STRATUS CONSULTING

Climate Change Impacts in the Southeastern United States

Draft Discussion Paper

Prepared for:

Office of Air and Radiation, Climate Change Division
Office of Water, Water Policy Staff
Region 4
U.S. Environmental Protection Agency
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Acronyms and Abbreviations

ACF	Apalachicola Chattahoochee Flint River
CCSP	U.S. Climate Change Science Program
CO_2	carbon dioxide
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
GCM	Global Climate Model
GDP	gross domestic product
GHG	greenhouse gas
GSM	Great Smoky Mountain
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
MDA8	maximum daily 8-hour average concentration
mm	millimeter
O_3	ozone
PM	particulate matter
ppm	parts-per-million
SAP	Synthesis and Assessment Product
SRES	Special Report on Emission Scenarios
VOC	volatile organic compound

1. Introduction

The Southeast United States may be one of the most vulnerable regions in the United States to climate change (e.g., Smith, 2004; Karl et al., 2009). It faces risks from climate change because it has a long and low-lying coastline [41% of the coterminous U.S. coastline (NOAA, 1975)] that is exposed to sea level rise and hurricanes; it is already relatively warm and thus will not, for the most part, benefit from more heat; it will be exposed to more risks of disease; and it has high biodiversity. In addition to being home to almost 60 million people, the Southeast has over 400,000 farms on almost 80 million acres (USDA, 2008), over 127 million acres of timberland (USFS, 2010), 33% of U.S. coterminous estuaries (NOAA, 1990), and nearly 30% of all U.S. wetlands (Dahl, 1990). For these and other reasons, the region faces many risks from climate change.

The purpose of this discussion paper is to present a brief synthesis of *policy-relevant* impacts of climate change in the Southeast region. The discussion paper summarizes literature on impacts on the following sectors: human health, water resources, agriculture, ecosystems, coastal resources, transportation and infrastructure, and environmental justice and vulnerable populations. We include the following states in our definition of the Southeast region [which are the states included in the U.S. Environmental Protection Agency's (EPA's) Region 4]: Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee. Note that much of the literature does not necessarily define the region this way. Typically, the region is defined to include the states above without Kentucky, but with Virginia, Arkansas, Louisiana, Texas, and Oklahoma.

This discussion paper relies heavily on three assessments about the current knowledge of climate change impacts, adaptation, and vulnerability.

- *Climate Change 2007: Impacts, Adaptation, and Vulnerability* (IPCC, 2007a)
- *Global Climate Change Impacts in the United States* (Karl et al., 2009)
- The final reports of the Synthesis and Assessment Products (SAPs) published by the U.S. Climate Change Science Program (CCSP) in 2008.

This discussion paper summarizes climate change impacts in the Southeast. Section 2 covers observed and projected changes in climate (i.e., temperature, precipitation, sea level rise, and extreme events including hurricanes, tornados and severe thunderstorms, inland flooding, drought, and heat). Section 3 describes the impacts of climate change on specific sectors. Section 3.1 covers the health impacts of climate change, including a discussion on heat, extreme weather events, infectious diseases, air quality, and the distribution of health risks. Section 3.2 covers climate change impacts on water resources and includes a discussion about water supply, water uses, existing stresses, water demand, and water quality. Section 3.3 addresses the climate

change impacts on the agriculture sector, which includes both crops and livestock. Section 3.4 describes climate change impacts on ecosystems, including impacts on biodiversity, forests, and fisheries. Section 3.5 discusses impacts on coastal resources, highlighting coastal erosion, ocean acidification, and coastal wetland loss. Section 3.6 covers impacts to transportation and infrastructure. Section 3.7 discusses some of the environmental justice and vulnerable population issues associated with climate change in the Southeast. Section 3.8 provides a summary of how climate change impacts all the sectors discussed in the discussion paper.

This discussion paper is the first of two such papers designed to provide background for and stimulate discussion at an EPA-sponsored workshop on adaptation planning in the Southeast. Thus, this discussion paper is not meant to be an exhaustive analysis of climate change impacts and vulnerabilities in the Southeast. Rather, it is intended to briefly review key impacts, two of which – water and coastal resources – are the focus of a second discussion paper on adaptation planning in the Southeast.

2. Observed and Projected Changes in Climate

Future changes in greenhouse gas (GHG) emissions depend on many factors, including population growth, technology, economic growth, environmental stewardship, and government. The Intergovernmental Panel on Climate Change (IPCC) estimated a wide range of potential changes in GHG emissions in its Special Report on Emission Scenarios (SRES; Nakićenović and Swart, 2000). The SRES scenarios are grouped into four scenario families (A1, A2, B1, and B2). The four scenario families capture six individual emissions scenarios that the IPCC developed to reflect different future conditions regarding population growth, economic growth, variability in growth across the world, the level of economic integration, the strength of environmentalism, and improvements in technology.

Three scenarios were used by the studies included in this discussion paper: A1FI, A1B, and B1. The A1FI scenario represents the "fossil intensive" scenario and results in the highest emissions and the highest atmospheric concentrations of carbon dioxide (CO_2, Schröter, 2005). The A1B scenario represents a "balanced" development of high and low carbon emitting energy technologies. It assumes that no one energy source is relied on too heavily and that similar improvement rates apply to all energy supply and end-use technologies (Nakićenović and Swart, 2000). Finally, the B1 scenario is the lowest emission scenario, characterized by a high level of environmental and social action. This scenario has low population growth, high gross domestic product (GDP) growth, low energy use, high changes in land use, low resource availability of conventional and unconventional oil and gas, and the introduction of clean and resource-efficient

technologies. A more detailed description of the SRES scenarios is provided in the appendix.[1] Records of temperature, precipitation, extreme events, and sea level rise all help to explain how climate has changed and how it is expected to change in the future. This section presents the observed and projected changes in climate in the Southeast.

2.1 Temperature

Records of temperate trends over the last century indicate that the Southeast has not experienced a significant change in temperature. Since 1970, however, it has experienced about a 2°F rise in temperature, with the greatest seasonal increase occurring in the winter (Karl et al., 2009).

Climate models project warming to occur in the Southeast, with different emissions scenarios predicting that temperatures could rise by about 4.5°F (under the B1 scenario) to 9°F (under the A1FI scenario) on average by the 2080s. The greatest temperature increases are projected to occur in the summer (Karl et al., 2009).

Another relevant impact of increased temperatures is the number of projected days in which temperatures will exceed a certain threshold. This is particularly important for vulnerable populations, such as the young and elderly who have a more difficult time adapting to the heat. Figure 1 shows the estimated number of days per year with peak temperatures over 90°F (Karl et al., 2009).

The number of freezing days for most of the Southeast has declined by four to seven days per year since the mid-1970s (see Figure 2; Karl et al., 2009).

2.2 Precipitation

Figure 3 shows observed seasonal changes in precipitation in the region from 1901 to 2007. Average fall precipitation in the Southeast increased by 30% since the early 1900s, and summer and winter precipitation declined by nearly 10% in the eastern part of the region (Karl et al., 2009). South Florida has seen nearly a 10% drop in precipitation in the spring, summer, and fall (Karl et al., 2009).

1. The IPCC is producing a new set of GHG emissions scenarios which will cover a wider range of potential future GHG concentrations than the SRES scenarios covered (Moss et al., 2007).

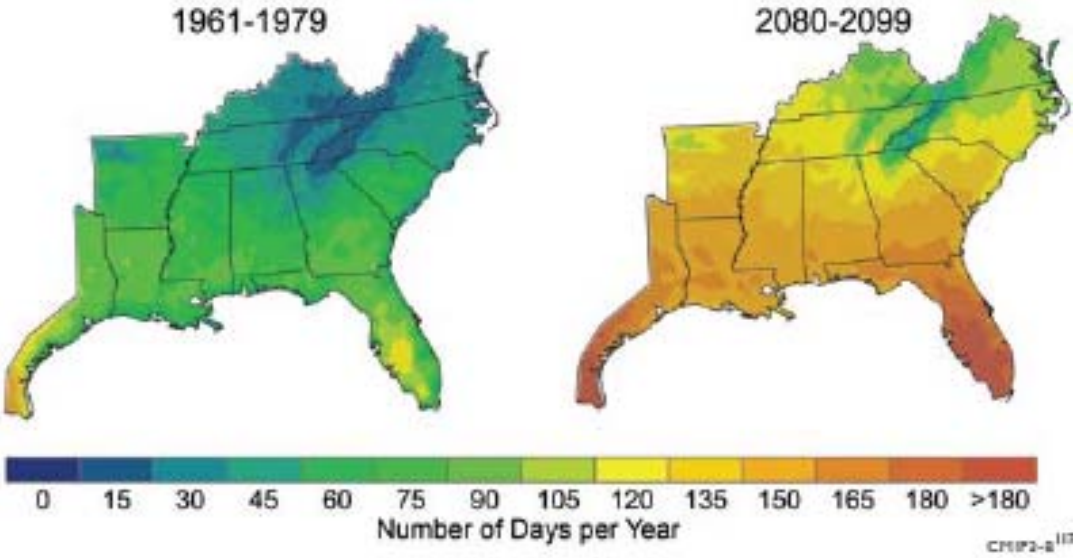

Figure 1. Number of days per year with peak temperature over 90°F.

Source: Karl et al., 2009.

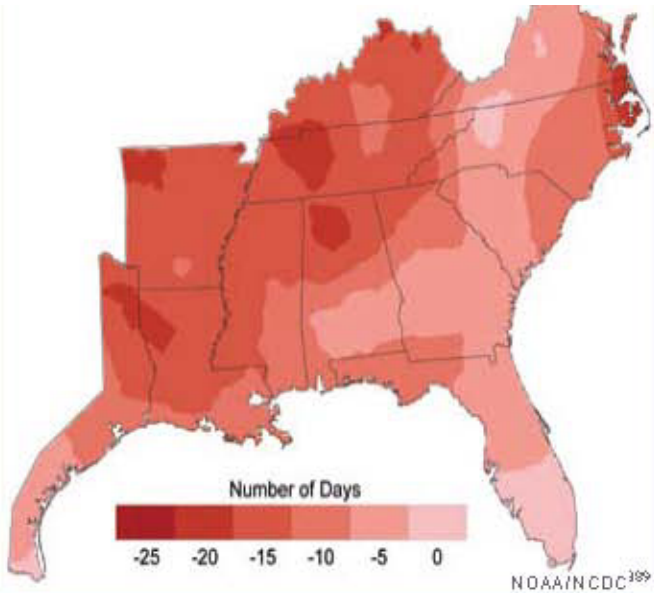

Figure 2. Change in freezing days per year: 1976–2007.

Source: Karl et al., 2009.

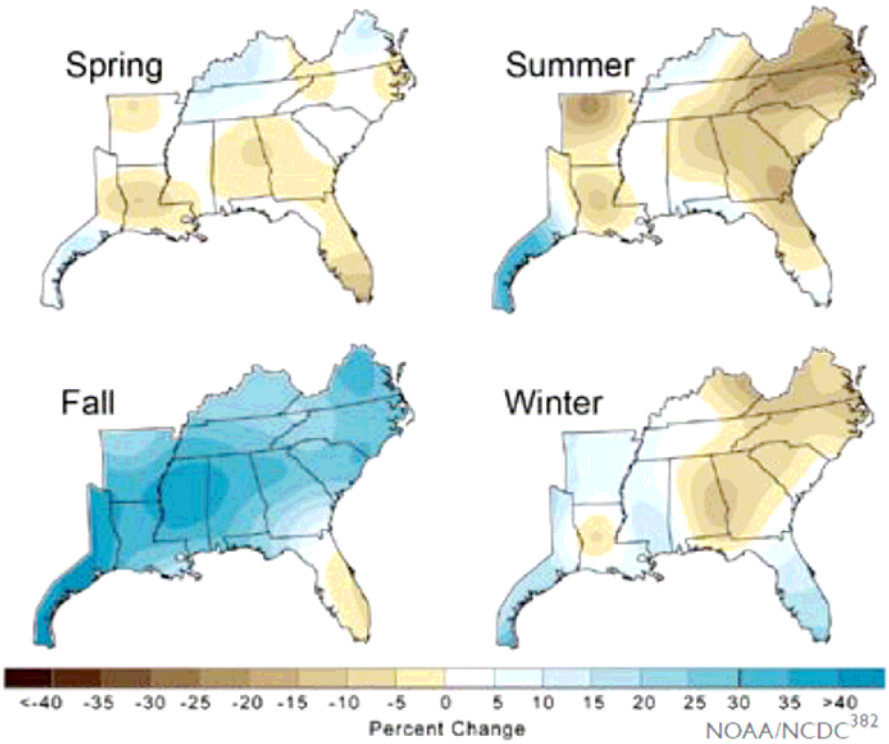

Figure 3. Observed changes in precipitation: 1901–2007.

