Contents

Summary and Recommendations: Collaborating to Improve Community Resiliency to Natural Disasters

Natural disasters can devastate communities. The most severe disasters result in deaths and end up costing residents, businesses, local governments, and the state millions of dollars in property damage and economic losses. In Tennessee, notable examples from the last 25 years include the April 1998 tornado in Nashville, which killed one and caused hundreds of millions of dollars in property damage; the April 2011 flooding along the Mississippi River, which destroyed 601 residences and caused $22.6 million in damage; the November 2016 fire that began in Great Smoky Mountains National Park and killed 14 while causing $2 billion in damage; the March 3, 2020, tornados, which resulted in 25 deaths and property damage that will stretch into the hundreds of millions of dollars across three counties in middle Tennessee; and the tornado that hit Hamilton County on April 12, 2020, which resulted in two deaths and several damaged or destroyed buildings. Moreover, the range of possible natural disasters extends far beyond weather events to include incidents like earthquakes and public health emergencies—such as the ongoing pandemic caused by COVID-19.

The most severe natural disasters result in deaths and can cost residents, businesses, local governments, and the state millions of dollars in property damage and economic losses.

The potential for natural disasters threatens every community in Tennessee. Individuals, businesses, community groups, and governments play an important role in limiting the negative effects of these events, in part by adopting strategies that allow them to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruptions to everyday life, thereby making their communities more resilient. Building community resilience includes understanding the risks communities face, and the actions they can take to reduce vulnerabilities and rebound more quickly when disruptions occur.

To better understand the historical, present, and projected occurrence of natural disasters in Tennessee, and to assess what should be done to prepare for future events, Senate Bill 1114 by Senator Jeff Yarbro and House Bill 1120 by Representative Bob Freeman in the 111th General Assembly would have created a state government task force on community resilience to examine present and projected losses resulting from these events, develop recommendations to reduce vulnerabilities, and report its findings to the General Assembly (see appendix A). Following discussion of the bill, the House State Committee referred it to the Tennessee Advisory Commission on Intergovernmental Relations for study. Although communities may be threatened by a wide variety of potential disasters—such as cyberattacks, terrorism, and mass-shootings—the sponsors requested that the Commission specifically

- identify risks for extreme weather events and earthquakes across the state,
- document the current status of planning to reduce the effects of these specific natural disasters and build community resilience in Tennessee at the state and local level,
- identify best practices for building community resilience, and
- determine the cost of action and inaction.

On average, Tennessee incurs hundreds of millions of dollars in damages each year from natural disasters, and this is projected to nearly double by 2055.

Without continued resilience efforts, Tennessee could see the annual cost of natural disasters nearly double from $343.5 million to $595 million per year by 2055.

From 1996 to 2018, there was an average of $343.5 million annually in property damage and economic losses resulting from natural disasters in Tennessee, according to analysis by 3 Sigma Consultants, LLC—the consulting firm the Commission contracted with to analyze past and future extreme weather events and earthquakes. Based on 3 Sigma's analysis, Tennessee could see the annual cost of natural disasters nearly double to $595 million per year by 2055.[1] This includes an increase in damage from flooding, heavy rain, and other hydrologic events from $243 million per year currently to $346 million per year; an increase in damage from tornados, dust devils, and funnel clouds from $69 million to $172 million per year; and an increase in damage from straight winds from $12 million per year to $30 million per year. The number of days where the temperature is hot enough to have health effects is also expected to increase, especially in West and Middle Tennessee. Similarly, although none of the more than 5,500 earthquakes in Tennessee in the last 25 years caused significant damage, projections show that counties along Tennessee's western border and those in some areas of East Tennessee are at greater risk of damaging earthquakes in the next 100 years. See appendix B for 3 Sigma's full report entitled *Natural Hazard Community Resilience in Tennessee*.

The State of Tennessee and its local governments are working individually and collaboratively to prepare for natural disasters.

There are a variety of strategies that can be adopted to build resilience in the face of natural disasters, including hazard mitigation, which is an action taken to "reduce the loss of life and property by lessening the impact of disasters."[2] Hazard mitigation is the foundation of community resilience, according to the Federal Emergency Management Agency. While hazard mitigation contributes to resilience, community resilience goes beyond

[1] Projections are in current dollars, not adjusted for inflation, and do not take into consideration mitigation or resilience strategies taken to reduce the effects of natural disasters.
[2] Federal Emergency Management Agency 2017c.

reducing physical vulnerabilities and includes reducing social and economic vulnerability as well. For example, acquiring property in a flood plain in order to reduce exposure to future flooding is hazard mitigation, but turning that newly vacant land into space for a park, playground, or walking trail builds social connectedness and conserves the land for the foreseeable future—both are examples of community resilience. Economic vulnerabilities may be less obviously tied to a mitigation strategy but are just as important. For example, if a community's economy includes too much reliance on a single business sector, the ability to quickly recover from a natural disaster that damages or destroys businesses is more difficult.

Many of the strategies that build resilience are already being implemented by the state and local communities in Tennessee.

The good news is many of the strategies that build resilience are already being implemented in Tennessee. For example, Pigeon Forge has been recognized nationally for its efforts to reduce the risks it faces from wildfires by adopting strategies such as curbside brush removal and participation in the Ready, Set, Go! pilot program, which prepares residents and businesses for evacuations. Other hazard mitigation strategies adopted in Tennessee include improving storm-water systems and purchasing residential property in flood-prone areas—both of which the Metropolitan Government of Nashville and Davidson County implemented to reduce its risk from future flooding following a catastrophic 2010 flood—while community storm shelters, such as the 600-person safe room Lake County built in one of its public schools, can save lives during tornados and severe storms. Although each of the examples identified in this report can be effective, they represent neither an exhaustive nor a prescriptive list of the strategies that might be adopted.

One of the most important things individuals, local governments, and states can do is evaluate the risks they face from natural disasters and determine what actions they will take to prepare for, withstand, and recover from them. For individuals and families in Tennessee, the Tennessee Emergency Management Agency (TEMA) provides planning resources, including a checklist of disaster supplies for families—such as water, flashlights, and batteries—for use in preparing for natural disasters and other emergencies (see appendix C). During the COVID-19 pandemic, the state of Tennessee has made a concerted effort to make resources available for individuals, families, and businesses to keep people safe, healthy, and financially secure.[3]

For local governments and the state, planning for natural disasters includes the development of hazard mitigation plans. Completing these plans not only helps local governments and the state assess their risks and adopt specific strategies to prepare for and recover from natural disasters, it also makes counties and states that have had their plans approved by the

[3] See https://www.tn.gov/governor/covid-19.html for information on available resources.

Federal Emergency Management Agency (FEMA) within the last five years eligible for federal hazard mitigation assistance grants. Local governments receive planning support from TEMA and may apply for FEMA planning grants to assist with hazard mitigation plans. Developing these plans involves

- analyzing both weather and seismological data to assess risks;
- identifying vulnerabilities related to these risks that could result in loss of life, as well as damage to critical infrastructure and other property; and
- adopting preferred strategies to reduce the effects of and speed recovery from future disasters.

In addition to the Tennessee Emergency Management Agency's efforts, other state agencies, as well as universities, are working in partnership, going beyond hazard mitigation, to promote community resilience in Tennessee.

In Tennessee, the state and most counties have FEMA-approved hazard mitigation plans. The state's latest hazard mitigation plan received FEMA approval in 2018. Of Tennessee's 95 counties, 75 have received FEMA approval for their local hazard mitigation plans, seven are revising or reviewing their plans, and 13 have either not submitted a plan or their plan has lapsed.

Tennessee state agencies and local governments are helping communities build resilience to prepare for, adapt to, and recover rapidly from natural disasters.

In addition to TEMA's efforts, other state agencies and universities are also working in partnership, going beyond just hazard mitigation to promote community resilience in Tennessee. For example, the Tennessee Department of Economic and Community Development (ECD) is collaborating with TEMA and the Tennessee Department of Environment and Conservation (TDEC) to develop flood control projects in local communities using funding from the US Department of Housing and Urban Development's National Disaster Resilience Competition grant. TDEC has considered developing a Tennessee Citizens Resilience Academy pilot program, which would involve collaboration with higher education and community-based organizations, to provide training that educates and empowers Tennesseans to lead their community in the effort to prepare for and recover from a natural disaster. As part of another pilot program, TDEC is collaborating with local, state, and federal government agency partners to convene strategic planning and community engagement sessions in communities across the state to explore local solutions for building community capacity to prepare for, respond to, and recover from a variety of foreseen and unforeseen circumstances, including certain types of natural disaster. Local governments have embraced collaborative approaches as well, in particular Shelby County, which brought together stakeholders from several jurisdictions to develop both its Mid-South Regional Resilience Master Plan and its earlier Greenprint 2015/2040 resilience plan.

Representatives from ECD and TDEC have expressed interest in creating a state-level interagency council to further coordinate state resilience planning. Six states have already established such councils to support collaboration and promote resilience. Similarly, seven states, including three that have established councils, have appointed chief resilience officers to coordinate interagency and intergovernmental efforts on community resilience. These councils and resilience officers have all been established within the last seven years, and data on their effectiveness at reducing the cost of natural disasters are limited. TEMA has expressed reservations regarding the need to create a new collaborative body, saying it already "performs interagency coordination to ready the state for disaster and to reduce the effects of disruptions on daily life" and that it has "coordinated the investment in building resilient communities for more than four decades." Because Tennessee local governments and state agencies are implementing strategies to prepare for, withstand, and rapidly recover from disruptions to everyday life, and because interagency collaboration is already occurring, **the state should ensure that ongoing resilience efforts continue—including collaboration among state agencies and local governments. The Commission takes no position on the exact structure of these collaborative efforts, but they should include, in addition to hazard mitigation strategies, a focus on community resilience-planning features such as assessing social and economic vulnerabilities and engaging community members in the decision-making process.**

Other states' resilience councils and chief resilience officers were all established within the last seven years, and data on their effectiveness at reducing the cost of natural disasters are limited.

Resilient Communities Are Better Prepared to Bounce Back from Disruptions.

When natural disasters occur, they can lead to loss of life, damage to property, and economic hardships. Tennesseans have experienced several natural disasters in recent years, including two devastating tornado events in parts of Middle and East Tennessee. Preparing for such disruptions to everyday life is part of what builds *community resilience*, which broadly refers to "the capacity of individuals, communities, and systems to survive, adapt, and grow in the face of stress and shocks, and even transform when conditions require it," according to the Rockefeller Foundation, who founded the 100 Resilient Cities initiative.[4] The importance of making community resilience a priority has recently become painfully clear for many Tennesseans.

Community resilience broadly refers to "the capacity of individuals, communities, and systems to survive, adapt, and grow in the face of stress and shocks, and even transform when conditions require it."

The Rockefeller Foundation, which founded the 100 Resilient Cities initiative

Tennesseans, including those still rebuilding from recent tornados in Middle and East Tennessee,[5] are currently dealing with the COVID-19 pandemic. While the virus itself is a threat to public health, efforts to control its spread have had economic consequences for individuals, communities, and the state. On March 30, 2020, Governor Bill Lee issued Executive Order 22, which encouraged the public to remain at home whenever possible, while still maintaining access to essential services and activities. Days later, the seriousness of the situation led to Executive Order 23, which made it a requirement that the public only leave home for essential activities.

While much of the public health response has been coordinated through the Tennessee Department of Public Health, in collaboration with local health departments across the state, local governments have acted in additional ways to respond to COVID-19. For example, Jefferson County developed a web-based response hub that maps the spread of the virus and identifies the location of testing sites, healthcare providers, and hospital beds.[6] Rutherford County has also used a web-based platform to help connect citizens with restaurants that are still operating through take-out or drive-through services.[7] Groups like Municipal Technical Advisory Service, County Technical Advisory Service, Tennessee Correctional Institute, Tennessee Sheriffs' Association, and the Tennessee Association of Chiefs of Police teamed up to provide resources to law enforcement

[4] Rockefeller Foundation 2017.
[5] On March 3, 2020, tornados in three counties in middle Tennessee resulted in 25 deaths and property damage that will stretch into the hundreds of millions of dollars. The tornado took a similar path to the April 1998 tornado in Middle Tennessee, which killed one and caused hundreds of millions of dollars in property damage. Brackett and Childs 2020 and Rose "A Tornado Climatology of Middle Tennessee (1830-2003)". On April 12th, Hamilton County was hit by an EF3 tornado, resulting in two deaths and several damaged or destroyed buildings. Breslow and Mays 2020.
[6] Jefferson County "Jefferson County, Tennessee, Coronavirus Response."
[7] Rutherford County "Restaurant Status."

and jails on how to respond to COVID-19.[8] While many businesses temporarily closed, those who can are working from home, but many others find themselves unemployed. On April 27, 2020, Governor Lee lifted the order to stay at home and began allowing restaurants to open and retail stores to operate with reduced capacity.[9] Mayors of Memphis, Nashville, Knoxville, and Chattanooga have formed the Tennessee Major Metros Economic Restart Task Force to share input and collaborate on restarting the economy.[10] While the top concern is public health, the effect that COVID-19 is having on the economy is also concerning, in no small part because these economic effects may linger long after the immediate public health risks have diminished.[11]

From 1996 to 2018 in Tennessee, there was an average of over 1,415 natural disasters per year totaling $343.5 million annually in property damage and economic losses.

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Each year, Tennessee incurs hundreds of millions of dollars in damages on average from natural disasters, and this is projected to nearly double by 2055.

From 1996 to 2018 in Tennessee, there was an average of over 1,415 natural disasters per year totaling $343.5 million annually in property damage and economic losses, according to analysis by 3 Sigma Consultants, LLC, the consulting firm the Commission contracted with to analyze past and future extreme weather events and earthquakes. See appendix B for the

[8] County Technical Advisory Service "Law Enforcement and Jails COVID-19 Resources."
[9] Tennessee Governor Bill Lee Executive Order 29.
[10] Jeong 2020.
[11] Shilling 2020.

full report. Some natural disasters have been more costly than others. To determine the costs of natural disaster events in Tennessee, 3 Sigma used National Weather Service classifications, which they then combined into ten natural disaster event categories.[12] See table 1 for past and projected costs of natural disasters by event category.

Table 1. Average Natural Disaster Costs Annually from 1996 to 2018, and Projected Average Natural Disaster Costs Annually from 2035 to 2055

Natural Disaster Type	Average Natural Disaster Costs Per Year		Total Increase (Decrease)
	From 1996 to 2018	From 2035 to 2055	
Cold	$34,523	$33,117	($1,406)
Dry	5,068,659	17,094,953	12,026,294
Frozen Precipitation	5,530,686	7,738,509	2,207,823
Heat	2,624,680	11,970,353	9,345,673
Hydrologic	242,855,555	345,943,949	103,088,394
Lightning	1,396,387	3,476,468	2,080,081
Rotational Winds	68,895,718	172,310,551	103,414,833
Straight Winds	12,490,270	30,103,347	17,613,077
Wildfire	4,513,274	6,121,602	1,608,328
Earthquake	66,919	77,157	77,157
Total	$343,476,671	$594,870,006	$938,346,677

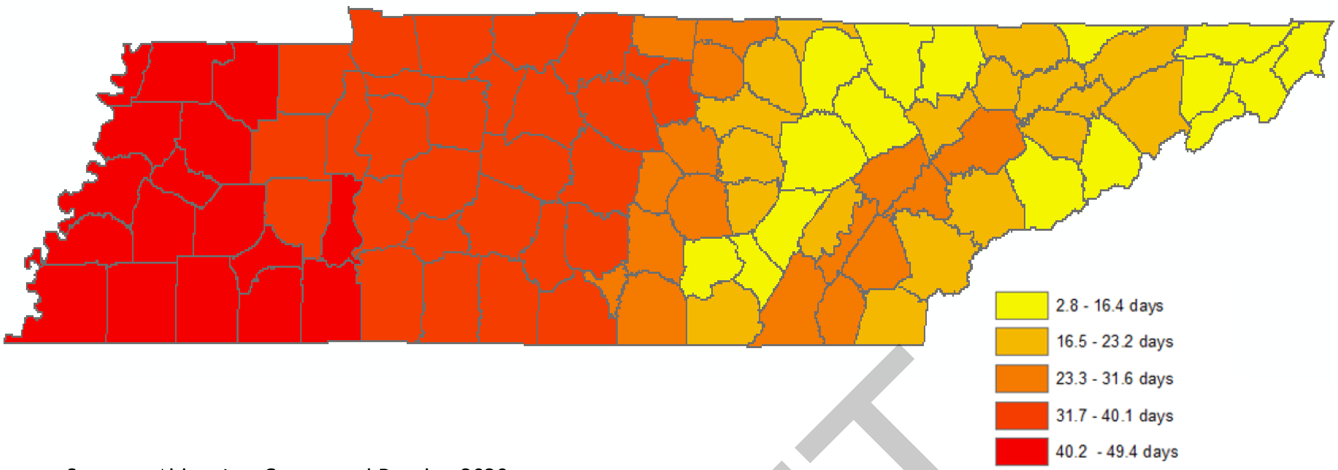
Source: Abkowitz, Camp, and Dundon 2020. Projections are in current dollars, not adjusted for inflation.

Based on 3 Sigma's analysis, as Tennessee experiences an increase in the frequency of natural disaster events, costs of these disasters are projected to nearly double to $595 million per year by 2055. This includes an increase in damage from flooding, heavy rain, and other hydrologic events from $243 million per year currently to $346 million per year; an increase in damage from tornados, dust devils, and funnel clouds from $69 million to $172 million per year; and an increase in damage from straight winds from $12 million per year to $30 million per year.[13] The number of days where the temperature is at or above 95 degrees—hot enough to have health effects—is also expected to increase, especially in West and Middle Tennessee (see map 1). Similarly, every county in Tennessee is projected to experience an increase of 1.09 to 2.26 inches in average annual total precipitation, with the greatest increase concentrated in the southern part of East Tennessee (see map 2). Moreover, although none of the more than 5,500 earthquakes in Tennessee in the last 25 years caused significant damage, projections show that counties along Tennessee's western border, and those in some areas of East Tennessee, are at greater risk of damaging earthquakes in the next 100 years (see map 3).[14]

In Tennessee, some natural disasters have been more costly than others.

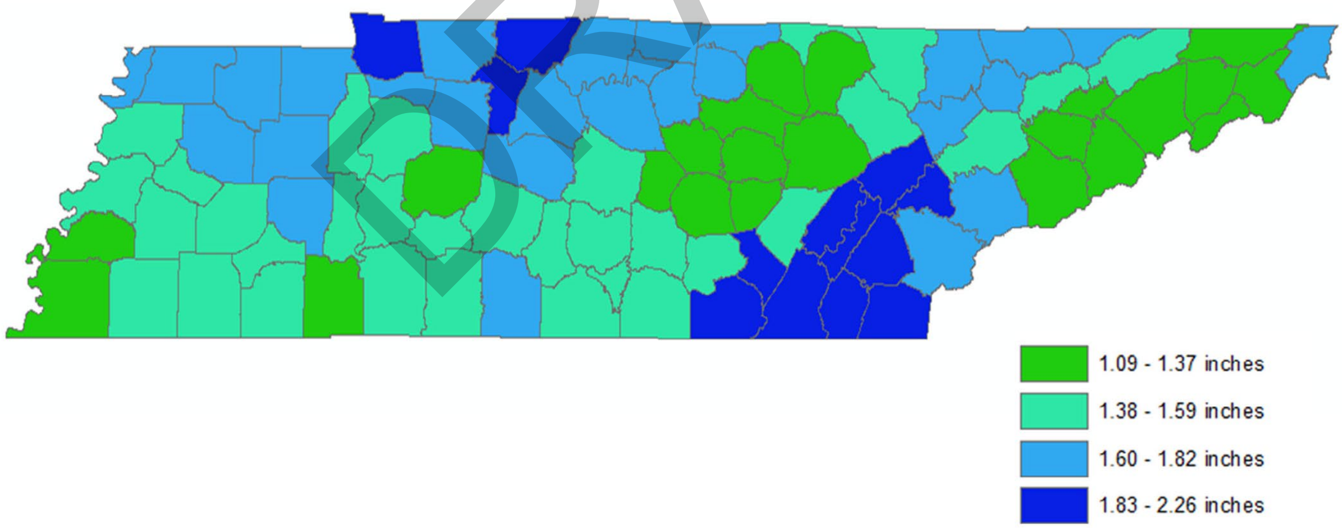
[12] See Abkowitz, Camp, and Dundon 2020, for an explanation of how these events are classified in appendix A. For a list of disaster event types in each category see table 4.2.
[13] Projections are in current dollars, not adjusted for inflation, and do not take into consideration mitigation or resilience strategies taken to reduce the effects of natural disasters.
[14] Abkowitz, Camp, and Dundon 2020.

Map 1. Projected Increase in Average Number of Days Per Year with Maximum Temperature at or Above 95˚F for 2035 to 2055



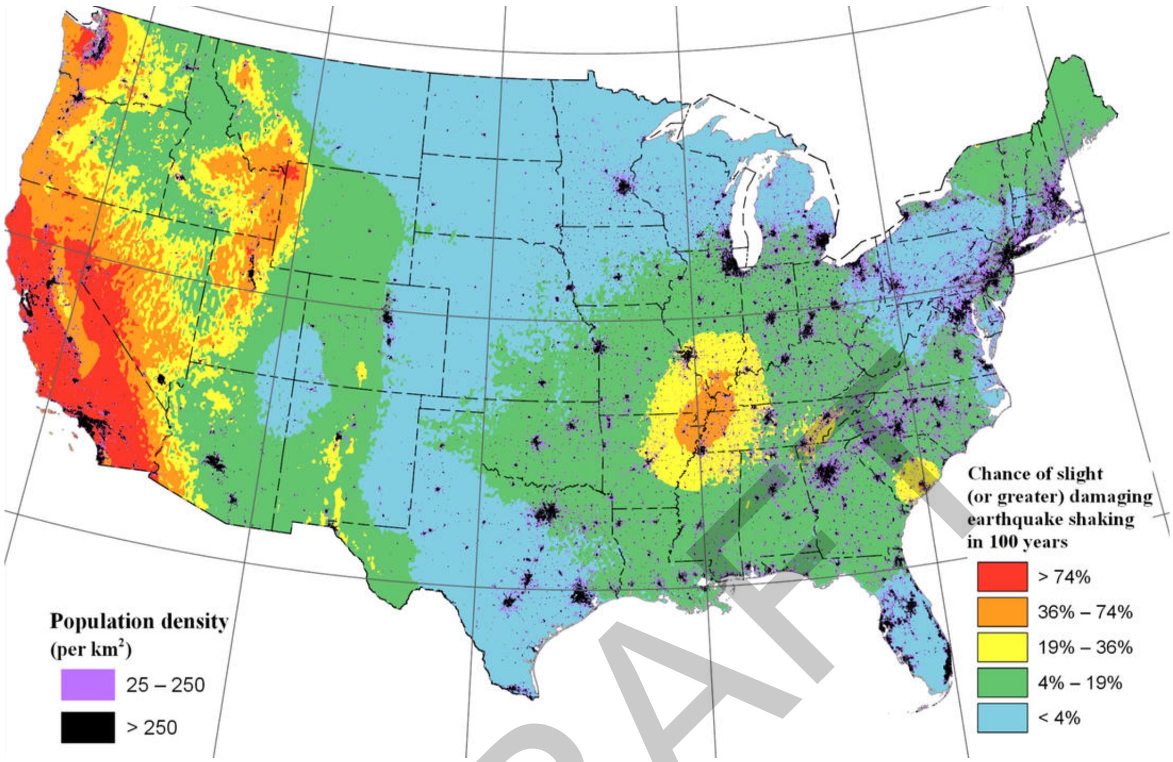
Source: Abkowitz, Camp, and Dundon 2020.

Map 2. Projected Change in Average Total Precipitation Per Year for 2035 to 2055



Source: Abkowitz, Camp, and Dundon 2020.

Map 3. Chance of Damaging Earthquake in the Next 100 Years



Source: Abkowitz, Camp, and Dundon 2020.

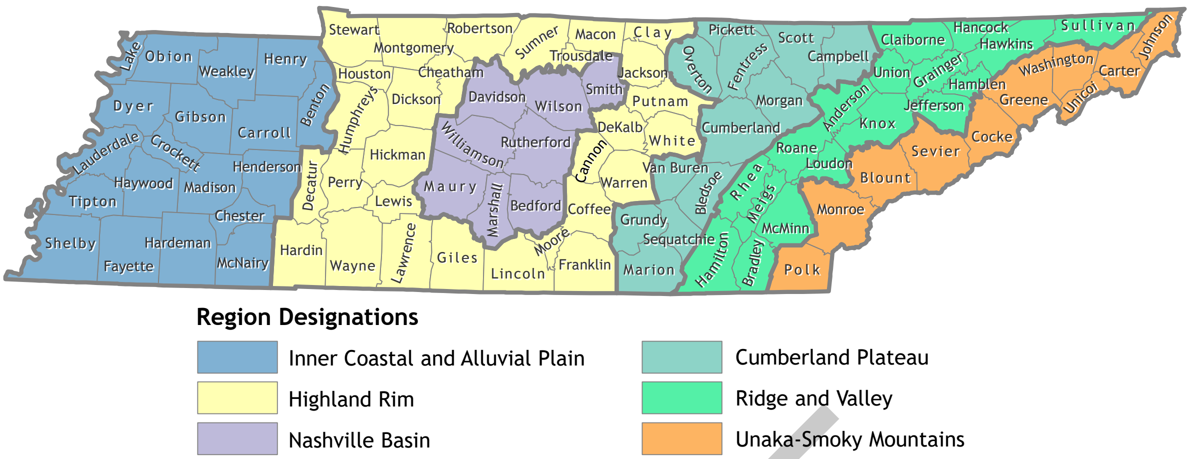
Natural disaster events and costs vary across the state.

Tennessee can be divided into six regions that are diverse and have distinct patterns of weather.[15] Regions include the Inner Coastal and Alluvial Plain, the Highland Rim, the Nashville Basin, the Cumberland Plateau, the Ridge and Valley, and the Unaka-Smoky Mountains. Each region has unique challenges, but commonalities exist. The top-three greatest-frequency natural disaster events are the same across all six regions—straight winds, frozen precipitation, and flooding, hydrologic events. Straight wind events occur the most often for five of the six regions—all but the Inner Coastal and Alluvial Plain region, which has more frozen precipitation than straight winds. Hydrologic events are the third greatest in frequency for all six regions. See map 4 for the six climate regions and maps 5, 6, 7, and 8 for the average number of natural disaster events per year for each region in Tennessee from 1996 to 2018.

Tennessee can be divided into six regions that are diverse and have distinct patterns of weather.

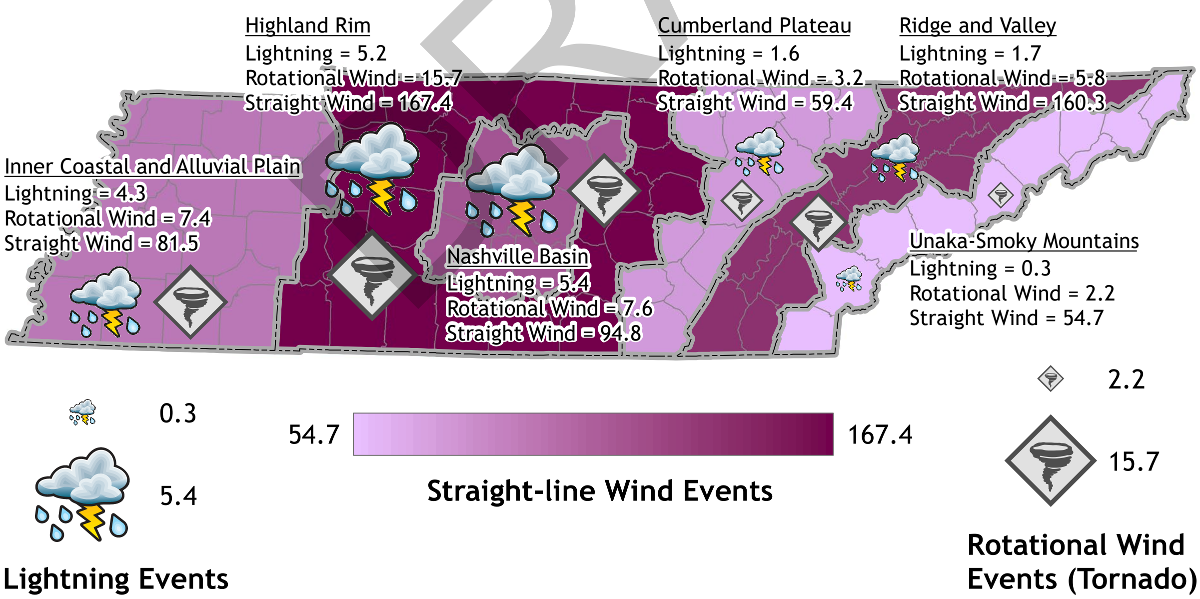
[15] Abkowitz, Camp, and Dundon 2020, created the six regions for the purposes of this report.

Map 4. Tennessee Counties by Climate Regions



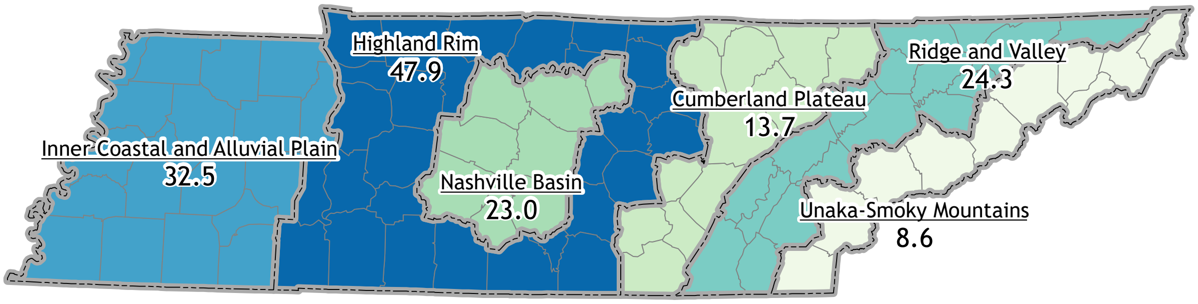
Source: Map created by TACIR staff using data from Abkowitz, Camp, and Dundon 2020.

Map 5. Average Hydrologic Events Per Year by Climate Region in Tennessee from 1996 to 2018



Source: Map created by TACIR staff using data from Abkowitz, Camp, and Dundon 2020.

Map 6. Average Heat and Drought Events Per Year by Climate Region in Tennessee from 1996 to 2018

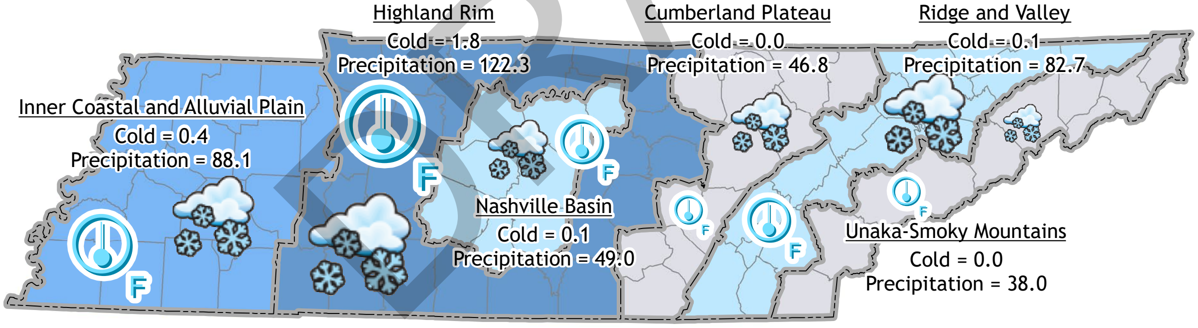


Hydrologic Events (Flood / Heavy Rain)

8.6 47.9

Source: Map created by TACIR staff using data from Abkowitz, Camp, and Dundon 2020.

Map 7. Average Extreme Cold and Frozen Precipitation Events Per Year by Climate Region in Tennessee from 1996 to 2018



Extreme Cold / Wind Chill Events

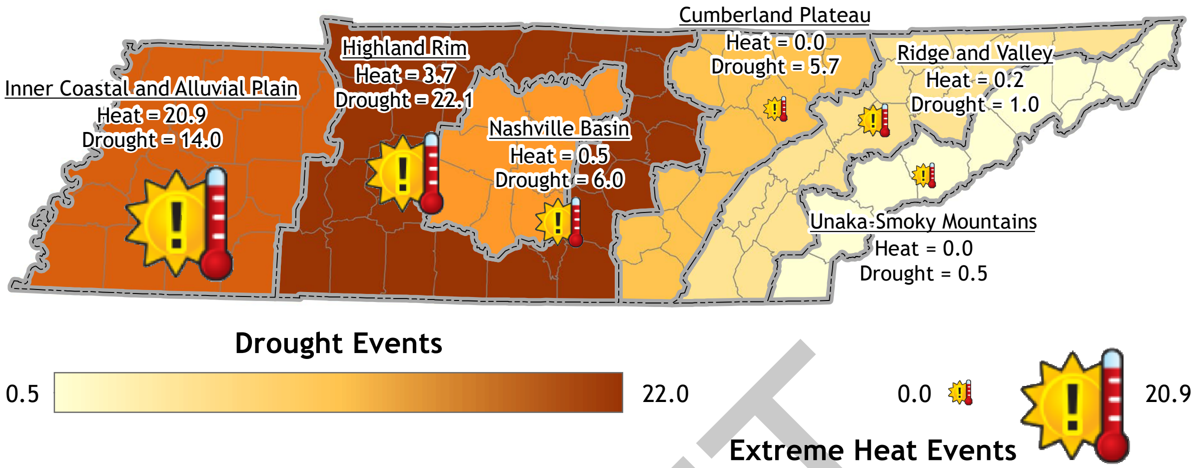
0.0 1.8

38.0 122.3

Frozen Precipitation Events (Snow, Sleet, Ice)

Source: Map created by TACIR staff using data from Abkowitz, Camp, and Dundon 2020.

Map 8. Average Rotational Winds (Tornados), Straight Winds, and Lightning Events Per Year by Climate Region in Tennessee from 1996 to 2018



Source: Map created by TACIR staff using data from Abkowitz, Camp, and Dundon 2020.

Though the most common natural disaster event in the past 25 years is straight winds, the costliest natural disaster type for five of the six regions was flooding, heavy rain, and other hydrologic events. The average cost per year ranges from $2.5 million in the Unaka-Smoky Mountains region to $135 million in the Inner Coastal and Alluvial Plain region. In the Highland Rim region, the average cost of damage per year caused by tornados, dust devils, and funnel clouds was $15.1 million—twice that of flooding, heavy rain, and other hydrologic events, which was $7.1 million.

By 2055, the costliest natural disasters for some regions will be tornados, dust devils, and funnel clouds.

By 2055, the costliest natural disasters for some regions will be tornados, dust devils, and funnel clouds—including the Cumberland Plateau and the Ridge and Valley regions—that have historically experienced greater costs from flooding, heavy rain, and other hydrologic events, according to 3 Sigma. The Highland Rim region is projected to continue to see its greatest costs in damage caused by tornados, dust devils, and funnel clouds. As the annual number of days above 95 degrees is anticipated to increase,[16] the Highland Rim, Inner Coastal and Alluvial Plain, Nashville Basin, and Ridge and Valley regions will see costs increase from extreme heat events, while the other regions see either no change (Cumberland Plateau region) or a decrease in costs (Unaka-Smoky Mountains region). Though temperatures are expected to increase across the state, the Cumberland Plateau, Nashville Basin, and the Ridge and Valley Region may still see a small increase in costs from extreme cold and wind chill events. Most of the state could experience a decrease in costs from $34,500 to just over $33,100.[17] See table 2 and table 3.

[16] According to the 3 Sigma report by Abkowitz, Camp, and Dundon 2020, the increase in the annual number of days above 95 degrees will be 42.2 for the Inner Coastal and Alluvial Plain, 36.4 for the Highland Rim, 34.5 for the Nashville Basin, 7.6 for the Cumberland Plateau, 20 for the Ridge and Valley, and 1.5 for the Unaka-Smoky Mountains.
[17] Abkowitz, Camp, and Dundon 2020.

Table 2. Present Day Cost of Natural Disasters by Region
Average Annual Risk Cost ($): 1996-2018

Hazard	Cumberland Plateau	Highland Rim	Inner Coastal and Alluvial Plain	Nashville Basin	Ridge and Valley	Unaka-Smoky Mountains	Total
Cold	$ 2,258	$ 27,711	$ 1,323	$ 3,203	$ 28	$ -	$ 34,523
Dry	587,278	2,254,243	1,450,124	623,418	99,385	54,210	5,068,659
Frozen Precipitation	2,078,423	1,586,287	254,659	1,544,134	22,481	44,701	5,530,686
Heat	-	383,989	2,168,410	49,693	18,070	4,518	2,624,680
Hydrologic	3,733,613	7,109,013	135,093,418	81,844,373	12,580,878	2,494,260	242,855,555
Lightning	78,393	353,958	198,821	382,589	190,638	191,987	1,396,387
Rotational Winds	2,599,400	15,118,576	25,656,877	15,416,168	8,998,612	1,106,085	68,895,718
Straight Winds	581,629	1,807,993	5,611,000	1,413,288	2,306,955	769,404	12,490,270
Wildfire	752,212	752,212	752,212	752,212	752,212	752,212	4,513,274
Earthquake	1,473	1,131	47,464	11,335	3,943	1,573	66,919
Total	$ 10,413,206	$ 29,393,984	$ 171,186,846	$ 102,029,078	$24,969,261	$ 5,417,377	$ 343,476,672

Numbers may not add up because of rounding.

Source: Abkowitz, Camp, and Dundon 2020.

Table 3. Projected Future Cost of Natural Disasters by Region
Average Annual Risk Cost ($): 2035-2055

Hazard	Cumberland Plateau	Highland Rim	Inner Coastal and Alluvial Plain	Nashville Basin	Ridge and Valley	Unaka-Smoky Mountains	Total
Cold	$ 2,442	$ 24,265	$ 1,106	$ 5,268	$ 36	$ -	$ 33,117
Dry	1,739,752	7,846,962	4,484,869	2,525,882	331,658	165,829	17,094,953
Frozen Precipitation	2,506,566	2,263,745	322,052	2,557,338	29,737	59,072	7,738,509
Heat	-	190,911	9,490,708	356,595	142,139	-	11,970,353
Hydrologic	4,763,094	10,594,561	169,339,600	140,444,944	17,349,189	3,452,562	345,943,949
Lightning	167,245	851,146	452,668	1,136,559	437,372	431,478	3,476,468
Rotational Winds	5,621,540	38,849,826	57,927,227	45,778,268	21,465,547	2,668,142	172,310,561
Straight Winds	1,257,932	4,623,260	12,723,153	4,202,868	5,471,194	1,824,940	30,103,347
Wildfire	900,490	1,065,003	943,783	1,238,174	987,076	987,076	6,121,602
Earthquake	1,531	1,391	51,736	16,210	4,495	1,793	77,157
Total	$ 16,960,593	$ 68,101,069	$255,736,901	$ 198,262,106	$46,218,443	$ 9,589,099	$ 594,792,849

Numbers may not add up because of rounding.

Source: Abkowitz, Camp, and Dundon 2020.

Communities use many different mitigation strategies to increase resilience to natural disasters and reduce the resulting cost of damage.

Hazard mitigation, which is an action taken to "reduce the loss of life and property by lessening the impact of disasters,"[18] is the foundation of community resilience, according to FEMA. Communities implement a variety of strategies to mitigate the effects of natural disasters, including mitigation strategies that reduce physical vulnerabilities like buildings and

Hazard mitigation is an action taken to "reduce the loss of life and property by lessening the impact of disasters."

[18] Federal Emergency Management Agency 2017c.

infrastructure. There are many similarities between mitigation strategies and resilience strategies, but resilience goes further than mitigation by working to reduce social vulnerabilities, such as poor access to healthcare, and economic vulnerabilities, such as a lack of a diversified economy. See table 4 for examples of resilience and mitigation measure and indicators.

