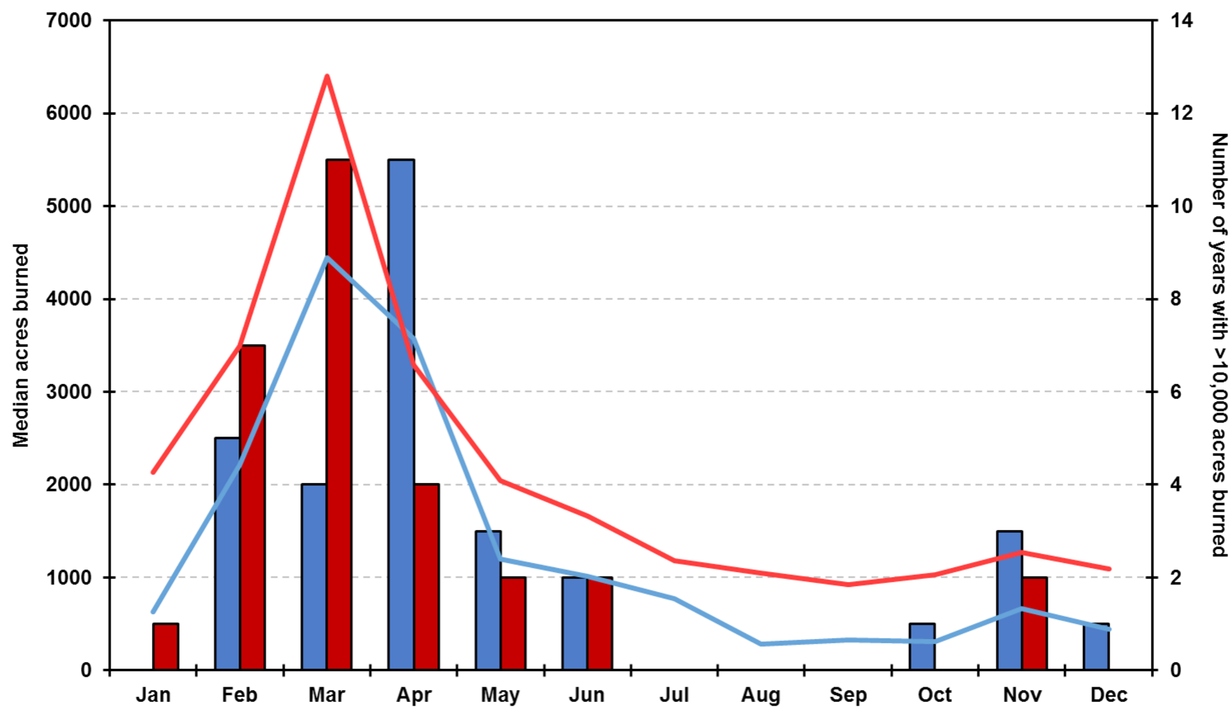

Figure 4.3. The median number of acres burned annually (lines) by wildfires and the number of years with large wildfires (bars) in state forests and private lands by month for the states of Georgia (red) and North Carolina (blue) from 1980–2016[17].

Fire data from state and private lands in Georgia and North Carolina reveal a prominent peak in wildfire activity in the late winter and early spring (Fig. 4.3). This time window corresponds with the leaf-off period for deciduous trees (i.e. senescent, dry vegetation) and the period of the year in which strong frontal systems periodically usher in strong winds and very dry air. Consequently, if drought conditions are present, only a single ignition is necessary to initiate a rapidly spreading wildfire. A small, secondary peak occurs in November when fresh leaf litter is present on the forest floor. Wildfire data from Tennessee also shows this secondary peak[18]. The lack of wildfires in the late fall may be due frequent occurrence of rainfall most years and the absence of days with extremely low humidity and strong winds.

Many of the wildfires in the SAM are human caused, either by the work of an arsonist or by accidents (e.g., campfires, outdoor burning, etc.). Unlike the western U.S., lightning ignites relatively few wildfires, as thunderstorms are infrequent during the periods of the year in which the forest floor is dry.

4.3. The Nature of the 2016 Drought and SAM Wildfires

The 2016 wildfires occurred during the autumn (September–October) phase of the Southeast drought, which was characterized by widespread and persistent dryness.

Weather Stations with records exceeding 130 years					
	Atlanta GA	Asheville NC	Greenville SC	Chattanooga TN	Knoxville TN
Length of record	140 years	149 years	134 years	139 years	147 years
Total Precipitation (inches)					
One month 10/28–11/27/17					
Amount	0.00	0.00	0.20	0.06	0.27
Deficit	-4.00	-3.60	-3.50	-4.80	-3.60
Ranking	**1st driest**	**1st driest**	2nd driest	**1st driest**	**1st driest**
Three months 8/28–11/27/16					
Amount	3.59	1.10	1.72	2.24	1.87
Deficit	-8.40		-8.90	-9.90	-7.40
Ranking	8th driest	**1st driest**	**1st driest**	**1st driest**	**1st driest**
Mean Temperature (°F)					
Three months 8/28–11/27/16					
Observed	69.9	61.9	67.2	68.4	66.4
Departure	+5.2	+4.1	+4.1	+5.5	+5.0
Ranking	**1st warmest**	**1st warmest**	2nd warmest	**1st warmest**	**1st warmest**

Table 4.1. Precipitation and temperature statistics for selected weather stations around the SAM with very long records[19].

Weather stations with the longest period of record (i.e., >130 years) in the SAM region recorded their driest one month (10/28–11/27/2017) and three months on record (8/28–11/27/2016) (Table 4.1). Given the long period of record, this level of dryness would be expected to occur less than once every 100 years on average. Asheville, North Carolina went 37 consecutive days (10/22–11/27) without measurable precipitation, making it the second longest streak of dry days in its 149 year record. Atlanta, Georgia went 43 consecutive days (10/17–11/28) without measurable precipitation, making its streak the longest in a record going back 140 years. The extreme dryness was also accompanied by record warmth and numerous sunny days, as the four stations with 130 plus years of record all observed their warmest three months on record. Consequently, forest soil evaporation rates were well above normal.

