3 Risk Assessment

Many kinds of natural and technological hazards impact the state of Alabama. To reduce the loss of life and property to the hazards that affect Alabama, state and local officials must have a robust and up-to-date understanding of the risks posed by these hazards. In addition, federal regulations and guidance require that certain components be included in the risk assessment section of state hazard mitigation plans (see Title 44 Code of Federal Regulations (CFR) Part 201 for federal regulations for mitigation planning and the State Mitigation Plan Review Guide for the Federal Emergency Management Agency's (FEMA) official interpretation of these regulations). The required components are as follows:

- An overview of the type and location of all natural hazards that can affect the state, including information on previous occurrences of hazard events and the probability of future hazard events. According to the State Mitigation Plan Review Guide, the probability of future hazard events "must include considerations of changing future conditions, including the effects of long-term changes in weather patterns and climate;"
- An overview and analysis of the state's vulnerability to these hazards. According to the CFR, the state risk assessment should address the jurisdictions most threatened by the identified hazards, as well as the state assets located in the identified hazard areas;
- An overview and analysis of the potential losses to the identified vulnerable structures. According to the CFR, the state risk assessment should estimate the potential dollar losses to state assets and critical facilities located in the identified hazard areas.

The Alabama State Hazard Mitigation Plan Update approved by FEMA in 2013 assessed statewide risks based on the best available data at the time and complied with existing federal regulations and policy. The 2018 revisions update the previous analyses to reflect the best available data as of December 2017, and to reflect the official FEMA policy on assessing the probability of future hazard events. While the 2013 plan update included limited analysis of climate change, this update includes a thorough review of the anticipated effects of climate change on the future probability of hazard events for each of the profiled hazards.

3.1 Overview

The structure of the risk assessment chapter is intended to support the development of effective mitigation strategies, and to demonstrate compliance with federal regulations and policy. Following the overview provided in Section 5.1, Section 5.2 identifies and profiles the hazards that affect the state of Alabama, Section 5.3 provides detailed vulnerability assessments and loss estimates for a subset of the identified hazards, and Section 5.4 discusses the impacts of development trends on vulnerability.

Section 5.1 is further subdivided into one subsection on the hazards identified as affecting the state (5.1.1), one subsection on the ranking methodology used to determine which hazards would receive detailed vulnerability assessments, (5.1.2), and one section on the hazards profiled in county plans (5.1.3). Section 5.2 presents the greatest volume of information with one subsection for each on the fourteen identified hazards (5.2.1 through 5.2.14). Each of these fourteen subsections provides a general description of the hazard, a discussion of the nature of the hazard in Alabama, a review of the history of the hazard in Alabama, and a summary of the future probability of the hazard in Alabama. The summary of the future probability of each hazard addresses the anticipated effects of climate change, as well as the areas likely to be most vulnerable to the hazard.

3.1.1 Identified Hazards

The list of hazards to be included is reviewed by the State Hazard Mitigation Team (SHMT) with each plan update. This has led to minor adjustments over the years. For example, in the 2007 plan update, a high winds category was created to include hurricane wind, tornadoes, and windstorms. Storm surge from hurricane was grouped into the flood hazard category which also included riverine flooding and flash flood. In addition, tsunami was added as a hazard and all man-made and human-caused hazards were removed. During the 2010 plan update process, no significant changes were made to the list of hazards addressed. During the 2013 plan update process, it was determined that coastal erosion would be expanded upon based on available data (included in flood), rogue waves would not be addressed, and sea level rise would be added.

During the 2018 plan update process, the SHMT considered hazard additions and adjustments at the Risk Assessment Methodology and Outreach Strategy Meeting on December 1, 2017. It was determined that the plan update should address all the hazards included in the previous plan, with one slight adjustment to the treatment of sea level rise. To support more effective and resilient mitigation strategies, this plan discusses the flooding impacts of sea level rise in Section 5.2.5, and the coastal change impacts of sea level rise in Section 5.2.10. Based on the analysis in Section 5.2.5, mitigation actions to address current flood hazards can be designed to address future flood hazards as well. Based on the analysis in Section 5.2.10, coastal planning and management activities can be adapted to slow the advance of coastal land change and reduce the damage to properties, infrastructure, and the economy.

The hazard list includes hazards that have occurred in the past as well as those that may occur in the future. In addition, hazards with the greatest chance of significantly affecting the state and its residents are included. A variety of sources were consulted to determine hazards that have impacted the state historically or that may occur in the future. These included national, regional, and local sources. Some of the specific sources include:

- Alabama Emergency Management Agency (AEMA);
- US Geological Survey (USGS);
- Alabama Disaster Center;

- Alabama Forestry Commission;
- National Oceanic and Atmospheric Administration (NOAA);
- Geological Survey of Alabama (GSA);
- Alabama Department of Economic and Community Affairs (ADECA);
- FEMA.

Input from experts at these agencies was also solicited during the review of the hazards. Additional details on the process can be found in Section 4: Planning Process. The list of 2018 hazards to be included is as follows:

1. Dam Failure;
2. Drought;
3. Earthquakes;
4. Extreme Temperatures;
5. Flooding (riverine flooding, storm surge, flash floods);
6. Hail;
7. High Winds (hurricanes, tornadoes, windstorms);
8. Landslides;
9. Lightning;
10. Sea Level Rise and Coastal Land Change;
11. Sinkholes and Land Subsidence;
12. Tsunamis;
13. Wildfires; and
14. Winter Storms

The SHMT re-affirmed this hazard list at the Risk Assessment Methodology and Outreach Strategy Meeting on December 1, 2017.

Two important sources for characterizing the hazards that affect the state are: 1) the record of significant meteorological events compiled in the National Weather Service (NWS) Storm Events Database, and 2) the record of federal disaster declarations compiled by FEMA. These data sources are briefly summarized below.

3.1.1.1 NWS Storm Events Database

Since 1950, NWS offices across the US have submitted reports on significant storm events to NWS headquarters. NWS field offices are instructed to document events that:

- Have sufficient intensity to cause loss of life, injuries, significant property damage and/or disruption to commerce;
- Are rare or unusual and generate media attention; or
- Are otherwise significant meteorological events, such as record temperatures or precipitation event.

These reports are then checked by staff at NWS headquarters and compiled into the Storm Events Database, a searchable online platform that can be accessed at www.ncdc.noaa.gov/stormevents.

The Storm Events Database includes a wealth of information that can help characterize hazards within a state and assess historical vulnerability. This information includes the time, date, and location of documented events; a narrative description of the event; the number of injuries and deaths associated with the event; and the estimated amount of property and crop damage caused by the event.

The Storm Events Database is cited frequently throughout this risk assessment and is the source of much of the information on the nature of hazards in Alabama and past occurrences within the state. Three important caveats must be noted, however. First, there are unique periods of record available depending on the event type. While NWS has consistently collected data on some event types from 1950 to the present, data collection for many event types only began in 1996. Second, some uncertainty is introduced into the database by weather phenomena that involve multiple hazards. Tropical cyclones, for example, can cause damage through high winds, storm surge, flooding, and/or tornadoes. NWS field offices are instructed to separate the observed damages into different event types depending on the immediate cause, but this can become a subjective decision. Finally, the damage estimates included in the Storm Events Database come with some limitations. The damage estimates are collected from diverse sources by staff with little or no training in damage estimation and are not compared with actual costs. In addition, the damage estimates only include direct physical damage to property, crops, and public infrastructure. Although damage estimates for individual events may be quite inaccurate, as estimates from many events are added together the errors become progressively smaller.[1]

In this report, all Storm Event Database damage estimates are adjusted to 2017 dollars. This adjustment was made using the Consumer Price Index Inflation Calculator developed by the Bureau of Labor Statistics. The July 2017 value of $1 dollar in July of each year was retrieved to compile a list of inflation coefficients. These coefficients were then multiplied by the reported damage estimates to adjust each estimate to 2017 dollars.

3.1.1.2 FEMA Disaster Declarations Summary

Another important data source for characterizing hazards in Alabama was the FEMA Disaster Declarations Summary, a dataset summarizing all federally declared disasters. This information begins with the first disaster declaration in 1953 and features all three disaster declaration types: major disaster, emergency and fire management assistance. The dataset includes declared recovery programs and geographic areas and is updated daily. The disaster declaration information summarized in this report was obtained from the dataset posted on January 8, 2018.

Since 1960, various parts of Alabama have been declared federal disaster areas. On four occasions (in 1977, 1993, 2004, and 2017), the entire state was included in a declaration, each time for a different hazard. The southern counties tend to experience more disaster declarations related to hurricanes and coastal storms, while the northern counties tend to experience more

[1] Downton, M., Miller, Z., and Pielke, R., 2005. Reanalysis of US National Weather Service Flood Loss Database. Natural Hazards Review, Vol. 6, No. 1.

disaster declarations related to tornadoes and ice storms, the latter of which may also be accompanied by flooding. Since 2013, the two disasters that had the largest number of declared counties were Hurricane Irma in September 2017 (entire state declared) and Hurricane Nate in October 2017 (47 counties declared). 5.1.1.1.1.1.1Table 3.1 shows the federal disaster declarations in the state from 1960 through the beginning of January 2018.

Table 3.1 Federal Disaster Declarations in Alabama (Through January 8, 2018)

Date	Disaster Number	Type of Incident	# of Counties Declared
February 27, 1961	109	Floods	Info not available
November 7, 1969	280	Hurricane Camille	2
April 9, 1970	285	Heavy Rain, Tornadoes and Flooding	2
March 27, 1973	369	Tornadoes and Flooding	28
May 29, 1973	388	Severe Storms and Flooding	12
April 4, 1974	422	Tornadoes	20
January 18, 1975	3007	Tornadoes	5
March 14, 1975	458	Severe Storms and Flooding	23
April 23, 1975	464	Severe Storms and Flooding	8
October 2, 1975	488	Severe Storms, Tornadoes and Flooding	15
April 24, 1976	3064	Tornadoes	2
April 9, 1977	532	Severe Storms and Flooding	9
July 20, 1977	3045	Drought	67
August 9, 1978	563	Severe Storms and Flooding	1
March 17, 1979	3074	Flooding	9
April 18, 1979	578	Storms, Wind, and Flooding	28
September 13, 1979	598	Hurricane Frederic	11
April 20, 1980	619	Severe Storms, Tornadoes and Flooding	2
April 10, 1981	638	Severe Storms, Tornadoes and Flooding	1
May 14, 1981	639	Severe Storms and Flooding	1
December 13, 1983	695	Severe Storms, Tornadoes and Flooding	4
May 11, 1984	3088	Severe Storms and Tornadoes	4
September 7, 1985	742	Hurricane Elena	2
November 17, 1989	848	Severe Storms and Tornadoes	2

Date	Disaster Number	Type of Incident	# of Counties Declared
February 17, 1990	856	Severe Storms, Tornadoes and Flooding	27
March 21, 1990	861	Severe Storms, Tornadoes and Flooding	33
January 4, 1991	890	Severe Storms and Flooding	12
March 15, 1993	3096	Severe Snowfall and Winter Storm	67
March 3, 1994	1013	Severe Winter Storms, Freezing and Flooding	10
March 30, 1994	1019	Severe Storms, Tornadoes and Flooding	7
July 8, 1994	1034	Severe Storms and Flooding – Tropical Storm Alberto	10
April 21, 1995	1047	Severe Storms, Tornadoes and Flooding	5
October 4, 1995	1070	Hurricane Opal	38
February 23, 1996	1104	Severe Winter Storms, Ice and Flooding	14
March 20, 1996	1108	Severe Storms, Tornadoes and Flooding	3
July 25, 1997	1185	Hurricane Danny	3
March 9, 1998	1208	Flooding, Severe Storm	6
April 9, 1998	1214	Thunderstorms, Tornado	6
September 30, 1998	1250	Hurricane Georges	14
January 15, 1999	1261	Ice Storm, Freezing Rain	11
February 18, 2000	1317	Winter Storm	3
March 17, 2000	1322	Severe Storm, Flooding	2
December 18, 2000	1352	Tornado	11
March 5, 2001	1362	Severe Storm, Flooding	6
December 7, 2001	1399	Severe Storm, Tornado	19
October 9, 2002	1438	Tropical Storm Isidore	2
November 14, 2002	1442	Severe Storm, Tornado	29
May 12, 2003	1466	Severe Storm, Thunderstorms, Tornado, Flooding	24
September 15, 2004	1549	Hurricane Ivan	67
July 10, 2005	1593	Hurricane Dennis	45
August 29, 2005	1605	Hurricane Katrina	22
March 1, 2007	3292	Severe Storms and Tornadoes	7

Date	Disaster Number	Type of Incident	# of Counties Declared
September 10, 2008	1789	Hurricane Gustav	2
September 26, 2008	1797	Severe Storms and Flooding – Hurricane Ike	2
April 28, 2009	1835	Severe Storms, Flooding, Tornado, and Straight-line Winds	21
May 8, 2009	1836	Severe Storms, Flooding, Tornado, and Straight-line Winds	6
June 3, 2009	1842	Severe Storms, Flooding, Tornado, and Straight-line Winds	4
December 22, 2009	1866	Tropical Storm Ida	2
December 31, 2009	1870	Severe Storms and Flooding	14
May 3, 2010	1908	Severe Storms, Tornadoes, Straight-line Winds, Flooding	3
April 28, 2011	1971/3319	Severe Storms, Tornadoes, Straight-line Winds, Flooding	43
February 1, 2012	4052	Severe Storms, Tornadoes, Straight-line Winds, Flooding	3
September 21, 2012	4082	Alabama Hurricane Isaac	8
May 2, 2014	4176	Severe Storms, Tornadoes, Straight-Line Winds, Flooding	21
January 21, 2016	4251	Severe Storms, Tornadoes, Straight-Line Winds, Flooding	39
September 11, 2017	3389	Hurricane Irma	67
October 8, 2017	3394	Hurricane Nate	39
November 16, 2017	4349	Hurricane Nate	8

3.1.2 Ranking Methodology

The identified hazards vary in their probability of affecting the state and in their potential impact on the state. The SHMT and FEMA therefore determined that only a subset of the hazards should receive detailed vulnerability assessments. To identify the hazards for which detailed vulnerability assessments would yield the most benefit, AEMA completed a Risk Factor (RF) analysis. An RF analysis characterizes the degree of risk posed by identified hazards in a planning area based on a set of factors deemed important by the SHMT and other stakeholders. The identified hazards are assigned a numeric value for each risk factor, and a formula is then applied to aggregate the values into an RF value. The higher the RF value, the greater the hazard risk.

The RF approach used by the SHMT to rank hazard risk in Alabama is summarized in Table 3.2. The risk assessment categories shown in the table are based on FEMA's Comprehensive Preparedness Guide (CPG) 101 (see pg. 3-11 of CPG-101). Those categories include: probability, impact, spatial extent, warning time and duration. Probability indicates how frequently a given hazard event will occur. Impact looks at the systemic loss of life, property, and economic well-being induced in a given hazard event. Spatial extent indicates the geographic area a given hazard event will cover and whether a hazard event is expected to be state-wide, regional, or extremely localized. Warning time evaluates how far in advance a community will know of an impending hazard event, considering hazard-specific warning systems. Finally, duration indicates the length of time the hazard event will last. The numeric value assigned for each category relies mainly on historical data, local knowledge, consensus opinions from the SHMT and information collected through development of the hazard profiles.

To calculate a composite RF ranking, weighting factors were derived from a review of best practice plans and agreed upon by the SHMT. The weighting factors for each risk assessment category are also shown in Table 3.2. To calculate the RF value for a given hazard, the assigned risk value for each category was multiplied by the weighting factor, and the weighted values were added together.

The RF approach complements more quantitative analyses by reflecting participants' local knowledge and experience and providing a consistent metric across different hazards. Nevertheless, Alabama recognizes limitations to this approach. In some cases, for example, risk levels may not be entirely compatible with multi-hazard events. There may also be differences in how hazards are scored in dense urban areas as compared to rural areas. Despite its limitations, however, the method serves as a useful tool for providing systematic and consistent prioritization of qualitative hazard information. In addition, the method can be used to help prioritize mitigation strategies.

Table 3.2 Summary of Risk Factor approach

Risk Assessment Category	Degree of Risk Level	Criteria	Index	Weight
Probability *What is the likelihood of a hazard event occurring in a given year?*	**Unlikely**	Less than 1% annual probability	**1**	**30%**
	Possible	Between 1% & 49.9% annual probability	**2**	
	Likely	Between 50% & 90% annual probability	**3**	
	Highly Likely	Greater than 90% annual probability	**4**	
Impact *In terms of injuries, damage, or death, would you anticipate impacts to be minor, limited, critical, or catastrophic when a significant hazard event occurs?*	**Minor**	Very few injuries, if any. Only minor property damage & minimal disruption on quality of life. Temporary shutdown of critical facilities.	**1**	**30%**
	Limited	Minor injuries only. More than 10% of property in affected area damaged or destroyed. Complete shutdown of critical facilities for more than one day.	**2**	
	Critical	Multiple deaths/injuries possible. More than 25% of property in affected area damaged or destroyed. Complete shutdown of critical facilities for more than one week.	**3**	
	Catastrophic	High number of deaths/injuries possible. More than 50% of property in affected area damaged or destroyed. Complete shutdown of critical facilities for 30 days or more.	**4**	
Spatial extent *How large of an area could be impacted by a hazard event? Are impacts localized or regional?*	**Negligible**	Less than 1% of area affected	**1**	**20%**
	Small	Between 1 & 10.9% of area affected	**2**	
	Moderate	Between 11 & 25% of area affected	**3**	
	Large	Greater than 25% of area affected	**4**	
Warning Time *Is there usually some lead time associated with the hazard event? Have warning measures been implemented?*	**> 24 Hrs**	*Self-Defined (NOTE: Levels of warning time and criteria that define them may be adjusted based on hazard addressed.)*	**1**	**10%**
	12 To 24 Hrs		**2**	
	6 To 12 Hrs		**3**	
	< 6 Hrs		**4**	
Duration *How long does the hazard event usually last?*	**< 6 Hrs**	Self-Defined *(NOTE: Levels of warning time and criteria that define them may be adjusted based on hazard addressed.)*	**1**	**10%**
	< 24 Hrs		**2**	
	< 1 Week		**3**	
	> 1 Week		**4**	

The values assigned to each of the identified hazards and the final RF rankings are shown in 5.1.1.1.1.1.1Table 3.3. The SHMT determined that hazards with RF rankings greater than 2.5 pose a high risk to Alabama and should receive detailed vulnerability assessments. Hazards with

RF rankings between 2 and 2.5 were deemed medium risks, and hazards with RF rakings less than 2 were deemed low risk. As data availability and resources permit, the medium and low risk hazards may receive future vulnerability assessments. The three hazards with RF rankings exceeding 2.5 were floods, high winds, and sea level rise. In addition, the SHMT selected one hazard for detailed vulnerability assessment despite its lower ranking. The earthquake hazard had a medium RF ranking of 2.1. Nevertheless, data for earthquake vulnerability assessments are readily available through the free Hazus program, and a detailed vulnerability assessment was included in the 2013 plan. This revision therefore updated the vulnerability assessment for the earthquake hazard.

Table 3.3 Qualitative Ranking for Identified Hazards

Hazard	Risk Assessment Category					Risk Factor
	Probability	Impact	Spatial Extent	Warning Time	Duration	
Flooding	4	4	3	3	3	3.6
High Winds	4	3	3	4	3	3.4
Sea Level Rise	3	3	2	1	4	2.7
Winter Storms	2	3	3	1	2	2.4
Wildfire	3	2	2	2	3	2.4
Extreme Temperatures	4	1	2	1	3	2.3
Drought	2	2	3	1	4	2.3
Landslides	3	2	1	4	1	2.2
Sinkholes and Subsidence	3	2	1	4	1	2.2
Lightning	4	1	1	4	1	2.2
Earthquakes	1	3	2	4	1	2.1
Hail	3	1	1	3	2	1.9
Dam Failures	2	2	1	4	1	1.9
Tsunamis	1	2	2	2	1	1.6

3.1.3 Hazards Profiled in County Plans

As part of the plan update process, the hazard profile sections of all local hazard mitigation plans were reviewed to determine which hazards were identified and profiled by local jurisdictions. This process is also briefly described in Section 1.3.2.1 (Hazard Identification and Profiles).

Some local plans simply provided a table listing what hazards affect the local jurisdictions and what hazards do not. Others provided a ranking system. For consistency, this plan update reviews the hazards that are identified and profiled in the local plans. 5.1.1.1.1.1.1Table 3.4 summarizes the number of counties that profiled each of the hazards identified as affecting the state.

Table 3.4 Summary of County Hazard Mitigation Plans

Hazard	Number of Counties that Profile Hazard
Dam Failures	55
Drought	62
Earthquakes	62
Extreme Temperatures	42
Flooding	64
Hail	48
High Winds	67
Landslides	60
Lightning	49
Sinkholes and Subsidence	58
Sea Level Rise and Coastal Land Change	6
Tsunamis	10
Wildfire	60
Winter Storms	67

High wind hazard profiles differ between state and county plans and can include severe storms, hurricanes, tropical storms/cyclones, microbursts, and tornadoes. While some counties included an extreme temperature profile, others mentioned characteristics of extreme temperatures within other hazard profiles, such as drought/extreme heat, and winter storms/extreme cold. Human-made hazards were also profiled by several counties and included hazardous materials release, chemical spills, radiation leaks, nuclear accidents, acts of terrorism, criminal activities, transportation system failures. Additional profiled hazards in a few plans include avalanche, communicable disease/pandemic, celestial impact, dense fog, and volcano.

3.2 Hazard Profiles

3.2.1 Dam Failure

3.2.1.1 Description

A dam is a barrier constructed across a watercourse to store, control, or divert water. Dams vary widely in form and function. They can be constructed of earth, rock, concrete, or mine tailings, and they can support irrigation, electrical generation, flood control, navigation, and/or recreation. Although dams represent a vital component of our national infrastructure, most dams are not owned by public entities. Across the US, 56 percent of dams are privately owned, twenty percent are owned by local governments, 4.8 percent are owned by state governments, 4.7 percent are owned by federal government, and 2.4 percent are owned by public utilities. The ownership of the remaining dams is undetermined.[2]

Dam failure is the uncontrolled release of water (and any associated wastes) from a dam. This hazard often results from a combination of natural and human causes, and can follow other hazards such as hurricanes, earthquakes, and landslides. Common causes of dam failure include:[3]

- Flooding caused by prolonged rainfall;
- Overtopping caused by poor design or debris blockage;
- Foundation defects caused by slope instability;
- Cracking caused by the natural settling of a dam; and
- Internal erosion caused by leakage or piping.