Table 4. Examples of Resilience and Mitigation

Criteria	Example Measures	Example Indicators	Resilience	Mitigation
Stakeholder Engagement(A)	Collaboration with all stakeholders to develop priorities for mitigation action—citizens, nonprofits, private sector, and public sector	Open meetings, public comment periods, and diverse methods of disseminating information, which facilitates awareness of risks, vulnerabilities, and strategies in a way that promotes engagement, priority identification, and strategy implementation	Yes	Yes
Risk Identification(A)	Identification of natural and man-made risks	The community is capable of assessing, managing, prioritizing, and monitoring risks.	Yes	Yes
Vulnerability Identification(A)	Identification of public and private vulnerabilities related to infrastructure, buildings, agriculture, and individuals so that public health, safety, and assets may be evaluated in the context of risks	The community has developed an inventory of risks by likelihood and evaluated the potential effect on physical, social and economic assets.	Yes	Yes
Priority Identification(A)	Identification of risks and assets along with a priority ranking of how to use the available resources to reduce vulnerabilities	A diverse group of citizens participate in public meetings to objectively evaluate the potential risks and the vulnerable assets in their community and then identify how they want to allocate limited resources to protect against these risks.	Yes	Yes
Plan Development(A)	The community has cross-referenced plans that identify risks, vulnerabilities, and action items based on priorities and available resources.	a) Local Hazard Mitigation Plan b) Community Resilience Framework	Yes	Yes

Table 4. Examples of Resilience and Mitigation (continued)

Criteria	Example Measures	Example Indicators	Resilience	Mitigation
Strategy Implementation(A)	Once the community develops its priorities, adequate resources are allocated to implement mitigation strategies.	If a community is vulnerable to having homes in a flood plain flooded then the local government allocates enough resources to buyout the homes in the flood plain and then establishes policies to prevent future developments in areas prone to flooding.	Yes	Yes
Infrastructure(B)	The community is aware of its infrastructure needs and allocates adequate resources to maintain its infrastructure.	The community has a) spatial planning frameworks to redirect development away from high-risk areas b) project and policy appraisals, include environmental factors c) regulatory and economic standards, such as building codes	Yes	Yes
Communication Systems(C)	The public has access to the technology, infrastructure, and knowledge necessary to receive and transmit information.	Cell service and broadband is accessible across the community via multiple providers and most residents are connected. Free high-speed wireless connections available via hotspots.	Yes	No
Transportation Systems(D)	The community has a wide range of transportation options beyond a single occupancy vehicle, including public transit, as well as pedestrian and biking infrastructure.	a) The transportation system is robust, protecting connectivity, and providing the capacity necessary to meet the travel demands. b) The transportation system has redundancy with alternative routes at critical points and alternative modes available. c) The resources like people and equipment are available to maintain and report parts of the transportation system.	Yes	No

Table 4. Examples of Resilience and Mitigation (continued)

Criteria	Example Measures	Example Indicators	Resilience	Mitigation
Social Systems (e.g., Health Care)(E)	The community has a local hospital with adequate capacity to serve the community's needs. There are enough doctors, health care providers, equipment, and supplies to provide a range of health care services.	a) Health care facilities have enough equipment and supplies to function for a minimum of 96 hours without resupply b) Health care facilities have a staffing strategy to ensure adequate personnel are available during an emergency c) Health care facilities have excess capacity to deal with a surge of patients and have a backup plan if capacity is exceeded.	Yes	No
Economic Systems(F)	Economic systems must be diverse and inclusive. The economy may be vulnerable to damage and disruption that causes direct costs, or indirect costs.	The community has a diverse range of job opportunities for various skill levels and is not overly dependent on one sector of the economy.	Yes	No
Individual Responsibility(G)	Individuals in the community care for themselves and others day-to-day and during emergency situations and can recover quickly after disaster.	Most individuals in the community have a social support system of family and friends, enabling them to get help during tough times without being overwhelmed by adverse circumstances.	Yes	No

Source: (A) Federal Emergency Management Agency 2016c; (B) Organization for Economic Cooperation and Development 2018; (C) Community Resilience Organizations "Community Resilience Assessment;" (D) Leobons Campos, and Bandeira 2019; (E) US Department of Health and Human Services "Climate Resilience Toolkit, Sustainable and Climate Resilient Health Care Facility Initiative, Element 4 Checklist." (F) Homeland Security 2016. "Draft Interagency Concept for Community Resilience Indicators and National-Level Measures;" (G) US Department of Health and Human Services "Public Health Emergency Preparedness: Individual Resilience."

Through a review of mitigation actions taken in Tennessee and other states, staff identified several examples in each of the natural disaster event categories for local governments to consider.[19] Although each of the examples identified can be effective, they represent neither an exhaustive nor a prescriptive list of the strategies that might be adopted. Individuals and communities need the flexibility to choose strategies that best align with their needs. See appendix D for a list of case studies highlighting actions communities have taken to mitigate natural disasters across the country.

[19] FEMA also provides a list of possible mitigation strategies; however, the agency acknowledges that these are only a starting point and that each community must assess its risks, resources, and priorities to develop and implement their individual mitigation action plan to reduce risk. Federal Emergency Management Agency 2013. Natural disaster event categories include flooding, heavy rain, and other hydrologic events, excessive heat and drought, cold and frozen precipitation, tornados, dust devils, funnel clouds, and straight winds, wildfires, and earthquakes.

Flooding, Heavy Rain, and Other Hydrologic Events

There are many strategies to reduce the costs of flooding, heavy rain, and other hydrologic events. Mitigation strategies for flooding that have been effective in Tennessee and other states include acquiring and demolishing property located in flood zones, limiting future development in flood zones—also known as floodplain management—and improving stormwater drainage. In Nashville, prior to a catastrophic flood in May of 2010, which caused more than $2 billion in property damage,[20] Metro Nashville Water Services purchased and demolished 90 homes that presumably would have been destroyed in the 2010 flood, according to the 2014 Audit of the Metro Water Services Home Buyout Program. The audit found that since the flood, over 200 homes have been acquired and demolished.[21] Local governments in other states have had similar success with acquisition programs. The city of Tulsa, Oklahoma, purchased and removed over 900 flood-prone properties, turning the land into greenways that help with flood control during major storms and provide recreational opportunities. The city's actions have also reduced negative economic effects caused by flooding.[22] Following its own catastrophic flood in 1997, the city of Fort Collins implemented regulations that "prohibited residential construction in . . . flood plains and required nonresidential development to be built at least two feet above projected flood levels."[23] When another potentially devastating flood occurred in 2013, only eight structures were damaged of the nearly 14,000 structures built in the city since the 1997 flood.

Mitigation strategies for flooding that have been effective in Tennessee and other states include acquiring and demolishing property located in flood zones, limiting future development in flood zones—also known as floodplain management—and improving stormwater drainage.

Stormwater drainage improvements help reduce runoff, flooding, and erosion caused by heavy rainfall.[24] For example, Nashville's Riverfront Park was designed in response to the 2010 flood and included more than three acres designed to drain stormwater runoff while removing debris and pollution, with an additional five acres draining to a 375,000-gallon cistern below the park that is then used to water the grass and plants. The project not only helps protect downtown from future flooding but also provides a public park and gathering space for residents and visitors.[25] In 2002, the Poarch Creek Indian Reservation in Alabama replaced and expanded a drainage system in one priority housing area to protect against frequent surface water flooding from severe storms. Since the $60,000 project was completed in 2002, the area has not experienced surface water flooding, and the system successfully managed eight inches of rain from Hurricane Ivan in 2004.[26]

Stormwater drainage improvements help reduce runoff, flooding, and erosion caused by heavy rainfall.

[20] Abkowitz, Camp, and Dundon 2020; Naturally Resilient Communities "Case Study: Riverfront Park, Nashville, Tennessee."
[21] Metropolitan Nashville Office of Internal Audit 2014.
[22] Naturally Resilient Communities 2017.
[23] Pew Charitable Trusts 2019.
[24] Federal Emergency Management Agency 2013.
[25] Naturally Resilient Communities "Case Study: Riverfront Park, Nashville, Tennessee."
[26] Federal Emergency Management Agency 2011.

Mitigation actions for extreme heat and dry or drought conditions primarily include planting trees and designing infrastructure to reduce urban heat—known as green infrastructure—water conservation, and using climate data for forecasting and planning.

Excessive Heat and Drought

Mitigation actions for extreme heat and dry or drought conditions primarily include planting trees and designing infrastructure to reduce urban heat—known as green infrastructure—water conservation and using climate data for forecasting and planning. Green infrastructure helps mitigate extreme heat by integrating the natural environment with engineered systems.[27] For example, Knoxville is planting more trees as part of its Street Tree Master Plan, resulting in several benefits, one of which is the cooling effect that trees produce, lowering city temperatures and reducing costs for energy consumers.[28] The 2011 City of Knoxville *Urban Forest Management Plan* found that every tree planted on Knoxville public property produces $83 in economic benefits.[29] Similarly, the city of Austin, Texas, responded to significantly higher urban temperatures compared to surrounding rural areas by adopting several mitigation strategies, including designing roofs, walls, and pavements to reflect sunlight and absorb less heat and sometimes incorporating vegetation, tree planting, and the development of structures to provide shade.[30]

In 2018, an interagency and intergovernmental working group studied water conservation during times of drought and published *TN H2O: Tennessee's Roadmap to Securing the Future of Our Water Resources.*

In 2018, then-Governor Haslam brought together an interagency and intergovernmental working group to study and report on water conservation during times of drought. The group published *TN H2O: Tennessee's Roadmap to Securing the Future of Our Water Resources*, which recommended several broad actions, including educating the public and policymakers on the value of water and conservation efforts and emphasizing the importance of collaboration in managing water resources.[31] For example, the *TN H2O* report recommended the state "better delineate the Memphis aquifer recharge area and better understand how recharge takes place within it." In areas of the state that rely on surface water, the report recommended developing "water budgets for Tennessee's major basins to forecast water needs and availability with reasonable scientific accuracy." Georgia is another example of a state making a water conservation effort. There, the Clayton County Water Authority constructed a surface flow wetland that increased water supply by allowing a shallow layer of water to flow across vegetation and filter it for reuse and storage. The mitigation strategy was implemented in 2004, and in both 2007 and 2008, the system was tested by a drought. The county water authority was able to provide needed water, and its reservoirs remained at or near capacity throughout the drought, while a large reservoir in a neighboring county experienced record lows.[32]

Water utilities and farmers are using other means of mitigating the effects of drought, including the use of climate data for planning and decision-

[27] US Environmental Protection Agency "Green Infrastructure for Climate Resiliency."
[28] Knoxville Knox County Metropolitan Planning Commission 2002.
[29] City of Knoxville 2011.
[30] Ray 2015.
[31] Tennessee Department of Environment and Conservation 2018.
[32] U.S. Climate Resilience Toolkit "Water Recycling in Clayton County, Georgia."

making. For example, utilities in Tampa, Florida, and Denver, Colorado, use climate forecasting tools to help plan months ahead for water supply and potential reductions, reducing uncertainty and making conservation, storage, and use decisions that demonstrate the importance of reliable climate data.[33] Using seasonal climate outlooks for temperature and precipitation helps farmers decide what crops to grow, when and where to plant, when to harvest, and when and how much to irrigate.[34]

Cold and Frozen Precipitation

Cold weather and frozen precipitation events, which include snow, frost, sleet, freezing fog, hail, and ice storms, can cause significant damage to electric utility poles and lines. Utilities are using mitigation strategies to protect their infrastructure and continue to provide power to their customers during and after ice storms. For example, in 2011, the Electric Power Board (EPB) of Chattanooga installed fiber-optic cable throughout its service area, in part to upgrade the communications equipment it uses to manage its electric system in an effort to reduce outages.[35] Three years later, during a three-day snowstorm, 76,000 customers lost power, but EPB's fiber-supported "Smart Grid automatically restored 40,000 customers within a few seconds or minutes."[36] Utilities are also replacing old poles with new, more durable poles. A review of areas in Kansas and Oklahoma with updated poles found that the new infrastructure suffered minimal or no damage during subsequent strong storms.[37]

Cold weather and frozen precipitation events, which include snow, frost, sleet, freezing fog, hail, and ice storms, can cause significant damage to electric utility poles and lines.

Tornados, Dust Devils, Funnel Clouds, and Straight Winds

The main strategies used to mitigate damaging winds focus on building and strengthening infrastructure, including adopting and enforcing building codes and constructing shelters. Communities in Tennessee and across the country are working to reduce the effects of tornados, dust devils, funnel clouds, and straight winds. In 2002, Lake County built a safe room in one of its schools that serves both the school and the broader community during severe storms. The room holds up to 600 people and provides "near-absolute protection" during tornados and severe wind events. According to the county schools' supervisor of facilities, the room is "probably the safest place in the county.".[38] Similar actions were taken in Creston, Iowa, where a community college constructed two dormitories with tornado safe rooms. During an EF2 tornado, students who took

Communities in Tennessee and across the country are working to reduce the effects of tornados, dust devils, funnel clouds, and straight winds.

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[33] U.S. Climate Resilience Toolkit "Climate Outlooks Help Water Supply Planning." U.S. Climate Resilience Toolkit. "Water Utility Plans for Climate Uncertainty."
[34] U.S. Climate Resilience Toolkit "Climate Outlooks Increase Farmer's Odds for Success." U.S. Climate Resilience Toolkit "Precise Soil, Climate, and Weather Data Help Dairy Optimize Water Use."
[35] Tennessee Emergency Management Agency 2018b.
[36] Electric Power Board 2014.
[37] National Rural Electric Cooperative Association 2018.
[38] Federal Emergency Management Agency 2002.

In 2019, the city of Pigeon Forge, Tennessee, received the National Wildfire Mitigation Award for providing a curbside brush removal program for residents to protect the community and reduce the risk of wildfires and for participating in the Ready, Set, Go! pilot program, which prepares residents and businesses for evacuations.

shelter in the safe rooms did not report any injuries or deaths; while three students who were not able to use the safe rooms sustained injuries.[39] The total project cost was $242,700, and the estimated potential losses, had the safe room not been available during the EF2 tornado, were $16.1 million. Some local governments are subsidizing the cost of safe rooms to encourage people to build them. In Cooke County, Texas, the local governments implemented a residential rebate program to incentivize homeowners to build tornado shelters and safe rooms—150 residents benefited and now have the opportunity to use them during extreme weather events.[40]

Constructing buildings to withstand tornados is commonly done to protect infrastructure and save lives during strong wind events. Williamson County is an example of a local government that strengthened its emergency operations building infrastructure to withstand several types of natural disasters. The Williamson County Public Safety Center broke ground in 2014 and was designed and built to withstand an EF5 tornado, which can produce winds up to 250 miles per hour.[41] The building, which became operational in 2016, is an emergency operations center and can house several public and private entities during a crisis. Some local governments in other states have enacted stronger residential building codes after catastrophic tornados and hurricanes. For example, a city that is frequently hit by tornados, Moore, Oklahoma, adopted residential building codes in 2013 that required building be constructed to withstand an EF2 tornado.[42] In 2015, Moore was hit by an EF2 tornado, and buildings constructed according to the updated cost performed as expected with only minor damage.[43]

Wildfires

Mitigation strategies for wildfires focus on maintaining defensible space around infrastructure, which at times includes educating property owners on brush removal and building with fire-resistant materials. Three years after the 2016 Great Smoky Mountain wildfires, which resulted in 14 deaths and $2 billion in property damage,[44] the city of Pigeon Forge, Tennessee, received the National Wildfire Mitigation Award for its efforts. These included providing a curbside brush removal program for residents to protect the community and reduce the risk of wildfires and participating in the Ready, Set, Go! pilot program, which prepares residents and businesses

[39] Federal Emergency Management Agency 2017b.
[40] Federal Emergency Management Agency 2015g.
[41] Interview with Rogers Anderson, mayor, Williamson County, Bill Jorgenson, director, Williamson County Public Safety Administration, and Todd Horton, director, Williamson County Emergency Management Agency, August 26, 2020, and Williamson County Office of Public Safety "Public Safety Center."
[42] Brandes 2014; McCleland 2018.
[43] Ramseyer, Floyd, Holliday 2017.
[44] National Park Service 2016.

for evacuations.[45] Other states have also implemented mitigation strategies to protect infrastructure by clearing land in order to maintain defensible spaces. In Colorado, a state with a history of large wildfires, a move by the US Forest Service "to cut down nearby vegetation and trees killed by beetles made all the difference for firefighters battling [the 2018 Buffalo Fire in Silverthorne, Colorado]." Between 200 and 300 homes were spared during the Buffalo Fire, because the fire did not have the fuel needed to advance on nearby subdivisions.[46] In the state of Washington, landowners and government agencies are working together to plan and manage forests and wildfire-risk by treating and harvesting timber and setting controlled fires.[47] These efforts have not only reduced the risk of catastrophic fires and improved the safety of nearby communities, they have also created jobs, generated revenue, and contributed to economic expansion.

Earthquakes

Most mitigation strategies for earthquakes focus on practice earthquake drills (to prepare the community), stronger building standards, and retrofitting buildings and other infrastructure to minimize damage. In West Tennessee, where the New Madrid fault is located, TEMA hosts the state's annual participation in the Great Central US ShakeOut earthquake drill, which is open and free to the public.[48] Businesses, communities, individuals, organizations, and schools learn how to prepare and respond so as to reduce damage and injuries from a large earthquake in the region. Another example from Tennessee are the efforts of the Memphis Light, Gas and Water utility, which has invested over $80 million in earthquake mitigation, including buying and retrofitting an existing building to house its Customer Care, Commercial Resource and Information Technology Centers in order to maintain business continuity.[49] Retrofitting buildings is a strategy also used in other parts of the country including California, which mostly focuses on upgrading and retrofitting buildings both on private and public property and adopting and enforcing stronger building codes at the city and state levels.[50] One southeastern example comes from Charleston, South Carolina, where, similar to Tennessee, they experienced a 7.2 magnitude earthquake in 1886. In 2010, a historic theater building was retrofitted during a major renovation to avoid a collapse in a future catastrophic earthquake.[51]

Most mitigation strategies for earthquakes focus on practice earthquake drills (to prepare the community), stronger building standards, and retrofitting buildings and other infrastructure to minimize damage.

[45] Tennessee Department of Agriculture 2019.
[46] Daley 2018.
[47] Federal Emergency Management Agency 2019.
[48] Tennessee Emergency Management Agency 2018a.
[49] Memphis Light, Gas and Water 2011.
[50] California Seismic Safety Commission 2020. See also https://ssc.ca.gov/ for more information on California earthquake preparedness.
[51] Federal Emergency Management Agency 2016c.

In Tennessee, state agencies have many programs to mitigate hazards and improve community resilience.

Several state agencies in Tennessee play a role in building community resilience.

Several state agencies in Tennessee play a role in building community resilience. For example, the Tennessee Department of Health builds resilience across the state through the Emergency Preparedness program, which includes assembling a team of nurses to respond to emergencies and distribute medicine and medical supplies in the event of a disaster.[52] The Tennessee Department of Transportation (TDOT) also promotes resilience in several ways, including both the development of the 2015 report *Assessing the Vulnerability of Tennessee Transportation Assets to Extreme Weather* and ongoing mitigation efforts to reduce the effects caused by transportation projects.[53] And the Tennessee Department of Agriculture (TDA) is working to improve resilience in communities by mitigating the effects of drought, erosion, insects, and diseases on agricultural activities.[54] The TDA also administers the FIREWISE program, which assists communities with development and redevelopment strategies that prevent wildfires.[55] Several more agencies play an important role in building resilience to natural disasters, but three agencies—TEMA, the Tennessee Department of Environment and Conservation (TDEC), and the Tennessee Department of Economic and Community Development (ECD)—play a broader role in helping communities prepare for, withstand, and rapidly recover from such events.

Tennessee Emergency Management Agency

TEMA is building resilience by developing of a state hazard mitigation plan, assisting local governments in developing their own hazard mitigation plans, and by implementing the mitigation strategies identified by such plans so as to reduce the loss of life and destruction of property. Every five years, hazard mitigation plans must be reviewed by TEMA and approved by FEMA in order to be eligible for assistance through the hazard mitigation grant program, the pre-disaster mitigation grant program, and the flood mitigation assistance program. The state's latest hazard mitigation plan received FEMA approval in 2018, but TEMA is developing an enhanced hazard mitigation plan (ESMP), which requires integrating planning across agencies, demonstrating a comprehensive approach to mitigation,

[52] Interview with John G. Benitez, medical director, Emergency Preparedness, Tennessee Department of Health, May 24, 2019; and Tennessee Department of Health "CEDEP Emergency Preparedness."

[53] Interview with Alan Jones, Senior Research Analyst, Long Range Planning Division, Tennessee Department of Transportation, June 5, 2019; and Tennessee Department of Transportation 2015.

[54] See the Tennessee Department of Agriculture website for a variety of services offered to protect agriculture.

[55] Burn Safe TN "Welcome to the Firewise Tennessee Communities Program."

and making states eligible for additional funding after a disaster.[56] There are 15 states with FEMA-approved ESMPs.[57]

TEMA has three regional planners who help local governments identify risks and opportunities, find funding sources, and recognize needs when creating hazard mitigation plans. TEMA also recently launched a web-based dashboard as a resource for local governments, showing approved and proposed hazard mitigation projects by county. Local governments may also apply for FEMA planning grants to assist with hazard mitigation plans. Developing these plans involves

- analyzing both weather and seismological data to assess risks;
- identifying vulnerabilities related to these risks that could result in loss of life, as well as damage to critical infrastructure and other property; and
- adopting preferred strategies to reduce the effects of and speed recovery from future disasters.

Most Tennessee counties have FEMA-approved hazard mitigation plans. Of Tennessee's 95 counties, 75 have received FEMA approval for their plans, seven are revising or reviewing their plans, and 13 have either not submitted a plan or their plan has lapsed.[58] Of those 13, some counties may have begun work on their plan, such as Loudon County, Grainger County, and Union County.[59] TEMA regularly updates an online map indicating county hazard mitigation plan adoption status.[60]

TEMA also takes a leadership role in the Tennessee Silver Jackets organization, which focuses on bringing together multiple state, federal, and local agencies to learn from one another and apply their knowledge to reduce the risk of flooding and other natural disasters. Participating agencies in Tennessee include ECD, TDEC, TDOT, TEMA, and the Tennessee Wildlife Resources Agency. In 2016, the Tennessee Silver

The Tennessee Emergency Management Agency and most Tennessee counties have developed FEMA-approved hazard mitigation plans.

[56] Tennessee Emergency Management Agency 2018b. Email correspondence with Patrick Sheehan, director, Tennessee Emergency Management Agency, December 16, 2019. According to Title 44, Section 201.5 of the Code of Federal Regulation, "in order for a State to be eligible for the 20 percent HMGP funding, the Enhanced State Mitigation plan must be approved by FEMA within the five years prior to the current major disaster declaration."
[57] California, Colorado, Florida, Georgia, Iowa, Kentucky, Missouri, Nevada, North Carolina, North Dakota, Ohio, Oregon, South Dakota, Washington, and Wisconsin. See Federal Emergency Management Agency "Hazard Mitigation Plan Status."
[58] Tennessee Emergency Management Agency "Local and County Mitigation Planning." See the following for a map of Tennessee counties with FEMA approved hazard mitigation plans https://www.tn.gov/tema/emergency-community/mitigation/local-and-county-mitigation-planning.html.
[59] Interview with Buddy Bradshaw, mayor, Loudon County, Tennessee and Daryl Smith, EMA director, Loudon County, on August 1, 2019; Email correspondence with Joshua D. Gardner, district coordinator, Tennessee Emergency Management Agency, April 3, 2020.
[60] Tennessee Emergency Management Agency "Local and County Mitigation Planning." See the following for a map of Tennessee counties with FEMA approved hazard mitigation plans https://www.tn.gov/tema/emergency-community/mitigation/local-and-county-mitigation-planning.html.

Jackets published the Tennessee Post Disaster Guide to help communities in Tennessee prepare for future natural disasters and provide guidance on available resources for recovery to emergency management personnel.[61]

Beyond the programs offered to individuals and communities in Tennessee, there are additional actions that individuals can take to prepare themselves and their families for natural catastrophes and extreme weather events. The United States Department of Homeland Security (USDHS) and TEMA both offer guidance for individuals and families, which includes recommendations for food and water storage, what supplies to have on hand, and how to plan for natural disasters, along with many other helpful guidelines. For example, the USDHS launched the Ready Campaign in 2003, which was "designed to educate and empower the American people to prepare for, respond to and mitigate emergencies, including natural and man-made disasters."[62] It provides information for over 30 disasters and emergencies, affords opportunities for individuals to get involved in training programs, and makes information available to help families plan for future events. Similarly, TEMA provides resources for individuals and families to help prepare for threats in Tennessee, including a checklist of what is needed for an emergency kit (see appendix C).[63] Moreover, during the COVID-19 pandemic, the state of Tennessee continues to make resources available for individuals, families, and businesses to keep people safe, healthy, and financially secure.[64]

The Tennessee Department of Economic and Community Development is collaborating with local, state, and federal government agency partners to convene strategic planning and community engagement sessions in communities across the state to explore local solutions for building community resilience.

Tennessee Department of Environment and Conservation

Like TEMA, TDEC is also building resilience in several ways. TDEC's resiliency efforts focus on energy and environmental resources, which aligns with TDEC's mission to enhance the quality of life for citizens of Tennessee and be stewards of our natural environment. TDEC's Office of Policy and Sustainable Practices (OPSP) administers many educational, technical assistance, and recognition programs, including the Sustainable Resilience for Communities program and the State Revolving Fund (SRF), and has considered piloting a program known as the Tennessee Citizens Resilience Academy (TCRA).

During the spring of 2019, TDEC-OPSP launched the Sustainable Resilience for Communities program, which provided tailored technical assistance through strategic planning and community engagement sessions. All Tennessee communities were invited to apply for the program, and seven were selected to participate. The program participants included the Town of Stanton, the Town of Spring City, Lake County, Humphreys

[61] Tennessee Silver Jackets 2014. See also Silver Jackets "Tennessee" and Tennessee Silver Jackets 2016.
[62] Ready "About the Ready Campaign."
[63] Tennessee Emergency Management Agency "Prepare."
[64] State of Tennessee "COVID-19 Resources."

County, Morgan County, Cocke County, and Montgomery County. Each jurisdiction identified its priorities, which collectively included solid waste management, agricultural best management practices, economic development, transportation infrastructure, flood mitigation, stormwater management, water and wastewater infrastructure, sustainable growth, and hazard mitigation. TDEC-OPSP will work with these communities through the summer of 2020 to improve public health, economic growth, water quality, operational capacity of utilities, and resilience to extreme weather and flooding.[65]

TDEC is using the SRF program as a springboard to strengthen community resilience. For example, the SRF program promotes resilient, innovative, and green practices through EPA Capitalization Grants, which are used to finance clean water and drinking water projects. Furthermore, the SRF program is piloting efforts to increase awareness regarding projects that are attempting to solve issues related to water loss, flood resilience, asset management, and more. Two such pilots are currently underway: water-loss remediation in Oliver Springs and flood resilience planning and design in Dyersburg.[66]

TDEC has considered pursuing a Tennessee Citizens Resilience Academy pilot program, which would involve collaboration with higher education and community-based organizations. The program will train community leaders in participating cities on the scientific, social, economic, and ecological components of limiting the negative effects of natural disasters, allowing them to both adapt to changing conditions and prepare for, withstand, and rapidly recover from disruptions to everyday life. The expectation is that best-practices and lessons learned during the initial training will be shared with other Tennessee communities during future training events, which, by engaging proven strategies, can build resilience across the state.[67]

The Tennessee Department of Environment and Conservation has considered pursuing a Tennessee Citizens Resilience Academy pilot program, which would involve collaboration with higher education and community-based organizations.

TDEC is also working with the University of Memphis and Vanderbilt University to develop a community vulnerability assessment that will grade communities using a resilience index. This will include sub-indices focused on the specific criteria important to different state and federal agencies, which is needed to facilitate grant applications and other specific needs. The vulnerability tool should be complete by 2022.[68]

[65] Ibid.

[66] Email correspondence with Kendra Abkowitz, director, Tennessee Department of Environment and Conservation, Office of Policy and Sustainable Practices, December 11, 2019. See also Tennessee Department of Environment and Conservation "State Revolving Fund Program."

[67] Email correspondence from Kendra Abkowitz, director, Tennessee Department of Environment and Conservation, Office of Policy and Sustainable Practices, December 11, 2019; and Tennessee Department of Environment and Conservation "Office of Policy and Sustainable Practices."

[68] Email correspondence with Kendra Abkowitz, director, Tennessee Department of Environment and Conservation, Office of Policy and Sustainable Practices, December 11, 2019.

Staff from both the Department of Economic and Community Development and the Tennessee Department of Environment and Conservation have advocated for a permanent council to promote interagency coordination; identifying gaps and minimizing redundant efforts to ensure efficient use of resources.

Tennessee Department of Economic and Community Development

ECD is collaborating with TEMA, TDEC, the University of Memphis, Vanderbilt University, and the Delta Regional Authority on the Rural by Nature initiative, which aims to build resilience within rural areas of West Tennessee using $44.5 million in funding through the US Department of Housing and Urban Development's National Disaster Resilience Competition grant that was awarded in 2016.[69] Tennessee was eligible because of a major flood that occurred along the Mississippi River in April 2011 during which 601 residences were destroyed and $22.6 million in damage accrued.[70] Projects include wastewater system improvements, installation of a levee pump station, flood control, creek chute restoration, and the converting of land currently in a floodplain to wetlands and greenways for biking or hiking. The initiative also includes the development of an online tool for project management and community planning, which tracks the status of projects by generating custom progress reports and—by adjusting variables such as housing, employment, education or other socioeconomic variables to find the most cost-effective options for each community— can be used by local leaders to see the effect of different resiliency strategies.[71]

In 2017, ECD formed an interagency resilience council to engage stakeholders, establish partnerships with other agencies through collaboration, and meet certain grant requirements.[72] Although this resilience council was disbanded, some from both ECD and TDEC have advocated for reconstituting a permanent council to promote interagency coordination—identifying gaps and minimizing redundant efforts to ensure efficient use of resources.[73] At least six other states have established a similar council in the last seven years.[74] For example, in late 2019, the New Jersey Interagency Council on Climate Resilience, which consists of representatives from 10 state agencies and several quasi-governmental agencies, was created to "develop consistent statewide policies and actions and establish both short and long-term action plans."[75] Though data are limited when it comes to determining how effective interagency resilience

[69] Interview with Kent Archer, grants director, Brooxie Carlton, deputy assistant commissioner of community and rural development, and Tracey Davis, grants coordinator, Tennessee Department of Economic and Community Development, June 19, 2019. See also Tennessee Department of Economic and Community Development "Disaster CDBG Program." Certain counties became eligible for the grant after severe storms and flooding in 2011.
[70] Federal Emergency Management Agency 2011b.
[71] Ibid.
[72] Interview with Kent Archer, grants director, Tennessee Department of Economic and Community Development, June 19, 2019.
[73] Ibid.
[74] New Hampshire Coastal Risk and Hazards Commission 2016, New Jersey Executive Order 89, Nevada Executive Order 2018-4, Rhode Island Executive Order No. 17-10, Virginia Executive Order 24, and Washington State Senate Bill 5106 2019-2020.
[75] New Jersey Executive Order 89 and New Jersey Department of Environmental Protection "Interagency Council on Climate Change."

councils are at reducing the cost of natural disasters, working across state agencies in a collaborative effort to create a vision for resilience in the state is the overarching goal of these councils and that objective was met in all six states. Moreover, the National Association of Counties explains the benefits of interdepartmental collaboration: it "helps to promote consistency within and concurrency between plans while also increasing the probability of the resilience plan's implementation."[76] While TEMA supports interagency collaboration and partnerships, it has expressed reservations regarding the need to create a new collaborative body. TEMA says it already "performs interagency coordination to ready the state for disaster and to reduce the effects of disruptions on daily life" and that it has "coordinated the investment in building resilient communities for more than four decades."[77]

ECD staff involved in the former resilience council say that if it were reestablished, there are improvements that could be made to the process, including having a resilience champion to lead the council's resilience efforts and advocate on the council's behalf.[78] Seven other states, including three with a resilience council, have taken the approach of appointing a Chief Resilience Officer (CRO) to collaborate with various agencies, build a shared vision on resilience, and bring together stakeholders for collaboration and coordination of resources.[79] For example, in North Carolina, there is a CRO and two deputy CROs that focus on building relationships across agencies, including those that may not normally concern themselves with resilience and the messaging needed to holistically plan for future disasters.[80]

Tennessee communities are already engaging in resilience efforts in addition to hazard mitigation.

Some Tennessee local governments are organizing collaborative councils to build resilience in their communities.

Tennessee communities are already engaging in resilience efforts, in addition to hazard mitigation, to the extent that technical, financial, and administrative resources allow. Collaborative resilience initiatives have taken different forms in Tennessee, and the efforts of the two local jurisdictions—Shelby County and the City of Chattanooga—highlighted below illustrate some of the different approaches to building community resilience.

[76] National Association of Counties 2019.
[77] Email correspondence with Patrick Sheehan, director, Tennessee Emergency Management Agency, December 16, 2019.
[78] Panel discussion of community resilience, TACIR, January 17, 2020.
[79] Florida Executive Order No. 19-12, Louisiana Office of the Governor 2020, New Jersey Executive Order No. 89, Oregon Chapter 762, (2015 Laws), North Carolina Executive Order No. 80, Rhode Island Executive Order No. 17-10, and Virginia Executive Order No. 24. South Carolina is in the process of establishing a CRO. See State of South Carolina 2020.
[80] Amanda Martin, deputy chief resilience officer, State of North Carolina, November 14, 2019.

The Memphis-Shelby County Office of Sustainability, located within the Department of Planning and Development, has worked collaboratively to improve community resilience through two notable grants from the US Department of Housing and Urban Development.

The Memphis-Shelby County Office of Sustainability, located within the Department of Planning and Development, has worked collaboratively to improve community resilience through two notable grants from the US Department of Housing and Urban Development. The first was the 2011 Sustainable Communities Regional Planning grant, which designated $2.6 million to develop the Greenprint 2015/2040 Plan. The regional plan allowed for the building of parks, greenways, bike trails, and walking paths, byways, waterways, conservation lands, natural areas, wildlife management areas, open space areas, community gardens, and stormwater management areas for parts of Tennessee, Mississippi, and Arkansas.[81] Anticipated resilience benefits from the Greenprint Plan included the conservation of land that was prone to flooding, improved health, enhanced community connectedness, and economic benefits associated with attracting new businesses. The Shelby County Resilience Council was established to formalize the development and implementation of the plan.[82] The second grant was awarded in January of 2016. Shelby County was awarded $60 million as part of the National Disaster Resilience Competition grant, which would allow for several watershed and wetland restoration projects. For example, one such project in the City of Millington along Big Creek, where a new floodplain is being created for floodwaters to bypass nearby communities. The project also creates a new wetland for the water fill without posing a danger to people or infrastructure. When the land is not flooded, it will be accessible to the community through new greenway trails, walking trails, and ball parks. The grant was also used to develop the Mid-South Regional Resilience Master Plan, which identifies "resilience opportunities that can only be achieved when planning at a regional scale, such as watershed or aquifer management."[83]

Like Shelby County, the City of Chattanooga is planning to produce a regional resilience plan. In 2020, the city requested proposals for a regional resiliency plan, which will include 18 other mayors and county executives. According to the Chattanooga State of the City 2019 address, the plan will "serve as a platform for us to work together on the more far-reaching effects of climate change, like the loss of cultural resources when an area is devastated; support for businesses seeking to become more resilient; and being smarter about the impact development may have on our climate preparedness."[84] The vendor will work closely with an interagency resiliency steering committee to develop a community resilience strategy that reflects local priorities.[85]

[81] Shelby County "Greenprint 2015/2040."
[82] Shelby County 2017.
[83] Resilient Shelby 2019.
[84] City of Chattanooga 2019b.
[85] City of Chattanooga 2019a.

The resilience of a community is dependent on its economy recovering after natural disasters and other devastating events.

When natural disasters occur, it may disrupt the economy, destroy businesses and contribute to job loss. Several state agencies provide support to communities to help bolster economic resilience for sectors of the economy. For example, the Tennessee Department of Insurance and Commerce regulates insurance companies to ensure that they can pay claims when a natural disaster or other serious disruption occurs,[86] the DOA provides resources and funding for farmers to help develop their businesses,[87] and the Tennessee Department of Tourist Development works with those affected by natural disasters to develop marketing plans that can restore their tourism economy.[88]

Several state agencies provide support to communities to help bolster economic resilience for sectors of the economy.

According to the US Economic Development Agency, the best way to increase economic resilience, so a community can quickly recover from a natural disaster, is through economic diversification.[89] In Tennessee, ECD is accomplishing this in several ways, including the work of the economic development districts, which are working to attract a variety of businesses to their community. For example, the Southeast Development District explains that "attracting a broader class of industries and training workers with new skills will help with economic diversification and make our region more resilient in the long run."[90] Similarly, the Upper Cumberland Development District recommends that "economic development leaders should proactively work to promote employment across multiple sectors by attracting industries outside of manufacturing. Diversification of the region's industrial clusters will decrease potential upset from loss of large employers in local communities and create more resiliency within the Upper Cumberland."[91] And the East Tennessee Development District is providing resources for the creation of local small businesses, collaborating with colleges and universities on education and workforce development, and working to prepare a high-speed broadband infrastructure development plan for Campbell County.[92]

For the individual businesses affected by disasters, there are resources available to assist in preparation and recovery. For example, during the COVID-19 pandemic, the University of Tennessee Center for Industrial

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86 Rachel Jrade-Rice, director of insurance, Tennessee Department of Insurance and Commerce, June 27, 2019.
87 Tennessee Department of Agriculture, "Business Development Division."
88 Pete Rosenboro, assistant commissioner, Amanda Murphy, director of communications, and Susan McMahon, legislative liaison, Tennessee Department of Tourist Development, September 13, 2019.
89 US Economic Development Administration "Economic Resilience."
90 Southeast Tennessee Development District 2018.
91 Upper Cumberland Development District 2017.
92 East Tennessee Development District 2018.

Services, Institute for Public Service is providing continuity planning support for businesses and guidance for managing supply chain disruptions.[93] When the disaster has passed, the US Small Business Administration Disaster Loan program offers low-interest loans that can be used to replace "real estate, personal property, machinery and equipment, and inventory and business assets."[94]

Other states are taking steps to improve community resilience.

Resilience efforts across the country are varied and reflect the unique needs of the jurisdictions implementing them.

As evidenced in Tennessee, resilience efforts across the country are varied and reflect the unique needs of the jurisdictions implementing them. Since the establishment of the Colorado Resiliency Office in 2013, several states have also acted to support local communities and make their state governments more resilient and. The Colorado Resiliency Office developed a framework to guide its resilience policy and works with local governments to help them do the same.[95] In 2020, West Virginia passed Senate Bill 586, which created the State Resilience Office to manage the Disaster Recovery Trust Fund, and established a board to assist the office in its duties. Like Tennessee, universities in some states are central to the state's resilience efforts. For example, the Institute for a Disaster Resilient Texas at Texas A&M University was established in 2019 to create and maintain web-based data analytics tools, provide evidence-based information and solutions to state and local partners, and communicate comprehensive flood-related information to support disaster planning, mitigation, response, and recovery by the state, its political subdivisions, and the public.[96]

Nearly every state has some form of climate office that provides services similar to the Institute for Disaster Resilient Texas. State climate offices generally provide weather observations and data collection, summarize and communicate weather and climate information to the community, demonstrate the value of climate information and how it can be used in the decision-making process, perform climate risk assessments and weather event evaluations, and conduct climate research, diagnosis, and projections.[97] East Tennessee State University and other public universities have partnered to provide many of these services in Tennessee.[98]

[93] University of Tennessee "COVID-19: Business Continuity Planning" and University of Tennessee "Importance of Supply Chain Distribution Planning."
[94] US Small Business Administration "Disaster Loan Assistance."
[95] Colorado Resiliency Office 2015.
[96] Texas House Bill 2345, 2019.
[97] Robinson 2004.
[98] Email correspondence with Andrew Joyner, associate professor, East Tennessee State University, December 6, 2019.