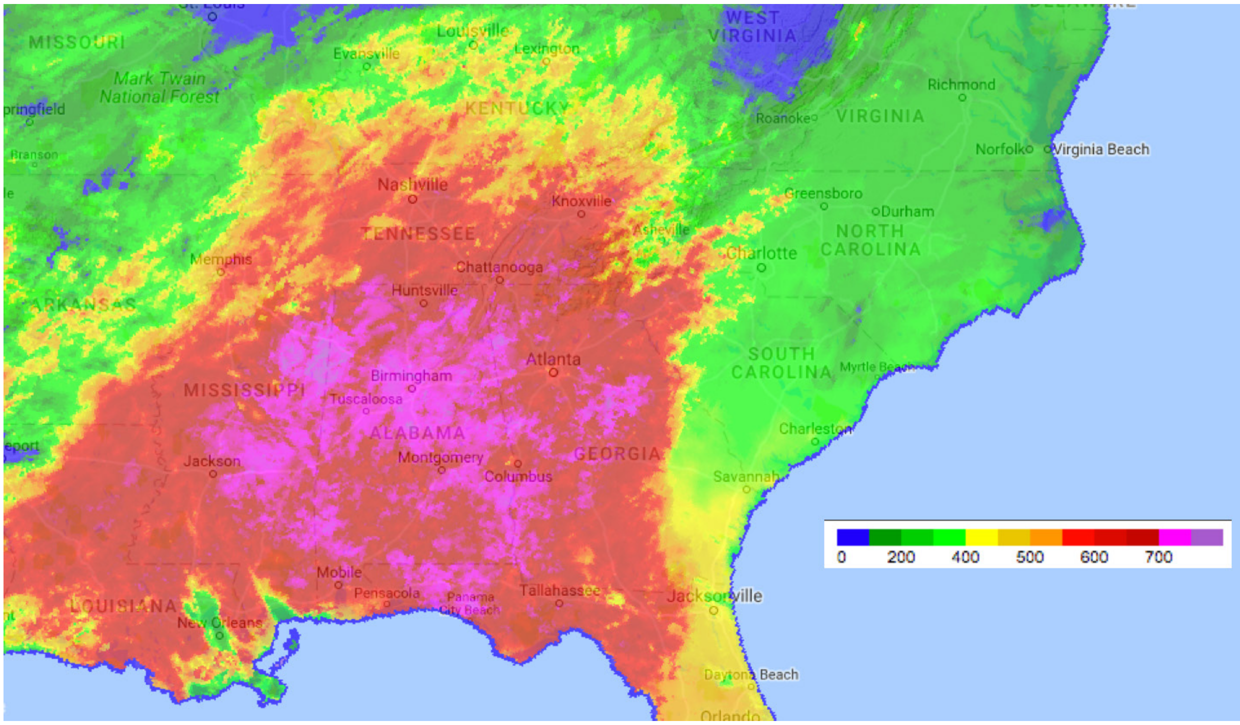

Figure 4.4. Map of Keetch-Byram Drought Index (KBDI) values across the Southeast U.S. on November 27, 2016[21].

The lack of precipitation and record warmth combined to desiccate the forest floor across the SAM. The Keetch-Byram Drought Index (KBDI) is commonly used to quantify the moisture deficits in the forest soil and assess fire risk[20]. The KBDI incorporates the effects of evaporation and precipitation to provide a measure of deep duff and upper soil layer dryness. One caveat is that the KBDI is developed for sandy soils, which are generally not present in the SAM. The highest values of the KBDI occurred at the end of the period of extreme dryness in late November across much of Mississippi, Alabama, Georgia, and southern Tennessee (Fig. 4.4). Values in this region exceeded 600, which equate with severe drought and increased wildfire occurrence. Indeed, the extreme dryness set the stage for the ignition of numerous fires in this region, the vast majority of which were extinguished before getting out of control[22]. This included several fires in Shelby County, Alabama that were ignited by an explosion on the Colonial pipeline, which carries fuel to the East Coast from Texas[23]. Most of the wildfires in the SAM occurred slightly northeast of the region of highest KBDI values. However, the KBDI still exceeded 600 in many places, which is extraordinarily high relative to what is normally observed in the area for that time of the year.

All of the major wildfires in the SAM occurred in the month of November after litterfall was well underway beneath the tree canopy, except for the Rough Ridge fire in Georgia, which was ignited by lightning on October 16th. Due to the lack of high winds and rainfall, litterfall was delayed and occurred over a much longer period.

The prime fuel source for ignition of the SAM fires was the dry leaf litter on the forest floor[24, 25].

Because there was no measurable rain until the 28th of the month in many locations, the leaf litter was extremely dry. Additionally, sunny skies and warmer than normal temperatures resulted in low relative humidity that accentuated the drying of the leaf litter. The low humidity also prevented the development of radiation fog during the long nights, which is common in the valleys during this time of the year[26]. Normally, these fogs will moisten the leaf litter.

The leaf litter was even more flammable because it was unpacked, with many air pockets between the leaves. Due to its aeration, the litter was extraordinarily deep. One firefighter commented that the leaf litter was as high as his hips in places in wind-blown drifts[27]. The aeration of the leaf litter can be tied to the absence of rainfall, as a single rainfall event is sufficient to pack down the fresh leaf litter and remove much of its air. Also, the rainwater intercepted by the leaf litter assists in the decomposition of the leaves and a reduction in the concentration of volatile organic compounds (VOC). Without rain, these VOCs may alter the flammability of the leaf litter, a phenomenon still under investigation[28].

The underlying duff layer provided extra fuel to wildfires in parts of the forest where it was present. The duff, which lies underneath the leaf litter, was quite dry and flammable, as indicated by KBDI values that exceeded 600 across portions of the SAM. The dryness of the duff can be tied both to the record 3- month precipitation deficits (between 8/28 and 11/27/2016) and also to the lack of precipitation observed across portions of the SAM in the prior months (i.e., summer phase of the drought).

4.4. Other Factors that Contributed to Make the SAM Wildfires Extraordinary

As discussed in the prior section, extreme dryness coupled with numerous warm, sunny days set the stage for the extraordinary wildfire event in the SAM. The persistence of these conditions during the fall phase of the drought desiccated the leaf litter and, in some cases, the underlying soil duff layer to provide a high fuel load for the fires.

Other factors contributed to make the SAM wildfire event extraordinary. Many of the fires were ignited by arsonists; in fact all but one of the large wildfires was started by humans, suggesting that much fewer fires would have occurred without these ignitions[29]. Humans have also played a role through fire suppression practices carried out the last >80 years. This has increased the amount of vegetation biomass, especially in the understory, thereby providing additional fuel for the spreading fires.

Considerable time and resources were required to contain many of the fires. This allowed a number of the wildfires to grow to a very large size. Many of these wildfires occurred in areas of steep terrain that were often some distance from the nearest road, which prevented the use of bulldozers. In many instances, firefighters had to hike some distance from the nearest road to manually construct fire breaks using only hand tools[30]. These efforts required a very high number of firefighters. For example, over 700 firefighters worked to contain the 7000-plus acre Party Rock wildfire in North Carolina at a cost of nearly 8 million dollars[31, 32]. Because the western U.S. fire season was just winding down, the supply of firefighters nationally was low.

Many of them were fatigued and had just started taking a much needed vacation. Others were on furlough and could not be readily called back to duty[33].

Efforts to contain the wildfires were also stymied by a gradual leaf fall that, in many cases, covered fire lines that had just been constructed by firefighters[34, 35]. In a typical November, leaves are knocked off their branches by rain or strong winds within a narrow time window by one or more precipitation events and/or strong cold frontal passages. However, the persistent ridging pattern and surface high pressure anchored over the eastern U.S. deflected most low pressure systems with their rain and winds to the west and north of the SAM. To compound matters, the period of leaf fall started later than normal, as evidenced by a peak in the fall foliage that was 7-10 days later than normal across the SAM[36]. Consequently, leaves were still falling after many of the wildfires had started. This lateness can be attributed to the warmer than normal temperatures and the persistent atmospheric ridging pattern associated with the drought.

The SAM wildfire episode was made more unique by the fact that the duff layer dried out and was deeply burned in a number of fires[37, 38]. Because of fire suppression over the years, the duff layer had gradually deepened in parts of the forest that supported its development. As a result, there was more fuel available for the wildfire to burn[39]. Duff burns slowly and produces high quantities of smoke that often result in very low visibilities and exceptionally reduced air quality downwind[40]. On some occasions, the thick smoke hampered firefighters' efforts to contain the fires, and afternoon breezes periodically reignited the smoldering duff, thus restarting fires that had to be extinguished a second time[41].