Source: Karl et al., 2009.

In general, climate model projections of precipitation change are less reliable than their projections of temperature change. This is particularly the case at the scale of states or within states. The projections can vary substantially across models from projecting significant decreases in precipitation to others showing significant increases. One way to address this lack of agreement among climate models is to look at the average over many models. For example, the IPCC averaged the results of many models and used such information to develop likely changes at the subcontinental scale (e.g., the Southeast; Christensen et al., 2007). Figure 4 shows projected annual precipitation change[2] averaged over 10 climate models out to the 2070s relative to about 1990 using MAGICC/SCENGEN.[3] These projections reflect the A1B SRES scenario.

2. Change in precipitation is relative to the reference year 1990. Specifically, the changes are relative to an observed dataset over the period 1980 to 1999.

3. MAGICC/SCENGEN is a user-friendly software package that projects regional climate for a number of user-defined inputs, including region, emission scenario, climate models, and year. The estimates are based on GCM output but assume that regional changes in temperature and precipitation are linearly related to changes in global mean temperature. See Wigley (2008) for more information and a link to the actual model.

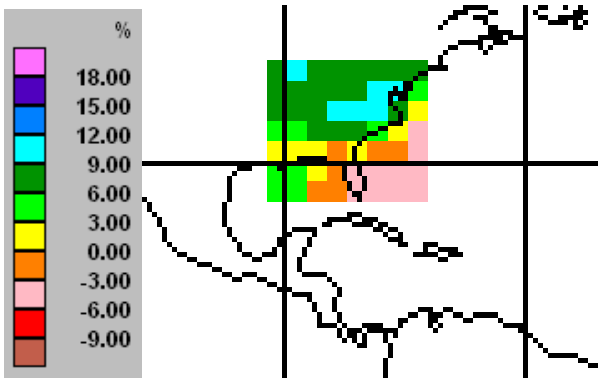

Figure 4. Projected changes in annual average precipitation in the region by 2070.

Averaged together, these models project that Southern states (Florida, Mississippi, and Alabama) tend to have a decrease in precipitation by 2070, and the northern states in the region tend to have an increase in precipitation by 2070. Basically, the farther north, the more likely there is to be increased precipitation by 2070. This is consistent with global predictions that the high latitude Tropics (around 30°N) *generally* will see a decrease in precipitation and more northern latitudes *generally* will see increases in precipitation.

Figure 5 (also generated from MAGICC/SCENGEN) shows the projected change in seasonal precipitation by 2070 using the A1B emissions scenario. The Southern states are projected to have less precipitation in the spring, summer, and winter, with an increase in precipitation in the fall. The rest of the Southeast could also have less precipitation in the winter, and more precipitation in the fall. During the summer, the precipitation projections are more variable across the Southeast with the Southern states receiving less precipitation, the coastal states receiving a bit more, and the inland states receiving about the same amount or less precipitation.

In total, the climate models suggest that the lower South will get drier than today. Change in the upper South is less clear. While precipitation is projected to increase, so is temperature. It is not clear if the higher evapotranspiration (evaporation and increased demand for moisture by vegetation) will offset the increased precipitation. It is interesting that the springtime precipitation in the upper South is projected to increase, but not summer precipitation. This suggests that spring runoff and flooding could increase, but so could drought during the summer.

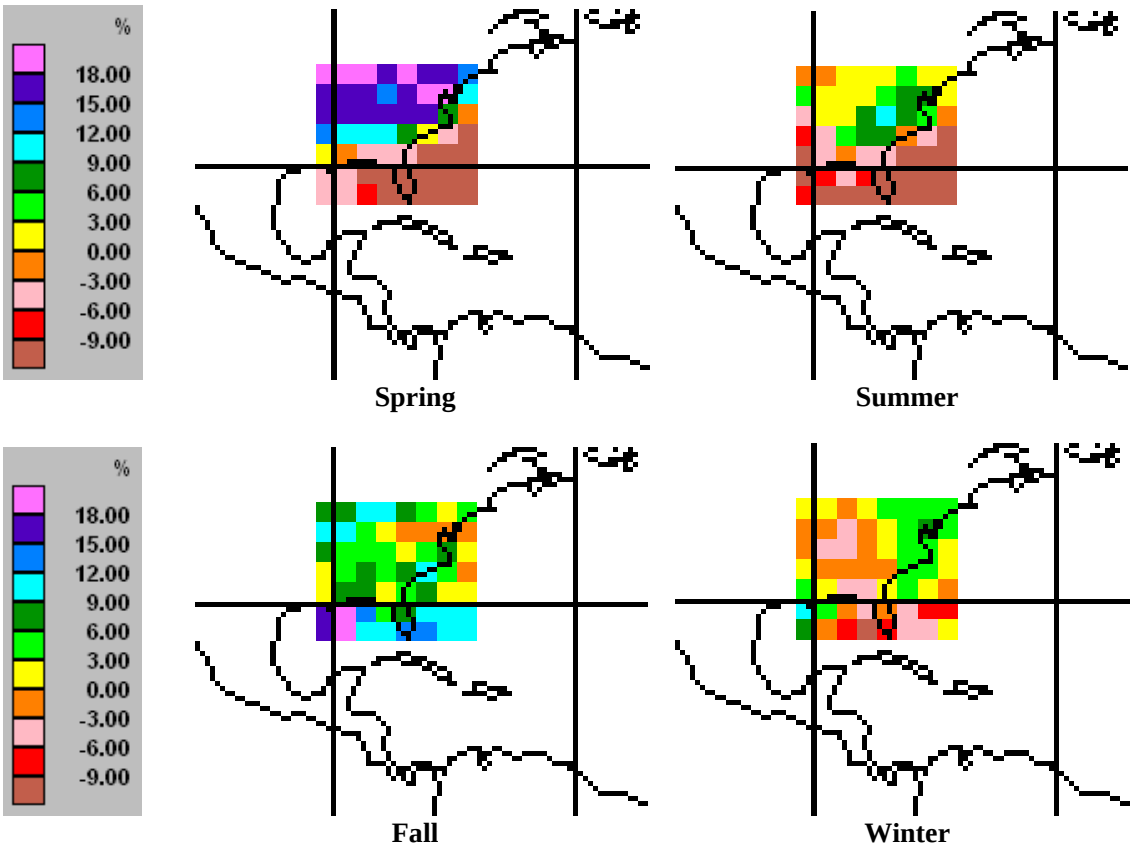

Figure 5. Projected changes in seasonal precipitation in the region by 2070.

One of the key findings from CCSP's *Synthesis and Assessment Report 3.3: Weather and Climate Extremes in a Changing Climate* (SAP 3.3) is that North America has already experienced, and is very likely to continue experiencing, more frequent and intense heavy precipitation events and a higher proportion of total rainfall in these events (CCSP, 2008d). This finding holds true for the Southeast as well. Karl et al. (2009) found that the amount of precipitation falling in the heaviest 1% of rain events increased by 20% in the past century averaged over the United States. In the Southeast, there has been an increase in heavy downpours in many parts of the region (Karl et al., 2009). These heavy precipitation events could lead to an increased chance of flooding in the Southeast. At the same time, certain areas may experience an increased chance of droughts where precipitation has declined during the spring, summer, and winter months.

2.3 Extreme Events

While many studies focus on how changes in the average climate will impact human and natural systems, it is oftentimes more important to understand how extreme events will influence these systems (Parmesan and Martens, 2009). Extreme events include hurricanes, tornados and severe thunderstorms, inland flooding, droughts, and heat waves. This section summarizes the observed and projected trends in these extreme events.

2.3.1 Hurricanes

The intensity, power, and destructive energy (i.e., a combination of intensity, duration, and frequency) of hurricanes is likely to increase (Emanuel, 2005; CCSP, 2008b, 2008d; Karl et al., 2009). In particular, the intensity of the strongest hurricanes (Categories 4 and 5) have already increased (Karl et al., 2009). From 1975 to 1989, for example, the North Atlantic produced 16 Categories 4 and 5 hurricanes (Webster et al., 2005). From 1990 to 2004, however, the North Atlantic produced 25 Categories 4 and 5 hurricanes (Webster et al., 2005).

Warmer sea surface temperatures provide more energy to sustain hurricanes. Although the trend in rising sea surface temperatures correlates with the trend in increasing hurricane frequency, scientists still do not know exactly whether and how climate change will impact hurricane frequency (CCSP, 2008d; Karl et al., 2009). To date, "There is no evidence for a long-term increase in North American mainland land-falling hurricanes" (CCSP, 2008d). Even so, an increase in the intensity and destructive power of hurricanes could increase the number of Category 3 and higher hurricanes along the central Gulf Coast (Savonis et al., 2008).

Each 1.8°F increase in tropical sea surface temperatures is projected to increase storm-related rainfall rates by 6 to 18% and increase the surface wind speeds of the strongest hurricanes by about 1 to 8% (Karl et al., 2009).

Assuming that average sea levels rise at least 2 feet by 2100 (IPCC, 2007c), the Southeast will likely see an increase in storm surge, which could easily be the most costly consequence of climate change (Karl et al., 2009). Hurricane intensity is also projected to increase, which will likely increase the size of storm surges (Knutson and Tuleya, 2004). The actual degree of projected increase in storm surges, however, has not yet been determined (CCSP, 2008d).

Other impacts of sea level rise include increased risks of erosion, storm surge damage, and flooding for coastal communities, especially in the Southeast (Karl et al., 2009). Rising sea levels will also convert wetlands to open water, exacerbate coastal flooding, and increase the salinity of estuaries and freshwater aquifers (CCSP, 2009).

Figure 6 shows the number of Atlantic tropical storms and hurricanes that have made landfall on the United States.

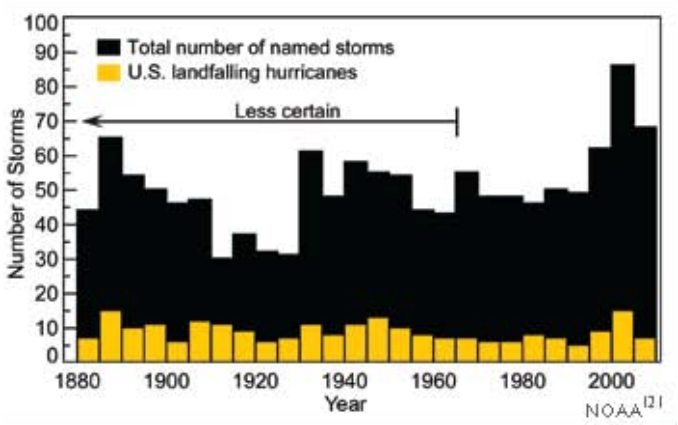

Figure 6. Atlantic tropical storms and hurricanes that have made landfall on the United States.

Source: Karl et al., 2009.

2.3.2 Tornados and severe thunderstorms

Since the 1950s, there has not been a clear trend in the frequency or strength of tornadoes for the United States (Karl et al., 2009). Projecting increases or decreases in tornadoes and severe thunderstorms is difficult due to modeling small-scale conditions involved in thunderstorm development (Karl et al., 2009), although Trapp et al. (2007) found that the number of days with conditions that are associated with severe thunderstorms could increase.