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Appendix A: House Bill 1120

House State Committee 1

Amendment No. 1 to HB1120

Keisling
Signature of Sponsor

AMEND Senate Bill No. 1114 House Bill No. 1120*

by deleting all language after the enacting clause and substituting instead the following:

SECTION 1. Tennessee Code Annotated, Title 4, Chapter 1, Part 4, is amended by adding the following language as a new section:

(a) There is created the state government advisory task force on extreme weather, natural catastrophes, and community resilience.

(b) The task force shall consist of twenty-four (24) members as follows:

(1) One (1) member appointed by the speaker of the house of representatives;

(2) One (1) member appointed by the speaker of the senate;

(3) One (1) representative from the department of agriculture appointed by the commissioner of agriculture;

(4) One (1) representative from the department of health appointed by the commissioner of health;

(5) One (1) representative from the department of environment and conservation appointed by the commissioner of environment and conservation;

(6) One (1) representative from the department of commerce and insurance appointed by the commissioner of commerce and insurance;

(7) One (1) representative from the department of finance and administration appointed by the commissioner of finance and administration;

(8) One (1) representative from the department of human services appointed by the commissioner of human services;

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House State Committee 1

Amendment No. <u>1 to HB1120</u>

<u>Keisling</u>
Signature of Sponsor

AMEND Senate Bill No. 1114 House Bill No. 1120*

(9) One (1) representative from the department of safety and homeland security appointed by the commissioner of safety and homeland security;

(10) One (1) representative from the department of tourist development appointed by the commissioner of tourist development;

(11) One (1) representative from the department of transportation appointed by the commissioner of transportation;

(12) One (1) representative from the department of economic and community development appointed by the commissioner of economic and community development;

(13) One (1) representative from the department of education appointed by the commissioner of education;

(14) The executive director of the Tennessee housing development agency;

(15) The director of the Tennessee emergency management agency or alternate designee appointed by the adjutant general to act as a representative of the department of military;

(16) One (1) researcher involved in the scientific program of an institute of higher learning in this state who specializes in the area of meteorology or climatology, to be appointed by the speaker of the house of representatives;

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(17) One (1) researcher involved in the program of an institute of higher learning in this state who specializes in the area of extreme weather vulnerability assessment, to be appointed by the speaker of the senate;

(18) One (1) county mayor appointed by the speaker of the senate;

(19) One (1) city mayor appointed by the speaker of the house of representatives;

(20) One (1) Tennessee business representative appointed by the speaker of the senate;

(21) One (1) public member appointed by the speaker of the house of representatives;

(22) One (1) representative from the U.S. Army Corps of Engineers;

(23) One (1) representative from the Tennessee Valley Authority; and

(24) One (1) director of a development district selected by the commissioner of environment and conservation.

(c)

(1) The task force shall:

(A) Assess the historical, present, and projected occurrence of natural catastrophes and extreme weather events affecting this state, which include, but are not limited to, floods, wildfires, extreme temperatures, heat waves, severe storms, blizzards, and drought;

(B) Examine present and projected losses associated with the occurrence of extreme weather events and other natural catastrophes affecting this state, and land management practices that potentiate extreme weather events and other natural catastrophes, resulting in increased flooding, wildfires, and drought conditions;

(C) Develop recommendations to address vulnerabilities and adverse impacts in this state associated with the occurrence of extreme weather events and other natural catastrophes, including, but not limited to, adverse impacts in this state associated with any projections related to the occurrence of extreme weather events and other natural catastrophes, and any barriers to the state's provision of services and resources and economic prosperity due to the occurrence of such events; and

(D) Develop recommendations to increase the state's resilience to extreme weather events and other natural catastrophes in this state.

(2) The task force shall include an examination of the following in its assessment and recommendations:

(A) The economic impact to the state of any projections related to the occurrence of extreme weather events and other natural catastrophes, including, but not limited to, the impact on forestry, agriculture, water and other natural resources, food systems, zoning, wildlife, hunting, infrastructure, transportation, economic productivity and security, education, and public health;

(B) Proposals to prepare for and reduce the adverse impacts associated with extreme weather events and other natural catastrophes that result in loss of life, property, or otherwise impact the economy of the state; and to increase the state's resiliency to future occurrence of such events in this state;

(C) Legislative remedies for consideration by the general assembly;

(D) Necessary state policies or responses, including directions for the provision of clear and coordinated services and support to reduce the impact of natural catastrophes and extreme weather events and increase resiliency in this state; and

(E) Potential financial resources available for increasing resiliency throughout the state.

(d)

(1) Members of the task force shall serve without compensation or reimbursement for any expenses incurred while participating in the business of the task force.

(2) Vacancies among the members of the task force must be filled in the same manner as in the original selection of members.

(e) The selection of members of the task force should be inclusive and reflect the racial, gender, geographic, urban, rural, and economic diversity of the state.

(f) The task force shall be co-chaired by the representative of the department of environment and conservation and the director of the Tennessee emergency management agency. The task force shall meet quarterly and the co-chairs shall call the first meeting of the task force.

(g) The task force must agree upon its findings and recommendations by a majority vote of its total membership. A majority of the members constitutes a quorum.

(h) The task force is administratively attached to the department of environment and conservation, which shall provide necessary project management and administrative support at the request of the task force. The co-chairs of the task force may call on appropriate state agencies for reasonable assistance in the work of the task force.

(i) The task force shall hold public meetings and utilize technological means, such as webcasts, to gather feedback on the recommendations from the general public

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and from persons and families affected by extreme weather and other natural catastrophes in this state.

(j) The creation of this task force does not alter or inhibit the Tennessee emergency management agency's functions as authorized under title 58.

(k)

(1) The taskforce shall submit a report of its findings and recommendations to the general assembly no later than July 1, 2020.

(2) This section is repealed on July 1, 2020.

SECTION 2. This act shall take effect upon becoming a law, the public welfare requiring it.

Appendix B: Natural Hazard Community Resilience in Tennessee

3 Sigma Consultants, LLC

Natural Hazard Community Resilience in Tennessee

Final Report

January, 2020

prepared for:
Tennessee Advisory Commission on
Intergovernmental Relations (TACIR)

prepared by:
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Janey Camp
Leah Dundon

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B/C – Benefit/Cost Ratio

CMIP – Coupled Model Intercomparison Project

EDA – Economic Development Administration

FEMA – Federal Emergency Management Agency

GHG – Greenhouse Gas

HUD – Department of Housing and Urban Development

HVAC – Heating, Ventilation and Air Conditioning

IBC – International Building Code

IPCC – Intergovernmental Panel on Climate Change

IRC – International Residential Code

IWUIC – International Wildland-Urban Interface Code

NCA – National Climate Assessment

NIBS – National Institute of Building Sciences

NOAA – National Oceanographic and Atmospheric Administration

NWS – National Weather Service

PGV – Peak Ground Velocity

PTSD – Post-Traumatic Stress Disorder

RCP – Representative Concentration Pathway

ROI – Return on Investment

TACIR – Tennessee Advisory Committee on Intergovernmental Relations

TDEC – Tennessee Department of Environment and Conservation

TDOT – Tennessee Department of Transportation

USGS – United States Geological Survey

DISCLAIMER

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EXECUTIVE SUMMARY

Introduction

At the request of the Tennessee General Assembly, the Tennessee Advisory Commission on Intergovernmental Relations (TACIR) has been directed to perform a study to assess the current status of community resilience plans to extreme weather events and other natural catastrophes (i.e., earthquakes), hereafter referred to as "natural hazards". The National Research Council defines resilience as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events[1]."

In support of this effort, an initiative was undertaken to identify different natural hazard risks across the State of Tennessee, and to determine the cost of action and inaction related to community resiliency. The geographical region of interest was to provide assessments at the county, regional and state levels, as appropriate. This report describes the results of that effort.

Study Approach

The study was conducted utilizing the conceptual framework displayed in Figure E.1.

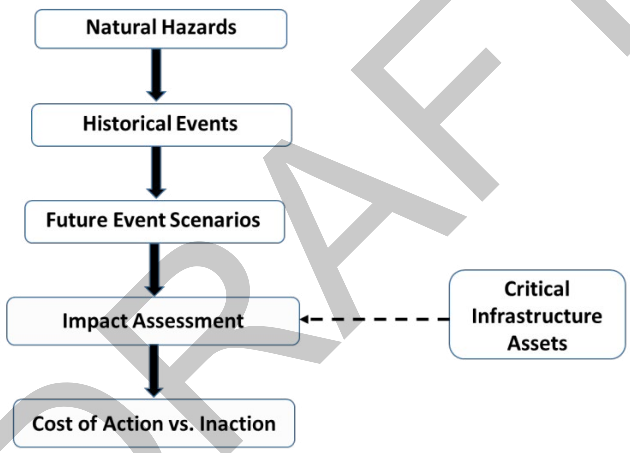

Figure E.1 – Study Approach

The first step in this process involved the identification of natural hazards posing a threat to the State. Due to the varying weather experienced in Tennessee as well as earthquake hazard, separate geographical regions were established to represent this effect.

Historical event data on the frequency and consequence of prior natural hazard events were utilized to establish existing conditions and to serve as a baseline for comparative analysis of existing natural hazard risk and what may be anticipated in the future.

A time horizon of the period from 2035-2055 was selected to identify and assess future event scenarios. This time frame was viewed as representative of the long term planning horizon for resilience actions to be undertaken, recognizing traditional planning and funding processes. The type and likelihood of future event scenarios utilized trend analysis of historical event data, in addition to future climate and earthquake projections. The impacts of future event scenarios recognized the location and types of critical infrastructure

[1] National Research Council (NRC). (2012). Disaster Resilience: A National Imperative. National Academies Press. Washington, DC.

upon which communities would be dependent on their availability and accessibility during a disaster, as well as changes in population demographics.

A variety of potential resilience strategies are available for consideration to reduce the negative consequences associated with future natural hazard events[2]. These strategies are targeted at various impacts and have different financial and implementation requirements. Investment in these strategies represents an explicit action to strengthen resilience, as opposed to a do-nothing, inaction decision. The benefits from disaster cost savings relative to the cost of implementing resilience initiatives can form the basis for assessing whether/how to proceed.

<u>Geographic Regions</u>
Tennessee comprises several distinct geographical regions, whose varied topography leads to diverse climate conditions that produce various forms of extreme weather. The likelihood of seismic activity also varies across the State. For these reasons, for the purposes of this study, the State was partitioned into the following six geographic regions (see Figure E.2):

- Cumberland Plateau
- Highland Rim
- Inner Coastal and Alluvial Plain
- Nashville Basin
- Ridge and Valley
- Unaka-Smoky Mountains

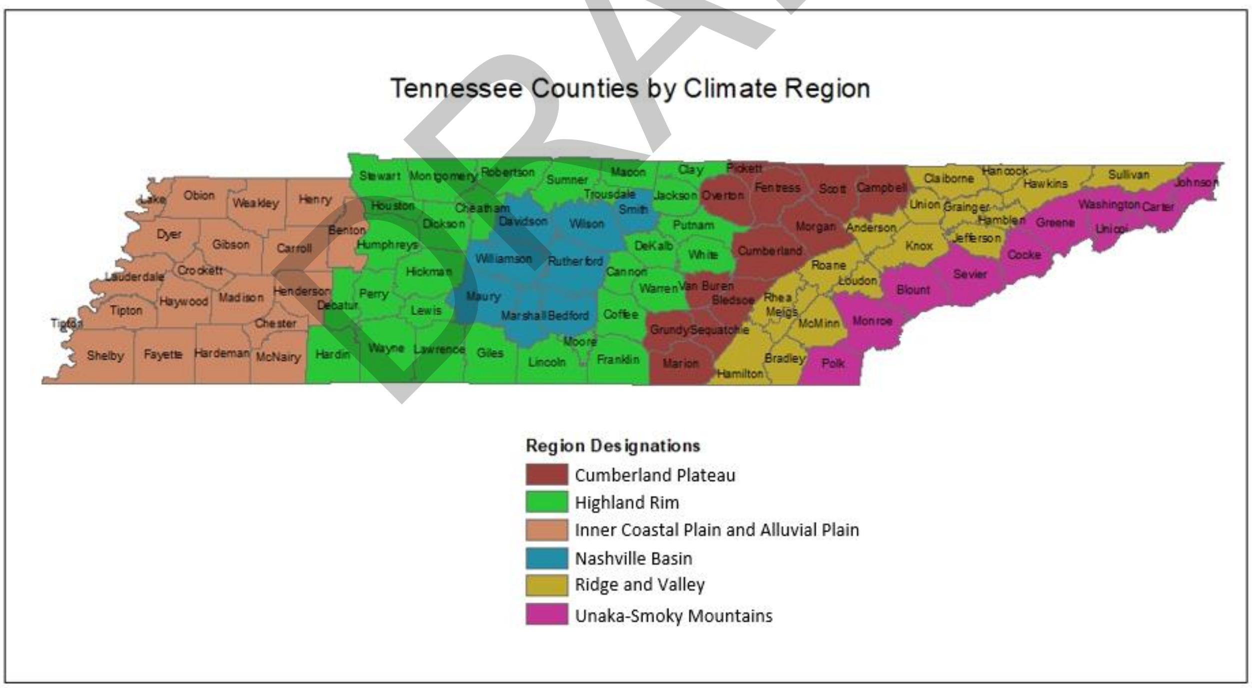

Figure E.2 – Tennessee Climate Regions

[2] The focus here is on consequence mitigation rather than incident prevention given that natural hazard events are considered an act of God.

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Historical Natural Hazard Events

Using the Storm Events Database, maintained by the National Weather Service (NWS), extreme weather events which occurred in the State during the period of 1996-2018 were evaluated.[3] During this time, over 30,000 extreme weather events were recorded in Tennessee, corresponding to nine different weather event categories. For each category, the average annual number of events was compiled for each study region (see Table E.1). In reviewing this information, it can be seen that every region in Tennessee experiences a variety of extreme weather events, implying that **no location in the State is immune from the hazards associated with extreme weather**.

Table E.1 - Average Annual Natural Hazard Events: 1996-2018

Hazard	Cumberland Plateau	Highland Rim	Inner Coastal & Alluvial Plain	Nashville Basin	Ridge & Valley	Unaka-Smoky Mountains	TOTAL
Cold	0.0	1.8	0.4	0.1	0.1	0.0	2.4
Dry	5.7	21.7	14.0	6.0	1.0	0.5	48.8
Frozen Precipitation	46.8	122.3	88.1	49.0	82.7	38.0	427.0
Heat	0.0	3.7	20.9	0.5	0.2	0.0	25.3
Hydrologic	13.7	47.9	32.5	23.0	24.3	8.6	150.0
Lightning	1.6	5.2	4.3	5.4	1.7	0.3	18.5
Rotational Winds	3.2	15.7	7.4	7.6	5.8	2.2	41.8
Straight Winds	59.4	167.4	81.5	94.8	160.3	54.7	618.1
Wildfire	13.9	13.9	13.9	13.9	13.9	13.9	83.4
Earthquake	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	144.3	399.6	262.9	200.3	289.9	118.2	1,415.2

Historically, Tennessee has not been considered a region of significant seismic activity. The most seismically active area in the eastern U.S., however, is the New Madrid zone, which runs along the Mississippi River on the western side of Tennessee. The only "major" earthquake that the State has experienced occurred in the winter of 1811-1812, when the New Madrid zone experienced three large earthquakes that ranged in magnitude of 7-8 on the earthquake magnitude scale. East Tennessee represents another earthquake zone, although historically generating less significant seismic activity in comparison to New Madrid (see Figure E.3).

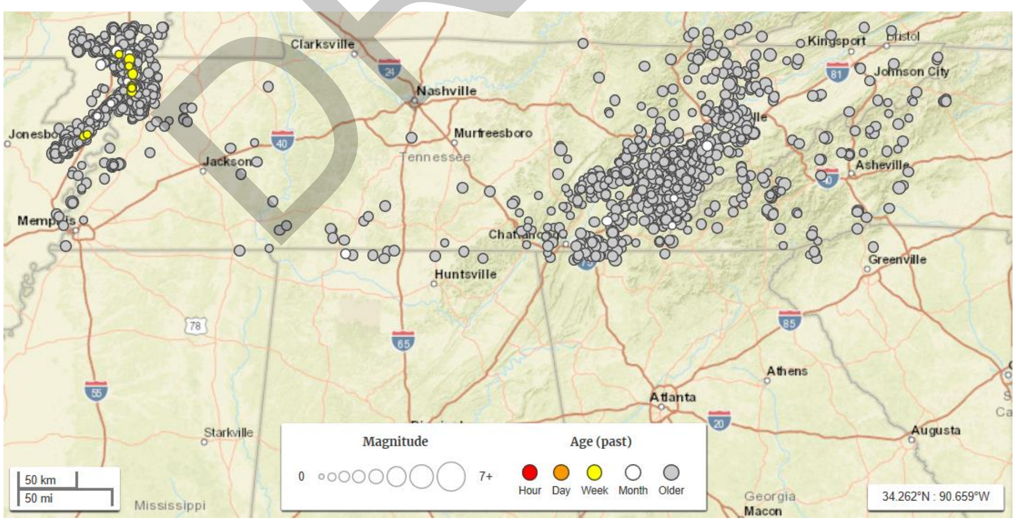

Figure E.3 - Earthquakes in Tennessee from January 1996 to October 2019

[3] Although the NWS began collecting records in 1950, the data collection process was not standardized until 1996.

Future Projected Natural Hazard Events

Using the most recent climate modeling available, temperature and precipitation projections were obtained for each geographic region. Two future climate scenarios were considered: 1) RCP 8.5 – the "business as usual" case, where the world continues burning significant amounts of fossil fuels and population growth is high; this is currently the emission trajectory that has been tracking for approximately a decade, and 2) RCP 4.5 - presumes greenhouse gas (GHG) emissions peak around 2050, and then decline to stabilize at a CO_2 level of about 570 ppm by 2070; it is assumed that reforestation is substantial in parts of the globe, with moderate economic growth and a rise in renewables as an energy source.

Figure E.4 shows a map of the projected increase in days per year with a maximum temperature at or above 95°F for RCP 8.5, while Figure E.5 displays a map of the projected increase in average annual total precipitation for RCP 8.5.

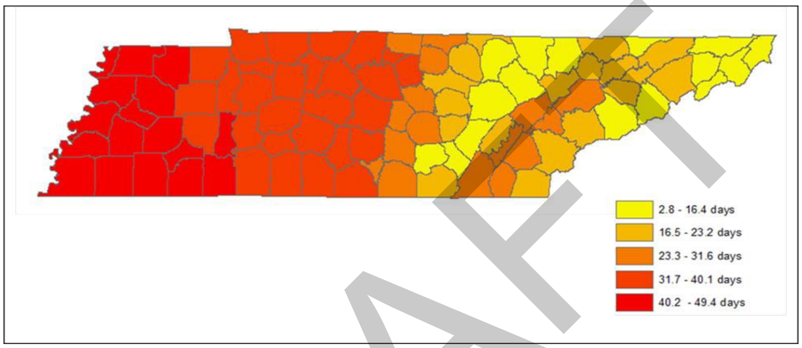

Figure E.4 – RCP 8.5: Projected Increase in Annual Days with Maximum Temperature at or Above 95°F

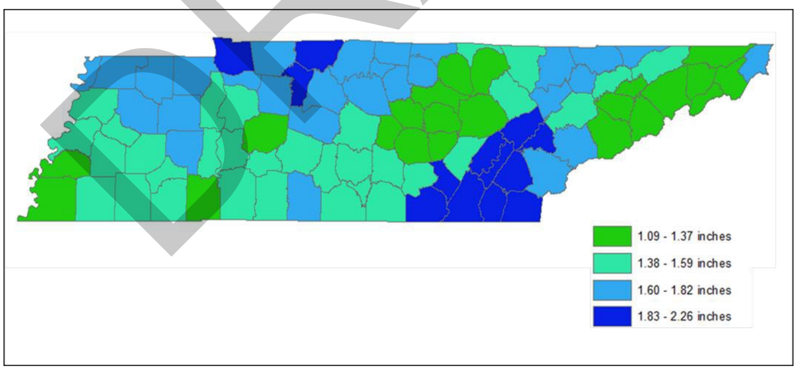

Figure E.5 – RCP 8.5: Projected Change in Average Annual Total Precipitation

In the RCP 8.5 scenario, it can be seen that a **significant increase in the annual number of hot days is anticipated.** This will, however, be accompanied by a **concurrent, but less significant, decrease in the annual number of cold days and corresponding freeze-thaw cycles**. Of additional concern, however, is the **projected increase in the annual frequency of very heavy precipitation events, circumstances that tend to correlate with flooding and severe winter storm potential**. These effects are similar, but slightly less pronounced in the RCP 4.5 scenario.

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Future projections for other extreme weather types utilized NatCatSERVICE, a comprehensive global natural hazard catastrophe database maintained by MunichRE, an international reinsurance group. The analysis consisted of evaluating trends in the occurrence of these events in the U.S. over the historical time period to project the change in event frequency for the study time horizon.

The likely occurrence of a significant earthquake event during the study time horizon is based on models of tectonic plate boundary movement, bedrock and geologic data, and recent seismic activity. Figure E.6 displays a map of the likelihood of a damaging earthquake over the time period that includes the study time horizon. The areas in orange (and yellow) represent locations in the State considered to be at highest risk to sustain damages.

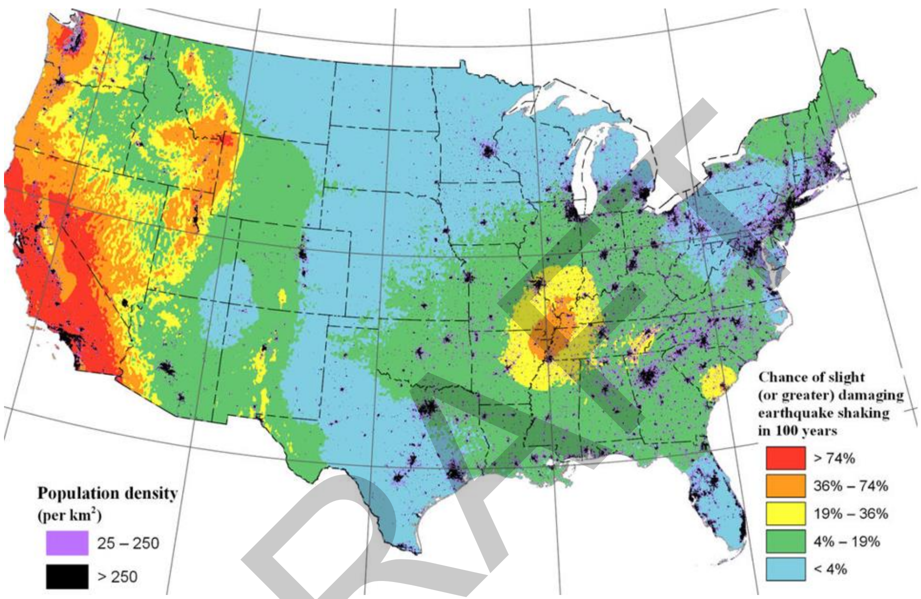

Figure E.6 - Seismic Hazard Map

Critical Infrastructure

While serious harm rendered to any infrastructure is problematic, it is particularly impactful if the affected infrastructure is critical to basic system functions that support societal well-being. The study used the 2012 International Building Code in determining what is considered critical infrastructure, resulting in the following asset categories:

- Mass gathering places
- Power generation
- Communication
- Water and wastewater treatment plants
- Public health facilities
- Law enforcement
- Emergency response
- Transportation

It was observed that virtually every county in the State has each type of critical infrastructure situated in its jurisdiction. As expected, those counties with larger amounts of critical infrastructure correspond to

locations that have urbanized areas (e.g., Shelby - Memphis; Davidson - Nashville; Knox - Knoxville; Hamilton - Chattanooga).

Cost of Inaction

The cost of inaction was estimated for the present time as well as the projected time horizon. In both cases, the analysis was conducted separately for each geographic region. The present day analysis was based on historic event frequencies and corresponding impacts associated with each of those events. Future projections utilized the present day analysis as a baseline, augmented by factors representing projected natural hazard event frequencies and changing demographics.

Tables E.2 and E.3 display the results of these respective analyses. Note that no current cost of inaction for earthquakes appears in Table E.2; this reflects the fact that no damaging earthquakes occurred in the State between 1996 and 2018. **Overall, the present cost of inaction was estimated to be on the order of hundreds of million dollars a year. If inaction persists, that amount is expected to nearly double by mid-century.**

Table E.2 – Current Annual Cost of Inaction

Average Annual Risk Cost ($): 1996-2018							
Hazard	Cumberland Plateau	Highland Rim	Inner Coastal & Alluvial Plain	Nashville Basin	Ridge & Valley	Unaka-Smoky Mountains	**TOTAL**
Cold	2,258	27,711	1,323	3,203	28	-	34,523
Dry	587,278	2,254,243	1,450,124	623,418	99,385	54,210	5,068,659
Frozen Precipitation	2,078,423	1,586,287	254,659	1,544,134	22,481	44,701	5,530,686
Heat	-	383,989	2,168,410	49,693	18,070	4,518	2,624,680
Hydrologic	3,733,613	7,109,013	135,093,418	81,844,373	12,580,878	2,494,260	242,855,555
Lightning	78,393	353,958	198,821	382,589	190,638	191,987	1,396,387
Rotational Winds	2,599,400	15,118,576	25,656,877	15,416,168	8,998,612	1,106,085	68,895,718
Straight Winds	581,629	1,807,993	5,611,000	1,413,288	2,306,955	769,404	12,490,270
Wildfire	752,212	752,212	752,212	752,212	752,212	752,212	4,513,274
Earthquake	1,473	1,131	47,464	11,335	3,943	1,573	66,919
TOTAL	10,413,206	29,393,984	171,186,846	102,029,078	24,969,261	5,417,377	343,476,672

Table E.3 – Projected Annual Cost of Inaction

Average Annual Risk Cost ($): 2035-2055 (RCP 8.5)							
Hazard	Cumberland Plateau	Highland Rim	Inner Coastal & Alluvial Plain	Nashville Basin	Ridge & Valley	Unaka-Smoky Mountains	**TOTAL**
Cold	2,442	24,265	1,106	5,268	36	-	33,117
Dry	1,739,752	7,846,962	4,484,869	2,525,882	331,658	165,829	17,094,953
Frozen Precipitation	2,506,566	2,263,745	322,052	2,557,338	29,737	59,072	7,738,509
Heat	-	1,980,911	9,490,708	356,595	142,139	-	11,970,353
Hydrologic	4,763,094	10,594,561	169,339,600	140,444,944	17,349,189	3,452,562	345,943,949
Lightning	167,245	851,146	452,668	1,136,559	437,372	431,478	3,476,468
Rotational Winds	5,621,540	38,849,826	57,927,227	45,778,268	21,465,547	2,668,142	172,310,551
Straight Winds	1,257,932	4,623,260	12,723,153	4,202,868	5,471,194	1,824,940	30,103,347
Wildfire	900,490	1,065,003	943,783	1,238,174	987,076	987,076	6,121,602
Earthquake	1,531	1,391	51,736	16,210	4,495	1,793	77,157
TOTAL	16,960,593	68,101,069	255,736,901	198,262,106	46,218,443	9,589,099	594,792,849

It is important to recognize that the values in these tables are extremely conservative in that they focus almost exclusively on property damage, and lack consideration of the economic damage associated with indirect tangible and intangible loss and damage. Examples of indirect tangible loss and damage include loss of industrial production, traffic disruption and emergency costs. Intangible loss and damage refer to, among other things, loss of life, health effects, loss of ecological goods, inconvenience of post-flood recovery, and increased vulnerability of survivors[4]. For example, estimates of the economic damage for each fatality (referred to as the

[4] Guidelines for socio-economic damage evaluation, http://www.floodsite.net/html/work_programme_detail.asp?taskID=9

value of a statistical life) in the United States is around $10 million[5]. **Given these considerations, it is likely that the cost of inaction is on the order of billions of dollars a year.**

Cost of Action Versus Inaction

The National Institute of Building Sciences (NIBS) recently published a study on the financial impacts of investing in natural hazard resilience actions. The estimated benefit/cost ratios (B/C), expressed as dollars saved for each dollar of resilience investment, are reported in Table E.4.

Table E.4 – Benefit/Cost by Hazard and Resilience Action

	Exceed 2015 Code Requirements	Meet 2018 Code Requirements	Utilities & Transportation Case Studies	Federally Funded Programs
Overall Hazard B/C Ratio	4:1	11:1	4:1	6:1
Riverine Flood	5:1	6:1	8:1	7:1
Wind	5:1	10:1	7:1	5:1
Earthquake	4:1	12:1	3:1	3:1
Wildland-Urban Interface Fire	4:1	N/A	N/A	3:1

The NIBS study implies that resilience actions the State could undertake would provide a minimum return-on-investment of 3:1, with much higher returns associated with flood and wind resilience initiatives. This implies that **prudent investment of resilience resources could save the State a minimum of hundreds of millions of dollars a year in expected disaster costs. These benefits, according to the NIBS study, would accrue to developers, property owners, lenders, tenants, and the community at large.**

In addition to savings due to avoided disaster costs, investment in resilience actions can act as an economic stimulus by providing job opportunities and other forms of economic development. Also, while codes are generally applicable to new construction and major renovations, many resilience measures might be cost-effective for existing buildings that are not otherwise part of a significant construction initiative.

Case Studies

To illustrate how future natural hazard risks may impact Tennessee and potential resilience actions to consider, several cases studies were prepared and are included in this report, representing plausible events that could occur during the study period. They include:

- Drought in the Highland Rim region
- Wildfire in the Unaka-Smoky Mountains
- Flooding in the Nashville Basin
- Earthquakes in west Tennessee and along the Cumberland Plateau
- Extreme heat in the Inner Coastal and Alluvial Plain
- Winter Storm in the Ridge and Valley region

Each case study is organized according to background information, event scenario, consequential impacts, and potential resilience strategies.

Key Findings

In the course of performing this study, a number of important findings were discovered. They include the following:

[5] Kniesner, Thomas J. and Viscusi, W. Kip, The Value of a Statistical Life (April 10, 2019). Forthcoming, Oxford Research Encyclopedia of Economics and Finance; Vanderbilt Law Research Paper No. 19-15. Available at SSRN: https://ssrn.com/abstract=3379967 or http://dx.doi.org/10.2139/ssrn.3379967

- Tennessee experiences a large number of natural hazard events on an annual basis. Moreover, all locations in the State are exposed to multiple types of natural hazards.
- The frequency and severity of natural hazard events are expected to increase in the future. In particularly, a significant increase in the annual number of hot days is anticipated. This will, however, be accompanied by a concurrent, but less significant, decrease in the annual number of cold days and corresponding freeze-thaw cycles.
- A projected increase in the annual frequency of very heavy precipitation events can also be expected, circumstances that tend to correlate with flooding and severe winter storm potential.
- The current cost of inaction is at least several hundred million dollars a year, an amount considered to be extremely conservative given the lack of analysis consideration of the impacts associated with human casualties (fatalities and injuries), as well as most of the associated indirect tangible and intangible damages. Given these considerations, it is likely that the cost of inaction is on the order of billions of dollars a year.
- The annual cost of inaction is expected to double by mid-century.
- Resilience actions the State could undertake could provide a return-on-investment of anywhere from 3:1 to 12:1. This suggests that prudent investment of resilience resources could save a minimum of hundreds of millions of dollars a year in expected disaster costs. These benefits would accrue to developers, property owners, lenders, tenants, and the community at large.
- In addition to savings due to avoided disaster costs, investment in resilience actions can act as an economic stimulus by providing job opportunities and other forms of economic development.

1. INTRODUCTION

At the request of the Tennessee General Assembly, the Tennessee Advisory Commission on Intergovernmental Relations (TACIR) has been directed to perform a study to assess the current status of community resilience plans to extreme weather events and other natural catastrophes (i.e., earthquakes), hereafter referred to as "natural hazards". The National Research Council defines resilience as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events[6]." Study objectives consist of: 1) identifying different natural hazard risks across the State, 2) documenting the current status of community resilience planning in Tennessee at the State and local level, 3) identifying best practices for community resiliency planning, and 4) determining the cost of action and inaction related to community resiliency.

This report describes an effort undertaken to address the first and fourth items on this list of objectives. The ensuing discussion includes the following topics: 1) study approach 2) study geographic regions, 3) historical natural hazard events that have occurred within the State, 4) future projected natural hazard events, 5) identification of critical infrastructure potentially exposed to natural hazard events, 6) a comparison of the cost of resilience action versus inaction, and 7) case studies of potential future natural hazard event scenarios that could occur in Tennessee, involving different natural hazard types and geographical locations. Several appendices are also included which provide additional detail to the narrative in the main body of the report.

[6] National Research Council (NRC). (2012). Disaster Resilience: A National Imperative. National Academies Press. Washington, DC.

2. STUDY APPROACH

The study was conducted utilizing the conceptual framework displayed in Figure 2.1. The geographical region of interest was to provide assessments at the county, regional and state levels, as appropriate.

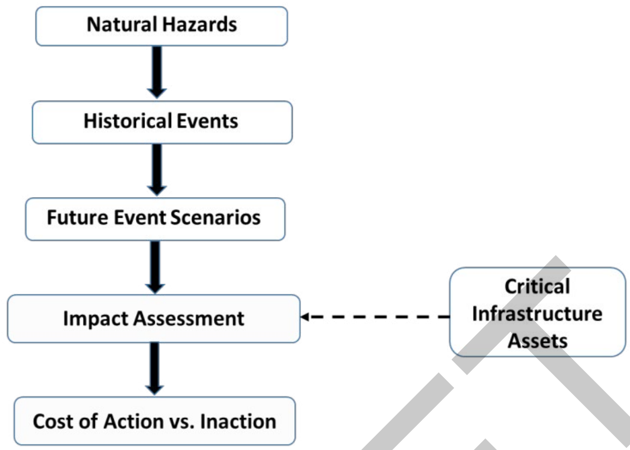

Figure 2.1 – Study Approach

The first step in this process involved the identification of natural hazards posing a threat to the State. Extreme weather events were defined according to National Weather Service (NWS) classifications, while the definition of an earthquake relied on terminology used by the U.S. Geological Survey (USGS). Due to the varying weather experienced across Tennessee, as well as varying degrees of earthquake hazard, separate geographic regions were established to represent these characteristics.

Historical event data consisted of information on the frequency and consequence of prior natural hazard events that have been observed in the State. Data from several sources were utilized in performing this task. The outcome of this task served as the baseline for comparative analysis of existing natural hazard risk and what may be anticipated in the future.

A time horizon of the period from 2035-2055 was selected to identify and assess future event scenarios. This time frame was viewed as being representative of the long term planning horizon for resilience actions to be undertaken, recognizing traditional planning and funding processes. The type and likelihood of future event scenarios utilized trend analysis of historical event data and future climate projections. The impacts of these future event scenarios recognized the location and types of critical infrastructure upon which communities would be dependent on their availability and accessibility during a disaster, as well as changes in population demographics.

A variety of potential resilience strategies are available for consideration to reduce the negative consequences associated with future natural hazard events[7]. These strategies are targeted at various impacts and have different financial and implementation requirements. Investment in these strategies represents an explicit action to strengthen resilience, as opposed to a do-nothing, inaction decision. Although investment in resilience activities represents a tangible economic cost, it is offset by the potential savings accrued from reducing the loss

[7] The focus here is on consequence mitigation rather than incident prevention given that natural hazard events are considered an act of God.

and damage associated with future natural hazard events. The benefits from disaster cost savings relative to the costs of implementation can form the basis for assessing whether/how to proceed.

3. GEOGRAPHIC REGIONS

Tennessee is comprised of several distinct geographic regions. The lowlands of west Tennessee are bordered by the Mississippi River and a portion of the Tennessee River. Middle Tennessee is characterized by rolling hills and river valleys, extending eastward to the Cumberland Plateau. East Tennessee is dominated by the Unaka-Smoky Mountains.

This varied topography leads to diverse climate conditions that produce various forms of extreme weather. Frequent storms bring excessive rainfall that often lead to local and widespread flooding, as well as landslides. Storm events can be accompanied by damaging winds and hail, and may occur as tornadoes. Yet, extended dry periods characterized by excessive heat are also prevalent, increasing the threat of drought. Winter storms and severe cold temperatures with the potential to paralyze an area for an extended period of time are also common.

The Tennessee Department of Environment and Conservation (TDEC) has designated State physiographic provinces, or "geographic regions" as they are referred to in this report[8]. TDEC defined seven regions, including a narrow band along the Mississippi River constituting a separate region called the Alluvial Plan. For this study, as the climate conditions in the Alluvial Plain and the Inner Coastal Plain areas are quite similar, they were combined into a single geographic region. The six geographic regions were therefore defined as:

- Cumberland Plateau
- Highland Rim
- Inner Coastal and Alluvial Plain
- Nashville Basin
- Ridge and Valley
- Unaka-Smokey Mountains

These regional definitions also aligned well with earthquake hazard potential in the State.

A map showing the geographic coverage of each region is displayed in Figure 3.1, including the names of those counties located within each region. Table 3.1 provides similar information in list form.

[8] Tennessee Department of Environment and Conservation. 2017. TN Ambient Air Monitoring Plan, https://www.epa.gov/sites/production/files/2017-12/documents/tnplan2017.pdf

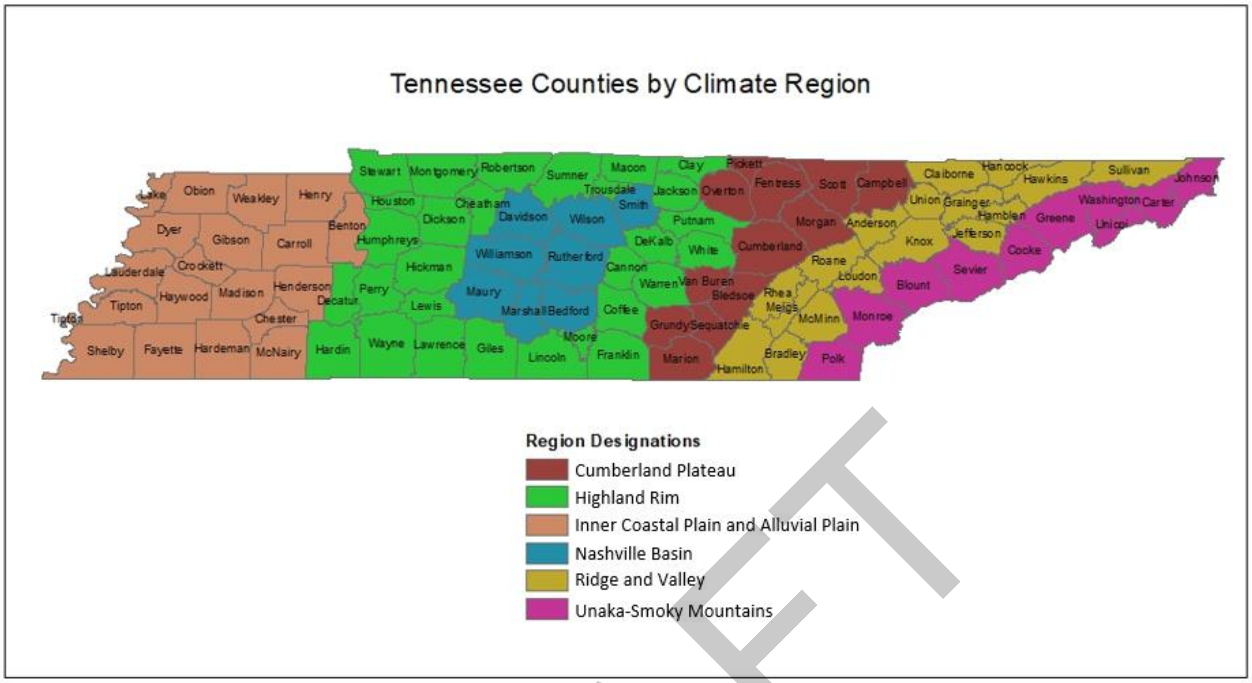

Figure 3.1 – Tennessee Climate Regions

Table 3.1 - TN Counties by Study Region

Inner Coastal & Alluvial Plain	Highland Rim	Nashville Basin	Cumberland Plateau	Ridge & Valley	Unaka-Smoky Mountains
• Lake	• Stewart	• Davidson	• Overton	• Claiborne	• Johnson
• Obion	• Montgomery	• Wilson	• Pickett	• Hancock	• Carter
• Weakley	• Robertson	• Smith	• Fentress	• Hawkins	• Unicoi
• Henry	• Sumner	• Williamson	• Van Buren	• Sullivan	• Sevier
• Dyer	• Macon	• Rutherford	• Grundy	• Union	• Blount
• Gibson	• Clay	• Maury	• Marion	• Grainger	• Monroe
• Carroll	• Houston	• Marshall	• Sequatchie	• Hamblen	• Polk
• Benton	• Dickson	• Bedford	• Bledsoe	• Anderson	• Greene
• Lauderdale	• Cheatham		• Cumberland	• Knox	• Washington
• Crockett	• Jackson		• Morgan	• Jefferson	• Cocke
• Tipton	• Putnam		• Scott	• Roane	
• Haywood	• Dekalb		• Campbell	• Loudon	
• Madison	• Cannon			• Meigs	
• Henderson	• White			• McMinn	
• Chester	• Warren			• Rhea	
• Shelby	• Coffee			• Hamilton	
• Fayette	• Franklin			• Bradley	
• Hardeman	• Lincoln				
• McNairy	• Giles				
	• Lawrence				
	• Wayne				
	• Hardin				
	• Decatur				
	• Perry				
	• Lewis				
	• Hickman				
	• Humphries				
	• Trousdale				
	• Moore				

4. HISTORICAL NATURAL HAZARD EVENTS

4.1 Extreme Weather

NWS has long been involved in tracking extreme weather events, starting in 1950 with the establishment of an information system to characterize such occurrences in the U.S. Referred to as the Storm Events Database, it contains the records of storms and other weather phenomena having sufficient intensity to cause loss of life, injuries, significant property damage, and/or disruption to commerce. This suggests that extreme weather events with similar characteristics are more likely to meet the intensity threshold in heavier populated areas where more people and infrastructure are potentially exposed.