When duff burns, it can destroy much of the root mass. Most of the fine roots, which are ones most responsible for the majority of water and nutrient uptake, are located in the upper soil layers, including the duff layer. The loss of the fine roots can weaken and in some cases kill overstory trees, especially if a drought period follows the fire, as the trees will not have had time to replace the lost roots and the lack of water can result in excessive stress for the trees[42]. Initial surveys reveal low tree mortality in areas where the duff was burned. However, there is a concern that many of these root-damaged trees will suffer delayed mortality in the coming years, as they are much more susceptible to the ravages of pests and disease[43].

4.5. The Gatlinburg Fire and Lessons Learned

During the 2016 SAM wildfire episode, the largest fires generally burned at a low intensity, spreading slowly over a week or more before being contained. They were predictable and presented little danger to firefighters[44]. However, the light winds that supported their tame fire behavior was punctuated by a few short periods of strong, gusty winds that greatly increased their intensity and their speed of movement. In a few cases, these rapidly spreading fires presented a threat to nearby communities, and firefighters were challenged to protect building structures. The Party Rock fire in North Carolina, for example, forced the evacuation of more than a thousand people and various road closures in the Lake Lure recreational area[45]. The wind-fanned, Gatlinburg, Tennessee inferno, killed 14 people, injured another 134, and destroyed over 2,400 structures[46]. In this section, several aspects of this wildfire are summarized to draw out lessons learned (Fig. 4.5).

Figure 4.5. The Chimney Tops 2 wildfire, approaching Gatlinburg, Tennessee. Courtesy of the National Park Service (NPS) Incident Management Team[47].

The origin of the Gatlinburg inferno can be traced to the Chimney Rocks 2 fire in nearby Great Smoky Mountain NP (GSMNP), which was ignited five days beforehand by arsonists. Under generally light winds, the wildfire burned at a low intensity and spread slowly for several days. Due to the steep terrain, firefighters were unable to establish a fire break around the perimeter of the blaze[48]. When strong southerly winds developed ahead of an approaching intense low pressure system, a mountain wave developed, which accelerated the winds and dried out the air. This caused the wildfire to surge rapidly northward into the Gatlinburg area. At one point, the fire advanced 3 miles in just four and a half hours[49]. The winds blew hot embers downwind, igniting desiccated leaf litter and vegetation, and starting new fires[50]. The strongest gusts from this mountain wave approached hurricane force in local places and downed tree limbs onto power lines, which sparked even more fires. Due to the very rapid spread of the fire, the time of day, and damaged communications infrastructure, evacuation orders were issued too late to be effective or were never received. Given the rapid and chaotic movements of the fires, many residents and tourists could not safely evacuate.

The wind event was well forecasted. The National Weather Service (NWS) in Morristown, Tennessee issued forecasts of strong winds beginning several days before the inferno. One day beforehand, they warned of the possibility of "very windy conditions" with "winds gusts over 60 MPH possible". Rainfall was also forecasted to occur, however, the dry air accompanying the strong "downsloping" winds delayed its arrival[51]. Forestry officials were aware of these forecasts but greatly underestimated the potential for these winds to push the fire more than six miles into the town of Gatlinburg within a single day[52]. The meteorological combination of strong winds, associated with a mountain wave, and severe drought had never before been witnessed by anyone in GSMNP. Everyone involved in the firefighting effort commented that they "had never seen anything like this and could never even imagine that this could happen"[53].

The Gatlinburg fire provides a vivid example of what can happen within the wildland-urban interface when a high wind event occurs in the presence of a severe drought. This danger is well known in the western U.S., where fast moving and deadly wildfires are common. Because of the increase in vegetation due to fire suppression across the SAM, wildfires have more fuel to consume, especially in the understory vegetation. Consequently, surface fires can spread more quickly, both upward into the canopy and horizontally up and down the mountain slopes[54]. Given the difficulty of containing fires along steep slopes, they can readily spread across the wildland-urban interface when winds are strong.

The steep mountain slopes and lush vegetation present in Gatlinburg and other cities in the SAM are aesthetically pleasing, but they greatly increase the vulnerability of these communities to fast-moving wildfires. Gatlinburg is extremely susceptible because many buildings are constructed of flammable materials, especially rustic buildings, such as log cabins. Unfortunately, the city has issued more than 200 permits to rebuild structures using the same flammable building materials that burned to the ground in the 2016 inferno[55].

Another danger is the presence of dense understory vegetation that lies right next to many homes with no fire breaks whatsoever. In many instances, this vegetation consists largely of rhododendron or mountain laurel, which under drought conditions are more flammable than other understory tree species. Because of fire suppression, these understory shrubs have spread widely across parts of the forest where they never existed before[56].

According to Henri Grissino-Mayer, a fire ecology expert at the University of Tennessee, numerous communities in southeastern TN, besides Gatlinburg, are extremely vulnerable to rapidly spreading wildfires, and he contends that they are ignoring this hazard[57, 58]. Unfortunately, this danger is increasing each year, as more and more people build vacation homes in the region. In addition, projections from climate models suggest that the drought conditions that set the stage for these wildfires will happen more frequently in the future.

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Chapter 5. Public Health

5.1. Introduction

The public health impacts of the 2016 Southeast U.S. drought identified in this research were attributed solely to the drought-induced wildfires in the southern Appalachian Mountains. Because droughts typically disrupt human systems in indirect, subtle, and complex ways, rigorous research is often necessary to tease out its impacts on public health. Given the short time that has elapsed since the drought, no such studies to date have been identified. Because health data is not collected specifically with drought in mind, it is challenging to identify connections between drought and health outcomes (e.g., gastrointestinal and vector-borne disease).

Section 5.2 of this chapter provides a brief background on the subtle and widely varying impacts of drought on public health. Section 5.3 summarizes the deaths and injuries resulting directly from the 2016 wildfires. Section 5.4 identifies the spatiotemporal patterns of wildfire smoke and ties them to the circulation patterns that transported and dispersed the wildfire smoke. Section 5.5 describes the reported respiratory issues that were associated with the wildfire smoke. In section 5.6, the preparedness of communities to the wildfire smoke is examined. This includes the monitoring of air quality and the issuance of advisories and warning, as wildfire smoke spread across the region. In addition, challenges are identified in the interpretation of these air quality alerts, specifically in decisions on whether or not to cancel or curtail outdoor activities.

5.2. Background

Droughts can affect public health in a wide variety of ways. The lack of precipitation may lead to crop failures, which results in malnutrition and famine in the developing world. In the developed world, on the other hand, there is a greater “safety net” and resources to cope with the financial losses. However, the challenges of cultivating crops and culling livestock during a major drought impose emotional distress on farmers that can lead to mental health issues[1].

Reductions in the volume of surface water supplies can concentrate pollutants and bacteria thereby promoting waterborne disease. The decrease in the coverage of wet areas in the landscape during a drought (e.g., dry streams and wetlands) may also concentrate insects (e.g., mosquitoes) in the remaining wet areas and promote the emergence of vector-borne diseases, such as La Cross encephalitis. The extreme heat that often accompanies drought during the summer increases bacterial loads in surface water and promotes harmful algal blooms (HABs). As soils dry out during a drought, atmospheric dust concentrations often increase, especially along gravel and dirt roads and agricultural regions. And exposure to this dust can lead to various respiratory issues.

