SUSTAINING TENNESSEE IN THE FACE OF CLIMATE CHANGE: GRAND CHALLENGES AND GREAT OPPORTUNITIES

A Study by the Sustainable Tennessee Organization, August 2012

This report communicates current knowledge of climate change and its potential impacts on the environmental and socio-economic conditions and quality of life in the State of Tennessee. It presents complementary opportunities for adaptation and mitigation.

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EXECUTIVE SUMMARY

In recent decades, the concept of sustainability has emerged as a guiding principle for public and private institutions. Sustainability emphasizes decision-making that secures positive, long-term economic, social and environmental benefits. A broad range of factors pose barriers or threats to achieving sustainability objectives. Climate change is one such threat. Yet changes in climate will interact with other drivers of sustainability including public health, education, and economic development.

While the issue of climate change has long been discussed as a global challenge, questions are increasingly being asked regarding what climate change might mean at the local level, where individuals live, work, and play. This report, *Sustaining Tennessee in the Face of Climate Change: Grand Challenges and Opportunities,* was prepared for consideration by decision-makers within the government, business communities and nongovernmental organizations of the State of Tennessee, its 95 counties and its municipalities. Written by the Sustainable Tennessee Organization, a diverse group of concerned researchers from universities and institutions across the State, the report represents a first-step toward elucidating the issue of climate change and sustainability in the State of Tennessee. The report summarizes the interactions between climate change and other key issues relevant to the future well-being of Tennesseans, what we know and don't know about climate change at the State level, and what the potential consequences of climate change might be for Tennessee. Yet, at the same time, the report emphasizes the broad range of opportunities that exist to both manage the risks and create 'win-win' outcomes that generate benefits for our communities and industries while pursuing sustainability objectives.

Key findings from the report are outlined below.

Observed and Projected Climate Change

- Since the industrial revolution, the global average temperature has increased by 2˚F. This increase has largely been attributed to human emissions of greenhouse gases (GHGs), a finding that is consistent with scientific research dating back to the early19th century. This warming has been accompanied by rising sea levels, retreat of ice sheets and glaciers and increases in the frequency and/or intensity of some extreme climate events in some global regions.

- Climate trends across the United States and Tennessee specifically mirror these global trends. Tennessee's major cities, for example, have warmed by approximately 2˚F since 1950. Extreme rainfall events in the U.S. Southeast have become more intense, although there is less evidence of a long-term trend in average annual rainfall.

- Climate models are unambiguous in projecting increases in temperatures at global, national, and regional scales. The Tennessee region is projected to warm between 5 and 9˚F by the end of the 21st century. This warming is projected to be accompanied by increased frequency of extreme heat days, extreme rainfall events, and drought conditions. Nevertheless, uncertainties persist in understanding of future climate changes in Tennessee, which highlights the need for the identification of actions that are robust to such uncertainty.

Climate Change Impacts

- Projected changes in climate can have adverse consequences for Tennessee's natural landscapes such as shifts in the distribution of plant and animal species, including the State's prized forest ecosystems. Ecosystem disturbances associated with extreme weather events may become more common, as might invasive and pest species.

- Freshwater ecosystems are likely to be adversely affected by rising stream and lake temperatures that influence suitable habitat for Tennessee's wildlife. Water quality is also likely to decline.

- Human health is vulnerable to the direct and indirect effects of climate change. The key direct consequence is increased heat-related illness and mortality. However, health can be influenced by climate indirectly through changes in disease vectors (e.g., mosquitoes and ticks) as well as changes in air quality including ground-level ozone and allergens.[1]

- Water resources may be adversely affected by reduced reliability of supply due to increasing drought frequency as well as by increased demand from the growing Tennessee population.
- The energy sector will be affected by rising temperatures and reduced water availability that decrease the efficiency of electricity generation as well as by rising demand for electricity, particularly for space cooling.
- Transit systems can be disrupted by extreme weather events that increase travel times as well as the risk of injuries. Climate change may also accelerate degradation of transit systems requiring increased maintenance. The challenge of meeting such needs will be exacerbated by the growing demand for new infrastructure to accommodate growth.
- Tennessee's agriculture is vulnerable to both higher temperatures that stress crops as well as increased risk of drought. Extreme events such as flooding and hail also pose risks to agriculture as do crop pests. However, the crop type (annual versus perennial) and the timing of the stress have a significant influence on the resulting impact.
- Tourism and migration of residents in and out of Tennessee will be influenced by perceptions of the frequency and intensity of climate-related natural hazards (e.g., tornados and Gulf Coast hurricanes) as well as long-term shifts in seasonal conditions and impacts to the amenities provided by Tennessee's climate and landscapes.

Great Opportunities for Tennessee

- Despite the challenges, a broad array of opportunities is available to Tennesseans to pursue sustainability objectives in a changing climate. Decision-makers should begin strategic planning for climate change by updating prior assumptions about the past being a sufficient guide for the future and identifying ways of incorporating 'climate-friendly' and 'climate-resilient' actions into routine management decisions.
- Given the uncertainties regarding the future, public and private institutions should adopt a risk management approach to addressing

the threats posed by climate change to sustainability. This includes developing an understanding of climate thresholds in systems of value and the likelihood of those thresholds being exceeded in response to changes in climate and other environmental and socioeconomic factors.

- In addition, however, Tennesseans should also actively seek to implement those many actions that generate positive economic, social and environmental outcomes. Rather than viewing actions that address climate change and promote sustainability as barriers to economic development and social progress, Tennesseans should focus on those actions that achieve multiple objectives that best-position the State for a bright future.
- Investments in improved surveillance systems will enhance the capacity of Tennesseans to monitor the status and trends of systems and assets of value. This will enhance detection of climate impacts and threats to sustainability as well as aiding in the identification of emerging opportunities posed by environmental or socioeconomic change.
- Finally, there is a clear need to enhance knowledge regarding potential changes in the State's climate at scales relevant to Tennesseans, the integrated assessment of those changes given other social and economic trends, and the costs and benefits of possible response options. Acquiring such knowledge will require a collaborative and ongoing research effort that links academic research with the knowledge of local managers in public and private institutions.

Table of Contents

1 SUSTAINABILITY IN A CHANGING CLIMATE

Over the past several decades, the concept of sustainability has emerged as a strategic guiding principle for a range of organizations from local, state and federal governments to businesses and private corporations. While definitions of sustainability have evolved over time and remain flexible, three key elements are essential for sustainable development: economic growth, social progress, and environmental stewardship.[2]

In order to meet long-term sustainability objectives, it will be necessary for Tennessee to manage the new risks and potential opportunities posed by climate variability and climate change in addition to addressing ongoing challenges from constantly changing socioeconomic conditions. Sustaining the health of Tennessee's growing population will be dependent upon ensuring adequate levels of air and water quality. Extreme weather events and natural disasters may become more frequent and last longer during the decades to come, and it will be a challenge to keep Tennesseans out of harm's way, The State of Tennessee has multiple climate-sensitive industries such as agriculture, forestry and tourism, which thrive off of the State's scenic amenity. Facilitating growth of these industries in the face of a changing climate will help them to remain prominent features in Tennessee's economy.

Despite the importance of climate change to Tennessee, there is currently little information on this topic that is focused on the State. This report therefore represents one step toward enhancing the knowledge base regarding climate change in Tennessee and its implications. It reflects the work of a broad network of institutions across the State and contains information that highlights critical considerations for the State's people and industries. A key challenge for Tennesseans will be the need to work together across different sectors, locations, and levels of government in order to develop integrated solutions for mitigating or adapting to potential climate change impacts.

This report first provides some of the context relevant to understanding various threats to the sustainability of Tennessee's people, economy, and environment. The report then provides a snapshot of the economic, social, and environmental conditions that will influence how climate change may affect sustainability in the decades ahead. Next, the implications of changes in climate for Tennessee are discussed for ecological assets and services as well as human-managed systems. The report concludes with a discussion of how organizations at the local and State level can best pursue actions that manage the risks of climate change while also achieving broader sustainability objectives for Tennessee (e.g., long-term economic growth, social progress and environmental stewardship).

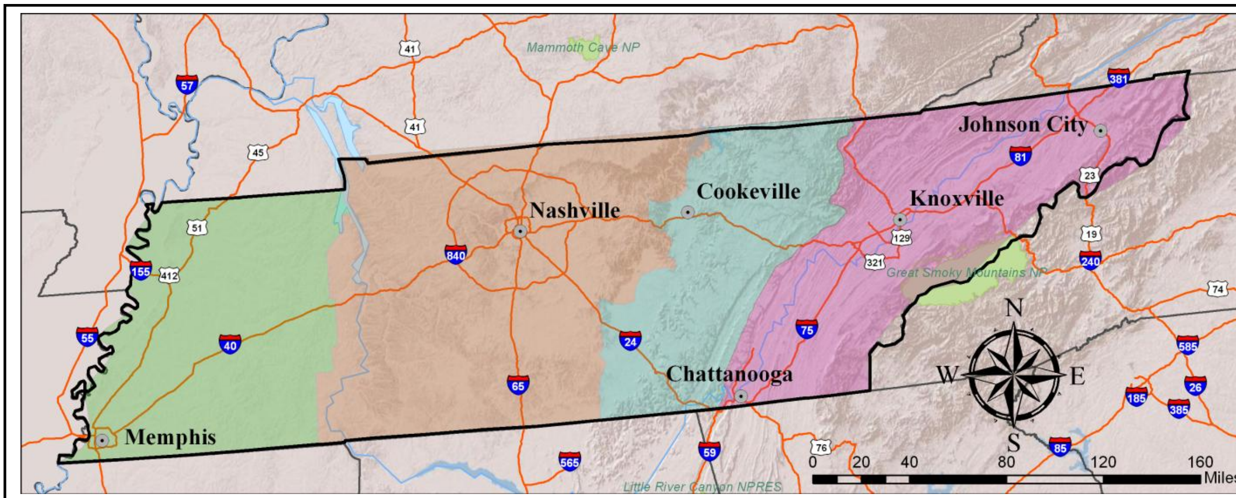
2 TENNESSEE NOW

In order to understand the implications of climate change and other threats to Tennessee's sustainability, this report first examines the existing landscape and climate of our State, as well as its population, natural resources and economy. These characteristics not only define the uniqueness of Tennessee, but also influence how the various challenges discussed later in Sections 3–5 will affect the future of the State.

2.1 Tennessee's Landscape and Climate

Tennessee has three distinct geographical and cultural regions represented by the three stars at the center of the State flag: West, Middle and East Tennessee. The lowlands of West Tennessee are bordered by the Mississippi River on the west and a portion of the Tennessee River on the east. Aside from the city of Memphis, land in West Tennessee is primarily agricultural. Nashville, the State's capital, is located in Middle Tennessee, an area characterized by rolling hills and fertile river valleys extending eastward to the Cumberland Plateau. East Tennessee is dominated by the Appalachian Mountains and foothills, including the Cumberland Mountains, the ridge-and-valley area with its principle urban areas of Knoxville, Chattanooga and the Tri-Cities, and the Great Smoky Mountains that straddle our border with North Carolina.

The varied topography of Tennessee leads to diverse climate conditions, [3] but overall the State has a temperate climate with hot, humid summers and mild winters. Tennessee has four major climate (Figure 1). Across the State, the average annual temperature varies from over 62°F in the extreme southwest to near 45°F atop the highest peaks of the east. Tennessee's moist air primarily comes from the Gulf of Mexico to the south, so there is a gradual decrease of average precipitation from south to north across the State. The average annual precipitation across Tennessee ranges from approximately 40 inches in the northern portions of the Great Valley of East Tennessee to up to 80 inches in the peaks of the Smokey Mountains. Average annual snowfall varies from 4 to 6 inches in the southern and western parts of the State to more than 10 inches in the mountains of the east. However, due to relatively mild winter temperatures, snow cover in most locations rarely persists for more than a few days.



Tennessee Climate Division	Average Annual Temperature	Average Annual Precipitation
Western	59 ± 1 °F	51 ± 9 inches
Middle	58 ± 1 °F	53 ± 8 inches
Cumberland Plateau	56 ± 1 °F	56 ± 8 inches
Eastern	57 ± 1 °F	50 ± 7 inches

Figure1. Map of Tennessee's four climate divisions and their associated average annual temperature and precipitation.[4]

Tennessee's climate is also prone to variability that contributes to extreme events. Tennessee's most important flood season occurs during the winter and early spring when frequent storms bring general rains of high intensity that contribute to local or more widespread flooding. Such storms can also be accompanied by damaging winds and hail and may occur as tornadoes. Heavy summer thunderstorms also result in local flash flooding. Flood-producing rains are general rare in the fall, although occasional tropical storm systems may cause serious floods as they pass through the area. Tennessee winters can be accompanied by ice storms in some areas.

2.2 Tennessee's Economy

Tennessee currently has a diverse economy (Figure 2). In 2011, Tennessee's gross domestic product was $233 billion, up 1.9% from 2010.[5] Although Tennesseans are employed across a variety of economic sectors, Tennessee's major industries include manufacturing, agriculture and tourism. As will be discussed in Section 5, all three of these sectors can be affected directly by climate change (e.g., loss of crops due to severe ice storms) or indirectly (e.g., reduced water availability for manufacturing following prolonged droughts).

Fishing, boating, swimming and camping along the many lakes of Tennessee, together with the several State and national parks, have made tourism one of the major industries in the State. Tourism is included within the Trade, Transportation, Utilities group on Figure 2 and brings in $55.1 billion dollars of revenue across the State, from the Great Smokey Mountains National Park in the east to Memphis, the birthplace of Blues, in the west.

Manufacturing is the second highest grossing industry in Tennessee, earning a total of $50.1 billion Dollars of revenue. Tennessee's top manufactured products include processed foods, transportation equipment, and chemicals as well as textiles, primary and fabricated metals and lumber products. General Motors, Nissan, and Volkswagen already have major manufacturing plants located in Tennessee, and Audi, Hyundai, and Volvo are considering building plants in west Tennessee. The chemical industry has traditionally been strong in Kingsport, home to the Eastman Chemical company. Memphis

International Airport boasts the nation's largest air cargo port, for Memphis is the headquarters for the shipping giant, FedEx.

Tennessee's water resources have been a major factor supporting both industry and tourism. The dams constructed along the Tennessee and Cumberland River systems during the 1930s and the lakes so formed have helped with flood control, facilitated water transportation and continue to provide abundant low cost hydroelectric power and extensive recreation areas.[6] Three major waterways, the Mississippi, Cumberland and Tennessee Rivers, are suitable for commercial traffic.

Although surpassed in monetary value by industrial activity, agriculture remains a vital feature of Tennessee's economy. The wide range of climates in Tennessee, from river bottom to mountaintop, coupled with variations in soils, has resulted in a large number of crops that thrive in the State. Length of growing season is linked to topography in a way similar to temperature, but most of the State is included in the range of 180 to 220 growing days.[7] Tennessee's primary agricultural exports include cattle and cotton.

Forestry is another important part of Tennessee's economy. Direct benefits from forestry include 73,400 jobs and annual wages of $2.4 billion, and supplier industries provide an additional 184,300 jobs and $5.6 billion in wages with a total economic contribution exceeding $33.7 billion. Timberland, containing principally hardwood types, covers approximately one-half of the total area of Tennessee. This has led to a highly diversified woodworking industry and made the area around Memphis the center of production for wood flooring. The temperate climate of the State is very favorable for logging operations, allowing full-scale activity during nine months of the year and to a lesser extent during the winter months.