According to data collected by the Association of State Dam Safety Officials (ASDSO), most dam failures in the US are caused by extreme weather events or overtopping (60 percent and 20 percent, respectively), and other relatively common causes include piping (10 percent) and deterioration (6 percent).

Deficient condition or design is often an underlying cause of dam failure, and the number of deficient dams in the US is on the rise. The average age of dams in the US is 56 years, and about one-third were built more than 50 years ago (the intended lifespan of most dams).[4] As the nation's dams age, investments in maintenance, upgrades, and repairs are not keeping pace with the

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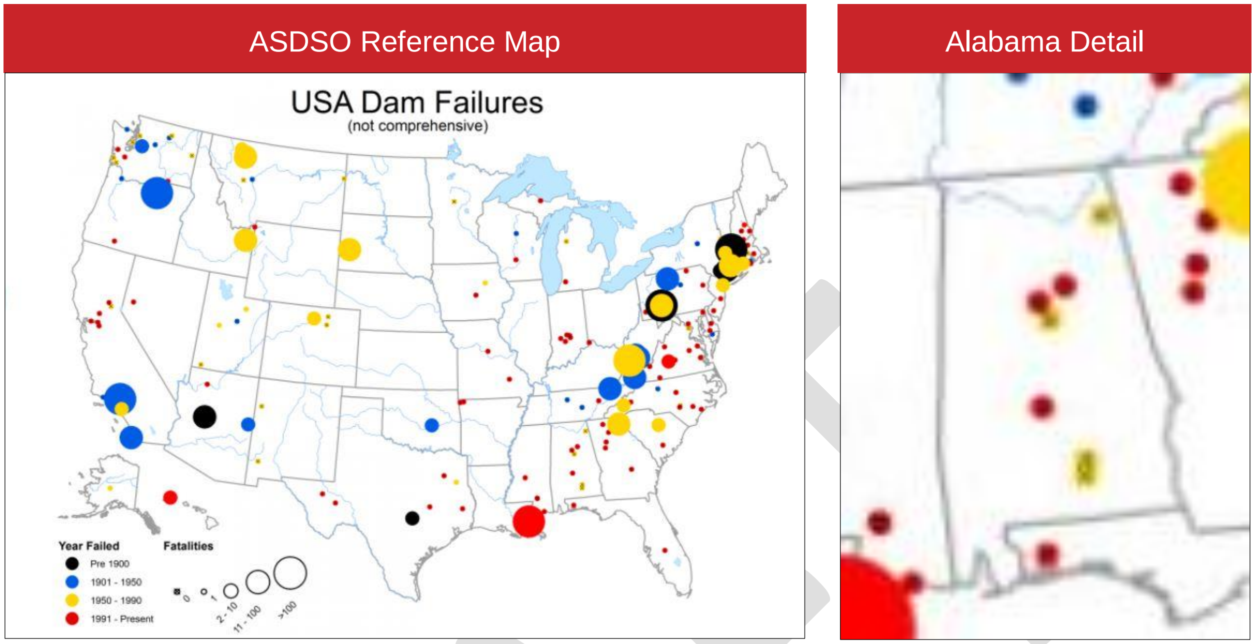
[2] Federal Emergency Management Association, 2017. Dam Ownership in the US. Website accessed at: https://www.fema.gov/dam-ownership-united-states
[3] Association of State Dam Safety Officials, 2018. What are the Causes of Dam Failures? Website accessed at: https://damsafety.org/what-are-causes-dam-failures
[4] Center for American Progress, 2012. The 10 States Most Threatened by High-Hazard, Deficient Dams. Website accessed at: https://www.americanprogress.org/issues/economy/news/2012/09/20/38679/the-10-states-most-threatened-by-high-hazard-deficient-dams/

need. According to the American Society of Civil Engineers (ASCE), the number of high hazard potential dams that are known to be deficient has risen from 1,367 in 2005 to 2,170 in 2017.[5,6] This is largely the result of the patchwork of state and federal dam safety programs that provides oversight of dams and resources for inspection and maintenance. The federal government oversees about 6.5 percent of the nation's dams, but state governments are responsible for the remaining 93.5 percent.[7] Each state program has different strengths and weaknesses, but many are limited by a lack of statutory authority, limited budgets, and limited staff.

The impact of dam failure in the US is known to be significant but is not well understood. In the absence of a comprehensive nationwide program, the exact number of dam failures that have occurred is unknown. According to the ASDSO, however, dam failures have been documented in every state and are known to have taken thousands of lives.[8] The ASDSO received reports of 173 dam failure and 587 dam incidents between 2005 and 2013 (an incident is a condition that could have resulted in dam failure). The ASDSO has also mapped a subset of dam failures with known locations (a comprehensive database is not available). This map shows that most failures have caused limited loss of life, but a few have caused more than a hundred fatalities [9] (5.1.1.1.1.1.1Table 3.4Figure 3.1). Dam failures can also have significant economic and environmental costs. The inundation of neighboring communities can damage property and infrastructure, and the release of agricultural or industrial wastes can pollute downstream waterways.

[5]The American Society of Civil Engineers, 2017. 2017 Infrastructure Report Card: Dams. Website accessed at: https://www.infrastructurereportcard.org/cat-item/dams/
[6] American Society of Civil Engineers, 2009. 2009 Report Card for America's Infrastructure. Website accessed at: https://www.infrastructurereportcard.org/2009/fact-sheet/dams.html
[7] Federal Emergency Management Agency, 2013. Dam Safety in the US. Retrieved at: https://www.fema.gov/media-library-data/1402876995238-1c041ca9a4489ea27152c515ed72e38f/DamSafetyintheUnitedStates.pdf
[8] Association of State Dam Safety Officials, 2018. Failures and Incidents at Dams. Website accessed at: https://damsafety.org/dam-failures
[9] Ibid.

Figure 3.1 Dam Failures Reported by State Officials (ASDSO, 2015)



The potential impacts of a dam failure depend on the amount of water impounded by the dam and the density, type, and value of downstream development. Many federal and state dam safety programs use a FEMA classification system to divide dams into one of three categories based on the potential impacts of dam failure. The categories are high, significant, and low and are based on the potential for loss of life and damage to property (5.1.1.1.1.1.1Table 3.5). It is important to emphasize that this system does not reflect the condition of the dam or its physical integrity. In addition, as more development occurs downstream of a dam, its hazard potential can increase. Across the US, dam safety regulators have limited ability to restrict development in downstream areas, and the number of high hazard potential dams is rising.[10]

Table 3.5 Dam Hazard Classifications (FEMA, 2004)

Class	Health and Safety Impacts	Economic Impacts
High Hazard	Probable loss of life	Widespread damage to homes, industrial and commercial buildings, important utilities, highways, or railroads
Significant Hazard	No loss of life expected	Damage to isolated homes, utilities, highways, or railroads
Low Hazard	No loss of life expected	Slight damage to farm buildings, forest or agricultural land, or minor roads

[10] Association of State Dam Safety Officials, 2018. Dams 101. Website accessed at: https://damsafety.org/dams101

3.2.1.2 Nature of the Hazard in Alabama

The state of Alabama has more than 132,000 miles of river and stream channels and more than 4,800 large dams (defined as dams with a capacity greater than 50,000 acre-feet or a height greater than 25 feet) that support irrigation, electrical generation, flood control, navigation, and/or recreation.[11,12] Many of the state's largest dams are on the Black Warrior, Coosa, Tallapoosa, and Tennessee Rivers. These include 14 hydroelectric dams operated by Alabama Power that provide more than 6 percent of the company's power generation and 7 dams operated by the Tennessee Valley Authority. The state's thousands of smaller dams are distributed throughout Alabama and serve many purposes, from flood control and sediment reduction to irrigation, livestock watering, and recreation.

Because most of Alabama's dams are not subject to record-keeping or inspection requirements, it is difficult to paint a complete picture of the magnitude of the dam failure hazard in the state. Alabama is the only state in the country without a dam safety program. State officials therefore have negligible authority to oversee dams and limited resources to collect information on their location, hazard potential, and condition. ADECA has compiled an inventory of the state's dams and their estimated hazard potential, but information on dam condition and other characteristics is generally not available. Since Alabama has tens of thousands of small ponds, ADECA only includes dams with a capacity greater than 50,000 acre-feet or a height greater than 25 feet in their inventory.

Based on state records, 195 of Alabama's 4,800 dams (or 4.1% of all large dams) are classified as having a high hazard potential. As noted above, a dam's hazard potential is based on the potential impact if it were to fail, not its condition or chance of failing. 5.1.1.1.1.1.1Table 3.5Figure 3.2 shows the number of high hazard potential dams by county. The counties with the largest number of high hazard potential dams are generally located in the greater Tuscaloosa area and greater Birmingham area.

The US Army Corps of Engineers (USACE) National Inventory of Dams (NID) also includes records for dams in Alabama. These records are only up to date, however, for the small percentage of dams subject to federal oversight. For these dams, the records include information on both dam hazard potential and dam condition. Of the 70 dams in Alabama subject to federal oversight, 46 are classified as high hazard potential dams. Of these high hazard potential dams, most are classified as satisfactory or fair condition, and three are classified as poor or unsatisfactory condition. These three dams are:

- The Logan Martin Dam located on the Coosa River in St. Clair County
- The Little Bear Creek Dam located on Little Bear Creek in Franklin County

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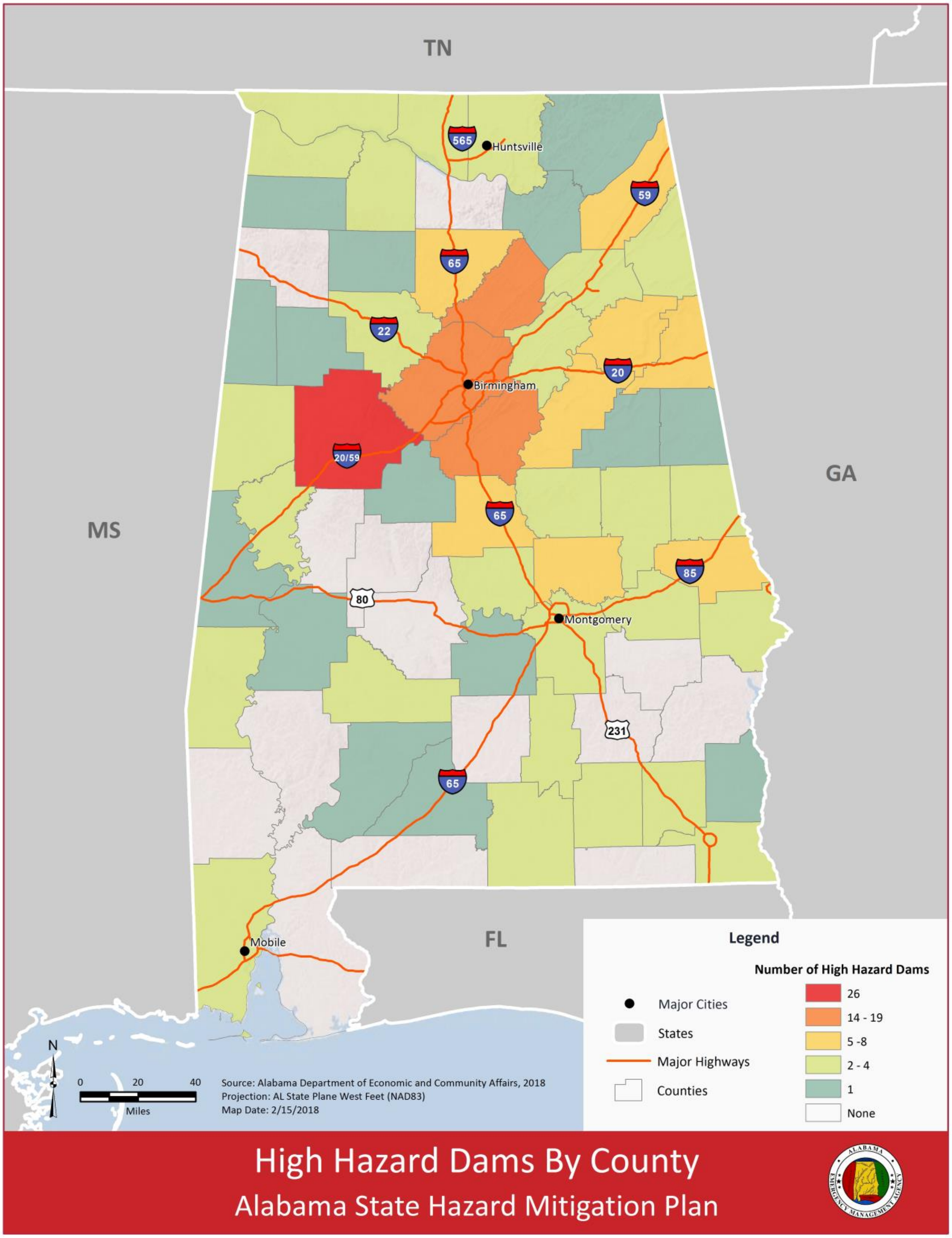
[11] Alabama Rivers Alliance, 2018. About Alabama's Rivers. Website accessed at: https://alabamarivers.org/about-alabamas-rivers/

[12] Alabama Department of Economic and Community Affairs. Personal communication from Wardell Edwards. February 7, 2018.

- The Bear Creek Dam located on Bear Creek in Franklin County

Figure 3.2 High Hazard Potential Dams by County (ADECA, 2018)



3.2.1.3 Dam Failure History in Alabama

There is no official, comprehensive record of dam failures in Alabama that documents all dam failure incidents in the state. At the discretion of local officials, however, some jurisdictions have reported selected dam failures to the ASDSO and to the Alabama section of the ASCE. 5.1.1.1.1.1.1Table 3.6 catalogues these reported dam failures. It should be emphasized that this list is by no means comprehensive, and that the number of dam failures omitted from this list is unknown.

Table 3.6 Historical Dam Failure Events (ASDSO and ASCE, 2017)

Date	Location	Description
1990	Shelby County	Three earthen dams in Shelby County sustained damage during the flood of February 3 to 17, 1990. Heavy rains and flooding saturated the Holly Brooke Lake Dam, causing the face to slump. Six families were evacuated and the water level of the 55-acre pond impounded by the dam was lowered to prevent failure.
1990	Crenshaw County	A dam at Magnolia Shores Lake in Crenshaw County was overtopped during the heavy rains and flooding of March 23, 1990. The downstream slope was damaged, and the lake was drained to prevent a break in the dam.
1990	Crenshaw County	The C. D. Clark Dam in Dozier, Crenshaw County, failed and washed out 50 yards of northbound US Highway 29. Lake Tholocco, a 600-acre lake on the Fort Rucker reservation near Ozark, was also drained because of excessive flow through its emergency spillway.
1994	Multiple counties	Local officials reported 160 dam breaks during the July 1994 floods. The state does not require local officials to report dam breaks, however, and the actual number of breaks was likely higher.
2004	Jefferson County	East Lake Dam in Birmingham overtopped during heavy rainfall in 2004, resulting in severe slope erosion and near failure. 270 residents were evacuated. If failure had occurred, several homes and roadways could have been destroyed.
2004	St. Clair County	Keith Lake Dam in St. Clair County failed during heavy rainfall in 2004. The dam failure created a path of destruction 3,600 feet long and 1,350 feet wide and led to the evacuation of homes, decreased property values, and environmental damages, as well as significant damage to a downstream dam.
2009	Etowah County	A private dam failed near the Gallant community in Etowah County during the heavy rains and flooding of January 6, 2009. The failure produced twelve feet of flooding, leading to the evacuation of nearby residents and the closure of several roads. Property damage was reported to be $100,000.
2012	St. Clair County	The 55-acre lake at Camp Sumatanga in St Clair County drained to nearly empty in 2012 due to a collapsed pipe. No significant downstream damage was reported.

Date	Location	Description
2013	Shelby County	A Shelby County dam failed due to soil piping along the 60" discharge pipe in 2013. Approximately 200 million gallons of water were released in less than an hour. There was significant damage to roadways and downstream properties.

3.2.1.4 Probability of Dam Failures in Alabama

Dam failures result from multiple natural and human factors that are highly site-specific, and their probability cannot be expressed in quantitative terms. In states with dam safety programs that require dams to be inspected and maintained, the relative probability of dam failures in different jurisdictions can be expressed in qualitative terms. Because there are no inspection and record-keeping requirements in Alabama, the relative hazard in different jurisdictions cannot be determined. Over time, however, the probability of a costly dam failure within the state is growing. This is because many of the state's aging dams are not receiving regular inspection and maintenance, and because the population in the areas downstream of dams is growing.

3.2.1.4.1 Future Probability

The most common cause of dam failure is flooding due to heavy rains. As the frequency of heavy rains increases with climate change (see 3.2.5.4.1 Future Probability on flood hazards), the incidence of dam failure in Alabama may increase. The higher frequency of heavy rains is a particular concern for Alabama's coastal counties, which are more likely to experience hurricanes.

3.2.1.4.2 Risk and Vulnerability

A community's vulnerability to dam failure is a function of the probability of failure, the exposure of people and property to the uncontrolled release of water, and the susceptibility of people and property to the hazard.

An Emergency Action Plan (EAP) is an important safeguard against the loss of life and property that can result from the failure of a high hazard potential dam. EAPs are formal documents that identify potential emergency conditions at a dam and specify actions to be followed to minimize dam failure impacts. One of the most important components of an EAP is the inundation map. The inundation map shows the locations, people, and infrastructure that could be affected by a dam failure by estimating the area that would be flooded by a complete dam breach. While all 46 federally-regulated, high hazard dams in Alabama are required to have an EAP, the state does not require that non-federal high hazard potential dams develop EAPs. As discussed above, 195 of Alabama's 4,800 dams (or 4.1% of all large dams) are classified as having a high hazard potential. Since only 46 of these dams are federally-regulated, the remaining 149 high hazard potential dams are not required to develop EAPs or inundation maps. Should a dam incident occur at one of these dams, local and state emergency managers would therefore have limited information on the possible extent of flooding and evacuation and response needs.

As discussed above, the counties in the greater Tuscaloosa and greater Birmingham areas are home to the largest numbers of dams with high hazard potential. Failure of high hazard potential dam is likely to cause loss of life and significant economic loss.

3.2.2 Drought

3.2.2.1 Description

Drought, which is a normal part of nearly all climates, is a water shortage originating from a deficiency in expected precipitation caused by unusual weather patterns. If these weather patterns persist for several months to several years, the drought is considered to be long-term; a short-term drought may last several weeks to a few months.[13] In addition to its duration, a drought's severity can also depend on such factors as intensity, geographic extent, and regional water supply demands by humans and vegetation. Further, the severity of a drought can be influenced by climatic factors including high temperatures, prolonged high winds, and low relative humidity.[14]

Although the severity and location of drought events in the US have varied, much of the country has suffered from the effects of a drought during the past century. Despite general increases in annual and seasonal precipitation totals in the Unites States since 1900, severe droughts continue to occur.[15] Severe droughts can result in the loss of agricultural crops and forest products, undernourished wildlife and livestock, lower land values, and higher unemployment. Droughts may cause a shortage of water for human and industrial consumption, hydroelectric power, recreation, and navigation. Water quality may also decline and the number and severity of wildfires may increase.[16] Of all the weather-related disasters in the US, drought has historically had the greatest impact on the largest number of people. Since 1980, there have been 25 drought events across the US with losses exceeding $1 billion each and resulting in the deaths of 2,993 people.[17]

Due to its multi-dimensional nature, a drought is difficult to define and conducting a comprehensive risk assessment is challenging. For example, in contrast with other natural hazards, the effects of drought are not immediately apparent and may impact a larger geographic area. Additionally, because the effects of a drought event are slow to accumulate and may linger

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[13] National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information (NCEI). Drought Termination and Amelioration.
Retrieved at https://www.ncdc.noaa.gov/temp-and-precip/drought/recovery/

[14] FEMA, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library-data/20130726-1545-20490-4487/mhira_in.pdf

[15] National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information (NCEI). Drought Termination and Amelioration.
Retrieved at https://www.ncdc.noaa.gov/temp-and-precip/drought/recovery/

[16] Federal Emergency Management Agency, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library-data/20130726-1545-20490-4487/mhira_in.pdf

[17] National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information (NCEI). Drought Termination and Amelioration.
Retrieved at https://www.ncdc.noaa.gov/temp-and-precip/drought/recovery/

after an event, the beginning and end of a drought are difficult to determine. Finally, the lack of a universally accepted and precise definition of drought adds to the confusion in tracking the existence and severity of droughts.[18]

Although there is no single, concise definition of a drought, droughts can be grouped into four general types. 5.1.1.1.1.1.1.1Table 3.7 provides common descriptions and definitions of the four drought types.

Table 3.7 Types of Drought

Drought Type	Description/Definition
Meteorological	Defined solely on the degree of dryness, expressed as a departure of actual precipitation from an expected average or normal amount based on monthly, seasonal, or annual time scales.
Hydrological	Related to the effects of precipitation shortfalls on stream flows and reservoir, lake, and groundwater levels.
Agricultural	Defined principally in terms of soil moisture deficiencies relative to water demands of plant life, usually crops.
Socioeconomic	Associates the supply and demand of economic goods or services with elements of meteorological, hydrologic, and agricultural drought. Socioeconomic drought occurs when the demand for water exceeds the supply as a result of a weather-related supply shortfall. This type of drought may also be called a water management drought.

There have been many quantitative measure and indices that attempt to define the severity of a drought, which can vary based on the region and application. However, the most commonly used index is the Palmer Drought Severity Index (PDSI). The PDSI was developed in the 1960s and is still frequently used to indicate drought conditions throughout the US. The PDSI may be more widely applied as it accounts for several other factors in addition to total precipitation, including temperature and soil recharge. 5.1.1.1.1.1.1.1Table 3.8 provides the PDSI drought classifications; a negative PSDI indicates drought conditions.