2.3.3 Inland flooding

During the last 30 years, the frequency of light and moderate precipitation events has not changed or even decreased throughout the United States. Heavy precipitation events, however, have increased in the Southeast, which could likely lead to more frequent and severe flooding events (Karl et al., 2009). As an example of the economic impact of flooding, between the years 1983 and 1987, the Southeast[4] experienced $3.5 billion (1995 dollars) in total flood losses (Pielke and Downton, 2000). According to data from Pielke et al. (2002) for the Southeast, flood

4. Pielke and Downton (2000) define the Southeast to include Alabama, Florida, Georgia, North Carolina, South Carolina, and Virginia.

damages were fairly constant from 1955 to around 1970. Since 1970, the trends have been more variable and have actually increased in recent years (Pielke et al., 2002).

Flooding events can cause a variety of human health impacts, such as physical injuries and increased incidence of waterborne diseases. Heavy precipitation events can also trigger sewage overflows, contaminating drinking water and freshwater and coastal waters (Karl et al., 2009). In addition to health impacts, flooding can also cause adverse economic impacts (e.g., property damage, increased insurance rates).

Major floods tend to occur in the foothills of mountainous areas and on the northern side of the Gulf of Mexico (O'Connor and Costa, 2003). Hurricanes have contributed the moisture to many of these events; the combination of hurricane storm surges and associated rainfall can cause serious damage along the Gulf, as happened during Hurricane Katrina (NCDC, 2005). Thus, more intense precipitation events and more intense hurricanes can increase flood risks in the region. The risks could be made worse as population growth and development put more people and property in flood zones. Development can make landscapes impermeable, which increases runoff and flood risks.

In addition to health and safety considerations, flooding can stress waste management resources. For example, in the wake of Hurricane Katrina in 2005, more than 100 million tons of debris required removal from Alabama, Mississippi, and Louisiana, and cleanup costs exceeded $3 billion (Luther, 2008). In addition to the cost and resource-intensive cleanup effort, the disposal of storm and flood debris depletes existing landfill capacity and/or requires the permitting and development of emergency disposal facilities which will require longer-term monitoring by regulatory officials.

2.3.4 Droughts

In the last three decades, the percentage of the Southeast region experiencing moderate to severe drought has increased (Karl et al., 2009). Droughts in the Southeast may not be as severe or as frequent as compared to the rest of the United States, particularly the Southwest (CCSP, 2008d). Droughts can have a variety of impacts, including increased risk of wildfires when droughts are followed by periods of high temperatures and low humidity, changes in the distribution and types of insects, and failure of some crops (CCSP, 2008d). It also impacts energy, recreation/tourism, timber, livestock, and other environmental sectors. The primary cause of droughts is an extended period of deficient precipitation. The intensity of droughts, however, can be exacerbated by increased rates of evaporation (due to high temperatures), high winds, lack of cloud cover, and/or low humidity (CCSP, 2008d).

Current drought trends are shown in Figure 7. There has been an increasing trend of summer drought in the region over the period 1958–2007, with significant trends along the East Coast and in northern Florida (Karl et al., 2009). The trend of increasing droughts is significant in parts of northern Florida, southern Georgia, and coastal areas of North and South Carolina (Figure 7).

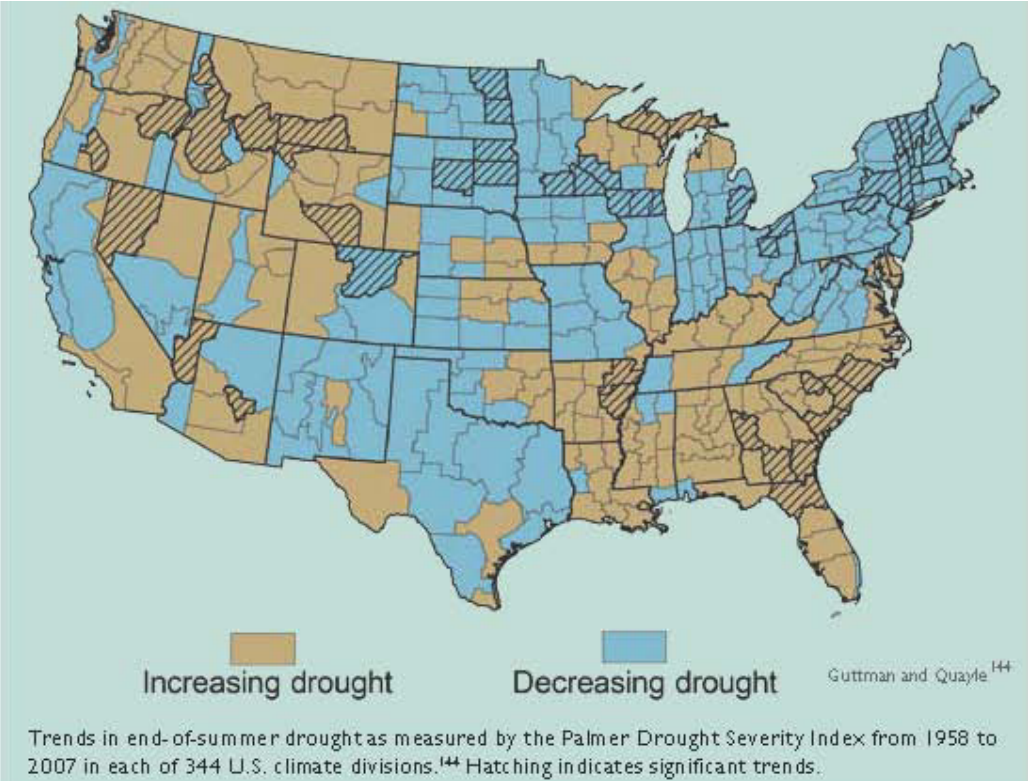

Figure 7. Observed drought trends 1958–2007.

Source: Karl et al., 2009.

As noted above, climate models tend to project a decrease in precipitation in Florida and the Deep South, particularly in the summer, which would increase drought in the future.

Even where precipitation is projected to increase, higher temperatures can still result in drought since warmer temperatures increases the rate of evaporation (CCSP, 2008d). Should precipitation increases come in more intense events, less water will infiltrate into groundwater. Fewer days of precipitation could mean that within-season droughts could increase, punctuated by intense rain events that could increase the risk of flooding.

"No formal attribution studies for changes in drought severity in North America have been attempted" (CCSP, 2008d). As such, it is difficult to assign climate change as the primary reason for observed changes in drought frequency, intensity, duration, and extent. In fact, some droughts could be exacerbated by human activities, such as excessive water withdrawals and consumption (CCSP, 2008d).

2.3.5 Heat

Heat waves

A heat wave is a period of several days to weeks of abnormally hot weather, often with high humidity. Heat waves have become more frequent in the last 40 to 50 years in the United States (Karl et al., 2009). By the end of this century, heat wave events that now occur once every 20 years are projected to occur about every other year (under a high emissions scenario), and very hot days are projected to be about 10°F hotter than they are today (Karl et al., 2009).

Heat island effect

Temperature increases in the Southeast (and elsewhere) will exacerbate the heat island effect. Heat island effects occur in larger cities with many paved surfaces and little vegetation. The paved surfaces absorb, produce, and retain more heat than surrounding areas and can raise surrounding temperatures. Over the last century, this effect has raised average urban air temperatures by 2 to 5°F more than surrounding areas during the day and 20°F more at night (Karl et al., 2009).

According to CCSP's *Synthesis and Assessment Report 4.6: Analysis of the Effects of Global Change on Human Health and Welfare and Human Systems* (SAP 4.6), Florida, Georgia, North Carolina, and South Carolina are likely to be impacted by urban heat island effects. Kentucky, Tennessee, Mississippi, and Alabama are not likely to be impacted by urban heat island effects (CCSP, 2008a).

2.4 Sea Level Rise

Estimates of global sea level rise are very sensitive to the initial assumptions. Below are four examples of studies that have estimated the global rise in sea level by 2100 (using 1990 as the baseline):

- IPCC (2007c) project that sea level will rise 0.6 to 2 feet by 2100. This estimate, however, does not incorporate the potential acceleration of melting of the Greenland or the West Antarctic ice sheets.

- Rahmstorf et al. (2007) used an empirical approach to compare observed sea level rise and temperatures changes and estimated that sea level will rise between 1.6 to 5.9 feet by 2100.
- Pfeffer et al. (2008) included increased ice dynamics and found that sea level rise will be no higher than 6.5 feet by 2100, with the most likely rise being 2.6 feet.
- CCSP (2008b) projects that sea level rise will be between 2 and 4 feet in the next 50 to 100 years.[5]

While the precise amount of sea level rise by 2100 is uncertain, scientists agree that sea levels are rising and will rise at an increased rate in the future (IPCC, 2007c).

The global estimates above reflect the average sea level rise over the world's oceans due to thermal expansion and melting of ice sheets and glaciers. Relative sea level rise, on the other hand, looks at both global estimates and vertical movement of the land (e.g., subsidence – sinking of the land) at a regional or local level. In general, the Southeast Coast is subsiding, which means relative sea level rise is higher than the global average. In Florida, for example, based on monitoring at several long-term tide stations, the relative rate of sea level rise varies between 2.04 and 2.43 millimeters (mm) per year (CCSP, 2008b).[6] This is higher than the global rate of sea level rise of 1.7 mm per year (CCSP, 2008b).

3. Sector Impacts

3.1 Human Health

Synthesis and Assessment Product 4.6: Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems (SAP 4.6) concluded that climate change will most likely increase health risks for the United States (CCSP, 2008a). The conclusions are relevant to the Southeast although there is limited published literature on the specific vulnerability of populations in this region to climate variability and change. The conclusions include:

5. This projection was for Gulf Coast states and does not include the entire Southeast region as defined in this report.

6. These estimates of relative sea level rise were from the tide station in Fernandia Beach, Mayport, Miami, and Key West, Florida.

- It is very likely that heat-related illnesses and deaths will increase over coming decades.
- It is uncertain the extent to which projected increases in the frequency and intensity of extreme weather events might increase associated health impacts. Health risks associated with extreme events are likely to increase due to an increasing population and the degree to which people are physically or financially constrained in or uninformed about their ability to prepare for and respond to extreme weather events.
- There is a growing body of evidence that ozone (O_3) concentrations would be more likely to increase than decrease in the United States as a result of climate change, if one assumes that precursor emissions are held constant. An increase in O_3 could cause or exacerbate heart and lung diseases.

The region's population is large and changing

When comparing 2008 population estimates of all 10 EPA regions, EPA Region 4 has the largest population serving nearly 60 million people. Between 1960 and 2008, the population for EPA Region 4 increased by 114%, of which Florida accounts for almost 42% to this increase. The region also has 72 coastal counties and approximately 2,000 miles of coastline. Of that, the state of Florida makes up 67.5% of those miles. According to the U.S. Census Bureau, 14.8% of the region's population lives below the poverty level.

Source: U.S. Census Bureau, 2010.

- Few studies have been conducted on the potential impact of climate change on particulate matter (PM; U.S. EPA, 2009a). Preliminary results show the potential for increases or decreases in PM concentrations in different regions around the United States and for different components of PM (e.g., sulfate, nitrate, ammonium, black carbon, organic carbon) in the same region (U.S. EPA, 2009a).
- Climate change, including changes in CO_2 concentrations, could impact the production, distribution, dispersion, and allergenicity of aeroallergens and the growth and distribution of weeds, grasses, and trees that produce them (McMichael et al., 2001; Confalonieri et al., 2007).
- Several food and water-borne diseases are likely to be transmitted among susceptible populations, although climate will seldom be the only contributing factor.
- The very young and old, the poor; those with health problems, disabilities, and other vulnerabilities; and certain occupational groups are at greater risk.
- Vectors known to carry diseases such as dengue fever are present throughout the Southeast. Insufficient information is available to project how climate change could affect the distribution and seasonality of these vectors and the pathogens they carry, or how climate change could affect disease transmission dynamics. A key factor in determining whether there are more outbreaks and whether they are contained is the strength of the public health system.

3.1.1 Heat

Exposure to heat is already the leading cause of weather-related deaths in the United States and more than 3,400 deaths between 1999 and 2003 were reported as resulting from exposure to extreme heat (Karl et al., 2009). In addition to their potential for increasing heat-related health effects, heat islands also can influence local production and dispersion of air pollutants, such as O_3 and PM 2.5 (CCSP, 2008a).