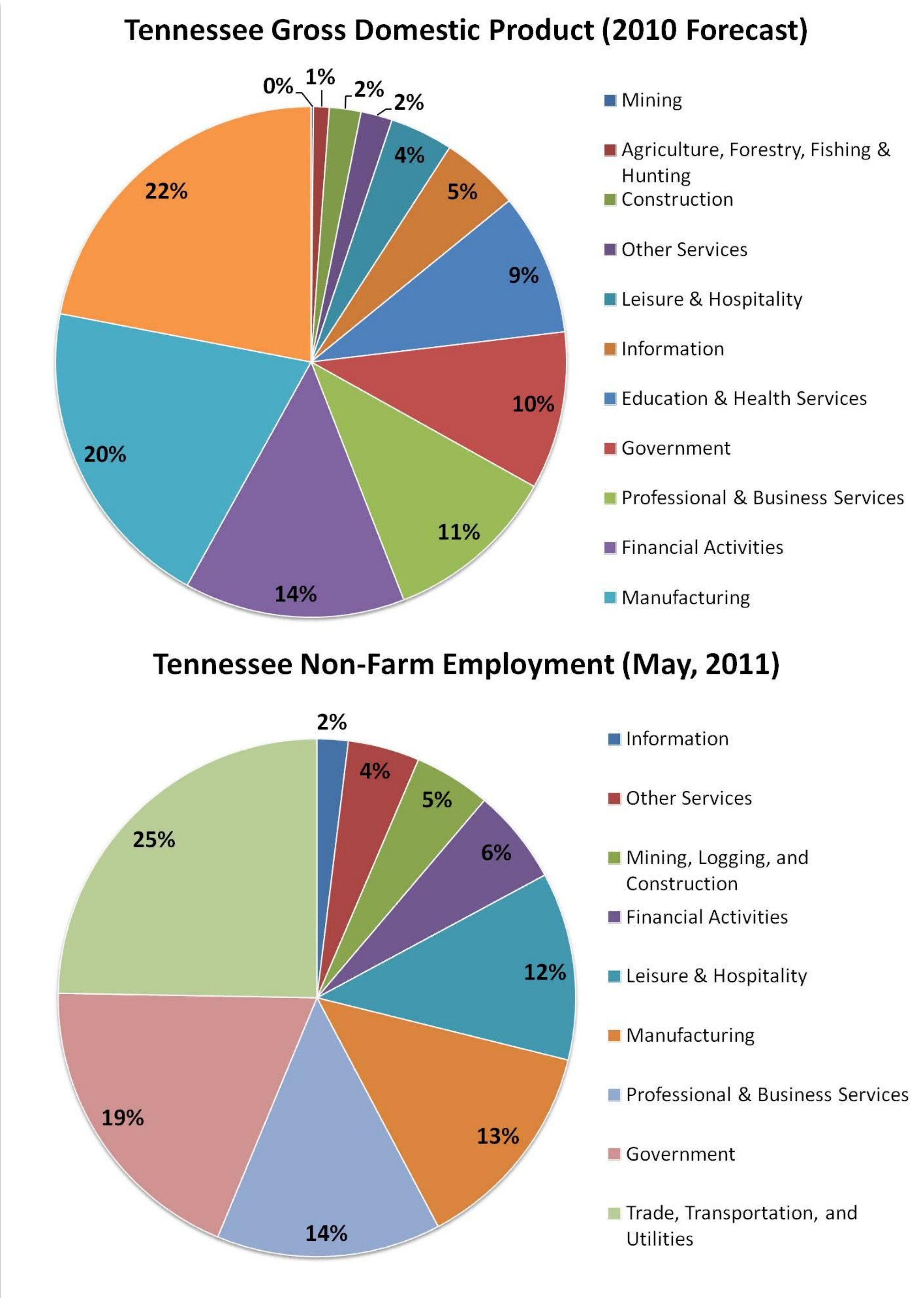


Figure 2. Contribution of different economic sectors to Tennessee's GDP (top) and employment (bottom)[8]

2.4 Tennessee's Energy Supply

Tennessee is nationally notable for the fact that it has generated more electricity than it consumes ever since the time of the Manhattan Project in Oak Ridge during World War II. Currently, Tennessee ranks 19th among U.S. states in net electricity generation and 20th in total per capita energy consumption.[9] Much of Tennessee's electricity generation can be attributed to the facilities and operations of the Tennessee Valley Authority (TVA). Tennessee's electricity generation collectively accounted for over 48,000 metric tons of carbon dioxide (CO_2) emissions in 2010, making it 18th largest emitter of this GHG.[10]

Even though Tennessee is no longer a major coal producer, coal remains the State's primary energy source and was used to generate 41% of Tennessee's 2010 summer Megawatts (MW).[11] The remainder of Tennessee's electric power comes from other fossil fuels (petroleum and natural gas), nuclear sources, renewable energy sources (e.g., hydropower, solar and wind), and pumped storage facilities. Natural gas production from throughout Tennessee is increasing, and hydrofracking methods are being explored to increase production rates from formations such as the Chattanooga Shale. Two of TVA's three nuclear plants are located in Tennessee. The Sequoyah nuclear plant in Soddy-Daisy generated 2,278 MW in 2010, and the Watts Bar nuclear near Spring City generated 1,123 MW in 2010.[12]

Although the majority of Tennessee's electricity is generated from fossil fuels (primarily coal) and nuclear power, the State is building its portfolio of "green" energy resources. Tennessee has been one of the dominant suppliers of hydroelectric power east of the Rocky Mountains since the emergence of TVA during the 1930s, Tennessee hosts the Southeast's first major wind farm on Buffalo Mountain near Oliver Springs. The wind farm's generation capacity has increased from 2 to 24 MW over the past decade.[13] The use of solar panels is increasing due to grants and incentives (e.g., the recent installation of roof-mounted units at Wampler's Farm Sausage in Lenoir City).

Tennessee ranks 15th of U.S. states in petroleum energy consumption, in part due to the heavy volume of highway traffic including truck freight on the

State's highways. Tennessee is also emerging as a national leader in pursuing potentials for cellulosic ethanol production from switchgrass (see Box 6).

2.4 Tennessee's People

In 2010, Tennessee had a total population of 6.3 million.[14] Like much of the U.S. Southeast, Tennessee is projected to grow relatively rapidly over the next several decades if it remains on its current path of economic development and immigration.[15] This growth will be particularly strong in Tennessee's urban centers of Knoxville, Nashville, Chattanooga, and Memphis where climate, scenic amenity, and access to jobs attract businesses and new migrants into the State. Per capita personal income in the State averaged $27,334 in 2010, with median household income at $51,914 and 23.8% of the population living below the poverty line.[16] Although Tennessee is now largely industrial with most people living in urban areas, many Tennesseans still derive their livelihood from the land.

Tennessee offers a range of educational opportunities for its population including nationally competitive colleges and universities. Tennessee's high school graduation rate has been rising steadily over the past decade, surpassing the national average in 2008; however, there is still room for further improvement. The 2011 report card on public education in Tennessee revealed that the State has yet to reach its targets for high school graduation rates[17], ranking 31st among the nation's 50 states.[18] Post-high school education is closely tied to personal income and more broadly to overall economic growth, and the State's progress on higher education has been slower. Tennessee ranked 41st in the 2010 *New Economy Index* which measures the extent to which State economies are knowledge-based and globalized,[19] suggesting ample opportunity to build upon the State's progress in education and position Tennessee for the jobs and economy of the 21st century.

Tennessee has made steady progress on some health indicators in recent decades, but still ranks 39th overall.[20] For example, infant mortality has declined in the State but remains well above the national average, with the 4th highest rate in 2006.[21] Meanwhile, chronic diseases such as obesity and diabetes have increased in recent years, with TN having the 4th highest rate of obesity and 6th highest rate of diabetes in the United States in 2011.[22] Tennessee also has some of the highest rates of asthma in the nation, with Knoxville, Chattanooga, and Memphis among the top ten worst cities in the United States for asthma in 2012.[23] The Asthma and Allergy Foundation of America named Knoxville the nation's number one Spring Allergy Capital in both 2011 and 2012 based on a combination of pollen counts, medication rates and ratio of allergists to patients.[24]

2.5 Tennessee's Natural Resources

Tennessee has an incredible abundance of plant and animal species due to its variable topography and climate and its plentiful caves and aquatic habitats.[25] Tennessee's natural systems have high levels of ecological importance but are subjected to pressures arising from climate change, land-use changes, and invasive species. For example, all unprotected eastern hemlock trees are expected to succumb to the spread of a nonnative insect, the hemlock woolly adelgid, over the next few decades as rising temperatures allow the pest to spread northward.[26] The State's natural resources are perhaps best explored by first examining land and its uses and then exploring the State's water resources.

Land Use

Tennessee's urban and suburban areas have expanded in recent years, thereby causing the total amount of land allocated to forests and agricultural production to decline. Population growth and urbanization have affected current land-use patterns dramatically, and these changes are projected to intensify over the next several decades.[27]

The amount of forested land in Tennessee has generally been on the rise since the last century when many of trees were harvested for railroads and the land was put temporarily into agriculture. Today, most of the forested areas are natural second growth stands with less than 4% of Tennessee forests being plantations. In the early part of the twenty-first century, about 69% of forest land was in private ownership by individuals, 10% was owned by the forestry industry, and 13% was under federal or State government.[28] However these numbers have been rapidly changing. Largely as a result of poor forest management, a recent widespread outbreak of the native southern pine bark beetle destroyed many pine stands.[29] Combined with the pressure for land development for residential use, the number of landowners is increasing dramatically and average tract size is declining. Since 2008, much of the forested land in the Cumberland Mountains was sold as the market for wood moved overseas.[30] Much of the large private forest land has become second home development (especially on the Cumberland Plateau).[31]

Agricultural land is an important component of Tennessee's landscape. The total Tennessee area allocated to field crops in 2011 was 4.897 million acres. The top uses of that land were hay (1.880 million acres), soybeans (1.3 million), corn (0.8 million acres), cotton (0.5 million acres) and wheat (0.4 million acres).[32] This allocation of land use responds to a large extent to the relative profitability of each activity, which is in turn impacted by changes in prices, cost of production, and yields.

Water Resources

The Tennessee River Valley has one of most biologically diverse fisheries and mussel populations in the world with many unique species are only found in this region.[33] These aquatic populations can only be maintained with adequate stream flows and good water quality. Tennesseans have an ongoing need to balance increased water demand (from population growth and agriculture/industry) with water supply (from variable precipitation, slowly replenished groundwater resources and engineered storage systems).

Except for a small area east of Chattanooga, Tennessee lies entirely within the Mississippi River watershed (Figure 3). Westernmost Tennessee is drained by several small rivers directly into the Mississippi River. The rest of the State drains either into the Cumberland or Tennessee Rivers, both of which flow northward near the end of their courses to join the Ohio River along the Kentucky-Illinois border. The Tennessee River is formed by the juncture of the Holston and French Broad rivers at Knoxville. Other important Tennessee rivers include the Clinch, Little Tennessee, Hiawassee, Elk, Duck and Harpeth Rivers. Tennessee's streams exhibit seasonal flow, with a pronounced peak flow in the spring and lowest flow rates in the fall. Natural stream flow has been obscured by the dams which have been constructed along all of Tennessee's major rivers.

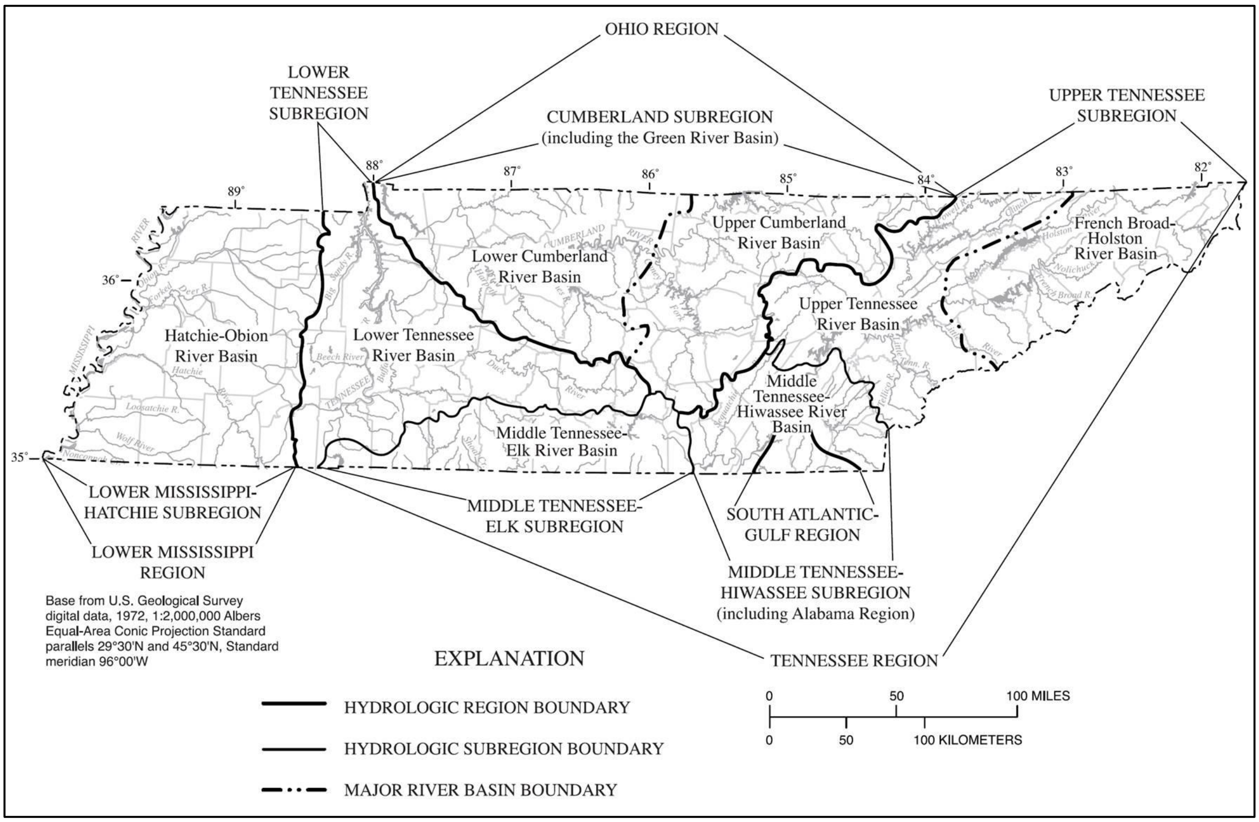


Figure 3. Hydrologic regions of Tennessee.[34]

Currently, most of Tennessee has ample surface and ground water resources to meet the demand of its population and economic sectors.[35] Total available water storage from Tennessee's combined surface and ground water systems is estimated to be 200 trillion gallons.[36] In comparison, in 2005, total water use was approximately 10.6 billion gallons (Figure 4), with 82% for non-consumptive thermoelectric cooling water.[37]Annual use of water resources in Tennessee is therefore less than 0.005% of the total estimate of stored water in the State.