[18] Federal Emergency Management Agency, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library-data/20130726-1545-20490-4487/mhira_in.pdf

Table 3.8 Palmer Drought Severity Index (PDSI) Classifications

PDSI Classifications	
4.0 or more	Extremely Wet
3.0 to 3.99	Very Wet
2.0 to 2.99	Moderately Wet
1.0 to 1.99	Slightly Wet
0.5 to 0.99	Incipient Wet Spell
0.49 to -0.49	Near Normal
-.05 to -0.99	Incipient Dry Spell
-1.0 to -1.99	Mild Drought
-2.0 to -2.99	Moderate Drought
-3.0 to -3.99	Severe Drought
-4.0 or less	Extreme Drought

Another resource that defines the geographic extent and severity of drought in the US is the US Drought Monitor (US Drought Monitor). The US Drought Monitor is a map that is updated each week to illustrate the current location and intensity of drought. Like the PDSI, the US Drought Monitor is based on many indicators, not just levels of precipitation. The US Drought Monitor categorizes drought on a D0 to D4 scale as shown below in 5.1.1.1.1.1.1Table 3.90.[19]

[19] University of Nebraska, National Drought Mitigation Center. US Drought Monitor. Retrieved at http://droughtmonitor.unl.edu/

Table 3.9 US Drought Monitor Classifications

Category	Description	Possible Impacts	PDSI
D0	Abnormally Dry	Going into drought: short-term dryness slowing planting, growth of crops or pastures. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered	-1.0 to -1.9
D1	Moderate Drought	Some damage to crops, pastures; streams, reservoirs, or wells low, some water shortages developing or imminent; voluntary water-use restrictions requested	-2.0 to -2.9
D2	Severe Drought	Crop or pasture losses likely; water shortages common; water restrictions imposed	-3.0 to -3.9
D3	Extreme Drought	Major crop/pasture losses; widespread water shortages or restrictions	-4.0 to -4.9
D4	Exceptional Drought	Exceptional and widespread crop/pasture losses; shortages of water in reservoirs, streams, and wells creating water emergencies	-5.0 or less

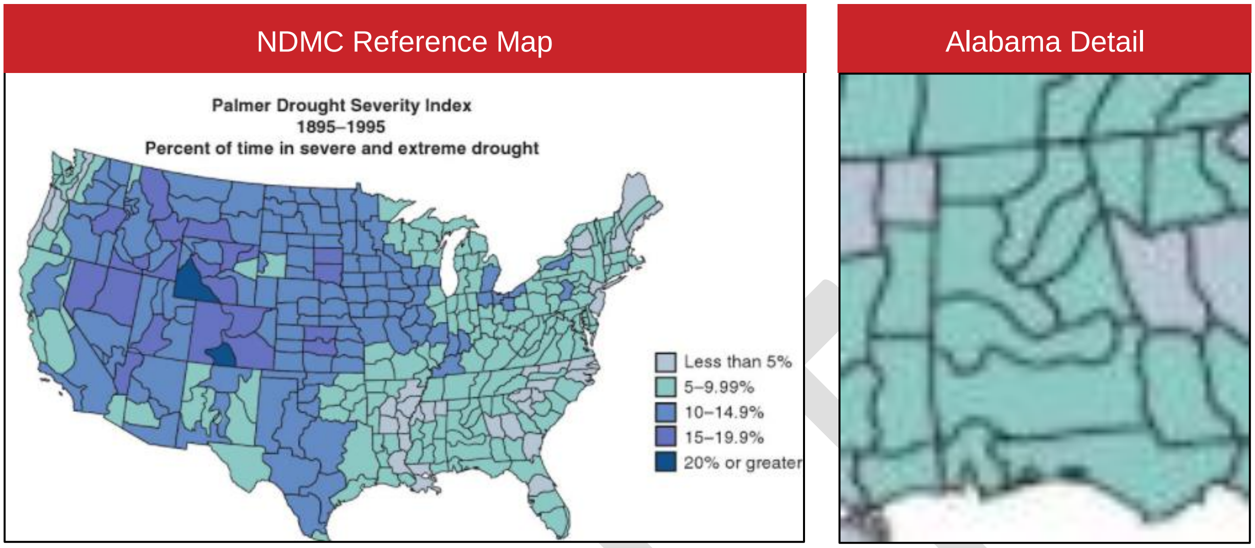
3.2.2.2 Nature of the Hazard in Alabama

As discussed above, drought can occur in virtually all climates in the US, including both areas with high and low average rainfall. Further, the effects of a drought are gradual and often impact large areas in comparison to other natural hazards like tornadoes that are more localized. Lastly, the duration and extent of drought conditions are influenced by a lack of rainfall, which itself is difficult to predict in terms of amount, duration, and location. These factors make it difficult to describe the nature of drought in Alabama with respect to which areas of the state have the highest exposure to the hazard.

The challenge of defining the extent of the drought hazard in Alabama is illustrated in the national map of drought conditions produced by the National Drought Mitigation Center, or NDMC (5.1.1.1.1.1.1Table 3.9Figure 3.3). This map shows the frequency of severe and extreme drought conditions between 1895 and 1995, and represents the latest available long-term summary of drought conditions across the US.[20] The NDMC map shows that severe drought conditions in Alabama are relatively uncommon. While severe or extreme drought conditions occurred between 10 and 15 percent of the time in much of the Midwest, West, and Southwest; severe or extreme drought conditions occurred less than 10 percent of the time in Alabama. The NDMC map does not, however, show any geographic variability within the state. This lack of spatial variability shows the limitations of drought indices (such as the Palmer Drought Severity Index) that are based only on physical parameters.

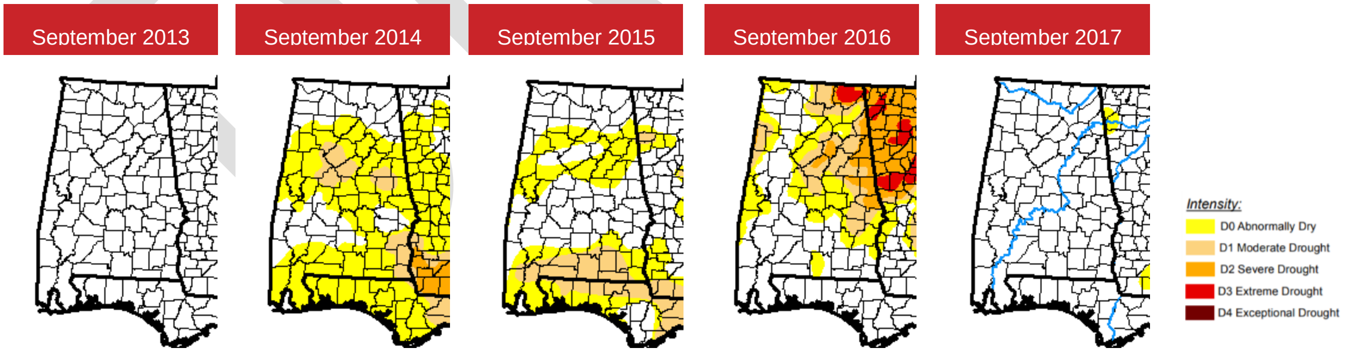
[20] http://drought.unl.edu/Planning/Monitoring/HistoricalPDSIMaps.aspx

Figure 3.3 Percent of Time in Severe and Extreme Drought, 1895-1995 (NDMC, 2018)



Drought indices that integrate physical and socioeconomic parameters tend to show more local variability and provide more meaningful information for decision makers. These indices often show rapidly evolving conditions as both user demands and available supplies shift over time. The US Drought Monitor is an example of a drought index that reflects both physical parameters and socioeconomic impacts. Every week, the US Drought Monitor consults with a network of more than 350 observers across the country to integrate observed local impacts into a map of drought conditions. 5.1.1.1.1.1.1Table 3.9Figure 3.4 shows the US Drought Monitor map for the five most recent Septembers in Alabama. The rapidly shifting patterns in drought classifications hint at the complex interactions between human and natural systems that produce drought conditions.

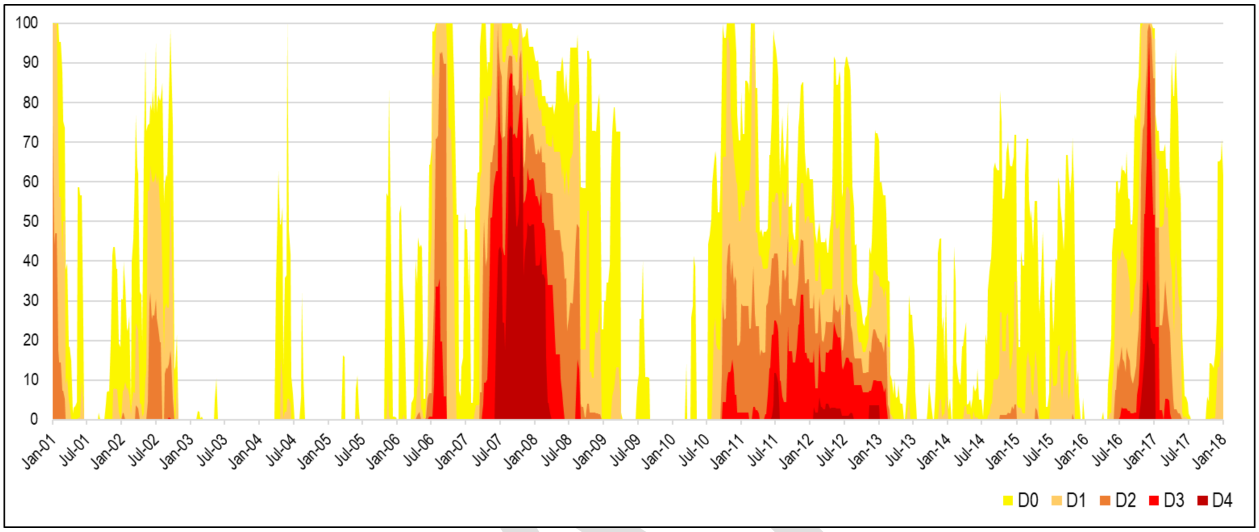
Figure 3.4 Drought Classifications for Five Successive Septembers (US Drought Monitor, 2018)



While widespread, persistent drought conditions are relatively uncommon in Alabama, abnormally dry conditions do affect some part of the state nearly every year. 5.1.1.1.1.1.1Table 3.9Figure 3.5 illustrates the frequency and severity of droughts recorded in the state since 2001. Specifically, the figure shows the percentage of land area in Alabama experiencing drought conditions as

categorized by the US Drought Monitor. As shown in the figure, abnormally dry events are more frequent than severe to exceptional droughts, but severe droughts have a longer duration. Additionally, severe droughts tend to impact a larger percent of state. A more detailed account of drought history in Alabama is provided below.

Figure 3.5 Percent of Land Area in Alabama Experiencing Drought (US Drought Monitor, 2018)



When a drought does occur in Alabama, the social, economic, and environmental impacts have the potential to be severe and widespread. Examples of the potential effects of drought in the state of Alabama, including effects the state has experienced in past drought events, are as follows:

- Damage to livestock and crops;
- Increased local vulnerabilities to sinkholes and wildfire;
- Water usage conflicts;
- Accelerated coastal erosion;
- Damaged fisheries; and
- Inflated energy prices due to loss of hydro-power.

3.2.2.3 Drought History in Alabama

According to FEMA, Alabama has had one drought that resulted in a federal disaster declaration. The drought, which occurred in 1977, was declared an emergency in all 67 counties of the state.

More recently, according to the NWS Storm Events Database, severe drought events have been reported in Alabama almost every year between 2006 and 2017. The majority of these events impacted multiple counties and lasted several months to several years. Additionally, the severity of droughts reported as determined by the US Drought Monitor has varied from moderate to

exceptional (D1 to D4). Although drought events have occurred frequently, and the severity of several droughts has been exceptional, NOAA's Storm Events Database indicates that no deaths or injuries occurred as a result. However, the most severe drought events in terms of duration, intensity, and extent resulted in widespread agricultural, hydrologic, and sociological impacts.

As shown in 5.1.1.1.1.1.1Table 3.9Figure 3.5 above, between 2000 and 2017, there were two significant droughts during which D4 drought conditions impacted a substantial portion of the state. These drought events occurred from 2007 to 2008 and from 2016 to 2017. The following provides a more detailed description of these events and a brief summary of their impacts based on information obtained from the Storm Events Database:

- From the March 2007 through December 2008, most of central and northern Alabama experienced moderate and exceptional drought conditions. March, traditionally the wettest month of the year, was instead one of the driest on record in 2007. May 2007 became the month that plunged much of the northern area of the state into a historic drought situation. The D3 status (extreme drought) was retained for the entire month. Area rivers remained at low flow levels, and some reached historically low levels, the lowest recorded for this time of year in more than 50 years. Soil moisture was also at historic lows, at the first percentile or below. Hay cutting ran behind and at a lower production rate. Non-irrigated corn in some areas was believed to be a complete loss. Overall yields were reduced, and the dry conditions caused even further reductions in the expected yields. Local extension agents rated the corn and wheat crops as poor to very poor. Extension agents also reported that cotton and soybeans were stressed due to lack of soil moisture. Pasturelands produced very low yields of hay due to lack of growth, thus farmers were forced to reduce cattle herds. Drought emergencies were issued by the Alabama Forestry Commission, meaning that prolonged drought conditions were creating a situation where the probability of catastrophic fire activity was high.

  By June 2007, drought conditions spread south through central Alabama and central counites reached D4 (exceptional drought) status. Crops continued to be highly stressed due to the lack of rainfall, with losses ranging from 50 to nearly 100 percent. The number of mandatory water restrictions continued to increase, with fines and surcharges being enforced for excessive water usage. Many residential lawns, shrubbery, and gardens became severely stressed by the very dry conditions. Through August 2007, major rivers and reservoirs continued to run much below normal. Navigation on major rivers became significantly impacted, and many boat landings on major lakes became unusable due to extremely low lake levels.

  Drought conditions continued into January 2008 across most of central and northern Alabama, the threat of water shortages for municipal water systems persisted, and most water restriction plans already in place continued. By January, agricultural impacts were minimized since it was between growing seasons. By March 2008, several storm systems across central Alabama brought limited improvement; the last remaining area of D4 drought was eliminated and the D3 area was reduced as well.

Drought conditions continued to improve through June 2008. August 2008 marked the first substantial rainfall for the Central Tennessee Valley since the beginning of the drought. In October 2008, a storm system brought some rainfall to the east central part of the state, which helped ease D2 drought conditions. Finally, by December 2008, very heavy rainfall put an end to drought conditions in the remaining affected counties. The Drought Monitor issued on December 16, 2008 reported an end to the drought conditions.

- In May 2016, D2 drought conditions were introduced into the northeastern portion of Alabama, and subsequently spread to encompass much of north central Alabama. By the end of July 2016, drought conditions deteriorated in the far western edges of northwest Alabama along the Mississippi state line. Conditions in the area were classified as D2 to D3; D3 conditions also expanded through north central Alabama. Below normal rainfall and above average temperatures continued across central Alabama through September 2016, with drought conditions continuing to worsen.

  By October 2016, the Governor of Alabama issued a Drought Emergency Declaration for all of central Alabama; which prohibited all outdoor burning. No measurable rain was recorded that month in the southwest of the state, leading to D2 drought conditions. Many locations across central Alabama received little or no rainfall during the month of October. Drought conditions continued to worsen with D3 conditions expanding to cover a large portion of central Alabama and with D4 conditions occurring across east central Alabama. This prolonged period of dry weather resulted in worsening drought conditions across central Alabama. By the end of November, 39 counties in central Alabama were experiencing D3 to D4 drought conditions. However, several rounds of beneficial rainfall at the end of November helped alleviate these conditions.

  Below normal rainfall continued for the majority of central Alabama during the month of December. There were a few areas that received near or just above normal monthly rainfall amounts, including the northwest counties and those counties along and south of the I-85 corridor. Drought conditions did not worsen in any county across central Alabama, while six counties were downgraded one drought level category.

  Rainfall continued in January and February 2017, improving drought conditions across central Alabama and lowering the drought intensity to D2 and D1 conditions. Through May 2017, significant rainfall over portions of central Alabama eased the drought conditions. By August 2017, there were no drought conditions present in the state.

As shown in 5.1.1.1.1.1.1Table 3.10, severe drought events in Alabama have significantly affected agriculture. To provide an estimate of the economic loss, 5.1.1.1.1.1.1Table 3.10 includes indemnity payments for losses suffered due to drought in Alabama.[21] The data is from the US Department of Agriculture's Risk Management Agency. On average, a total of $21,239,838 has been paid in the state annually for agricultural loss resulting from drought. The greatest

[21] University of Nebraska, National Drought Mitigation Center. Drought Indemnity Payment Data. Retrieved at http://drought.unl.edu/Planning/Impacts/DroughtIndemnityData.aspx

amount of indemnity payments occurred in 2000. Recently, since 2006, indemnity payments are highest in years during which severe drought conditions have been reported. For example, between 2006 and 2008, indemnity payments totaled $107,484,469.

Table 3.10 Indemnity Payments for Losses Suffered from Drought in Alabama

Year	Indemnity Payment
1989	$4,650,131
1990	$61,162,359
1991	$6,467,996
1992	$1,252,901
1993	$24,302,234
1994	$355,637
1995	$21,380,107
1996	$11,011,138
1997	$20,011,224
1998	$25,405,242
1999	$25,907,889
2000	$72,835,802
2001	$13,991,483
2002	$15,242,492
2003	$262,027
2004	$3,191,851
2005	$2,576,453
2006	$41,545,014
2007	$47,119,706
2008	$18,819,749
2009	$4,060,393
2010	$40,012,370
2011	$46,804,629
2012	$19,350,399
2013	$523,961
2014	$23,992,596

In recognition of the potential widespread impacts of drought and to ensure consistent communication of drought conditions and impacts, the Alabama Department of Economic and Community Affairs – Office of Water Resources (ADECA-OWR) prepared the Alabama Drought Management Plan (DMP) in May 2013. The DMP establishes state-level operating procedures and a framework for the assessment of drought conditions, assists stakeholders and water managers in mitigating drought conditions and encourages water conservation practices.[22] Shortly thereafter, in April 2014, the state passed the Alabama Drought Planning and Response Act which formally established the state government's role in planning, monitoring, and responding to drought conditions. The law also established the Alabama Drought Assessment and Planning Team (ADAPT), a subcommittee of which is responsible for monitoring all available climate and hydrological data and forecasts to assess current drought conditions and potential impacts. The ADECA-OWR coordinates the monitoring of drought conditions in Alabama.[23]

3.2.2.4 Probability of Drought in Alabama

As discussed above, the state of Alabama has experienced severe drought conditions as defined by the Palmer Drought Severity Index approximately five to ten percent of the time. At the same time, abnormally dry conditions as defined by the US Drought Monitor are observed to affect some part of the state nearly every year. Because the impacts of a drought event are typically widespread, it is likely that when drought conditions occur, a large percent of the state will be affected. Therefore, drought conditions are highly likely events that can be expected throughout the state. However, because the severity and frequency of a drought event is difficult to forecast given the complexity of conditions that determine its extent and impacts, it is difficult to quantify the relative probability of drought hazards across the state.

3.2.2.4.1 Future Probability

As discussed above, it is difficult to forecast drought events. Although several agencies at the federal, regional, and state levels monitor indicators of drought conditions including precipitation, streamflow, and temperature, these resources only provide information on current conditions or short-term forecasts. However, according to the National Climate Assessment report, "hydrological droughts are expected to increase in frequency and intensity across most of the country through the end of the 21st century."[24] With respect to the Southeast, although some forecast models predict drought to increase specifically across the Gulf Coast, these models are uncertain due to variations in future precipitation projections. However, the National Climate Assessment report does predict that future climate-related issues and increasing development

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[22] Alabama Department of Economic and Community Affairs, Office of Water Resources. Drought Planning and Management in Alabama. Retrieved at http://adeca.alabama.gov/Divisions/owr/Pages/Drought.aspx

[23] Alabama Department of Economic and Community Affairs, Office of Water Resources. Drought Planning and Management in Alabama. Retrieved at http://adeca.alabama.gov/Divisions/owr/Pages/Drought.aspx

[24] Ingram, K., K. Dow, L. Carter, J. Anderson, eds. 2013. Climate of the Southeast US: Variability, change, impacts, and vulnerability. Washington DC: Island Press.

patterns in the Southeast will likely threaten water supplies in the Southeast, which may also increase the risk of drought.

3.2.2.4.2 Risk and Vulnerability

A community's vulnerability to loss from drought is a function of the probability of drought, the exposure of water supplies and economic activities to the hazard, and the susceptibility of water supplies and economic activities to the hazard. As discussed, and as demonstrated in the large percentage of plans that recognize drought as a significant hazard, the risk of drought is prevalent throughout the state and the impacts are potentially widespread.

Agriculture is an important economic activity in Alabama that is highly vulnerable to drought. This vulnerability is amplified by the prevalence of rain-fed agriculture in the state. In Alabama, only 15 percent of the land currently available for farming is irrigated, compared to 61 percent of cropland in Mississippi and 40 percent in Georgia.[25] Figure 5.6 shows the distribution of harvested cropland in Alabama, and Figure 5.7 shows the percent of cropland that was irrigated at the time of the 2012 Census of Agriculture. Across much of the state, less than eight percent of cropland is irrigated. Many farmers are therefore at risk of lower yields and reduced revenues when droughts occur. To incentivize investments in irrigation infrastructure, the Alabama Legislature introduced an income tax credit for agricultural irrigation systems in 2012. Legislation enacted in 2017 has increased this tax credit for the tax years beginning after December 31, 2017 through December 31, 2022

Additionally, as drought can be exacerbated by extreme heat, areas of the state that experience high temperatures may also be more vulnerable to the adverse impacts of drought conditions. See Section 3.2.4 for a more detailed discussion of extreme temperatures in the state. Severe drought can also increase the potential for wildfires, and as such, areas that are more susceptible to wildfires may be more vulnerable to drought. See Section 5.2.13 for a more detailed discussion of the risk wildfires pose in the state.