Although the Storm Events Database contains records beginning in January 1950, changes have occurred in the data collection process as new event types have been added over time. Since 1996, however, the data collection process has not changed, meaning that a consistent analysis across different extreme weather types can be conducted for the period of 1996-2018.

During this period, 29 different extreme weather event types have been recorded in the State (see Table 4.1). The definitions for each of these event types are provided in Appendix A. In the context of this study, it is important to note that many of these event types do not represent unique weather, but rather gradations in the severity of certain weather forms. For example, “excessive cold/wind chill” represents conditions that are more severe than “cold/wind chill”. Another example is the relationship between “funnel cloud”, “dust devil”, and “tornado”, all of which represent rotational winds. Because of these relationships, the 29 extreme weather event types were aggregated into nine extreme weather event categories as displayed in Table 4.2.

Table 4.1 - Tennessee Extreme Weather Event Types

Blizzard	Frost/Freeze	Sleet
Cold/Wind Chill	Funnel Cloud	Strong Wind
Debris Flow	Hail	Thunderstorm Wind
Drought	Heat	Tornado
Dust Devil	Heavy Rain	Tropical Depression
Excessive Heat	Heavy Snow	Tropical Storm
Extreme Cold/Wind Chill	High Wind	Wildfire
Flash Flood	Ice Storm	Winter Storm
Flood	Lightning	Winter Weather
Freezing Fog	Marine High Wind	

For each of the nine weather event categories, the average annual number of recorded events was compiled for each geographic zone as shown in Table 4.3, and by each of the ninety-five counties that comprise the State, for which the results appear in Appendix B.2. In the case of wildfires, due to the paucity of such data in the Storm Events Database, the study team utilized wildfire data for Tennessee as reported by the National Institute of Standards and Technology[9]. During the historical observation period, an annual average of 1,422 wildfires were recorded in the State. Unfortunately, locational information was not available, making it impossible to assign a specific annual wildfire number to each study geographic region. As a result, the average number of annual wildfire were divided equally among the six geographic regions, resulting in 320 annual wildfires associated with each region.

[9] National Interagency Fire Center, National Report of Wildland Fires and Acres Burned by State, https://www.nifc.gov/fireInfo/fireInfo_statistics.html.

In reviewing the information provided in Table 4.3, it can be seen that every region in Tennessee experiences several extreme weather events and a variety of event types, implying that **no location in the State is immune from the hazards associated with extreme weather**. What is also notable is the frequency of frozen precipitation and straight wind events that the State experiences. Of additional interest are the number of recorded hydrologic, rotational wind and drought events, as these are often associated with relatively severe impacts.

4.2 Earthquakes

Historically, Tennessee has not been considered a region of significant seismic activity, particularly when compared to the west coast of the U.S. The most seismically active area in the eastern U.S., however, is the New Madrid zone, which runs along the Mississippi River on the western side of Tennessee and spans across multiple states[10]. The only "major" earthquake that the State has experienced occurred in the winter of 1811-1812, when the New Madrid zone experienced three large earthquakes that ranged in magnitude of 7-8 on the earthquake magnitude scale (see Figure 4.3)[11]. East Tennessee represents another earthquake zone in the State, although historically generating less significant seismic activity in comparison to New Madrid.

Table 4.2 - Aggregate Extreme Weather Event Categories

Aggregate Extreme Weather Event Category	NWS Extreme Weather Event Type	
Cold	Cold/Wind Chill	Extreme Cold/Wind Chill
Dry	Drought	
Frozen Precipitation	Blizzard Frost/Freeze Heavy Snow Sleet Winter Weather	Freezing Fog Hail Ice Storm Winter Storm
Heat	Excessive Heat	Heat
Hydrologic	Debris Flow Flood Tropical Depression	Flash Flood Heavy Rain Tropical Storm
Lightning	Lightning	
Rotational Winds	Dust Devil Tornado	Funnel Cloud
Straight Winds	High Wind Strong Wind	Marine High Wind Thunderstorm Wind
Wildfire	Wildfire	

[10] Missouri Department of Natural Resources. 2019. Facts about the New Madrid Seismic Zone. Accessed October 2019. Available at https://dnr.mo.gov/geology/geosrv/geores/techbulletin1.htm.
[11] USGS. 2019. The New Madrid Seismic Zone. Accessed October 2019. Available at https://www.usgs.gov/natural-hazards/earthquake-hazards/science/new-madrid-seismic-zone?qt-science_center_objects=0#qt-science_center_objects.

Table 4.3 – Extreme Weather Events by Geographic Region: 1996-2018

Hazard	Cumberland Plateau	Highland Rim	Inner Coastal & Alluvial Plain	Nashville Basin	Ridge & Valley	Unaka-Smoky Mountains	TOTAL
Cold	1	42	9	2	2	--	56
Dry	130	499	321	138	22	12	1,122
Frozen Precipitation	1,077	2,813	2,026	1,128	1,901	875	9,820
Heat	--	85	480	11	4	1	581
Hydrologic	315	1,101	748	529	559	197	3,449
Lightning	37	120	98	124	40	7	426
Rotational Winds	73	360	171	175	133	50	962
Straight Winds	1,367	3,850	1,874	2,181	3,686	1,258	14,216
Wildfire	320	320	320	320	320	320	1,920
TOTAL	3,320	9,190	6,147	4,608	6,667	2,720	32,552

Since 1974, seismographs have been deployed by the USGS and others to monitor seismic activities in an attempt to predict the next large earthquake. While the aforementioned 1811-1812 earthquakes are the largest on record for Tennessee, small earthquakes that often are not felt by individuals occur almost weekly in the New Madrid zone. According to the USGS, since 1996, over 5,500 earthquakes have occurred in Tennessee alone (see Figure 4.4). Approximately 95% of these earthquakes had a magnitude of 2.5 or less, and the largest recorded was estimated to be a 4.4, occurring in 2018 near Decatur (in the eastern portion of the State).

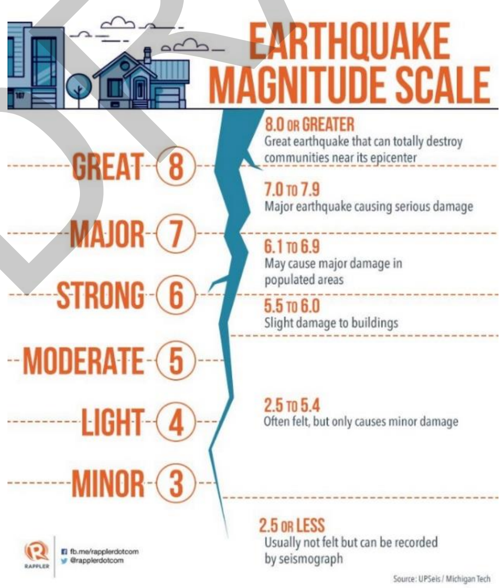

Figure 4.3 - Earthquake Magnitude Scale[12]

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[12] UPSeis. 2019. Geological and Mining Engineering and Sciences, Michigan Tech. Accessed October 2019. Available at http://www.geo.mtu.edu/UPSeis/index.html.

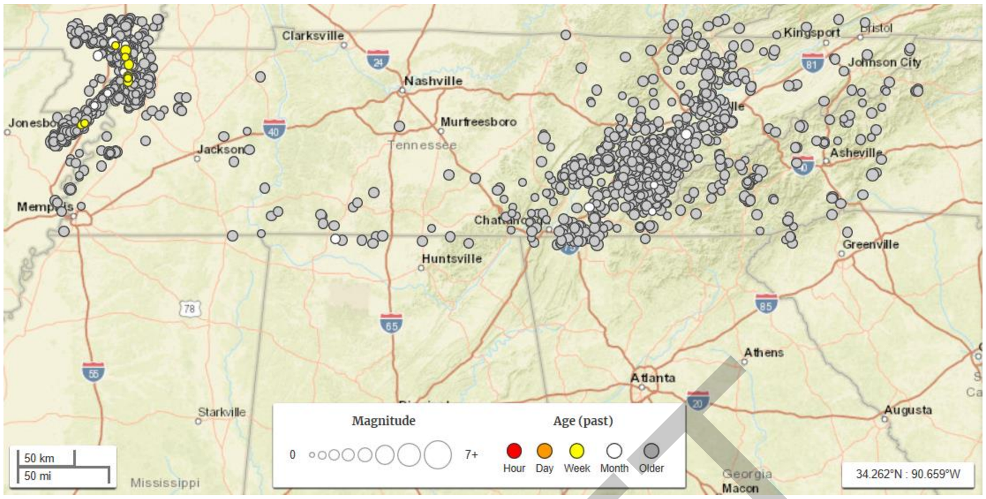

Figure 4.4 - Earthquakes in Tennessee from January 1996 to October 2019[13]

[13] Source: USGS

5. FUTURE PROJECTED NATURAL HAZARD EVENTS

5.1 Extreme Weather

Separate analyses were performed to estimate the frequency of future extreme weather events associated with temperature/precipitation and other types of extreme weather, respectively.

5.1.1 Temperature and Precipitation

The World Climate Research Programme started the Coupled Model Intercomparison Project (CMIP) in 1995 to harmonize the work of many climate research modeling centers around the world, and to increase the comparability of model results through established protocols.[14] This work is ongoing, with modeling updates regarding projected temperature and precipitation provided as scientists learn more about our changing climate. Using CMIP5, the most current data available, this study utilized the information by downscaling the data at the level of a 12 x 12 kilometer grid for a specific area in each geographic region within the State[15].

Climate models are complex mathematical representations of the climate system that are useful in projecting future temperature and precipitation conditions over time under a range of different scenarios. They are tested in a number of ways, including by modeling historic data and comparing model results to actual observed results. In order to assure comparability of results among the many climate modeling groups around the world, the Intergovernmental Panel on Climate Change (IPCC) developed a set of scenarios that standardize model starting conditions and inputs. The models are then used to project the global average temperature change (and precipitation levels) based on the concentrations of greenhouse gases (GHG) in the atmosphere over time (out to year 2100), making assumptions about the many factors that influence GHG concentrations and temperature. There are four scenarios, called representative concentration pathways (RCPs), and each includes a range of assumptions about factors such as economic growth, global land use, the primary energy source of developing countries, diets, technology development, and population, and how and when such factors may change over time.

A summary of each RCP scenario appears in Table 5.1. Figure 5.1 shows the four primary RCP scenarios, and the projected range of corresponding global average temperature increase if the world follows that particular path. For this study, the Tennessee geographic region temperature and precipitation changes over time were projected using RCP 8.5 and RCP 4.5. RCP 8.5 was selected as this is the path that the data demonstrates the world is currently well aligned with and has been tracking for nearly a decade; it is also considered the worst case scenario. Under RCP 4.5, global emissions stabilize mid-century and sharply decline afterwards. Impacts to temperature and precipitation changes at mid-century are not very different between RCP 4.5 and RCP 8.5, which diverge more strongly after mid-century. RCP 2.6 was not selected as an option because it is no longer recognized as a plausible scenario, and RCP 6 was not considered in lieu of the upper and lower bounds already captured by including an assessment of RCP 4.5 and RCP 8.5.

Tables 5.2 and 5.3 display the CMIP5 results for the Inner Coastal and Alluvial Plains geographic region for RCP 8.5 and 4.5 scenarios, respectively. CMIP5 results for each geographic region are listed in Appendix C.

[14] World Climate Research Programme, Coupled Model Intercomparison Project 5 (CMIP5), available at https://esgf-node.llnl.gov/projects/cmip5/.

[15] A mid-latitude position in each of the six climate regions was selected for processing in this fashion. As the climate throughout each ecoregion is similar, the projected results are likely to be representative of that climate region.

Table 5.1 – RCP Scenarios

RCP	Summary Description
RCP 8.5	The "business as usual" case, where the world continues burning significant amounts of fossil fuels and population growth is high. This is the emission trajectory that has been tracking for approximately a decade.
RCP 6	Emissions grow steadily and peak in 2060, then decline, population reaches 10 billion people, CO_2 concentrations reach 620 ppm by 2100 (they are currently at ~410 ppm, pre-industrial is 280 ppm).
RCP 4.5	Presumes GHG emissions peak around 2050, and then decline to stabilize at a CO_2 level of about 570 ppm by 2070. Assumes that reforestation is substantial in parts of the globe, with moderate economic growth and a rise in renewables as an energy source.
RCP 2.6	Represents humanity quickly and aggressively addressing GHG emissions. Assumes a peak of global CO_2 emissions around 2020 and rapidly decline to zero by 2080. Most analysts agree this path is no longer a plausible scenario.

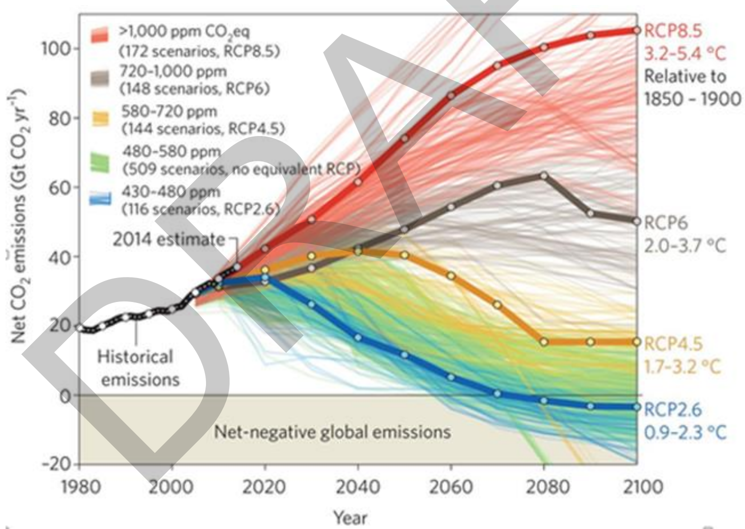

Figure 5.1 - RCPs Over Time and Corresponding Global Temperature Increase[16]

As one might expect, in the RCP 8.5 scenario, a significant increase in the annual number of hot days is anticipated, although with a concurrent, but less significant, decrease in the annual number of cold days and corresponding freeze-thaw cycles. These effects are similar, but less pronounced in the RCP 4.5 scenario. Of additional concern is the projected increase in the annual frequency of very heavy precipitation events, circumstances that tend to correlate with flooding and severe winter storm potential. Similar trends were observed in the other geographic regions, with varying magnitudes of projected change depending on location.

[16] Source: Fuss, Sabine, Josep G. Canadell, Glen P. Peters, Massimo Tavoni, Robbie M. Andrew, Philippe Ciais, Robert B. Jackson et al. "Betting on negative emissions." Nature Climate Change 4, no. 10 (2014): 850.

Table 5.2 - CMIP5 Results for the Inner Coastal and Alluvial Plains: RCP 8.5 Scenario

RCP 8.5		
Inner Coastal and Alluvial Plains	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	56.2 days	+42.2 days
Avg. # days per year below freezing	50.0 days	-24.2 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	34.4 times	- 5.9 times
Avg. # of "very heavy" (95th percentile precipitation) events per year	13.0 times	+1.7 times

Table 5.3 - CMIP5 Results for the Inner Coastal and Alluvial Plains: RCP 4.5 Scenario

RCP 4.5		
Inner Coastal and Alluvial Plains	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	43.7 days	+31.1 days
Avg. # of days per year below freezing	59.8 days	-20.1 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	38.2 times	-3.5 times
Avg. # of "very heavy" (95th percentile precipitation) events per year	12.2 times	+1.6 times

County level projections for the temperature and precipitation measures shown in Table 5.2 are presented in Figures 5.2-5.5, respectively.

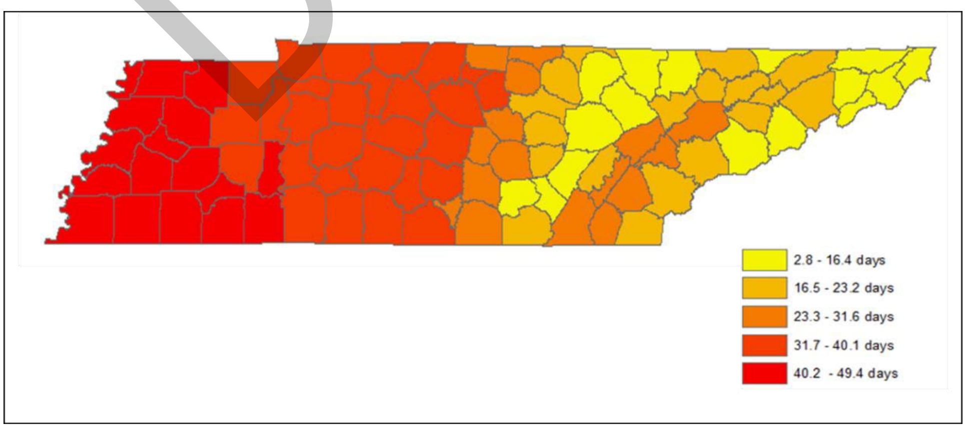

Figure 5.2 - Projected Increase in Days Per Year with Maximum Temperature at or Above 95°F

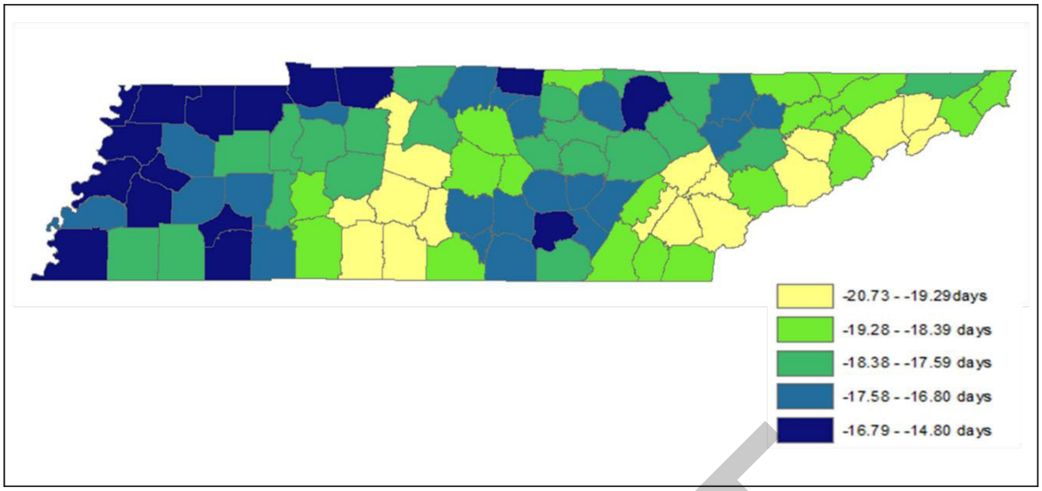

Figure 5.3 - Projected Decrease in Annual Freeze-Thaw Cycle Days

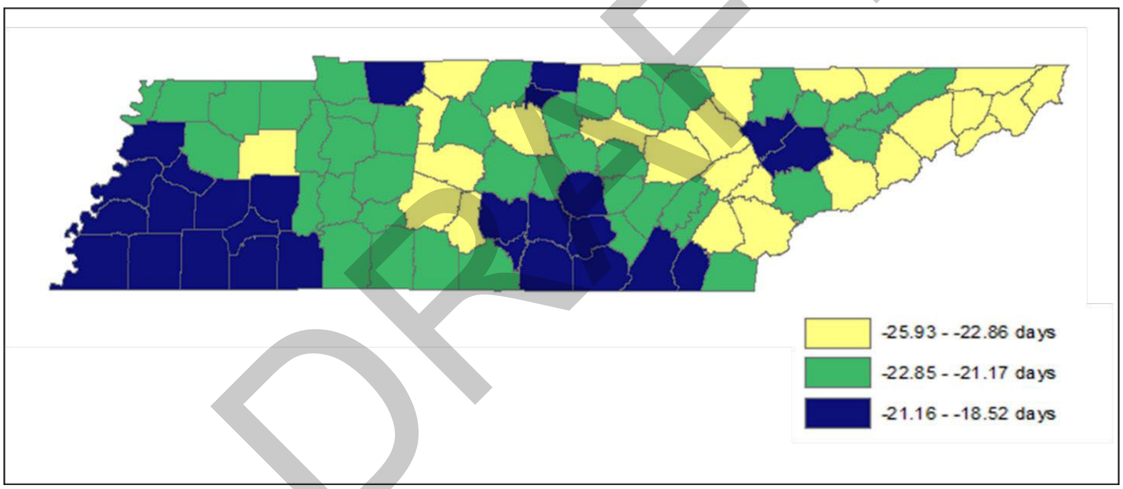

Figure 5.4 – Projected Decrease in Days Per Year Where Temperature Drops Below Freezing

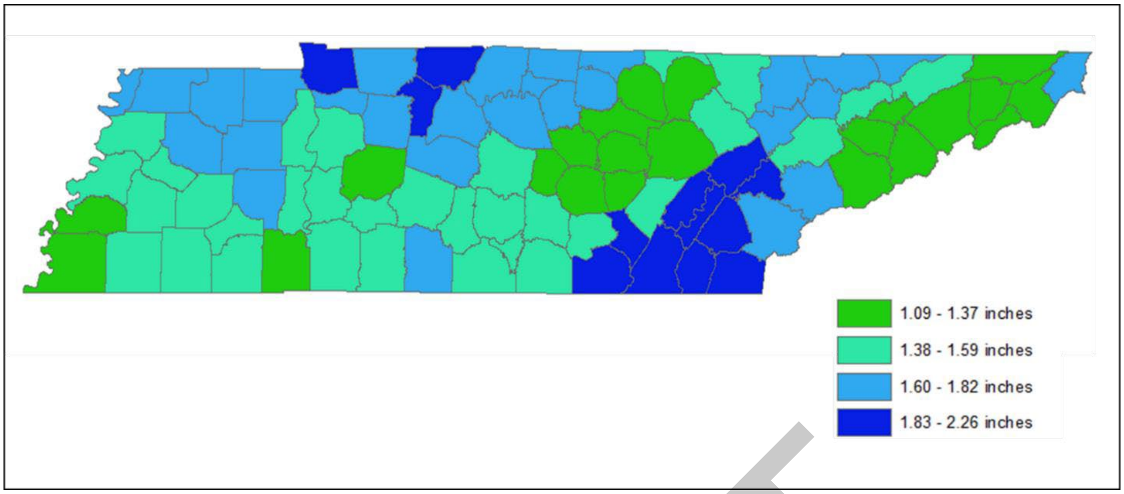

Figure 5.5 - Projected Change in Average Annual Total Precipitation

5.1.2 Other Extreme Weather Types

NatCatSERVICE is a comprehensive global natural hazard catastrophe database maintained by MunichRE, an international reinsurance group. Records date back to 1980, and retrospectively all great disasters since 1950. Catastrophic events include those classified as geophysical (earthquake, volcano, dry mass movements), meteorological (storms), hydrological (flooding, wet mass movements), and climatological (extreme temperature, drought, wildfire). Each record in the database is characterized by the following attributes: date; event type; nature of the event; loss data (insured losses, overall losses, bodily injuries), infrastructure areas; affected industries; and event description (e.g., wind strength, precipitation levels, earthquake magnitude). The database gathers information from a wide range of sources, using data mining and surveys among Internet portals, institutions, direct contacts, and specialized companies. Frequency and monetary loss data is made available through an online tool where the user can designate the period of interest (years), location (country/continent) and event type[17].

For this study, NatCatSERVICE data for the U.S. covering the period from 1996-2018 were utilized[18]. The following natural hazard event types were analyzed: 1) heatwave/wildfire, 2) floods, 3) convective storms[19], and 4) winter storms. The analysis consisted of evaluating trends in the occurrence of these events over the historical time period to project the change in event frequency for the study time horizon. Trend analysis was performed using linear regression.

The analysis results are displayed in Figures 5.6-5.9 for each respective event type. The number of heatwave/wildfire observations are increasing over time (Figure 5.6), with similar results indicated for floods (Figure 5.7) and convective storms (Figure 5.8). By contrast, winter storm trends are nearly flat (Figure 5.9), indicative of a warming climate, yet still a notable concern.

[17] MunichRE, https://www.munichre.com/en.html, sourced October 2019.
[18] As NatCatSERVICE data cannot be disaggregated beyond the country level, it is assumed that these nationwide trends are indicative of trends being experienced in Tennessee.
[19] The term "convective storms" can be considered synonymous with "thunderstorms".

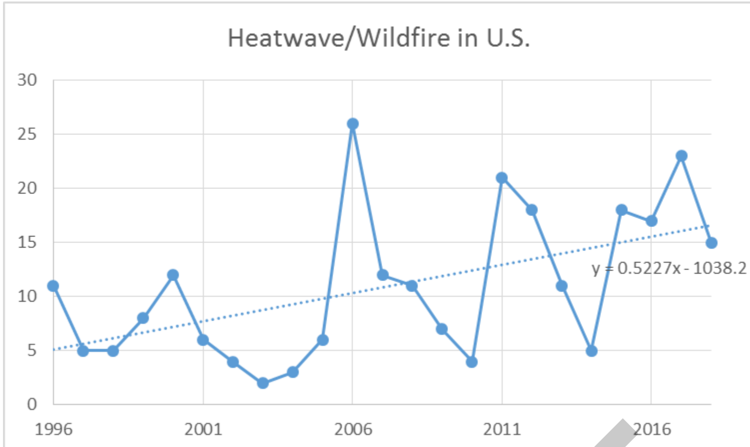

Figure 5.6 – Heatwave/Wildfire Trend Analysis

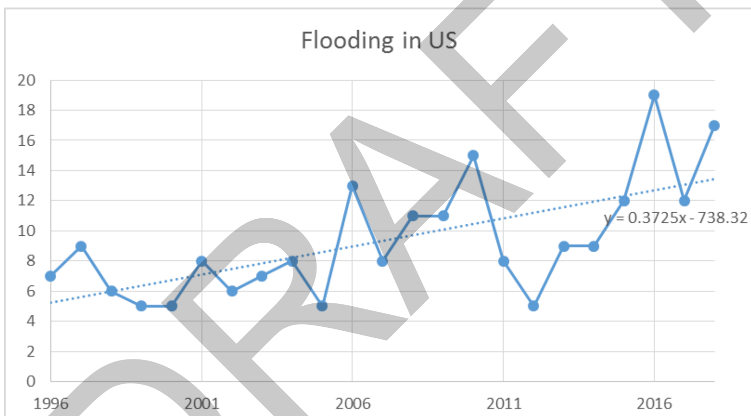

Figure 5.7 – Flood Trend Analysis

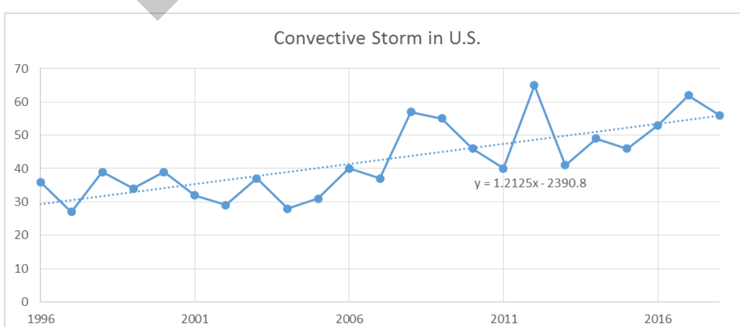

Figure 5.8 – Convective Storm Trend Analysis

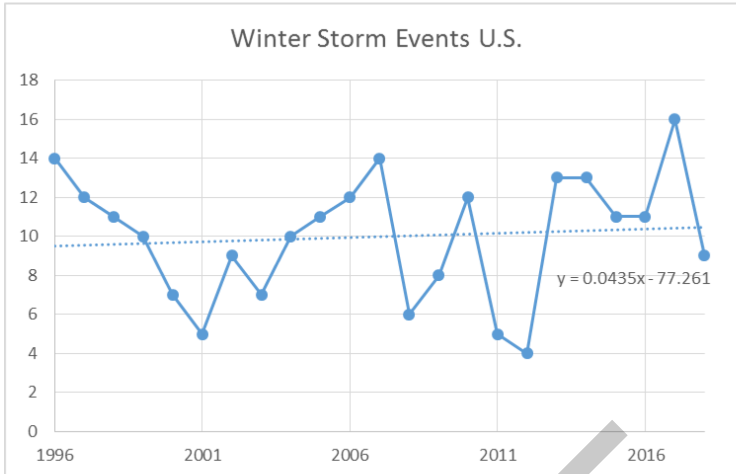

Figure 5.9 – Winter Storm Trend Analysis

5.2 Earthquake Prediction

Earthquakes typically originate deep in the ground along fault lines, where tectonic plates collide or slide past each other. There is considerable uncertainty associated with the timing and intensity of a future earthquake and its corresponding magnitude in a location such as the New Madrid or east Tennessee seismic zone. The proximity of the epicenter, depth, surrounding geology, and overlying terrain/soil types are critical factors in determining earthquake strength and impact.[20]

While scientists cannot predict with certainty when another moderate to large earthquake might occur in the State, they are constantly monitoring the area and collecting data about stresses along the fault, such as tracking the number of small earthquakes and their size as potential indicators of movement along the fault boundaries. The most common approach to predicting earthquake potential is a probabilistic seismic hazard analysis, which provides an estimate of the likely occurrence of a significant earthquake event in the foreseeable future based on models of tectonic plate boundary movement, bedrock and geologic data, and recent seismic activity.

The USGS has created hazard maps to identify areas that are at greatest risk due to seismic activity. The likely occurrence of a significant earthquake event during the study time horizon is based on models of tectonic plate boundary movement, bedrock and geologic data, and recent seismic activity. Figure 5.10 displays a map of the likelihood of a damaging earthquake over the time period that includes the study time horizon. The areas in orange (and yellow) represent locations in the State considered to be at highest risk to sustain damages. As this relates to the study geographic regions, the Nashville Basin is in the green zone, the Unaka-Smoky Mountains and Cumberland Plateau straddle the green and yellow zones, the Highland Rim and Ridge & Valley are in the yellow zone, and the Inner Coastal and Alluvial Plains straddles the yellow and orange zones. Note that Figure 5.10 covers a 100-year time frame, meaning that the annual likelihood of a damaging earthquake is derived by dividing the percentage shown by 100.

[20] Missouri Department of Natural Resources. 2019. Facts about the New Madrid Seismic Zone. Accessed October 2019. Available at https://dnr.mo.gov/geology/geosrv/geores/techbulletin1.htm.

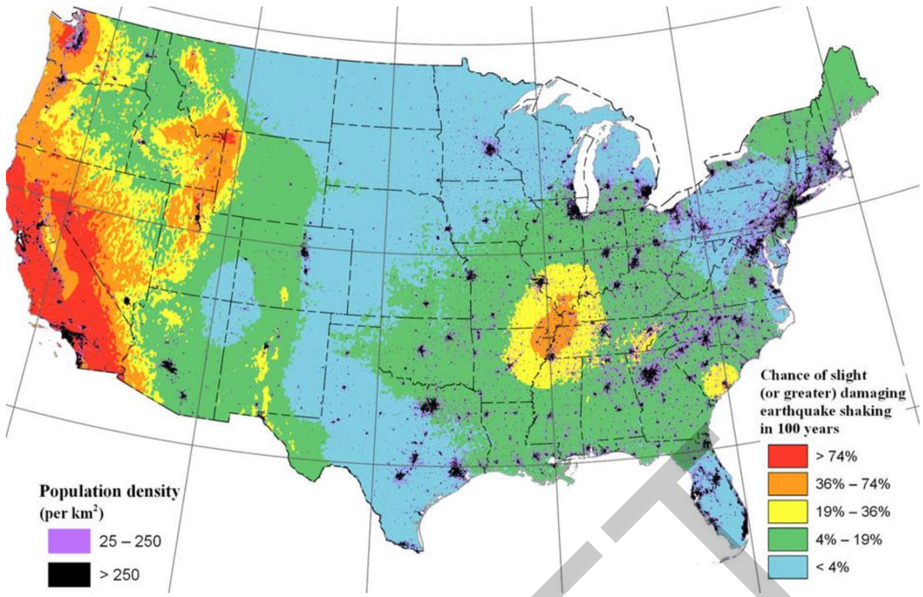

Figure 5.10 - Seismic Hazard Map[21]

[21] Source: USGS

6. CRITICAL INFRASTRUCTURE

When a natural hazard event occurs, infrastructure is at risk of incurring damage. While serious harm rendered to any infrastructure is problematic, it is particularly impactful if the affected infrastructure is critical to basic system functions that support societal well-being. In defining what constitutes a critical asset, for the purpose of this study, the 2012 International Building Code (IBC) was used to make this determination[22]. According to the IBC, critical infrastructure corresponds to those facilities that are associated with Risk Category III and Risk Category IV, defined as follows:

Risk Category III: Structures that can house a large number of people in one place, or contain occupants with limited mobility or without the ability to move without incurring harm. This may include theaters, lecture halls, schools, prisons, and community centers. It may also include utility infrastructure that is required to protect the health and safety of a community such as power generating stations, telecommunication centers, and water and sewage treatment plants.

Risk Category IV: Police stations, fire stations, emergency communication centers and similar emergency facilities, hospitals, infrastructural facilities required to maintain the operations of these facilities during an emergency, and facilities containing hazardous materials that could threaten the public if released into the environment.

The substance of these definitions of critical infrastructure can be translated into the following subject categories:

- Mass gathering places
- Power generation
- Communication
- Water and wastewater treatment plants
- Public health facilities
- Law enforcement
- Emergency response
- Transportation

Note that a separate category for hazardous materials was not included. The rationale for this decision was two-fold: 1) hazardous materials in various quantities are prevalent throughout an area due to the multiple purposes for which such materials are used, and 2) much of the power generation and water/wastewater treatment processes involve large quantities of hazardous materials; hence these facilities are representative of hazardous materials sites located within the area of interest.

The study subsequently identified types of facilities and data sources that could be utilized as representative candidates for describing critical infrastructure associated with each category. They are listed in Table 6.1. The amounts of each type of critical infrastructure located in each county are presented in Table 6.2. More detailed tables showing the types of critical infrastructure facilities associated with each column in Table 6.2 are presented in Appendix D.

[22] International Code Council, 2011. 2012 International Building Code, http://tyrone.org/wp-content/uploads/2017/05/icc.ibc_.2012.pdf

Table 6.1 – Critical Infrastructure Facilities

Mass Gathering Places	
	Places of worship
	Child care centers
	Colleges and universities
	Convention centers
	Major sport venues
	Private schools
	Public schools
	Community centers
	Major retail locations (malls)
Power Generation	
	Biodiesel plants
	Electric substations
	Ethanol plants
	Oil refineries
	Petroleum terminals
	Power plants
Communication	
	Cellular towers
Water and Wastewater Treatment Plants	
	Drinking water treatment plants
	Wastewater treatment plants
Public Health Facilities	
	Hospitals
	Nursing homes
	Public health departments
	Urgent care facilities
	Veterans Health Administration medical facilities
Law Enforcement	
	Local law enforcement locations
Emergency Response	
	American Red Cross headquarters
	Emergency medical service stations
	Fire stations
	Local EOCs
	State EOC
	National Guard facilities
	Military facilities
Transportation	
	Locks
	Airports
	Controlled access highways (no. of miles)
	Class I railroads (no. of miles)
	Ports/Terminals

Table 6.2 – Critical Infrastructure Facilities by County

TN County	Communication	Law Enforcement	Public Health	Water Treatment	Emergency Response	Power Generation	Mass Gathering	Transportation	TOTAL
Anderson	23	6	16	19	37	47	107	96	**351**
Bedford	9	3	9	9	25	8	53	19	**135**
Benton	49	4	3	8	13	8	17	26	**128**
Bledsoe		2	3	6	13	4	14	2	**44**
Blount		6	17	5	39	50	143	52	**312**
Bradley	2	4	13	5	18	22	103	72	**239**
Campbell	12	9	7	24	28	19	41	107	**247**
Cannon		2	3	3	10	1	13	0	**32**
Carroll	11	8	9	16	25	14	34	47	**164**
Carter	13	5	11	20	21	17	63	12	**162**
Cheatham	1	4	5	12	18	6	45	26	**117**
Chester	4	3	4	5	12	5	14	0	**47**
Claiborne	8	4	5	12	19	9	43	32	**132**
Clay	25	2	3	14	10	4	9	6	**73**
Cocke		3	6	9	17	10	40	59	**144**
Coffee	5	3	16	6	21	12	54	39	**156**
Crockett	8	6	4	15	10	1	13	13	**70**
Cumberland	28	3	15	12	30	18	40	43	**189**
Davidson	3	32	86	28	92	119	818	175	**1353**
Decatur	9	3	5	7	15	4	11	12	**66**
DeKalb	11	4	5	7	16	3	13	1	**60**
Dickson	3	7	8	8	22	11	57	49	**165**
Dyer		4	8	12	17	45	34	21	**141**
Fayette	17	8	7	13	18	18	20	72	**173**
Fentress	2	3	3	3	19	2	16	1	**49**
Franklin	64	8	11	16	34	21	36	40	**230**
Gibson	1	9	14	21	32	20	61	22	**180**
Giles		5	7	3	16	7	26	22	**86**
Grainger		4	2	12	9	4	17	22	**70**
Greene	37	5	12	24	26	39	69	71	**283**
Grundy	6	5	2	5	12	8	16	8	**62**
Hamblen		5	12	2	20	26	61	10	**136**
Hamilton	17	18	53	20	89	47	363	282	**889**
Hancock	23	2	5	5	9	4	6	0	**54**
Hardeman		8	5	10	16	16	32	27	**114**
Hardin	12	4	10	9	29	11	26	17	**118**
Hawkins		4	9	26	26	19	43	1	**128**
Haywood		2	4	14	29	18	12	58	**137**
Henderson	4	4	7	6	28	10	27	30	**116**
Henry	18	5	10	6	23	9	46	3	**120**
Hickman	1	2	4	7	18	5	14	16	**67**
Houston	11	2	3	1	7	2	11	2	**39**
Humphreys		5	5	14	15	18	14	28	**99**
Jackson	52	2	4	3	16	1	9	4	**91**
Jefferson	80	6	7	17	18	17	35	40	**220**
Johnson	36	2	3	7	16	7	17	7	**95**
Knox	6	9	76	34	81	163	417	83	**869**
Lake	30	4	3	4	6	3	7	3	**60**
Lauderdale	8	7	5	11	14	13	25	36	**119**
Lawrence	22	7	9	10	28	7	50	3	**136**
Lewis	21	2	2	5	2	2	14	2	**50**
Lincoln	41	3	9	11	27	6	40	7	**144**
Loudon		3	13	12	22	34	42	68	**194**
Macon	23	3	6	8	8	1	16	75	**140**
Madison	54	6	24	12	26	31	114	33	**300**
Marion	37	7	5	18	25	16	27	51	**186**
Marshall	20	5	5	6	17	10	25	18	**106**
Maury		4	18	8	33	24	92	36	**215**
McMinn		6	13	23	31	33	60	31	**197**
McNairy		5	5	8	27	16	27	0	**88**
Meigs		2	2	3	12	6	11	12	**48**
Monroe	30	7	7	14	34	27	46	49	**214**
Montgomery	43	7	17	15	31	29	179	24	**345**
Moore	5	1	2	3	15	1	8	0	**35**
Morgan	16	3	2	7	15	10	25	1	**79**
Obion		9	9	13	17	20	46	45	**159**
Overton	2	3	3	3	24	3	24	0	**62**
Perry	18	3	3	6	9	2	10	3	**54**
Pickett	1	2	2	3	5	1	4	0	**18**
Polk	33	5	3	16	17	13	15	36	**138**
Putnam	27	9	16	10	32	21	74	47	**236**
Rhea		4	7	18	24	16	30	44	**143**
Roane	11	5	10	20	29	38	60	95	**268**
Robertson	8	6	10	8	30	14	77	58	**211**
Rutherford	3	6	34	10	78	20	195	41	**387**
Scott	29	4	4	10	13	5	30	43	**138**
Sequatchie		2	2	3	11	4	7	0	**29**
Sevier	3	6	10	26	40	35	88	18	**226**
Shelby	30	34	107	47	168	90	1262	173	**1911**
Smith	3	4	4	12	15	5	15	25	**83**
Stewart	1	3	3	14	19	7	11	4	**62**
Sullivan	10	7	29	20	51	60	147	46	**370**
Sumner	4	9	31	24	44	29	141	76	**358**
Tipton	6	6	5	17	30	13	44	3	**124**
Trousdale	1	3	4	3	4	2	12	2	**31**
Unicoi		2	6	11	10	3	19	27	**78**
Union	28	4	2	9	15	6	19	4	**87**
Van Buren	8	2	2	1	9	1	6	1	**30**
Warren	29	3	10	13	28	10	45	1	**139**
Washington	47	5	32	10	44	45	129	75	**387**
Wayne	19	4	6	10	22	5	12	3	**81**
Weakley		8	8	23	22	21	38	0	**120**
White	1	2	5	3	31	4	17	1	**64**
Williamson	4	5	27	9	47	24	173	73	**362**
Wilson	4	5	19	15	28	23	118	30	**242**

It can be seen that virtually every county in the State has each type of critical infrastructure situated in its jurisdiction. As expected, those counties with larger amounts of critical infrastructure correspond to locations that contain urbanized areas (e.g., Shelby - Memphis; Davidson - Nashville; Knox - Knoxville; Hamilton - Chattanooga).