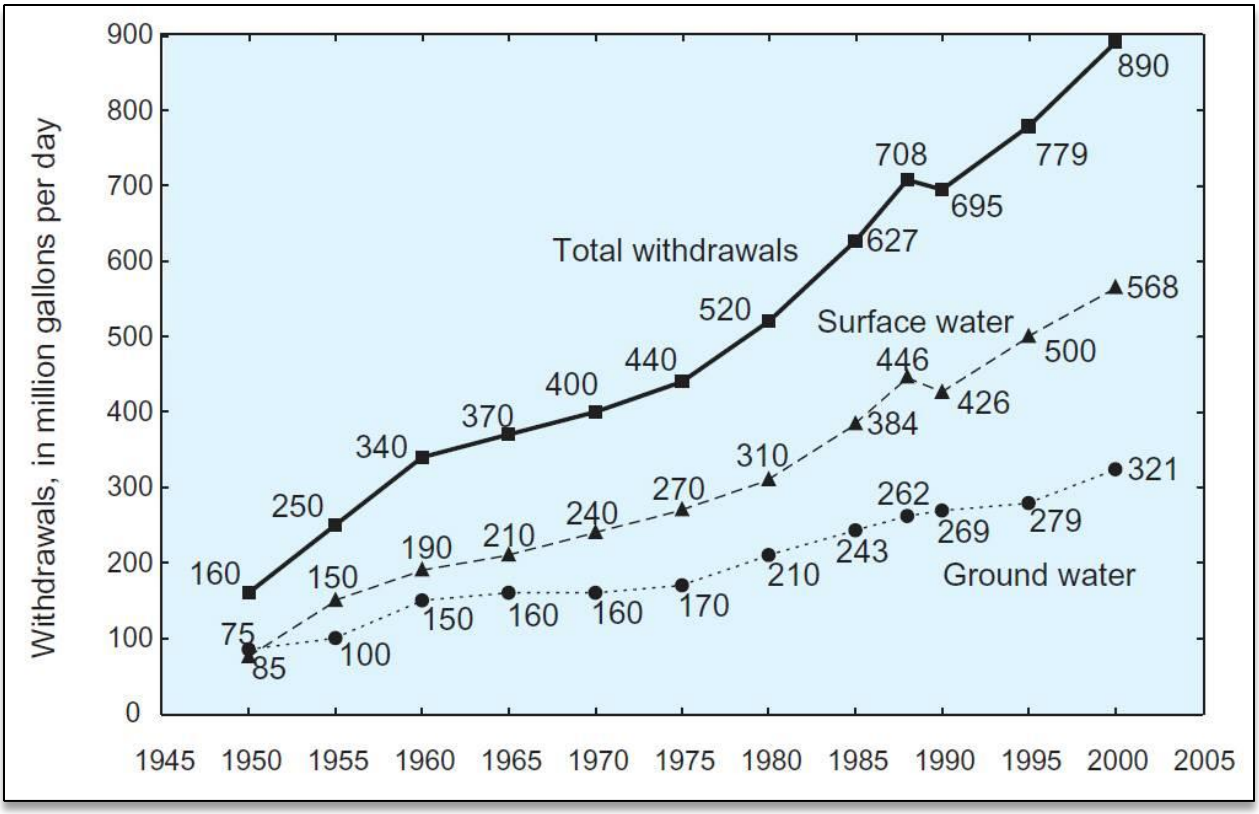


Figure 4. Surface, ground, and total water use by public water supply in Tennessee, 1950-2000.[38]

Ground water is available in differing quantities across the State and in different types of aquifers (Figure 6). In eastern Tennessee, small quantities of ground water are withdrawn from wells or obtained from springs. Ground water is obtained from karst (cave and cavern) systems within central Tennessee. The most extensive ground-water resources, however, are present in unconsolidated and semi-consolidated sand and gravel aquifers in western Tennessee.

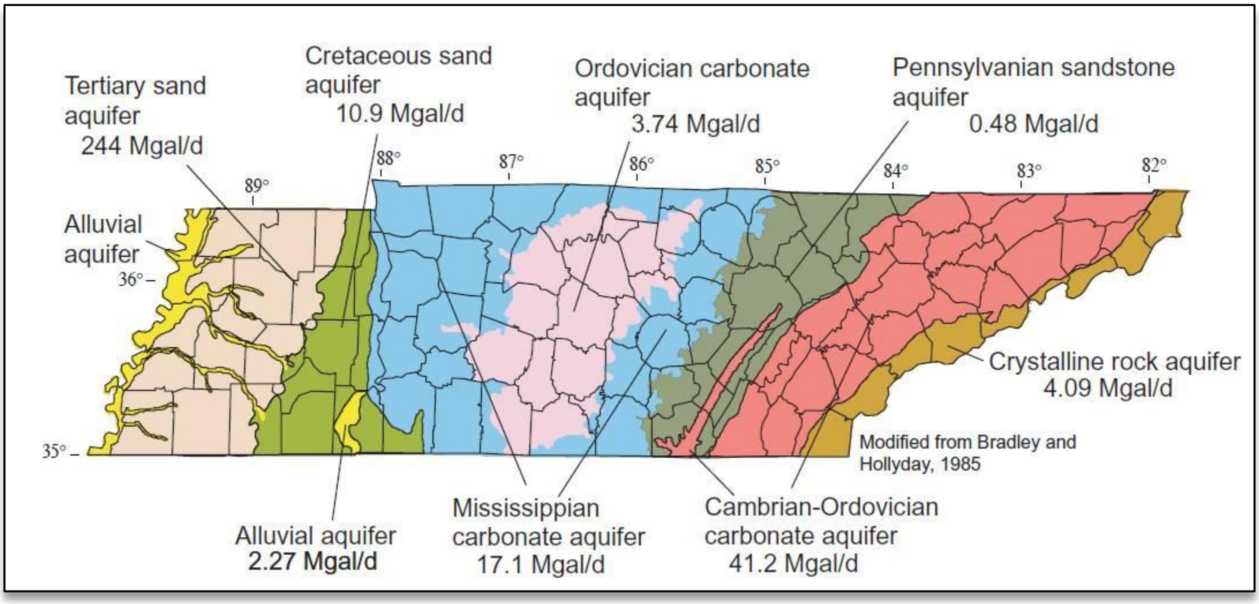


Figure 5. Principal aquifers and ground-water withdrawal totals for 2000.[39]

3 GRAND CHALLENGES FOR TENNESSEE'S FUTURE

Tennessee has the potential for a bright and sustainable future, provided that its citizens can capitalize on opportunities ahead while overcoming some challenges that affect economic growth, social progress, and environmental stewardship. In this section, we first summarize the range of threat's to Tennessee's sustainability before focusing in more detail on climate change as a cross-cutting challenge that will affect multiple aspects of the State's future.

3.1 Threats to Tennessee's Sustainability

While there is growing concern about potential effects of climate change from global to local scales, climate change is not the only challenge to the sustainability of Tennessee (Figure 6). The prosperity of Tennesseeans is affected by a range of factors associated with changes in both environmental and socioeconomic pressures. Certainly, environmental threats include extreme weather events (e.g., the May 2010 Nashville floods, the April 2011 hailstorm, the June 2012 heat wave) which can cause significant damage to property, injuries and even deaths. Experience with such extreme weather events, and the potential for such events to become more frequent or severe in the years ahead, is one of the key reasons for concern regarding climate change. Other environmental challenges such as invasive species and agricultural pests also pose ecological as well as economic consequences. Meanwhile, traditional environmental issues such as water quality, air quality, and conservation of ecosystems and biodivesity remain priority foci for environmental policy.

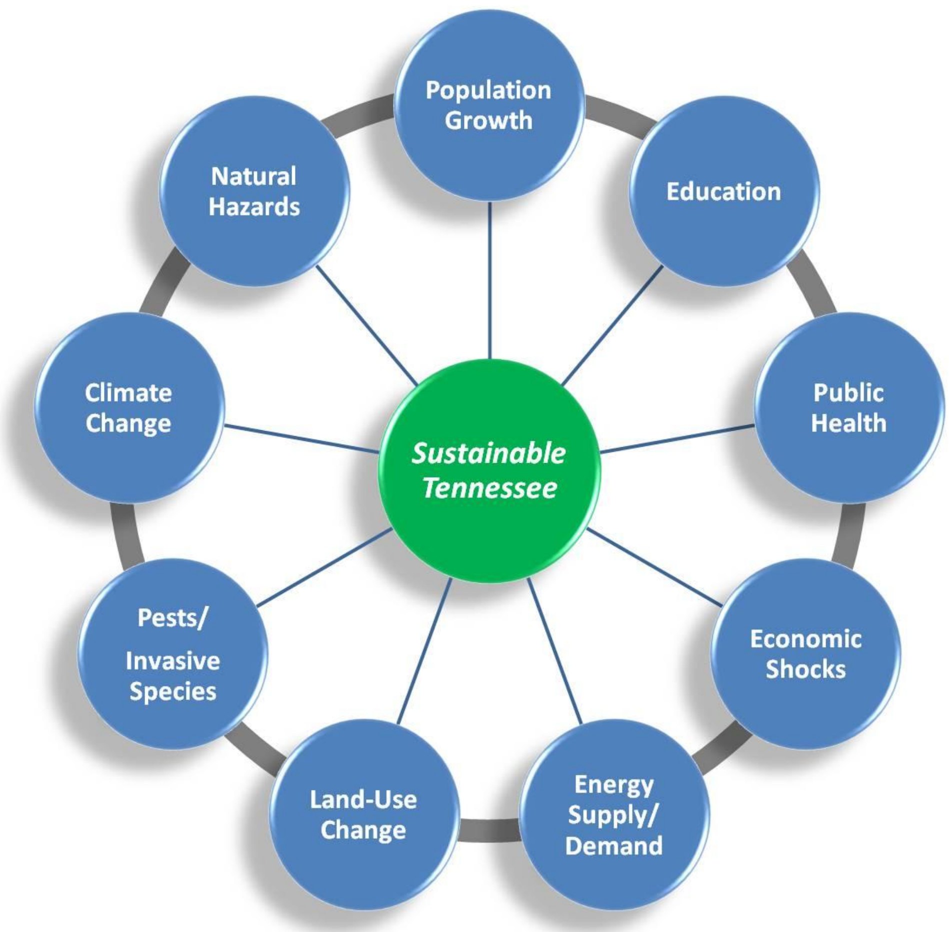


Figure 6. Key threats to achieving sustainability objectives in the State of Tennessee.

It is important to note that these various threats to sustainability do not act independently. Instead, there are significant interactions among them, which can both exacerbate and complicate the challenge, but also create opportunities for integrated and efficient management. Threats to air quality, water quality, and ecosystem services are often closely linked to patterns of economic growth, development, and land use. Meanwhile, connections between education and public health have been well documented for decades.

For example, population growth is a significant driver of the State's economy but also puts pressure on public services such as education, health care, and infrastructure. As of July 19, 2012, Tennessee's unemployment rate was 8.1%,[40] below the national average, but still indicative of persistent challenges for job creation and economic growth arising from the global economic crises. Stimulating economic growth in the State depends upon making progress in both education and public health by addressing some of the challenges identified in Section 2. Economic growth is a major factor that influences the ability for Tennessee to address other threats to sustainability. As a case-in-point, the Tennessee Department of Transportation's 2005 long-range financial plan projected 25-year budget shortfalls of between $6 billion, assuming investment continues along the status quo, and $36 billion, if the State were to make significant gains in maintenance and expansion of transportation options.[41] Critical infrastructure such as transportation underpins a range of economic sectors not to mention the quality of life for Tennesseans. As noted in Section 2, the State's health status has seen improvements in recent years but still ranks 39th, with growing rates of diabetes and obesity recognized as key challenges.[42]

Tennessee's sustainability will be influenced by interactions between climate change, land use and the energy sector (Figure 7). Hence, climate change should not be considered in isolation. Rather, the various environmental and socioeconomic challenges identified above will influence the vulnerability of Tennesseans to future climate change and their capacity to manage emerging risks . The healthier the State's economy and people, the more resilient they will be to the adverse effects of climate change. In addition, a sustainable Tennessee is one that can take advantage of new opportunities and innovations, recruit new talent and industries to the State, and work toward social and economic progress without adversely affecting the environment.

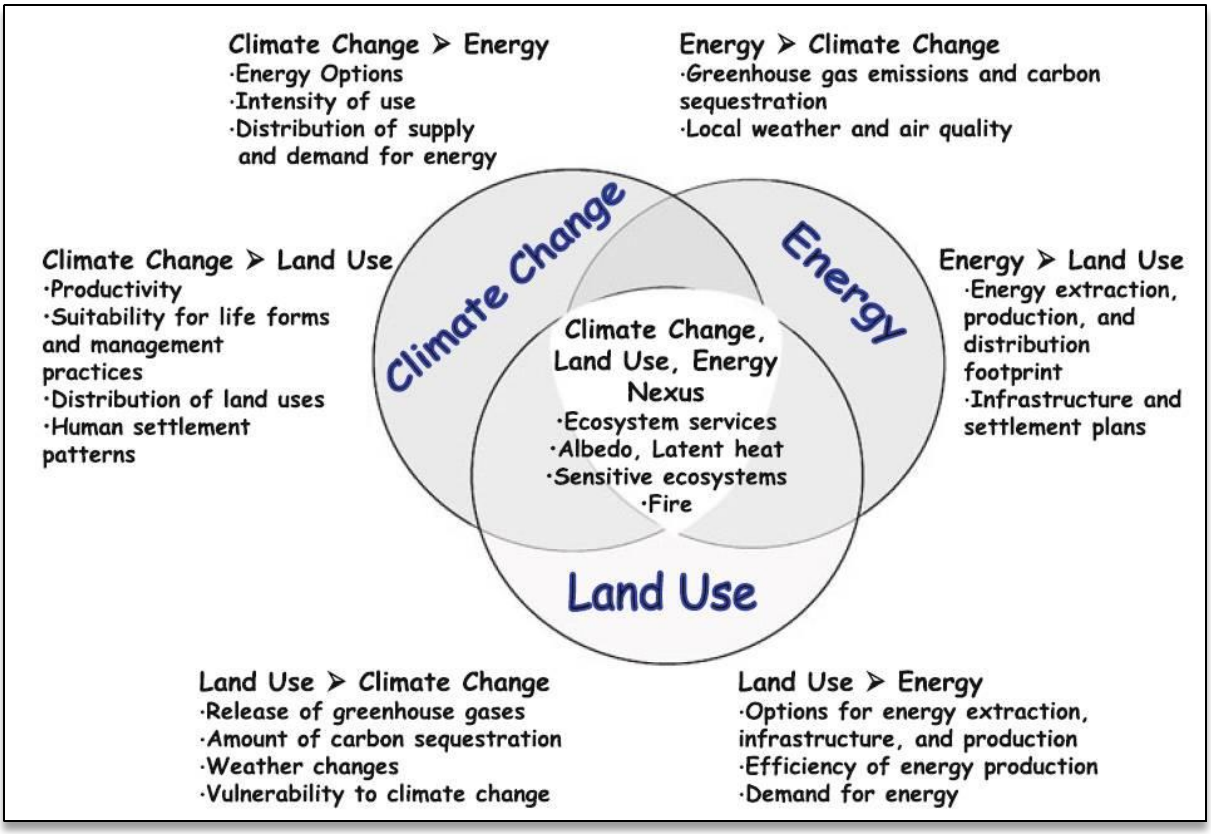


Figure 7. Illustration of key interactions among climate change, energy and land use.[43]

3.2 A Closer Look at Climate Change in Tennessee

Although climate change science has a long history (Box 1), more is understood about past, present and future climate change at the global scale than about climate change in any one region such as the U.S. Southeast or Tennessee. This lack of understanding results from several factors, related to both the supply of and demand for knowledge regarding climate change:

- Projections of changes in regional climate conditions do not necessarily agree. While multiple models project similar warming trends for the Southeastern region of the U.S. in the decades ahead, they disagree about whether precipitation will increase or decrease, when such changes might occur, and how large the changes might be. Furthermore, the resolution of global climate models (GCMs) is too course to reliably simulate extreme weather events that are of particular concern to the public.

- There has been less focus by the scientific community on climate change in Tennessee. To date, U.S. investments in regional studies of climate change have been focused on coastal vulnerability to sea-level rise and the potential of increasing droughts the Southwest.