Figure 8 shows the temperature-mortality relative risks (using average daily temperatures, not daily high temperatures) for 11 U.S. cities between 1973 and 1994 (Curriero et al., 2002). The Southern cities are Charlotte, NC; Atlanta, GA; Jacksonville, FL; Tampa, FL; and Miami, FL. The temperature threshold for causing increased mortality is higher in the Southern cities, which appears to be around 80°F. Although it is generally assumed that warmer regions of the country are at lower risk of heat wave-related mortality, the relative risks are nearly as large for high temperatures in some Southern cities as in Northern cities.

3.1.2 Extreme weather events

Many areas in the Southeast are vulnerable to hurricanes and flooding. The coast is generally low-lying so almost all coastal areas have been or can be hit by hurricanes and tropical storms. River flooding is also a widespread threat throughout the region. Direct morbidity and mortality due to an event increase with the intensity and duration of the event, and can decrease with advance warning and preparation. Health also can be affected indirectly.

The mental health impacts (e.g., post traumatic stress disorder, depression) may also be important. Extreme events are often multi-strike stressors, with stress associated with the event itself; the disruption and problems of the recovery period; and the worry or anxiety about the risk of recurrence of the event (Tapsell et al., 2002). During the recovery period, mental health problems can arise from the problems associated with geographic displacement, damage to the home or loss of familiar possessions, and stress involved with the repairs. Anxiety and depression, the most common mental health disorders, can be directly attributable to the experience of the event (e.g., being flooded) or indirectly during the recovery process (e.g., Gerrity and Flynn, 1997). These psychological effects tend to be much longer lasting and can be worse than the physical effects experienced during an event and its immediate aftermath.

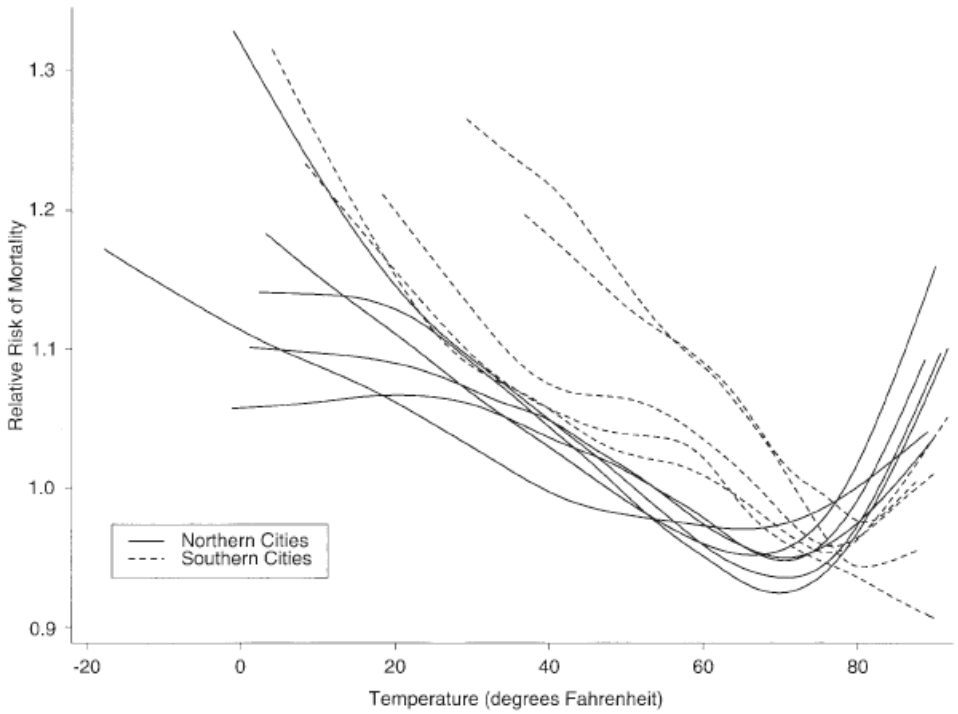

Figure 8. Temperature-mortality relative risks for 11 U.S. cities, 1973–1994.

Source: Curriero et al., 2002.

3.1.3 Infectious diseases

Although climate is one determinant of the geographic range, seasonality, and incidence of a range of vectorborne and zoonotic diseases, the status of the public health infrastructure means that outbreaks are typically controlled quickly, limiting morbidity and mortality. Climate change may provide conditions conducive for the spread of these diseases to new areas, but a strong public health infrastructure can be expected to identify and contain any outbreaks that could occur.

Water and foodborne diseases continue to cause significant morbidity throughout the United States. Most pathogens of concern for food- and waterborne exposure are enteric and transmitted by the fecal-oral route. Climate may affect the pathogen directly by influencing its growth, survival, persistence, transmission, or virulence. In addition, there may be important interactions between land-use practices and climate variability. Therefore, changing climate or environments may alter the transmission of pathogens or affect the ecology and/or habitat of zoonotic reservoirs (NRC, 2001).

Studies in North America (United States and Canada; Fleury et al., 2006; Naumova et al., 2007), Australia (D'Souza et al., 2004), and several countries across Europe (Kovats et al., 2004) report striking similarities in correlations between peak ambient temperatures (controlled for season) and peak clinical cases of salmonellosis. These studies support the conclusion that increasing temperatures will likely increase salmonellosis rates.

3.1.4 Air quality

It is possible but not certain that the Southeast will face increased ground-level O_3 concentrations. Many different factors affect ground-level O_3 concentrations, such as weather conditions, gas emissions from vehicles and industry that lead to O_3 formation [e.g., nitrogen oxides and volatile organic compounds (VOCs)], natural emissions of VOCs from plants, and other wind-carried pollutants (Karl et al., 2009). "A warmer climate is projected to increase the natural emissions of VOCs, accelerate O_3 formation, and increase the frequency and duration of stagnant air masses that allow pollution to accumulate, which will exacerbate health symptoms. Increased temperatures and water vapor due to human-induced CO_2 emissions have been found to increase O_3 more in areas with already elevated concentrations, meaning that global warming tends to exacerbate O_3 pollution most in already polluted areas" (Karl et al., 2009, p. 94).

Acute exposure to elevated concentrations of O_3 is associated with increased hospital admissions for pneumonia; chronic obstructive pulmonary disease; asthma, allergic rhinitis, and other respiratory diseases; and premature mortality (e.g., Mudway and Kelly, 2000; Gryparis et al., 2004; Bell et al., 2005, 2006; Ito et al., 2005; Levy et al., 2005; NRC, 2008a).

These results suggest that any increase in O_3 concentrations in the Southeast would be expected to increase the number of people affected. Scientists are not entirely certain how O_3 concentrations will change because of climate change in the Southeast. The EPA (U.S. EPA, 2009a) found that seven global-to-regional climate and air quality modeling systems did not consistently predict the changes in climate-related O_3 patterns for the Southeast (projected out to 2050): three of the seven models predict a decline in O_3, while the other four predict an increase. The predicted mean MDA8 (maximum daily 8-hour average O_3 concentration) O_3 concentration ranged from –6 to 4.5 parts per billion (U.S. EPA, 2009a).

Climate change will also impact other aspects of air quality, including concentrations of pollen and PM. Climate change, including changes in CO_2 concentrations, could impact the production, distribution, dispersion, and allergenicity of aeroallergens and the growth and distribution of weeds, grasses, and trees that produce them (McMichael et al., 2001; Confalonieri et al., 2007). These changes in aeroallergens and subsequent human exposures could affect the prevalence and severity of allergy symptoms. However, the scientific literature does not provide definitive data or conclusions on how climate change might impact aeroallergens and subsequently the prevalence of allergenic illnesses in the United States (Ebi et al., 2008).Precipitation is one driver

of PM concentrations, as it removes PM from the atmosphere (U.S. EPA, 2009a). Because projections of precipitation are so variable (depending on the model used), it is difficult to project what will happen to PM concentration under climate change. Further complicating the issue, increased frequency of wildfires due to warmer climate could potentially increase PM in some regions, however, this effect is not well characterized (U.S. EPA, 2009a).

3.1.5 Distribution of health risks

Balbus and Malina (2009) define health-related vulnerability as "the summation of all risk and protective factors that ultimately determine whether an individual or subpopulation experiences adverse health outcomes." The impacts of climate change on the health sector will not be evenly distributed because of biogeophysical factors and population vulnerabilities due to societal, cultural, environmental, political, and economic factors (Balbus and Malina, 2009). Vulnerable groups include the elderly, pregnant women and children, those with chronic medical conditions, people with mobility and cognitive constraints, and the urban and rural poor (Balbus and Malina, 2009). In general, low-income communities and communities of color are disproportionately represented in these vulnerable groups (Balbus and Malina, 2009). Table 1 lists groups particularly vulnerable to various climate-related exposures.

Table 1. Groups with increased vulnerability to climate change

Climate-related exposures	Group with increased vulnerability
Heat stress	Elderly, those with chronic medical conditions, infants and children, pregnant women, urban and rural poor, outdoor workers
Extreme weather events	Poor, pregnant women, and those with chronic medical conditions and mobility and cognitive constraints
Ozone (air pollution)	Children, those with pre-existing heart or lung disease and diabetes, athletes, outdoor workers

Source: Balbus and Malina, 2009.

3.2 Water Resources

Among the important water resources issues currently facing the Southeast that could be exacerbated by climate change are water supply, demand for water, flooding, and water quality. This section summarizes the current literature on climate change impacts on the water resources sector.

3.2.1 Water supply

There are many large and small rivers and water bodies in the region, and many of the large rivers cross state boundaries. Region 4 has four of the eight largest rivers in the continental United States: the Mississippi, Ohio, Tennessee, and Mobile rivers. Streamflow generally peaks in the winter and spring periods, except in Florida where there are summer and fall peaks. As a region, the Southeast has a large amount of reservoir storage compared to mean annual flows (Lettenmaier et al., 2008).

Karl et al. (2009) report that there has been an increasing trend of summer drought in the region over the period 1958–2007, with significant trends along the East Coast and in northern Florida (see Figure 7 in Section 2.3.4).

3.2.2 Water uses

Table 2 shows the 2005 water withdrawals in the region. As can be seen, in all states except Florida and Mississippi, thermoelectric cooling is the major use. Irrigation is the major freshwater use in Florida and Mississippi. In all states, the second largest use is the combined sum of public supply, domestic, and industrial uses. Sources of freshwater come primarily from surface water in Alabama, Georgia, Kentucky, Mississippi, South Carolina, and Tennessee. Groundwater dominates in Florida. North Carolina has a 50/50 ratio of groundwater to surface water sources.

Groundwater supplies in the Southeast are also important because certain areas in the region rely on groundwater for drinking water and irrigation. In Florida and Mississippi, for example, people who are served by public water supplies withdraw nearly 90% of their water supply from groundwater. Mississippi withdraws groundwater to provide 92% of its irrigation water while Alabama, Florida, Georgia, South Carolina, and Tennessee rely on groundwater withdrawals for at least 46% of their irrigation water (Kenny et al., 2009).[7] Information on climate change impacts on groundwater in the region is limited. One study by Kirshen (2002), however, found that groundwater levels in the northeastern United States may follow similar trends as surface water.

7. Irrigation water is used via sprinklers, micro-irrigation, and surface (flood) systems (Kenny et al., 2009).

Table 2. Total water withdrawals in the Southeast region in 2005 in million gallons per day

	Public supply	Domestic	Irrigation	Livestock	Aquaculture	Industrial		Mining		Thermoelectric power	
State	**Fresh**	**Fresh**	**Fresh**	**Fresh**	**Fresh**	**Fresh**	**Saline**	**Fresh**	**Saline**	**Fresh**	**Saline**
Alabama	802	39.1	161	28.1	74.9	550	0	27.8	0	8,270	0
Florida	2,540	190	3,070	17.8	9.19	243	1.19	195	0	558	11,500
Georgia	1,180	120	752	28.4	38.4	532	22.6	49.4	0	2,680	36.9
Kentucky	558	34.8	18.9	45.9	20.4	186	0	36.6	0	3,430	0
Mississippi	369	56.4	1,560	18.9	279	197	0	11.9	0	355	82.6
North Carolina	921	161	292	120	1,020	394	0	46.1	0	8,350	1,550
South Carolina	647	127	91.6	11.3	1.31	419	0	9.06	0	6,540	0
Tennessee	914	36.7	55.4	29.7	59.5	783	0	21.7	0	8.940	0

Source: Kenny et al., 2009.