7. COST OF INACTION

The annual cost of inaction was estimated for the present time as well as the projected time horizon for the RCP 8.5 scenario. In both cases, the analysis was conducted separately for each geographic region.

The present day analysis was based on historic event frequencies and corresponding economic impacts associated with those events. Economic impacts were estimated based on information obtained from the Storm Events Database, a National Institute of Standards and Technology study on the cost of wildfires[23], and information provided by NOAA[24] and other federal agencies[25].

The results appear in Table 7.1. **Note that every geographic region is presently incurring annual costs of inaction totaling millions of dollars a year, with the Inner Coastal & Alluvial Plain and the Nashville Basin regions incurring annual costs of inaction in the range of hundreds of millions of dollars a year. Overall, the State is most threatened by hydrologic and high wind (straight and rotational) events.**

Table 7.1 – Present Day Cost of Inaction

Average Annual Risk Cost ($): 1996-2018							
Hazard	Cumberland Plateau	Highland Rim	Inner Coastal & Alluvial Plain	Nashville Basin	Ridge & Valley	Unaka-Smoky Mountains	**TOTAL**
Cold	2,258	27,711	1,323	3,203	28	-	34,523
Dry	587,278	2,254,243	1,450,124	623,418	99,385	54,210	5,068,659
Frozen Precipitation	2,078,423	1,586,287	254,659	1,544,134	22,481	44,701	5,530,686
Heat	-	383,989	2,168,410	49,693	18,070	4,518	2,624,680
Hydrologic	3,733,613	7,109,013	135,093,418	81,844,373	12,580,878	2,494,260	242,855,555
Lightning	78,393	353,958	198,821	382,589	190,638	191,987	1,396,387
Rotational Winds	2,599,400	15,118,576	25,656,877	15,416,168	8,998,612	1,106,085	68,895,718
Straight Winds	581,629	1,807,993	5,611,000	1,413,288	2,306,955	769,404	12,490,270
Wildfire	752,212	752,212	752,212	752,212	752,212	752,212	4,513,274
Earthquake	1,473	1,131	47,464	11,335	3,943	1,573	66,919
TOTAL	10,413,206	29,393,984	171,186,846	102,029,078	24,969,261	5,417,377	343,476,672

The projected future analysis utilized the present day analysis as its baseline, augmented by factors representing population growth (Table 7.2) and future projected natural hazard event frequencies (Table 7.3)[26]. The projected future annual costs of inaction appear in Table 7.4. **It can be seen that if inaction persists, relative to the present day, the annual cost of inaction is expected to nearly double by mid-century.**

It is important to recognize that the values in these tables are extremely conservative in that they focus almost exclusively on property damage, and lack consideration of the economic damage associated with indirect tangible and intangible loss and damage. Examples of indirect tangible loss and damage include loss of industrial production, traffic disruption and emergency costs. Intangible loss and damage refers to, among other things, loss of life, health effects, loss of ecological goods, inconvenience of post-flood recovery, and increased vulnerability of survivors. For example, estimates of the economic damage for each fatality (referred to as the value of a statistical life) in the United States is around $10 million. **Given these considerations, it is likely that the cost of inaction is on the order of billions of dollars a year.**

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[23] National Institute of Standards and Technology, The Costs and Losses of Wildfires, November 2017.
[24] NOAA, Calculating the Cost of Weather and Climate Disasters, https://www.ncdc.noaa.gov/billions
[25] How Much Economic Damage Do Large Earthquakes Cause? https://www.kansascityfed.org
[26] Future project wildfire frequencies based on: Jolly, W.M, et al. Climate-induced variations in global wildfire danger from 1979 to 2013. Nature Communications. 6: 7537.

Table 7.2 – Regional Population Growth Factors[27]

Population Growth Factor	
Nashville Basin	1.43
Unaka-Smoky Mountains	1.14
Cumberland Plateau	1.04
Ridge & Valley	1.14
Inner Coastal and Alluvial Plain	1.09
Highland Rim	1.23

Table 7.3 – Event Growth Factors for RCP 8.5 Scenario

Event Growth Factors Under RCP 8.5 Scenario						
Hazard	Cumberland Plateau	Highland Rim	Inner Coastal & Alluvial Plain	Nashville Basin	Ridge & Valley	Unaka-Smoky Mountains
Cold	0.74	0.71	0.67	0.69	0.70	0.77
Dry	2.83	2.83	2.83	2.83	2.83	2.83
Frozen Precipitation	1.16	1.16	1.16	1.16	1.16	1.16
Heat	6.36	4.19	4.01	4.88	6.26	6.00
Hydrologic	1.23	1.21	1.15	1.20	1.21	1.21
Lightning	2.08	2.08	2.08	2.08	2.08	2.08
Rotational Winds	2.08	2.08	2.08	2.08	2.08	2.08
Straight Winds	2.08	2.08	2.08	2.08	2.08	2.08
Wildfire	1.15	1.15	1.15	1.15	1.15	1.15

Table 7.4 – Projected Future Cost of Inaction for RCP 8.5 Scenario

Average Annual Risk Cost ($): 2035-2055 (RCP 8.5)							
Hazard	Cumberland Plateau	Highland Rim	Inner Coastal & Alluvial Plain	Nashville Basin	Ridge & Valley	Unaka-Smoky Mountains	**TOTAL**
Cold	2,442	24,265	1,106	5,268	36	-	33,117
Dry	1,739,752	7,846,962	4,484,869	2,525,882	331,658	165,829	17,094,953
Frozen Precipitation	2,506,566	2,263,745	322,052	2,557,338	29,737	59,072	7,738,509
Heat	-	1,980,911	9,490,708	356,595	142,139	-	11,970,353
Hydrologic	4,763,094	10,594,561	169,339,600	140,444,944	17,349,189	3,452,562	345,943,949
Lightning	167,245	851,146	452,668	1,136,559	437,372	431,478	3,476,468
Rotational Winds	5,621,540	38,849,826	57,927,227	45,778,268	21,465,547	2,668,142	172,310,551
Straight Winds	1,257,932	4,623,260	12,723,153	4,202,868	5,471,194	1,824,940	30,103,347
Wildfire	900,490	1,065,003	943,783	1,238,174	987,076	987,076	6,121,602
Earthquake	1,531	1,391	51,736	16,210	4,495	1,793	77,157
TOTAL	16,960,593	68,101,069	255,736,901	198,262,106	46,218,443	9,589,099	594,792,849

A similar analysis was performed for the RCP 4.5 scenario, with the results appearing in Tables 7.5 and 7.6. As cam be seen, the results are not very different from the RCP 8.5 scenario. This is to be expected, however, as any significant distinction between the two scenarios does not become apparent until after mid-century (see Table 5.1). **What this means is that regardless of any actions that the world may be able to take to reduce its carbon emissions, extreme weather risk will remain unfettered until at least mid-century.**

[27] Regional population growth factors were derived as weighted averages of individual county growth projections for counties located in each respective region. The individual county growth projections appear in Appendix B.1.

Table 7.5 – Event Growth Factors for RCP 4.5 Scenario

Event Growth Factors Under RCP 4.5 Scenario						
Hazard	Cumberland Plateau	Highland Rim	Inner Coastal & Alluvial Plain	Nashville Basin	Ridge & Valley	Unaka-Smoky Mountains
Cold	0.74	0.78	0.67	0.69	0.70	0.77
Dry	2.83	2.83	2.83	2.83	2.83	2.83
Frozen Precipitation	1.16	1.16	1.16	1.16	1.16	1.16
Heat	6.36	3.51	3.47	5.00	4.50	6.00
Hydrologic	1.13	1.12	1.15	1.18	1.16	1.16
Lightning	2.08	2.08	2.08	2.08	2.08	2.08
Rotational Winds	2.08	2.08	2.08	2.08	2.08	2.08
Straight Winds	2.08	2.08	2.08	2.08	2.08	2.08
Wildfire	1.15	1.15	1.15	1.15	1.15	1.15

Table 7.6 – Projected Future Cost of Inaction for RCP 4.5 Scenario

Average Annual Risk Cost ($): 2035-2055 (RCP 4.5)							
Hazard	Cumberland Plateau	Highland Rim	Inner Coastal & Alluvial Plain	Nashville Basin	Ridge & Valley	Unaka-Smoky Mountains	**TOTAL**
Cold	2,442	26,131	1,106	5,268	36	-	34,983
Dry	1,739,752	7,846,962	4,484,869	2,525,882	331,658	165,829	17,094,953
Frozen Precipitation	2,506,566	2,263,745	322,052	2,557,338	29,737	59,072	7,738,509
Heat	-	1,661,409	8,210,935	371,453	106,604	-	10,350,401
Hydrologic	4,394,522	9,772,569	169,339,600	138,409,510	16,641,059	3,319,771	341,877,031
Lightning	167,245	851,146	452,668	1,136,559	437,372	431,478	3,476,468
Rotational Winds	5,621,540	38,849,826	57,927,227	45,778,268	21,465,547	2,668,142	172,310,551
Straight Winds	1,257,932	4,623,260	12,723,153	4,202,868	5,471,194	1,824,940	30,103,347
Wildfire	900,490	1,065,003	943,783	1,238,174	987,076	987,076	6,121,602
Earthquake	1,531	1,391	51,736	16,210	4,495	1,793	77,157
TOTAL	16,592,020	66,961,443	254,457,128	196,241,530	45,474,778	9,456,308	589,185,000

8. COST OF ACTION VERSUS INACTION

The National Institute of Building Sciences (NIBS) recently published a study on the financial impacts of investing in natural hazard resilience actions[28]. The study focused on four specific natural hazards: 1) riverine and coastal flooding, 2) hurricanes, 3) earthquakes, and 4) wildfires (i.e., fires at the wildland-urban interface)[29]. The assessment was based on measuring the savings from investing in resilience activities by calculating estimated reductions in disaster impacts due to: 1) future deaths, non-fatal injuries and cases of post-traumatic stress disorder (PTSD), 2) property repair costs, 3) sheltering costs for displaced households, 4) business interruption costs, 5) loss of economic activity in the broader community, 6) loss of service to the community when fire stations, hospitals, and other public buildings are damaged, 7) cost for urban search and rescue, and 8) administrative fees associated with insurance.

Sources of data for conducting this assessment included federal spending on 23 grant programs administered by the Federal Emergency Management Agency (FEMA), Economic Development Administration (EDA), and the Department of Housing and Urban Development (HUD), combined with any state and local funds required to match some of those programs. Notably, the study did not include spending on resilience activities performed directly by the federal government (e.g., U.S. Army Corps of Engineers flood control project, U.S. Department of Agriculture prescribed burns).

It is important to recognize that several disaster-related impacts are not included in the NIBS study. Any disaster can disconnect people from friends, school, work and other familiar places, ruin family heirlooms, and harm pets. Larger disasters may cause permanent harm to community culture and way of life, and greatly impact socially vulnerable populations. Moreover, there may be longer-term consequences to public health and the environment. To the extent that a future disaster event generates these additional impacts, the benefits of a resilience action will exceed the return-on-investment reported herein.

NIBS established its baseline for comparison of action versus inaction by referencing the following: 1) the costs and benefits of designing all new construction to exceed select provisions in the 2015 International Building Code (IBC)[30] and International Residential Code (IRC)[31], and implementation of the 2015 International Wildland-Urban Interface Code (IWUIC)[32], 2) design based on meeting the 2018 IRC and IBC codes versus 1990-era design and National Flood Insurance Program requirements, 3) case studies involving utility and transportation infrastructure based on EDA grants and California state projects, and 4) the impacts of federal mitigation grants provided by FEMA, EDA, and HUD.

The IBC is a set of requirements for design and installation of innovative materials in the built environment to provide safeguards from hazards in order to preserve public health and safety. The 2015 IBC includes standards on flood-resistant material, adds new requirements for tornado shelters in certain buildings, clarifies special seismic inspection requirements, and clarifies determination of substantial damage and significant improvement. The 2018 IBC adds a requirement to perform structural observation of high-rise and risk category IV buildings relative to seismic risk, and updates structural design requirements for buildings in high wind regions.

[28] National Institute of Building Sciences. (2018). Natural Hazard Mitigation Saves: 2018 Interim Report.
[29] Hurricanes have not been recorded in Tennessee and therefore are not considered in this study.
[30] International Code Council. (sourced 2019), International Building Code, https://www.iccsafe.org/products-and-services/i-codes/2018-i-codes/ibc/
[31] International Code Council. (sourced 2019), International Residential Code for One and Two Family Dwellings, https://www.iccsafe.org/products-and-services/i-codes/2018-i-codes/irc/
[32] International Code Council. (sourced 2019), 2015 International Wildland-Urban Interface Code, https://codes.iccsafe.org/content/document/556?site_type=public

The IRC creates minimum regulations for one- and two-family dwellings (of three stories or less), relative to building, plumbing, mechanical, fuel gas, energy and electrical provisions. The 2018 IRC updates seismic maps and corresponding design criteria, and increases the amount of studs used in high wind regions to support headers.

The 2015 IWUIC applies to the construction, alteration, movement, repair, maintenance and use of any building, structure or premises within designated wildland-urban interface areas. It requires non-combustible roof and rated cladding, glazing and underfloor protection, assured water supply, and defensible space.

The estimated benefit/cost ratios (B/C), expressed as dollars saved for each dollar of resilience investment, are reported in Table 8.1. These results reflect national averages based on the aforementioned data sources. Where possible, the NBIS study also estimated B/C ratios for specific states. In the case of Tennessee, the study reported B/C ratios of 3:1, 6.55:1 and 6.86:1 for earthquakes, floods, and wind, respectively. Whereas only 15% of Tennessee counties would directly benefit from investment in earthquake resilience based on 2015 IBC standards, over 75% of the counties in the State would benefit from investing to meet the 2018 IBC requirements.

Table 8.1 – Benefit/Cost by Hazard and Mitigation Action

	Exceed 2015 Code Requirements	Meet 2018 Code Requirements	Utilities & Transportation Case Studies	Federally Funded Programs
Overall Hazard B/C Ratio	4:1	11:1	4:1	6:1
Riverine Flood	5:1	6:1	8:1	7:1
Wind	5:1	10:1	7:1	5:1
Earthquake	4:1	12:1	3:1	3:1
Wildland-Urban Interface Fire	4:1	N/A	N/A	3:1

The NIBS study implies that resilience actions the State could undertake would provide a minimum return-on-investment of 3:1, with much higher returns associated with flood and wind resilience initiatives. This implies that **prudent investment of resilience resources could save the State a minimum of hundreds of millions of dollars a year in expected disaster costs.** Of particular note are the various stakeholders the NIBS study identified as beneficiaries from resilience investment. They include developers, property owners, lenders, tenants, and the community at large. Although each group accrues benefits from investing in disaster avoidance, the NIBS study found that property owners and tenants stand to gain the most from such actions.

In addition to the savings due to avoided costs associated with disaster loss and damage, investment in resilience actions can act as an economic stimulus by providing opportunities to spur job growth and other forms of economic development. Also, while codes are generally applicable to new construction and major renovations, many mitigation measures might be cost-effective for existing buildings that are not otherwise part of a significant construction initiative.

9. CASE STUDIES

To illustrate how future natural hazard risks may impact Tennessee and potential resilience actions to consider, several case studies were prepared and are presented below, representing plausible events that could occur during the future study horizon. They include:

- Drought in the Highland Rim region
- Wildfire in the Unaka-Smoky Mountains
- Flooding in the Nashville Basin
- Earthquakes in west Tennessee and along the Cumberland Plateau
- Extreme heat in the Inner Coastal and Alluvial Plain
- Winter Storm in the Ridge and Valley region

Each case study is organized according to background information, event scenario, consequential impacts, and potential resilience strategies.

9.1 Drought in the Highland Rim Region

9.1.1 Background

Drought is ultimately an absence of water[33]. It is classically defined as a period of below average precipitation in a given location, which results in prolonged shortages in water supply (the supply can be atmospheric precipitation, surface water, or ground water). A drought can last for months or years, or it may be declared after only a two-week period[34].

Water availability for domestic use in the southeast U.S. is anticipated to decline in the future[35]. In 2000, the U.S. Drought Monitor began tracking and reporting drought conditions nationwide. Since that time, Tennessee has experienced several periods of drought (see Figure 9.1), the most significant one lasting 116 weeks between February 2007 and April 2009. In October 2007, over 70% of the State was considered to be in D4 drought status (exceptional drought with widespread crop/pasture losses and water shortages leading to emergency status)[36].

[33] NOAA. 2019. Definition of Drought. Available at https://www.ncdc.noaa.gov/monitoring-references/dyk/drought-definition.
[34] Cornell. http://monroe.cce.cornell.edu/environment/drought
[35] USGCRP (2014). Carter, L. M., J. W. Jones, L. Berry, V. Burkett, J. F. Murley, J. Obeysekera, P. J. Schramm, and D. Wear, 2014: *Ch. 17: Southeast and the Caribbean. Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 396-417.
[36] Drought.gov - https://www.drought.gov/drought/states/tennessee

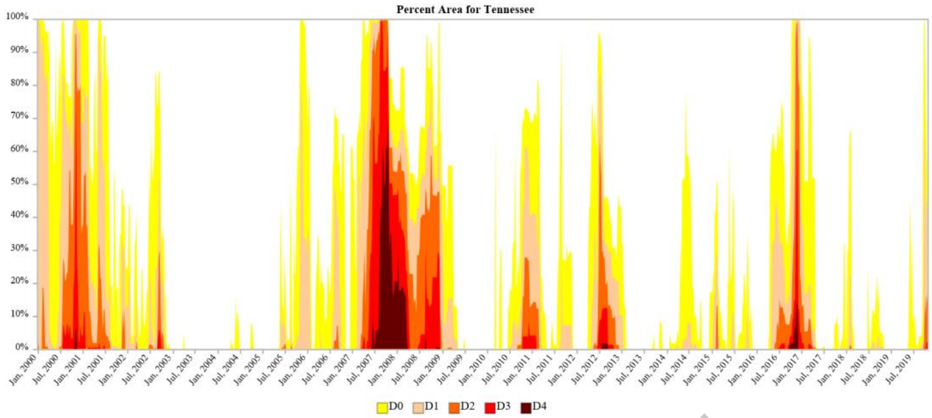

Figure 9.1 - Historic Drought Periods in Tennessee (January 2000-October 2019)[37]
D0 = Abnormally Dry, D1 = Moderate Drought, D2 = Severe Drought, D3 = Extreme Drought, D4 = Exceptional Drought

9.1.2 Contributing Factors

Lack of precipitation over a prolonged period is considered the most common factor contributing to drought conditions. Water usage at a rate that exceeds nature's ability to replenish water supply can also cause drought. Tennessee relies on surface waters (rivers, streams, reservoirs, lakes) for irrigation, navigation, power generation, recreation, habitat and municipal drinking consumption. In some portions of the State, groundwater is also used as a source for several of these applications. Areas reliant upon groundwater can suffer from drought similarly to surface water supply locations. However, areas utilizing surface waters can often see a replenishment of the supply more directly through precipitation, whereas groundwater supplies require aquifer recharge that can take years or decades, sometimes requiring augmentation by humans through aquifer recharge.

9.1.3 Concerns for the Highland Rim Region

As previously noted, Tennessee has experienced its share of drought periods in the past few decades, some of which have been significant. Future projections for the southeast U.S. by the National Climate Assessment (NCA)[38] include small increases in precipitation. However, temperature increases, coupled with increased water demand by a growing population, as well as additional demand for irrigation of crops due to heat, energy generation (including cooling waters) and other uses, are anticipated to strain available water resources. Increased temperatures can also lead to faster evaporation following precipitation events and from surface waters. The projected trends for water availability as defined by the U.S. Global Change Research Program and NCA show decreases across the southeast U.S., including Tennessee (see Figure 9.2). Note that the entire Highland Rim region is identified as having a moderate decline in water availability[39].

Drought can affect many sectors and populations. Extended drought can lead to human casualties, both directly or indirectly, due to dehydration, malnutrition and associated diseases. Much of the Highland Rim region is rural and heavily dependent on an agriculture economy. Drought can prove devastating to crop productivity and survival, especially in the warm summer months when crops typically grow more rapidly. Livestock may also become emaciated or die due to lack of water or diminished food sources.

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[37] Source: Drought.gov
[38] National Climate Assessment, 2018, Southeast Region Chapter, available at https://nca2018.globalchange.gov/chapter/19/.
[39] The area shaded with dashed lines signifies stronger confidence in the projections.

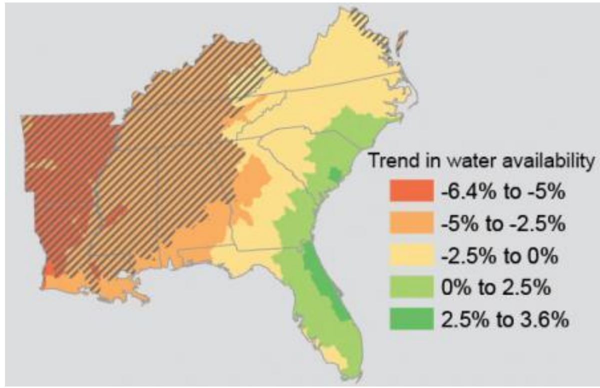

Figure 9.2 - Predicted Change in Water Availability Between 2010 and 2060[40]

Impacts to infrastructure systems include both reduced flows for hydropower and/or cooling water for other power generation activities, and low flows in navigable waterbodies, thereby reducing or halting cargo movements, which can in turn lead to business disruptions for those depending on the cargo that cannot be delivered. Additional impacts may include water shortage for industrial uses, damage to habitat (both terrestrial and aquatic) due to limited water supply, reduced water quality due to lower flushing of aquatic systems, and even brown- or black-outs due to strains on energy production.

9.1.4 Potential Resilience Strategies

Developing resilience strategies is challenging in that drought typically is not a localized event, and it is difficult to accurately predict and/or know when it is going to start or end. Central to managing the impact of drought is to ensure access to adequate water supplies for essential services. The following are some potential resilience strategies:

- In areas where surface water (rivers and streams) is primarily used for water supply, having high quality backup wells may prove useful for meeting critical drinking water needs in a community. Having partner agencies who can truck in bottled water or potable water in tanks may also prove beneficial.
- During times of drought, water conservation becomes even more critical. Public education and outreach prior to a drought can help prepare citizens and businesses on how to best utilize limited available water supplies in a drought situation.
- Utilizing rainwater harvesting and storage from rooftops can help provide water supply during times of drought. In some areas, gray water (water from showers and handwashing) can be repurposed for irrigation. Using recycled wastewater that has been properly treated can also provide water supply for purposes such as crop irrigation and, in some cases with suitable treatment, it could be used for potable water.
- Diversifying crops, planned crop rotation to minimize erosion, and investing in drought-resistant species can reduce agricultural impacts. This can be accomplished in part through support provided by local agricultural extension agents to identify alternative crops that are both drought resistant and economically attractive for area farmers.

[40] Source: U.S. Global Change Research Program

9.2 Wildfire in the Unaka-Smoky Mountains

9.2.1 Background

Whether a wildfire starts, and how much damage it may do once ignited, involves a complex relationship among climate and weather factors, forest management practices and preparedness, natural ecosystems, and the human built environment. In general, states are responsible for responding to wildfires that occur on local, state, or private lands, while the federal government addresses fires that begin on federal lands.[41] Although the largest fires have historically occurred in the western part of the U.S., more fires occur in the East. MunichRe has recognized that changing climate conditions are a significant factor in the increasing fire risk and costly damages.[42]

Tennessee has over 14.1 million acres of forested land, with 556,000 acres situated in U.S. National Forests.[43] In late November 2016, a fire ignited in the Great Smoky Mountains National Park near Gatlinburg, ultimately becoming the largest fire in the Park's history, causing up to $2 billion in property damage (2,121 homes destroyed), injuring nearly 200, and taking 14 human lives.[44]

9.2.2 Contributing Factors

When the 2016 fire occurred, east Tennessee was experiencing a severe, prolonged and "unusual" drought (see Figure 9.3).[45] This dry condition, combined with extreme winds, fueled the spread and destruction of the fire. The National Park Service concluded that drought conditions and lack of preparedness (especially proper communications between park officials and first responders) contributed to the losses, while noting that it "appears that we are entering an era where the 'unprecedented' is happening with increasing frequency. This signifies a massive organizational challenge for our federal land agencies – particularly those that have worked in relatively stable systems for a long time and that are simultaneously facing increasing budget constraint."[46]

[41] *Wildfire Statistics,* Congressional Research Service, October 3, 2019, available at https://fas.org/sgp/crs/misc/IF10244.pdf.
[42] *Climate Change increases wildfire risk in California,* Munich Re, available at https://www.munichre.com/topics-online/en/climate-change-and-natural-disasters/climate-change/climate-change-has-increased-wildfire-risk.html.
[43] *Tennessee Forest Health Highlights*, 2009, Tennessee Division of Forestry and U.S. Forrest Service, available at https://fhm.fs.fed.us/fhh/fhh_09/tn_fhh_09.pdf.
[44] *Chimney Tops 2 Fire Review, Individual Fire Report*, National Park Service, U.S. Department of the Interior, Division of Fire and Aviation, available at https://www.wildfirelessons.net/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=2291b1f9-d65a-4915-2257-d76919c16132&forceDialog=0.
[45] *Id.*
[46] *Id.* at 106.

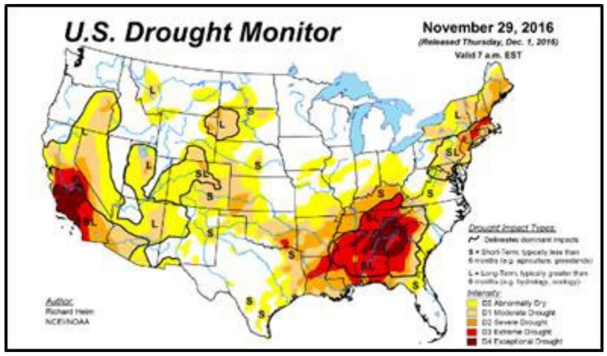

Figure 9.3 - Drought Conditions in November, 2016

A recent study undertaken in response to the Camp fire in California identified important factors within the control of the local and state governments to mitigate risks - integrating and updating state building codes and fire hazard maps. A 2008 California law mandated fire resistant roofs, but only in high fire hazard zones, using zones defined by maps created in the late 1990s, based on now outdated climate information. Even so, the effectiveness of the 2008 law was observed in the data as shown in Table 9.1[47].

Table 9.1 – Impact of California Fire Resistant Roof Law

	Homes built 2008 or later	Homes built before 2008
No damage	50%	17.7%
Minor damage	8.8%	3.3%
Totally destroyed or major damage	40.6%	79.0%

While the 2008 building code appears to have contributed to saving a significant percentage of homes, nearly one-half of the homes built to the "better" 2008 standard were still destroyed. As a result, California is developing new fire hazard zone maps, which will include updated climate and weather information, as well as more current development data.[48]

9.2.3 Concerns for Unaka-Smoky Mountain Region

Although precipitation projections to the middle of the century indicate only small total increases in precipitation for the Unaka-Smoky Mountain region, it is less understood how precipitation patterns will change, and may be interspersed with longer periods of drought, or how/whether wind patterns will change, factors that can increase potential wildfire risk. Temperatures in this region are expected to rise, both in terms of annual averages and days with extreme high temperatures.[49] The recent U.S. National Climate Assessment devotes a chapter to the southeast region of the U.S., stating that "[i]n the future, rising temperatures and increases in the duration and intensity of drought are expected to increase wildfire occurrence and also reduce the effectiveness of prescribed fire."[50]

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[47] D. Kesley, April 11, 2019, from Destined to Burn, McKlatchy, "while your house may burn while your neighbors survives the next wildfire." Available at https://www.sacbee.com/news/california/fires/article227665284.html

[48] L. Pickoff-White, *MAP: Do you Live in a High Risk Fire Zone*, The California Report, July 16, 2019, available at https://www.kqed.org/news/11759209/map-do-you-live-in-a-high-risk-fire-zone. Importantly, a fire hazard zone is not a risk zone; hazard zones indicate how a fire will behave and where it can spread, not the damage it can do.

[49] See CMIP output for Temperature for Unaka-Smoky Mountain Region. Both RCP 8.5 and RCP 4.5 show rising temperatures by mid-century.

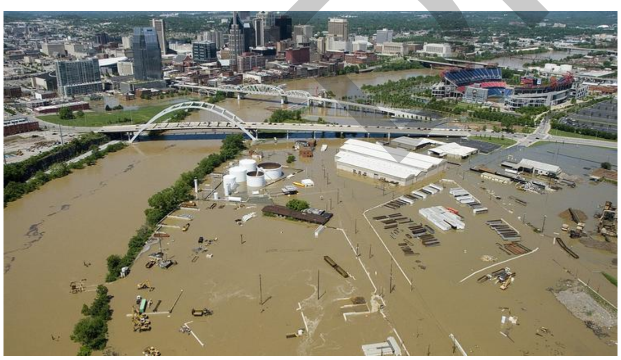
[50] National Climate Assessment, 2018, Southeast Region Chapter, available at https://nca2018.globalchange.gov/chapter/19/.

9.2.4 Potential Resilience Strategies

Among the strategies under consideration to strengthen wildfire resilience are the following:

- Integrate fire building codes and updated climate data. Currently, Tennessee does not have a statewide mandate to account for area-specific fire risk when building residential structures, although the State has adopted the International Building Code of 2012.[51] A comprehensive review to determine whether and, if so, how to integrate updated climate and weather data into building codes has potential to lower damage to newly built homes in fire hazard areas.
- Engage/incentivize local governments to review the costs and benefits of adopting more protective fire building standards or identifying fire hazard zones. Local governments, such as counties, have substantial authority in Tennessee to impose more restrictive building requirements than the State law mandates. Our review revealed no peer-reviewed research on these topics in east Tennessee. However, post-fire press interviews with local officials and residents found that: 1) Sevier County building codes do not require more fire-resistant building materials or maintain certain distances between structures and trees, 2) structures rebuilt after the fire were not required to build to more protective standards, and 3) some residents voluntarily adopted increased "Firewise"[52] building standards after the fire.
- Undertake a research study to collect data on homes impacted by the 2016 fire. Such a study would provide the County and State with needed data regarding precise building materials and practices that contributed to homes burning or not burning in the fire, and information on homes/structures that were rebuilt, and to what standards. Collecting this data over time, and after the next fire, can prove invaluable to better understand the potential impact of building codes and fire prevention practices on damage reduction and cost expenditures.
- Support local governments to improve/incentivize voluntary fire resilience practices. These may include:
  - clearing fuel around structures (e.g., brush, leaves)
  - identifying and communicating local safe zones, such as large parking lots away from burning material, that can provide shelter during fires
  - improved public communication regarding climate conditions that increase fire risk[53]

<u>9.3 Flooding in the Nashville Basin</u>



[51] Tennessee law requires the state fire marshal to promulgate rules establishing minimum statewide building standards, including fire resistant ratings and requirements. Tenn. Code Ann. § 68-120-101(a). The 2012 International Business Code has been adopted by the state fire marshal for this purpose. *See Tennessee Fire Marshall's Office Currently Adopted Codes,* updated August 4, 2016, available at *https://www.tn.gov/content/dam/tn/commerce/documents/fire_prevention/posts/2016.08.04_sfmo_code_adoption_and_history.pdf*.

[52] National Fire Protection Association; https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Firewise-USA

[53] These items were in part generated during hazard mitigation planning undertaken by Eastern Tennessee State University for Sevier County.

9.3.1 Background

Floods are the most common and costly disaster worldwide and Tennessee has experienced its share of flood events. The southeastern U.S. has been experiencing more heavy downpours since the 1980s, and the NCA projects that the region will continue to see precipitation events with greater intensity, higher frequency, and longer duration[54]. Notably, in May 2010, over 13 inches of precipitation fell in a 48-hour period over much of middle Tennessee, breaking historic rainfall amount and flood levels[55].

9.3.2 Contributing Factors

There are several different types of floods and corresponding contributing factors. For example, floods can be episodic or chronic; they can also be highly localized or span large areas.

Flash flooding is caused by an inability of the ground and stormwater management systems to absorb and handle a short, intense storm event. Flash floods occur in a short time span during or immediately following a precipitation event – usually less than 6 hours. These occurrences create a significant amount of runoff (due to the ground being oversaturated and unable to absorb additional water, and/or in between extended dry periods where the soil reflects the water due to excessive dryness). Inland and riverine flooding can occur when water levels rise over the top of river banks due to excessive rain from tropical storms migrating inland, persistent storms over the same area for extended periods of time, or combined runoff from rainfall and snowmelt[56]. Inland and riverine flooding can also occur in communities that are located downstream of where a flooding event initially occurs. Additionally, failures of infrastructure such as dams and levees due to deferred maintenance or extraneous events can result in flood impacts.

Culverts and stormwater infrastructure that have been designed based on historic precipitation data may not be able to handle future precipitation patterns. Moreover, flood impacts will be exacerbated by continued development that generates additional impervious areas.

9.3.3 Concerns for the Nashville Basin

The Nashville Basin is characterized by an abundance of water resources, comprising rivers, streams and lakes. The area receives a moderate amount of precipitation each year, with the region having experienced its share of flooding in recent years[57].

In the Nashville Basin, there is a mix of urban and developed communities as well as rural, predominantly agricultural areas. As the region continues to grow with significant population increases anticipated in the next few decades, potentially more communities and infrastructure will be at flood risk.

Flooding can wreak havoc on a community in many ways. Buildings can incur structural damage due to the forces of flood waters, and electrical and HVAC systems can become compromised after becoming wet. Mold and mildew can also damage building materials, the contents, and create a human health hazard. Flooded roadways and bridges can prevent emergency responders from accessing affected areas, block individuals from reaching safety, and restrict personal mobility. These risks are particularly acute for socially vulnerable populations (e.g., elderly, young, impoverished, etc.). Additionally, floodwaters can carry debris such as logs

[54] USGCRP (2014). Carter, L. M., J. W. Jones, L. Berry, V. Burkett, J. F. Murley, J. Obeysekera, P. J. Schramm, and D. Wear, 2014: *Ch. 17: Southeast and the Caribbean. Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 396-417.

[55] NOAA/NWS. Remembering the May 2010 Flood. Available at https://www.weather.gov/ohx/may2010flood.

[56] NOAA. Severe Weather 101. Available at https://www.nssl.noaa.gov/education/svrwx101/floods/types/.

[57] News Channel 3. Federal emergency officials to review Tennessee flood damage. March 13, 2019. Available at https://wreg.com/2019/03/13/federal-emergency-officials-to-review-tennessee-flood-damage/

and other large objects, hazardous materials and sewage, carcasses of dead animals and/or people, and poisonous snakes. Transportation impacts can also have secondary and regional impacts when supply chains are disrupted due to disruptions to freight corridors. Indirect impacts of flooding can include loss of wages from missed work days, illness, and stress-related mental health issues.

Given that portions of the Nashville Basin are more rural in nature, concerns for impacts to agriculture also exist. Many field crops are planted in low-lying areas due to the fertility of the soils and access to water for irrigation. Agricultural lands can flood at prime times in the crop growing season, affecting yield and sometimes completely destroying crops, leaving farmers with significant financial burden from lost income. In addition to field crops, livestock can succumb to injury and death in swift flood waters or by being cutoff for an extended period of time from food supplies and veterinary care. Transportation system impacts due to flooding can also limit a farmer's ability to ship products to market.

9.3.4 Potential Resilience Strategies

The metropolitan Nashville-Davidson County area has taken a proactive approach to flood management that began prior to the 2010 flood event. Metro Water Services has implemented policies and regulations for low-impact development, aggressively working to remove properties from harm's way through a home buyout program that has been in place since the late 1970s, implementing a 4-foot freeboard requirement on new construction, and working to rehabilitate the stormwater and combined sewer overflow (CSO) system. Despite these accomplishments, Nashville still has a "wish list" of homes to buy out, and flash flooding still occurs in many parts of the County due to more short-duration, intense storm events than previously experienced.

Other, smaller municipalities may be competing for federal mitigation funds or post-disaster recovery funds and may lack the staff and resources to take an aggressive and proactive approach similar to Nashville-Davidson County. Suburban areas that are growing quickly, but remain predominantly rural (e.g., Sumner County) may have to build up to the level of flood protection desired. Implementing policies such as low-impact development regulations and instituting a stormwater fee can reduce flood risk at minimal cost to the local government and taxpayers. Identifying flood mitigation projects that have a high return-on-investment (ROI) and funded by federal resources represent another resilience strategy.

Below is a list of flood resilience activities for implementation consideration:

- Increase greenspace and pervious areas to absorb and slow runoff from heavy precipitation events. This can be accomplished by encouraging homeowners and businesses to use pervious pavers and/or gravel for driveways and parking lots as opposed to pavement or asphalt. Additionally, creating natural buffers around streams and rivers can help slow flood waters and increase absorption.
- Implement low impact development policies. Such policies require developers to reduce the potential for runoff to flood stormwater or sewer systems by capturing it on-site for gradual release, using detention basins/ponds or other green infrastructure (possibly with treatment for improved water quality).
- Prevent development in floodplains and remove people/structures that are in high flood risk areas. Regulations that prohibit or restrict development in floodways (as defined by FEMA flood insurance rate maps or otherwise) can reduce the number of people and infrastructure assets at risk.
- Protect critical infrastructure located in or near floodplains. Water and wastewater treatment plants, natural gas pipelines, roads, bridges, etc. are often situated in close proximity to flood-prone areas. Hardening and/or protecting these assets with levees, floodwalls, and/or ensuring that redundancies are in place will allow for flooding to occur with lesser impact. Power systems for pumps and other equipment used for water and wastewater treatment systems should be elevated above anticipated flood levels (ideally above the 500-year return period elevation or higher for future protection).