Nevertheless, a range of information is available from a number of sources that informs how the climate is likely to change in the Tennessee region. First, information for the United States as a whole largely reflects what's been observed at the global level (Figure 8). For example, a 2011 report undertaken through the National Research Council found the climate change has already led to an average annual temperature increase of 2.0°F,[44] increased frequency and intensity of extreme events like heavy precipitation (up 5%), heat waves, sea-level rise along most of the coasts (> 8 inches along portions of Atlantic and Gulf coasts), and a rapid disappearance of Arctic sea ice (3-4% per decade with end-of-summer ice decreasing by 11% per decade).

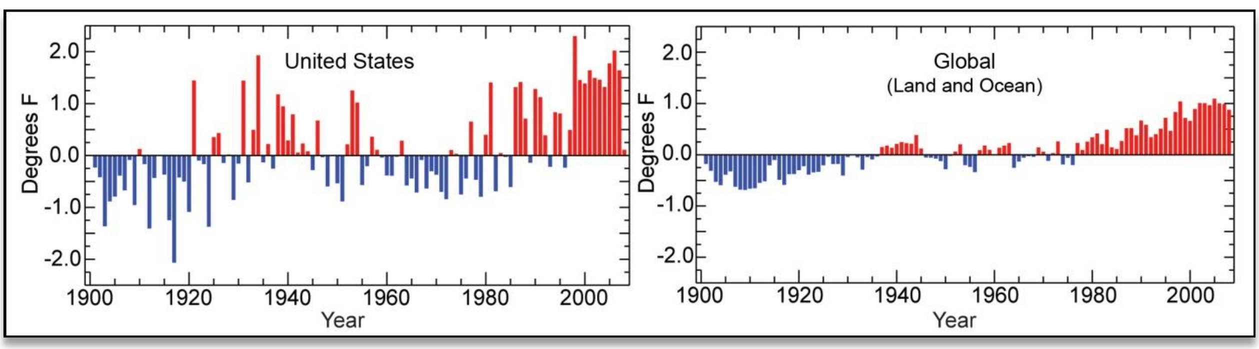


Figure 8. Annual temperature anomalies for the United States (left) and the world (right) for the years 1901 to 2008. Values for each year represent the departure from the long-term average. Red bars represent years warmer than average while blue bars represent years cooler than average.[45]

Observed changes in the U.S. Southeast also reflect a signal of warming temperatures of approximately 2.0°F since 1970, with the greatest seasonal increase in temperature occurring during the winter months.[46] Despite that strong warming trend in recent decades, the average annual temperature of the Southeast did not change significantly over the past century as a whole. Since the mid-1970s, the Southeast has also experienced a decline in the number of days where temperatures fall below freezing. Observed changes in

Box 1. Evidence for Global Climate Change: A Quick Review of the Facts

Although global climate change is often discussed as a relatively recent scientific and, at times, political issue, the evidence for global climate change dates to the early 19th century. The following represents a brief summary of the climate change science timeline:

- **1820**: Human-induced climate change was first proposed by mathematician Joseph Fourier when he observed that Earth should be much colder than it is given its distance from the Sun.
- **1850s:** John Tyndall demonstrated that atmospheric gasses such as carbon dioxide (CO_2) trap heat to a much greater extent than oxygen and nitrogen.
- **1899–1903**: American geologist T.C. Chamberlain and Swedish chemist Svante Arrehenius independently hypothesized that rising CO_2 levels in the atmosphere can lead to changes in Earth's climate and estimated that a doubling of CO_2 might increase global temperatures by 9–11°F.
- **1938**: Callendar observed that CO_2 concentrations had increased 10% over the previous 100 years and estimated that a doubling of CO_2 concentrations would increase global temperatures by 4°F.
- **1956**: Plass estimated that human activity could raise temperatures 2°F per century.
- **1957**: Revelle and Suess introducd strong scientific concepts underlying climate change mechanims and warned of the dangers of warming.
- **1958**: Keeling developed baseline measurements of atmospheric CO_2 concentrations that are have been collected from the Mauna Loa observatory ever since. These data are uncontested documentation of the rise in atmospheric concentrations of CO_2. **1965–1966**: The President's Science Advisory Committee and the U.S. National Academy of Sciences warned of the consequences of increasing emissions of CO_2 from fossil fuels.
- **1979:** The JASON committee predicted that atmospheric CO_2 might double by the year 2035, resulting in global average temperature increases of 4–5°F.
- **1988**: The Intergovernmental Panel on Climate Change (IPCC) was formed by the United Nation's Environment Programme and the World Meteorlogical Organization.
- **1990**: The U.S. Congress passed the Global Change Act to coordinate research on global climate change and created a process for the periodic assessment of climate change and its implications for the United States.
- **1992**: The U.N. Framework Convention on Climate Change (UNFCCC) calling for immediate action to reverse the trend of mounting greenhouse gas (GHG) emissions was approved. It remains the principle policy framework for international efforts to reduce GHG emissions.

Throughout this history of climate change science, three key lines of evidence have provided our understanding of its causes and consequences:

- **Fundamental Physics** – Much of our understanding of climate change and its consequences is based on the physical and chemical fundamentals of our planet. For example, the greenhouse effect is a consequence of the water vapor in the Earth's atmosphere. As water vapor absorbs infrared radiation (i.e., heat) it has a warming influence on that atmosphere. Similarly, other GHGs (such as CO_2, methane, and nitrous oxide) are also known to absorb heat and contribute to atmospheric warming. As the atmosphere warms from GHGs emitted by human activities, it holds an even greater amount of water vapor, and this 'positive feedback' is a key driver of global climate change. Other aspects of global climate change, such as sea-level rise, are also a product of fundamental physics – the warming of the oceans leads to thermal expansion, contributing to rising sea levels.

- **Observations –** An extensive body of evidence from sources as disparate as atmospheric measures, rock layers, ice cores, coral reefs, tree rings, and preserved pollen, provide indisputable evidence that both atmospheric concentrations of GHGs like CO_2 and global temperatures have been continuously increasing since the Industrial Revolution.[47, 48] Atmospheric concentrations of CO_2 in 2011 reached 391 parts per million (ppm), an increase of 45% since the industrial revolution. Meanwhile, 9 of the 10 years between 2002 and 2011 were among the 10 warmest years in the temperature record dating back to 1880.[49] Five independent analyses of the temperature record, including one by a group of prominent skeptics, all reached the same conclusion: the warming trend is real and the warmest decade on record is the current decade.[50]

- **Global Climate Models –** Models of the Earth's climate are another line of evidence in climate change science. They yield important insights regarding how various natural (e.g., ocean circulation and solar radiation) and human-induced factors (GHGs, land use change, and aerosols) interact to influence the climate. Applications of such models provide a number of key insights. First, because changes in climate lag GHG emissions, Earth is already committed to additional changes in its climate. Second, limiting changes in global mean temperature to less than 2°C above preindustrial level (considered by many to be a threshold for 'dangerous' climate change) is considered high unlikely given current global economic growth and technology. Third, observed trends in global warming can only be explained by including the effects of the GHGs emitted by human activities.

These lines of evidence give us sufficient reason to be concerned about climate change and its consequences. Further concern arises from what climate models suggest about the future magnitudes of global climate change for plausible scenarios of future GHG emissions. In 2007, the IPCC reported that global warming of 4-11°F could occur by the year 2100 along with up to 30 inches of sea-level rise. Various studies since 2007 indicate emissions of GHGs continue unabated at global scales and suggest that larger magnitudes of sea-level rise might occur. Such changes are anticipated to also influence extreme events, with fewer cold days "virtually certain;" more heat waves and extreme rainfall events "very likely;"and increases in droughts, tropical cyclone activity, and extreme sea levels "likely."[51] These general findings, however, do not necessarily provide the level of detail needed to inform decision-making about climate change at national, regional, or local levels.

Southeast rainfall patterns suggest rainfall has generally increased in the fall months, but declined in other months, resulting in an overall increase in the area in the Southeast experiencing drought. Furthermore, the U.S. Department of Agriculture has recently revised its growing zones maps, for plant hardiness zones have migrated northward.[52]

Table 1. Observed average changes in temperature and precipitation in the U.S. Southeast over the past century[53]

Season	Temperature Change (°F)			Precipitation Change (%)	
	1901-2008	1970-2008		1901-2008	1970-2008
Annual	0.3	1.6	**Annual**	6.0	-7.7
Winter	0.2	2.7	**Winter**	1.2	-9.6
Spring	0.4	1.2	**Spring**	1.7	-29.2
Summer	0.4	1.6	**Summer**	-4.0	3.6
Fall	0.2	1.1	**Fall**	27.4	0.1

Observations indicate that temperatures in the U.S. Southeast have been rising over the past century (Table 1). Tennessee's major cities have seen increases of approximately 2°F since mid-century (Table 2), and these findings are consistent with observations for the Southeast and the U.S. as a whole. This warming has been more apparent in minimum (i.e., night time) temperatures than in maximum temperatures. While changes in land use around Tennessee's cities means not all of this warming can be directly attributed to global climate change, such warming trends are nevertheless the source of concerns regarding an increased likelihood of temeprature extremes, such as the record breaking heat wave of June/July, 2012.[54] However, no significant changes in daily precipitation have been apparent across Tennessee's metropolitan areas.

Table 2. Observed warming trends in Tennessee cities[55]

City	Observed Warming (°F [1950 – 2011])	
	Minimum Temperature	Maximum Temperature
Chattanooga	+2.3	+1.6
Knoxville	+0.7	+0.7
Memphis	+4.5	+1.6
Nashville	+1.8	+0.5

While understanding of recent trends in climate can be gained by analyzing observed weather data, gaining insights regarding future changes in climate relevant to Tennessee requires the use of climate models. At the global scale, climate models consistently project future increases in global mean temperature in the decades ahead; however, estimates span a wide range, in part due to uncertainties regarding future GHG emissions (see Box 1). For example, Figure 10 shows temperature changes that might be expected across North America by the middle and end of the 21st century based on averaging across simulations carried out using over a dozen different climate models. These maps indicate that the Tennessee region is likely to warm by approximately 3–5°F by mid-century and 5–9°F by the century's end. Projected average seasonal precipitation changes across North America by century's end (Figure 9) suggest the Tennessee region may have drier summers without any increased rainfall in spring, winter and fall to compensate for the lost moisture.

In addition to such national scale information, groups of researchers across the State have undertaken studies of climate change that specifically focus on Tennessee. For instance, projected changes in Tennessee climate and effects on its resources have been evaluated for "wet," "dry" and "middle" climate change scenarios by researchers from Oak Ridge National Laboratory (ORNL) and the University of Tennessee-Knoxville (UTK) based on results for three of the climate models used in national and global analyses (e.g., Figures 10 and 11). Temperatures are projected to increase compared to 1980-1997 in all five ecological provinces of Tennessee in all months for the three climate model used in the study. Warmer temperatures are projected for 2080 than for 2030. By 2030, the "dry" scenario for September is projected to have the greatest increase (5°F) over the 18-year average and the "middle" scenario for January the lowest increase (0.1°F). By 2080, the greatest increase is projected for the "dry" scenario in September (11 °F) and the lowest for the "middle" scenario in December (1.4°F).

Precipitation patterns are more complex and harder to project than temperature patterns. While some GCMs predict that Tennessee will become wetter, others project a drier climate. In the ORNL/UTK analysis,[56] the "wet" scenario tends to have wetter summer months than the "middle," and both experience more annual precipitation than the 1980-1997 average. The "dry" scenario projects drier months than the 18-year average except for January, March, August, and November in 2030 and January and December in 2080. These changes in precipitation are generally within the monthly standard deviation of the long-term record from 1980-1997. Multi-model averages for precipitation indicate little variation in total yearly precipitation in Tennessee. This is consistent with the aforementioned historical precipitation records for Tennessee cities that show no long-term trend.

These different climate scenarios highlight the uncertainty associated with projections of climate change from individual climate models. For example, for temperature projections, different climate models all indicate that temperatures in Tennessee temperatures on average will rise in future decades. Yet, some models project more pessimistic outcomes with respect to warming than others. Meanwhile, rainfall projections from different models can result in projections that differ not only in magnitude but also in the direction of the change (i.e., up or down). Such uncertainty poses challenges to making decisions about how to respond to climate change, suggesting a risk-based approach to decision-making is warranted (see Section 6).[57]

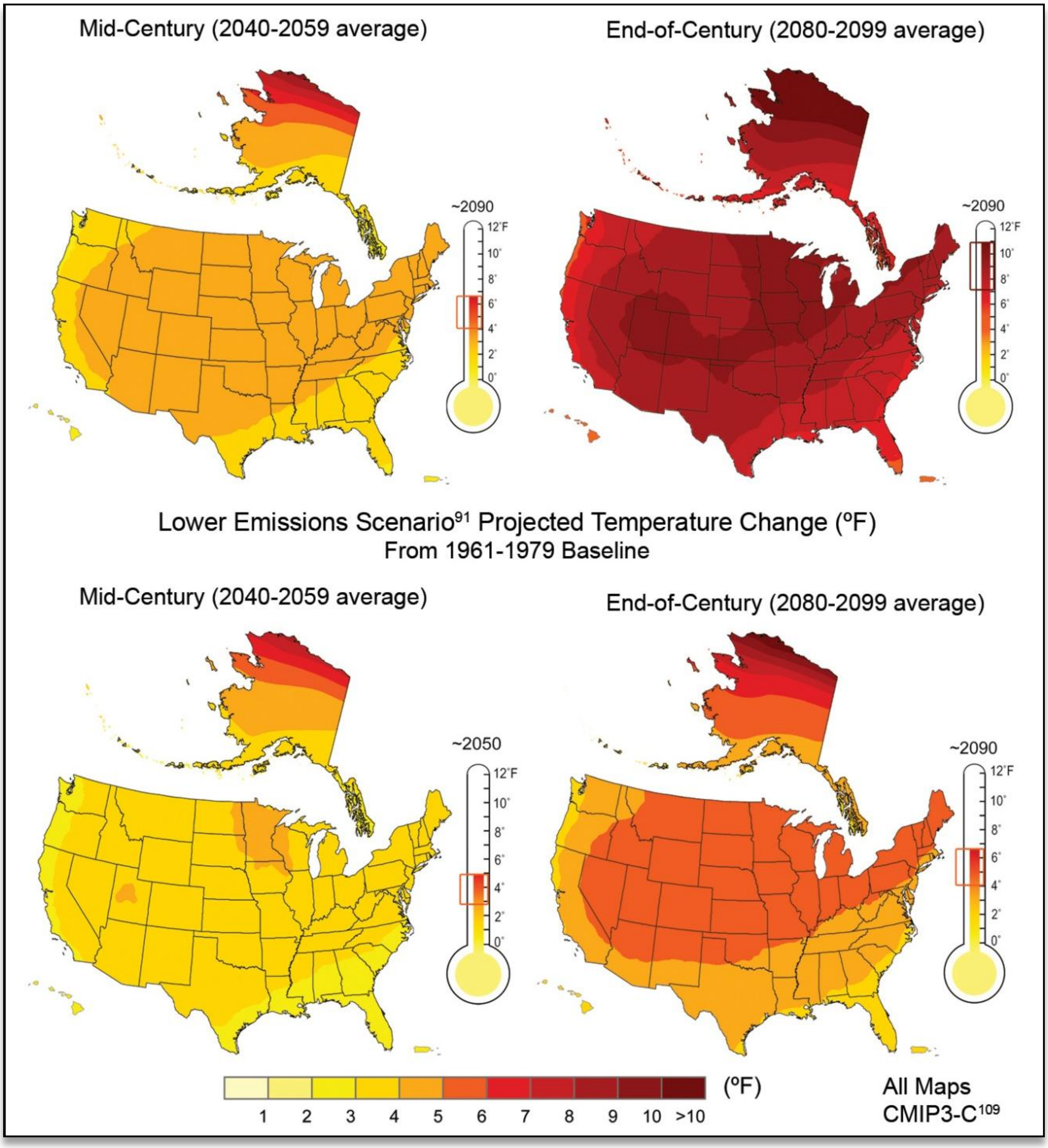


Figure 9. Projected changes in U.S. temperatures over the 21st century. The maps show average projected changes in precipitation (as simulated by 16 GCMs) relative to a 1961-1979 baseline. Simulations represent mid- (left) and late-21st (right) century projections assuming relatively high (top) or low (bottom) emissions of GHG gases.[58]