There are many instream uses of water. Approximately 11% of the U.S. total hydropower production is in the Southeast. Increased temperatures will likely increase power consumption in the summer, thereby increasing power plant water use. There are also major navigable inland waterways in the region with many linked to the Gulf of Mexico. Finally, there are valuable instream ecosystems that rely upon adequate flows throughout the year. In addition, water in streams and lakes provides habitat for fish and other species. Flows must be maintained for aquatic ecosystems to survive. Karl et al. (2009) found that the divergence in Global Climate Model (GCM) outputs does not make it possible to make projections in future seasonal streamflows. For water managers, however, the important management variable is the variation in the seasonal and annual flows and the nonstationarity of the climate.

3.2.3 Existing stresses

There are already water management stresses in the region such as the water supply dispute between Georgia, Alabama, and Florida in the Apalachicola Chattahoochee Flint River (ACF) system; South Carolina and North Carolina over interbasin water transfer in the Catawba-Wateree and Yadkin-Pee Dee rivers; the dead zone in the Gulf of Mexico from pollutants carried by the Mississippi River; coastal and inland flooding; loss of river navigation due to low flows; saltwater intrusion into coastal aquifers; and loss of thermal electric generating capacity due to insufficient and overly warm cooling water. Information on the distribution of these stresses among different socioeconomic conditions, including Native Americans, is not readily available. Increasing water temperatures, increased power demand, and increased water use demand will likely exacerbate existing stresses.

3.2.4 Water demand

Figures 9 and 10 show current population density in the Southeast and projected trends in population growth for the entire United States, respectively. Figure 10 also shows pressures on freshwater supplies (Hightower and Pierce, 2008). The largest net increase in population from 1995 to 2025 is expected to occur in three states: California, Texas, and Florida – each of which is projected to gain more than 6 million people (Campbell, 1997). The most recent population estimates from the U.S. Census predict high increases in population in the Southeast region by 2030 (U.S. Census Bureau, 2005). Even though the U.S. population has increased significantly since 1985, total U.S. water withdrawals by major category of water use have remained approximately constant (Kenny et al., 2009).[8] Even so, it is possible that demand might increase significantly in the Southeast as a result of increased population growth.

8. This statement does not apply to public supply withdrawals, which have actually increased since 1985 (Kenny et al., 2009).

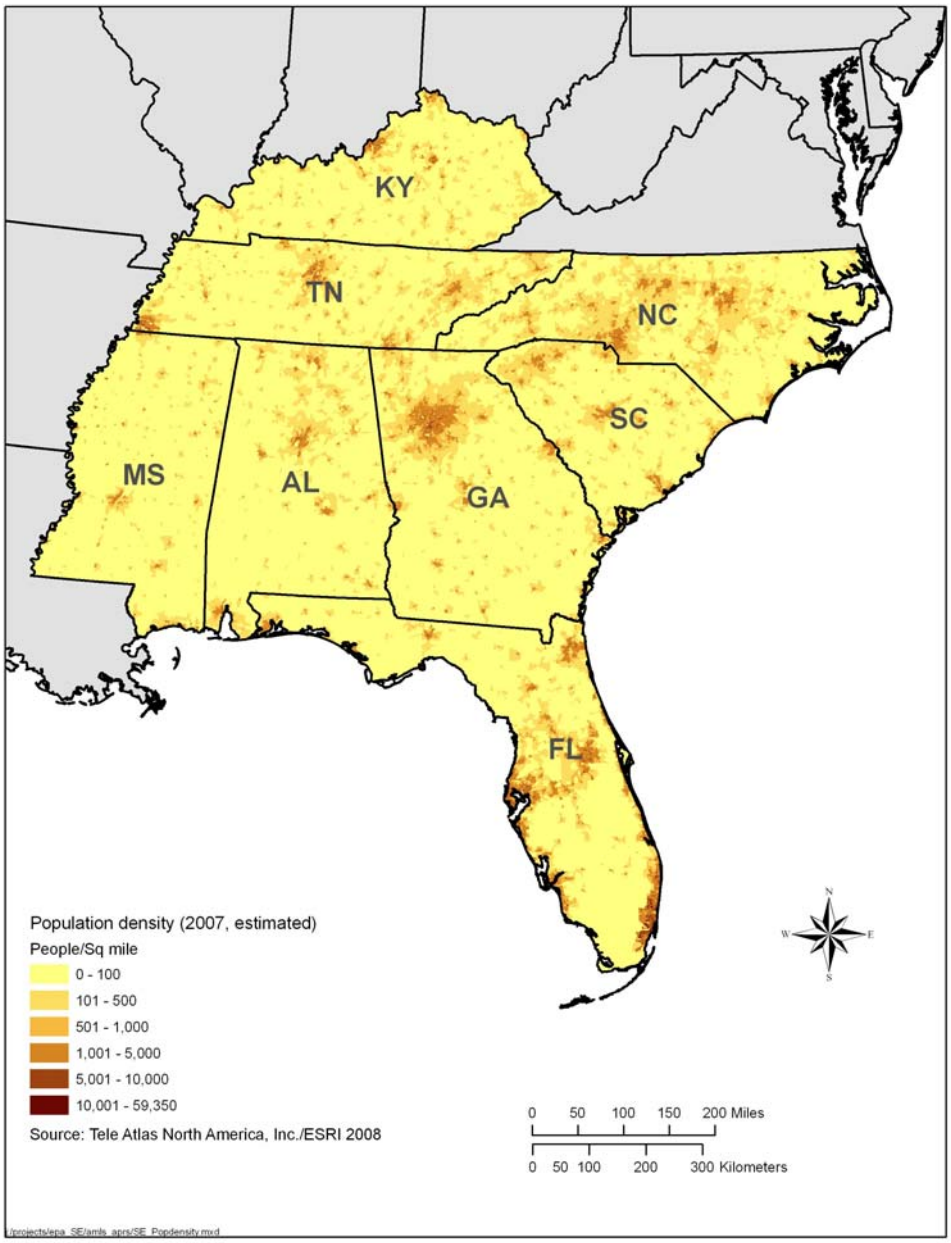

Figure 9. Current population density in the Southeastern United States.

Source: Wright et al., 2009.

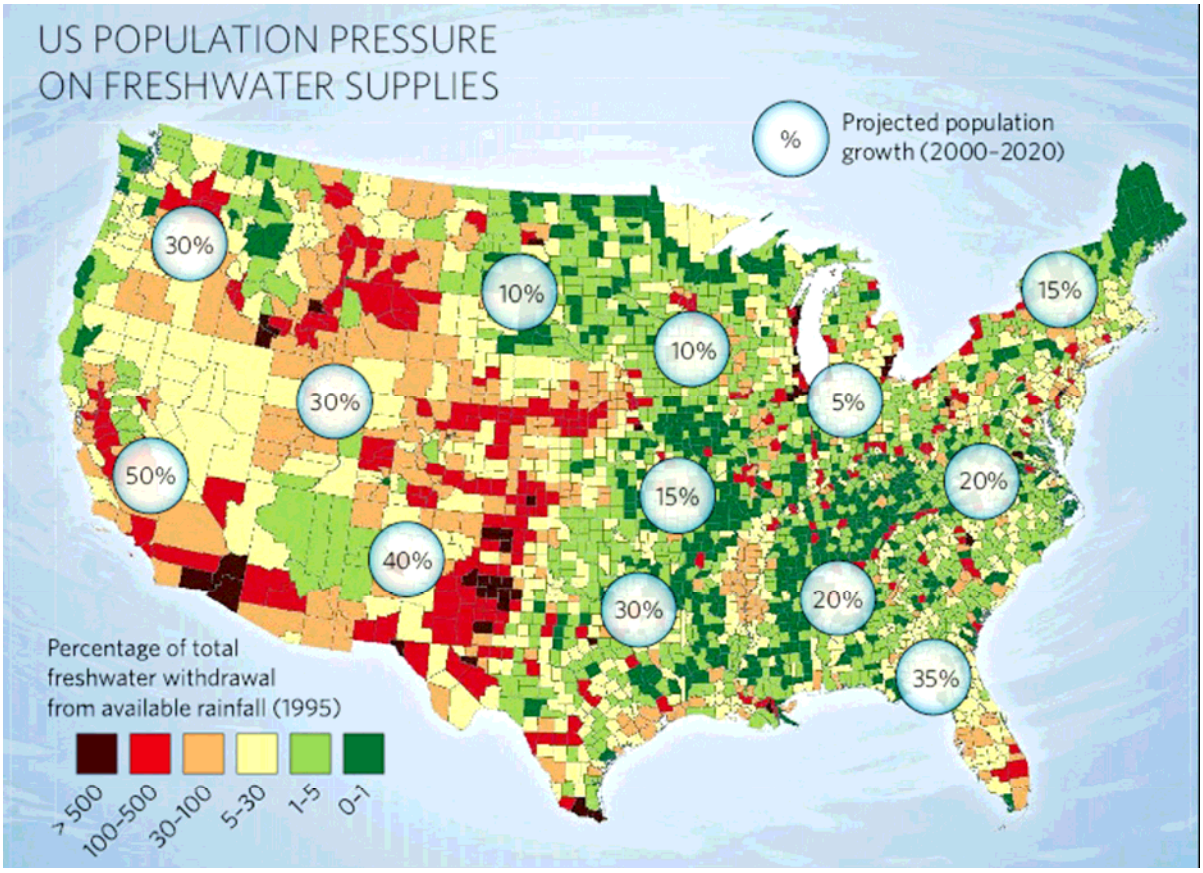

Figure 10. U.S. population pressure on freshwater supplies.

Source: Hightower and Pierce, 2008.

In addition, Karl et al. (2009) project water demands to increase as temperatures increase, particularly for irrigation unless more efficient systems are installed. Higher temperatures will also increase cooling water requirements for electrical generation, while at the same time driving up cooling needs.

3.2.5 Water quality

Temperature increases and changes in precipitation patterns (i.e., more frequent and intense heavy precipitation events) will likely create additional stress on water quality in the Southeast. A number of assessed waters in the Southeast are already listed as impaired (U.S. EPA, 2009e). The bullets below describe some of these anticipated stresses (Lettenmaier et al., 2008;

U.S. EPA, 2008; Karl et al., 2009). The bullets below describe some of these anticipated stresses (Lettenmaier et al., 2008; U.S. EPA, 2008; Karl et al., 2009).

- Higher air temperatures will increase water temperatures, which will likely lead to a decrease in dissolved oxygen (DO) in water bodies. Hypoxic conditions are more likely to occur (i.e., when DO reaches a minimum threshold that no longer allows aquatic species to survive). Also, increased temperatures result in higher pathogen replication, persistence, survival, and transmission (CDC, 2009).
- Higher water temperatures will likely lead to more thermal stratification in lakes and reservoirs in the Southeast resulting in less oxygen mixing.
- Higher water temperatures will likely lead to more algae growth.
- Increases in the number of extreme storm events (tropical and inland) will likely result in more runoff of nutrients; pathogens from human and animal waste; sediment from cropland and animal feeding operations; pesticides from combined sewer overflows and nonpoint source runoff; and toxins from industrial, commercial, and other sources. This can lead to more algae and plant growth, which results in less DO. Greater runoff can also result in greater pathogen impairments (U.S. EPA, 2009d).
- Decreases in overall summer precipitation will likely cause reduced water flows, which will contribute to warmer water temperatures and further stress water quality. This is particularly important in the context of seasonal droughts. During low-flow periods, nutrients will become concentrated and flush out of systems more slowly.
- Increases in rates of marine water intrusion into shallow or coastal drinking water aquifers will decrease source water quality and may require public water systems to install expensive and energy consumptive microfiltration (e.g., reverse osmosis) to meet drinking water standards.[9]

3.3 Agriculture

Agriculture in the Southeastern United States is quite diverse. It not only includes the traditional row crops such as corn, soybean, and wheat, but also exotic tropical fruits, small fruits such as blueberries and strawberries, sugarcane, peanut and cotton, ornamental crops, vegetables, turf, and many other crops. For example, ornamental crops, vegetables, and turf are growing rapidly

9. Many of the preceding stresses might also affect source water quality and require expensive drinking water treatment.

in economic importance in Florida and in the other states. This diversity is partially due to the diverse ecosystems of the Southeast, which range from the Everglades in Florida to the Appalachian Mountains. These ecosystems are defined by both the local weather conditions and local soil conditions. The agricultural production systems in the South have changed drastically over time, as a result of climate change, economics, land use change, and many other factors. Rice had been grown in South Carolina for centuries, while citrus was grown in coastal areas of Georgia. Due to climate change, these crops can no longer be grown in South Carolina and Georgia (Gerrit Hoogenboom, Professor, University of Georgia, personal communication, January 19, 2010). Even in Florida the "line" that defines the potential ecoregion where citrus can be grown seems to be moving south (Gerrit Hoogenboom, Professor, University of Georgia, personal communication, January 19, 2010).