Wildfires ignited during periods of drought produce smoke can lead to respiratory issues (Delfino et al., 2016). Wildfire smoke contains very fine particulate matter (e.g., PM2.5), which is about 60 times smaller than the width of a human hair[2]. Because of their small size, these particles can lodge deep in the lungs, where they irritate and narrow the lining of the respiratory tract. This may result in coughing, wheezing, and shortness of breath, especially for individuals who have preexisting respiratory problems, such as asthma[3]. Older adults and children are more prone to these impacts. Wildfire smoke also contains carcinogenic chemicals, such as benzene, formaldehyde, and carbon monoxide[4]. Long term exposure to elevated concentrations of PM2.5 can lead to serious health problems, including premature death and aggravation of respiratory and cardiovascular disease[5].

5.3. Reported Deaths and Injuries from the Wildfires

As reported in the prior chapter, 14 people were killed and another 134 individuals were injured in the rapidly spreading Gatlinburg wildfire. Another death occurred in a chain-reaction collision of 18 vehicles in Powell County Kentucky, as dense smoke from a nearby wildfire reduced visibility to near zero. A motorist who stepped out of his vehicle was struck and killed by a moving vehicle[6, 7].

One death was reported in the firefighting efforts across the region. A volunteer fireman was killed near Harlan, Kentucky due to injuries sustained from a falling tree[8]. Miraculously, there were no injuries reported in any of the firefighting activities across the region, even though the efforts involved many thousands of firefighters. This speaks volumes for the safety training of the firefighters. Also, many of the fires advanced slowly and were well-behaved under light and variable winds; consequently, the firefighters were not subject to dangerous conditions[9]. However, these tame conditions were punctuated by short periods of high winds in which the firefighters were subject to high levels of danger– e.g., the Gatlinburg, Tennessee inferno and the Party Rock-Lake Lure, North Carolina wildfire.

5.4. The Transport of the Wildfire Smoke

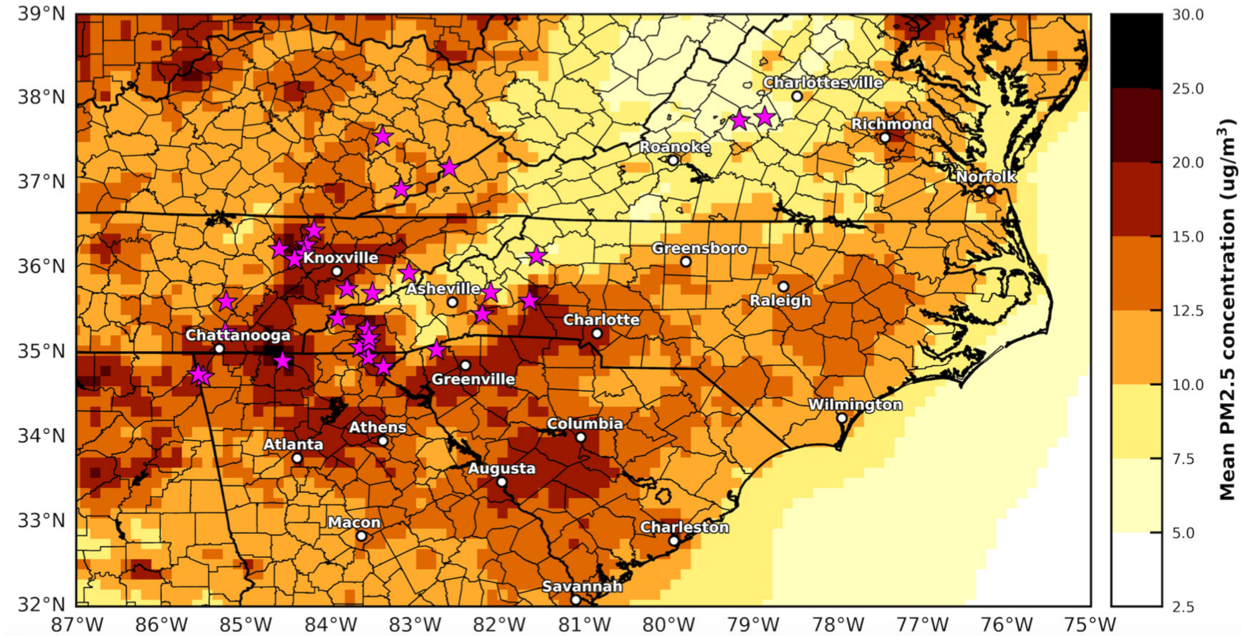

Figure 5.1. Average PM2.5 concentration in the bottom 10m of the atmosphere from November 5–19, 2016[10].

During the wildfire phase of the drought, winds transported the smoke to populated areas distant from the blazes. Figure 5.1 reveals the elevated PM2.5 concentrations across the Southeast U.S. during the period in which the wildfires were the most active. Much of the PM2.5 was from the wildfire smoke; however, there was some contribution from anthropogenic sources (e.g., over large urban areas, such as Washington, D.C.). The prevailing winds during the month dictated where the wildfire smoke was transported. The winds blew from the north to west on many days, thus wildfire smoke PM2.5 concentrations were generally higher within the southern Appalachian Mountains (i.e., near the wildfires) and southeastward (e.g., left panel of Fig. 5.2). The prevailing north to westerly winds were punctuated by short periods in which the winds blew out of the south and southeast, causing the wildfire smoke to drift north to northwest (e.g., right panel of Fig. 5.2). Archived animations of AQI (Fig. 5.3) from the EPA's AirNow model reveal the regional scale movements of wildfire smoke across the region during the November 2016 event[11].

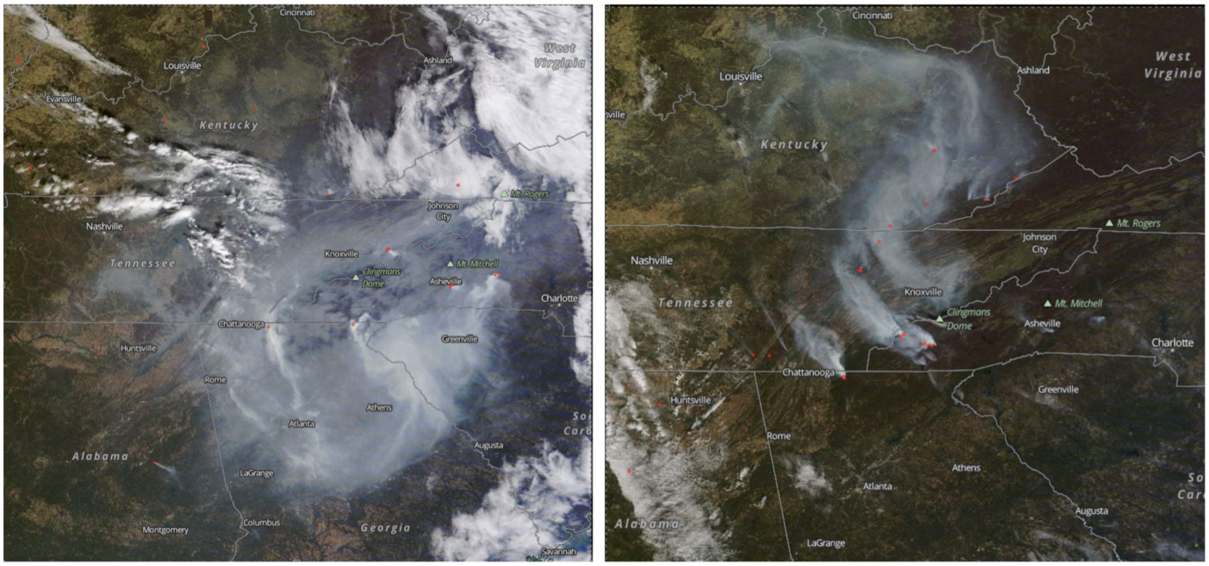

Figure 5.2. Visible satellite image depicting the patterns of wildfire smoke on November 14th (left) and November 7th (right)[12].