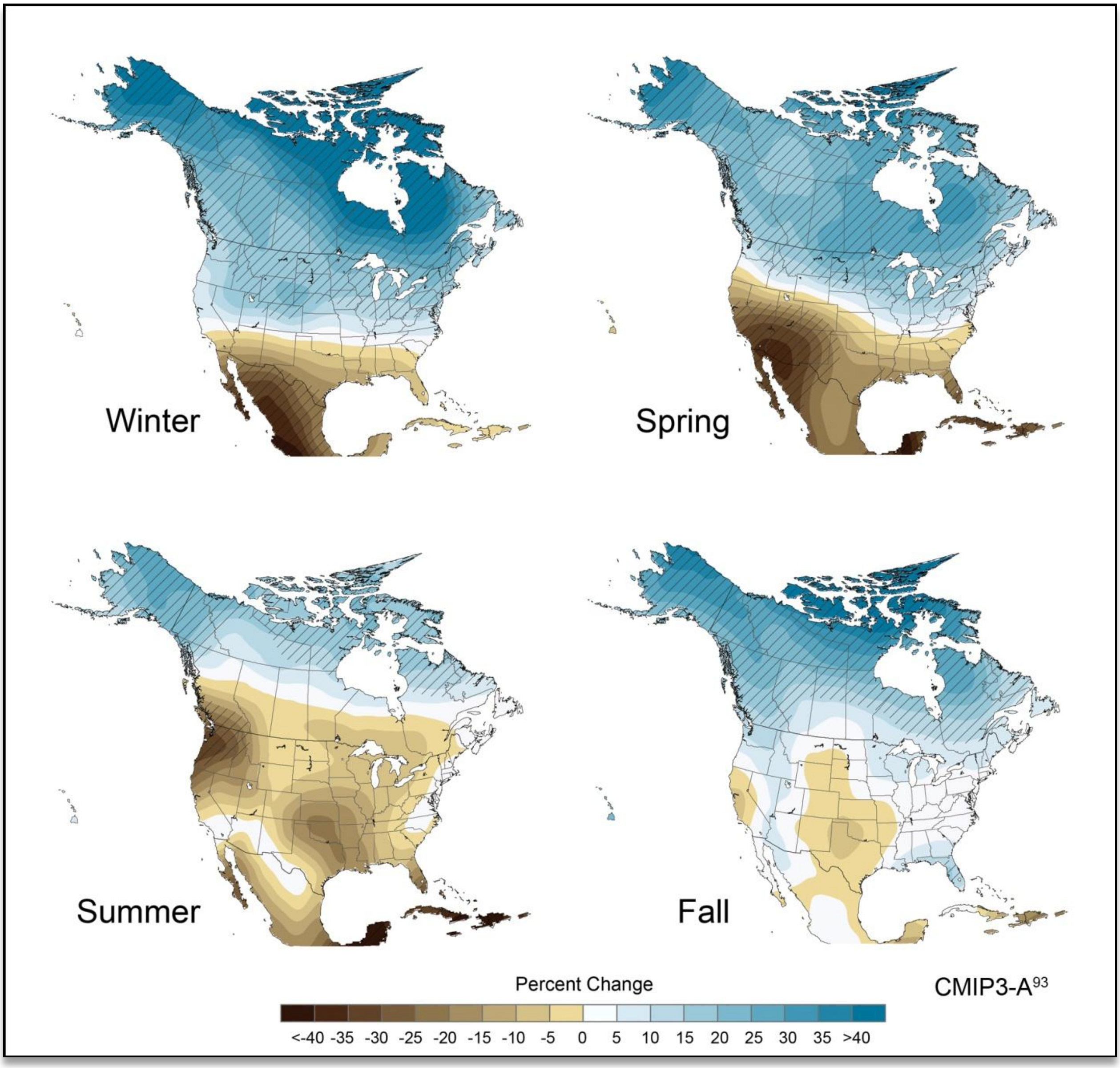


Figure 10. Projected changes in seasonal rainfall in North America over the 21st century. The maps show average projected changes in precipitation (as simulated by 16 GCMs) relative to a 1961-1979 baseline. Simulations represent late-21st century projections assuming relatively high emissions of GHGs. Confidence in the projected changes in highest in the hatched areas. [59]

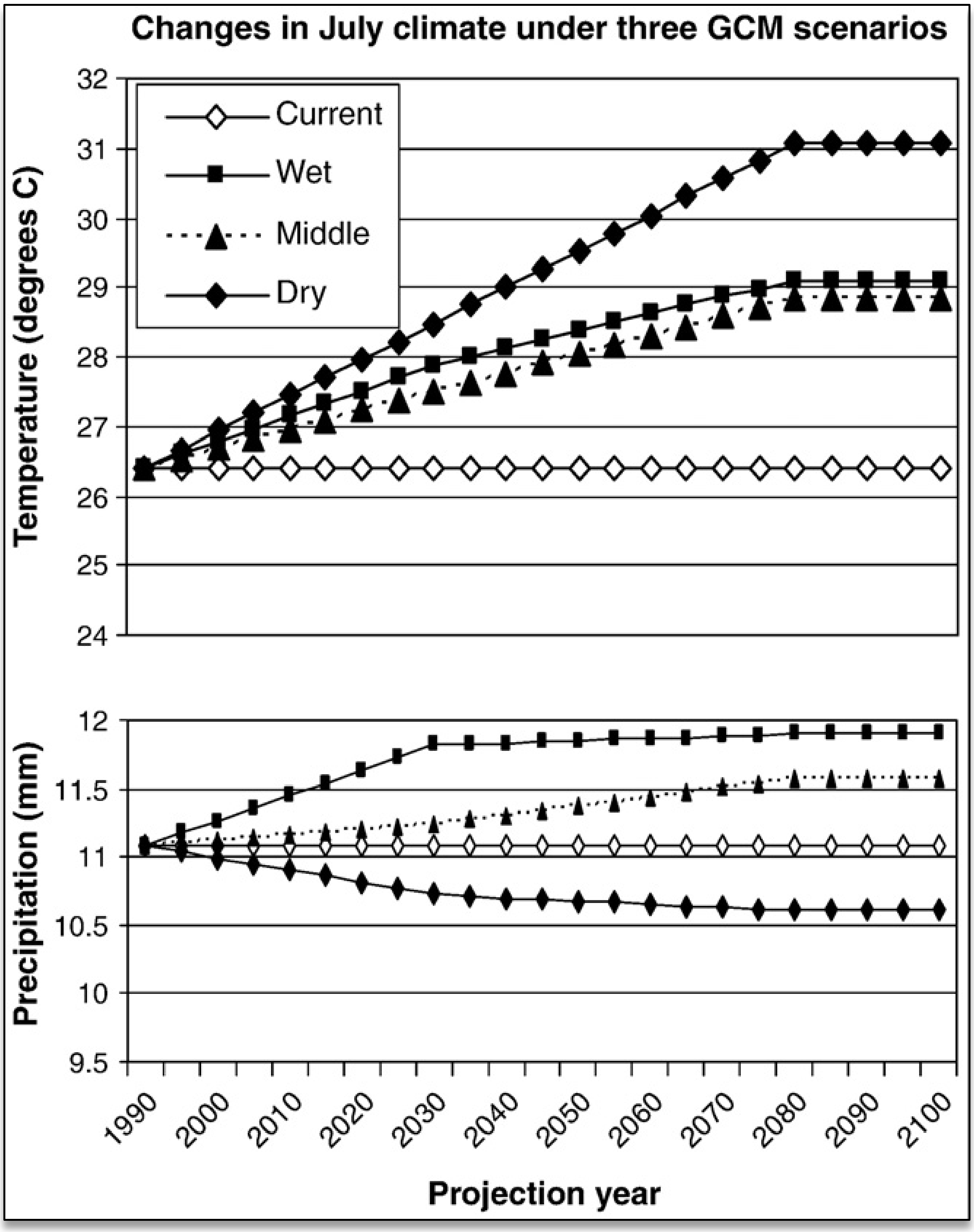


Figure 11. Projected changes in July temperature and rainfall as compared to 1980 through1997for three different Tennessee climate scenarios: wet, dry and middle[60]

3.3 Climate Change and Extreme Weather Events

A key vulnerability from climate change is potential alteration of the dynamics of extreme weather events including their extent, frequency, and intensity. Key extreme events affecting Tennessee are droughts, wildfires, hurricanes, tornadoes, floods, ice storms, and outbreaks of pests, diseases, and invasive species. These events have repercussions throughout all parts of Tennessee's social, economic, and environmental systems. While it is not possible to relate any one event to climate change, it is the anticipated trend toward greater frequencies and/or intensities of extremes that is of concern.

Little information is available specifically on the implications of climate change on extreme events in Tennessee, and there are persistent scientific challenges in generating confident insights regarding how such extremes may respond to a warming climate. Nevertheless, there is strong evidence that at least some types of extreme weather events will become more intense in the years ahead. For example, analysis of multiple climate model simulations for the 21st century indicate that the projected increase in average temperatures will translate into a significant increase in extreme heat events and heat waves.[61] Summer 2012 showed record-breaking temperatures across the U.S., including the Nashville, Chattanooga, and Knoxville areas.[62] Similarly, the distribution of rainfall across North America is anticipated to shift toward events with greater intensity (Figure 12), [63]which would likely increase the risk of flooding. As a case-in-point, the flooding in Nashville in May, 2010 has been estimated at a 1-in-500-year event. However, it's unclear whether that event was truly an extremely rare anomaly or an indication of the need to update assumptions regarding the future likelihood of extreme events.

4 POTENTIAL CHANGES IN ECOSYSTEM SERVICES

Tennesseans receive both direct and indirect benefits from the natural resources and processes provided by the State's diversity of plants and animals and their interactions with the environment. Such benefits are generally referred to as ecosystem services. They include products like clean drinking water and processes such as the pollination of crops. Ecosystem services occur in four broad categories: provisioning, such as the production of food and water; regulating, such as the control of climate and disease;

supporting, such as nutrient cycles and crop pollination; and cultural, such as spiritual and recreational benefits.

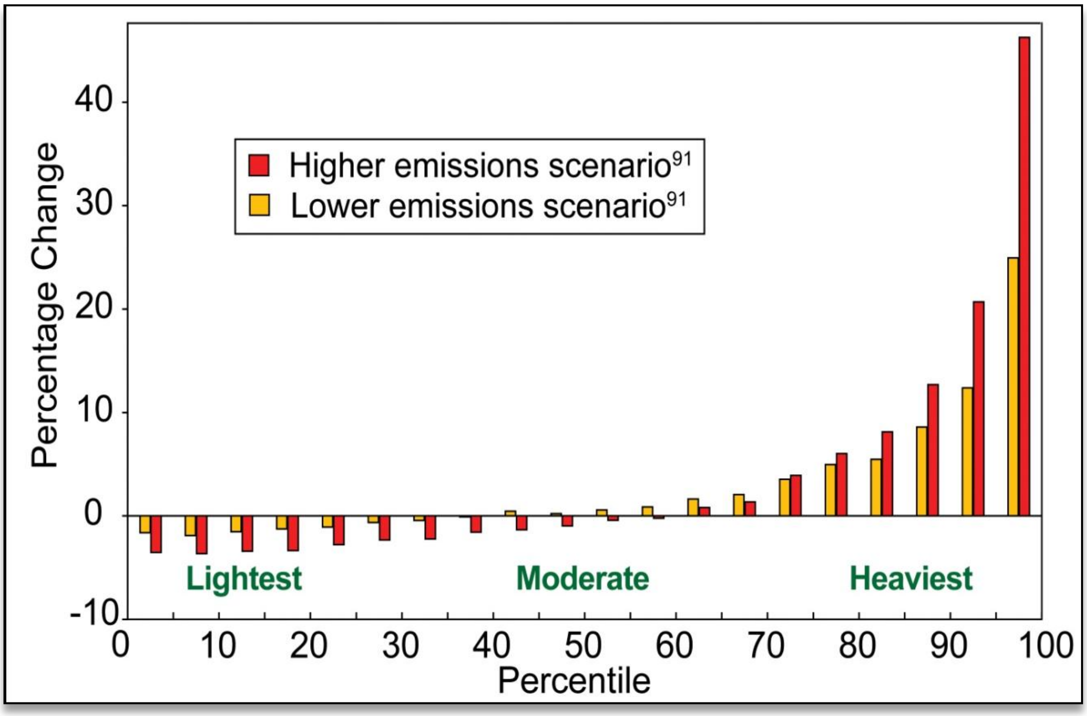


Figure 12. Projected changes in the intensity of precipitation in North America by the end of the 21st century relative to the end of the 20th century. Changes are presented for two different emissions scenarios (low and high) applied to multiple climate models (as in Figures 11 and 12).[64]

4.1 Terrestrial Ecosystem Effects

Climate change will have a strong effect on Tennessee forests by altering tree growth processes and by changing the typical species composition of forests across the State. Climate changes in Tennessee will cause an initial decline in total forest biomass. But as tree species that are better adapted to the warm climate take over, biomass will begin to rise again. Researchers from ORNL and UTK have projected shifts in forest species composition that are likely to occur under three different climate change scenarios (dry, middle and wet) discussed previously.[65] These projections indicate a declining importance of oaks and other commercially important species and an increase in hickories and other less valuable woods. Tennessee's Southern Mixed Forest is likely to change the most, to the point that a forest once rich in species diversity may become dominated by only four species (loblolly pine and three oaks).[66]

In addition to direct impacts from changing temperatures and moisture levels, Tennessee forests are also likely to experience indirect impacts from climate change because of changes in disturbances like wildfire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms or landslides. The altered frequency, intensity, timing and duration of disturbances will have implications for ecosystems and their services. [67] Climate change may also exacerbate ozone pollution[68] and change the rates at which atmospheric pollutants (such as chemicals and dust particles) are dispersed.[69] Increased levels of ozone and atmospheric pollutants are detrimental to forest health.

Box 2. Managing Risks through Mitigation and Adaptation

In contemplating the options available to society to manage the threats posed by climate change to sustainability, researchers and decision-makers often look to two strategies:

- **Mitigation** – Reduction in human emissions of greenhouse gases (GHGs) that contribute to global climate change; and
- **Adaptation** – Societal and ecological adjustments to minimize the consequences of climate change and/or take advantage of potential opportunities

These two strategies are sometimes distinguished as '*protecting the climate from society*' versus '*protecting society from the climate*'. Both strategies have limitations. Mitigation is constrained by human behaviors and rates and costs of technological change in global energy systems. However, rapid and/or high magnitudes of climate change may exceed the capacity of human systems to adapt due to economic, technological, social, or cultural factors. Hence, both strategies will be needed to manage climate risk, and if pursued in an integrated way, mitigation and adaptation can be complementary. For example, certain energy-friendly technologies (like increased thermal efficiency of buildings) can reduce energy demand while also keeping down the costs of space cooling as temperatures rise. At the same time, however, some adaptation actions can exacerbate GHG emissions – a consequence some have labled as 'maladaptive'.[70] In addition to mitigation and adaptation strategies, some researchers have been exploring *geoengineering* strategies[71]whereyby humans might deploy technologies to reduce the amount of solar radiation reaching the Earth and/or artificially enhance carbon uptake of Earth's system. The high costs, effectiveness, and potential consequences of such solutions for other systems have raised questions regarding their feasibility.