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[25] Alabama Agricultural Experiment Station, 2017. NRCS funds to demonstrate and promote best irrigation practices in Alabama. Retrieved at: http://aaes.auburn.edu/news/nrcs-funds-to-demonstrate-and-promote-best-irrigation-practices-in-alabama/

Figure 3.6 Harvested Cropland in Alabama (USDA, 2012)

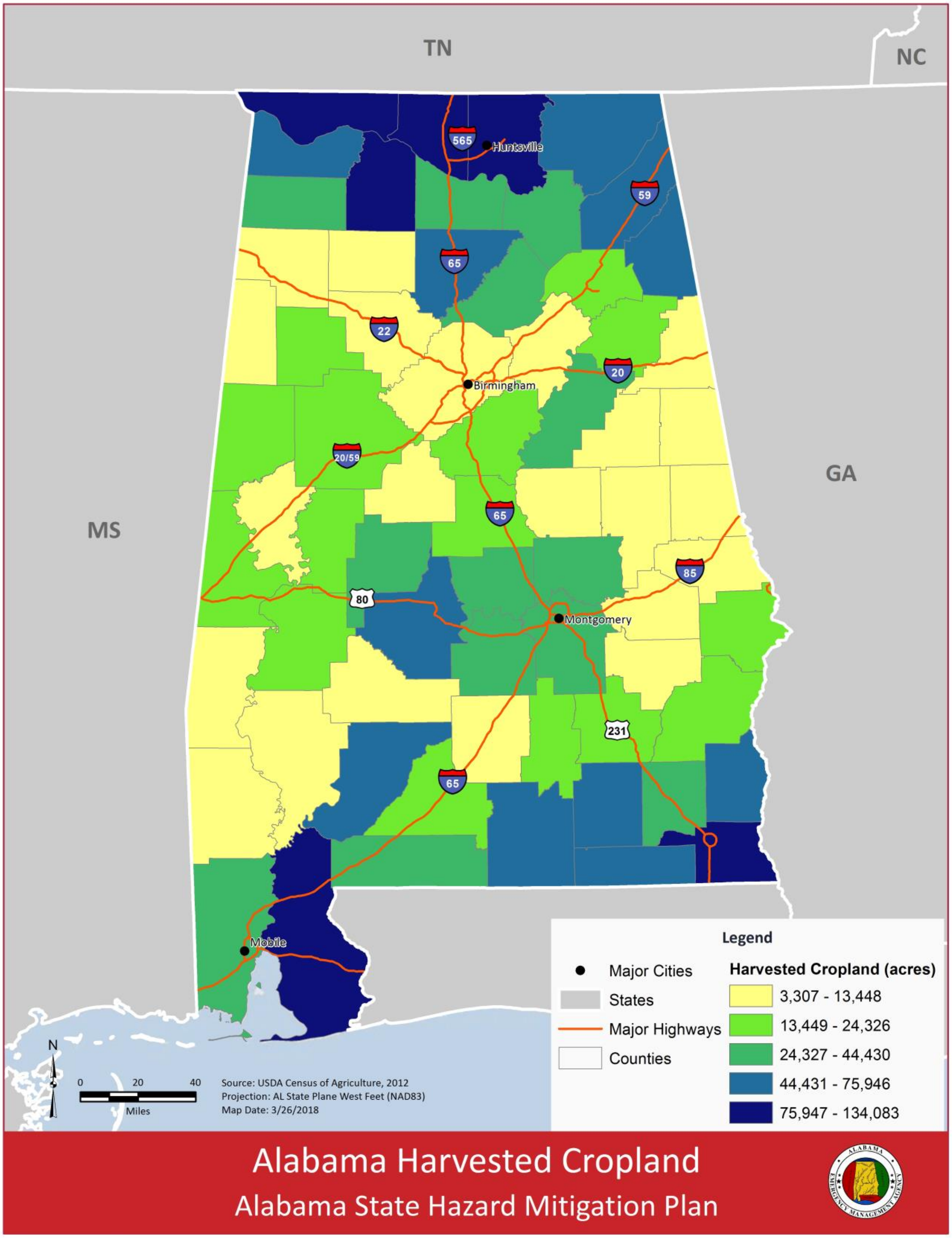
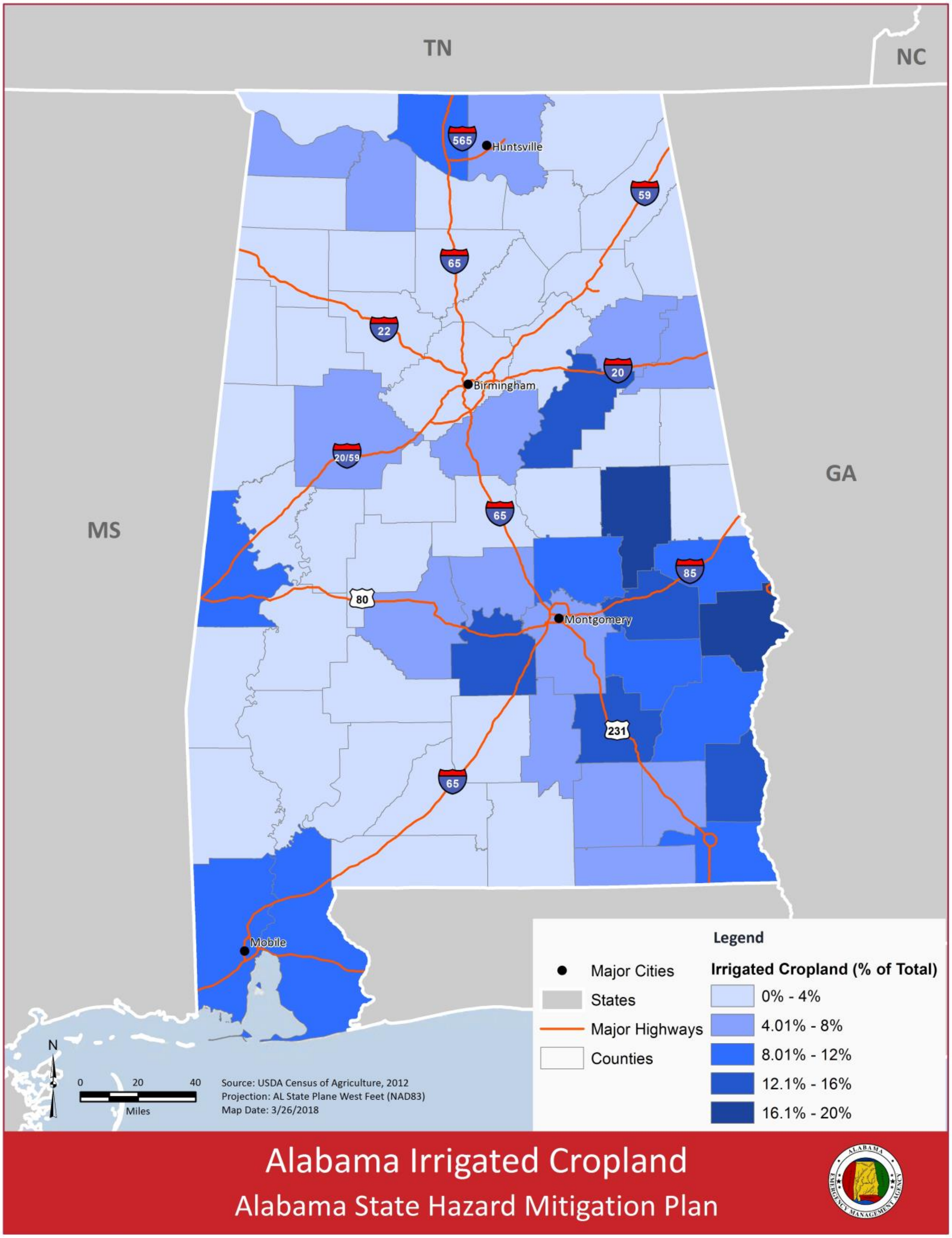


Figure 3.7 Irrigated Cropland in Alabama (USDA, 2012)



3.2.3 Earthquakes

3.2.3.1 Description

An earthquake is “a sudden motion or trembling caused by an abrupt release of accumulated strain on the tectonic plates that comprise the Earth's crust.”[26] Most earthquakes originate along faults close to or at plate boundaries. Because the rocks on either side of these faults are locked together by the weight of the overlying rock, the movement of adjacent plates relative to one another causes stress to accumulate at the faults. When the stress exceeds the frictional bond locking the rocks together, the elastic strain energy that was stored over tens or hundreds of years is suddenly released. A small percentage of earthquakes originates within plates. The powerful forces that build mountains along continental margins can buckle the Earth’s crust or create faults within a plate’s interior. The movement of the continental crust over the Earth’s interior can also create small amounts of compression or extension within a plate, causing rock movement along faults that formed long ago.

When rocks suddenly slip along a fault, intense seismic vibrations travel from the site of the rupture (called the focus of the earthquake) and cause the ground to shake. Three types of seismic waves are generated: compressional (P) waves and shear (S) waves that travel through the body of the earth, and surface waves that skirt along the surface. Unreinforced buildings are most vulnerable to S waves, which cause structures to vibrate from side to side. The strength of ground shaking generally increases with the amount of energy released and decreases with distance from the epicenter of the earthquake.

Seismic activity is often measured in terms of the magnitude of an earthquake at its epicenter. The Richter scale is a scale commonly referred to by the general public, and geologists use similar magnitude scales today. This scale is based on the amplitude of seismic waves recorded by seismographs and uses a logarithmic scale. An increase in magnitude of one unit therefore represents a tenfold increase in the amplitude of the earthquake. Near the epicenter, an earthquake with a magnitude of 3 will be felt indoors by some people but will do no damage to buildings; one that reaches 6 will topple chimneys and weak walls; and one that measures 8 will cause nearly total damage to human structures.

Two ways of measuring the intensity of ground shaking at a particular place are the Modified Mercalli Intensity (MMI), and the peak ground acceleration (PGA). The MMI is expressed as Roman numerals between I and XII and is based on observations of earthquake damage and effects. An earthquake with an MMI of III will be felt noticeably indoors; one with an MMI of VII will cause light damage in buildings of poor construction; and one with an MMI of XII can cause complete structural damage. A more objective measure of the degree of shaking is given by the PGA. Ground motion acceleration is measured using accelerographs and is expressed as a

[26] Federal Emergency Management Agency, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library-data/20130726-1545-20490-4487/mhira_in.pdf

percentage of the force of gravity. The PGA is the maximum value of acceleration for a particular strong motion record and is widely used by engineers to describe the intensity of ground shaking a building must be designed to withstand without collapse.

It is possible to relate measurements of magnitude to measurements of felt intensity using the MMI or instrumental intensity using the PGA (5.1.1.1.1.1.1Table 3.11).[27,28] The relationships are approximate, however, and assume that the location of interest is near the earthquake's epicenter, and that the focus of the earthquake is relatively shallow. Ground shaking generally begins to be felt at a magnitude of 3.0, MMI of II, and PGA of 0.17% g. Damage to buildings of poor construction generally begins at a magnitude of 5.0, MMI of VII, and PGA of 10% g. Finally, damage to ordinary buildings generally begins at a magnitude of 5.5, MMI of VIII, and PGA of 34% g.

Table 3.11 Relationship Between Measures of Magnitude, Felt Intensity, and Instrumental Intensity

Magnitude	MMI	PGA (%g)	Perceived Shaking	Potential Damage
Less than 5	I	<0.17	Not felt.	None
Less than 5	II-III	0.17 - 1.4	Felt by some indoors.	None
Less than 5	IV-V	1.4-9.2	Felt by nearly everyone.	None
5	VI-VII	9.2 - 34	Most people are alarmed and run outside.	Damage is negligible in buildings of good construction, considerable in buildings of poor construction.
5.5	VIII	34 – 65	Most people are alarmed and run outside.	Damage is slight in specially designed structures, considerable in ordinary buildings, great in poorly built structures.

[27] Federal Emergency Management Agency, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library-data/20130726-1545-20490-4487/mhira_in.pdf
[28] Virginia Department of Emergency Management, 2013. Commonwealth of Virginia Hazard Mitigation Plan. Retrieved at: http://www.vaemergency.gov/emergency-management-community/recovery-and-resilience/commonwealth-of-virginia-hazard-mitigation-plan/

Magnitude	MMI	PGA (%g)	Perceived Shaking	Potential Damage
~6	IX	65 – 124	Most people are alarmed and run outside.	Damage is considerable in specially designed buildings. Buildings shift from their foundations and partly collapse.
Greater than 6.5	X - XII	> 124	Most people are alarmed and run outside.	Most masonry structures are destroyed. The ground is badly cracked. Considerable landslides occur on steep slopes.

Although earthquakes have caused much less economic loss annually in the US than other hazards such as floods, they have the potential to cause sudden and devastating loss.[29] Within 1 to 2 minutes, earthquakes can cause the collapse of buildings and bridges, the destruction of critical infrastructure, injuries, and death. Impacts can result directly from ground-shaking, or from secondary hazards such as surface faulting, ground failure, fire, hazardous material release, flash flooding, avalanches, and dam failure. Surface faulting and ground failure pose a particularly great threat to the integrity of structures. Surface faulting occurs when differential movement on either side of a fault splits the ground at the surface. Ground failure can occur through sinkholes, landslides, or liquefaction (a process in which water-saturated sediment temporarily loses strength and acts as a fluid).

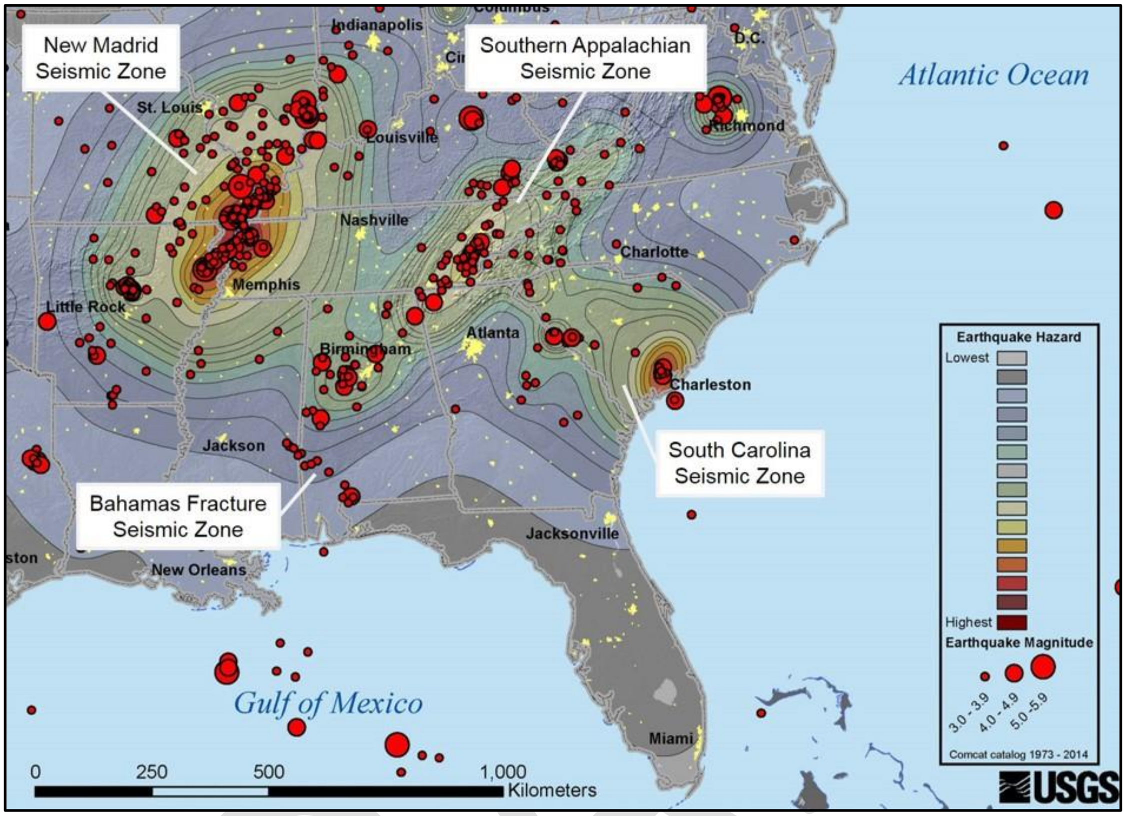
The factors determining the impact of an earthquake include the intensity of ground shaking, the occurrence of secondary hazards, and the design of the structures subject to these hazards. Communities that adopt and enforce up-to-date seismic codes can reduce the loss of life and property when earthquakes occur.

3.2.3.2 Nature of the Hazard in Alabama

In the US, the zone of greatest seismic activity is along the Pacific coast in Alaska and California. The eastern and central US, however, have experienced significant earthquakes. Earthquakes felt in Alabama are associated with four seismic zones: the Southern Appalachian Seismic Zone, the Bahamas Fracture Seismic Zone, the South Carolina Seismic Zone, and the New Madrid Seismic Zone. (5.1.1.1.1.1.1Table 3.11Figure 3.8).

[29] Federal Emergency Management Agency, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library-data/20130726-1545-20490-4487/mhira_in.pdf

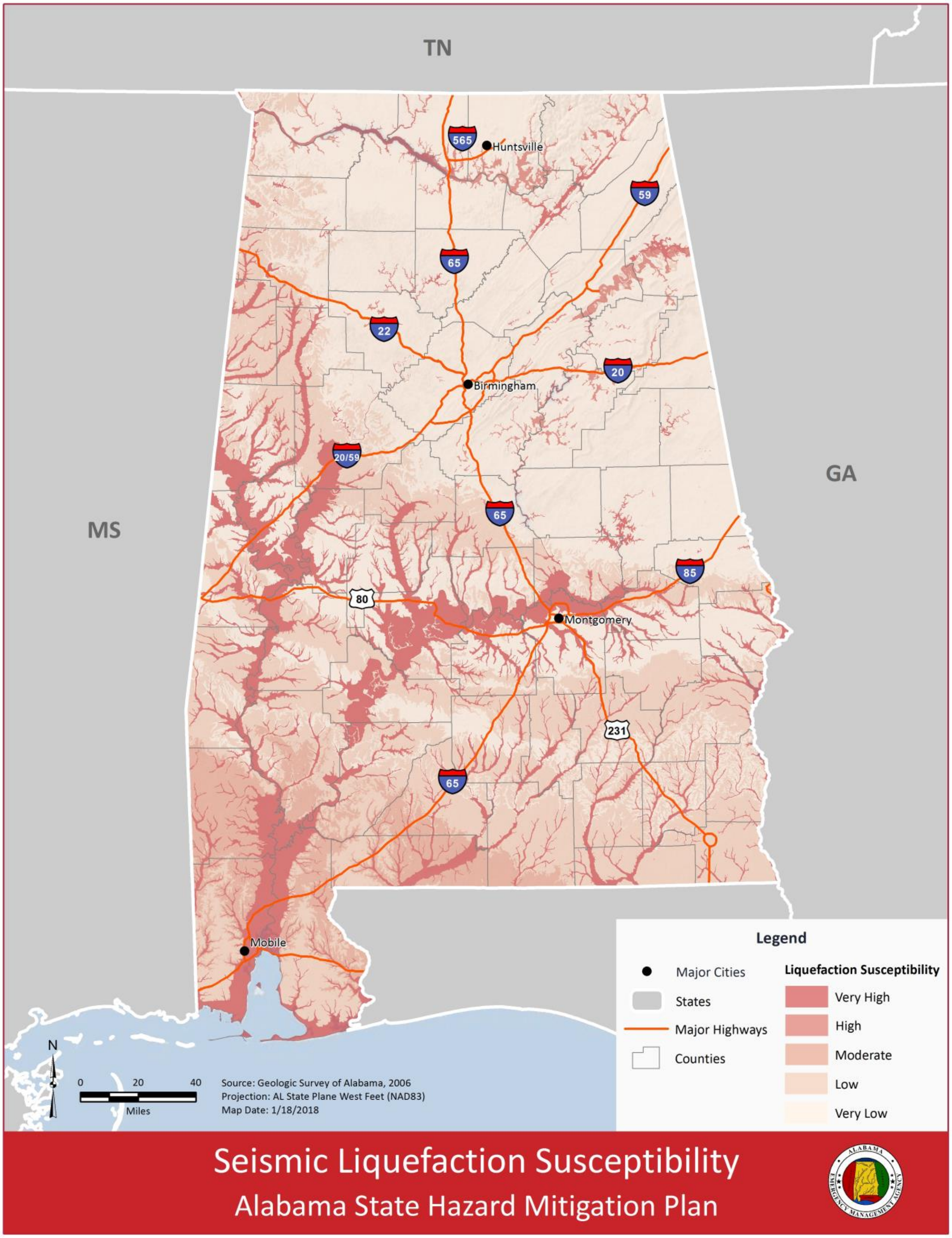
Figure 3.8 Seismic Zones of the Southeastern US (USGS, 2017)



As discussed above, secondary seismic hazards can significantly increase the impact of an earthquake. One secondary hazard of particular concern in Alabama is ground failure through landslides, sinkholes, or liquefaction. To help the AEMA understand the distribution of areas susceptible to liquefaction, the GSA conducted a modeling study and produced a set of susceptibility maps (5.1.1.1.1.1.1Table 3.11Figure 3.9). The coastal plains and major floodplains of Alabama were determined to be highly susceptible to liquefaction and subsequent ground failure. The GSA has recommended additional studies to better understand the distribution of areas susceptible to landslides and sinkholes. Given that these phenomena were triggered during the magnitude 4.9 Fort Payne earthquake in 2003, the GSA finds that it is highly likely that landslides and sinkholes will be triggered by future events, especially in the central and northeastern portions of the state.[30] The small proportion of structures across the state built to withstand intense earthquakes also increases the potential impact of earthquakes in Alabama.

[30] Ebersole, S. M. and Perry, S. L., 2008. Seismic Amplification and Liquefaction Susceptibility Mapping in Alabama. Geologic Investigations Program, Open File Report 0807.

Figure 3.9 Seismic Liquefaction Susceptibility (GSA, 2008)



3.2.3.3 Earthquake History in Alabama

The GSA maintains a catalog of earthquakes centered in Alabama with records dating to 1886. According to this catalog, 83% of seismic activity centered in the state consists of minor earthquakes with magnitudes below 3.0 (5.1.1.1.1.1.1Table 3.11 and 5.1.1.1.1.1.1Table 3.11Figure 3.10). These earthquakes are not felt by most people, and generally do not cause damage to buildings. Only 57 earthquakes in the GSA catalog (16% of the total) exceeded 3.0, and only one earthquake (0.3% of the total) exceeded a magnitude of 5.0. Damage to poorly constructed buildings generally begins at a magnitude of 5.0. 5.1.1.1.1.1.1Table 3.11Figure 3.11 shows the epicenters and magnitudes of historical earthquakes in Alabama. Comparing the location of these epicenters to the location of seismic zones in the Southeastern US (5.1.1.1.1.1.1Table 3.11Figure 3.8) shows that most of the earthquakes centered in Alabama are associated with the Southern Appalachian Seismic Zone or the Bahamas Fracture Seismic Zone.