- Enhance public education and awareness. Most flood-related deaths occur due to people not heeding warnings and/or trying to cross flood waters unsuccessfully in vehicles. Individuals need to be educated on flash flooding and how to stay safe when such situations arise. They also need to be aware of community resources, such as shelters, in the event of a flood.
- Invest in a multi-faceted approach to warning citizens, including methods to reach socially vulnerable populations.
- Create system redundancies. Distribute emergency response personnel and equipment throughout the region so that individuals needing help are not cut off due to flooding. Ensure that alternative routes are available for both residents and emergency response personnel.
- Institute a higher than necessary freeboard requirement that requires the finished floor elevation in a structure be higher than anticipated flood levels.

9.4 Earthquakes in West Tennessee and Along the Cumberland Plateau

9.4.1 Background
Earthquakes occur as tectonic plates on the earth's crust slide past each other, releasing energy in the form of ground shaking and wave propagation from the area of slippage (also known as the epicenter). Earthquakes happen worldwide every day[58], some being significant while others are barely noticed by people in the vicinity. Earthquake damage occurs due to waves that move through the Earth's surface from the epicenter. The magnitude, frequency and direction of the waves can result in different levels of damage.

9.4.2 Contributing Factors
As tectonic plates move past one another, it can cause friction that results in slippage, which spawns an earthquake. Seismographs are used to identify both small slippages or ground shaking that might indicate a larger earthquake is about to happen. However, scientists cannot really predict when an earthquake is going to happen nor its corresponding strength.

Evidence of historic earthquakes by studying faults and geologic formations can help identify when and how significant historic earthquakes occurred, serving as data points in estimating the size and location of future earthquakes. Models and scenarios have been developed to estimate future slippages and how the waves would propagate from estimated epicenters to help with planning and preparedness. Additionally, historical evidence that shows where slippage may have occurred at regular intervals can be used to estimate the probability of occurrence of another earthquake in that vicinity[59].

[58] USGS. Recent Earthquakes Map Viewer. Available at https://earthquake.usgs.gov/earthquakes/map//.
[59] USGS. Earthquakes 101. Available at https://www.usgs.gov/natural-hazards/earthquake-hazards/science/science-earthquakes?qt-science_center_objects=0#qt-science_center_objects

9.4.3 Concerns for West Tennessee and the Cumberland Plateau

The most seismically active area in the eastern U.S. is the New Madrid seismic zone, which runs along the Mississippi River on the western side of the State[60]. According to the USGS, since 1996, over 5,500 earthquakes have occurred in Tennessee. Approximately 95% of those earthquakes were at a magnitude of 2.5 or less. The most significant earthquakes that the State has experienced on record was when the New Madrid zone had a series of three large earthquakes that ranged in magnitude of 7-8 in the winter of 1811-1812[61]. The magnitude of these earthquakes was approximated based on understanding of damages induced and through comparison to other earthquakes over time. Accounts from that period report that church bells rang for hundreds of miles away and the earthquakes were significant enough to create Reelfoot Lake.

While scientists cannot predict when another major earthquake will occur along the New Madrid fault line, they are convinced that another major earthquake will happen. The fault is highly active and the impacts could be severe due to the abundance of soils in the area that are not very stable structurally. In soft sediment that is present in west Tennessee, liquefaction (where soils become less stable and flow more like a liquid) is a significant concern because it affects the stability of foundations of buildings, roadways, and other infrastructure. The energy of some seismic waves tends to be absorbed by solid rock, while the slower waves may pass through the solid rock and become absorbed and amplified by soft sediments. Thus, much worse earthquake damage is often observed in areas with soft sediments where the waves are amplified.[62]

An area receiving less attention relative to the New Madrid seismic zone is in the eastern portion of the Tennessee. The largest recorded earthquake in that area was estimated to be a 4.4 in magnitude, occurring in 2018 near Decatur. This region has more bedrock and different soil types that present lesser concerns than the west Tennessee region.

Much effort and focus has been on New Madrid, with exercises such as the Great Shake Out and other activities to help emergency response personnel and community leaders prepare for a large earthquake event in the region. TDOT and other agencies have worked to retrofit bridges and other infrastructure to withstand the vibrations and waves that may accompany a large earthquake in west Tennessee. In much of that region, stricter building codes have been established at the local level to help reduce the impacts of a significant earthquake event.

One concern for earthquakes and the fault line in east Tennessee is that similar efforts to retrofit infrastructure to reduce the impacts of a significant earthquake have not been as rigorous. Additionally, while moderate earthquakes have occurred there recently, the area may not be doing as much to educate and prepare residents on what to do in the event of a significant earthquake occurrence.

Another concern, especially in west Tennessee, is the tension between building development and the need to construct or retrofit buildings in accordance with earthquake building codes[63]. The tradeoff of making construction "affordable" and also ensuring safety for a low probability, high consequence future earthquake event is presenting a challenge for local policy makers and building officials.

[60] Missouri Department of Natural Resources. 2019. Facts about the New Madrid Seismic Zone. Accessed October 2019. Available at https://dnr.mo.gov/geology/geosrv/geores/techbulletin1.htm.
[61] USGS. 2019. The New Madrid Seismic Zone. Accessed October 2019. Available at https://www.usgs.gov/natural-hazards/earthquake-hazards/science/new-madrid-seismic-zone?qt-science_center_objects=0#qt-science_center_objects.
[62] Earle, S. (2015). *Physical Geology*. Victoria, B.C.: BC campus. Retrieved from https://opentextbc.ca/geology/
[63] EERI. "Mitigation works: Earthquake". Earthquake Engineering Research Institute. Available at http://mitigation.eeri.org/files/resources-for-success/00022.pdf.

The most obvious earthquake impacts are related to structural collapse, which can result not only in property damage, but also human casualties. Buildings, roadways and bridges can collapse when their foundations and/or supports are compromised and become unstable. Unstable or steep slopes may result in landslides as the result of ground shaking. Fires can occur due to damaged power lines or underground pipelines, while water pipeline breaks can result in localized flooding. Urban areas may be particularly susceptible due to building and population density, in addition to having a larger number of multi-story buildings that can be less stable during shaking.

9.4.4 Potential Resilience Strategies

While it is virtually impossible to predict the timing or magnitude of an earthquake, the impacts can be reduced through planning, and making preparations for response and recovery activities. Resilience activities to consider include:

- Investing in community education to better understand the risks, consequences and response actions associated with natural hazards[64].
- Identifying vulnerable buildings and critical infrastructure in locations where ground shaking and seismic waves may lead to liquefaction and destabilization of foundations.
- Identifying potential landslide locations that may be vulnerable due to existing slope and/or soil conditions.
- Determining routes for emergency response personnel to utilize that avoid locations that may be compromised by an earthquake, and establishing transportation network redundancies to access key facilities and/or vulnerable populations.
- Ensuring that utilities have plans in place to shut off gas and water lines, if necessary.
- Performing community drills and exercises that include all potential stakeholders (e.g., schools, hospitals, businesses, utilities, non-profit service organizations, etc.).
- Hardening and/or retrofitting infrastructure to meet adequate earthquake codes/guidelines. While all buildings and infrastructure assets cannot feasibly be hardened and/or retrofitted with the latest advances in seismic damper technologies, efforts can be made to prioritize where funding would be most cost-effective in maintaining a functioning community.

9.5 Extreme Heat in the Inner Coastal and Alluvial Plain

[64] While most Tennesseans are aware of what to do in the event of a tornado, many may not know to get out into open areas in an earthquake, nor may they realize that a foreshock and small tremor could be the warning sign for a larger earthquake.

9.5.1 Background
Occurrences of extreme heat, or heat waves, are common in Tennessee, especially in the western part of the State, which has average high temperatures in the summer between 85°F and 90°F.[65]

Extreme heat injures or kills more people in the U.S. than any other extreme weather event, including floods, lightning, tornados and hurricanes.[66] Temperature alone is not a sufficient measure of the impact of heat on the human body. A number of factors are important, including whether a person is in direct sun or the shade, type of clothing being worn, relative humidity, and level of physical exertion[67]. The "heat index" was developed to address some of these factors, and provides a measure of temperature and humidity. According to the NWS, any day in which the heat index exceeds 105° is dangerous, with sunstroke and heat exhaustion likely[68]. For example, if the air temperature is 96°F with 65% humidity, the heat index is 121°F. Importantly, like traditional temperatures, heat index values are premised on temperatures in the shade and assume light wind, so "exposure to full sunshine can increase heat index values by up to 15°F."[69] The elderly and the very young are more vulnerable to heat stress.[70] Extreme heat can also compromise infrastructure integrity, increase air pollution levels, damage crops, and promote bacterial or algae growths in water bodies, potentially impacting marine ecosystems.[71]

As recently as August 2019, because of the combination of high humidity and high temperatures, Tennessee experienced conditions where the heat index reached 105°F-115°F in some locations. The heat wave generated NWS advisories, significant media coverage, and a spike in hospital admissions.[72]

9.5.2 Contributing Factors
NOAA reports that because of a cooling trend that occurred in the southeast U.S. in the 1960s, Tennessee, like much of the Southeast, has not experienced the rate or magnitude of warming in the last decade that most of the rest of the U.S. has witnessed (see Figure 9.4).[73] But heat – and extreme heat – is a reality for the State, and especially in west Tennessee.

[65] Runkle, J., K. Kunkel, D. Easterling, L. Stevens, B. Stewart, R. Frankson, and L. Romolo, 2017: Tennessee State Climate Summary. *NOAA Technical Report NESDIS 149-TN,* 4 pp.
[66] NOAA National Weather Service, Severe Weather Awareness – Heat Waves, available at https://www.weather.gov/mkx/heatwaves. A heat wave in 1995 claimed over 700 lives in the Chicago area, and a European heat wave in 2003 killed 50,000 people.
[67] Korey Stringer Institute, Web Bulb Globe Temperature Monitoring, University of Connecticut, available at https://ksi.uconn.edu/prevention/wet-bulb-globe-temperature-monitoring/#.
[68] National Weather Service, Nashville, TN Weather Forecast Office, available at https://www.weather.gov/ohx/1995heatwave.
[69] NOAA, National Weather Service, Heat Index, available at https://www.weather.gov/safety/heat-index.
[70] The Tennessee Commission on Aging and Disability (TCAD) has established disaster preparedness guidance for those over 60, including preparing for heat waves. TCAD, Heat Waves, available at https://www.tn.gov/aging/learn-about/disaster-preparedness/heat-waves.html.
[71] *Kenward, A., Brady, J., Bronzan, J., and Sanford, T., U.S. Faces Dramatic Rise in Extreme Heat, Humidity, Climate Central, July 2016, available at* https://www.climatecentral.org/news/sizzling-summers-20515#dangerdays.
[72] Taylor, E., Excessive Heat Warnings issues for entire mid-South, News Channel 3, available at https://wreg.com/2019/08/13/excessive-heat-warnings-issued-for-entire-mid-south/.
[73] Runkle, J., K. Kunkel, D. Easterling, L. Stevens, B. Stewart, R. Frankson, and L. Romolo, 2017: Tennessee State Climate Summary. *NOAA Technical Report NESDIS 149-TN,* 4 pp.

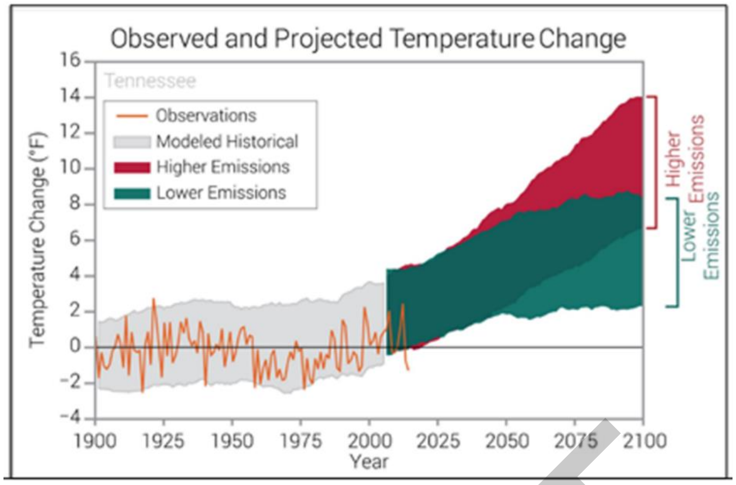


Figure 9.4 – Tennessee Observed and Projected Temperature Change[74]

9.5.3 Concerns for the Inner Coastal and Alluvial Plain

Historical records indicate that from 1950 to1980, the Inner Coastal and Alluvial Plains experienced on average 14 days per year above 95°F and 2 days above 100°F[75]. By mid-century, it is projected that there will be 56 days on average every year to be above 95°F and 14 days per year to be above 100°F in the western part of the State.[76] This is a significant increase that will likely impact hospital admissions, crops, and outdoor worker productivity, especially those involved in agriculture and maintenance activities. Impacts are likely to increase in severity as heat waves become more frequent and intense. In this sense, the changing climate can be viewed as a "threat multiplier."[77]

One example of a heat related impact that is likely to increase is heat stress hospital visits. Heat stress impacts human lives as well as taxing healthcare resources. The Tennessee Department of Health and the Center for Disease Control and Prevention track hospital related emergency room visits and admissions for heat stress on a per county basis. As shown in Figure 9.5, the counties that comprise the Inner Coastal and Alluvial Plains region have more heat related hospital visits than other parts of the State, reflecting the reality that the western part of the state is the hottest[78,79]. As shown in Figure 9.6, such visits are trending in an increasing direction.

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[74] Figure excerpted from Runkle, J., et al., 2017, Tennessee Climate Summary, NOAA Technical Report NESDIS 149-TN.
[75] U.S. DOT FHWA Climate Data Processing Tool, CMIP5 results.
[76] Id.
[77] The Department of Defense has issued numerous reports since 1990 expressing concern about the impact of a changing climate on national security, including on military preparedness, base and training infrastructure, global conflict, and more. The U.S. Military has referred to climate change as a threat multiplier, in that it increases or intensifies risks that may already exist without a changing climate. U.S. Department of Defense, Quadrennial Defense Review 2014, available at https://archive.defense.gov/pubs/2014_Quadrennial_Defense_Review.pdf.
[78] Tennessee Department of Health, Heat Related Illness ED Visits Data, available at https://www.tn.gov/content/tn/health/cedep/environmental/data/healthdata/heat-related-illness/heat-related-illness-ed-visits-data.html
[79] This data comes from hospital records where heat stress is listed as a primary or other diagnosis. Accordingly, these figures may be underreporting; for example, emergency department visits with heart related symptoms may have been caused by heat stress but if the documentation did not expressly identify heat stress, it would not be included.

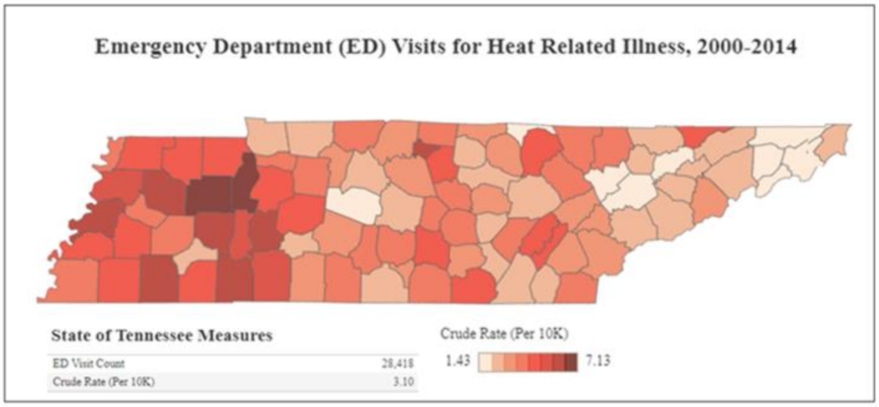

Figure 9.5 – County Emergency Department Visits for Heat-Related Stress[80]

9.5.4 Potential Resilience Strategies

The following are a sample of extreme heat resilience strategies:

- Invest in technology and coordinate closely with the NWS to provide more advanced detection, warning and communication to the public of extreme heat events.
- Conduct public outreach and education to individuals most vulnerable to heat events, such as the elderly or outdoor workers. To efficiently allocate resources, counties with higher per-capita heat stress hospital visit rates could be prioritized.
- Create an inventory of critical infrastructure that may be impacted by substantial increases in extreme heat. Such an inventory could lead to more detailed inspections to determine if there are strategies that could be employed.
- Provide air conditioned shelters and access to water for those in need (local businesses could partner with local governments to help in this regard).
- Start heat education early, so children understand the impacts of heat on their bodies, and can begin to advocate for themselves or advise others on heat stress preparedness, such as their parents.

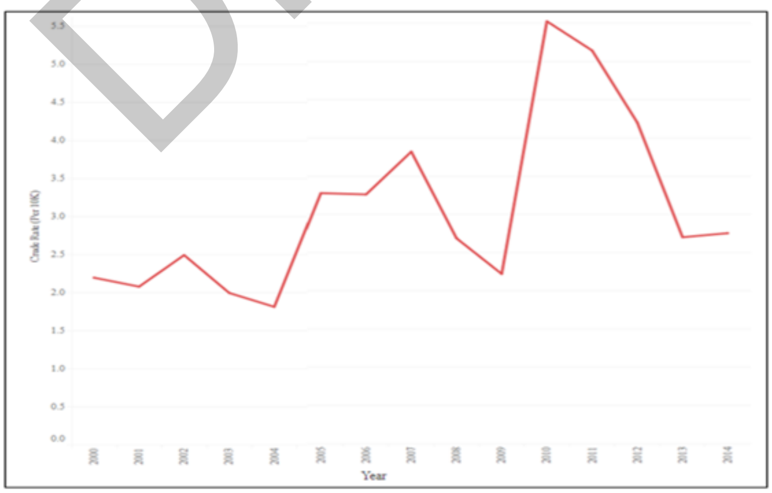

Figure 9.6 – Time Series of Heat Related Emergency Department Visits[81]

[80] Source: Tennessee Department of Health, Health Related Illness ED Visits Data.
[81] Source: Tennessee Department of Health, Heat Related Illness ED Visits Data

9.6 Winter Storm in the Ridge and Valley Region

9.6.1 Background

Winter storms pose a significant threat to public safety and the potential to cause major property damage and disruption to commerce, due to the large variety of storm characteristics that accompany these events. It is not uncommon for severe winter storms to provide a combination of perils, including snow, ice, freezing temperatures, and high winds.

Human exposure to winter storms creates a higher risk of car accidents, hypothermia, frostbite, carbon monoxide poisoning, and heart attacks from overexertion. Of particular concern are the impacts that severe winter storms may have on vulnerable populations, especially the homeless or those living in households without heat. Older adults, young children and sick individuals are also at greater risk.

These problems can be exacerbated by storms that last for several days, make roads impassable, cause massive power outages, and/or cripple communication systems. Moreover, the combination of vulnerabilities to critical infrastructure in the transportation, energy and communication sectors have more far reaching effects on other critical infrastructure (e.g., water treatment plants, public health facilities).

9.6.2 Contributing Factors

Winter storms are a product of weather systems that bring cold and moist air together, with the intensity of these forces and the location where they clash impacting its ensuing severity. Oddly enough, there is reason to project a future increase in snowfall during winter storms due to a warming Earth, as larger amounts of moisture are contained in a warmer atmosphere. Scientists are also studying a possible connection between a warming Arctic and cold spells in the eastern United States. The concept, coined the North American Winter Temperature Dipole, is one where a rapidly warming Arctic can weaken the jet stream, allowing frigid polar air to travel farther south. This can lead to a winter "bomb cyclone", the result of a clash between a very cold East Coast and the warm Atlantic Ocean waters offshore which fuel storm intensity and precipitation amounts. A recent study by North Carolina State University found that in the future these storms could develop lower pressures and feature stronger winds and more precipitation[82].

[82] Marciano, C.G., G.M. Lackmann, and W.A. Robinson. (2015). Changes in U.S. East Coast Cyclone Dynamics with Climate Change, *Journal of Climate*, https://doi.org/10.1175/JCLI-D-14-00418.1

Given these factors, a likely scenario is that winters will likely get shorter due to global warming. However, during the period when it is cold enough to snow, one can expect greater potential for more severe winter weather events[83].

9.6.3 Concerns for the Ridge and Valley Region

The Ridge and Valley region is located in an area where the potential for extreme winter events is possible. Its terrain and elevation, as well as being situated in an area susceptible to Artic blasts and high moisture levels, provide many of the essential ingredients for severe winter weather. As previously stated, although the period during which this region may be exposed to winter weather will diminish in the future, when winter storms do occur, the consequences could be more pronounced.

Such a scenario is extremely realistic, as evidenced by the "Superstorm of 1993" that hit the Ridge and Valley region. Heavy snow fell during March of that year, accompanied by high winds, causing blizzard conditions (see Figure 9.7). Tens of thousands of residents were without power, airports shut down, schools and businesses closed, and several fatalities were recorded. Emergency crews worked to help people in need, and even the military was called in to use helicopters to drop food and supplies to isolated homes. In terms of human impact, the Superstorm of 1993 was more significant than most hurricanes or tornadoes, and ranks among the deadliest and most costly weather events of the 20th century, according to the National Weather Service[84].

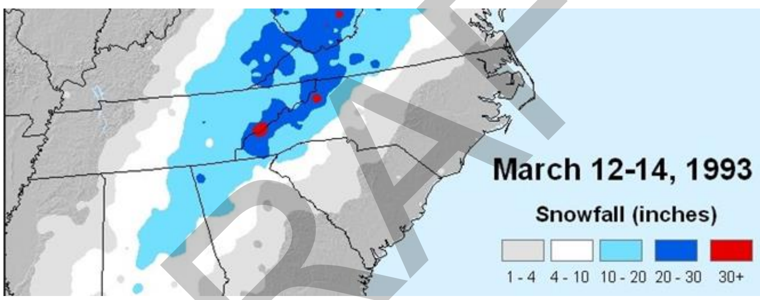

Figure 9.7 – Snowfall Amounts for Superstorm of 1993

9.6.4 Potential Resilience Strategies

Much can be done in advance of the winter season in order to prepare for and protect against the perils associated with extreme winter weather events. Some resilience strategies apply to managing critical infrastructure, while others focus on what individuals can do to lower the risks they may incur.

Listed below are some winter storm resilience strategies that critical infrastructure managers should consider:

- Check the structural ability of roofs to sustain unusually heavy weight from snow accumulation, and of the structure in general to withstand high winds.
- Cut away tree branches that could fall on critical infrastructure during a storm.
- Promptly remove ice and snow from tree limbs, roof and other structures.
- Implement strategies to deliver resources to vulnerable populations.
- Ensure that transportation access is maintained to enable the organization to function satisfactorily in the workplace and when deployed to locations that need assistance.

[83] Milloy, T. (2015). How Climate Change May Lead to Bigger Blizzards, FRONTLINE, https://www.pbs.org/wgbh/frontline/article/how-climate-change-may-lead-to-bigger-blizzards/
[84] National Weather Service. (sourced 2019). Superstorm of 1993 "Storm of the Century", https://www.weather.gov/ilm/Superstorm93

- Strengthen building codes to enable new construction to withstand anticipated winter storm hazards.

In addition, FEMA has developed recommendations for individuals to help protect themselves before and during a severe winter storm event[85]:

- Stock up on milk, bread, and other essentials before the storm begins.
- Stay off roads if at all possible.
- Prepare for power outages.
- Avoid carbon monoxide poisoning. Only use generators and grills outdoors and away from windows. Never heat your home with a gas stovetop or oven.
- Listen for emergency information and alerts.
- Look for signs of hypothermia and frostbite.
- Limit your time outside. If you need to go outside, wear layers of warm clothing.
- Avoid overexertion when shoveling snow.

[85] Department of Homeland Security. (sourced 2019). Snowstorms and Extreme Cold, https://www.ready.gov/winter-weather

10. KEY FINDINGS

This study was undertaken to identify different natural hazard risks across Tennessee, and to determine the cost of action and inaction related to community resiliency. In performing this task, several important findings can be reported. They include the following:

- Tennessee experiences a large number of natural hazard events on an annual basis. Moreover, all locations in the State are exposed to multiple types of natural hazards.
- The frequency and severity of natural hazard events are expected to increase in the future. In particularly, a significant increase in the annual number of hot days is anticipated. This will, however, be accompanied by a concurrent, but less significant, decrease in the annual number of cold days and corresponding freeze-thaw cycles.
- A projected increase in the annual frequency of very heavy precipitation events can also be expected, circumstances that tend to correlate with flooding and severe winter storm potential.
- The current cost of inaction is at least several hundred million dollars a year, an amount considered to be extremely conservative given the lack of analysis consideration of the impacts associated with human casualties (fatalities and injuries), as well as most of the associated indirect tangible and intangible damages. Given these considerations, it is likely that the cost of inaction is on the order of billions of dollars a year.
- The annual cost of inaction is expected to double by mid-century.
- Resilience actions the State could undertake could provide a return-on-investment of anywhere from 3:1 to 12:1. This suggests that prudent investment of resilience resources could save a minimum of hundreds of millions of dollars a year in expected disaster costs. These benefits would accrue to developers, property owners, lenders, tenants, and the community at large.
- In addition to savings due to avoided disaster costs, investment in resilience actions can act as an economic stimulus by providing job opportunities and other forms of economic development.

APPENDIX A – DEFINITION OF NATIONAL WEATHER SERVCE EXTREME WEATHER EVENT TYPES RECORDED IN TENNESSEE (1996-PRESENT)

Blizzard - A winter storm which produces the following conditions for 3 consecutive hours or longer: (1) sustained winds or frequent gusts 30 knots (35 mph) or greater, and (2) falling and/or blowing snow reducing visibility frequently to less than 1/4 mile. If the event is considered significant, even though it affected a small area, it should be entered into the database.

Cold/Wind Chill – Period of low temperatures or wind chill temperatures reaching or exceeding locally/regionally defined advisory (typical value is -18º F or colder) conditions, on a widespread or localized basis. There can be situations where advisory criteria are not met, but the combination of seasonably cold temperatures and low wind chill values (roughly 15º F below normal) must result in a fatality. In these situations, a cold/wind chill event may be documented if the weather conditions were the primary cause of death as determined by a medical examiner or coroner. Normally, cold/wind chill conditions should cause human and/or economic impact. This event is only used if a fatality/injury does not occur during a Winter Precipitation event.

Debris Flow - A combination of water, soil, rock and other material that forms on the sides of hill slopes and moves rapidly downhill. Debris flows are fast moving and highly destructive due to the amount of material being carried with the flow. Large boulders, trees, and massive amounts of sediment can be carried in a debris flow. Moderate to heavy rain that falls over a wildfire burn area and causes flash flooding is usually considered a debris flow.

Drought - A deficiency of moisture that results in adverse impacts on people, animals, or vegetation over a sizeable area. Conceptually, drought is a protracted period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield. There are different kinds of drought: meteorological, agricultural, hydrological, and social-economic. Droughts are rated as D0, D1, D2, D3, or D4 based on the intensity of the moisture deficiency and other factors. A drought event is included in the database when the drought is rated as a D2 classification, or higher.

Dust Devil - A ground-based, rotating column of air, not in contact with a cloud base, usually of short duration, rendered visible by dust, sand, or other debris picked up from the ground, resulting in a fatality, injury, or damage. Dust devils usually result from intense, localized heating interacting with the micro-scale wind field. Dust devils that do not produce a fatality, injury, or significant damage are also entered as an event if they are unusually large, noteworthy, or create strong public interest.

Excessive Heat - This results from a combination of high temperatures (well above normal) and high humidity. An Excessive Heat event is reported in the database whenever heat index values meet or exceed locally/regionally established excessive heat warning thresholds, on a widespread or localized basis. Fatalities (directly-related) or major impacts to human health occurring during excessive heat warning conditions are reported using this event category. Fatalities or impacts to human health occurring when conditions meet locally/regionally defined heat advisory criteria are reported within the Heat event category instead.

Extreme Cold/Wind Chill - A period of extremely low temperatures or wind chill temperatures reaching or exceeding locally/regionally defined warning criteria (typical value around -35º F or colder), on a widespread or localized basis. Normally these conditions should cause significant human and/or economic impact. However, if fatalities occur with cold temperatures/wind chills but extreme cold/wind chill criteria are not met, the event is recorded in the database as a Cold/Wind Chill event. This event is only used if a fatality/injury does not occur during a Winter Precipitation event.

Flash Flood - A rapid and extreme flow of high water into a normally dry area, or a rapid water level rise in a stream or creek above a predetermined flood level, beginning within six hours of the causative event (e.g., intense rainfall, dam failure, ice jam-related), on a widespread or localized basis. Ongoing flooding can intensify to flash flooding in cases where intense rainfall results in a rapid surge of rising flood waters.

Flood - Any high flow, overflow, or inundation by water which causes or threatens damage. In general, this would mean the inundation of a normally dry area caused by an increased water level in an established watercourse, or ponding of water, generally occurring more than six hours after the causative event, and posing a threat to life or property. This can be on a widespread or localized basis. River flooding may be included in the Flood category. However, such entries should be confined only to the effects of the river flooding, such as roads and bridges washed out, homes and businesses damaged, and the dollar estimates of such damage.

Freezing Fog - Fog which freezes on contact with exposed objects and forms a coating of rime and/or glaze, on a widespread or localized basis, resulting in an impact on transportation, commerce, or individuals. Freezing fog can occur with any visibility of six miles or less. Even small accumulations of ice can have an impact.

Frost/Freeze - A surface air temperature of 32º F or lower, or the formation of ice crystals on the ground or other surfaces, over a widespread or localized area for a period of time long enough to cause human or economic impact.

Funnel Cloud - A rotating, visible extension of a cloud pendant from a convective cloud with circulation not reaching the ground. This would include cold-air funnels which typically form in a shallow, cool air mass behind a cold front. The funnel cloud should be large, noteworthy, or create strong public interest to be included in the database.

Hail - Frozen precipitation in the form of balls or irregular lumps of ice. Hail 3/4 of an inch or larger in diameter will be entered. Hail accumulations of smaller size which cause property and/or crop damage, or casualties, are also recorded.

Heat - A period of heat resulting from the combination of high temperatures (above normal) and relative humidity. A Heat event occurs and is recorded whenever heat index values meet or exceed locally/regionally established advisory thresholds. Fatalities or major impacts on human health occurring when ambient weather conditions meet heat advisory criteria are reported using the Heat category. If the ambient weather conditions are below heat advisory criteria, a Heat event entry is permissible only if a directly-related fatality occurred due to unseasonably warm weather, and not man-made environments.

Heavy Rain – An unusually large amount of rain which does not cause a Flash Flood or Flood, but causes damage or other human/economic impact. Heavy rain situations, resulting in urban and/or small stream flooding, are classified as a Heavy Rain event or another suitable event that occurred at the same time.

Heavy Snow - Snow accumulation meeting or exceeding locally/regionally defined 12 and/or 24 hour warning criteria, on a widespread or localized basis. This could mean such values as 4, 6, or 8 inches or more in 12 hours or less; or 6, 8, or 10 inches in 24 hours or less. In some heavy snow events, structural damage, due to the excessive weight of snow accumulations, may occur in the few days following the meteorological end of the event.

High Wind - Sustained non-convective winds of 35 knots (40 mph) or greater lasting for one hour or longer or winds (sustained or gusts) of 50 knots (58 mph) for any duration (or otherwise locally/regionally defined), on a widespread or localized basis. In some mountainous areas, the above numerical values are 43 knots (50 mph) and 65 knots (75 mph), respectively. The High Wind event name is not used for severe local storms, tropical cyclones, or winter storm events. Events with winds less than the High Wind event threshold numbers, resulting in fatalities, injuries, or significant property damage, are encoded as a Strong Wind event.

Ice Storm - Ice accretion meeting or exceeding locally/regionally defined warning criteria (typical value is 1/4 or 1/2 inch or more), on a widespread or localized basis. This event is also recorded for a fatality/injury that results from hypothermia in a power loss situation due to an ice storm.

Lightning - A sudden electrical discharge from a thunderstorm, resulting in a fatality, injury, and/or damage directly related to the lightning strike. Anyone seeking or receiving medical attention following a lightning incident is counted as a lightning injury. Anyone reporting numbness, a tingling sensation, a headache, or other pain following a lightning incident, whether or not they receive treatment, is also counted as an injury.

Marine High Wind - Non-convective, sustained winds or frequent gusts of 48 knots (55 mph) or more, resulting in a fatality, injury, or damage, over the waters and bays of the ocean, Great Lakes, and other lakes with assigned specific Marine Forecast Zones. A peak wind gust (estimated or measured) or maximum sustained wind value is entered.

Sleet - Sleet accumulations meeting or exceeding locally/regionally defined warning criteria (typical value is ½ inch or more).

Strong Wind - Non-convective winds gusting less than 50 knots (58 mph), or sustained winds less than 35 knots (40 mph), resulting in a fatality, injury, or damage. Inland counties which experience strong winds/damage associated with tropical cyclones are recorded under the Tropical Depression or Tropical Storm category, as appropriate, rather than as a Strong Wind event.

Thunderstorm Wind - Winds arising from convection (occurring within 30 minutes of lightning being observed or detected), with speeds of at least 50 knots (58 mph), or winds of any speed (non-severe thunderstorm winds below 50 knots) producing a fatality, injury, or damage. Maximum sustained winds or wind gusts (measured or estimated) equal to or greater than 50 knots (58 mph) are always entered. Events with maximum sustained winds or wind gusts less than 50 knots (58 mph) are entered only if they result in fatalities, injuries, or serious property damage.

Tornado - A violently rotating column of air, extending to or from a cumuliform cloud or underneath a cumuliform cloud, to the ground, and often (but not always) visible as a condensation funnel. In order for a vortex to be classified as a tornado, it must be in contact with the ground and extend to/from the cloud base, and there should be some semblance of ground-based visual effects such as dust/dirt rotational markings/swirls, or structural or vegetative damage or disturbance. An Enhanced Fujita (EF) or Fujita (F) Damage Scale value is entered, depending on the year of occurrence.

Tropical Depression - A tropical cyclone in which the 1-minute sustained wind speed is 33 knots (38 mph), or less. Tropical Depression should be included as an entry if its effects, such as gradient wind, freshwater flooding, and along the coast, storm tide, are experienced.

Tropical Storm - A tropical cyclone in which the 1-minute sustained surface wind ranges from 34 to 63 knots (39 to 73 mph) inclusive. The tropical storm should be included as an entry when its effects, such as wind, storm tide, freshwater flooding, and tornadoes, are experienced.

Wildfire - Any significant forest fire, grassland fire, rangeland fire, or wildland-urban interface fire that consumes the natural fuels and spreads in response to its environment. “Significant” is defined as a wildfire that causes one or more fatalities, one or more significant injuries, and/or property damage (optional: include significant damages to firefighting equipment if loss estimates are available). In general, forest fires smaller than 100 acres, grassland or rangeland fires smaller than 300 acres, and wildland use fires not actively managed as wildfires should not be included.

Winter Storm - A winter weather event which has more than one significant hazard (i.e., heavy snow and blowing snow; snow and ice; snow and sleet; sleet and ice; or snow, sleet and ice) and meets or exceeds locally/regionally defined 12 and/or 24 hour warning criteria for at least one of the precipitation elements, on a widespread or localized basis. Normally, a Winter Storm would pose a threat to life or property.

Winter Weather - A winter precipitation event that causes a death, injury, or a significant impact to commerce or transportation but does not meet locally/regionally defined warning criteria. A Winter Weather event could result from one or more winter precipitation types (snow, or blowing/drifting snow, or freezing rain/drizzle), on a widespread or localized basis.