These ecosystem impacts will have broader socioeconomic consequences. Potential consequences of changing tree growth and tree species abundance for the forest industry are difficult to discern, due primarily to external factors, such as land changes and changes in domestic and global markets for forestry products. Certainly, as forest biomass and composition change, forest products mills will have to adapt (see Box 2). Changes in species composition will require the industry to change the type and mix of products they provide. The changes will be less difficult for some segments of the industry to address than others. Forest managers will need to alter their practices to address the drier and warmer summers and increased insect and disease problems. For intensively-managed forests (which comprise less than 10% of the State's forests), the drier summers and shallow soils could require more intensive site preparation and intermediate treatments, which could increase stand establishment costs by 50% or more in some locations.[72] As illustrated by the southern pine beetle outbreak in the early 2000s, stress placed on forests from drought can have serious consequences for all forest uses but particularly for the forest industry. Furthermore, changes in forest productivity, carbon sequestration, forest water resources and the way people relate to the forests (such as recreation) may be less resilient to climate than to economic pressures in the forest industry.[73] Because trees are so long-lived and climate changes are occurring so rapidly, both the projections and planning for new management must be able to address these complexities.

Opportunities

Limited opportunities for adaptation exist for natural terrestrial ecosystems, but ecosystems that are managed for their services may have greater options for interventions. Some of these options include:

- **Vegetation management to control invasive species that might benefit from climate change or, for production forestry, planting of species more appropriate for current and emerging climatic conditions**
- **Reduce other non-climatic pressures on terrestrial ecosystems such as deforestation and habitat fragmentation, impaired air quality, and invasive species**
- **Undertake strategic planning in ecosystem-serviced based industries to enable anticipatory adjustments to management practices and changes**

4.2 Aquatic Ecosystem Impacts

Maintaining adequate stream flow for all living things that need it will likely become more challenging as Tennessee's climate changes. Sustainable water management will require consideration of changing water availability (based on changing precipitation and runoff patterns) in conjunction with changing water demands (particularly from growing urban areas) and pollutant loads (which will be affected by air temperatures as well as stream flow patterns). Although the U.S. Southeast has traditionally been a water-rich region, increased demand at major metropolitan areas makes the local and regional water supply systems vulnerable even under moderate drought conditions.[74] Close monitoring and careful planning is required to prevent the impacts of droughts from becoming progressive, persistent (at longer timescales >1 month) and pervasive (over a large area). When precipitation is plentiful, water supply systems may need to be drawn down in advance to avoid downstream flooding. Thus, uncertainty in seasonal climate, competition among water uses, and policies for allocation will pose significant challenges for water management in Tennessee and the Southeast more broadly.

Either decreasing or increasing stream flows might have dramatic consequences for aquatic ecosystems. Lower stream flows may lead to declines in water quality that hurt organisms living within the stream channel as well as those being supplied by water from the stream. Abrupt and heavy rainfall may scour and incise channels, especially if the streams are underlain by soft deposits and less resistant rocks.[75] In west Tennessee, the channels in the alluvial and loess plains might become severely eroded under heavy rains, whereas in the Cumberland Plateau region, fewer changes to the shapes of rivers and streams are likely. When the shape of a stream channel is altered rapidly, stream habitat quality is degraded through the loss of natural pool-riffle sequences.[76] Many of Tennessee's unique aquatic species would be greatly impacted by the loss of a riffle habitat.[77] In addition to the loss of physical habitat structure from more frequent floods, unstable channels fill streams with sediment and cause harm to some fish communities.[78]

Increases in water temperatures will affect habitat suitability and reproductive cycles of many different aquatic organisms.[79] Wetland species are particularly vulnerable to temperature changes and shifts in wet-dry seasonal patterns. The major concern with shifts in reproduction timing is whether there are sufficient food resources for juvenile fish after they emerge from eggs. Many fish spawn at specific times when food is available and competition from other fish that may be emerging is minimized. For example, in the Great Smoky Mountains National Park, brook trout spawn in September and October, and rainbow trout spawn in February and March. Game fish are important to the Tennessee tourist industry, and potential impacts to these species need to be assessed and managed appropriately in the future considering climate change scenarios.

Opportunities

As with terrestrial ecosystems, aquatic ecosystems and the species they support may have limited opportunities to adapt naturally. Nevertheless, useful strategies for increasing the resilience of such systems to climate change include:

- **Evaluate management of water resources to identify potential competition among ecological and human demands for water arising from future climate change**
- **Reduce other pressures on water quantity and particularly quality by managing riparian zones to provide stream shading and buffering as well as reducing point and non-point source pollution**
- **Expand monitoring efforts to better detect impacts on aquatic ecosvstems from climate and non-climate stresses**

5. POTENTIAL CHANGES FOR PEOPLE AND PLACES

In addition to its implications for the natural ecosystems of Tennessee and their associated services, climate change has the potential to affect the overall quality of life and well-being of Tennesseans. Effects may arise from direct exposure of people and property to climate extremes as well as indirectly through impacts on ecosystem services that link humans to the broader environment. Such impacts will likely be greatest for those people, places, and assets that have the following characteristics:

- Located in areas such as flood plains that are prone to experiencing impacts from extreme climatic events;
- Associated with significant exposure of populations and/or assets, such as urban areas with high population densities, high value cultural assets, or critical infrastructure;

- Particularly sensitive or otherwise disadvantaged such as the poor, elderly, or socially marginalized populations or systems with low resilience to extremes of climate; or
- Already stressed or degraded by age and/or by demand levels that exceed what the system or was designed to deliver

More specific information regarding how climate change may affect such vulnerable systems and populations is provided below.

5.1 Human Health

The Center for Disease Control's (CDC's) Climate Change and Policy Framework has identified several environmental stressors that may have a significant impact on health effects, particularly on vulnerable populations (Table 3).[80] Tennesseans will face effects from a number of pathogens with the potential to be affected by global climate change. These diseases include vector-borne and zoonotic diseases, food and water-borne diseases, and influenza. For example, Malaria, Eastern Equine Encephalitis (EEE), Rocky Mountain spotted fever and Lyme disease are all vector-borne diseases that have been reported in Tennessee. Such diseases have been linked to climate variability, and thus it follows that they will be influenced by climate change as well. For example, the Tennessee State Government advised the public in April of 2012 that the year's tick season was anticipated to be more active than normal due to a mild winter and spring.[81] Similarly, an outbreak of West Nile Virus in the United States accompanied the warm dry conditions of the summer of 2012.[82] EEE has been recently found in some Tennessee horses and has the potential to spread to humans as conditions change. Certain food-borne infections in seafood may be impacted by rising sea surface temperatures and associated ocean acidification.[83] If such diseases manifest themselves, Tennesseans may start to avoid seafood for fear of contamination. This could lead to repercussions for grocery stores and restaurants throughout the State.

Table 3. Weather events, health effects, and populations most affected by climate.[84]

Weather Event	Health Effects	Populations Most Affected
Heat waves	Heat stress	Elderly, children, athletes, people with respiratory disease, those working outdoors
Extreme weather events (rain, flooding, tornadoes, lightning)	Injuries, drowning	Low-lying land dwellers, populations with low socioeconomic status
Changes in average temperature and rainfall, flood frequency	Increased risk of vector-, food- and water-borne disease	Multiple populations at risk, particularly the elderly and children
Drought, ecosystem migration	Food and water shortages, malnutrition	Populations with low socioeconomic status, elderly, children
Extreme weather events, drought	Mass population movement	General population
Increases in ground-level ozone, airborne allergens, and other pollutants	Respiratory disease exacerbations (COPD, asthma, allergic rhinitis	Elderly, children, those with respiratory disease
Climate change and extreme events generally	Mental health consequences	Young, displaced persons, populations associated with the agricultural sector

The annual incidence of Malaria cases reported in Tennessee is low;[85] it is currently a disease associated with travel with no cases of the disease being acquired within Tennessee itself. However, the incidence of Malaria might change with the warming climate. The CDC suggests that the distribution of vectors currently restricted to warmer climates will expand into the United States. For instance, recently Dengue has reemerged in southern Florida.[86]

Increased risks from diseases with seasonal distributions could also occur. For example, Cryptosporidium, Vibrio, and STEC occur more commonly in summer months. Food-borne and water-borne illnesses that may be impacted by climate change include Cryptosporidium, Vibrio, Shiga toxin-producing Escherichia coli (STEC), and Legionella. Prolonged elevated temperatures may increase the duration of the season when animal reservoir species are colonized and transmitting pathogens through the farm-to-fork continuum. Legionellosis is not commonly reported in Tennessee but may become a concern as climate changes. Similar to food-borne illness, Legionellosis incidence peaks during warmer months and risk appears to increase with rainy, humid weather which are likely to occur with global climate change. It has been estimated that 80% of Legionellosis outbreaks are associated with potable water systems in buildings.[87]

Influenza has the potential to cause widespread morbidity and mortality. It has been proposed that climate change can dramatically alter the global ecosystem and thus influence the development of new and emerging infectious diseases. The recent H1N1 pandemic underscores the impact of changes in the influenza virus resulting in a triple reassortant swine-origin virus. Influenza is seasonal although it occurs more commonly in winter months. The effect of climate change on “flu season” is unknown.

Heat-related illness (e.g., heat exhaustion and heatstroke) and death can occur when high temperatures overwhelm the body’s ability to thermo-regulate.[88] Climate models project continued warming at an increased rate, with an even greater rate of increase in extreme heat. Average temperatures in the Southeast are projected to increase 5–9°F by 2080 (see Section 3.2). An annual increase of 9°F would mean a 10.5°F increase in summer and a higher heat index (combination of air temperature and relative humidity that represents human-perceived equivalent temperature). Metropolitan areas are at increased risk of prolonged high temperatures compared to surrounding suburban and rural areas. This has been described as the urban heat island effect, where urban structures and pavement tend to retain more heat than less built-up surrounding areas. This effect is particularly seen at night, with sustained high temperatures and less cooling. This can be a risk for adverse human health effects since there is less relief at night.

The risks associated with extreme heat events can be exacerbated by high humidity as well as poor air quality. High temperatures are associated with increased levels of ground level ozone arising from atmospheric pollutants from human sources as well as biogenic emissions of volatile organic compounds. As such, climate change may interact with trends in regional air quality to influence health outcomes.

Air quality is also influenced by biogenic allergens, which may also increase in the future as vegetation responds to changes in climate and increasing atmospheric CO_2 concentrations. Warmer winters seem to lead to higher incidences of allergies for Tennesseans.

Opportunities

The effects of climate change on the health of Tennesseans will largely be dictated by the risk factors present within the population and the response of public health agencies. Common options for addressing risks to health include the following:

- **Enhance public health education regarding methods to reduce exposure of the public to disease vectors as well as extreme climatic events**
- **Establish early warning systems and response plans for heat waves**
- **Address the current burden of chronic disease to enhance the resilience of populations and communities to the effects of climate change**
- **Evaluate emergency management procedures, resources and infrastructure for potential vulnerabilities to changing frequencies**

5.2 Water Supply & Demand

In addition to effects on aquatic ecosystems discussed above, climate change can induce effects on water related to human health. Although no long-term trend in surface and ground-water is evident from available data, parts of Tennessee and the U.S. Southeast, in general, are susceptible to temporary water shortfalls due to periodic multi-year drought.[89] Climate change predictions for the 21st century in Tennessee suggest that the impacts of these periodic droughts will be more severe in the future. An additional factor in assessing future drought impacts is population growth, which has varied in Tennessee from 6% to16% over ten year periods between 1960 and 2010.[90] Increased water use for public supply tracks well with increases in population over the same interval (Figure 5). Thus, population growth along with a decrease in available water predicted by climate-change models will amplify water shortages resulting from periodic drought. Impacts of periodic drought on water supply are summarized in Table 4. Secondary impacts of reduced surface and ground water levels include decreased water quality, aquatic habitat impairment or loss (Section 4.2); limited access and extent of recreational waterways; reduced hydroelectric generation capabilities, reduced fossil fuel and nuclear reactor cooling capacity (Section 5.3); and reduced navigable waterways.[91]

The effects of a long-term decrease in water availability are less certain and may be more regional in nature. Periodic drought years are often followed by years of ample precipitation allowing for replenishment of surface water impoundments and recharge of subsurface water. However, long-term decreases in water availability could result in long-term decline of base flow in streams and ground-water levels. The water supply impacts of declines in stream base flow are likely to be greatest in central and eastern Tennessee, where these resources are essential for domestic and public supply. Long-term decline in ground water levels would have the most severe impacts in western Tennessee, especially where recharge is not keeping pace with pumping, such as the Memphis metropolitan area.

Climate change also brings the potential for increased frequency of high-magnitude stream flows by heavier rainfall events. Surface impoundments may be able to store some of this flow and retain it for future use while also reducing flood risk. For example, flood control and disaster mitigation is one of the benefits provided by the TVA river management system, with avoided damages estimated at $240 million per year.[92] However, a shift toward increases in rainfall intensity would reduce the potential for recharge of subsurface supplies. Thus, increased frequency of heavy rainfall events would likely amplify the decline of ground water levels.[93]

Table 4: Potential Impacts of Drought on Tennessee's Water Supply[94]

Potential Impact	Qualifier
Reduced groundwater levels	
Lower stream flows in streams	
Water pressure issues in water systems, if demand is not managed	
Some reservoir intakes exposed	*Where reservoirs are below normal*
Some intakes for water resources below dams or waterpower development exposed or with inadequate water	*Where minimum flows not met*
Increased treatment due to poorer water quality	*Potential taste/odor/dissolved iron and manganese problems*
Non-essential uses are interrupted	
Increased aeration costs due to lower dissolved oxygen in reservoir releases	
Increased algal and aquatic-plant growth	*Resulting in taste and odor problems*

These potential impacts of climate change on Tennessee's water supply should also be considered in relation to changes in water demand. Growing demand for water by the State's growing population will be exacerbated by likely increases in demand as consumers attempt to manage counteract the effects of potential declines in rainfall. This may include increased water demand for irrigation water (residential, commercial, and agricultural).

Opportunities

Water resource management systems offer numerous opportunities for increasing resilience and sustainability in a changing climate, including measures that enhance supply as well as those that reduce demand. Some useful adaptation options could include:

- **Incorporate consideration for climate change into strategic water resources management planning**
- **Increase deployment of technologies for water recycling, rainwater harvesting, and other conservations measures to reduce the impacts of population growth on water resources**
- **Work with utilities to educate consumers on opportunities for water conservation**
- **Evaluate potential changes in risk in flood prone areas due to potential changes in the frequency/intensity of extreme rainfall events**
- **Increase restrictions on certain types of water use and/or impose water use efficiency standards on relevant industries**
- **Pursue cooperative exchange among water management districts to minimize conflict and facilitate water-use agreements that will better serve community needs.**

5.3 Energy Supply & Demand

The implications of climate change, combined with other stressors, on U.S. energy supply and demand have been receiving increased attention in recent years, including three reports led by ORNL.[95] These reports suggest that climate change will have greater impacts on energy peak capacity than average capacity and that increased cooling needs will lead to increased demands for electricity. Increased demand for electricity will be complicated by reduced seasonal or long-term water supplies for hydroelectric power and/or thermal power plant cooling in some regions as well as reductions in overall thermoelectric power efficiencies due to higher ambient air and water temperatures.

The major climate vulnerability of concern for energy systems in Tennessee is possible effects of changes in water availability, especially seasonally, for electricity generation – which, in Tennessee, means TVA. In recent history, TVA has been less affected by seasonal droughts than other Southeast power producers in states such as North and South Carolina and Georgia. This can be attributed, at least in part, to TVA's extensive system of reservoirs and dams assures a high level of reserve capacity (Section 5.2). However, recent summer heat waves have shown the susceptibility of the State to power losses due to lack of sufficient cooling water (Box 3).