Figure 3.10 Alabama Earthquake Magnitude (GSA, 2017)

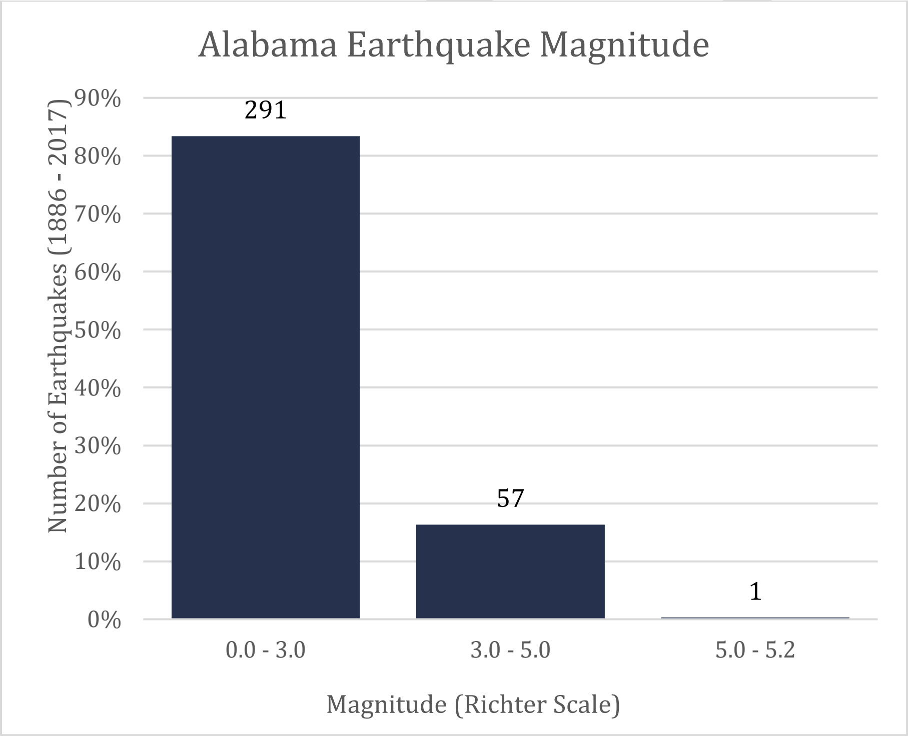
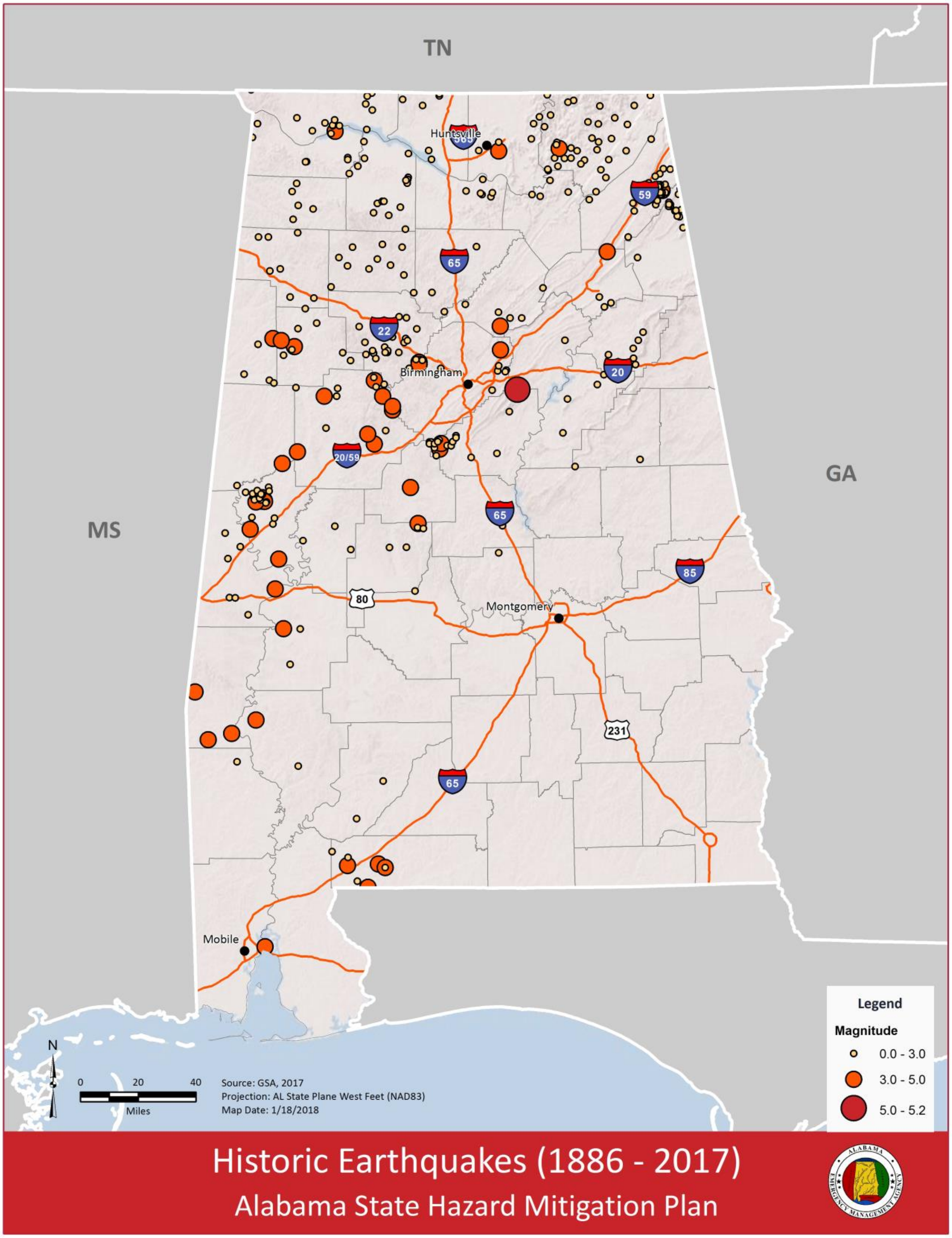


Figure 3.11 Alabama Earthquake History (GSA, 2017)



Earthquakes centered in Alabama are not the only earthquakes with the potential to impact the state. Intraplate earthquakes associated with the New Madrid Seismic Zone to the northwest and the South Carolina Seismic Zone to the east (5.1.1.1.1.1.1Table 3.11Figure 3.8) are often felt in Alabama and have the potential to cause considerable damage. In 1811 and 1812, a series of earthquakes estimated to be approximately 7.7 in magnitude occurred in the area of northeast Arkansas and southeast Missouri. Because the earthquakes shook the rigid craton (a large, stable block of the earth's crust forming the nucleus of the continental plate), their shocks waves traveled great distances, cracking pavement and ringing church bells as far away as Washington D.C. According to the GSA, the intensity of ground shaking in Alabama ranged from an MMI of IV in the southeast to an MMI of VII in the northwest. An MMI of VII is high enough to cause considerable damage in buildings of poor construction. In 1886, a magnitude 7.3 earthquake occurred in Charleston, South Carolina, about 400 miles east of Alabama's border. According to the GSA, the earthquake "caused minor damage in the northeastern part of the state." For example, a 1933 photo of the Alexander-Hurt-Whatley house in Tuskegee shows a large crack in one wall reported to have been caused by the Charleston quake. While these earthquakes were centered in other states, they demonstrate how earthquakes in the New Madrid Seismic Zone and South Carolina Seismic Zone have the potential to cause considerable damage in Alabama.

5.1.1.1.1.1.1Table 3.12 summarizes the impacts of the seven earthquakes centered in the state that caused structural damage. The information in the table was compiled from the GSA and the USGS.[31,32] For each earthquake, the table lists the approximate location of the epicenter, the magnitude, the maximum felt intensity, and the reported impacts. The GSA has also developed MMI maps of the felt shaking intensity for the three largest earthquakes centered in Alabama. These are reproduced below the table (5.1.1.1.1.1.1Table 3.12Figure 3.12). It is important to note the range of magnitudes and the difference between the location of the epicenter and the location of reported impacts. These features show how the impact of an earthquake depends not only of the level of ground shaking, but on the amount and quality of nearby development as well. Note that since the 2013 plan update, no earthquakes have caused structural damage in Alabama.

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[31] Geological Survey of Alabama, 2018. Historical Earthquakes in Alabama. Website accessed at: https://gsa.state.al.us/gsa/geologic/hazards/earthquakes/alquakes

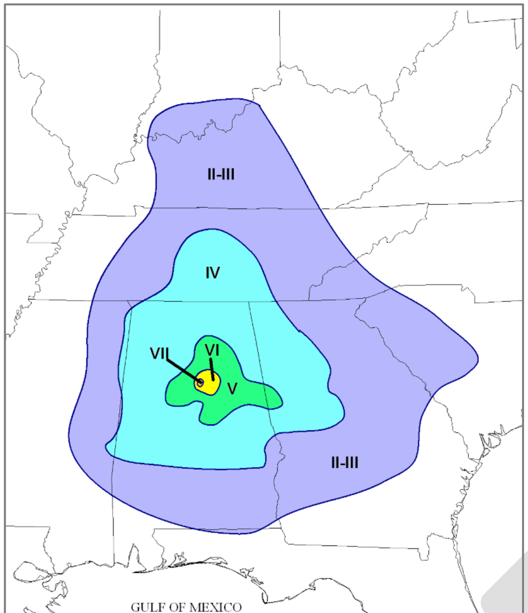
[32] US Geological Survey, 1987. Historical Seismicity in the Southern Appalachian Seismic Zone. Open-File Report 87-433. Retrieved at: https://pubs.usgs.gov/of/1987/0433/report.pdf

Table 3.12 Historical Earthquakes in Alabama that Produced Structural Damage (1916 – 2017)

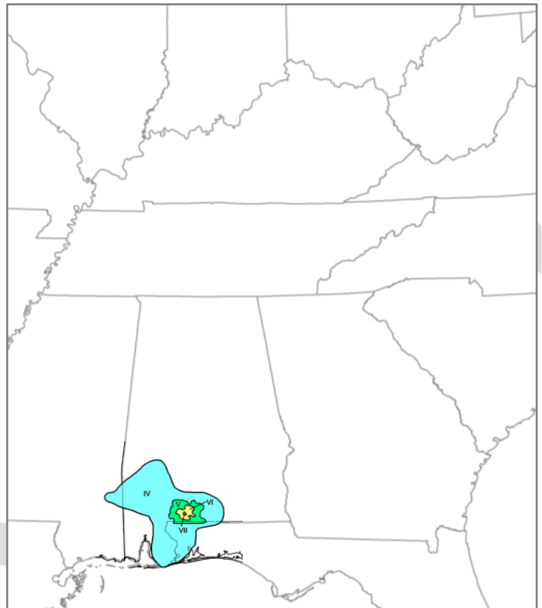
Year	Epicenter	Magnitude	Maximum Intensity (MMI)	Reported Impacts
1916	Town of Irondale, Northern Shelby County	5.2	VII	This is the largest recorded earthquake to originate in Alabama. Near the epicenter, chimneys were knocked down, windows broken, and frame buildings badly shaken. While Irondale was a sparsely populated rural area in 1916, it is now a suburb of the state's most populous city, Birmingham. A similar earthquake today would have a much greater impact.
1957	Town of Guntersville, Marshall County	4.3	VI	This earthquake shook residents in most of northern and central Alabama, southern Tennessee, and western Georgia. The earthquake was felt by, awakened, and alarmed many. Minor damage was reported to several chimneys, walls, and cement steps.
1959	City of Huntsville, Madison County	3.9	VI	This earthquake damaged chimneys in Hazel Green and Meridianville and cracked plaster in Huntsville. According to accounts collected by the USGS, the earthquake also "shook violently the buildings at New Sharon, knocking canned goods from shelves and sending frightened residents fleeing from their homes."
1975	Community of Palmerdale, Jefferson County	4.4	VI	This earthquake cracked a sheetrock ceiling and shifted lamps on tables at Palmerdale, north of Birmingham. It caused slight damage at Watson, where furniture was displaced slightly. The quake was also felt in southern Tennessee.

Year	Epicenter	Magnitude	Maximum Intensity (MMI)	Reported Impacts
1989	Littleville, Colbert County	3.9	VI	A Colbert County official reported that south of Florence, between Littleville and Russellville, a basement wall collapsed beneath a house. Only slight damage was reported north of the epicenter at Florence, where windows were cracked, and hairline cracks formed in plaster. The earthquake was also felt in Lauderdale, Lawrence, and Morgan counties in northwest Alabama.
1997	City of Brewton, Escambia County	4.9	VII	This is the second-largest recorded earthquake to originate in Alabama. Effects from the shaking were seen as far away as Lawrence County where a berm around a pond failed, spilling water and fish across a road. Shaking from the earthquake was felt into Florida and Mississippi. The impact of this earthquake was limited by the rural character of the area near the epicenter.
2003	City of Fort Payne, DeKalb County	4.9	VI	Building damage caused by this earthquake included broken windows, minor cracks in masonry, and chimneys that collapsed or broke. The earthquake also caused the development of minor landslides and sinkholes and muddied the underground water supply for the town of Valley Head, causing the pumps to shut down. The depth of the earthquake limited significant damage in the nearby city of Fort Payne. The quake was felt in several neighboring states.

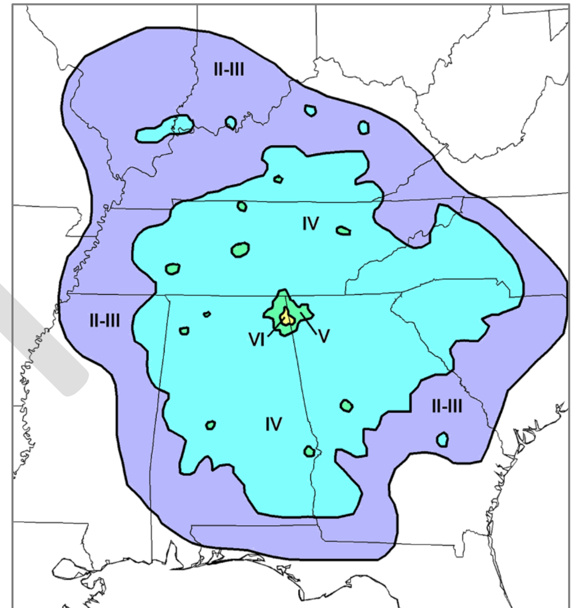
Figure 3.12 Felt Intensity Maps for Three Largest Historical Earthquakes Centered in Alabama (GSA, 2013)



1916 Irondale Earthquake
(5.2)



1997 Escambia County Earthquake
(4.9)



2003 Fort Payne Earthquake
(4.9)

3.2.3.4 Probability of Earthquakes in Alabama

The best available guides to the magnitude and frequency of seismic hazards in Alabama are the probabilistic ground motion maps produced by the USGS. These maps display the intensity of ground motions for various probability levels, and are applied in seismic provisions of building codes, insurance rate structures, risk assessments, and other public policy. The latest available maps are the 2014 USGS National Seismic Hazard Maps. These maps include the PGA likely to occur at two probability levels: the 500-year event (10% probability of exceedance in 50 years) and the 2,500-year event (2% probability of exceedance in 50 years). The USGS selected these frequencies to reflect the average design life of a building (50 years) and the different levels of risk tolerance for different applications.

5.1.1.1.1.1.1Table 3.12Figure 3.14 shows the PGA in Alabama with a recurrence interval of 2,500 years (2% probability of exceedance in 50 years), as well as the location of historical epicenters (a summary of these historical epicenters by magnitude is provided in 5.1.1.1.1.1.1Table 3.12). As described above, PGA is expressed as a percentage of the force of gravity, or %g. Damage to buildings of poor construction generally begins at a PGA of 10% g. The areas with the highest probability of significant shaking events include the greater Birmingham region, DeKalb County, and Escambia County.

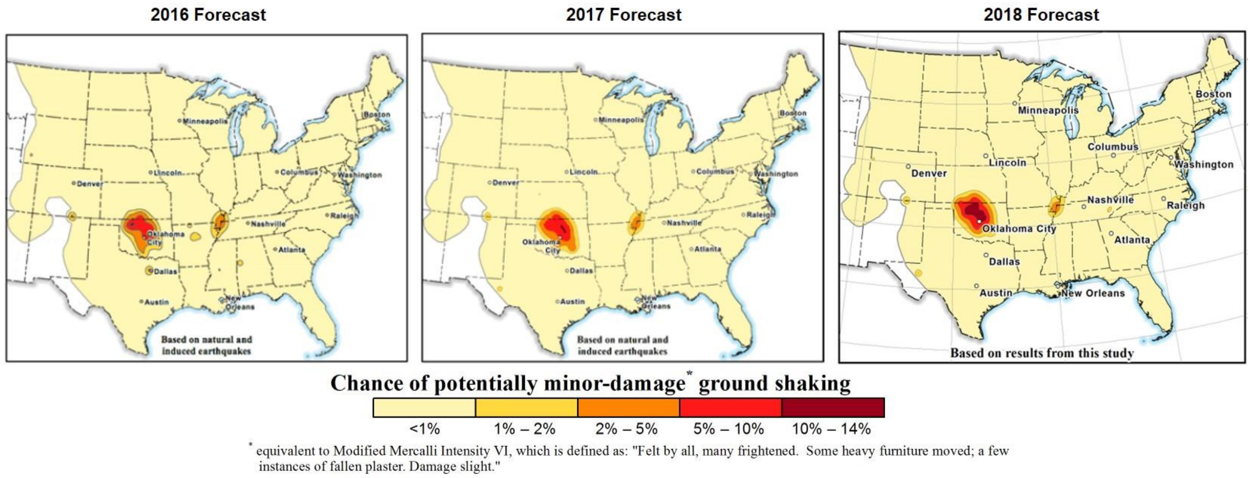
Alabama could also be impacted by earthquakes in the New Madrid Seismic Zone or South Carolina Seismic Zone. According to a study the USGS and the University of Memphis Center for Earthquake Research and Information (CERI), the probability of a magnitude 6.0 or greater earthquake occurring in the New Madrid region in the next 50 years is 25-40%, and the probability of a magnitude 7.0 or greater earthquake is 7-10%. If a strong New Madrid earthquake with a magnitude equal to the historic 1811-1812 earthquakes (7.0-8.0), were to occur today, the estimated damage to the central US would be in the hundreds of billions of dollars, including more than ten billion dollars in Alabama alone. In Alabama, the shaking would be the most severe in the northwestern part of the state. Non-structural items (such as light fixtures and bookshelves) would be at greatest risk for damage from such an event, but structural damages to weaker buildings and utilities (such as pipelines) could also occur. This damage could be caused by direct ground shaking, or by secondary hazards such as ground failure, fire, hazardous material release, or dam failure.

In recent years, induced earthquakes have emerged as a significant concern in the central and eastern United States. Starting around 2009, the average annual number of earthquakes of magnitude 3 or more began to increase sharply, from 21 per year between 1973 and 2008, to 99 per year between 2009 and 2013. In 2014 alone, the USGS reported 659 earthquakes of magnitude 3 or more in the central and eastern United States. Most induced earthquakes in the central and eastern United States are thought to be caused by deep wastewater disposal related to industrial activity.[33] As rates of fluid injection rise and fall, earthquake activity rates are observed

[33] United States Geological Survey, 2018. Induced Earthquakes. Retrieved at: https://earthquake.usgs.gov/research/induced/hazards.php

to rise and fall as well. From 2015 to 2018, for example, fluid injection generally decreased (especially in some areas of Oklahoma and southern Kansas), and rates of earthquakes were observed to steadily decline. To assist with emergency planning and preparedness, the USGS has begun to incorporate the induced earthquake hazard in its one-year seismic hazard forecasts. This is achieved by incorporating an updated earthquake catalog that includes all induced earthquake activity. The 2016, 2017, and 2018 forecasts all show areas of high induced earthquake hazard in Oklahoma-southern Kansas and in the New Madrid Seismic Zone. While the 2016 forecast also showed a small area of high induced earthquake hazard in western Alabama, the 2017 and 2018 forecasts did not (Figure 5.13).

Figure 3.13 One-Year Seismic Hazard Forecasts for 2016 - 2018 (USGS)



It is important to emphasize that earthquakes are low probability, high consequence events. Although a large earthquake exceeding a magnitude of 5.0 may occur only once in the lifetime of a person or asset, the earthquake and its secondary hazards can have devastating impacts.

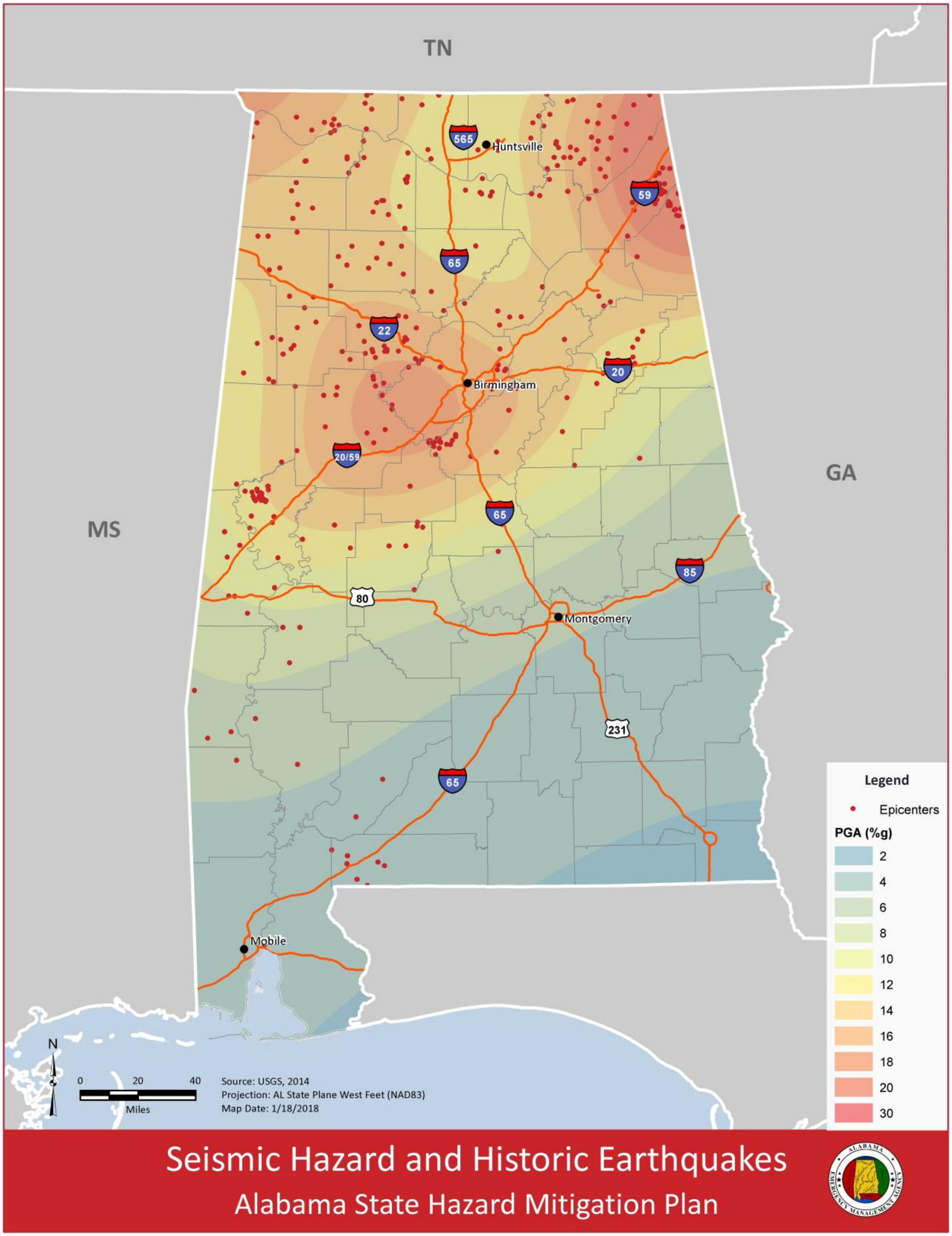
3.2.3.4.1 Future Probability

The future probability of earthquakes in Alabama is not expected to change with climate change.