Drought conditions in the Southeast U.S. are typically associated with the persistence of an anticyclone (i.e., high pressure) across the region. Consequently, winds are generally light, and wildfire smoke is slow to disperse. Moreover, a subsidence inversion (from sinking motions in the middle troposphere) can trap the wildfire smoke and prevent it from dispersing upwards into the atmosphere. As a result, the smoke can become concentrated in the bottom 5,000–8,000 feet of the atmosphere. The light gray areas in Figure 5.2 reveal these higher concentrations of smoke. During the nighttime and morning hours, this trapping effect is often accentuated by a low-level, radiation inversion. Because of the lack of clouds, light winds, and the dry atmosphere in a drought, radiation inversions can be especially strong and persistent. Their influence, coupled with the confining effects of complex terrain of the Appalachian Mountains, further trap the wildfire smoke, especially in valleys situated near the fires. For instance, the left panel in Figure 5.2 indicates blotchy gray white areas in extreme western North Carolina. In some cases, the wildfire smoke becomes so concentrated that visibility approaches zero and driving conditions are very hazardous (e.g., chain-reaction vehicle collision in Kentucky, described in the prior section).

Air Quality Index Levels of Health Concern	Numerical Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health warnings of emergency conditions. The entire population is more likely to be affected.
Hazardous	301 to 500	Health alert: everyone may experience more serious health effects

Figure 5.3. The air quality index (AQI) scale[13].

On various days in November 2016, the wind transport of the wildfire smoke and the concentrating of this smoke beneath inversions increased PM2.5 levels to unhealthy levels in major cities distant from the wildfires (Table 5.1).

Date	Asheville, NC	Knoxville, TN	Greenville, SC	Atlanta, GA	Chattanooga, TN	Columbia, SC	Hickory, NC	Charlotte, NC	Charleston, SC	Athens, GA
11/1	52	68	58	68	58	44	55	55	28	54
11/2	61	78	50	57	58	50	55	55	31	41
11/3	44	64	58	59	47	55	53	56	38	41
11/4	20	23	38	54	38	52	20	33	40	33
11/5	53	59	39	52	54	43	24	50	35	52
11/6	55	52	70	70	70	59	22	67	39	58
11/7	72	152	59	62	57	45	29	39	60	33
11/8	113	169	45	62	58	45	75	51	37	25
11/9	79	56	38	76	52	63	70	47	56	44
11/10	9	36	93	112	90	34	27	30	24	116
11/11	38	64	132	82	55	94	38	78	102	162
11/12	152	59	30	76	152	27	21	33	61	16
11/13	167	112	106	60	174	25	85	51	21	32
11/14	158	164	188	151	177	86	153	65	37	120
11/15	141	131	173	112	82	168	152	82	155	154
11/16	65	79	126	63	57	155	93	154	158	113
11/17	52	67	91	64	70	85	94	99	117	88
11/18	86	66	99	70	62	76	133	83	78	68
11/19	64	53	52	50	27	58	57	58	61	29
11/20	17	26	45	45	11	32	12	23	27	13
11/21	11	49	52	53	25	40	14	29	41	22
11/22	149	54	53	68	68	53	59	71	40	40
11/23	156	105	67	66	62	64	71	59	39	50
11/24	56	96	49	52	48	64	54	52	35	30
11/25	46	53	53	55	34	65	53	55	33	27
11/26	38	49	25	59	45	54	33	38	36	36
11/27	92	59	48	63	53	62	47	56	33	28
11/28	89	57	57	53	38	47	58	52	28	31
11/29	15	24	20	41	27	24	17	22	36	16
MEAN	**74**	**73**	**69**	**67**	**64**	**61**	**58**	**57**	**53**	**54**

Table 5.1. Daily air quality index (AQI) values for PM2.5 across selected cities in the Southeast for the first 29 days of November. Code yellow, orange, and red days are highlighted[14].

The metropolitan areas of Asheville, North Carolina and Knoxville, Tennessee, which were nearest the fires, displayed the poorest air quality during the month. The air quality was lowest between November 11 and 16, as the atmosphere was especially stagnant. Several plumes of wildfire smoke drifted slowly southeastward and greatly reduced the air quality in major cities as far away as Columbia and Charleston, South Carolina.

5.5. Respiratory Impacts from the Wildfire Smoke

To date, there have not been any systematic analyses of the health effects and outcomes from the poor quality associated with the wildfires, except for a pilot study that is summarized in the callout box above. Consequently, much of what is currently available are media reports. Many of the media reports of respiratory effects from the wildfire smoke occurred between November 11th and 16th, the period in which the wildfires were especially active and the atmosphere was the most stagnant. Two hundred patients were hospitalized for shortness of breath and breathing issues due to the wildfire smoke in the Chattanooga, Tennessee[15, 16]. These hospital admissions occurred between the 11th and 14th of the month, the period in which the PM2.5 air quality index was in the "code red" range (Table 5.1). Archived animations from EPA's Air Now website[17] reveal that the Chattanooga metropolitan area displayed "code purple" conditions for combined ozone and PM from the evening of 11/13 through the evening of 11/14. Code purple values on the AQI index indicates that "the entire population is more likely to be affected by the poor air quality" (e.g., Fig 5.3).

East Tennessee Children's Hospital in Knoxville, Tennessee observed a spike in emergency room visits during this same period, with many patients suffering respiratory issues associated with asthma[18, 19]. According to the chief of emergency medicine at Grady Health System in Atlanta, Georgia, there was a "big increase in the number of patients coming in", especially those with preexisting conditions, such as asthma[20]. The Spartanburg, South Carolina Regional Health Care System saw "sporadic increases" in patients with respiratory issues related to the wildfire smoke[21]. The media also reported that many people who suffered milder respiratory symptoms from the smoke sought treatment from their family physician[22]. There were also media reports that the wildfire smoke was causing people's eyes to burn[23].