APPENDIX B – COUNTY PROFILES

B.1 - County Population Growth Projections

County	2017	2035-2055 (annual average)	Growth Factor
Anderson	76284	81367	1.07
Bedford	48157	65240	1.35
Benton	15979	14523	0.91
Bledsoe	14772	15927	1.08
Blount	130122	159749	1.23
Bradley	105417	127818	1.21
Campbell	39771	37499	0.94
Cannon	14071	14025	1.00
Carroll	27982	24873	0.89
Carter	56369	48927	0.87
Cheatham	40059	41076	1.03
Chester	17547	19339	1.10
Claiborne	31795	30153	0.95
Clay	7719	6387	0.83
Cocke	35258	33077	0.94
Coffee	55088	65168	1.18
Crockett	14429	14704	1.02
Cumberland	59287	68427	1.15
Davidson	692506	894795	1.29
Decatur	11768	10883	0.92
DeKalb	19451	20737	1.07
Dickson	52794	65463	1.24
Dyer	37741	37226	0.99
Fayette	40170	51349	1.28
Fentress	18105	17889	0.99
Franklin	41775	41978	1.00
Gibson	49605	53699	1.08
Giles	29267	27025	0.92
Grainger	23156	23345	1.01
Greene	68891	71031	1.03
Grundy	13314	10533	0.79
Hamblen	64153	74203	1.16
Hamilton	360849	435430	1.21
Hancock	6551	5421	0.83
Hardeman	25322	21637	0.85
Hardin	25666	23687	0.92
Hawkins	56601	52014	0.92
Haywood	17723	13883	0.78

Henderson	27955	29820	1.07
Henry	32383	31786	0.98
Hickman	24367	24735	1.02
Houston	8135	7943	0.98
Humphreys	18357	17633	0.96
Jackson	11620	11726	1.01
Jefferson	53970	60713	1.12
Johnson	17757	16804	0.95
Knox	460411	561114	1.22
Lake	7580	7835	1.03
Lauderdale	26784	25741	0.96
Lawrence	43230	44143	1.02
Lewis	11898	10869	0.91
Lincoln	33735	34156	1.01
Loudon	52128	65559	1.26
McMinn	53011	55764	1.05
McNairy	25953	25890	1.00
Macon	23712	29444	1.24
Madison	97955	105421	1.08
Marion	28589	30483	1.07
Marshall	32229	38356	1.19
Maury	91096	118668	1.30
Meigs	12064	12341	1.02
Monroe	46274	49606	1.07
Montgomery	199992	323433	1.62
Moore	6341	6562	1.03
Morgan	21650	22390	1.03
Obion	30469	26471	0.87
Overton	22150	23156	1.05
Perry	7977	7967	1.00
Pickett	5131	4614	0.90
Polk	16821	16982	1.01
Putnam	76684	92684	1.21
Rhea	32632	36198	1.11
Roane	52876	48795	0.92
Robertson	70034	89587	1.28
Rutherford	315800	529503	1.68
Scott	21972	21199	0.96
Sequatchie	15084	18543	1.23
Sevier	98110	131171	1.34
Shelby	938673	1060404	1.13
Smith	19585	21541	1.10
Stewart	13207	12942	0.98

Sullivan	156684	148314	0.95
Sumner	183017	256380	1.40
Tipton	61913	75166	1.21
Trousdale	8368	10579	1.26
Unicoi	17749	17173	0.97
Union	19208	18791	0.98
Van Buren	5677	4905	0.86
Warren	40588	41170	1.01
Washington	128710	154755	1.20
Wayne	16691	15170	0.91
Weakley	33342	30052	0.90
White	26815	29232	1.09
Williamson	224452	368176	1.64
Wilson	135376	198113	1.46

B.2 – NWS Storm Events by County: 1996-2018

County	Drought	Heat	Hydrologic	Rotational Winds	Frozen Precipitation	Straight Winds	Lightning	Cold
Anderson	1	0	31	3	87	177	0	0
Bedford	21	1	41	16	93	129	1	0
Benton	17	7	43	16	74	110	2	0
Bledsoe	0	0	43	6	71	127	0	0
Blount	2	1	33	12	154	272	2	0
Bradley	1	0	27	16	128	199	2	0
Campbell	1	0	22	1	83	154	0	0
Cannon	23	0	28	10	52	75	2	0
Carroll	19	20	38	11	107	110	5	1
Carter	2	0	35	3	134	109	1	0
Cheatham	11	1	40	12	75	118	3	0
Chester	12	22	23	6	93	56	2	0
Claiborne	1	0	22	9	102	152	1	0
Clay	14	0	22	1	74	102	4	0
Cocke	2	0	23	3	127	189	2	0
Coffee	27	1	38	19	112	167	8	0
Crockett	20	26	36	7	67	59	1	0
Cumberland	23	0	42	10	141	92	11	0
Davidson	13	2	135	37	253	635	32	1
Decatur	12	20	43	5	78	69	2	0
Dekalb	22	0	21	4	70	98	5	0
Dickson	13	1	52	12	125	211	4	0
Dyer	18	28	30	16	87	72	6	0
Fayette	15	25	32	6	108	102	4	0
Fentress	20	0	36	8	146	129	11	0
Franklin	34	7	48	22	176	157	10	14
Gibson	20	23	49	14	138	115	4	0
Giles	19	1	42	8	76	126	7	0
Grainger	1	0	13	1	59	151	2	0
Greene	2	0	31	6	143	281	5	0
Grundy	28	0	21	4	78	83	1	0
Hamblen	1	0	20	1	81	134	1	0
Hamilton	1	1	57	23	149	311	6	1
Hancock	1	0	11	1	47	85	0	0
Hardeman	12	24	23	7	115	91	1	0
Hardin	11	21	30	9	95	77	1	2
Hawkins	1	0	24	1	76	171	1	0
Haywood	20	26	26	5	76	56	4	0

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Henderson	13	20	30	10	117	101	3	0
Henry	20	19	21	9	103	103	9	2
Hickman	10	1	27	18	108	170	4	0
Houston	16	1	32	7	49	78	0	0
Humphreys	16	1	24	14	68	127	2	0
Jackson	18	0	21	8	64	105	2	0
Jefferson	1	0	14	7	81	162	5	0
Johnson	1	0	17	3	92	71	0	0
Knox	1	2	49	8	161	313	1	0
Lake	18	29	16	4	66	39	3	0
Lauderdale	19	32	24	4	80	85	2	0
Lawrence	11	1	92	22	153	227	11	0
Lewis	10	1	30	12	64	77	1	0
Lincoln	29	12	56	21	133	173	7	13
Loudon	1	0	24	8	83	170	1	0
Macon	14	0	37	5	74	106	7	0
Madison	14	28	68	14	151	119	9	1
Marion	0	0	23	12	75	184	1	0
Marshall	18	1	33	8	89	77	7	0
Maury	15	1	50	17	123	210	14	1
McMinn	1	0	39	22	96	246	1	0
McNairy	9	21	24	9	91	76	5	0
Meigs	1	0	22	1	55	108	0	0
Monroe	2	0	23	16	57	242	1	0
Montgomery	16	1	55	31	119	225	6	0
Moore	26	10	26	11	90	95	3	13
Morgan	1	0	31	5	90	160	0	0
Obion	19	27	35	6	88	88	4	0
Overton	18	0	30	5	114	116	9	0
Perry	10	1	31	10	59	91	0	0
Pickett	13	0	7	5	76	46	0	0
Polk	2	0	14	11	59	161	0	0
Putnam	20	0	59	11	193	183	12	0
Rhea	1	0	33	4	71	171	1	0
Roane	1	0	36	4	79	212	3	1
Robertson	12	1	33	19	133	186	2	0
Rutherford	20	3	65	38	200	296	15	0
Scott	1	0	23	5	78	120	2	0
Sequatchie	0	0	20	11	64	118	0	1
Sevier	2	0	44	4	196	294	2	0
Shelby	17	48	158	10	246	290	22	4
Smith	19	0	34	8	77	125	0	0

Stewart	16	1	37	8	82	130	3	0
Sullivan	1	1	35	3	144	192	6	0
Sumner	12	1	68	23	195	291	11	0
Tipton	18	34	45	8	121	105	4	0
Trousdale	17	0	18	7	32	61	0	0
Unicoi	1	0	18	1	93	71	1	0
Union	1	0	16	3	42	140	1	0
Van Buren	25	0	17	1	61	38	2	0
Warren	25	0	24	8	97	109	1	0
Washington	1	0	31	9	107	157	1	0
Wayne	10	1	46	12	82	110	1	0
Weakley	20	21	27	9	98	97	8	1
White	24	0	21	9	84	105	1	0
Williamson	12	1	69	20	147	294	27	0
Wilson	20	2	102	31	146	415	28	0

B.3 – Temperature and Precipitation Projections by County

County	Projected (2035-2055) Avg. annual # days above 95°F	Observed (1950-1980)	Projected (2035-2055) Avg. annual # times low temps fluctuate around freezing (freeze-thaw cycle)	Observed (1950-1980)	Projected (2035-2055) Avg. annual # of days per year below freezing	Observed (1950-1980)	Projected (2035-2055) Avg. annual # of "very heavy" (95th percentile precipitation) events	Observed (1950-1980)
Anderson	23.5	2.9	70.1	87.0	73.3	93.9	12.7	11.4
Bedford	42.5	8.5	57.5	74.9	60.1	80.4	12.3	11.1
Benton	50.1	12.6	67.4	85.1	70.7	92.8	12.0	10.7
Bledsoe	17.6	1.9	73.1	90.5	77.2	98.4	12.7	11.5
Blount	22.1	2.6	65.6	84.4	69.3	91.6	13.3	11.7
Bradley	36.6	5.8	60.1	78.5	61.8	82.1	12.2	11.0
Campbell	16.8	1.6	83.4	100.4	88.1	110.0	13.0	11.5
Cannon	35.2	5.3	66.9	85.2	69.8	91.4	12.1	11.0
Carroll	52.1	12.9	59.5	77.6	63.4	86.3	11.9	10.5
Carter	6.5	0.2	87.2	105.8	94.5	119.4	14.2	12.5
Cheatham	46.9	10.1	62.8	82.2	66.5	90.7	12.2	10.7
Chester	56.6	13.3	57.5	74.0	60.4	80.0	12.0	10.6
Claiborne	18.5	1.4	85.5	104.2	90.2	113.9	13.6	11.9
Clay	33.8	5.6	69.6	88.2	73.3	96.5	12.3	10.9
Cocke	17.7	1.9	77.1	96.2	82.3	105.5	13.9	12.5
Coffee	31.9	4.2	56.4	73.2	59.8	79.5	12.6	11.4
Crockett	60.3	14.8	46.8	63.1	50.0	70.0	11.8	10.4
Cumberland	13.4	1.2	73.3	91.2	79.2	102.6	13.1	11.9
Davidson	46.7	9.6	56.3	74.4	60.0	82.4	11.8	10.4
Decatur	53.8	12.9	65.1	83.2	67.7	89.0	12.3	10.9
DeKalb	34.7	6.0	67.1	84.9	70.7	92.6	12.2	11.0
Dickson	48.5	10.6	61.5	79.4	64.9	86.9	12.5	11.1
Dyer	59.0	14.4	45.9	61.6	49.7	69.8	11.8	10.3
Fayette	58.6	12.6	48.9	66.6	51.5	72.3	11.2	9.9
Fentress	16.1	1.3	70.3	86.9	75.9	97.3	13.7	12.3
Franklin	30.3	4.1	55.8	72.8	58.8	78.6	12.7	11.4
Gibson	56.1	13.2	52.7	69.7	56.5	78.0	12.0	10.5
Giles	43.7	9.3	61.0	80.4	62.6	84.8	12.1	10.9
Grainger	22.4	2.7	71.9	90.8	75.3	98.0	14.0	12.2
Greene	21.7	1.9	71.5	91.3	75.5	99.2	13.7	12.2
Grundy	17.6	1.3	60.3	76.5	64.9	85.3	12.7	11.5
Hamblen	25.0	3.3	68.6	87.6	71.6	94.0	14.0	12.3
Hamilton	34.8	5.6	59.0	77.4	61.2	81.9	11.9	10.7
Hancock	15.3	1.0	84.6	103.0	89.0	112.0	14.4	12.5
Hardeman	58.7	13.5	54.1	71.9	56.7	77.6	11.7	10.4
Hardin	60.1	16.0	60.2	77.6	62.1	81.9	12.4	11.0
Hawkins	19.9	2.0	72.4	90.8	75.7	97.8	13.8	12.3
Haywood	63.4	16.3	45.3	61.8	48.0	68.0	11.5	10.2
Henderson	52.9	12.8	59.3	76.1	62.6	83.0	12.1	10.7
Henry	50.4	12.7	62.6	78.9	66.9	88.2	12.3	10.7
Hickman	48.3	10.3	68.0	86.3	70.6	92.0	12.4	11.0
Houston	45.7	10.7	67.9	84.8	71.5	92.9	12.8	11.2
Humphreys	48.6	11.5	68.7	86.6	71.8	93.6	12.2	10.8
Jackson	35.1	5.8	65.2	82.9	68.8	90.8	12.4	11.0
Jefferson	25.0	3.6	67.4	86.8	70.9	93.5	13.6	12.2
Johnson	2.8	0.0	98.4	117.3	106.0	131.9	14.6	12.8
Knox	30.0	4.2	56.2	74.0	58.6	79.5	13.0	11.5
Lake	59.5	15.3	48.2	64.6	52.6	74.3	11.7	10.1
Lauderdale	64.0	16.6	43.9	60.4	46.9	67.6	11.6	10.2
Lawrence	41.3	8.1	65.0	84.3	67.0	89.1	12.2	11.0
Lewis	41.5	8.2	70.4	89.8	72.9	95.6	12.4	11.0
Lincoln	42.7	8.4	62.7	81.6	64.9	86.9	12.1	10.9
Loudon	30.9	4.1	58.4	79.2	60.6	84.7	12.9	11.3
Macon	37.8	6.7	62.4	77.2	66.8	85.4	12.4	10.8
Madison	58.1	13.4	51.4	68.2	54.5	75.0	11.6	10.2
Marion	26.6	3.4	55.6	73.4	58.5	79.4	12.4	11.1
Marshall	42.1	8.1	59.4	79.1	61.7	85.4	12.1	11.0
Maury	42.3	8.5	58.1	78.6	60.3	84.7	12.4	11.0
McMinn	32.0	4.9	64.0	84.2	65.8	88.6	13.1	11.7
McNairy	60.0	15.7	59.5	75.9	61.7	80.7	11.9	10.6
Meigs	35.0	6.1	60.3	79.6	61.8	83.5	13.4	11.8
Monroe	21.1	2.3	74.4	93.9	77.5	100.4	13.1	11.7
Montgomery	48.2	11.8	66.4	82.9	70.9	91.9	12.6	11.0
Moore	38.2	6.5	58.5	76.0	61.1	81.5	12.2	11.0
Morgan	16.6	1.6	72.8	91.0	77.1	100.1	13.7	12.2
Obion	55.6	13.2	56.4	72.7	60.8	82.3	12.0	10.4
Overton	22.8	2.7	70.4	87.9	75.2	97.8	12.7	11.5
Perry	49.2	10.8	71.4	90.0	74.1	96.2	12.3	10.9
Pickett	24.1	2.7	70.9	88.7	75.2	97.7	13.3	11.7
Polk	24.7	3.2	74.0	92.7	76.6	97.9	12.9	11.6
Putnam	25.6	3.4	66.5	84.3	72.3	95.5	12.4	11.2
Rhea	27.6	4.4	66.1	84.6	68.6	90.1	13.3	11.8
Roane	29.3	4.0	64.5	84.8	66.7	90.5	13.0	11.5
Robertson	43.3	8.6	59.8	77.9	65.2	89.0	12.3	10.8
Rutherford	45.5	9.4	57.7	76.1	60.2	82.0	12.1	10.8
Scott	15.1	1.1	81.7	99.3	87.6	110.6	13.4	11.9
Sequatchie	18.3	1.8	68.7	86.2	72.7	94.0	12.7	11.4
Sevier	15.9	1.8	87.4	107.0	94.1	118.2	13.9	12.5
Shelby	63.8	14.8	39.3	55.0	41.8	60.8	10.3	9.2
Smith	41.0	8.0	62.1	79.7	65.1	86.7	12.1	10.7
Stewart	45.6	10.7	68.5	84.7	73.1	94.2	12.4	10.9
Sullivan	14.1	0.7	74.5	92.6	79.4	102.3	13.4	11.9
Sumner	42.2	8.1	57.5	74.5	62.3	84.0	12.1	10.6
Tipton	65.3	15.9	44.7	61.6	47.7	68.5	11.1	9.8
Trousdale	45.0	9.1	58.1	75.1	61.3	82.2	12.1	10.6
Unicoi	5.4	0.1	96.1	116.0	102.5	128.2	13.7	12.2
Union	23.1	2.7	73.5	90.9	76.1	97.3	13.4	11.8
Van Buren	18.8	1.7	71.3	88.7	76.4	97.8	12.5	11.4
Warren	28.5	3.1	61.9	79.1	65.7	86.2	12.6	11.5
Washington	15.5	0.8	72.1	91.8	76.1	100.1	13.2	11.8
Wayne	44.7	9.5	72.7	91.8	75.2	97.7	12.4	11.1
Weakley	53.9	12.3	57.9	74.4	61.8	83.5	12.0	10.5
White	25.6	3.0	66.2	83.9	71.7	94.1	12.3	11.2
Williamson	44.2	8.3	60.2	80.2	62.6	86.7	12.3	10.9
Wilson	45.8	9.6	58.0	77.0	60.9	84.0	11.9	10.5

APPENDIX C – CMIP5 RESULTS BY CLIMATE REGION AND RCP SCENARIO

C.1 - Inner Coastal and Alluvial Plains

RCP 8.5		
Inner Coastal and Alluvial Plains	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	56.2 days	+42.2 days
Avg. # days per year below freezing	50.0 days	-24.2 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	34.4 times	- 5.9 times
Avg. # of "very heavy" (95^{th} percentile precipitation) events per year	13.0 times	+1.7 times

RCP 4.5		
Inner Coastal and Alluvial Plains	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	43.7 days	+31.1 days
Avg. # of days per year below freezing	59.8 days	-20.1 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	38.2 times	-3.5 times
Avg. # of "very heavy" (95^{th} percentile precipitation) events per year	12.2 times	+1.6 times

C.2 - Highland Rim

RCP 8.5		
Highland Rim	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	47.8 days	36.4 days
Avg. # of days per year below freezing	64.6 days	-26.7 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	44.5 times	-4.5 times
Avg. # of "very heavy" (95^{th} percentile precipitation) events per year	13.2 times	+2.3 times

RCP 4.5		
Highland Rim	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	37.8 days	+27.0 days
Avg. # of days per year below freezing	72.7 days	-21.7 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	47.1 times	-2.8 times
Avg. # of "very heavy" (95^{th} percentile precipitation) events per year	12.4 times	+1.3 times

C.3 - Nashville Basin

Nashville Basin	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	43.4 days	+34.5 days
Avg. # of days per year below freezing	55.7 days	-24.9 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	41.4 times	-4.7 times
Avg. # of "very heavy" (95th percentile precipitation) events per year	14.0 times	+2.2 times

RCP 4.5		
Nashville Basin	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	43.5 days	+34.7 days
Avg. # of days per year below freezing	56.4 days	-24.9 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	40.8 times	-4.8 times
Avg. # of "very heavy" (95th percentile precipitation) events per year	14.1 times	+2.2 times

C.4 - Cumberland Plateau

RCP 8.5		
Cumberland Plateau	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	8.9 days	+7.6 days
Avg. # of days per year below freezing	74.3 days	-26.7 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	39.4 times	-3.7 times
Avg. # of "very heavy" (95th percentile precipitation) events per year	14.3 times	+2.6 times

RCP 4.5		
Cumberland Plateau	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	15.9 days	+13.2 days
Avg. # of days per year below freezing	70.6 days	-21.7 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	42.1 times	-3.3 times
Avg. # of "very heavy" (95th percentile precipitation) events per year	13.2 times	+1.6 times

C.5 - Ridge and Valley

RCP 8.5		
Ridge & Valley	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	23.8 days	+20.0 days
Avg. # of days per year below freezing	61.1 days	-26.2 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	35.5 times	-4.2 times
Avg. # of "very heavy" (95th percentile precipitation) events per year	13.8 times	+2.3 times

RCP 4.5		
Ridge & Valley	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	18.4 days	+14.2 days
Avg. # of days per year below freezing	73.0 days	-22.0 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	37.6 times	-2.4 times
Avg. # of "very heavy" (95th percentile precipitation) events per year	13.0 times	+1.8 times

C.6 - Unaka-Smoky Mountains

Unaka-Smoky Mountains	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	1.8 days	+1.5 days
Avg. # of days per year below freezing	94.9 days	-28.0 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	40.7 times	-2.1 times
Avg. # of "very heavy" (95th percentile precipitation) events per year	16.5 times	+2.9 times

RCP 4.5		
Unaka-Smoky Mountains	Projected (2035-2055)	Change From Observed
Avg. # days above 95°F	0.9 days	+0.6 days
Avg. # of days per year below freezing	98.9 days	-22.1 days
Avg. # times low temps fluctuate around freezing (freeze-thaw cycle)	41.8 times	-1.0 times
Avg. # of "very heavy" (95th percentile precipitation) events per year	15.2 times	+2.1 times

APPENDIX D – TYPES OF ASSETS BY CRITICAL INFRASTRUCTURE CATEGORY

D.1 - Emergency Response

TN County	County FIPS	American Red Cross Headquarters	EMS Stations	Fire Stations	Local EOC	State EOC	Military Bases	TOTAL
Anderson	47001		17	18	2			37
Bedford	47003		10	14	1			25
Benton	47005		3	9	1			13
Bledsoe	47007		3	9	1			13
Blount	47009		17	20	2			39
Bradley	47011		3	14	1			18
Campbell	47013		12	15	1			28
Cannon	47015		1	9				10
Carroll	47017		3	20	1		1	25
Carter	47019		9	11	1			21
Cheatham	47021		4	13	1			18
Chester	47023			11	1			12
Claiborne	47025		2	16	1			19
Clay	47027		2	8				10
Cocke	47029		6	10	1			17
Coffee	47031		7	11	2		1	21
Crockett	47033		2	7	1			10
Cumberland	47035		8	21	1			30
Davidson	47037	1	48	40	1	1	1	92
Decatur	47039		2	11	2			15
DeKalb	47041		1	14	1			16
Dickson	47043		8	13	1			22
Dyer	47045			15	2			17
Fayette	47047		5	10	3			18
Fentress	47049		3	14	2			19
Franklin	47051		12	20	1		1	34
Gibson	47053		9	20	2		1	32
Giles	47055		3	12	1			16
Grainger	47057		2	5	2			9
Greene	47059		6	19	1			26
Grundy	47061		3	8	1			12
Hamblen	47063		9	10	1			20
Hamilton	47065	1	39	48	1			89
Hancock	47067		1	7	1			9
Hardeman	47069		3	12	1			16
Hardin	47071		1	25	3			29
Hawkins	47073		2	20	2		2	26
Haywood	47075		14	13	2			29
Henderson	47077		12	15	1			28
Henry	47079		6	15	2			23
Hickman	47081		7	10	1			18
Houston	47083		1	5	1			7
Humphreys	47085		6	7	2			15
Jackson	47087		2	13	1			16
Jefferson	47089		8	9	1			18
Johnson	47091		6	9	1			16
Knox	47093	1	39	40	1			81
Lake	47095		2	2	2			6
Lauderdale	47097		3	8	3			14
Lawrence	47099		10	17	1			28
Lewis	47101			2				2
Lincoln	47103		11	14	2			27
Loudon	47105		8	13	1			22
Macon	47111		3	3	2			8
Madison	47113	1		23	2			26
Marion	47115		4	20	1			25
Marshall	47117		4	11	2			17
Maury	47119		15	17	1			33
McMinn	47107		15	15	1			31
McNairy	47109		3	22	2			27
Meigs	47121		4	7	1			12
Monroe	47123		12	21	1			34
Montgomery	47125	1	11	16	1		2	31
Moore	47127		7	6	2			15
Morgan	47129		4	10	1			15
Obion	47131		6	10	1			17
Overton	47133		8	14	2			24
Perry	47135		1	6	2			9
Pickett	47137		2	2	1			5
Polk	47139		2	14	1			17
Putnam	47141		10	20	2			32
Rhea	47143		5	17	2			24
Roane	47145		4	24	1			29
Robertson	47147		13	14	3			30
Rutherford	47149	1	39	35	2		1	78
Scott	47151		2	10	1			13
Sequatchie	47153		3	7	1			11
Sevier	47155		18	20	2			40
Shelby	47157	1	83	80	3		1	168
Smith	47159		2	12	1			15
Stewart	47161		3	13	1		2	19
Sullivan	47163	1	24	24	1		1	51
Sumner	47165		19	22	3			44
Tipton	47167		13	16	1			30
Trousdale	47169		2	1	1			4
Unicoi	47171		3	5	2			10
Union	47173		6	8	1			15
Van Buren	47175		2	6	1			9
Warren	47177		12	15	1			28
Washington	47179		27	16	1			44
Wayne	47181		4	16	2			22
Weakley	47183		8	12	2			22
White	47185		15	15	1			31
Williamson	47187		25	21	1			47
Wilson	47189		14	13	1			28

D.2 - Local Law Enforcement

TN County	*County FIPS*	Local Law Enforcement Locations
Anderson	*47001*	6
Bedford	*47003*	3
Benton	*47005*	4
Bledsoe	*47007*	2
Blount	*47009*	6
Bradley	*47011*	4
Campbell	*47013*	9
Cannon	*47015*	2
Carroll	*47017*	8
Carter	*47019*	5
Cheatham	*47021*	4
Chester	*47023*	3
Claiborne	*47025*	4
Clay	*47027*	2
Cocke	*47029*	3
Coffee	*47031*	3
Crockett	*47033*	6
Cumberland	*47035*	3
Davidson	*47037*	32
Decatur	*47039*	3
DeKalb	*47041*	4
Dickson	*47043*	7
Dyer	*47045*	4
Fayette	*47047*	8
Fentress	*47049*	3
Franklin	*47051*	8
Gibson	*47053*	9
Giles	*47055*	5
Grainger	*47057*	4
Greene	*47059*	5
Grundy	*47061*	5
Hamblen	*47063*	5
Hamilton	*47065*	18
Hancock	*47067*	2
Hardeman	*47069*	8
Hardin	*47071*	4
Hawkins	*47073*	4
Haywood	*47075*	2
Henderson	*47077*	4
Henry	*47079*	5
Hickman	*47081*	2
Houston	*47083*	2
Humphreys	*47085*	5
Jackson	*47087*	2
Jefferson	*47089*	6
Johnson	*47091*	2
Knox	*47093*	9
Lake	*47095*	4
Lauderdale	*47097*	7
Lawrence	*47099*	7
Lewis	*47101*	2
Lincoln	*47103*	3
Loudon	*47105*	3
Macon	*47111*	3
Madison	*47113*	6
Marion	*47115*	7
Marshall	*47117*	5
Maury	*47119*	4
McMinn	*47107*	6
McNairy	*47109*	5
Meigs	*47121*	2
Monroe	*47123*	7
Montgomery	*47125*	7
Moore	*47127*	1
Morgan	*47129*	3
Obion	*47131*	9
Overton	*47133*	3
Perry	*47135*	3
Pickett	*47137*	2
Polk	*47139*	5
Putnam	*47141*	9
Rhea	*47143*	4
Roane	*47145*	5
Robertson	*47147*	6
Rutherford	*47149*	6
Scott	*47151*	4
Sequatchie	*47153*	2
Sevier	*47155*	6
Shelby	*47157*	34
Smith	*47159*	4
Stewart	*47161*	3
Sullivan	*47163*	7
Sumner	*47165*	9
Tipton	*47167*	6
Trousdale	*47169*	3
Unicoi	*47171*	2
Union	*47173*	4
Van Buren	*47175*	2
Warren	*47177*	3
Washington	*47179*	5
Wayne	*47181*	4
Weakley	*47183*	8
White	*47185*	2
Williamson	*47187*	5
Wilson	*47189*	5

D.3 - Power Generation

TN County	County FIPS	Biodiesel Plants	Electric Substations	Ethanol Plants	Oil Refineries	Petroleum Terminals	Power Plants	TOTAL
Anderson	*47001*		42				5	**47**
Bedford	*47003*		8					**8**
Benton	*47005*		7				1	**8**
Bledsoe	*47007*		4					**4**
Blount	*47009*		49				1	**50**
Bradley	*47011*		22					**22**
Campbell	*47013*		19					**19**
Cannon	*47015*		1					**1**
Carroll	*47017*		14					**14**
Carter	*47019*		15				2	**17**
Cheatham	*47021*		6					**6**
Chester	*47023*		5					**5**
Claiborne	*47025*		9					**9**
Clay	*47027*		3				1	**4**
Cocke	*47029*		10					**10**
Coffee	*47031*		12					**12**
Crockett	*47033*		1					**1**
Cumberland	*47035*		18					**18**
Davidson	*47037*		102			13	4	**119**
Decatur	*47039*		3			1		**4**
DeKalb	*47041*		2				1	**3**
Dickson	*47043*		10				1	**11**
Dyer	*47045*		45					**45**
Fayette	*47047*		18					**18**
Fentress	*47049*		2					**2**
Franklin	*47051*		19				2	**21**
Gibson	*47053*		20					**20**
Giles	*47055*		7					**7**
Grainger	*47057*		4					**4**
Greene	*47059*		39					**39**
Grundy	*47061*		8					**8**
Hamblen	*47063*		26					**26**
Hamilton	*47065*		35			8	4	**47**
Hancock	*47067*		3				1	**4**
Hardeman	*47069*		15				1	**16**
Hardin	*47071*		9				2	**11**
Hawkins	*47073*		18				1	**19**
Haywood	*47075*		14				4	**18**
Henderson	*47077*		10					**10**
Henry	*47079*		9					**9**
Hickman	*47081*		5					**5**
Houston	*47083*		2					**2**
Humphreys	*47085*		17				1	**18**
Jackson	*47087*		1					**1**
Jefferson	*47089*		16				1	**17**
Johnson	*47091*		7					**7**
Knox	*47093*		151			11	1	**163**
Lake	*47095*		3					**3**
Lauderdale	*47097*		13					**13**
Lawrence	*47099*		7					**7**
Lewis	*47101*		2					**2**
Lincoln	*47103*		6					**6**
Loudon	*47105*		31	1			2	**34**
Macon	*47111*		1					**1**
Madison	*47113*		30				1	**31**
Marion	*47115*		14				2	**16**
Marshall	*47117*		10					**10**
Maury	*47119*		24					**24**
McMinn	*47107*		32				1	**33**
McNairy	*47109*		12				4	**16**
Meigs	*47121*		6					**6**
Monroe	*47123*		25	1			1	**27**
Montgomery	*47125*		28				1	**29**
Moore	*47127*		1					**1**
Morgan	*47129*		10					**10**
Obion	*47131*		18	1			1	**20**
Overton	*47133*		3					**3**
Perry	*47135*		2					**2**
Pickett	*47137*		1					**1**
Polk	*47139*		9				4	**13**
Putnam	*47141*		21					**21**
Rhea	*47143*		13				3	**16**
Roane	*47145*		37				1	**38**
Robertson	*47147*		14					**14**
Rutherford	*47149*		18				2	**20**
Scott	*47151*		5					**5**
Sequatchie	*47153*		4					**4**
Sevier	*47155*		34				1	**35**
Shelby	*47157*		71		1	12	6	**90**
Smith	*47159*		4				1	**5**
Stewart	*47161*		6				1	**7**
Sullivan	*47163*		56				4	**60**
Sumner	*47165*		27				2	**29**
Tipton	*47167*		13					**13**
Trousdale	*47169*		2					**2**
Unicoi	*47171*		3					**3**
Union	*47173*		6					**6**
Van Buren	*47175*		1					**1**
Warren	*47177*		8				2	**10**
Washington	*47179*		43				2	**45**
Wayne	*47181*		5					**5**
Weakley	*47183*		20				1	**21**
White	*47185*		4					**4**
Williamson	*47187*		24					**24**
Wilson	*47189*		23					**23**

D.4 - Water and Wastewater Treatment

TN County	County FIPS	Water Plants	Wastewater Treatment Plants	TOTAL
Anderson	47001	7	12	19
Bedford	47003	3	6	9
Benton	47005	2	6	8
Bledsoe	47007	2	4	6
Blount	47009	3	2	5
Bradley	47011	3	2	5
Campbell	47013	14	10	24
Cannon	47015	1	2	3
Carroll	47017	6	10	16
Carter	47019	8	12	20
Cheatham	47021	4	8	12
Chester	47023	1	4	5
Claiborne	47025	4	8	12
Clay	47027	2	12	14
Cocke	47029	1	8	9
Coffee	47031	0	6	6
Crockett	47033	9	6	15
Cumberland	47035	4	8	12
Davidson	47037	6	22	28
Decatur	47039	3	4	7
DeKalb	47041	3	4	7
Dickson	47043	4	4	8
Dyer	47045	8	4	12
Fayette	47047	3	10	13
Fentress	47049	1	2	3
Franklin	47051	8	8	16
Gibson	47053	11	10	21
Giles	47055	1	2	3
Grainger	47057	4	8	12
Greene	47059	2	22	24
Grundy	47061	1	4	5
Hamblen	47063	2	0	2
Hamilton	47065	10	10	20
Hancock	47067	1	4	5
Hardeman	47069	2	8	10
Hardin	47071	3	6	9
Hawkins	47073	10	16	26
Haywood	47075	2	12	14
Henderson	47077	4	2	6
Henry	47079	2	4	6
Hickman	47081	3	4	7
Houston	47083	1	0	1
Humphreys	47085	4	10	14
Jackson	47087	1	2	3
Jefferson	47089	3	14	17
Johnson	47091	5	2	7
Knox	47093	10	24	34
Lake	47095	2	2	4
Lauderdale	47097	5	6	11
Lawrence	47099	6	4	10
Lewis	47101	3	2	5
Lincoln	47103	5	6	11
Loudon	47105	4	8	12
Macon	47111	4	4	8
Madison	47113	2	10	12
Marion	47115	4	14	18
Marshall	47117	2	4	6
Maury	47119	2	6	8
McMinn	47107	1	22	23
McNairy	47109	4	4	8
Meigs	47121	1	2	3
Monroe	47123	4	10	14
Montgomery	47125	3	12	15
Moore	47127	1	2	3
Morgan	47129	1	6	7
Obion	47131	7	6	13
Overton	47133	1	2	3
Perry	47135	2	4	6
Pickett	47137	1	2	3
Polk	47139	2	14	16
Putnam	47141	2	8	10
Rhea	47143	6	12	18
Roane	47145	6	14	20
Robertson	47147	2	6	8
Rutherford	47149	4	6	10
Scott	47151	2	8	10
Sequatchie	47153	1	2	3
Sevier	47155	4	22	26
Shelby	47157	23	24	47
Smith	47159	2	10	12
Stewart	47161	2	12	14
Sullivan	47163	4	16	20
Sumner	47165	4	20	24
Tipton	47167	5	12	17
Trousdale	47169	1	2	3
Unicoi	47171	5	6	11
Union	47173	3	6	9
Van Buren	47175	1	0	1
Warren	47177	3	10	13
Washington	47179	2	8	10
Wayne	47181	4	6	10
Weakley	47183	5	18	23
White	47185	1	2	3
Williamson	47187	3	6	9
Wilson	47189	5	10	15

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D.5 - Mass Gathering Places

TN County	County FIPS	Places of Worship	Child Care Centers	Colleges and Universities	Convention Centers	Major Sport Venues	Major State Government Buildings	National Shelter System Facilities	Private Schools	Public Schools	Malls	TOTAL
Anderson	47001	21	51						6	29		107
Bedford	47003	9	27	1					2	14		53
Benton	47005	2	6						1	8		17
Bledsoe	47007	1	7						1	5		14
Blount	47009	37	67	1					7	31		143
Bradley	47011	16	46	4					10	27		103
Campbell	47013	4	18	1					3	15		41
Cannon	47015		5						1	7		13
Carroll	47017	7	9	2					1	15		34
Carter	47019	10	30	2					1	20		63
Cheatham	47021	3	26						2	14		45
Chester	47023	4	2	1					1	6		14
Claiborne	47025	3	22	2					3	13		43
Clay	47027	1	3						1	4		9
Cocke	47029	5	20						1	14		40
Coffee	47031	11	20	1					3	19		54
Crockett	47033	1	4						1	7		13
Cumberland	47035	9	13	1					5	12		40
Davidson	47037	165	338	37	9	8	17		71	170	3	818
Decatur	47039	2	4						1	4		11
DeKalb	47041		5						2	6		13
Dickson	47043	15	21	1					4	16		57
Dyer	47045	8	10	2					2	12		34
Fayette	47047	4	5						4	7		20
Fentress	47049	3	5						1	7		16
Franklin	47051	7	12	1					4	12		36
Gibson	47053	17	21	1					1	21		61
Giles	47055	10	4	2					2	8		26
Grainger	47057	1	6						1	9		17
Greene	47059	13	25	1					5	25		69
Grundy	47061		5						3	8		16
Hamblen	47063	12	23	2					6	18		61
Hamilton	47065	122	116	8	1				35	80	1	363
Hancock	47067	1	2							3		6
Hardeman	47069	11	9	1					2	9		32
Hardin	47071	5	11	1					2	7		26
Hawkins	47073	13	10							20		43
Haywood	47075	4	3							5		12
Henderson	47077	3	10	1					2	11		27
Henry	47079	10	24	1					2	9		46
Hickman	47081	1	3						2	8		14
Houston	47083	3	3							5		11
Humphreys	47085	3	2						2	7		14
Jackson	47087		4						1	4		9
Jefferson	47089	8	10	1					3	13		35
Johnson	47091	2	7						1	7		17
Knox	47093	124	133	12	6				47	94	1	417
Lake	47095	1	3							3		7
Lauderdale	47097	5	10	1					1	8		25
Lawrence	47099	10	15	1					11	13		50
Lewis	47101	2	4	1					3	4		14
Lincoln	47103	8	19	1					1	11		40
Loudon	47105	5	23						2	12		42
Macon	47111	1	5						2	8		16
Madison	47113	29	37	6	1		2		11	28		114
Marion	47115	7	8						1	11		27
Marshall	47117	5	10							10		25
Maury	47119	21	40	2					8	21		92
McMinn	47107	16	23	2					4	15		60
McNairy	47109	5	9	1					4	8		27
Meigs	47121	2	4						1	4		11
Monroe	47123	7	17	1					4	17		46
Montgomery	47125	34	85	6					11	43		179
Moore	47127	2	3	1						2		8
Morgan	47129	5	10						2	8		25
Obion	47131	14	21						1	10		46
Overton	47133	2	12	1						9		24
Perry	47135	1	2						3	4		10
Pickett	47137		2							2		4
Polk	47139	3	5						1	6		15
Putnam	47141	9	31	4					9	21		74
Rhea	47143	12	5	2					3	8		30
Roane	47145	25	11	2					5	17		60
Robertson	47147	12	39						5	21		77
Rutherford	47149	36	78	5					17	59		195
Scott	47151	5	13	1					1	10		30
Sequatchie	47153		3						1	3		7
Sevier	47155	12	38		3				6	29		88
Shelby	47157	262	558	31	5	2	1		104	298	1	1262
Smith	47159	1	5							9		15
Stewart	47161	3	2							6		11
Sullivan	47163	43	49	2	1				10	42		147
Sumner	47165	17	60	3					12	49		141
Tipton	47167	12	16	1					1	14		44
Trousdale	47169	2	6	1						3		12
Unicoi	47171	3	8							8		19
Union	47173		9							10		19
Van Buren	47175		3						1	2		6
Warren	47177	6	23	1					4	11		45
Washington	47179	31	56	4	1				8	29		129
Wayne	47181		3						1	8		12
Weakley	47183	7	17	1		1			1	11		38
White	47185	3	4						1	9		17
Williamson	47187	21	79	4					18	50	1	173
Wilson	47189	18	58	3	1				11	27		118

D.6 – Transportation

TN County	County FIPS	Locks	Dams	Airports	Water Terminals	Miles of Class I Railroad	Miles of Controlled Access Highways	TOTAL
Anderson	47001	1	3		1	79	12	96
Bedford	47003		1			18	0	19
Benton	47005	2			2	14	9	26
Bledsoe	47007		2					2
Blount	47009		3	1		40	7	52
Bradley	47011				4	44	25	72
Campbell	47013		2			74	32	107
Cannon	47015							0
Carroll	47017	1				45	1	47
Carter	47019		2			5	5	12
Cheatham	47021	1	1		4	8	11	26
Chester	47023							0
Claiborne	47025					32		32
Clay	47027	1	5					6
Cocke	47029					38	22	59
Coffee	47031		1			8	30	39
Crockett	47033					13		13
Cumberland	47035		7				36	43
Davidson	47037	1	4	1	51		118	175
Decatur	47039				6		6	12
DeKalb	47041		1					1
Dickson	47043		2			29	18	49
Dyer	47045				3		18	21
Fayette	47047	2				54	16	72
Fentress	47049		1					1
Franklin	47051	2	2		1	35		40
Gibson	47053		1			21		22
Giles	47055						22	22
Grainger	47057		6			16		22
Greene	47059	2	1			36	32	71
Grundy	47061	1					7	8
Hamblen	47063						10	10
Hamilton	47065	1	2	1	34	179	65	282
Hancock	47067							0
Hardeman	47069					27		27
Hardin	47071	1	1		7	8		17
Hawkins	47073		1					1
Haywood	47075					34	24	58
Henderson	47077	2	4				24	30
Henry	47079	2			1			3
Hickman	47081		2				14	16
Houston	47083				2			2
Humphreys	47085		1		13		14	28
Jackson	47087	2	2					4
Jefferson	47089	5	7				28	40
Johnson	47091		4		3			7
Knox	47093				16		67	83
Lake	47095		1		2			3
Lauderdale	47097	2			5	29		36
Lawrence	47099		2		1			3
Lewis	47101	1	1					2
Lincoln	47103	1				6		7
Loudon	47105	1	3		6	35	24	68
Macon	47111		1			74		75
Madison	47113	3	1	1			28	33
Marion	47115	3	4		12		32	51
Marshall	47117	1	4				13	18
Maury	47119		9				27	36
McMinn	47107		1		5		25	31
McNairy	47109							0
Meigs	47121	2	1		9			12
Monroe	47123	5	3		2	33	7	49
Montgomery	47125				7		17	24
Moore	47127							0
Morgan	47129		1					1
Obion	47131		1			44		45
Overton	47133							0
Perry	47135	1			2			3
Pickett	47137							0
Polk	47139		6			30		36
Putnam	47141	2					45	47
Rhea	47143		1		1	42		44
Roane	47145	1	1		8	62	23	95
Robertson	47147					29	28	58
Rutherford	47149						41	41
Scott	47151	1				42		43
Sequatchie	47153							0
Sevier	47155		13				5	18
Shelby	47157		2	1	75		95	173
Smith	47159	1	3		4		17	25
Stewart	47161				4			4
Sullivan	47163		5	1			40	46
Sumner	47165				4	53	19	76
Tipton	47167		1		2			3
Trousdale	47169				2			2
Unicoi	47171						27	27
Union	47173	2	2					4
Van Buren	47175		1					1
Warren	47177		1					1
Washington	47179	1	1			54	19	75
Wayne	47181		1		2			3
Weakley	47183					0		0
White	47185		1					1
Williamson	47187					49	24	73
Wilson	47189				1		29	30

D.7 - Public Health

TN County	County FIPS	Hospitals	Nursing Homes	Public Health Departments	Urgent Care Facilities	Veterans Health Administration Medical Facilities	Total
Anderson	47001	1	13	1	1		16
Bedford	47003	2	4	1	2		9
Benton	47005	1	1	1			3
Bledsoe	47007	1	1	1			3
Blount	47009	2	13	1	1		17
Bradley	47011	2	7	1	3		13
Campbell	47013	2	4	1			7
Cannon	47015	1	1	1			3
Carroll	47017	2	5	1	1		9
Carter	47019	1	7	1	1	1	11
Cheatham	47021	1	3	1			5
Chester	47023		3	1			4
Claiborne	47025	1	3	1			5
Clay	47027	1	1	1			3
Cocke	47029	1	4	1			6
Coffee	47031	3	9	1	2	1	16
Crockett	47033		3	1			4
Cumberland	47035	1	9	1	4		15
Davidson	47037	15	50	3	14	4	86
Decatur	47039	1	3	1			5
DeKalb	47041	1	3	1			5
Dickson	47043	1	5	1	1		8
Dyer	47045	1	4	1	2		8
Fayette	47047	1	4	1	1		7
Fentress	47049	1	1	1			3
Franklin	47051	2	7	1	1		11
Gibson	47053	3	10	1			14
Giles	47055	1	5	1			7
Grainger	47057		1	1			2
Greene	47059	2	6	1	3		12
Grundy	47061		1	1			2
Hamblen	47063	2	5	1	4		12
Hamilton	47065	13	31	2	5	2	53
Hancock	47067	1	1	1		2	5
Hardeman	47069	1	3	1			5
Hardin	47071	1	6	1	1	1	10
Hawkins	47073	1	5	1		2	9
Haywood	47075	1	2	1			4
Henderson	47077	1	5	1			7
Henry	47079	1	7	1	1		10
Hickman	47081	1	2	1			4
Houston	47083	1	1	1			3
Humphreys	47085	1	3	1			5
Jackson	47087	1	2	1			4
Jefferson	47089	1	5	1			7
Johnson	47091	1	1	1			3
Knox	47093	13	47	2	12	2	76
Lake	47095		2	1			3
Lauderdale	47097	1	3	1			5
Lawrence	47099	1	6	1	1		9
Lewis	47101		1	1			2
Lincoln	47103	1	5	1	2		9
Loudon	47105	1	9	1	2		13
Macon	47111	1	4	1			6
Madison	47113	3	13	2	6		24
Marion	47115	1	2	1	1		5
Marshall	47117	1	3	1			5
Maury	47119	1	13	2	2		18
McMinn	47107	2	8	1	2		13
McNairy	47109	1	3	1			5
Meigs	47121		1	1			2
Monroe	47123	1	5	1			7
Montgomery	47125	2	11	1	2	1	17
Moore	47127		1	1			2
Morgan	47129		1	1			2
Obion	47131	1	6	1	1		9
Overton	47133	1	1	1			3
Perry	47135	1	1	1			3
Pickett	47137		1	1			2
Polk	47139	1	1	1			3
Putnam	47141	1	8	2	4	1	16
Rhea	47143	1	4	1	1		7
Roane	47145	2	6	1	1		10
Robertson	47147	1	8	1			10
Rutherford	47149	4	20	1	8	1	34
Scott	47151	1	2	1			4
Sequatchie	47153		1	1			2
Sevier	47155	1	7	1	1		10
Shelby	47157	23	64	1	15	4	107
Smith	47159	1	2	1			4
Stewart	47161		1	1		1	3
Sullivan	47163	5	18	1	5		29
Sumner	47165	3	21	1	6		31
Tipton	47167	1	3	1			5
Trousdale	47169	1	2	1			4
Unicoi	47171	1	4	1			6
Union	47173		1	1			2
Van Buren	47175		1	1			2
Warren	47177	1	6	1	2		10
Washington	47179	8	17	2	3	2	32
Wayne	47181	1	4	1			6
Weakley	47183	2	5	1			8
White	47185	1	3	1			5
Williamson	47187	2	22	1	2		27
Wilson	47189	2	12	1	4		19

D.8 – Communication

TN County	*County FIPS*	Cellular Towers
Anderson	*47001*	23
Bedford	*47003*	9
Benton	*47005*	49
Bledsoe	*47007*	
Blount	*47009*	
Bradley	*47011*	2
Campbell	*47013*	12
Cannon	*47015*	
Carroll	*47017*	11
Carter	*47019*	13
Cheatham	*47021*	1
Chester	*47023*	4
Claiborne	*47025*	8
Clay	*47027*	25
Cocke	*47029*	
Coffee	*47031*	5
Crockett	*47033*	8
Cumberland	*47035*	28
Davidson	*47037*	3
Decatur	*47039*	9
DeKalb	*47041*	11
Dickson	*47043*	3
Dyer	*47045*	
Fayette	*47047*	17
Fentress	*47049*	2
Franklin	*47051*	64
Gibson	*47053*	1
Giles	*47055*	
Grainger	*47057*	
Greene	*47059*	37
Grundy	*47061*	6
Hamblen	*47063*	
Hamilton	*47065*	17
Hancock	*47067*	23
Hardeman	*47069*	
Hardin	*47071*	12
Hawkins	*47073*	
Haywood	*47075*	
Henderson	*47077*	4
Henry	*47079*	18
Hickman	*47081*	1
Houston	*47083*	11
Humphreys	*47085*	
Jackson	*47087*	52
Jefferson	*47089*	80
Johnson	*47091*	36
Knox	*47093*	6
Lake	*47095*	30
Lauderdale	*47097*	8
Lawrence	*47099*	22
Lewis	*47101*	21
Lincoln	*47103*	41
Loudon	*47105*	
Macon	*47111*	23
Madison	*47113*	54
Marion	*47115*	37
Marshall	*47117*	20
Maury	*47119*	
McMinn	*47107*	
McNairy	*47109*	
Meigs	*47121*	
Monroe	*47123*	30
Montgomery	*47125*	43
Moore	*47127*	5
Morgan	*47129*	16
Obion	*47131*	
Overton	*47133*	2
Perry	*47135*	18
Pickett	*47137*	1
Polk	*47139*	33
Putnam	*47141*	27
Rhea	*47143*	
Roane	*47145*	11
Robertson	*47147*	8
Rutherford	*47149*	3
Scott	*47151*	29
Sequatchie	*47153*	
Sevier	*47155*	3
Shelby	*47157*	30
Smith	*47159*	3
Stewart	*47161*	1
Sullivan	*47163*	10
Sumner	*47165*	4
Tipton	*47167*	6
Trousdale	*47169*	1
Unicoi	*47171*	
Union	*47173*	28
Van Buren	*47175*	8
Warren	*47177*	29
Washington	*47179*	47
Wayne	*47181*	19
Weakley	*47183*	
White	*47185*	1
Williamson	*47187*	4
Wilson	*47189*	4

Appendix C: Tennessee Emergency Management Agency: Resources for Individuals and Families

Prepare

Preparedness is vitally important for all sectors of society: businesses, civic groups, communities, individuals, families, and neighborhoods.