3.2.3.4.2 Risk and Vulnerability

A detailed assessment of vulnerability to earthquakes in Alabama is provided in Section 5.3.

Figure 3.14 Alabama Hazard and Seismicity Map (USGS, 2014)



3.2.4 Extreme Temperatures

3.2.4.1 Description

The hazard of extreme temperatures encompasses instances of both extreme heat and extreme cold. Both extremes are profiled in this section.

3.2.4.1.1 Extreme Heat

Extreme heat can be defined by a period of excessively hot weather with higher than average temperatures, combined with high humidity. Extreme heat often occurs in the summer months, but can vary regionally.[34] Temperatures above 100°F are generally considered dangerous. Heat stress can be indexed by combining the effects of temperature and humidity, as shown in 5.1.1.1.1.1.1Table 3.13. The heat index estimates the relationship between dry bulb temperatures (at different humidity) and the skin's resistance to heat and moisture transfer. The higher the temperature or humidity, the higher the apparent temperature. The major human risks associated with extreme heat are:

- Heat/Sun stroke: Considered a medical emergency, heat/sun stroke is often fatal. It occurs when the body's responses to heat stress are insufficient to prevent a substantial rise in the body's core temperature. While no standard diagnosis exists, a medical condition is usually diagnosed when the body's temperature exceeds 105°F due to environmental temperatures. Rapid cooling is necessary to prevent death, with an average fatality rate of 15 percent even with treatment.
- Heat Exhaustion: While much less serious than heatstroke, heat exhaustion can cause victims to complain of dizziness, weakness, or fatigue. Body temperatures may be normal or slightly to moderately elevated. The prognosis is usually good with fluid treatment.
- Heat Syncope: This refers to sudden loss of consciousness and is typically associated with people exercising who are not acclimated to warm temperatures. Causes little or no harm to the individual.
- Heat Cramps: May occur in people unaccustomed to exercising in the heat and generally ceases to be a problem after acclimatization.

[34] Federal Emergency Management Agency, 2016. Preparing for Extreme Heat. https://www.fema.gov/media-library-data/1463677085878-9910a9fefba8ab4d6fc8e9195b1da115/Preparing_for_Extreme_Heat_EA_JS_edits_final_508.pdf

Table 3.13 Heat Index and Disorders (FEMA, 1997; NWS, 1997)

Danger Category	Heat Disorders	Apparent Temperatures (°F)
I Caution	Fatigue possible with prolonged exposure and physical activity	89-90
II Extreme Caution	Sunstroke, heat cramps, and heat exhaustion possible with prolonged exposure and physical activity	90-105
III Danger	Sunstroke, heat cramps, or heat exhaustion likely, heat stroke possible with prolonged exposure and physical activity	105 - 130
IV Extreme Danger	Heatstroke or sunstroke imminent	>130

In addition to affecting people, severe heat places significant stress on plants and livestock. The effects of severe heat on agricultural products may include reduced yields and even loss of crops.[35] Similarly, extreme temperatures can impact livestock. For example, heat stress severely reduces fertility as well as milk production in cows.[36]

3.2.4.1.2 Extreme Cold

Although less likely, extreme cold temperatures can also impact Alabama. Every winter, Arctic air and brisk winds can lead to very cold wind chill values in the US. Prolonged exposure to the cold can cause frostbite or hypothermia and become life threatening. Frostbite occurs when the extremities become excessively cold, and hypothermia is a serious health condition where a person's body temperature falls below 90°F. Both conditions are influenced by wind conditions. Various wind chill indices have been developed to predict cold temperature's effect on humans. For instance, a temperature of 5°F will have a wind chill of -19°F if the wind is blowing 30 mph. Cold weather can also impact crops and livestock. Cold air has the potential to freeze produce, which can damage or kill it.[37]

Older adults are more prone to being impacted by extreme heat and extreme cold events. This is because they do not adjust as well as other demographics to drastic changes in temperature, they are more likely to have a medical condition that changes normal body responses to heat, and cold, and they are more likely to take prescription medications that impact the body's ability to react to changes in temperature. Access to climate control, such as air conditioning and heating

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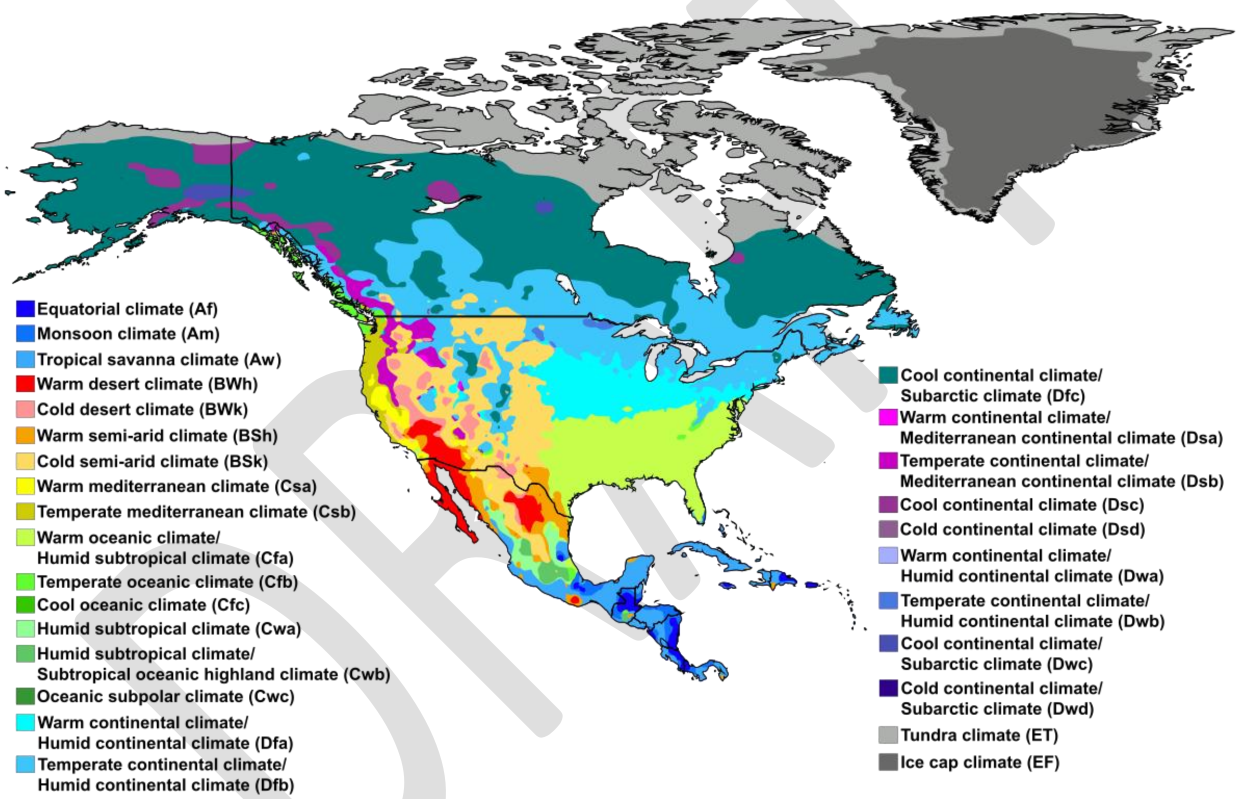
[35] Brown P. W., and C.A. Zeiher, 1997. Cotton heat stress.
[36] Dobson, H et al., 2007. "The High Producing Dairy Cow and Its Reproductive Performance." *Reproduction in domestic animals*. Retrieved at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2748269/
[37] National Oceanic and Atmospheric Administration, 2018. Cold Weather Safety. Retrieved at: http://www.nws.noaa.gov/os/cold/

systems, provides protection from the impacts of extreme heat and cold events and is one way to mitigate against the potential impacts of an extreme temperature event.[38]

3.2.4.2 Nature of the Hazard in Alabama

According to the Köppen-Geiger climate classification system, Alabama has a humid subtropical climate (5.1.1.1.1.1.1Table 3.13Figure 3.15).[39] This climate type is characterized by relatively high temperatures and evenly distributed precipitation throughout the year. Summers feature high temperatures with warm, oppressive nights, and are generally wetter than winters. The coldest month is generally mild, with occasional frosts.

Figure 3.15 Köppen-Geiger climate type map for North America (Peel et. al., 2007)



3.2.4.2.1 Extreme Heat

Summers in Alabama are among the hottest in the US, with high temperatures averaging over 90°F throughout the state. Because extreme heat is prevalent across the state, residents are accustomed to these conditions and are not significantly impacted. However, extreme heat has

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[38] Centers for Disease Control and Prevention, 2018. Heat and Older Adults. Retrieved at: https://www.cdc.gov/disasters/extremeheat/older-adults-heat.html
[39] Peel, M.C., Finlayson, B.L., and McMahon, T.A., 2007. Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences, 11, 1633-1644.

been known to induce heat stroke among older adults. Some cases have resulted in death. Additionally, some extreme heat events have had significant impacts on crops. Temperature records from Alabama weather stations can help illustrate the nature of the extreme temperature threat in Alabama. 5.1.1.1.1.1.1Table 3.14 summarizes the number of extreme heat days recorded by weather stations located in Alabama's four largest cities. Extreme heat days were defined as days in which the maximum temperature exceeded 90°F. For each station, the table shows the average annual number of extreme heat days recorded each month as well as across the entire year. The averages were calculated across the period of record for each station, which ranged from 45 years for the Huntsville station to 50 years for the Mobile station. Cities in the south experience more frequent extreme heat days, with Montgomery experiencing an average of 78 extreme heat days per year, and Mobile experiencing an average of 74 extreme heat days per year.

Table 3.14 Average Annual Number of Extreme Heat Days (SERCC, 2018)

Month/Station	Birmingham	Huntsville	Mobile	Montgomery
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	2	1	4	4
June	10	9	16	16
July	18	16	22	22
August	16	15	21	21
September	7	6	11	12
October	7	6	1	1
November	0	0	0	0
December	0	0	0	0
Annual	**53**	**47**	**74**	**78**

3.2.4.2.2 Extreme Cold

Winters are generally mild in Alabama, as they are throughout most of the southeastern US, with an average low temperature of 53°F.[40] The mild winter climate makes extreme cold temperatures fairly uncommon throughout the state. However, because residents are unaccustomed to the severe cold weather, there have been cases where the cold temperatures have caused death. Additionally, most crop species in Alabama do not have a tolerance to cold temperatures, making them more prone to impacts of cold weather. 5.1.1.1.1.1.1Table 3.15 summarizes the number of

[40] US Climate Data, 2018. Climate Alabama. Retrieved at: https://www.usclimatedata.com/climate/alabama/united-states/3170

extreme cold days recorded by weather stations located in Alabama's four largest cities. Extreme cold days were defined as days in which the minimum temperature was less than 32°F. As in the table for extreme heat days, 5.1.1.1.1.1.1Table 3.15 shows the average annual number of extreme cold days recorded each month as well as across the entire year. Cities in the north experience more frequent extreme cold days, with Birmingham experiencing an average of 55 extreme cold days per year, and Huntsville experiencing an average of 62 extreme cold days per year.

Table 3.15 Average Annual Number of Extreme Cold Days (SERCC, 2018)

Month/Station	Birmingham	Huntsville	Mobile	Montgomery
January	16	18	8	13
February	12	13	5	8
March	5	6	1	2
April	0	0	1	2
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	6	7	1	4
December	14	16	6	11
Annual	**55**	**62**	**22**	**39**

3.2.4.3 Extreme Temperature History in Alabama

3.2.4.3.1 Extreme Heat

The NWS Storm Events Database began collecting information on extreme heat events in 2008. Since that time, local field offices have reported 13 extreme heat episodes, or 1.4 episodes per year. Most of these episodes were relatively localized, affecting three counties or less. Two of the episodes, however, were widely felt across the state. The extreme heat episode of June 27 to 28, 2009 was reported to affect seven counties, while the extreme heat episode of August 15, 2010 was reported to affect eight counties. None of the events recorded since 2008 were reported to cause direct damage or death, but several were reported to cause injuries. 5.1.1.1.1.1.1Table 3.16 summarizes the extreme heat events recorded in the Storm Events Database since 2008,

as well as the 1980 heat wave identified by the Birmingham field office as the most noteworthy extreme heat event of the twentieth century.[41]

Table 3.16 Recorded Excessive Heat Events in Alabama (NOAA, 2018)

Date	Counties Impacted	Description
July through September, 1980	80 percent of the state	From mid-July, through mid-September, 1980, a sustained period of extreme heat and high humidity took its toll on the state. The month of July alone saw an estimated 120 heat-related deaths, the loss of more than 200,000 chickens, and the loss of half the state's corn crop. The hottest day of the summer was July 17th, when over 80 percent of the state reached 100°F, and nearly one quarter of the state reached 105°F. The highest reading on that day was 108°F recorded in the cities of Bessemer, Aliceville, and Jasper.
June 7 to 8, 2008	Madison	Heat illnesses prompted the hospitalization of four individuals. Temperatures climbed to between 90 and 95°F and heat index values reached 95 to 100°F.
July 21, 2008	Madison	A strong upper level ridge of high pressure in place across the southeastern US lead to temperatures in the upper 90s to low 100s across Madison County. A record high of 103°F was set at the Huntsville International Airport. This coupled with dewpoints in the mid-60s produced heat index values between 105 and 110°F. This caused some heat related illnesses in Madison county.
June 19, 2009	Lauderdale, Colbert	A large ridge of high pressure built over the region producing hot weather over several days. Daytime high temperatures reached the middle to upper 90s during this period. In combination with humid air, heat index values climbed into the 100 to 105°F range across northwest Alabama, including the Shoals. A newspaper reported that at least 12 people were treated for heat illness at a Florence hospital.
June 27 to 28, 2009	Lauderdale, Colbert, Cullman, Limestone, Lawrence, Madison, Morgan	A ridge of high pressure persisted over the region on the 27th and 28th, producing hot temperatures in the upper 90s to around 100°F. The heat combined with high humidity pushed heat index values into the 105 to 110°F range on both days.

[41] National Oceanic and Atmospheric Administration, NWS Birmingham, AL, 2018. Top 10 Weather Events in the 20th Century for Alabama. Retrieved at: https://www.weather.gov/bmx/climo_top10

Date	Counties Impacted	Description
August 15, 2010	Morgan, Madison, Colbert, Lauderdale, Lawrence, Limestone, Cullman, Franklin	Heat index values reached 110 to 115°F in northwest and north central Alabama.
July 10 to 11, 2011	Lauderdale, Colbert, Madison	Hot and very humid conditions produced dangerous heat during this period, mainly across northwest and north central Alabama. Overnight lows were in the mid to upper 70s at most locations, including a low of 80 at the University of Alabama in Huntsville on the morning of the 12th. High temperatures reached the upper 90s to around 100. Heat index values of 105 to 111 were observed. At least two fatalities have been blamed during this heat wave.
June 29 to July 1, 2012	Madison, Colbert, Montgomery	A strong ridge of high pressure shifted eastward from the Central Plains to the southeastern Continental US, bringing with it recording breaking temperatures. Afternoon highs rose over 100°F. With a moist airmass in place, the heat index value reached 112°F at the Montgomery Regional Airport on June 30.
July 14, 2015	North Alabama	Temperatures warmed into the middle to upper 90s during the afternoon of the 14th. With high dew points in the lower to middle 70s, heat index values reached at or above 105°F over most of north Alabama.
August 5, 2016	Lauderdale	As temperatures reached the middle to upper 90s with dew points in the middle to upper 70s, the heat index reached 110°F in Muscle Shoals and nearby locations during the afternoon hours.

3.2.4.3.2 Extreme Cold

Although extreme cold is less common in Alabama than extreme heat, Alabama residents are less accustomed to and less well-prepared for extreme cold, and therefore more vulnerable to these events. The NWS Storm Events Database began collecting information on extreme heat events in 1996. Since that time, local field offices have reported 109 extreme cold episodes, or 5.2 episodes per year. Most of these episodes were relatively localized, affecting three counties or less. Eleven of the episodes, however, were widely felt across the state. The most widely-felt were two extreme cold events recorded in 1996 that were reported to affect 50 counties, and events recorded in 2003 and 2014 that were reported to affect 39 counties each. None of the events recorded since 2008 were reported to cause direct property damage or injury, but one event was reported to cause direct crop damage, and several were reported to cause direct deaths. The extreme cold event of March 7, 1996 was reported to cause more than $81 million in direct crop damage (adjusted to 2017 dollars). Six of the recorded events were reported to cause

one death each, for a total of six deaths attributed to extreme cold. 5.1.1.1.1.1.1.1Table 3.17 summarizes the extreme cold events recorded in the Storm Events Database since 1996.

Table 3.17 Recorded Extreme Cold Events in Alabama (NOAA, 2018)

Date	Counties Impacted	Description
February 6, 2000	Montgomery	A new record low temperature of 20°F was measured at Dannelly Field.
April 9, 2000	Montgomery, Jefferson, Madison	Record low temperatures for April were recorded in each county.
July 24 to 25, 2000	Madison	A new record low temperature of 63°F was measured at the Huntsville International Airport.
August 15, 2000	Montgomery	An early morning temperature of 64°F was measured at Dannelly Field. This temperature tied the previous record low temperature for August.
September 17, 2000	Madison	A morning low temperature of 47°F was measured at the Huntsville International Airport. This temperature tied the previous record low temperature for September.
October 8 to 12, 2000	Madison Jefferson, Montgomery	Record low temperatures for the month of October were recorded in each county.
November 22, 2000	Montgomery	The morning low temperature recorded at Dannelly Field was 21°F. This measurement established a new record low temperature for November.
December 1, 2000	Madison, Montgomery, Jefferson	Record low temperatures were recorded for each county. This was the coldest December since records began in 1910.
December 31, 2000	Jefferson	A Birmingham man died from hypothermia after being found outside of the Norwood boarding house where he lived. The coroner reported that the man's body temperature was 77°F when he was found. The morning low reported at the Birmingham airport was 16°F.
March 26 to 28, 2001	Madison	The early morning low temperature recorded at the Huntsville International Airport was 27°F. This temperature established a new daily record low temperature.
May 23, 2001	Madison	The low temperature of 47°F tied the record low for this date which was first set in 1963.
August 21, 2001	Madison	The morning low temperature measured at the Huntsville International Airport was 57°F which established a new record low temperature for the date.
September 26 to 28, 2001	Jefferson, Madison, Montgomery	Record low temperatures for September were recorded in these counties.

Date	Counties Impacted	Description
October 17 to 18, 2001	Jefferson, Madison, Montgomery	Record low temperatures for October were recorded in these counties.
October 28 to 30, 2001	Madison, Montgomery	New record low temperatures for October were recorded in these counties.
February 28, 2002	Montgomery, Tuscaloosa, Colbert, Madison, Jefferson, Calhoun	Record low temperatures for February were recorded in these counties.
May 20 to 21, 2002	Madison, Montgomery, Jefferson	Record low temperatures for May were recorded in these counties.
January 24, 2003	All Counties	The coldest temperatures in 7 years occurred across much of North and Central Alabama and lasted for about two days. Early morning temperatures ranged from 2 to 10°F. The coldest temperatures were measured in outlying areas. Although no new records were established, these temperatures were very cold for the Deep South. Many area residents reported frozen and broken water pipes as a result of the extended cold. Several lawn sprinkler systems also froze and broke making many areas very icy. One woman in Talladega was found outside dead, apparently succumbing to the harsh, cold conditions. Many area farmers lost a large part of their strawberry crops.
January 7 to 8, 2015	Cullman, Colbert, Lawrence, Madison, Morgan, Limestone, Franklin, Lauderdale, Dekalb, Marshall, Jackson	An Arctic cold front pushed through the region on the afternoon of the 7th bringing gusty northerly winds of 20 to 30 mph. Temperatures fell through the 20s and quickly into the teens and single digits during the evening and overnight of the 7th. Wind chills fell below zero during the mid to late evening hours in northern Alabama. Although winds diminished considerably through the early morning hours of the 8th, wind chills remained below zero with temperatures bottoming out in the single digits.
January 7, 2017	Franklin	Minor winter weather was observed. With a very cold air mass in place, there were light snow fall accumulations. Additionally, cold air convection from the NW produced widespread apparent temperatures around 0F on the morning of Jan 7. Widespread sub-zero temperatures were observed.

3.2.4.4 Probability of Extreme Temperatures in Alabama

The probability of extreme temperatures in Alabama is a function of the state's geography and climate. With its humid subtropical climate type, the state is likely to experience many days with

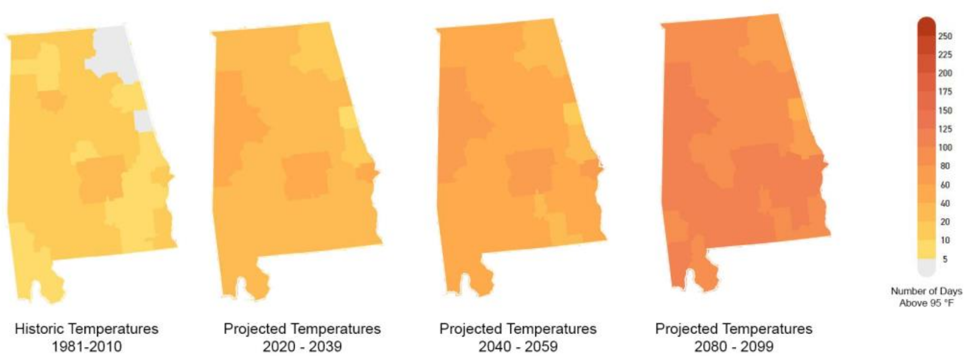
maximum temperatures in excess of 90°F, and somewhat fewer days with minimum temperatures lower than 32°F. As shown in 5.1.1.1.1.1.1.1Table 3.14 and 5.1.1.1.1.1.1.1Table 3.15, the number of days with extremely high maximum temperatures increases from north to south, while the number of days with extremely low minimum temperatures increases from south to north.