Given the media reports of increases in respiratory illness due to the wildfire smoke, the Southeast Regional Climate Center (SERCC) and the Carolinas Integrated Sciences and Assessments (CISA) program collaborated with the North Carolina Department of Health on a pilot study in 2017 to examine this association in more detail. They looked for relationships between daily PM2.5 levels (i.e., wildfire smoke concentration) and the number of respiratory emergency department (ED) visits across four counties of North Carolina, two situated in the mountains near the wildfires (Buncombe and Rutherford counties) and two located downwind in the Piedmont region of the state (Mecklenburg and Stanly counties). They were unable to identify significant relationships at the daily scale in any of the four counties. They tested not only for contemporaneous relationships (e.g., day-to-day peaks in PM2.5 corresponding to a day-to-day peaks in ED visits), but also lagged relationships out to 6 days (e.g., peak in PM2.5 corresponding to a peak in ED visits one to 6 days in the future). They looked at both aggregated counts across all respiratory disease types and particular disease classifications, including asthma, COPD, and acute bronchitis. They also looked at ischemic heart disease. Figure 5.4 shows a daily time series of PM2.5 and ED visits for the Asheville-Buncombe County, region of North Carolina, which had the highest mean PM2.5 counts during the wildfire period (Table 5.1). Though there is no discernable relationship between day-to-day PM 2.5 levels and ED visits, the plot does reveal a gradual increase in (residual) ED visits during the month (relative to the baseline). This could suggest a relationship between wildfire smoke and ED visits over longer time scales (e.g., beyond the 6-day lag investigated in the pilot study). The investigators hypothesize that ED visits may not be the best way to capture health impacts, especially asthma. Their pilot study underscores the challenges associated with documenting and teasing out health impacts from short-term exposure to wildfire smoke[25].

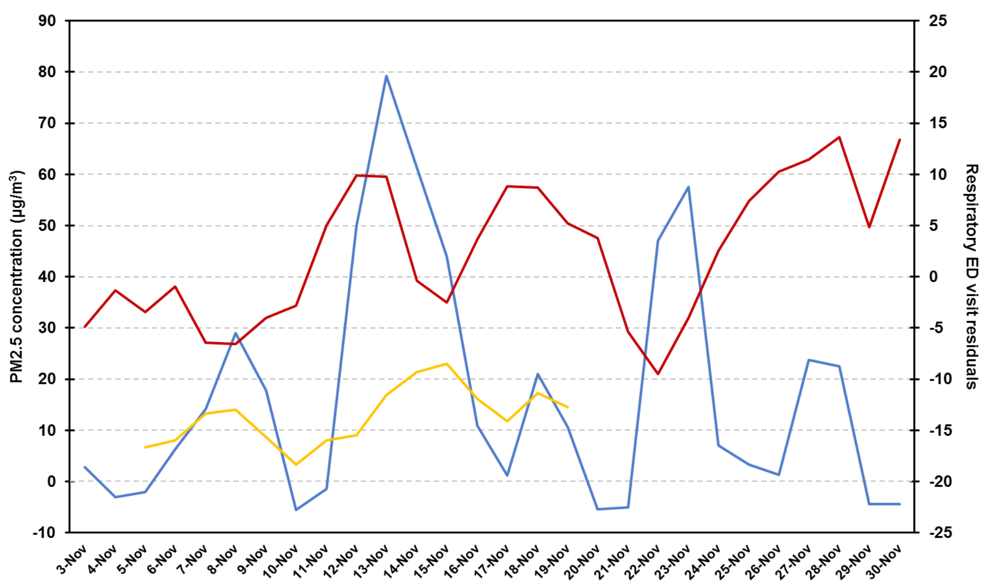

Figure 5.4. Daily values of PM2.5 (blue line) at a monitoring site in Asheville and EPA modeled PM2.5 (gold line) for Buncombe County, North Carolina along site residuals of respiratory emergency department (ED) visits (red line) for Buncombe County, North Carolina during the period of wildfires[24].

5.6. Community Preparedness and Preventive Measures

Numerous air quality advisories and warnings were issued in response to the wildfire smoke drifting across the region. These alerts were widely communicated by a variety of media sources, including local and national newspapers, television stations, and social media. The media also provided much information on what individuals should do to protect themselves from the wildfire smoke[26, 27, 28].

A number of federal, state, and local agencies monitor and forecast air quality levels on a daily basis as a part of their operations. These agencies work together (e.g., via conference calls) and coordinate on the issuance of air quality forecasts that are consistent across different jurisdictions[29]. The Environmental Protection Agency (EPA) runs the state of the art AirNow model to forecast the AQI (for ozone and PM combined) on an hourly time scale across the U.S.[30]. State-level air quality offices monitor daily PM2.5 levels at various stations, and some of these offices forecast 24-hour PM2.5 levels, either across all counties in their state (e.g., North Carolina) or parts of their state not in EPA compliance (e.g., Georgia)[31]. Local agencies in at least one metropolitan area (e.g., Winston Salem, North Carolina[32]) also make daily forecasts of PM2.5.

Other agencies also issued air quality alerts during the 2016 wildfires. The Department of Public Health in Kentucky used AQI forecasts to issue smoke inhalation advisories for poor air quality across the state[33]. Also, the National Weather Service (NWS) offices across the region issued air quality alerts that provided more details on areas in which high concentrations of wildfire smoke were expected. These details were identified by combining information from air quality offices with higher resolution meteorological data (e.g., hourly visibilities and visible satellite imagery)[34]. Finally, the North Carolina Division of Environmental Quality issued a guide that enabled people living in the mountains to translate estimated visibilities, specifically the distance to farthest visible mountain ridge, into an AQI[35] (e.g., Fig. 5.3).

Because people readily notice the odor and limited visibility from wildfire smoke, unlike ozone, more of them probably heeded the warnings, especially those with respiratory issues, such as asthma[36]. Some communities near the wildfires were especially proactive in protecting their citizens from the smoke. In Clay County North Carolina, for example, hundreds of citizens signed up to receive air quality updates via a web-based emergency notification system[36]. In at least six counties of western North Carolina, special masks (N95-rated) were distributed to protect people[37]. In addition, various school systems (e.g. Greenville County South Carolina and Haywood County North Carolina) took measures to limit student exposure to the wildfire smoke, for example, allowing those with respiratory issues to remain inside school buildings[38].

In some cases, public officials had difficulty translating the information in the air quality alerts into their decision-making process regarding planned outdoor events. For example, at what level on the AQI scale (Fig. 5.3) would it be prudent to cancel a high school football game[39]? Additionally, public officials wanted more details on the air quality over the course of the day, while forecasts only provided a single AQI value for a 24-hour period[40]. Unfortunately, there are limits in the ability to forecast air quality. This is especially the case in forecasting wildfire smoke concentrations, which often show considerable hour-to-hour variation over small distances (e.g., 1–10 miles)[41]. Air quality forecasting is especially challenging in the mountains, where terrain-mediated wind circulations and low-level inversions can complicate the movement and dispersal patterns of wildfire smoke.

In at least one case, officials decided not to cancel or postpone an outdoor event, even though poor air quality conditions were predicted. Organizers of a running road race in Asheville, North Carolina held the event despite a “code red” forecast for air quality (Fig. 5.4), which was verified on the race day[42]. Running organizers had expected about 1,800 runners and slightly more than 1,500 actually ran the race[43]. No information could be found on the impacts of the wildfire smoke on the runners.

The information gathered from this assessment, especially the media reports, provide a sampling of the health impacts of the wildfire smoke and community responses to the warnings and advisories; they don’t represent a comprehensive analysis of the health impacts or the activities that occurred in response to the poor air quality conditions. Moreover, there are other health outcomes from the drought, such as mental health impacts, that usually arise months to years later. A thorough, systematic study is therefore needed to objectively assess the health impacts of the drought and wildfire smoke and the effectiveness of the community response to these impacts. Finally, the North Carolina pilot study (e.g., Fig. 5.4) reveals that the public health impacts of wildfire smoke on humans are more nuanced and not necessarily straightforward, as suggested by the media reports. And to compound matters, there are wide gaps in research on this growing public health issue[44].