Agriculture is much more vulnerable to short-term climate variability. An early frost in the fall or a late frost in the spring can potentially wipe out a crop. Other extreme events, such as flooding or droughts, also affect agriculture production (see Sections 2.3.3 and 2.3.4 for more on climate change impacts on flooding and droughts). It is difficult for producers to prepare for these events, except for making changes to their management by changing crops or planting dates and other adaptation strategies. There are options for mitigation, but they are limited.

3.3.1 Crops

Changes in temperature, precipitation, and CO_2 concentrations will have varying impacts on Southeastern cropping systems. Decreased precipitation will most likely have negative effects on crop yield (CCSP, 2008c; Karl et al., 2009), but higher temperatures with no change in precipitation are projected to have different effects on crop yields. The combined effects of a 1.2°C increase in temperature and a 60 parts-per-million (ppm) increase in CO_2 in the Southern United States could lead to a 3% decrease in corn yield and a 8% decrease in sorghum yield; but a 4% increase in soybean yield, a 4% increase in cotton yield, and a 1% increase in peanut yield (CCSP, 2008c).

Using the Hadley model, NAST (2001) projected a slight increase in citrus yields by 2030, and a dramatic increase by 2090; a decrease of dryland (non-irrigated) soybean yields in the range of 10–30% by about 2030, and a decrease by up to 80% in about 2090. When looking at the Canadian and Hadley models together, the direction of change is not always consistent; however, both models predict that of all of the regions in the United States, the Southeast will face the largest losses in agricultural production as a result of climate change (NAST, 2001).

Floods and droughts also affect agriculture. In general, plants do not like "wet feet" and, therefore, too much rainfall can kill a crop if drainage is insufficient. Excessive rainfall events can delay spring planting, which can have negative impacts on production and farmers' incomes.

If these rainfall events occur during the growing season, they can cause crop loss due to anoxia, increased susceptibility to root diseases, increased soil compaction, and increased runoff and leaching of nutrients and other agricultural chemicals into groundwater and surface water (CCSP, 2008c). They can also cause water deficiencies during other times of the year, and could increase the potential for crop lodging (i.e., when crops lose the ability to stand up) due to associated wind gusts (CCSP, 2008c).

Too little water during periods of drought can also destroy crops. Two options farmers have are to apply supplemental irrigation during periods of insufficient rainfall or to accept reduced yields.

In addition to weather, biotic stresses such as pests, diseases, and weeds also play an integral part in crop production. For instance, the boll weevil caused the complete loss of the cotton crop in the Southeast. Only after the boll weevil was eradicated were farmers allowed to replant cotton, but with strict monitoring and control measures. Soybean rust was recently introduced into the United States, starting with the Southeast. This was a pest that was previously found in Asia, Africa, and Latin America. Although farmers can apply pesticides, this is not always an option due to economic costs or environmental regulations. Introduction of invasive species and noxious weeds can also have a significant impact on the local environment. Establishment of these plants will partially be controlled by local weather conditions, such as rainfall and drought or prolonged frost periods that kill these plants during the winter months. Kudzu, originally introduced to prevent soil erosion, has now turned into a weed that cannot be controlled (SE-EPPC, 2010).

Scientists are not completely certain how pathogens and pests will spread throughout the Southeast as a result of climate change. The ecology, epidemiology, and distribution of insects depends mainly on temperature, whereas humidity, rainfall, and temperature control the spread of pathogens (Coakley et al., 1999). Leaf and root pathogens may increase in areas that expect a rise in humidity and in frequency of extreme rain events, but may decrease in regions expected to experience droughts (CCSP, 2008c).

3.3.2 Livestock

Livestock production is as important as crop production in many of the Southeastern states. The types of livestock most susceptible to climate change in the Southeast include beef, dairy, poultry, and swine. Poultry and swine are generally located indoors, so the main impact of a warming climate will be rising energy costs to keep the animals cool (Karl et al., 2009; CCSP, 2008c). Karl et al. (2009) conclude that climate change will result in a decline in the production of cattle and other rangeland livestock.

Livestock animals are extremely sensitive to local weather conditions. A slight increase in temperature or humidity will reduce their comfort levels and can cause a reduction in performance, such as milk production, weight gain, or egg production. For example, Frank (2001) and Frank et al. (2001) found that the Southeast could see anywhere between a 3% and 10% decrease in the number of days for swine to grow from 50 to 110 kilograms (kg); a 1.4% to 2% decrease in beef productivity (based on the number of days required to reach finish weights); and a 0.2% to 6% decrease in the kg fat-corrected milk yield per cow per season.[10] Karl et al. (2009) predict that there will be significant impacts on beef cattle when temperatures continually exceed 90°F, increasing in danger as humidity level increases.

3.4 Ecosystems

The Southeast has a wide variety of ecosystems ranging from the Everglades in Florida to coniferous forests in Appalachia. Climate change will have varying impacts on all types of ecosystems and the benefits (i.e., ecosystem services) they provide. This section describes some of those impacts on biodiversity, forests, and fisheries in the Southeast.

3.4.1 Biodiversity

As defined by the Millennium Ecosystem Assessment (2005, p. 18), biodiversity is "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." Indicators of biodiversity include (but are not limited to): species richness (the number of species in a given area); the number of distinct plants or animals; the diversity of distinct gene sequences; the abundance, variation, and distribution of a particular species; ecosystem extent and status (e.g., land cover and land use); ecological capital (amount of resources available for providing services); or ecological function.

The Southeast is rich in biodiversity. The Florida Greater Everglades ecosystem alone has 1,033 plant taxa, 60 reptile taxa, 76 mammal taxa, 432 fish taxa, 349 bird taxa, and 38 amphibian taxa (Brown et al., 2006). Florida and Georgia have the third and fourth most endangered and threatened species of any state in the Union (USFWS, 2009).

Many different factors drive changes in biodiversity, such as habitat change, climate change, invasive species, overexploitation, and pollution (Millennium Ecosystem Assessment, 2005). Currently, climate change is not the most important driver of changes in biodiversity; however, it could be the largest driver by the end of the 21st century (Millennium Ecosystem Assessment,

10. All of these estimates are from baseline conditions out to 2040.

2005). Even so, there have already been measurable changes in global biodiversity due to climate change, particularly with regard to changes in species distributions, population sizes, timing of reproduction or migration events, and increases in the frequency of pest and disease outbreaks (Millennium Ecosystem Assessment, 2005). In the United States, climate change has already impacted terrestrial ecosystems by changing the timing of growing season length, phenology, primary production, and species distributions and diversity (Janetos et al., 2008). Other changes in biodiversity that could be attributed to climate change are difficult to identify due to a lack of observational data (Janetos et al., 2008).

Several observed and projected impacts on biodiversity in the Southeast include:

- Butterflies migrating in the spring will be affected by warmer spring temperatures and earlier emergence of vegetation (Janetos et al., 2008). Additionally, they exhibit distributional and/or range shifts in response to warming (Janetos et al., 2008). For example, butterfly populations are shifting to higher elevations and northward with a contraction at the southern end of their historical range (Karl et al., 2009).

- Saltwater intrusion into coastal forests and freshwater aquifers due to sea level rise thresholds (Karl et al., 2009).

- Lower soil moisture and higher temperatures leading to intense wildfires or pest outbreaks (e.g., southern pine beetle) in forests (Karl et al., 2009).

- Intense drought leading to drying of lakes, ponds, and wetlands (Karl et al., 2009).

- Decline in DO in streams, lakes, and shallow aquatic habitats will lead to increased fish kills and loss of aquatic species diversity (Karl et al., 2009).

- Coastal and tropical regions experiencing more coral bleaching, disease events, and storm intensity and destructive capabilities (Emanuel, 2005), as well as a reduction in pH (The Royal Society, 2005), which leads to acidification (Guldberg-Hoegh et al., 2007). All of these impacts have implications for biodiversity, particularly on coral reefs.

Coastal and mountain ecosystems are particularly vulnerable to climate change in the Southeast. These ecosystems contain tremendous amounts of biodiversity and could be adversely affected due to climate change. Burns et al. (2003) predict that if CO_2 levels double over baseline conditions, Great Smoky Mountain (GSM) National Park will lose approximately 17% of its mammalian diversity, including the red squirrel, the northern flying squirrel, and the southern red-back vole (Burns et al., 2003). This estimate depends heavily on the projected changes in forest vegetation. For example, GSM currently contains temperate deciduous forest and is projected to transform into warm temperate mixed forest (Burns et al., 2003).

Karl et al. (2009) predicts that there will be more frequent outbreaks of shellfish-borne diseases in coastal waters, altered distribution of native plants and animals, local loss of threatened or endangered species, displacement of native species by invasive species, and more frequent and intense wildfires. All of these impacts will have a direct effect on biodiversity in the Southeast. In Tennessee, for example, models predict that climate change could intensify infestations of the native southern pine beetle, which could result in 4 to 7.5 times the current annual mortality of pines (Tennessee Wildlife Resources Agency, 2009).

Another example of a biodiversity hotspot is the ACF river system in Alabama, Georgia, and Florida. This system drains more than 19,000 square miles of watershed and supports some of the richest biodiversity in North America. It also provides water for agriculture and for major cities in the area (e.g., Atlanta). Climate change in this region is expected to increase water demands and perhaps threaten this valuable ecosystem (Twilley et al., 2001). The Florida Everglades will also have similar impacts from climate change. However, the most significant impacts for this ecosystem will be rising sea levels and the impacts of more frequent and intense storm surges (Twilley et al., 2001).

3.4.2 Forests

Forests provide many ecosystem services, including watershed protection, water quality, and flow regulation; wildlife habitat and biodiversity conservation; recreational opportunities and aesthetic and cultural enjoyment; raw material for wood and paper products; and climate regulation, carbon storage, and air quality. Climate change will have both direct and indirect impacts on forests, though it can be difficult to tease apart the extent to which climate change is a driving factor of changes in forest ecosystems.

Ryan et al. (2008) identify several impacts of climate change on forest ecosystems:

- Change in the timing, magnitude, and frequency of disturbances, which will result in a change in species structure, composition, and function.
- Increase in forest productivity and carbon storage (assuming sufficient water and nutrients) due to rising atmospheric CO_2 concentrations. Degree of productivity and carbon storage will depend on site fertility, water availability, and stand age.
- Increase in photosynthesis and tree growth in forests where temperatures are rising at a moderate rate and where water is not a limiting factor.
- Decrease in forest productivity in eastern areas of the Southeast and an increase in forest productivity in western areas of the Southeast, assuming existing trends in precipitation continue.

- Drought events will very likely reduce forest productivity in the Southeast, particularly in the lower latitudes and lower altitudes.
- Potential increase in insect outbreaks as temperatures increase. For example, the southern pine beetle has already impacted millions of hectares of forest in the Southeast.

Forest ecosystems already experience natural disturbances, such as drought, storms (ice and wind), hurricanes, insect and pathogen outbreaks, introduced species, grazing, landslides, and fire (Dale et al., 2001; Ryan et al., 2008). Climate change will influence the timing, magnitude, and frequency of these disturbances, which in turn will affect forest ecosystems in the Southeast and elsewhere (Ryan et al., 2008). Recovery from disturbances can take anywhere from decades to centuries.