3.2.4.4.1 Future Probability

As Alabama experiences impacts from climate change, the average temperature will become warmer and excessive heat events will be more likely to occur. Climate change will mean that Alabama will experience more extremely hot days, there may be a reduction in crop yield, more livestock may be harmed and there may be an increase in the risk of heat stroke and other heat related diseases.[42]

The Climate Impact Lab provides climate projections for the rest of the 21st century based on Coupled Model Intercomparison Project Phase 5 (CMIP5). In this model, the gridded projections were aggregated to regional estimates. 5.1.1.1.1.1.1.1Table 3.17Figure 3.16 illustrates these projections for the number of extreme heat days. As these projections indicate, the number of extreme heat days is projected to increase throughout the state.[43] In addition, the number of heat waves (defined as consecutive days exceeding 95 °F) is expected to increase significantly by the end of the 21st century, with the projected increase ranging from 97% to 207%.[44]

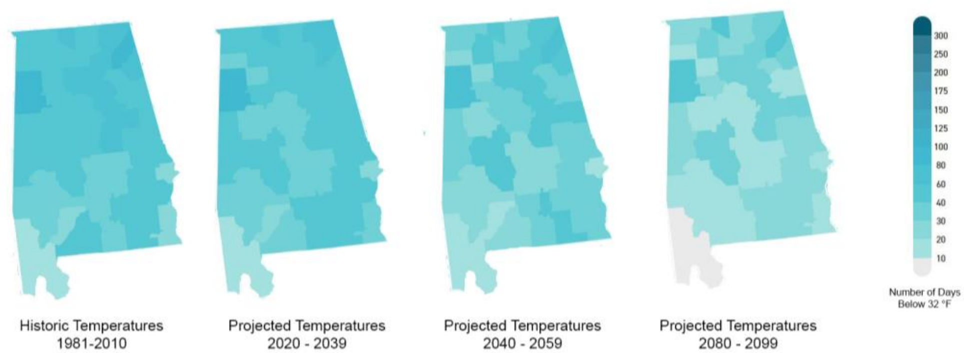
Figure 3.16 Projected Days Above 95°F (Climate Impact Lab, 2018)



[42] Environmental Protection Agency, 2016. What Climate Change Means for Alabama. Retrieved at: https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-al.pdf
[43] Climate Impact Lab, 2018. Climate Impact Map. Retrieved at: http://www.impactlab.org/map/#usmeas=absolute&usyear=2080-2099&gmeas=absolute&gyear=1986-2005
[44] Ingram, K., K. Down, L. Carter, J. Anderson, eds. 2013. Climate of the Southeast US: Variability, change, impacts, and vulnerability. Washington DC: Island Press.

The number of extreme cold days, in contrast, is projected to decrease. 5.1.1.1.1.1.1Table 3.17Figure 3.17 illustrates the CMIP5 projections for the number of extreme cold days. In addition, overall warming is projected to increase the length of the freeze-free season, or the period between the last spring frost and the first fall frost. In the northern tier of the state, the length of the freeze-free season may increase by as much as 30 days by the middle of the 21st century.[45] This change could have implications for pest management and crop damage, as well as vector-borne diseases and public health.

Figure 3.17 Projected Days Below 32°F (Climate Impact Lab, 2018)



3.2.4.4.2 Risk and Vulnerability

In the US, the projected increase in heat wave deaths is expected to be the single greatest driver of economic impacts from climate change.[46] A community's vulnerability to heat waves will depend not only on the probability of the hazard, but on the characteristics of the built environment, the characteristics of the exposed population, and any adaptation measures taken by the community. In developed areas, the heat-wave risk is related to both regional climate change and local urban heat island effects. Neighborhoods in the city center and neighborhoods with less vegetation are most impacted by the urban heat island effect and will have the greatest exposure to high temperatures (particularly at night).[47] In Alabama, the densest neighborhoods in the state's cities and town may be particularly vulnerable to extreme heat events. As discussed above, certain demographic groups are more susceptible to extreme heat than others. These groups include older adults, infants, young children, and people with chronic health problems.[48] Members of these groups who do not have access to air conditioning will be the most vulnerable to heat-

[45] Ibid.

[46] New York Times, 2017. As Climate Changes, Southern States Will Suffer More Than Others. By Brad Plumer and Nadja Popovich. Published June 29, 2017. Retrieved at: https://www.nytimes.com/interactive/2017/06/29/climate/southern-states-worse-climate-effects.html

[47] Lemonsu, A., Viguie, V., Daniel, M., and Masson, V., 2015. Vulnerability to heat waves: Impact of urban expansion scenarios on urban heat island and heat stress in Paris (France). Urban Climate, Volume 14, Part 4. Retrieved at: https://www.sciencedirect.com/science/article/pii/S2212095515300316

[48] National Oceanic and Atmospheric Administration, National Weather Service, 2017. Who is Most Vulnerable During a Heat Wave. Retrieved at: https://www.weather.gov/media/lsx/wcm/Heat/MostVulnerableHeatIndex.pdf

related health impacts. Society and technology could moderate the vulnerability of these groups, however. For example, cities could open cooling centers during heat waves for those who lack access to air conditioning.

3.2.5 Flooding

3.2.5.1 Description

Flooding is the inundation of normally dry land and is the leading cause of natural disaster losses in the US. Flooding can be caused by many different types of weather systems, including slow-moving frontal systems, inland-moving tropical cyclones, and intense summertime thunderstorms. In coastal areas, flooding can also be caused or intensified by high tides. When local weather stations issue flood warnings or report flood damages, they often classify flood events into categories based on the extent and velocity of rising waters.[49] 5.1.1.1.1.1.1Table 3.18 summarizes flood types based on the definitions used in the NWS Storm Events Database.

Table 3.18 Flood Types (NWS, 2016)

Flood Type	Extent	Description
Flash Flood	Areas near creeks and streams and low-lying areas	A life-threatening, rapid rise of water into a normally dry area beginning within minutes to multiple hours of the causative event (e.g., intense rainfall, dam failure, ice jam). Ongoing flooding can intensify to the shorter-term flash flooding in cases where intense rainfall results in a rapid surge of rising flood waters. Conversely, flash flooding can transition into ongoing flooding as rapidly rising waters abate. **Note:** This section provides in-depth information on the nature of flash flooding and past occurrences, but limited information on the relative probability of flash flooding across the state. This is because flash-flooding can happen anywhere when the local meteorological, soil, and land cover conditions are right.
Flood	Small to large-scale areas	Any high flow, overflow, or inundation by water which causes 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, that poses a threat to life or property. Floods can range from larger scale area floods to the smaller scale urban and small stream flooding that commonly occurs in poorly drained or low-lying areas.

[49] National Oceanic and Atmospheric Administration, National Weather Service, 2016. Storm Data Preparation. National Weather Service Instruction 10-1605.

Flood Type	Extent	Description
Coastal Flood	Low-lying coastal areas	Flooding of coastal areas due to the vertical rise above normal water level caused by strong, persistent onshore wind, high astronomical tide, and/or low atmospheric pressure, resulting in damage, erosion, flooding, fatalities, or injuries.
Nuisance Flooding	Low-lying coastal areas	Shallow coastal flooding caused by the convergence of extreme high tides with other meteorological conditions (e.g., onshore winds). This type of flooding can occur even on sunny days. While nuisance flooding can cause significant public inconvenience, it generally does not cause significant structural damage to buildings.
Storm Surge	Coastal regions	For coastal and select lakeshore areas, the vertical rise above normal water level associated with a storm of tropical origin (e.g., hurricane or tropical storm), caused by any combination of strong, persistent onshore wind, high astronomical tide, and low atmospheric pressure, resulting in damage, erosion, flooding, fatalities, or injuries.

The normally dry land that is covered with water during floods is known as the floodplain. For riverine flooding, the factors that determine the extent of the floodplain include rainfall intensity, duration, and extent; soil saturation; topography; and land cover. Higher streamflows are generated when rainfall is heavy, soils are frozen or saturated, slopes are steep, or drainage areas are highly impervious (covered with surfaces that do not absorb water such as roofs, roads, and parking lots). High streamflows tends to translate into larger floodplains where the land adjacent to rivers and streams is characterized by wide flat, areas (as opposed to steep river valleys).

For coastal and storm surge flooding, the factors that determine the extent of the floodplain include the size, strength, intensity, and speed of the storm that is driving storm surge and wave action; the direction the storm is moving relative to the shoreline; how steeply the sea floor is sloping along the shore; topography; and the astronomical tide. In general, storm surge is most damaging when it occurs along a shallow sloped shoreline, during high tide, and in developed areas with limited natural buffers (such as barrier islands, coral reefs and coastal vegetation).[50] Furthermore, the damage from storm surge and waves is greatest in the tropical cyclone's right front quadrant.

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[50]Wright, James M., 2007. Floodplain Management: Principles and Current Practices. Retrieved at: https://training.fema.gov/hiedu/docs/fmc/chapter%202%20-%20types%20of%20floods%20and%20floodplains.pdf

This is where the storm, its winds and ocean waves are all moving in an onshore direction due to the counter-clockwise rotation of hurricanes in the Northern Hemisphere.[51]

Both localized and widespread floods are considered hazards when people and property are affected. Injuries and deaths can occur when people are swept away by flood currents or when bacteria and disease are spread by floodwaters. Extensive property damage can be caused by the force or volume of floodwaters. Moving water creates hydrodynamic forces that can damage the walls of buildings, scour around their foundations, and damage roads and bridges. The magnitude of these forces is related to both the velocity and depth of flooding. Studies have shown that deep water moving at low velocities can cause as much damage as shallow water moving at high velocities. The debris carried by moving water can also cause damage, acting like battering rams against the walls of buildings. Standing water also exerts force on buildings through the weight of the water. Three feet of standing water can exert enough lateral force to collapse the walls of a typical frame house, and basement walls and floors are particularly susceptible to damage.[52] Soaking is another cause of property damage related to the volume of floodwaters. Soaking can damage plywood, gypsum wallboard, and household goods. In addition, floodwaters usually carry suspended sediments; debris; other contaminants such as oil, farm, and lawn chemicals; and untreated sewage. When floodwaters recede, these contaminants remain on flooded buildings and their contents. It is important to note that even when flooding does not cause property damage or loss of life, flood events can cause economic disruption through traffic diversions and temporary business closures. Shallow coastal flooding caused by extreme high tides often causes these public inconveniences, which is why this type of flooding is sometimes called "nuisance flooding."

The impact of floods is highly dependent on the amount, type, and design of development in the floodplain. The federal government has therefore developed nationwide programs to identify flood-prone areas (Risk Mapping, Assessment, and Planning, or Risk MAP) and to encourage development patterns that place fewer people and assets in harm's way through the National Flood Insurance Program (NFIP). To identify flood-prone areas, the Risk MAP program produces flood hazard maps (also known as Flood Insurance Rate Maps, or FIRMs) that delineate flood zones based on the expected frequency of flooding. 5.1.1.1.1.1.1Table 3.19 describes the flood zones used in current FIRMs. Note that Zone A and Zone V areas are also known as the Special Flood Hazard Area (SFHA). To encourage effective floodplain management, the NFIP makes more affordable flood insurance available to communities that adopt and enforce floodplain management regulations. Participating communities must meet the NFIP requirements for each flood zone.

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[51] Ibid.
[52] Federal Emergency Management Agency, 1998. Managing Floodplain Development Through the National Flood Insurance Program: Home Study Course. Retrieved at: https://www.fema.gov/pdf/floodplain/nfip_sg_unit_1.pdf

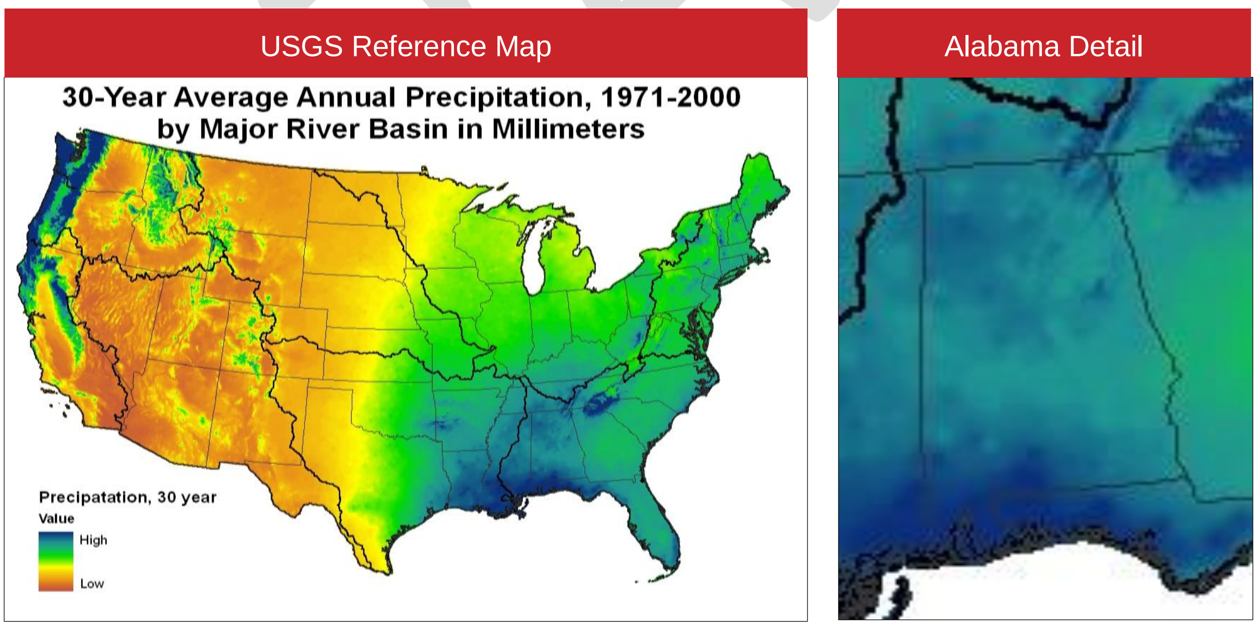
Table 3.19 NFIP Flood Zones

Zone	Frequency	Description
Zone A	1% annual chance or greater	Area of high hazard; also known as the Special Flood Hazard Area
Zone X (shaded)	Between 0.2% and 1% annual chance	Area of moderate flood hazard
Zone X (unshaded)	Less than 0.2% annual chance	Area of minimal flood hazard
Zone V	1% annual chance or greater	Coastal High Hazard Area—part of the Special Flood Hazard Area that is subject to additional hazards associated with storm-induced waves

3.2.5.2 Nature of the Hazard in Alabama

Alabama has a warm and humid climate characterized by often turbulent weather patterns and year-round precipitation. As shown in 5.1.1.1.1.1.1Table 3.19Figure 3.18, Alabama receives more rainfall than much of the US, particularly along the Gulf Coast of the state. These features of the state's climate, together with its location on the Gulf of Mexico, result in frequent riverine and coastal flooding events.

Figure 3.18 Average Annual Precipitation (USGS, 2000)



According to the NWS Storm Events Database, Alabama has experienced more than 1,000 significant or loss-producing flood events since 1996, or about 46 flood events per year. While flood events occur year-round, most take place in the months of April through July.

5.1.1.1.1.1.1Table 3.20 shows the number of reported flood events by county, with the counties listed from most reported flood events to least. As expected, the coastal counties experience particularly frequent flood events, including coastal flooding and storm surges

Table 3.20 Reported Flood Events by County, 1996-2017 (NWS, 2017)

County	Flash Flood	Flood	Coastal Flood or Storm Surge	All Flood Events
Madison County	148	25	0	173
Mobile County	115	11	19	145
Lauderdale County	112	18	0	130
Jefferson County	105	12	0	117
Baldwin County	82	12	8	102
Morgan County	74	10	0	84
Colbert County	69	4	0	73
Limestone County	59	10	0	69
Cullman County	56	7	0	63
Marshall County	45	18	0	63
Lamar County	57	5	0	62
Dekalb County	41	16	0	57
Shelby County	46	6	0	52
Tuscaloosa County	43	8	0	51
Lawrence County	43	7	0	50
Houston County	35	10	0	45
Elmore County	36	4	0	40
Montgomery County	33	7	0	40
Geneva County	26	12	0	38
Blount County	33	4	0	37
Escambia County	31	3	0	34
Talladega County	27	7	0	34
Choctaw County	33	0	0	33
Jackson County	31	1	0	32
Dale County	24	7	0	31
Walker County	28	2	0	30
Etowah County	23	6	0	29
Autauga County	24	4	0	28
Clarke County	25	2	0	27

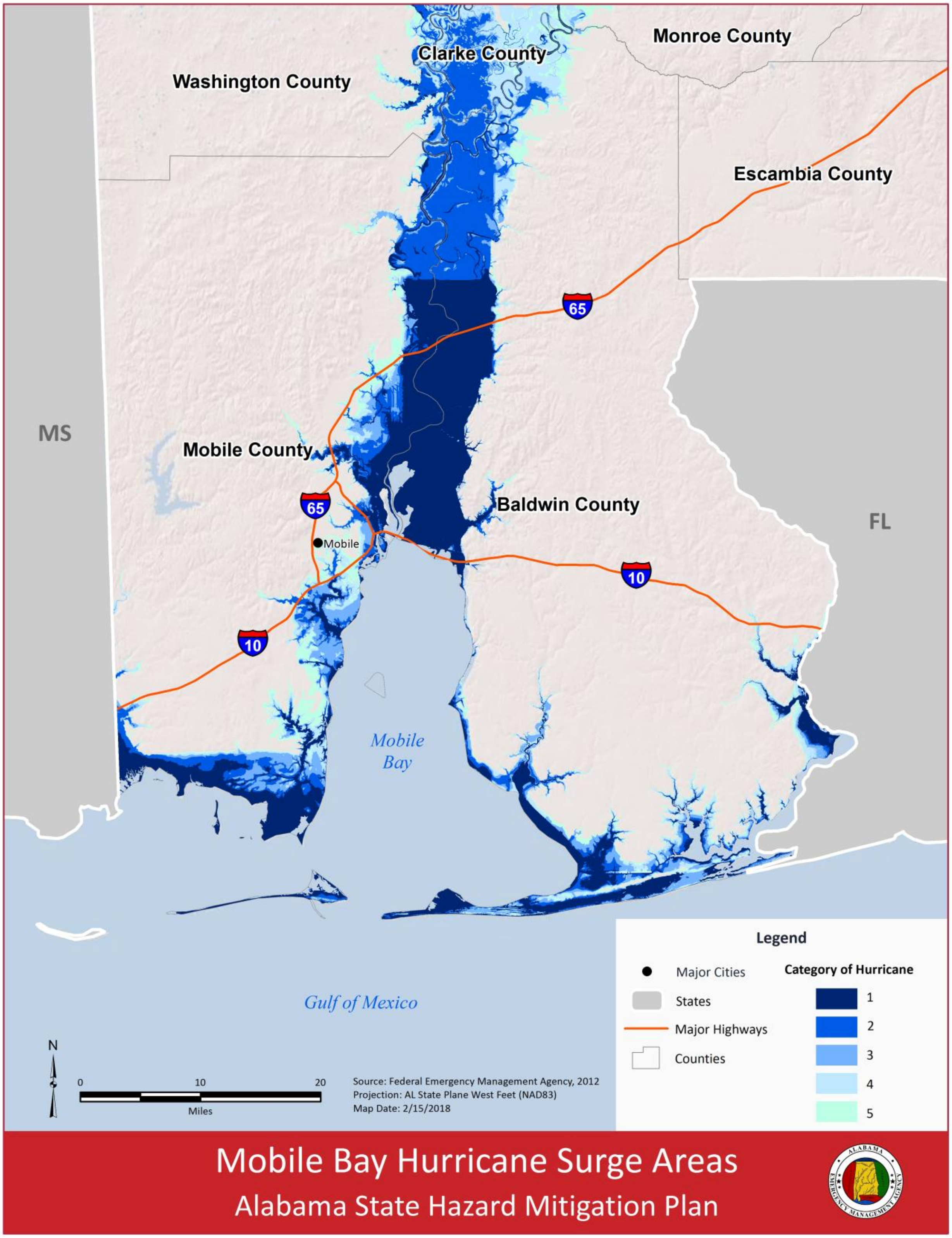
County	Flash Flood	Flood	Coastal Flood or Storm Surge	All Flood Events
Coffee County	20	7	0	27
Calhoun County	24	2	0	26
Franklin County	24	2	0	26
St. Clair County	24	2	0	26
Marion County	25	0	0	25
Randolph County	20	4	0	24
Sumter County	15	7	0	22
Pickens County	14	6	0	20
Washington County	20	0	0	20
Cherokee County	16	3	0	19
Clay County	18	1	0	19
Monroe County	17	2	0	19
Chambers County	15	3	0	18
Hale County	12	6	0	18
Lee County	16	2	0	18
Bibb County	14	3	0	17
Crenshaw County	15	2	0	17
Tallapoosa County	14	3	0	17
Covington County	15	1	0	16
Lowndes County	14	2	0	16
Winston County	16	0	0	16
Russell County	13	1	0	14
Butler County	12	1	0	13
Dallas County	12	1	0	13
Marengo County	7	6	0	13
Pike County	13	0	0	13
Conecuh County	12	0	0	12
Fayette County	11	0	0	11
Greene County	7	4	0	11
Chilton County	10	0	0	10
Macon County	9	1	0	10
Cleburne County	9	0	0	9
Henry County	6	3	0	9
Bullock County	8	0	0	8

County	Flash Flood	Flood	Coastal Flood or Storm Surge	All Flood Events
Perry County	7	1	0	8
Wilcox County	8	0	0	8
Barbour County	7	0	0	7
Coosa County	3	0	0	3

As discussed above, the extent of storm surge flooding is highly dependent on the size, strength, intensity, and speed of the storm that is driving storm surge and wave action. 5.1.1.1.1.1.1Table 3.20Figure 3.19 shows the sensitivity of storm surge flooding in Baldwin and Mobile counties to hurricane intensity (as categorized by the Saffir-Simpson hurricane wind scale). Since many factors influence storm surge heights, this figure shows the worst-case outcome at each location based on a series of storm surge scenarios. To emphasizes areas with the highest degree of exposure, the storm surge zones corresponding to the lowest hurricane intensity (Category 1 hurricanes) are displayed in the darkest color.[53] The data shown in 5.1.1.1.1.1.1Table 3.20Figure 3.19 were derived from storm surge inundation maps created by the National Hurricane Center (NHC) Storm Surge Unit with the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model. Emergency managers often use the SLOSH model in hurricane evacuation studies.

[53] Federal Emergency Management Agency, 2012. Summary of the Coastal Flood Loss Atlas. Retrieved at: https://data.femadata.com/MOTF/CFLA/CFLA_Summary_FINAL.pdf

Figure 3.19 Storm Surge Scenarios for Saffir-Simpson Hurricane Categories 1 through 5 (FEMA)



3.2.5.3 Flood History in Alabama

Alabama experiences flooding and flood impacts almost every year. To demonstrate the potential impacts of flooding in Alabama, 5.1.1.1.1.1.1Table 3.21 summarizes the six flood events recorded by the Storm Events Database that were reported to generate the highest losses. Each of these flood events generated losses in excess of $8 million (adjusted to 2017 dollars).