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Chapter 6. Tourism

6.1. Introduction

Our analyses indicate that the Southeast drought of 2016 impacted tourism and recreation in both negative and positive ways. Section 6.2 of this chapter provides a brief background on the ways that drought has impacted tourism in other regions. Sections 6.3 and 6.4 identify and discuss the negative and positive impacts, respectively, of the 2016 drought on tourism.

6.2. Background

Tourism and recreation are a very big business in the United States, with annualized expenditures totaling over 800 billion dollars[1]. Drought can impact tourism and recreation in a variety of ways. Long-term hydrological droughts greatly reduce surface and ground water supplies and therefore impact water and snow-dependent activities, including boating, rafting, fishing and skiing. This is particularly true in regions, such as California, where persistent, multi-year droughts are common. Tourist venues, such as Disneyland in Anaheim, California have adapted to these long droughts by developing various water conservation measures (e.g., recycling nearly all of the water that they use)[2]. Droughts can also alter the migration patterns of birds and animals and consequently have a detrimental effect on wildlife viewing and hunting[3].

Droughts also set the stage for wildfires, which can have big impacts in the tourism and recreation industry. In the worst case scenario, wildfires destroy tourist facilities or greatly reduce the aesthetic beauty of tourism destinations and recreational venues (e.g., scorched landscapes and burned forests). In many cases, news media reports and videos of wildfires and wildfire smoke provide negative images of tourist destinations months after the conflagrations, even when the tourist venues are situated far from the fires and smoke. For example, a media focus on a wildfire in a small part of southern California may discourage people from vacationing anywhere in the region. More generally, negative perceptions of drought (e.g., brown landscapes, water shortages) conveyed by the news media discourage tourists from vacationing in drought-stricken areas[4].

While water shortages and wildfires negatively impact various tourism venues and recreation areas, the persistence of pleasant weather (e.g., sunshine, light winds, and a lack of rain) during droughts encourage people to travel and recreate.

6.3. Negative Impacts of the Drought on Tourism

As discussed in Chapter 1, the 2016 drought was shorter in duration that other major droughts that have affected the Southeast U.S. Consequently, stream levels and groundwater tables in most places did not dip enough to trigger water shortages and impact tourism. However, there were impacts of the low water levels on various recreational activities along rivers and lakes. As the hydrological drought worsened during the fall of 2016, an increasing number of boaters lost access to public and private docks along Lake Lanier in North Georgia[5]. Also, an increasing number of boats hit the lake bottom while cruising along shoals and shallow coves[6]. The water level on the lake fell to a maximum of 10 feet below the top of the conservation pool near the end of December 2016. This scenario played out across other lakes in the drought-stricken region as well.

The extreme surface dryness associated with the drought set the stage for wildfires that impacted tourism and recreation in portions of the southern Appalachian Mountains (SAM). The most egregious losses occurred in the devastating Gatlinburg Tennessee wildfire, which was described in the last chapter. In the first part of this chapter, the economic losses in this tourist mecca and the adjacent Great Smoky Mountain National Park (GSMNP) are summarized. In addition, the rebuilding efforts taking place in 2017 are examined with an emphasis on the tourist community's vulnerability to future wildfires. The impacts of the Party Rock fire on tourism in the Lake Lure, North Carolina recreation area are also reviewed. Finally, impacts of wildfire on hiking are identified along the Appalachian Trail (AT).

6.3.1. Gatlinburg, Tennessee and Great Smoky Mountain National Park

More than 12 million people visit Gatlinburg, Tennessee and the broader area of Sevier County each year[7]. Besides the Dollywood theme park, the area contains a wide array of tourist venues that includes museums, scenic overlooks, candy shops, a space needle and a ski resort. The Gatlinburg wildfire, summarized in Chapter 4, destroyed more than 2,400 structures, mostly in and around Gatlinburg, and caused more than a billion dollars in damages. Roughly $922 million dollars in losses were filed, according to the Tennessee Department of Commerce and Insurance, which does not include losses from uninsured or underinsured properties[8]. Adjacent to Gatlinburg is GSMNP, which has more than 10 million visitors annually and is the most visited national park in the country. More than 11,000 acres of the park were burned, though only about 10 percent of this area was burned severely[9].

In spite of the damages, the city of Gatlinburg was closed for less than two weeks after the fire. While many Gatlinburg hotels sustained smoke damage and remained closed for repairs and replacement of furnishings, many tourist venues were not burned and did not incur any smoke damage, especially in downtown Gatlinburg where these businesses are concentrated[10]. However, attendance figures remained low because many people had the false impression from the media that the town had burned down to the ground, according to a local businessman, Eric Hensley[11]. It is estimated that the tourism industry in Gatlinburg lost $19 million in the first month after the fire (i.e. December 2016). The manager of a candy store reported that business was down about 30% during winter and spring of 2017[12].

Though only about 10% of GSMNP was affected by the wildfires, the Park saw a 17.4% drop in attendance during December 2016 relative to the prior year, which was due in part to the Gatlinburg entrance being closed for 9 days after the fires[13]. However, attendance recovered in

January 2017, with a 1.1% increase attendance compared to the prior year[14].
In the response to the fires, Gatlinburg received much financial aid, including over $21 million from the state of Tennessee, $3.3 million in Federal Emergency Management Agency disaster funds, and more than $9 million from a telethon lead by Dolly Parton. Great Smoky National Park received nearly $667,000 for emergency fire stabilization from the National Park Service and hopes to garner nearly a million more over the next three years[15].

In spite of the financial losses, the Sevier County Economic Council estimates that tourism revenue will increase by 3% in 2017, compared to the prior year. Though hundreds of rental properties were damaged, there were plenty of accommodations available in cabins and hotels in the months that followed[16]. In GSMNP, there was a 2.2% annual increase in attendance at the Gatlinburg gate to the park between September 2016 and 2017[17]. This increase was observed in spite of brief park closures due to the effects of tropical storms Irma and Nate[18].

The Gatlinburg tourist mecca is extremely vulnerable to wildfires, as reported in Chapter 4. However, the town has issued more than 200 permits to rebuild structures using the same flammable construction materials that fed the 2016 wildfire flames, according to Henri Grissino-Mayer, a fire ecology expert at the University of Tennessee. He says that residents and town officials erroneously believe that this was a “one in a 100-year event”. Consequently, they are ignoring recommendations to utilize fire retardant building materials, as recommended by the Federal Emergency Management Agency[19, 20].

6.3.2. Chimney Rock - Lake Lure, North Carolina

Extreme drought conditions set the stage for the Party Rock fire near the tourist hamlets of Chimney Rock and Lake Lure NC. While much smaller than Gatlinburg, the area has a tourist season population of roughly 12,000 people. Besides lake recreation, there are lots of hiking trails and rustic cabins. Lake Lure is also known for the movie “Dirty Dancing”, which was filmed there in the late 1980’s.

Unlike the Gatlinburg inferno, the Party Rock fire spread slowly on most days and was well behaved. Consequently firefighters managed to prevent the flames from reaching any building structures. Over a two-week period in November 2016, the wildfire burned over 7,000 acres and led to the evacuation of more than 1,000 residents[21]. It also closed the one main highway that connects the tourist businesses. The wildfire occurred during the height of the tourist season and forced many lodges and restaurants to close[22]. One estimate is that 50–100 business were affected by the fire[23].