It's likely one or more of these sectors will be first at the site of a disaster or an emergency, even before the first responders arrive.

And in catastrophic disasters, such as devastating earthquakes, essential services may not be available, or it may be days before responders can access an impacted area.

In either of these cases, individuals must be prepared to act on their own and to survive until help arrives.

There are myriad resources, from emergency kit checklists to family emergency management plans and to local emergency management contacts, available in the links on the left of this page.

These resources can help you, your family, and your community prepare now before the next disaster strikes.

Make a Plan

Four Steps to Emergency Planning

Start your emergency planning by learning what types of disasters will affect your area. Tennessee has 13 specific hazards TEMA has identified in our agency's statewide emergency planning process.

Step 1: Put together an emergency plan. Begin with a discussion of these four questions with your family, friends, or household.

1. How will I receive emergency alerts and warnings?
2. What is my shelter plan?
3. What is my evacuation route?
4. What is my family/household communication plan?

Step 2: Consider the specific needs of your household.

Discuss your needs and responsibilities and how people in the network can assist each other with communication, care of children, business, pets, or specific needs like the operation of durable medical equipment. Create your own personal network for specific areas where you need assistance. Keep in mind some these factors when developing your plan:

- different ages of members within your household
- responsibilities for assisting others
- locations frequented
- dietary needs
- medical needs including prescriptions and equipment
- disabilities or access and functional needs including devices and equipment
- languages spoken
- cultural and religious considerations
- pets or service animals
- households with school-aged children

Step 3: Fill out a Family Emergency Plan

Download and fill out a family emergency plan or use as a guide to create your own.

Step 4: Practice your plan with your family/household.

Your County's Emergency Management Agency (EMA) is a great resource for preparedness planning.

Emergency Kit

Checklists of Disaster Supplies

Basic Disaster Supplies:

- one gallon of water per person, and per pet, per day for at least three days, five to seven days preferable, especially in a rural area
- at least a three-day supply of non-perishable food for each person in the household
- flashlight

- battery-powered radio
- NOAA Weather Radio
- extra batteries
- first aid kit
- important medications
- whistle to signal for help
- moist towelettes, garbage bags for personal sanitation
- wrench or pliers to turn off utilities
- manual can opener for food
- local maps
- cell phone with charger or solar charger
- cash or traveler's checks and change

Additional Supplies:

- infant formula and diapers
- pet food and extra water for your pet
- important family documents (id, bank account records)
- first aid book
- sleeping bags or warm blankets
- change of clothing
- sturdy shoes
- fire extinguisher
- matches in a waterproof container
- feminine supplies and personal hygiene items
- paper and plastic utensils
- paper and pencil
- activities for children

Emergency Supplies for Children:

- non-perishable food items (dried fruit, peanut butter, etc.) for three-to-five days, or longer

- can opener
- first aid kit
- sleeping bags or warm blankets for everyone in your family
- change of clothes for three-to-five days, including sturdy shoes
- toothbrush, toothpaste, soap
- paper plates, plastic cups, paper towels, utensils
- water—at least one gallon per person, per day for three-to-five days, or longer
- battery-powered hand-cranked radio with extra batteries
- flashlights with extra batteries
- cell phone with charger, extra battery and solar charger
- whistle to signal for help
- local maps
- books, games, or puzzle
- a favorite stuffed animal

Emergency Items for Senior Citizens:

- reference checklist of basic disaster supplies
- weeks' supply of medications
- back-up plan for regular medical treatments
- back-up plan for medical devices requiring electricity
- extra eyeglasses
- extra hearing aid batteries
- extra wheelchair batteries
- extra oxygen
- mobility devices, such as canes or walkers
- records of prescriptions, dosage, and treatment info
- copies of medical insurance cards
- copies of Medicare or Medicaid cards
- family contact information
- copies of important documents (bank information, wills, medical directives)

- cash or travelers' checks

Emergency Items for Individuals with Disabilities:

- week-long supply of prescription medicines, along with a list of all medications, dosages, and allergies
- extra eyeglasses and hearing aid batteries
- braille or large print marked emergency supplies
- laminated cards with phrases or pictograms
- a weather radio with text display and flashing alert
- a TTY
- pen and paper in case you have to communicate with someone who does not know sign language
- extra wheelchair batters (manual wheelchair if possible)
- extra mobility device such as cane or walker, if used
- supplies for oxygen equipment
- a list of the style and serial number of medical devices, augmentative communications devices, or assistive technologies with operation instructions
- copies of medical insurance and medical cards
- contact information for doctors, relatives, friends
- service animal supplies, such as food and water, plus collar, ID tags, medical supplies
- handheld electronic devices loaded with movies and games.
- headphones to minimize distractions
- comfort snacks and toys for children

Items for Pets:

- one gallon of water per pet for three-to-five days, or longer
- medicines and medical records
- important documents such as adoption papers, vaccination documents
- first aid kit
- collar or harness with ID tag, rabies tag, and a leash
- crate or pet carrier

- sanitation supplies, such as pet litter, litter box, newspapers, plastic bags
- a photo of you and your pets together
- familiar pet items such as toys and treats

Financial Emergency Kit:

- photo ids to prove identity of family members
- birth certificates
- social security cards
- military service IDs
- pet ID tags
- housing payment records
- insurance policies
- income information
- tax statements
- health insurance information
- prescription cards
- immunization records
- list of medications
- physician contact information
- banking information
- insurance agent contact information

Prepare your Vehicle:

- flashlight with extra batteries and bulbs
- mobile device charger, battery-operated or solar powered
- maps
- tire repair kit
- jumper cables
- flares
- bottled water
- non-perishable food items

- winter: blanket, hat, mittens, shovel, sand, tire chains, windshield scraper, florescent distress flag
- summer: sunscreen, shade item such as an umbrella

Prepare the Kids

What you should know about Preparing Kids for Emergencies:

- ensure children are included in preparedness conversations.
- learn the building blocks of preparedness—Be Informed, Make a Plan, Build a Kit and Get Involved.
- know the emergency plan for your child’s school and child care facility.
- practice evacuation plans and other emergency procedures with children on a regular basis.
- learn different ways to help children cope during and after an emergency.
- make sure children have emergency contacts memorized or written down in a secure place.
- teach kids when and how to call important phone numbers like 911.

Emergency Planning Consideration for Kids:

- include your child's medication or supplies in your family’s emergency kit.
- include your child's favorite stuffed animals, board games, books or music in their emergency kit to comfort them in a disaster.
- get the kids involved in building their own emergency kit. Store important family documents on your phone in a safe secure app. Keep hard copies in secure place.
- emergencies can happen anytime.
- ask your child’s teacher about the plans the school has in place for emergencies.
- email, voice, or text. What will your child’s school use to communicate during an emergency?
- know your school's evacuation & reunification plans.
- talk to your kids about what to do before, during, and after a disaster.
- ask your child's school for a copy of their emergency plan for you to keep at home & work.
- create a backpack emergency card that your child can keep with them.

- create a family password or phrase to prevent your child from going with a stranger.

Emergency Supplies for Kids:

- non-perishable food items (dried fruit, peanut butter, etc.) for three-to-five days, or longer
- can opener
- first aid kit
- sleeping bags or warm blankets for everyone in your family
- change of clothes for three-to-five days, including sturdy shoes
- toothbrush, toothpaste, soap
- paper plates, plastic cups, paper towels, utensils
- water—at least one gallon per person, per day for three-to-five days, or longer
- battery-powered hand-cranked radio with extra batteries
- flashlights with extra batteries
- cell phone with charger, extra battery and solar charger
- whistle to signal for help
- local maps
- books, games, or puzzle
- a favorite stuffed animal

Online Resources

https://www.ready.gov/kids/parents

https://www.ready.gov/kids/games

https://www.ready.gov/kids/know-the-facts

https://www.ready.gov/kids/parents/coping

https://www.healthychildren.org/

https://www.cdc.gov/phpr/readywrigley/documents/backpack_emergency_card.pdf

https://www.fema.gov/media-library-data/1440449346150-1ff18127345615d8b7e1effb4752b668/Family_Comm_Plan_508_20150820.pdf

https://www.aap.org/en-us/advocacy-and-policy/aap-health-initiatives/Children-and-Disasters/Pages/default.aspx

Appendix D: Mitigation and Resilience Best Practices and Case Studies

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Hydrologic	Acquisition and relocation of properties in floodway and floodplain.	Birmingham, Alabama	Direct losses avoided during repeat flooding resulted in an estimated $63.7 million in losses avoided compared to $43.4 million total project cost.	Federal Emergency Management Agency 2017a.
	Improve stormwater drainage system.	Poarch Creek Indian Reservation, Alabama	Since completion, the area has not suffered surface water flooding and successfully managed over eight inches of rain during Hurricane Ivan.	Federal Emergency Management Agency 2019d.
	Homeowners elevate home in flood plain.	Jefferson County, Arkansas	The elevated home remained undamaged after a major flood event.	Federal Emergency Management Agency 2018.
	Counties implement floodplain management through higher floodplain regulatory standards and policy actions.	Colorado	During a major flood event, flood-related losses were reduced. The total project cost was $5.7 million, and estimated total losses avoided were $22.5 million.	Federal Emergency Management Agency 2017e.
	City focuses on floodplain management including six main initiatives: an emergency flood notification system, improvements to infrastructure that accommodate river flow, a community education and outreach campaign, the preservation and restoration of open space in floodplains, constructing detention areas to minimize flash flooding events, and new regulations and building standards that protect the people and property of Fort Collins.	Fort Collins, Colorado	During record-breaking floods, the city experienced minimal damage.	US Climate Resilience Toolkit 2019a; The Pew Charitable Trusts 2019a.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Hydrologic	City installs wireless sensors in combined storm sewers to monitor water levels.	South Bend, Indiana	During a 100-year rainfall event, the amount of raw sewage that flowed into the river was minimized.	Swiercz 2017.
	State implements acquisition, relocation, and elevation projects.	Iowa	The total project cost was $23.8 million, and the estimated total losses avoided were $24.3 million.	Federal Emergency Management Agency 2017f; Gupta et al. 2016.
	State acquires buildings prone to repetitive losses from flooding.	Missouri	Significant losses were avoided during multiple storm events. The total project cost was $44.2 million, and estimated losses avoided were $93.6 million.	Federal Emergency Management Agency 2017d.
	City constructs green roofs for stormwater management (also create cooling effect).	Kansas City, Missouri	An estimated average of 29 inches of stormwater per year could be retained by the systems and not run off into storm drains. The largest green roof saves $56,000 in annual water costs.	US Environmental Protection Agency 2018; Resilient Shelby 2019.
	Hospital builds floodwall, flood gates, and pumping system.	Binghamton, New York	During a major flood event, the system protected the hospital from floodwaters.	Resilient Shelby 2019.
	Homeowners elevate homes in areas with frequent flooding.	Nassau County, New York	Elevated houses survived two major hurricanes with no significant issues.	Federal Emergency Management Agency 2019a.
	City water utility participates in state voluntary flood buyout program and purchases over 400 properties.	Charlotte, North Carolina	Estimated losses avoided are over $25 million.	Resilient Shelby 2019.
	City acquires and demolishes properties and builds bioswales, rain gardens, and green streets in a neighborhood prone to flooding.	Cuyahoga Falls, Ohio	The neighborhood reported no damage after a major storm event.	Naturally Resilient Communities "Case Study: Cuyahoga Falls, Ohio."

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Hydrologic	Native American tribes (Modoc and Miami) construct elevated casino building in a floodplain.	Miami, Oklahoma	During a flooding event, water did not enter the building, and the casino reopened as soon as the waters receded. Estimated losses avoided were over $3 million.	Federal Emergency Management Agency 2019b.
	Native American tribe (Citizen Potawatomi Nation) maintains unimpaired waterways to keep channels flowing freely.	Shawnee, Oklahoma	Potential losses estimated over $40 million to the Tribe were avoided during a large flood event.	Federal Emergency Management Agency 2019c.
	City implements voluntary buy-out program, purchases over 900 flood-prone properties, and restores area into greenways for flood control and recreation, including flood bypasses, retention basins, waterfront parks, and open space.	Tulsa, Oklahoma	Since the project's creation, property owners and businesses in the area have not experienced major property losses because of flooding.	Naturally Resilient Communities "Case Study: Mingo Creek, Tulsa, OK."
	Medical university elevates critical infrastructure (hospital power plant).	Charleston, South Carolina	During a hurricane-related storm surge and record rainfall, power and patient care were not interrupted.	Federal Emergency Management Agency 2016g.
	County updates ordinances to eliminate building in floodways and require elevated structures in floodplains, and acquires properties through floodplain management program.	Greenville County, South Carolina	The local community supports the program, and 84 acres in the floodplain have been converted to open space.	Federal Emergency Management Agency 2016d.
	City implements rigorous floodplain management with higher building standards including storm water and drainage basin projects.	Myrtle Beach, South Carolina	Residents and property owners have experienced a decrease in flooding damage and save 25% on flood insurance premiums.	Federal Emergency Management Agency 2016e.
	City water utility acquires and demolishes homes in a floodplain.	Nashville, Tennessee	The water utilty purchased and demolished 90 homes prior to the historic 2010 flood, avoiding their destruction. It has purchased more than 200 homes since that flood.	Metropolitan Nashville Office of Internal Audit 2014.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Hydrologic	City develops waterfront park with bioswales, cistern, floodwall, and green roofs.	Nashville, Tennessee	The city built Riverfront Park with a variety of amenities for residents and revenue generation while also managing stormwater and flooding.	Naturally Resilient Communities "Case Study: Riverfront Park, Nashville, Tennessee."
	City improves stormwater drainage system and installs levee/floodwall system.	Austin, Texas	The neighborhood did not experience flooding during several major storm events.	Federal Emergency Management Agency 2015a.
	County acquires homes in high-risk flooding areas and restores floodplain to natural function of stormwater storage.	Harris County, Texas	Approximately $12.4 million in flood damages were avoided during a record rainfall event as a result of buy-out of 550 properties.	Federal Emergency Management Agency 2016h.
	City constructs stormwater detention pond.	Pine Forest, Texas	During record rainfall and flooding in the region, the community did not report flooding.	Federal Emergency Management Agency 2016b.
	City implements property buyout program in floodplain.	Austin, Texas	323 properties were removed before damaging historic floods overwhelmed the area.	Federal Emergency Management Agency 2016f.
	State elevates residential structures.	Snoqualmie, Washington	All 28 elevated homes would have been damaged by a flood. The total project cost was $1.3 million, and estimate losses avoided were $1.6 million.	Federal Emergency Management Agency 2017c.
	Cities installed tributary drainage improvement and flood drainage date.	Issaquah and Stanwood, Washington	The total cost for two projects was $1.25 million, and the estimated avoided losses were $1.2 million. As additional floods occur over time, losses avoided and the return on investment will increase.	Federal Emergency Management Agency 2017b.
	Local governments acquire 92 repetitive-loss properties and demolish structures.	Kenosha, Jefferson, and Crawford counties, Wisconsin	The total project cost was $11 million, and the estimated losses avoided was $14.6 million.	Federal Emergency Management Agency 2017h.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Heat	Water utility plans for uncertainty in water supply.	Denver, Colorado	Water utilities collaborate and use climate data to plan for safe, clean, reliable drinking sources in the future.	US Climate Resilience Toolkit 2018b.
	City works with community stakeholders and regional experts to plan for extreme weather and changing climate conditions.	Las Cruces, New Mexico	The city installed a demonstration rainwater harvesting project, conducted a green infrastructure assessment, and invested $400,000 in identified green infrastructure improvements to build social and economic resilience in a low to moderate income community.	US Climate Resilience Toolkit 2020.
	Mescalero Apache Tribe works with government agencies and other organizations to keep forests and waters healthy and to grow food.	Mescalero Apache Tribe, New Mexico	"As members of the Tribe take on various leadership roles in these efforts, the Mescalero Apache Tribe builds capacity at the same time as they increase their environment's resilience."	US Climate Resilience Toolkit 2017b.
	Agencies partner to develop an early warning system to prevent heat illness.	North Carolina	"...the team was able to "identify areas of action that then create robust, long-term solutions for community needs that are sustainable long after the research project ends," providing a tool to help protect North Carolina citizens for many years to come."	US Climate Resilience Toolkit 2019e.
	As part of its Street Tree Master Plan, city plants trees to help with lowering city temperatures and reducing cooling costs for energy consumers.	Knoxville, Tennessee	Planting trees results in several benefits, including cooling effects, and the 2011 City of Knoxville Urban Forest Management Plan found that every tree planted on Knoxville public property produces $83 in economic benefits.	Knoxville Knox County Metropolitan Planning Commission 2002; City of Knoxville 2011.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Dry	Farmer uses seasonal climate forecasting.	Alabama	Even though some seasonal climate outlooks turn out to be wrong, resulting in poor or even failed crops, this Alabama farmer says outlooks give him an added benefit over the long-term because they are based on probabilities. "Anything that improves his odds over multiple years ultimately means a more stable future for his farm and his family."	US Climate Resilience Toolkit 2017a.
	Water utility tracks climate patterns to help with water supply planning and invests in water infrastructure.	Tampa, Florida	Utility is better able to anticipate reduced surface water supply, plan, reserve, and use water resources to serve customers while sustaining local ecosystems.	US Climate Resilience Toolkit 2018a.
	County water authority conducted comprehensive assessments of resources, developed comprehensive water resource plan, and constructed surface flow wetlands to filter, reuse, and conserve water.	Clayton County, Georgia	During a severe drought in 2007 and 2008, the water authority was able to provide needed water to users and keep reservoir levels near capacity, while a large reservoir in a neighboring county experienced record lows. The cost of building the constructed wetlands is half the cost per gallon of capacity than the cost of a conventional treatment facility, and operating and maintenance costs are significantly lower.	US Climate Resilience Toolkit 2017d; Hewes 2009.
	City water managers evaluate assets and vulnerabilities to address short- and long-term risks to water supply.	Fredericktown, Missouri	City is developing a contract with private partner for water use during dry periods in the short-term and pursuing infrastructure to address longer-term supply.	US Climate Resilience Toolkit 2019b.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Dry	Farmer uses cover crops and no-till practice.	Ohio	More carbon in the soil (healthier soil) results in increased crop yields, reduced fertilizer, pesticide, and fuel costs, increased water storage, and less soil erosion.	US Climate Resilience Toolkit 2019c.
	State governor convenes an interagency and intergovernmental working group to study and report on water conservation for times of drought.	Tennessee	The working group published *TN H2O: Tennessee's Roadmap to Securing the Future of Our Water Resources* , which recommended several broad actions, including educating the public and policymakers on the value of water and conservation efforts and emphasizing the importance of collaboration in managing water resources.	Tennessee Department of Environment and Conservation 2018.
	The Department of Parks and Recreation identified six strategies to combat the urban heat island effect, including cool roofs, green roofs, cool pavements, green walls, tree planting, and the development of structures to provide shade.	Austin, Texas	These actions are part of the city's broader efforts to address prolonged and frequent heat and drought in the region.	Ray 2015.
	Dairy farmer uses soil, climate, and weather data and technology to determine when and how much to irrigate.	Morgan County, Utah	Uncertainty is reduced and farmers can set priorities and use water as efficiently as possible.	US Climate Resilience Toolkit 2017c.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Cold and frozen precipitation	Utility strengthens utility poles and reduce span lengths between poles.	Kansas	Facilities repaired after a significant ice storm in 2007 have withstood a number of more recent significant ice storms with very minimal or no damage.	National Rural Electric Cooperative Association 2018.
	Alfalfa Electric Cooperative replaced poles and lines to withstand greater physical loads.	Cherokee, Oklahoma	A heavily damaged section of line that was repaired after a 2013 historic ice storm has endured two severe ice storms in 2015, and the electric co-op experienced no major damage with that section of line during those storms.	US Department of Homeland Security 2019; National Rural Electric Cooperative Association 2018.
	Kiamichi Electric Cooperative strengthened some infrastructure.	Oklahoma	In subsequent storm events, the utility experienced less damage from ice, two tornadoes, and straight line winds.	National Rural Electric Cooperative Association 2018.
	Cimarron Electric Cooperative rebuilt with stronger, higher-rated poles designed to withstand greater physical loads.	Oklahoma	In a subsequent ice event, the utility only lost 129 poles, while a neighboring utility lost 6,000.	National Rural Electric Cooperative Association 2018.
	Electric utility installs fiber-optic cable throughout its service area in part to upgrade the communications equipment it uses to manage its electric system in an effort to reduce outages.	Chattanooga, Tennessee	During a three-day snowstorm three years later, 76,000 customers lost power, but the Electric Power Board's fiber-supported "Smart Grid automatically restored 40,000 customers within a few seconds or minutes."	Tennessee Emergency Management Agency 2018b; Electric Power Board 2014.
	In 1998, state department of insurance required insurance companies to provide premium discounts for hail impact-resistant roofs.	Texas	After a severe hailstorm in 2003, hail impact-resistant roofs were evaluated, and they worked. In 2008, when the mandate was lifted, resistant roof installations continued unaffected, and a culture was created of homeowners who "no longer deal with non-hail impact-resistant roofs."	National Institute of Building Sciences 2015.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Rotational and straight winds	State consolidated building codes from more than 400 local jurisdictions and state agencies and adopted a state building code in 1998, phasing out local laws and regulations and replacing them with universal statewide building codes.	Florida	In the decade following adoption of a statewide building code, actual losses from windstorms were reduced by as much as 72%, and after Hurricane Charley in 2004, 60% fewer residential claims and 42% less in damage cost compared to Hurricane Andrew in 1992.	Federal Emergency Management Agency "PrepTalks Discussion Guide: Using Codes and Standards to Build Resilient Communities;" Simmons et al. 2017; International Code Council 2018.
	Community college constructed two dormitories with tornado safe rooms.	Creston, Iowa	During an EF2 tornado, students who took shelter in the safe rooms did not report any injury or death, while three students who were not able to use the safe rooms sustained injuries. The total project cost was $242,700 and estimated potential losses were $16.1 million.	Federal Emergency Management Agency 2017g.
	City adopts stronger residential building codes to withstand an EF2 tornado.	Moore, Oklahoma	Two years after adoption of the codes, the city of Moore was hit by an EF2 tornado, and buildings constructed according to the updated code performed as expected with only minor damage. Residents are supportive and prefer stronger homes.	Brandes 2014; McCleland 2018; Ramseyer, Floyd, and Holliday 2017.
	County builds a safe room in one of its schools that serves both the school and the broader community during severe storms.	Lake County, Tennessee	The room holds up to 600 people and provides "near-absolute protection" during tornados and severe wind events. The room is "probably the safest place in the county," according to the county schools' supervisor of facilities.	Federal Emergency Management Agency 2002.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Rotational and straight winds	County strengthens its emergency operations building infrastructure to withstand several types of natural disasters.	Williamson County, Tennessee	Williamson County Public Safety Center was designed and built to withstand an EF5 tornado. It serves as an emergency operations center and can house several public and private entities in the event of an emergency.	Interviews with Williamson County representatives.
	Build rest areas with tornado shelters in tornado-prone areas.	Texas	Information not available.	Federal Emergency Management Agency 2016i.
	County implemented residential rebate program to incentivize homeowners to build tornado shelters and safe rooms.	Cooke County, Texas	Homeowners took shelter in their safe rooms during a tornado event, remained safe, and are satisfied with the program.	Federal Emergency Management Agency 2016k.
	City installed an early warning siren and alert system.	San Marcos, Texas	During a severe flood and tornado event the tornado sirens sounded to alert the public to stay indoors and shelter-in-place.	Federal Emergency Management Agency 2016m.
	Utility cooperative strengthened utility poles to withstand wind exposure.	Virginia	In a subsequent wind storm the strengthened portion of the system was not damaged.	National Rural Electric Cooperative Association 2018.
	States pass legislation requiring insurance discounts or credit programs.	Florida, Louisiana, Maryland, Mississippi, New York, South Carolina, and Texas	Legislation requires rate filings to include discounts, credits, or reductions in deductibles for installation of wind-resistant features on properties.	National Institute of Building Sciences 2015.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued).

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Wildfires	City implements proactive forest management including adopting WUI code, building fire-adapted and aware communities, and developing interagency partnership.	Flagstaff, Arizona	Cost-benefit analysis of economic losses related to large wildfires showed the need for resilience actions. The community has a strong culture of forest management and community buy-in and agency collaboration with resilience efforts was critical to implementation.	Gupta et al. 2016.
	Homeowner maintains defensible space around property and builds with fire resistant materials.	Calaveras County, California	The house survived a wildfire while two of the neighboring properties that were not cleared were consumed by the fire.	Federal Emergency Management Agency 2016a.
	Homeowner builds with fire resistant materials and landscaping and creates defensible space around structures.	Middletown, California	During a wildfire, the home suffered minor damage while neighboring houses were destroyed.	Federal Emergency Management Agency 2016c.
	Utilities and partners monitor and forecast wildfire threats caused by wind.	San Diego, California	Implementing the use of a wildfire index has helped the utility save money, reduce risk, and better serve their customers.	US Climate Resilience Toolkit 2019d.
	US Forest Service cuts down vegetation and trees killed by beetles.	Silverthorne, Colorado	During the 2018 Buffalo Fire, between 200 and 300 homes were spared because the fire did not have the fuel needed to advance on the subdivision.	Daley 2018.
	City provides a curbside brush removal program for residents to protect the community and reduce the risk of wildfires and participates in the Ready, Set, Go! pilot program, which prepares residents and businesses for evacuations.	Pigeon Forge, Tennessee	Three years after the 2016 Great Smoky Mountain wildfires, which resulted in 14 deaths and $2 billion in property damage, the city received the National Wildfire Mitigation Award for its mitigation efforts.	National Park Service 2016; Tennessee Department of Agriculture 2019.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Wildfires	County reduces understory fuel using nontraditional mechanical thinning process using skid steers instead of traditional prescribed burning.	Bastrop County, Texas	The county was able to get community buy-in and clear the understory and remove undesirable species growing under the tree canopy. In future wildfire outbreaks, the fire is more likely to stay on the ground and not go into the trees in an area with a history of large destructive fires.	Federal Emergency Management Agency 2016j.
Wildfires	Agencies and landowners cooperate and plan together to treat timber and induce controlled fires.	Mount Adams, Washington	Efforts have reduced fire risk, generated over $3 million in revenue, created jobs, and contributed $8 million in economic expansion.	US Department of Homeland Security 2019.
Earthquakes	City passes law requiring structural seismic upgrading or demolition of 14,000 unreinforced masonry buildings.	Los Angeles, California	Retrofitted and reinforced buildings performed better than unretrofitted buildings in a major earthquake.	Reitherman 2009.
Earthquakes	City studies resilience to identify gaps, actions to address them, and policies to recommend for resilience investments in the community.	Los Angeles, California	The city adopted ordinances requiring retrofits for certain buildings and water infrastructure based on recommendations proposed by the policy planning team.	Gupta et al. 2016.
Earthquakes	City retrofits existing fire station including both structural and non-structural retrofits.	Calistoga, California	Saved almost $1 million by not replacing it and is prepared for future earthquakes.	Hazard Mitigation Community Education and Outreach Best Practices Team "Best Practices Stories South Napa Earthquake DR-1493-CA."
Earthquakes	School district retrofits school building during renovation.	Napa, California	The retrofitted school building withstood a major earthquake and reopened four hours after the earthquake hit.	Hazard Mitigation Community Education and Outreach Best Practices Team "Best Practices Stories South Napa Earthquake DR-1493-CA."

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Earthquakes	Business owner adheres to retrofitting requirements in building codes for commercial properties.	Solano County, California	The retrofitted buildings withstood a major earthquake, while one building that was not retrofitted suffered $2 million in damage.	Hazard Mitigation Community Education and Outreach Best Practices Team “Best Practices Stories South Napa Earthquake DR-1493-CA.”
	Large brewing company assesses risk and invests in seismic upgrades.	Van Nuys, California	After 1994 Northridge earthquake, damage could have been over 60 times the cost of the mitigation program. The brewery returned to full operation seven days after the earthquake.	National Institute of Building Sciences 2015.
	Earthquake insurance provider offers discounts.	California	California Earthquake Authority provides 5% discount on insurance premiums on retrofitted homes.	National Institute of Building Sciences 2015.
	Historic theater building that is still operational is retrofitted while renovating.	Charleston, South Carolina	Building repaired and retrofitted to avoid collapse in future catastrophic earthquake.	Federal Emergency Management Agency 2016l.
	Utility invests over $80 million in earthquake mitigation projects.	Memphis, Tennessee	Memphis Light, Gas and Water installs, improves, replaces, and retrofits infrastructure and relocates some critical infrastructure.	Memphis Light, Gas and Water 2011.
	Tennessee Emergency Management Agency hosts the state’s annual participation in the Great Central US ShakeOut earthquake drill, which is free and open to the public.	Tennessee	In West Tennessee, where the New Madrid fault is located, businesses, communities, individuals, organizations, and schools learn how to prepare and respond to reduce damage and injuries from a large earthquake in the region.	Tennessee Emergency Management Agency 2018a.
	State could adopt and enforce hazard-resistant building codes.	Tennessee	A study scenario shows that seismic losses caused by a large earthquake estimated at $10.1 million could be avoided along the New Madrid fault in West Tennessee.	Federal Emergency Management Agency 2015b.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Policy Solutions to Reduce Local Flood Risk (The Pew Charitable Trusts 2019b)	**Using existing funds for mitigation by redirecting revenue and spending**			
	State legislature passed a rule in 1995 to give landowners a tax credit for restoring, enhancing, or creating wetlands on their property.	Arkansas	The state has approved over $4.5 million in tax credits for projects to protect or create wetlands and riparian zones, which have helped to control flooding in those areas by slowing the speed and volume of floodwaters and also helped improve the state's water quality.	The Pew Charitable Trusts 2019b.
	Small town created program in 1990 offering rebates to homeowners for projects that protect houses from flooding and sewer backups.	South Holland, Illinois	As of February 2019, the village had reimbursed 1,172 households more than $800,000 in rebates, which the households used to install $2.9 million worth of flood-proofing projects. The incentive has motivated homeowners to take action and as a result they have experienced less flooding.	The Pew Charitable Trusts 2019b.
	State Department of Fish and Wildlife program offers a property tax exemption for landowners who improve or maintain riparian land within 100 feet of a stream or river.	Oregon	From 2015 to 2019, the state issued $300,000 biennially in income tax credits under the program to preserve and maintain riparian zones and, as of 2016, has conserved about 1,457 acres of land along 99 miles of streams.	The Pew Charitable Trusts 2019b; Oregon Department of Fish and Wildlife “Riparian Lands Tax Incentive.”
	State legislature updates emergency relief assistance fund to encourage communities to take action to reduce flood risk.	Vermont	Communities in Vermont are proactively taking steps to meet new standards and lessen the impacts of future storms and flooding.	The Pew Charitable Trusts 2019b.
	State partners with nonprofit groups and other stakeholders to unify flood plain management efforts and distribute grants for local projects that address the root causes of flooding.	Washington	Form 2013 to 2018, the program has distributed more than $115 million in grants to restore rivers, floodplains, and habitats, letting rivers flow freely and removing engineered systems that no longer operate effectively.	The Pew Charitable Trusts 2019b.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Policy Solutions to Reduce Local Flood Risk (The Pew Charitable Trusts 2019b)	State legislature created a grant program in 1999 to mitigate flooding, prioritizing voluntary buyouts of properties at high risk of flooding, removing the structures, and converting the land to open space, such as wetlands or recreational areas.	Wisconsin	From 2002 to 2018, the program funded buyouts of 140 structures, reducing the risk for homeowners and helping to reduce losses from future floods.	The Pew Charitable Trusts 2019b.
	Creating revenue sources for mitigation			
	State legislature improved an existing flood control revolving loan fund in 2016 to help municipalities mitigate hazards and upgrade infrastructure.	Indiana	By providing low-interest loans to communities that otherwise couldn't afford needed mitigation projects, the revolving fund is enabling communities to address flooding with solutions that are fiscally sustainable.	The Pew Charitable Trusts 2019b.
	State allocated funding to create a flood mitigation program and watershed approach including watershed management authorities that assess hydrologic conditions and develop plans to minimize flood risk and improve water quality within their watersheds.	Iowa	Projects completed by watershed management authorities include restoring wetlands, building water detention basins, stabilizing riverbanks, and creating vegetated buffers. The mitigation program approved $1.4 billion for 10 local flood prevention projects, funded with sales tax revenue and local and federal funds.	The Pew Charitable Trusts 2019b.
	State created a shore protection revolving loan fund that offers loans to residents to create or restore living shorelines and other natural areas to reduce erosion and stabilize coastlines. The state also passed a law in 2008 requiring natural methods to protect shorelines.	Maryland	Since 1971, the loan program has distributed more than $3 million for 475 living shoreline projects, protecting over 200,000 linear feet of shoreline and creating over 3.75 million square feet of marsh. Restoring marsh grasses and other natural materials is helping to protect homes along the coastline.	The Pew Charitable Trusts 2019b.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

Extreme Weather Event Category*	Example Mitigation Strategies	Location	Outcomes	Sources
Policy Solutions to Reduce Local Flood Risk (The Pew Charitable Trusts 2019b)	State issues $50 million in bonds to renovate roads and bridges to be flood-ready and be sustainable in the long-term.	Minnesota	The department of transportation completed 34 flood mitigation projects including updating and creating new culverts to better withstand changing precipitation patterns, upgrading drainage systems, and raising roadways in flood-prone areas.	The Pew Charitable Trusts 2019b.
	Establishing smarter regulations to reduce flood risk			
	City council updated its flood damage prevention ordinance and adopted strong regulations on construction in flood plains.	Brevard, North Carolina	Development requirements are designed to ensure that projects don't increase the risk of downstream flooding. The regulations have also lowered flood insurance premiums for many residents because of incentives in the federal flood insurance program.	The Pew Charitable Trusts 2019b.
	City creates and funds a program to use nature-based solutions to reduce flooding.	Milwaukee, Wisconsin	Working with permitting authorities to use green infrastructure, the city captured an additional 5 million gallons of stormwater and wastewater runoff, and then developed the capacity to store another 7 million gallons.	The Pew Charitable Trusts 2019b.
	City updates zoning ordinance to encourage development in less flood-prone areas and improve flood resilience.	Norfolk, Virginia	"The measures are likely to be cost-effective; compared with other types of flood-mitigation programs, such as grants, fewer city expenditures are required. And by requiring more resilient construction and encouraging development on higher ground, Norfolk is better positioned to protect its residents and the naval base from the impacts of stronger storms and sea level rise."	The Pew Charitable Trusts 2019b; Gupta et al. 2016; Kutner et al. 2019.

*Abkowitz, Camp, and Dundon 2020. Lightning is one of the weather event categories, but the table does not include case studies specifically about lightning hazard.
Sources: See hazard mitigation case studies reference list for full citations.

Appendix D: Mitigation and Resilience Best Practices and Case Studies (continued)

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