Box 3: Nuclear Plant Shut Down by Lack of Cooling Water

By law, nuclear plants may not heat rivers above 86.9°F with their discharged water.[96] During portions of July and August of 2010, the Tennessee Valley Authority's (TVA's) Browns Ferry Nuclear Plant had to run at 50% or less of its capacity when the Tennessee River was found to have temperatures reaching 90°F.[97] During that time, TVA had to purchase replacement power for its consumers at expensive rates.

Photo from TVA's website

TVA ended up spending $80 million to construct an additional cooling tower at Browns Ferry.

Other concerns for the energy sector include possible effects of temperature increases on energy supplies and costs for residential, commercial and industrial buildings in summers, especially in the event of heat waves and most especially if peaking electricity demands during heat waves exceed supply capacities. Extreme weather events associated with climate change (e.g., wind storms or shifts from snow to ice during winter – both of which can increase risk of downed trees) may adversely impact energy facilities, including electricity transmission lines. All of these events may lead to an increase in energy prices for Tennesseans.

As discussed in Section 2.4, Tennessee has traditionally been a leader in hydropower generation and has recently become a national leader in developing "green" renewable energy sources such as wind, solar and bioenergy. Continuing to develop a diverse array of fossil fuel alternatives will allow Tennessee to be more resilient in the face of climate change.

Opportunities

As with water resources management, adaption in the energy sector can be pursued through both supply and demand-side measures. Some relevant adaptation options for this sector include:

- **Evaluating the needs for additional cooling technologies for power plants to ensure electricity generation remains robust to climate variability and change**
- **Increase deployment of energy efficient technologies in residential, commercial, and industrial buildings (e.g., insulating materials, efficient appliances)**
- **Deploy smart meters to enhance the capacity of energy generators to optimize system performance and the pricing of energy to reflect end user behavior and demand**
- **Bury power lines to avoid disruption during wind and ice storms, particularly those that supply critical industries or infrastructure**

Box 4: Climate Change and Interdependent Infrastructure

Tennessee's built environment is a foundation of social and economic development in the State. The term 'built environment' includes urban buildings and spaces, energy systems, transportation systems, water systems, sanitation systems, communication systems, health-care systems, and other products of human design and construction that are intended to deliver services in support of human quality of life. While these different elements are often designed, regulated, and operated by different entities, they comprise an integrated and interdependent system of assets and services. For example, local and regional transportation planning must account for the geographic distribution of people and commerce. Significant infrastructure supports water and wastewater management which, in turn, is essential for everything from industrial activity to emergency management. Disruption of electricity interferes with transportation systems, commercial activity, recreational activity, and telecommunications and can pose indirect threats to public health and safety. Hence, impacts on one part of the system can have cascading effects on other elements (Figure 4-1).

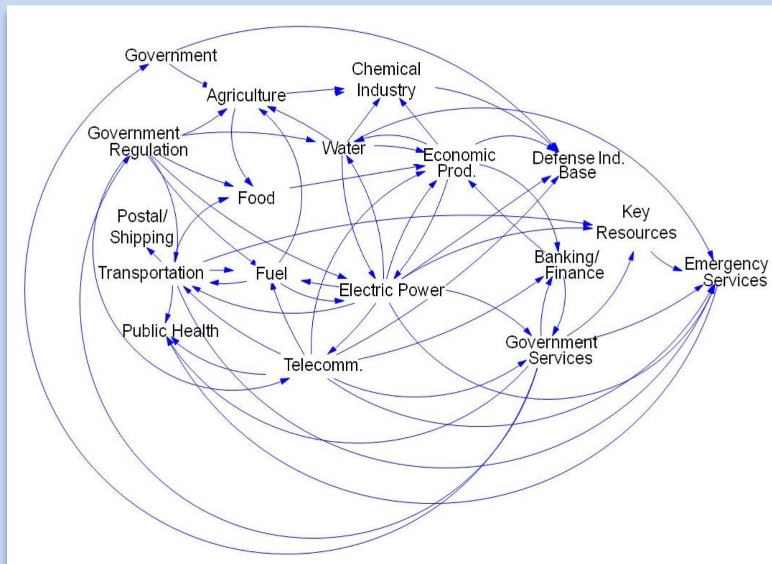


Figure 4-1. Illustration of infrastructure interdependencies[98]

One key issue for Tennessee is the aging of infrastructure, much of which dates to urban and regional capital investments many decades ago, some back to the turn of the century more than 100 years ago. Tennessee's built environment developed largely from driving forces related to transportation assets – for example, Memphis and Kingsport because of river shipping in the latter half of the 19th century and Knoxville, Chattanooga, and Johnson City after the railroad arrived, also in the latter half of the 19th century. Since the 1970s, however, most of the residential and commercial growth has been in spreading suburban developments, often connected with interstate highway development. Although new infrastructure and technologies are constantly coming on line, the legacy infrastructure creates potential points of fragility in the entire system, while natural degradation of infrastructure over time creates the need for continual investment in maintenance for an increasingly large infrastructure network. Addressing such challenges in a way that is cost-effective and robust to the demands of both development and a changing climate will be a core sustainability challenge for Tennessee in the years ahead.

5.4 Transportation

Tennessee's vast transportation system (including highways, airports, railroads, navigable waterways, and intermodal transfer terminals[99]) is not only vital to the well-being of the State, but also other regions of the nation. The importance of the State's transportation network means that the impacts of climate change on critical transportation infrastructure can be far-reaching, resulting in significant economic, social and environmental deterioration. Because the State's transit systems depend heavily on the existing infrastructure to function properly, failures in the system result in disruptions for commuters and potential economic and environmental impacts. Such impacts might include loss productivity of workers due to delays or missed work days or reduced use of mass transit systems in favor of personal vehicle use, thereby leading to increased carbon emissions.

Climate change may upset transportation infrastructure and operations in a variety of ways. For instance, impacts to roads and railways might include:

- pavement rutting and rail buckling;
- increased equipment wear and cargo overheating;
- compromised structural integrity from thermal expansion, erosion, scouring; and
- increasing frequency and extent of transportation network closures due to flooding, washouts and landslides.

In addition to direct physical impacts to transportation infrastructure, indirect social, economic and ecological impacts must also be considered (see Box 4). These indirect impacts might include delays in the delivery of raw materials and finished goods, rerouting or increased traffic congestion leading to additional delays and increased carbon emissions, and other impacts such as diminished health of maintenance and construction workers exposed to extreme hot weather conditions.

Because of the interconnectivity of the nation's transportation system, disruptions in one location can propagate to other areas and/or multiple modes of transportation may be affected by the same weather event. These effects were observed during Hurricanes Katrina and the Nashville Flood of 2010. In Tennessee, Nashville, Memphis, and Knoxville serve as key hubs in the nation's transportation network and climate change impacts to those areas can have propagating affects elsewhere. In the aftermath of Hurricane Katrina, for instance, there was an influx of population into Memphis and it is possible that populations from more southern states (e.g., Louisiana or Florida) may choose to relocate to Tennessee due to the slow onset of sea-level rise and diminishing coastal land or following potentially increasingly severe weather events. Furthermore, current Tennesseans may migrate from high impact areas to other geographical regions, which may cause additional infrastructure stresses in those locales (see Section 5.6).

The American Society of Civil Engineers (ASCE) recently estimated that the U.S. will end up spending $3 Trillion (cumulative) by 2040 if there is no investment in preventative maintenance of our nation's transportation system.[100] Climate change impacts are likely to expedite the deterioration of such systems, leading to an increase in infrastructure-related costs over a shorter time frame. On a somewhat positive note, the ASCE projects an increase in jobs for maintenance of transportation infrastructure over the coming decades.[101]

Box 5: An Example of Local Adaptation: Volkswagen Installs Hail Nets at Its Chattanooga plant

Due to the increasing severity of ice storms, the Chattanooga Volkswagen production plant spent ~$5 million in early 2012 to install a fabric hail net over half of its 5,000-space loading yard, thereby protecting shipments of new cars from costly body damage. Each hail-damaged car costs between $300 and $1500 to repair, depending on the number of significant dents.[102] The company has installed a similar hail net at its Nissan production plant in Smyrna.

These "hail nets" have recently been installed at the Chattanooga Volkswagen production plant.

Photo by Dan Henry (published 6 March 2012 in *Times Free Press*).

Opportunities

Tennessee's transit systems must manage the challenges of maintaining existing infrastructure and accommodating future growth while adapting to climate change. However, new technologies and approaches to transit planning provide powerful tools to assist decision-makers. Useful strategies could include:

- **Harden critical transportation infrastructure to make it more robust in the face of extreme climatic events**
- **Address outstanding maintenance and degradation issues in existing transit systems to increase their resilience to climate variability and change**
- **Incorporate consideration for climate change impacts into future transportation infrastructure planning and investment**
- **Share information, resources, best practices and lessons learned across jurisdictional lines and among different stakeholders**
- **Expand the diversity and redundancy of transportation options and technologies and pursue 'win-win' approaches that combine energy efficiency and resilience**
- **Enhance transit communication systems to provide greater real-time information and warnings regarding transit conditions and options**

5.5 Agriculture

Climate change will induce changes in typical crop yields, and changing yields may lead to changes in Tennessee land-use patterns. Expected changes in long-term climate might affect crop yields through changes in temperature, CO_2 fertilization, and precipitation. Temperatures influence the life cycle development of crops. Higher temperatures trigger a shorter life cycle in corn, which usually results in a loss of yield. To a certain point, increased atmospheric CO_2 concentrations act as a fertilizer, stimulating crop growth. Crop yield responses to changes in temperature, CO_2 levels and precipitation will vary among species based on the biological characteristics of the crops and the region where they are grown.

Analysis of the relevant literature[103] indicates a 2.1°F increase in temperature will result in a combined reduction in corn yields of 3%; and increased soybean and cotton yields of 3.9% and 3.5% respectively. The expected gains in soybeans and cotton yields are due to the fact that the CO_2 fertilization effect is larger than the negative effect of the increase in temperature. Another study[104] found that wheat yield variability is likely to increase in the southern U.S.

Therefore, as temperatures rise in Tennessee over the next 30 years, it is likely that the land planted in soybeans and cotton will increase and while corn and wheat acres decline. Of course this does not anticipate the potential improvements in seeds and practices impacting each of those crops or large-scale shifts in the types of crops planted in Tennessee (see Box 6). If farmers can adapt to higher temperatures by growing different varieties of crops, then yields from the South might be less sensitive to extreme heat.[105] The described changes in land use are also predicated under the assumption that changes in future crop prices and costs of production will not alter the equation. At this stage, the latter is a necessary simplifying assumption as there is a lack of research in this area.

Agriculture has greater potential to adapt to changes in temperature and precipitation than other sectors. Furthermore the Midwest drought during the summer of 2012 had benefits to the Tennessee farm economy. Hay and other crops are being shipped north from Tennessee, where production has been good, to areas where crops have failed.

Opportunities

The agricultural sector is one of the economy's most adaptive due to generations of experience with climate variability and the continual evolution of agricultural technologies, management practices, and markets. Key opportunities for this sector in Tennessee may include:

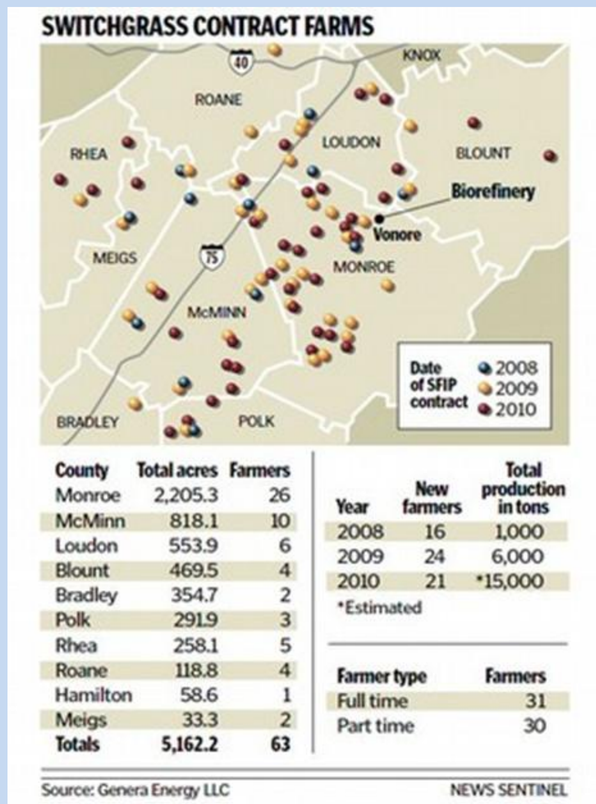
- **Undertake research to investigate the long-term suitability of different crops and crop varieties to potential changes in climatic conditions in Tennessee to inform long-term strategic planning for the industry**
- **Facilitate knowledge exchange and learning within the industry regarding emerging practices and technologies that enhance resilience**
- **Continue to invest in biofuel technologies and supply chains to continue Tennessee's leadership in developing sustainable energy resources**
- **Increase monitoring of pests and invasive species that may benefit from changing climatic conditions to the detriment of the State's agricultural enterprises**

5.6 Tourism and Recreation

Although Tennessee has a diverse array of tourism opportunities that attract visitors, those activities associated with outdoor recreation are perhaps the most vulnerable to climate change. When outdoors, people are directly exposed to weather conditions, and such recreation is often closely linked to the natural environment, which is also likely to be affected by climate change. The direct economic effects of projected climate changes on recreation have been evaluated using the Tourism Climatic Index (TCI).[106] The TCI assesses how changes in several climate variables such as precipitation, temperature, relative humidity, and wind affect a location's suitability for tourism and recreation.

Box 6: Climate Change and Biofuel Production in Tennessee

Emerging technologies, infrastructure, and markets for biofuels in Tennessee illustrate the links between the energy and agriculture sectors. The potential of biofuels production in the State of Tennessee largely rests on the relative abundance of woody resources and the potential to develop and expand the production of switchgrass (a perennial warm-season native grass)[107] as well as other bioenergy resources such as agricultural and forest residues. The high cellulosic yield and drought-resistant characteristic of switchgrass make of it a great candidate for feedstock for a second generation biofuels industry. These characteristics also allow switchgrass to substitute for some of the almost two million acres of hay in the State of Tennessee, giving it the potential to become a major agricultural component of the State. Although it seems unlikely that increasing temperatures will reduce switchgrass yields, there should be more agronomic research in this area.



County	Total acres	Farmers
Monroe	2,205.3	26
McMinn	818.1	10
Loudon	553.9	6
Blount	469.5	4
Bradley	354.7	2
Polk	291.9	3
Rhea	258.1	5
Roane	118.8	4
Hamilton	58.6	1
Meigs	33.3	2
Totals	**5,162.2**	**63**

Year	New farmers	Total production in tons
2008	16	1,000
2009	24	6,000
2010	21	*15,000

*Estimated

Farmer type	Farmers
Full time	31
Part time	30

Through recent State investments, East Tennessee currently leads the country in cellulosic biofuel production. For example, a demonstration-scale (250M gal/year) cellulosic ethanol plant in Vonore, Tennessee run by Genera Energy is the first of its kind in the nation. Three years in advance of the facility coming online, county extension agents worked with farmers in 10 surrounding counties within a one hour's drive of the facility to establish a switchgrass crop. Because switchgrass is native to Tennessee, it does not require much fertilizer and therefore has the potential to improve local water quality.[108] Switchgrass can be planted and harvested with equipment that most farmers already have on hand. Because the crop may be left in place for at least 10 years (with annual harvesting which leaves about 10 inches of stubble in place), soil erosion is reduced and long root systems are able to store carbon underground and improve soil quality. Long root systems also make switchgrass more resilient to seasonal droughts.