Whether net forest productivity will increase or decrease is not clear. Karl et al. (2009) conclude that forest growth will decline due to thermal stress and declining soil moisture, both of which are direct impacts of increasing temperatures. However, Ryan et al. (2008) find that increased concentrations of CO_2 may help counter this and actually lead to an increase in forest growth. Increased temperatures and lower soil moisture will increase forests' susceptibility to pest and insect outbreaks (e.g., the southern pine beetle) or diseases. Temperature controls many aspects of an insect's life history cycle and can also influence a forest's ability to defend itself from insect attacks (e.g., drought stress). Factors other than climate change also influence a forest's ability to defend itself (e.g., fire suppression, forest management practices).

Increased temperatures will also lead to more intense droughts in some areas of the Southeast. Droughts persisting over multiple growing seasons reduce the rate of decomposition, which leads to excess organic matter on the forest floor that could increase fire frequency or intensity (Dale et al., 2001; Alley et al., 2007; Karl et al., 2009). Different models predict that the seasonal severity rating of fire hazard will increase somewhere between 10% and 30% for the Southeastern United States (Dale et al., 2001).

Figure 11 presents projected shifts in location of forest types for the central and eastern United States. Note that commercially important loblolly pine is projected to be virtually gone from the region, while oak-hickory would be somewhat reduced but still be present in upland areas such as Kentucky and Tennessee. In Florida, the forest types are projected to shift from long-leaf slash pine to oak-gum-cypress. Along the Carolina's and Georgia coastlines, forests are estimated to shift from a mix of oak-gum-cypress and loblolly-shortleaf pine to predominantly oak-pine. Note that this analysis only presents where forest and other vegetation would exist, not how productive the vegetation will be.

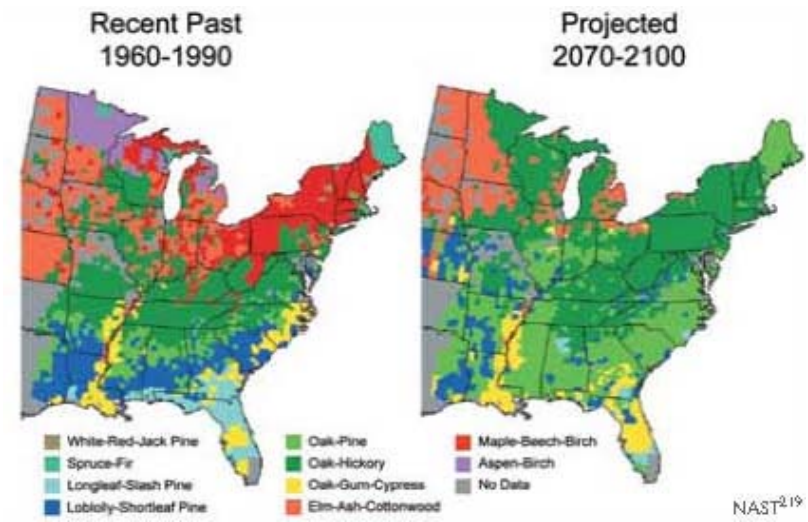

Figure 11. Current and projected shifts in forest types.

Source: NAST, 2001, as cited in Karl et al., 2009.

3.4.3 Fisheries

A summary of current and projected impacts on fisheries (both marine and freshwater) follows.

- Marine species in U.S. waters are moving northward and the timing of plankton blooms is shifting (Karl et al., 2009)
- Half of the wild trout populations are likely to disappear from the southern Appalachian Mountains because of the effects of rising stream temperatures (Karl et al., 2009)
- Projected losses of trout habitat for some warmer states, such as North Carolina and Virginia, are up to 90% (Karl et al., 2009)
- Rising sea levels will increase the vulnerability of spawning and nursery habitat through inundation of wetlands and coastal marshes and saltwater intrusion, leading to a loss of wetland-dependent coastal fish and shellfish (Karl et al., 2009)
- Increasing temperatures will cause certain species of fish to shift their geographical range (Janetos et al., 2008)
- Increasing frequency and intensity of storms may result in increased mortality of early life states, altered transport of larval fish, and altered recruitment (Connelly et al., 2007).

3.5 Coastal Resources

Impacts on coastal resources will likely be an important consequence of climate change (Karl et al., 2009). Region 4 has 41% of the coterminous U.S. coastline (NOAA, 1975). The significant climate change impacts include:

- Increased population and coastal zone development increase exposure to flooding in coastal floodplains from sea level rise, storm surge, and extreme rainfall events (IPCC, 2007a; U.S. EPA, 2009b). This increased population and building in the coastal zone would happen as flood risks increase because of sea level rise and more intense storms.
- Increased coastal erosion resulting from sea level rise leads to loss of barrier islands and wetlands (IPCC, 2007b; U.S. EPA, 2009b).
- Increased sea surface temperatures and rising sea levels may have increased intensity and destructive capacity of coastal storms and storm surge [see Section 2.3.1 for more discussion (e.g., Emanuel, 2005; Karl et al., 2009)].
- Rising sea surface temperatures and sea levels have increased bleaching of coral reefs.
- Increased CO_2 levels in the atmosphere leads to acidification of marine waters, which can adversely affect coral reefs and other "marine calcifiers" that use calcium carbonate to create skeletons or shells.
- Increased sea level rise, storm surge, and storm intensity will likely inundate or destroy wetland and barrier island habitat and convert marshlands to open water and forests to marshland.

Several of the impacts are considered in detail below.

3.5.1 Coastal erosion

Sea level rise and increased hurricane intensity will likely cause coastlines to experience periods of erosion and accretion, depending on dynamic natural and anthropogenic conditions. Coastal erosion is also affected by anthropogenic factors including activities like dredging, coastal engineering, land development, and construction of sea walls and dams. Barrier islands and wetlands, features of some coastlines, are vulnerable to changes in sea level, and may even have thresholds that, when crossed, could lead to irreparable damage (Nicholls et al., 2007). North Carolina, in particular, may experience further destruction of barrier islands due to sea level rise and storm activity (Riggs and Ames, 2003).

3.5.2 Ocean acidification

Ocean surface waters absorb CO_2, which at elevated levels contributes to ocean acidification (i.e., a decrease in the pH of seawater) and decreases carbonate saturation (Andersson et al., 2003; The Royal Society, 2005; Turley et al., 2006; Guldberg-Hoegh et al., 2007). Ocean acidification in particular has adverse effects on coral reefs and other marine calcifiers (Karl et al., 2009). Several impacts of ocean acidification and declining carbonate saturation include (1) reduced calcification rates in flora and fauna, and (2) nutrients and carbonate materials dissolve in sediments more readily (Andersson et al., 2003; The Royal Society, 2005; Turley et al., 2006). As noted in the IPCC, calcification rates in aragonitic corals may decline by 20 to 60% under a doubling of atmospheric CO_2 concentrations, with erosion outpacing reef formation at even lower concentrations (Fischlin et al., 2007).

Since 1750, increased CO_2 concentrations have lowered ocean surface pH by 0.1 units; however, it has been difficult to observe significant impacts on coastal ecosystems (Karl et al., 2009). Meehl et al. (2007) predicts that surface ocean pH will decrease by 0.1–0.4 units (i.e., based on a range of emissions scenarios) by 2100.

3.5.3 Coastal wetland loss

Coastal wetlands (marshes and mangroves) provide many ecosystem services for coastal areas. For example, they reduce peak flood flows by delaying and storing floodwaters; protect water quality; maintain resilience of natural coastal defenses through alluvial plain accumulation; act as a storm surge buffer; provide nurseries for coastal fisheries; and protect freshwater from saltwater intrusion. The interactions of climate change, land subsidence, coastal development, and shore stabilization practices have contributed to the decline of coastal wetlands. Cahoon et al. (2009) conclude that climate change has, and will continue, to cause the loss of coastal wetlands.

Some of the impacts of climate change on coastal wetlands include:

- For the mid-Atlantic, wetlands that currently keep pace with current rates of sea level rise would survive a 2 mm per year acceleration of sea level rise, but would not survive a 7 mm per year acceleration of sea level rise unless they had optimal hydrology and sediment supply conditions (Cahoon et al., 2009). Sea level is currently rising 3 mm per year (IPCC, 2007c), but could, as noted above, rise up to 20 mm per year by the end of the century.

Rising sea levels will inundate low-lying coastal areas, including wetlands, which will decrease the resilience of natural coastal defenses, increase the risk of saltwater intrusion, which leads to further erosion; and decrease nursery habitat for coastal fisheries. Assuming a 1 meter rise in sea level by 2100, and with all developed areas being protected from inundation, south and west Florida could lose approximately 829 square miles of coastal marshes and swamps (Park et al., 1989). Under this same scenario, the South Atlantic could lose 2,422 square miles of coastal marshes and swamps (Park et al., 1989). Two-thirds of the Everglades is currently less than 1 meter above sea level (NPS, Undated).

3.6 Transportation and Infrastructure

Synthesis and Assessment Product 4.7: Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I (SAP 4.7) found that climate change will have impacts on the transportation and infrastructure sector (CCSP, 2008b). While this report is not specific to the entire Southeast (it only covers coastal counties from Houston, Texas to Mobile, Alabama), it highlights some key issues that the rest of the Southeast will likely face. Key findings from the CCSP (2008b) report on the effects of climate change on infrastructure in the Gulf region include:

- Increases in mean and extreme high temperatures may require changes in materials, maintenance, and operations of transportation infrastructure and vehicles.
- Changes in precipitation, although uncertain, may increase short-term flooding, especially if extreme precipitation events increase in frequency. This will have a number of important impacts, including stressing the capacity of existing drainage systems, disrupting traffic management, increasing highway incidents, impacting airline schedules, etc. If prolonged flooding occurs, it could damage pavement substructure.
- Relative sea level rise may inundate existing infrastructure in low-elevation areas.
- Increased storm intensity may lead to greater service disruption and infrastructure damage.

NRC (2008b) found that the most important relevant impacts of climate change for the transportation and infrastructure sectors include increases in very hot days and heat waves, rising sea levels, increases in intense precipitation events, and increases in hurricane intensity. Table 3 summarizes some of the impacts of climate change on this sector.

Table 3. Potential climate changes and illustrative impacts on transportation

Potential climate change	Examples of impacts on operations	Examples of impacts on infrastructure
Increases in very hot days and heat waves	Impact on lift-off load limits at high-altitude or hot weather airports with insufficient runway lengths, resulting in flight cancellations or limits on payload (i.e., weight restrictions), or both Limits on periods of construction activity due to health and safety concerns	Thermal expansion on bridge expansion joints and paved surfaces Concerns regarding pavement integrity (e.g., softening), traffic-related rutting, migration of liquid asphalt Rail-track deformities
Rising sea levels, combined with storm surges	More frequent interruptions to coastal and low-lying roadway travel and rail service due to storm surges More severe storm surges, requiring evacuation or changes in development patterns	Inundation of roads, rail lines, and airport runways in coastal areas More frequent or severe flooding of underground tunnels and low-lying infrastructure
Increase in intense precipitation events	Potential for closure or restrictions at several of the top 50 airports that lie in coastal zones, affecting service to the highest-density populations in the United States Increases in weather-related delays and traffic disruptions Increased flooding of evacuation routes Increases in airline delays due to convective weather	Erosion of road base and bridge supports Reduced clearance under bridges Changes in harbor and port facilities to accommodate higher tides and storm surges Increases in flooding of roadways, rail lines, subterranean tunnels, and runways Increases in road washout, damages to rail-bed support structures, and landslides and mudslides that damage roadways and tracks Increases in scouring of pipeline roadbeds and damage to pipelines
More intense hurricanes (Category 4 to 5)	More frequent interruptions in air service More frequent and potentially more extensive emergency evacuations More debris on roads and rail lines, interrupting travel and shipping	Greater probability of infrastructure failures Increased threat to stability of bridge decks Impacts on harbor infrastructure from wave damage and storm surges

Source: NRC, 2008b.