While no structures were damaged in the fire, tourist businesses in the Chimney Rock – Lake Lure area suffered from negative perceptions in the wake of the fire, similar to Gatlinburg. According to Don Cason, the executive director of the Rutherford County Tourism Development Authority, tourist venues observed a 50–70% drop in business in the month following the wildfire[24].

6.3.3. The Appalachian Trail

During the fall of 2016, 150 miles of the Appalachian Trail (AT) were closed at various times due to the wildfires. This included 72 miles in GSMNP, 68 miles in North Carolina, and 10 miles in Georgia[25]. The trail closures had a negative impact on businesses that cater to the hikers in towns near the trail. Many hikers skipped the closed areas of the trails, which was especially unfortunate for those whose goal was to hike the entire trail. Also, two businesses that serve AT hikers in Bryson City were closed for five days because of a nearby wildfire. Neither business was damaged by the fire, and both reopened soon afterward[26].

6.4. The Positive Impacts of Warm, Dry Weather on Tourism

The relationship between drought and tourism is not entirely a negative one. The warm and dry weather conditions that prevail during periods of drought encourage people to travel and partake in outdoor activities. This is especially the case in moist climates[27], such as the Southeast U.S. where there are a relatively higher number of cloudy and/or rainy days.

Region	2016 Travel Expenditure	Change from prior year (2015)
Georgia	$ 25.6B	4.2%
North GA	$ 1.5B	4.6%
Northeast GA	$ 1.1B	5.1%
White County – Helen, GA	$ 0.7B	6.5%
North Carolina	$ 22.9B	4.4%
Northwestern NC	$ 1.1B	5.3%
Western NC	$ 2.5B	6.6%
Buncombe County – Asheville, NC	$ 1.1B	6.9%
Tennessee	$ 19.3B	4.7%
Eastern TN	$ 4.2B	6.3%
Sevier County – Gatlinburg, TN	$ 2.2B	9.1%
United States	$ 836.6B	1.0%

Table 6.1. Selected state, regional and county level travel expenditures for 2016 and their change (%) from the prior year[28].

One way to consider how the drought and its attendant dry weather influence tourism is to examine trends in the estimated monies generated directly and indirectly by travel. Figures garnered from the U.S. Travel Association revealed a slight upward trend of 1% nationally in travel expenditures for 2016 as compared to 2015 (Table 6.1)[28]. While this trend can be tied partly to an improving economy and lowering gas prices, the annual increase in 2016 (relative to 2015) was markedly higher (4.2–4.7%) in the states most impacted by drought. More significantly, the drought-stricken regions of the state with numerous tourist and recreational destinations saw even higher annual increases (4.6–6.6%). Interestingly, Sevier County-Gatlinburg, Tennessee saw the highest increase (over 9%) in the areas sampled, in spite of the devastating late November fire that depressed the numbers for the remainder of the year.

Number of days with less than 0.01 inches of precipitation					
Stations with records exceeding 130 years	Atlanta GA	Asheville NC	Greenville SC	Chattanooga TN	Knoxville TN
Length of record	140 years	149 years	134 years	139 years	147 years
One month 10/28-11/27/17					
# dry days	31	31	30	29	28
Departure from normal	+7.2	+8.2	+6.9	+7.0	+6.3
Ranking	**1st**	**1st**	**Tie for 1st**	**1st**	**Tie for 2nd**
Three months 8/28-11/27/16					
# dry days	82	84	80	84	83
Departure from normal	+15.8	+16.8	+13.9	+16.8	+16.1
Ranking	**1st**	**1st**	**1st**	**1st**	**1st**
Six months 5/28-11/27/16					
# dry days	149	131	136	150	138
Departure from normal	+21.2	+10.5	+9.1	+25.1	+13.3
Ranking	**2nd**	**19th**	**Tie for 17th**	**1st**	**Tie for 10th**

Table 6.2. The number of dry days (daily precipitation total <0.01 inches) at selected stations for the driest 1, 3, and 6 months of the 2016 drought[29].

Region	October 2016 change from prior year	November 2016 change from prior year	2016 change from prior year
North Carolina	8.9%	9.9%	3.4%
Northwestern NC	8.7%	20.4%	8.2%
Western NC	4.4%	12.4%	2.9%
United States	-0.3%	-2.5%	0.1%

Table 6.3. Annualized changes in hotel occupancy rates for October and November 2016[30].

During the 2016 drought, many locations experienced an exceptional number of dry days (Table 6.2)[29]. This was especially the case during the height of the drought (8/28–11/27/2016), as many locations recorded a record number of dry days (e.g. 80–84 out of 92 days). Because the station records in Table 6.2 extend back more than 130 years, this level of dryness is truly exceptional and would be expected to occur less than once every 100 years, at least by historical standards. For many locations in the southern Appalachian Mountains, this period encapsulates the height of the tourism season. It turns out that annual increases in hotel occupancy rates in the mountainous sections of North Carolina were much higher during October and November 2016 (4.4% to 20.4%), relative to the year as a whole (2.9% to 8.2%) (Table 6.3)[30].

Region	October 2016 change from prior year	November 2016 change from prior year	2016 change from prior year
Great Smoky Mountain NP	8.4% (1,466,584)	14.6% (810,894)	5.6% (11,312,785)
Blue Ridge Parkway: NC Section	8.0% (1,465,553)	0.7% (877,098)	0.0% (11,540,408)

Table 6.4. Annualized change in National Park attendance. Attendance figures are in parentheses[32].

Besides visiting the tourist venues of the region, many travelers come to view the colorful fall leaf foliage. Dr. Howard Neufeld, a biology professor who studies the fall foliage at Appalachian State University, reported that October 2016 was a good color season across portions of the North Carolina mountains (e.g., along the Blue Ridge Parkway at elevations of 2,000 to 4,000 feet)[31]. Monthly attendance figures for the Blue Ridge Parkway and GSMNP were especially high, increasing by 8.0 and 8.4%, respectively, relative to October of the prior year (Table 6.4)[32]. Because these increases were markedly greater than the increases reported for the year as a whole (0.0 and 5.6%), it is plausible that they can be attributed to the dry, sunny weather associated with drought.

Certain aspects of the 2016 drought contributed to the favorable fall foliage. Though there is a complicated relationship between the color quality of the fall foliage and antecedent weather conditions, the sunny skies associated with drought in the early fall helped bring out the colors more in various tree species[33]. Specifically, the daily exposure of leaves to sunlight accentuates their reddening (e.g., from a dull red to a bright, fiery red), especially if temperatures are near or below normal (which was not the case in 2016). The early fall dryness, however, caused the birch and tulip poplars to drop their leaves before showing much color[34].

The lack of rainfall and strong winds, which characterized the drought during the fall, allowed the leaves to stay on the trees longer, thus extending the period of favorable viewing. While exceptional summer dryness can lead to premature leaf drop in the fall, many areas along the North Carolina section of the Blue Ridge Parkway saw near normal precipitation during the summer months.

Dr. Neufeld thinks that weather is the best predictor for how many tourists visit the region[35]. If so, the high number of tourists can be tied more to the dry, sunny weather associated with the drought than to the reported color quality of the fall foliage.

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