A group of UTK and ORNL researchers recently estimated TCI scores for several recreation areas across Tennessee using "wet," "dry" and "middle" climate scenario projections for 2030 and 2080 in conjunction with current visitation numbers.[109] The visitation projections for all regions reflected changes of less than 10% in recreational use and associated economic values for all but one scenario. Total consumer surplus for the Big South Fork National River and Recreation Area, for example, was reduced by 2.1% and 6.1% under the "dry" scenario for 2030 and 2080, respectively. The "wet" scenario for the same area resulted in a slight (< 1%) increase in value for 2030 and a similar decrease by 2080. Two locations – Cosby and Obed - exhibited increased values for both periods and all scenarios. The Cosby site increased primarily because of warmer fall and winter conditions, which would extend the comfortable use seasons. On the Obed, fall and spring represent the busiest seasons for rock climbing – a period when the TCI scores are increased in future climate scenarios, relative to current scores. The remaining sites exhibited both increases and decreases in consumer surplus, most notably decreases for the "dry" scenario with less precipitation and higher temperatures than current conditions or other scenarios evaluated.

Beyond the direct effects of climate change on recreation, there are several potential indirect effects, which are more difficult to assess quantitatively. Most notably, the potential decline of species (such as trout and the remaining high elevation spruce-fir forests in the eastern part of the State) could have substantial economic impacts on forest-based recreation.[110] Under a range of future climate scenarios, it is estimated that the welfare loss per angler will range from $5.63 to $53.18 per visit. The economic impact of the potential loss of the high-elevation spruce-fir forests is more difficult to assess because most visitors visit these areas as part of multi-purpose trips. Moreover, no data are available to identify the relative importance of these forests in trip decisions or the values visitors place on such areas. Visitation patterns within the Great Smoky Mountains National Park, however, demonstrate the popularity of the spruce-fir forests, and any changes to this resource could affect recreational uses such as bird watching and backpacking.

Tourism in Tennessee's cities is perhaps more resilient to the effects of climate change. Nevertheless, extreme events like floods or tornadoes, though transient, can disrupt visitation through temporary closures and damage to infrastructure. In addition, over the long-term, increases in summer temperatures, in particular, could cause a shift in the timing of tourism in Tennessee as visitors opt to arrive during cooler times of the year. As the climate changes, Tennessee could also benefit from a comparative advantage over other destinations, particularly those in the deep South where the extremes of climate (e.g., temperature and tropical storms) may be more severe. Such outcomes remain speculative, but suggest there may be opportunities for tourism and hospitality services to adjust in order to capitalize on changing consumer preferences.

Opportunities

Sustaining the scenic amenity and recreational activities offered by Tennessee's climate, landscape and communities is a cross-cutting challenge. Modern infrastructure, public safety, and cost-of-living drive the popularity of Tennessee as do the State's mountains, forests, and waterways. Useful strategies for elevating Tennessee as a favored destination including the following:

- **Diversify existing recreation and tourism operations to reduce seasonality of revenue and expand predominantly summer enterprises into other months to avoid peak summer heat**
- **Capitalize on the expanding 'sustainable tourism' market by marketing Tennessee's natural amenity and incentivizing tourism businesses that can operate along sustainability principles**
- **Expand public education efforts to inform visitors about potential climate-related hazards as well as ways to minimize their impact upon the Tennessee environment**

6. TENNESSEE'S GREAT OPPORTUNITIES

In spite of the great challenges that Tennessee will face over the coming decades, there is also ample evidence that the State has many opportunities to advance the goals of sustainability. Some of these opportunities will be pursued automatically as individuals, communities, and industries instinctively adjust to changing social, economic, and environmental conditions. Other opportunities will require more strategic planning, coordination, and investment including policies that provide new incentives to pursue sustainable actions. In addition, one cannot exclude the possibility that transformational changes lie in Tennessee's future. Much like TVA transformed development of southern Appalachia in the latter half of the 20th century, new migrants, economic enterprises, and technologies could all contribute to great leaps forward in future decades.

So what should we be doing to prepare for climate change in Tennessee? Given the potential adverse consequences posed by climate change as well as uncertainties associated with their timing and magnitude, one option is to pursue a risk management approach in responding to climate change challenges. This would involve:

1) identifying desired future conditions for the State's natural resources, communities, and industries;
2) evaluating the likelihood that climate change and other factors will pose a challenge to the achievement of those objectives; and
3) developing and implementing adaptation/mitigation policies and measures that reduce the likelihood of failing to achieve those objectives to tolerable levels.

This risk management paradigm is well-established in both public and private institutions and thus there may be ample opportunities to 'mainstream' consideration for climate change into existing risk management practices. As we think about managing the risks of climate change, however, we should be cautious to avoid a defensive stance that is focused simply on avoiding losses. Such a mindset can cause us to overlook the broad range of positive opportunities and benefits associated with sustainability. New technologies and industries bring new jobs and economic growth. Increased efficiencies in transportation and energy can put more money back into the pockets of Tennesseans. Meanwhile, more robust health care systems that manage both current and emerging threats to public health will yield benefits independent of future climate change.

As Tennesseans move forward with the pursuit of sustainability and managing the opportunities and risks associated with climate change, attention should be directed toward the pursuit of a number of robust actions:

- **Plan for change.** Most importantly, Tennesseans must recognize that sustainability will not arise spontaneously. Rather a concerted effort will be needed to effectively plan and implement adaptive and climate-friendly actions pathways. As a first-step, public and private institutions at local and state, if not national, levels should begin developing adaptation policy frameworks and plans that will best-position Tennessee for a sustainable future.
- **Monitor, evaluate and learn.** Given extensive uncertainties about climate change impacts at particular times and in particular places and about payoffs of specific adaptation strategies (see Box 5), it is important to observe, evaluate, and reconsider risks and responses iteratively, sharing lessons learned as appropriate.
- **Address critical knowledge gaps.** Supporting adaptation and risk management efforts in Tennessee will require investments to enhance the knowledge base for local decision-making. Applied research that expands understanding of environmental, social, and economic processes in Tennessee and their interactions with management practice and policy will facilitate bridging gaps in knowledge that constrain adaptation. Such research should capitalize on the extensive knowledge within Tennessee's existing government agencies, businesses, and citizens.
- **Increase flexibility in management practices.** Given uncertainties not only about climate change but also about future trends in socioeconomic and policy conditions, it is important to stress flexibility – rooted in a

continuing learning process – in order to assure an ability to handle unexpected developments and surprises.

- **Reduce system sensitivities to climate variability and change.** For those systems that are especially susceptible to disruption, damage, or loss due to changes in climate variables, a risk management approach will focus attention on ways to reduce those sensitivities through changes in technologies, materials, and corporate strategies.
- **Take advantage of turnover of capital.** The depreciation of assets and the eventual need to replace them as they age creates a window of opportunities for investing in new technologies that move systems in directions that are better-adapted to climate change risks, usually at a lower net cost than retrofitting structures and equipment that will continue to be used for some time.
- **Enhance partnerships.** Adapting Tennessee's communities to the effects of climate change is a task that will span public and private institutions at local, state, and national scales. Hence, strengthening partnerships across all branches and scales of government, economic sectors, and other parts of U.S. society will aid in building the necessary capacity to plan, fund, and implement the policies and measures that will contribute to a sustainable Tennessee.

APPENDICES

A-1. Glossary

Adaptation: The process of changing to fit a new environment or different conditions; taking action to increase the ability to tolerate actual or anticipated effects of climate change.

Aerosols: A collection of airborne solid or liquid particles, with a typical size between 0.01 and 10 mm that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence climate in two ways: directly through scattering and absorbing radiation, and indirectly through acting as condensation nuclei for cloud formation or modifying the optical properties and lifetime of clouds.

Alluvial: relating to, consisting of, or formed by sediment deposited by flowing water

Anthropogenic: Resulting from or produced by human beings.

Aquifer: Any geological formation containing or conducting ground water, especially one that supplies the water for wells, springs, etc.

Built Environment: Products of human design and construction that are intended to deliver services in support of human quality of life., including urban buildings and spaces, energy systems, transportation systems, water systems, sanitation systems, communication systems, and health-care systems.

Carbon Sequestration: Storage of carbon: uptake and storage of carbon, especially by trees and plants that absorb carbon dioxide and release oxygen.

Climate: Climate in a narrow sense is usually defined as the "average weather" or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the State, including a statistical description, of the climate system.

Climate Change: A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

Climate Variability: Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Entomology: Branch of zoology dealing with insects.

Enzootic: Affecting animals in a restricted area: describes an animal disease that occurs only within a specific geographic area.

Geoengineering: The deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming

Global Circulations Models (GCMs): A mathematical model of the general circulation of a planetary atmosphere or ocean and based on the Navier–Stokes equations on a rotating sphere with thermodynamic terms for various energy sources (radiation, latent heat). These equations are the basis for complex computer programs commonly used for simulating the atmosphere or ocean of the Earth.

Global Climate: Roughly speaking it is meant to express the average temperature, average precipitation, average intensity of winds and similar features of Earth's atmosphere and the whole planet's surface.

Greenhouse Gases (GHGs): Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major GHGs are water vapor and carbon dioxide. Other GHGs include methane, ozone, chlorofluorocarbons, and nitrous oxide.

Intergovernmental Panel on Climate Change (IPCC): A scientific intergovernmental body, set up at the request of member governments. Its mission is to provide comprehensive scientific assessments of current scientific, technical and socio-economic information worldwide about the risk of climate change caused by human activity, its potential environmental and socio-economic consequences, and possible options for adapting to these consequences or mitigating the effects.

Invasive Species: An animal or plant species that is not native to that invades natural habitats.

Loess: Fine-grained soil; a fine-grained yellowish brown deposit of soil left by the wind.

Maladaptation: An adaptation that does not succeed in reducing vulnerability but increases it instead.

Mitigation: Taking action to decrease the intensive of Earth's radiative forcing in order to reduce the potential effects of global warming and associated changes in Earth's climate.

Potentiometric Surface: A hypothetical surface representing the level to which groundwater would rise if not trapped in a confined aquifer (an aquifer in which the water is under pressure because of an impermeable layer above it that keeps it from seeking its level).

Sustainable: An ecosystem condition in which biodiversity, renewability, and resource productivity are maintained over time.

Synergy: The interaction of elements that when combined produce a total effect that is greater than the sum of the individual elements.

Urbanization: The conversion of land from a natural state or managed natural state (such as agriculture) to cities; a process driven by net rural-to-urban migration through which an increasing percentage of the population in any nation or region come to live in settlements that are defined as "urban centers."

Vector -borne Disease: A disease that is transmitted to humans or other animals by an insect or other arthropod.

Zoonotic Disease: A disease that it is transmitted from animals to humans.

A-2. Acronyms/Abbreviations

ACSE – American Society of Civil Engineers

CDC – Centers for Disease Control and Prevention

CO_2 – Carbon dioxide

EEE – Eastern equine encephalitis

°F – Degrees Fahrenheit

GHG – Greenhouse gas

GCM – Global climate model or General circulation model

GDP – Gross domestic product

IPCC – Intergovernmental Panel on Climate Change

Mgal/d – Millions of gallons per day

MW – MegaWatts (a measure of electricity generation)

NRC – National Research Council of the National Academy of Sciences

ORNL – Oak Ridge National Laboratory

ppm – parts per million (a measure of atmospheric concentration)

STEC – Shiga toxin-producing Escherichia coli

TCI – Tourism climatic index

TVA – Tennessee Valley Authority

UNEP – United Nations Environment Programme

UNFCCC – United Nations Framework Convention on Climate Change

U.S. GCRP – U.S. Global Change Research Program

UTK – University of Tennessee – Knoxville

WMO – World Meteorological Organization

A-3. Helpful Resources

To learn more about Tennessee's weather and climate:

- Visit the Tennessee Climatological Service at http://climate.tennessee.edu/climate_data.html
- Visit the Southeast Climate Center at http://www.doi.gov/csc/southeast/index.cfm
- Visit the Southern Regional Climate Center at http://www.srcc.lsu.edu/

To learn more about the economic impacts of climate change on the State of Tennessee:

- Read *Economic Impacts of Climate Change on Tennessee* at http://www.cier.umd.edu/climateadaptation/Tennessee%20Economic%20Impacts%20of%20Climate%20Change%20Full%20Report.pdf

To learn more about other U.S. climate change research and assessment activities:

- Visit the U.S. Global Change Research Program's website at http://www.globalchange.gov/

To learn more about the history of climate change science:

- Read Naomi Oreskes' book, "Merchants of Doubt"

To learn more about potential impacts from global climate change and what people can and cannot due to avoid them:

- Read the 2012 book, "Global Weirdness: Severe Storms, Deadly Heat Waves, Relentless Drought, Rising Seas, and the Weather of the Future," by Climate Central, a nonprofit research organization

ENDNOTES

[1] Source: Bernard SM, Samet JM, Grambsch A, Ebi KL, Romieu I (2001) The potential impacts of climate variability and change on air pollution-related health effects in the United States. Environmental Health Perspectives 109:199-209
[2] See: International Union for Conservation of Nature and Natural Resources (1980) *World Conservation Strategy*. International Union for Conservation of Nature and Natural Resources, United Nations Environment Programme, World Wildlife Fund, Food and Agriculture Organization of the United Nations, United Nations Educational, Scientific and Cultural Organization. (Available at http://data.iucn.org/dbtw-wpd/edocs/WCS-004.pdf)
[3] Source: Tennessee Climatological Service (http://climate.tennessee.edu/)
[4] This map and data table were derived from the United States Geological Survey (USGS) coverage of climate divisions from the National Climatic Data Center accessed on 29 August 2012 (http://water.usgs.gov/GIS/metadata/usgswrd/XML/climate_div.xml#stdorder)
[5] Source: Bureau of Economic Analysis (www.bea.gov/)
[6] Source: Tennessee Valley Authority (www.tva.gov)
[7] Source: Degree Day Statistics from the National Weather Service Climate Prediction Center (www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/)
[8] Sources: GDP Estimates - 2010 Economic Report to the Governor of Tennessee; Employement statistics - U.S. Bureau of Labor Statistics (www.bls.gov/)
[9] Source: Energy Information Agency (www.eia.gov/electricity/state/tennessee/)
[10] Source: Energy Information Agency (www.eia.gov/electricity/state/tennessee/)
[11] Source: Energy Information Agency (www.eia.gov/electricity/state/tennessee/)
[12] Source: EIA 2010 report (http://www.eia.gov/electricity/state/pdf/sep2010.pdf)
[13] Source: Energy Information Agency (http://www.eia.gov/state/state-energy-profiles.cfm?sid=TN)
[14] Source U.S. Census Bureau Quick Facts (http://quickfacts.census.gov/qfd/states/47000.html)
[15] Source: Population Projections for the State of Tennessee (hwww.state.tn.us/tacir/population.html)
[16] Source U.S. Census Bureau Quick Facts (http://quickfacts.census.gov/qfd/states/47000.html)
[17] Source: Tennessee Department of Education (www.tennessee.gov/education/reportcard/)
[18] Source: America's Health Rankings (www.americashealthrankings.org/TN/graduation/2011)
[19] Source: Tennessee Higher Education Profiles and Trends 2012 (www.tn.gov/thec/Legislative/Reports/2012/Profiles--Trends-2012_w_cover_page.pdf)
[20] Source: United Health Foundation's America's Health Rankings 2011 (http://www.americashealthrankings.org/SiteFiles/Statesummary/TN.pdf)
[21] Source: U.S. Census Bureau (www.census.gov/compendia/statab/2012/ranks/rank17.html)
[22] Source: America's Health Rankings (www.americashealthrankings.org/TN/2011-1990)
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