The range of direct impacts of increasing temperatures (mean and extremes) on infrastructure and transportation in the Southeast include pavement damage, which will result in a need for more frequent maintenance; rail buckling, which could result in derailment of trains; vegetation growth, which creates slippery conditions on railroads and roads, as well as more visual obstructions for drivers; reductions in aircraft lift and efficiency, resulting in the need for longer runways and/or more powerful airplanes; reduced water levels, making it more difficult for marine transportation; and reduced ice cover, which is one of the few positive impacts (CCSP, 2008b).

3.7 Environmental Justice and Vulnerable Populations

One issue that has not been significantly addressed in the existing literature is the impact of climate change on vulnerable populations and implications for environmental justice issues in the Southeast. EPA defines environmental justice as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (U.S. EPA, 2009c). Certain parts of the population that may be especially vulnerable to climate change impacts include the poor, the elderly, those already in poor health, the disabled, those living alone, and/or indigenous populations dependent on one or a few resources (Wilbanks et al., 2008). Such groups represent a greater proportion of the population in some regions and localities than others. For example, the elderly make up a larger share of the population in warmer areas due to the desire to live in a warm climate (Karl et al., 2009).

The latest U.S. Global Change Research Program report, *Global Climate Change Impacts on the United States,* states:

> In the future (as in the past), the impacts of climate change are likely to fall disproportionately on the disadvantaged. People with few resources often live in conditions that increase their vulnerability to the effects of climate change. For example, the experience with Hurricane Katrina showed that the poor and elderly were the most vulnerable because of where they lived and their limited ability to get out of harm's way. Thus, those who had the least proportionately lost the most. And it is clear that people with access to financial resources, including insurance, have a greater capacity to adapt to, recover, or escape from adverse impacts of climate change than those who do not have such access. The fate of the poor can be permanent dislocation, leading to the loss of social relationships and community support networks provided by schools, churches, and neighborhoods (Karl et al., 2009, p. 101).

Additionally, the eight-state region of EPA Region 4 contains six federally recognized tribes and numerous state-recognized tribes. Native American communities broadly have unique vulnerabilities to climate change, such as limited relocation options due to reservation boundaries (Karl et al., 2009).

Table 4 presents the poverty status in Region 4 states (U.S. Census Bureau, 2010).

Table 4. Region 4 poverty status

	Total	Below poverty level	Percent below poverty level
Population estimates (as of July 1, 2008)	59,800,949		
Population from whom poverty status is determined	57,465,294	8,503,435	14.8
Population under 18 years	13,903,387	2,875,268	20.7
Population 65 years and over	7,771,993	892,403	11.5
Minority	19,437,310	4,506,753	23.2

Of the individual states in Region 4, the poverty status for children, elderly people, and minorities is highest in the state of Mississippi (U.S. Census Bureau, 2010). Poverty status for these same categories, on average across the Region, is highest in the states of Alabama, Kentucky, South Carolina, and Tennessee (U.S. Census Bureau, 2010).

3.8 Summary

The impacts of climate change will affect many sectors across the Southeast. The bullets below summarize the key impacts described in this discussion paper.

- Temperatures in the Southeast are projected to rise by about 4.5°F to 9°F on average by the 2080s. Climate models are not as clear on how precipitation in the Southeast will change. In general though, the models show a tendency to increased precipitation in the upper South and decreased precipitation in the lower South. The models tend to project increased spring precipitation, but decreased summer precipitation in many parts of the South. Such changes in climate would likely result in reduced river flow, lake levels and soil moisture in the lower South especially in the summer. It is not clear whether the upper South would become wetter or drier.

- Trends in flooding events show that floods are causing more monetary damages than they have in the past (Pielke and Downton, 2000; Pielke et al., 2002). Increased intensity of precipitation events and increases in intensity of the most powerful hurricanes will likely increase flood risks in the region.

- Because precipitation is projected to come in less frequent, more intense events (Karl et al., 2009), the likelihood of droughts could increase. Higher temperatures will also increase the likelihood of droughts (CCSP, 2008d).

- Increases in coastal storm intensity, sea level rise, and other climate change impacts will very likely increase stresses on coastal resources. Meanwhile the exposure of coastal resources to risks from climate will likely increase as population and development in the coastal plain increases (IPCC, 2007a; U.S. EPA, 2009a).

- Rising sea levels will eventually inundate low-lying coastal areas, including wetlands (marshes and mangroves), which will reduce the amount of habitat for wetland-dependent coastal fish and shellfish populations and lead to rapid saltwater intrusion into coastal forests and freshwater aquifers (Karl et al., 2009).

- By the end of the century, heat wave events that now occur once every 20 years are projected to occur about every other year (under a high emissions scenario), and very hot days are projected to be about 10°F hotter than they are today (Karl et al., 2009).

- Higher temperatures and extreme weather are very likely to increase adverse health impacts from heat-related illness and death, pollution, storm-related fatalities and injuries, and infectious diseases (Field et al., 2007; CCSP, 2008a; Karl et al., 2009). The very young and old, the poor, those with health problems and disabilities, and certain occupational groups are at greater risk (CCSP, 2008a).

- Higher temperatures will likely increase water demand and harm water quality, which could lead to fish kills and loss of aquatic species diversity. In addition, higher temperatures increase evaporation which contributes to reduced water supplies (Karl et al., 2009).

- Increases in intense precipitation may increase short-term flooding, which will stress the capacity of existing drainage systems, disrupt traffic management, increase highway incidents, affect airline schedules, etc. (CCSP, 2008b).

- Increases in mean and extreme high temperatures may require changes in materials, maintenance, and operations of transportation infrastructure and vehicles (CCSP, 2008b).

- Of all of the regions in the United States, the Southeast in projected to face the largest losses of crops as a result of climate change (NAST, 2001).
- Lower soil moisture and higher temperatures will increase the frequency and intensity of wildfires and pest outbreaks (such as the southern pine beetle) in Southeastern forests (Karl et al., 2009).
- The Southeast has a relatively high concentration of biodiversity, particularly in Florida (Brown et al., 2006), and climate change is projected in general to have significant adverse effects on biodiversity (Millennium Ecosystem Assessment, 2005).
    - Rising sea levels will increase the vulnerability of spawning and nursery habitat through inundation of wetlands and coastal marshes and saltwater intrusion, leading to a loss of wetland-dependent coastal fish and shellfish (Karl et al., 2009).
- Rising sea surface temperatures and sea levels will lead to increased rates of coastal erosion, loss of coastal wetlands, and bleaching of coral reefs (Karl et al., 2009). Increased CO_2 levels in ocean waters will increase rates of ocean acidification (Meehl et al., 2007).

In addition to these projected impacts, climate change is also expected to have impacts on quality of life, impacts on the energy sector, impacts on the economy (e.g., tourism and recreation), and impacts on environmental justice issues. The adverse impacts of climate change in the Southeast may be felt most acutely by vulnerable populations in the region.

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A. Brief Description of SRES Storylines and Associated Scenarios

The Intergovernmental Panel on Climate Change (IPCC) developed a Special Report on Emission Scenarios (SRES) to provide more consistent projections of greenhouse gas (GHG) emissions – projections that considered the complex social, economic, and technological relationships that underlie energy use and resulting emissions. The SRES approach aimed for an underlying consistency of these complex relationships. The result was a set of logical storylines that encompass the social and physical relationships driving GHG emissions (Nakićenović and Swart, 2000). For more details on these storylines and scenarios, please refer to the IPCC report at http://www.grida.no/climate/ipcc/emission/.

At the core of the SRES approach are four poles along two major axes:

- Economic vs. environmental
- Global vs. regional.

As shown in Figure A.1, combinations of these four poles give rise to four primary storylines:

- A1 – Economic growth and liberal globalization
- A2 – Economic growth with a greater regional focus
- B1 – Environmentally sensitive with strong global relationships
- B2 – Environmentally sensitive with a highly regional focus.

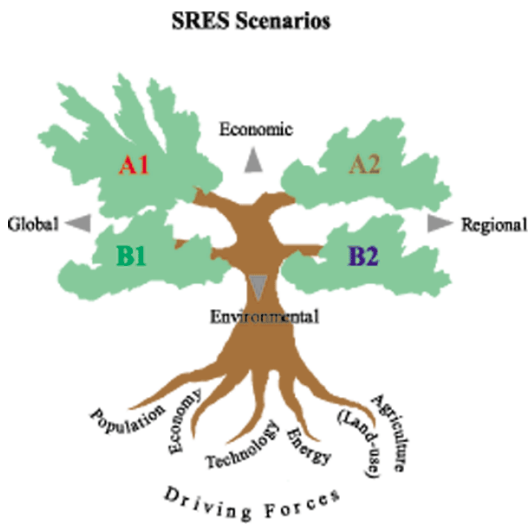

Figure A.1. Conceptual relationships underlying the SRES scenarios.

Source: Nakićenović and Swart, 2000.

Each storyline describes a global paradigm based on prevalent social characteristics, values, and attitudes that determine, for example, the extent of globalization, economic development patterns, and environmental resource quality. The storylines are by their nature highly speculative. Nonetheless, they provide identifiable starting points that are defined and consistent with available datasets for projecting some variables (most notably population, income, land use, and emissions). They have been used in previous and ongoing assessments and provide a basis for intercountry comparisons.

The A1 and B1 storylines focus on global solutions to economic, social, and environmental sustainability, with A1 focusing on economic growth and B1 focusing on environmental sensitivity. The A2 and B2 storylines focus on regional solutions with a strong emphasis on self-reliance. They differ in that A2 focuses on strong economic growth and B2 focuses on environmental sensitivity. The IPCC describes their differences as follows: "While the A1 and B1 storylines, to different degrees, emphasize successful economic global convergence and social and cultural interactions, A2 and B2 focus on a blossoming of diverse regional development pathways."

The A1 storyline, in general, assumes strong economic growth and liberal globalization characterized by low population growth, very high gross domestic product (GDP) growth, high-to-very high energy use, low-to-medium changes in land use, medium-to-high resource availability (of conventional and unconventional oil and gas), and rapid technological advancement. The A1 scenario assumes convergence among regions, including a substantial reduction in regional differences in per capita income in which the current distinctions between "poor" and "rich" countries eventually dissolves; increased capacity building; and increased social and cultural interactions. A1 emphasizes market-based solutions, high savings, and investment, especially in education and technology, and international mobility of people, ideas, and technology.

The A1 storyline is broken up into scenarios that characterize alternative developments of energy technologies. A1FI represents the "fossil intensive" scenario and results in the highest emissions and the highest atmospheric concentrations of carbon dioxide (Schröter, 2005). The A1B scenario represents a "balanced" development of energy technologies. It assumes that no one energy source is relied on too heavily and that similar improvement rates apply to all energy supply and end-use technologies (Nakićenović and Swart, 2000).

The A2 storyline describes a world with regional economic growth characterized by high population growth, medium GDP growth, high energy use, medium-to-high changes in land use, low resource availability of conventional and unconventional oil and gas, and slow technological advancement. This storyline assumes a very heterogeneous world that focuses on self-reliance and the preservation of local identities, and assumes that per capita economic growth and technological change are more fragmented and slower than in other scenarios. The A2 storyline only has one scenario, so the terms A2 storyline and A2 scenario are used synonymously.

The B1 storyline describes a convergent world that emphasizes global solutions to economic, social, and environmental sustainability. Focusing on environmental sensitivity and strong global relationships, B1 is characterized by low population growth, high GDP growth, low energy use, high changes in land use, low resource availability of conventional and unconventional oil and gas, and medium technological advancement. The B1 storyline assumes rapid adjustments in the economy to the service and information sectors, decreases in material intensity, and the

introduction of clean and resource-efficient technologies. A major theme in the B1 storyline is a high level of environmental and social consciousness combined with a global approach to sustainable development. The B1 storyline only has one scenario, so the terms B1 storyline and B1 scenario are used synonymously.

The B2 storyline, like the A2 storyline, focuses on regional solutions to economic, social, and environmental sustainability. The storyline focuses on environmental protection and social equality and is characterized by medium population and GDP growth, medium energy use, medium changes in land use, medium resource availability, and medium technological advancement. Similar to the A2 and B1 storylines, the B2 storyline has only has one scenario, so the terms B2 storyline and B2 scenario are used synonymously.

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