Table 3.21 Alabama Flood History, 1996-2017 (NWS, 2017)

Date	Estimated Damage (2017 dollars)	Counties Declared Disaster Areas	Description
March 8, 1998	$519 million	Barbour, Butler, Coffee, Conecuh, Covington, Crenshaw, Dale, Escambia, Geneva, Henry, Houston, Randolph	An intense Gulf storm deposited up to 14 inches of rain across southeast Alabama on March 6-8. Subsequent flooding damaged hundreds of homes, disrupted the water supply for 300 residents, and washed out many county and state roads. A portion of the levee in Elba failed, causing 2,000 people to evacuate. Communities suffering the worst damage were Malvern, Slocomb, Geneva, and Samson.
September 28, 1998	$28.5 million	NA	Torrential rains of 8 to 24 inches produced flash flooding in Geneva County. Numerous roads were damaged or washed out. Significant losses were incurred to peanut and cotton crops.
September 22, 2002	$8.45 million	NA	Very heavy rain fell across central Alabama during the early morning hours. The heaviest rain was measured generally from Tuscaloosa to Birmingham to Wedowee. Radar-estimated rainfall amounts averaged from 3 to 5 inches with many localized areas over 7 inches in only a few hours. The hardest hit area was the Birmingham Metropolitan area where the damage stretched from Bessemer to Pelham to Mountain Brook to Vestavia Hills. The flooding damaged more than 120 homes and 20 businesses and washed out several bridge and culverts. Many roads were temporarily closed and impassable, and over 200 automobiles suffered significant damage in Vestavia Hills.

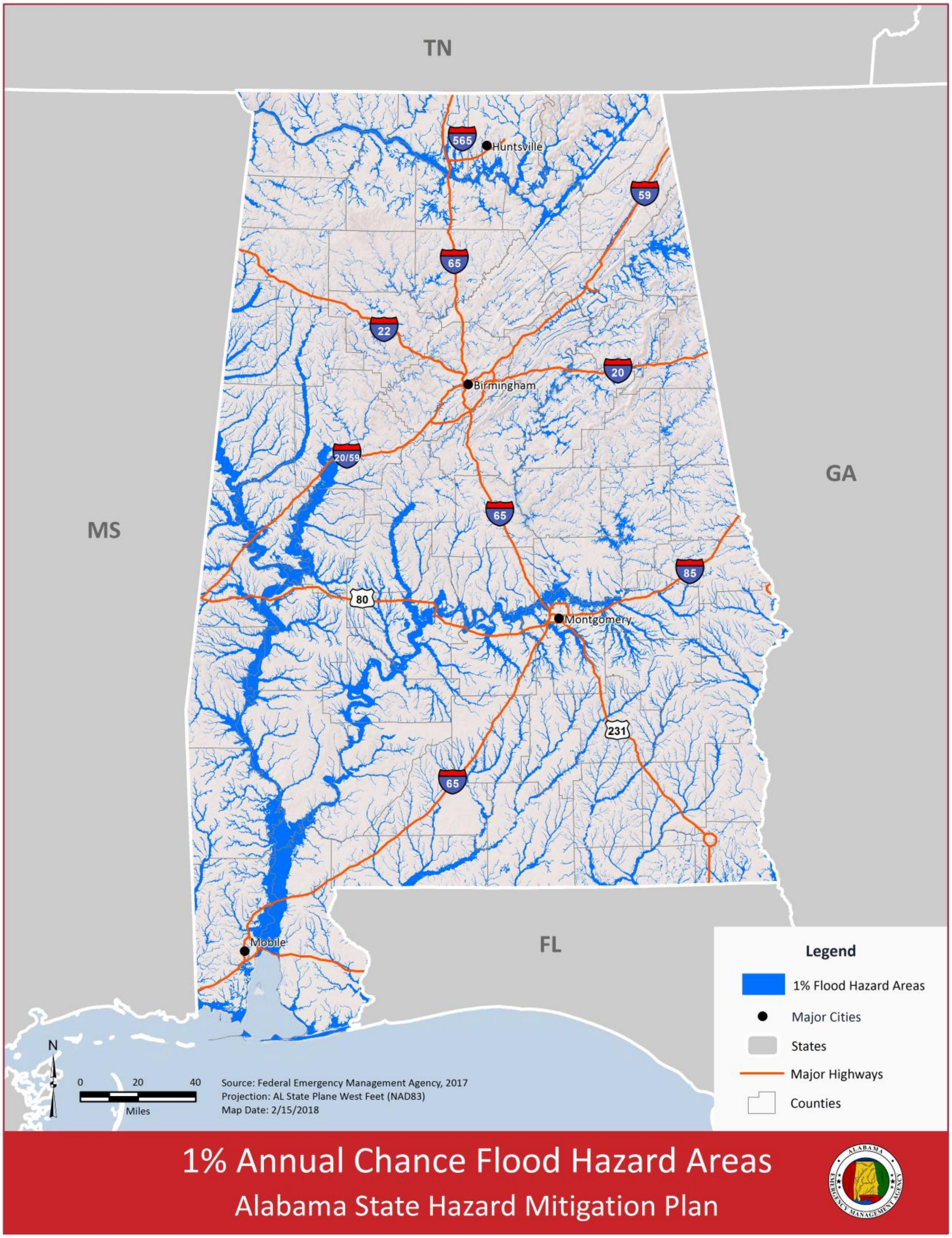
Date	Estimated Damage (2017 dollars)	Counties Declared Disaster Areas	Description
May 7, 2003	$1.33 billion	38 counties across the state	Heavy rains fell across the state. In Jefferson County, up to 12 inches of rain fell in a few hours, with 5 to 8 inches of the total occurring in just one hour. Especially hard hit were Leeds, Brookside, Cardiff, Fultondale, Trussville, and Birmingham. Numerous homes across the county were flooded. At least 120 roadways were impassable. Several sewage treatment plants were flooded, and minor contamination occurred. Several roadways had pavement removed and then washed away. Several bridges were damaged. Seventy-four mobile homes were damaged in the Irondale Trailer Park. Trussville reported that many municipal buildings, police cars, fire trucks, utility trucks, and businesses were damaged. Brookside reported that the city hall and fire department were heavily damaged from the flood waters. In Graysville, 10 people were rescued from their flooded vehicles and 20 homes were evacuated. In Fultondale, almost one million dollars of damage occurred to city services. At least 25 homes and businesses were damaged in Fultondale. In Morris, one manufacturing plant was flooded.
May 7, 2009	$8.47 million	Autauga, Bullock, Elmore, Montgomery	A slow-moving area of thunderstorms brought considerable flash flooding to several counties in central and southeast Alabama. A relatively narrow but rather long swath of rainfall of 3 to more than 7 inches stretched from northeastern Autauga County, across the city of Montgomery, and into southern Russell and northern Barbour Counties. Peak rainfall amounts approached 10 inches. Numerous county roads and city streets became impassable and suffered extensive damage due to flooding caused by torrential rainfall. The cities of Wetumpka, Millbrook, and Deatsville were especially hard hit. At least 43 homes, 10 business, and 2 churches also suffered damage due to the flooding.

Date	Estimated Damage (2017 dollars)	Counties Declared Disaster Areas	Description
April 29, 2014	$34.5 million	NA	A strong storm system brought record flooding along with severe thunderstorms that produced damaging winds and tornadoes to the region. Extremely heavy rain in a short period of time resulted in significant flash flooding issues across West Mobile, Midtown Mobile, and Downtown Mobile. The southern half of Baldwin county experienced historic flooding. 1400 homes and businesses experienced flooding and private property losses are estimated at $17 million with another $10 million estimated for infrastructure damage. Almost every road south of Highway 104 experienced flooding. Numerous roads were flooded between Highway 104 and just north of Interstate 10. Emergency management officials reported having to rescue dozens of people from homes and vehicles due the rapid rise of the water.

3.2.5.4 Probability of Floods in Alabama

The regulatory flood hazard maps developed by the Federal Emergency Management Agency (FEMA) represent the best available guides to the probability of flooding in Alabama. 5.1.1.1.1.1.1Table 3.21Figure 3.20 shows the extent of the 1-percent-annual-chance floodplain in Alabama. In any given year, the shaded locations have at least a 1-percent chance of experiencing inundation from riverine or coastal flooding. Over time, however, the chance of flooding in a given location increases. For example, a location with a 1-percent chance of flooding over one year has a 26-percent chance of flooding over 30 years, the typical term of a home mortgage.

Figure 3.20 Areas with a 1% or Greater Annual Chance of Flooding (FEMA)



3.2.5.4.1 Future Probability

The future probability of riverine flooding in Alabama is likely to change with changes in weather patterns and land cover. Both historical trends and future projections suggest that the frequency of heavy rains in the southeast will rise through the twenty-first century. According to the Southeast Regional Report for the National Climate Assessment, the entire southeast has seen increases in the frequency of extreme precipitation events since 1900, with particularly pronounced increases in the lower Mississippi River Valley and along the northern Gulf Coast.[54] Model simulations of future precipitation also show significant increases in the frequency of extreme rainfall in the southeast, as well as increases in annual rainfall. The increase in extreme precipitation is expected to be particularly pronounced along the southern Appalachians and in parts of Tennessee and Kentucky. As these changes in weather patterns intersect with changes in land cover related to development, Alabama can expect its risk of riverine flooding to rise.

The future probability of coastal flooding in Alabama will reflect changes in the probability of tropical cyclones and hurricanes, as well as changes in sea level with climate change. According to the National Climate Assessment, hurricane hazards are generally expected to increase through the twenty-first century. The measures of hurricane activity include intensity, frequency, and duration. Since high-quality satellite data first became available in the early 1980s, scientists have observed a substantial increase in all of these measures of hurricane activity for North Atlantic hurricanes, as well as an increase in the frequency of the strongest (Category 4 and 5) hurricanes.[55] Although simulations of future hurricane activity span a range of possible outcomes, on average the models project an increase in the annual number of Category 4 and 5 hurricanes by the late twenty-first century, as well as a slight decrease in the number of tropical cyclones.[56] Changes in the storm tracks of North Atlantic hurricanes are less well understood.[57]

Sea level rise is another factor that will have profound impacts on the future probability of coastal flooding. Coastal areas are seeing higher and higher sea levels as global changes interact with local factors. Across the globe, sea levels have remained relatively stable over the past few thousand years, climbing less than a few tenths of a millimeter per year.[58] Since the mid- to late-nineteenth century, however, sea level rise has accelerated dramatically. Sea levels rose by an average of 1.7 to 1.8 mm/year over the twentieth century, but rose by an average of 2.8 mm/year

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[54] Ingram, K., K. Down, L. Carter, J. Anderson, eds., 2013. Climate of the Southeast US: Variability, change, impacts, and vulnerability. Washington DC: Island Press.

[55] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the US: The Third National Climate Assessment. US Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.

[56] *Ibid.*

[57] Woolings, T., Gregory, J. M., Pinto, J. G., Reyers, M., and Brayshaw, D. J. (2012). Response of the North Atlantic storm track to climate change shaped by ocean–atmosphere coupling. Nature Geoscience volume 5, pages 313–317.

[58] National Aeronautics and Space Administration, Goddard Institute for Space Studies, 2007. Science Briefs: Sea Level Rise, After the Ice Melted and Today. Retrieved at: https://www.giss.nasa.gov/research/briefs/gornitz_09/

between 1993 and 2017. At the global scale, climate change is driving the rising seas. Warming oceans are causing ocean waters to expand, and the melting of land-based ice (glaciers and ice sheets) is causing ocean volumes to rise. At the local scale, a range of local factors can hasten or slow the rate of sea level rise seen by communities. These factors are described in greater depth in Section 3.2.10, and include land subsidence, changes in regional ocean currents, and tectonic movements. These global and local processes are certain to continue, driving sea level rise throughout the world. While future sea level rise is a certainty, however, the rate at which it will unfold is unknown. The best guide to future planning is therefore the range of local sea level rise scenarios developed by expert working groups. In the US, a federal task force convened by the US Global Change Research Program and the National Ocean Council has produced a comprehensive set of sea level rise scenarios for coastal communities across the country.[59] The scenarios developed for coastal Alabama are discussed further in Section 3.2.10.

Regardless of the timing, sea level rise along the Alabama coast will lead to more frequent floods that cause more damage. As discussed above, coastal flooding comes in many forms - from the shallow coastal flooding associated with extreme tides that mostly causes inconvenience, to the storm surges driven by hurricanes that can wreak havoc on coastal communities. Sea level rise will mean more frequent and damaging events for all forms of coastal flooding, from nuisance high tides to life-threatening storm surges.

Even on sunny days or during small storms, rising sea levels mean that extreme high tides can cause nuisance flooding more frequently and over a greater area. Nuisance flooding can be disruptive and expensive to the local economy, particularly in tourism-dependent areas such as the coastal areas of Mobile and Baldwin counties. Across the US, NOAA estimates that nuisance flooding is now occurring three to nine times more frequently than it did 50 years ago.[60]

Rising sea levels will also mean that deadly and destructive storm surges will push farther inland than they once did. This will place more people, property, and valuable infrastructure at risk, including essential facilities such as wastewater treatment plants. As storm surges push further inland, they can also accelerate the erosion of beaches, dunes, and coastal wetlands. These features serve as natural flood defenses by reducing the height and energy of large waves. The erosion of these natural defenses leaves coastal communities even more vulnerable to the next storm surge event.

3.2.5.4.2 Risk and Vulnerability

A detailed assessment of vulnerability to flooding in Alabama is provided in Section 5.3.

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[59] Sweet, W. V., Kopp, R. E., Weaver, C. P., Obeysekera, J., Horton, R. M., Thieler, E. R., & Zervas, C. (2017). Global and regional sea level rise scenarios for the US. NOAA Technical Report NOS CO-OPS 083. NOAA/NOS Center for Operational Oceanographic Products and Services.
[60] National Oceanic and Atmospheric Administration, National Ocean Service, 2018. What is high tide flooding? Retrieved at: https://oceanservice.noaa.gov/facts/nuisance-flooding.html

3.2.6 Hail

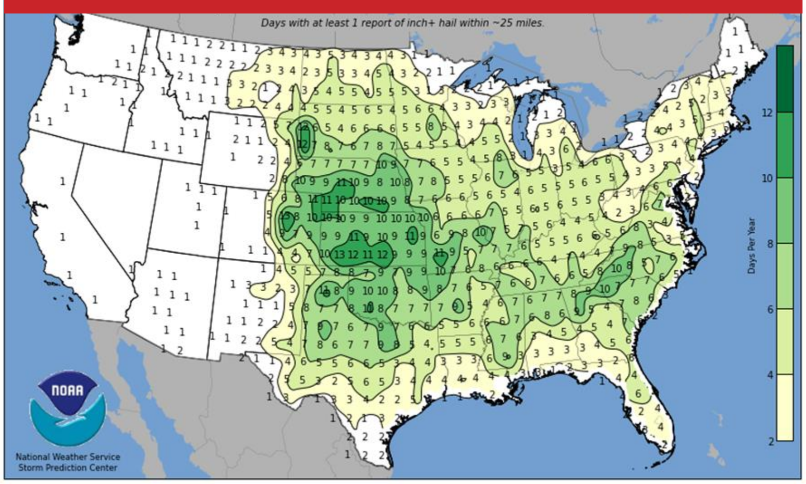
3.2.6.1 Description

Hail is defined by the NWS as "frozen precipitation in the form of balls or irregular lumps of ice."[61] This type of precipitation is produced by severe thunderstorms characterized by very cold upper level air and strong updrafts. The cold upper level air causes water droplets to freeze, and the strong updrafts keep the frozen droplets suspended while layers of ice are added. When the lumps of ice become too large to be suspended by updrafts, they fall to the ground as hail.

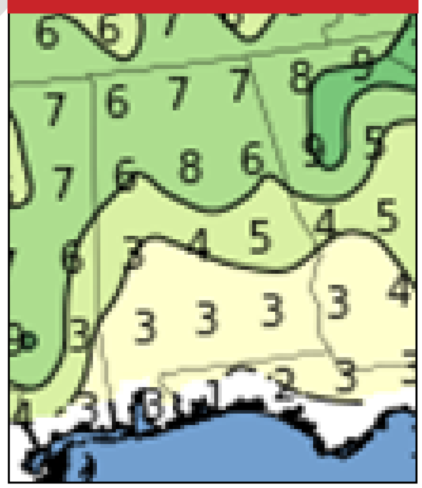
Hailstorms occur most frequently in the late spring and early summer when the jet stream moves northward across the Great Plains. This creates steep temperature gradients from the surface to upper air masses, producing the strong updrafts required for hail formation. While thunderstorms are most common along the Gulf Coast, thunderstorms that produce hail are more common in the Great Plains, where the temperature contrasts associated with the jet stream are greatest. 5.1.1.1.1.1.1Table 3.21Figure 3.21 shows the average number of severe hailstorms reported across the US each year, where severe hailstorms are defined as those producing hail with diameters of one inch or greater.

Figure 3.21 Severe Hail Days per Year, 2003-2012 (NOAA, 2012)

NOAA Reference Map



Alabama Detail



The size of hailstones is related to the intensity of the thunderstorms that produce them, and to the temperature at the surface. The higher the temperature at the Earth's surface, the greater the

[61] National Oceanic and Atmospheric Administration, National Weather Service, 2015. Storm Data Preparation. National Weather Service Instruction 10-1605. Retrieved at: http://www.nws.noaa.gov/directives/sym/pd01016005curr.pdf

strength of the updrafts within a thunderstorm, and the larger the hailstones that form. Most hailstones are less than two inches in diameter, but hailstones as large as softballs (4.5 inches in diameter) are sometimes observed.

In the US, hailstorms cause about $1 billion in economic loss each year.[62] Much of this loss is related to crop damage. Young plants (particularly those with long stems) are highly vulnerable to hail impact and associated winds, and peak hail activity coincides with peak agricultural seasons.[63] Damage to the roofs and windows of cars and buildings is another source of loss. The TORRO Hailstorm Intensity Scale (5.1.1.1.1.1.1Table 3.22) relates the size of hailstones to the probable crop and property damage. The damage caused by hail is often compounded by the other hazards that tend to accompany hailstorms, including tornadoes and thunderstorms. Large hail is often observed just north of a tornado track.

Table 3.22 TORRO Hail Intensity Scale

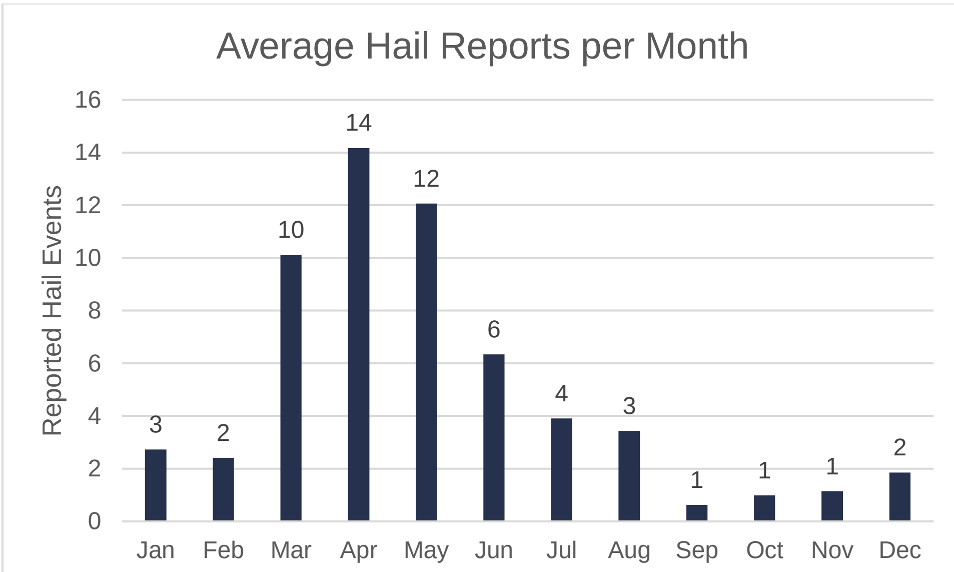
Intensity	Typical Hail Diameter (mm)	Intensity Category	Probable Damage
H0	5	Hard Hail	No damage
H1	5-15	Potentially Damaging	Slight general damage to plants, crops
H2	10-20	Significant	Significant damage to fruit, crops, vegetation
H3	20-30	Severe	Severe damage to fruit and crops, damage to glass and plastic structures, paint and wood scored
H4	25-40	Severe	Widespread glass damage, vehicle bodywork damage
H5	30-50	Destructive	Wholesale destruction of glass, damage to tiled roofs, significant risk of injuries
H6	40-60	Destructive	Bodywork of grounded aircraft dented, brick walls pitted
H7	50-75	Destructive	Severe roof damage, risk of serious injuries
H8	60-90	Destructive	Severe damage to aircraft bodywork
H9	75-100	Super Hailstorms	Extensive structural damage; risk of severe or even fatal injuries to persons caught in the open
H10	Greater than 100	Super Hailstorms	Extensive structural damage; risk of severe or even fatal injuries to persons caught in the open

[62] Federal Emergency Management Agency, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library-data/20130726-1545-20490-4487/mhira_in.pdf
[63] Ibid.

3.2.6.2 Nature of the Hazard in Alabama

Hailstorms in Alabama are not as common as hailstorms in the Great Plains, but severe hailstorms are reported every year. More hailstorms are reported in the northern part of the state, where severe thunderstorms are more common (5.1.1.1.1.1.1Table 3.21Figure 3.21). The frequency of hailstorms in Alabama is greatest in the spring, with the most episodes of severe hail generally reported in April (Figure 3.22).

Figure 3.22 Severe Hail Reports in Alabama Averaged by Month, 1955-2017 (NOAA, 2017)



3.2.6.3 Hail History in Alabama

Hailstorms in Alabama are moderately loss-producing atmospheric hazards. According to NOAA's Storm Events Database, hailstorms in Alabama caused more than $31.2 million in direct economic losses (adjusted to 2017 dollars) between 1955 and 2017. About $29.5 million of the reported losses were from property damage, and $1.7 million were from crop damage.

Since the Storm Events Database began collecting data on hail storms in 1955, local field offices have reported 3,765 hail episodes, or about 60 episodes per year. Five of the reported hail episodes produced property damage exceeding $1 million (adjusted to 2017 dollars), and two produced crop damages exceeding $75 thousand (adjusted to 2017 dollars). 5.1.1.1.1.1.1Table 3.23 summarizes these historical storms and their reported impacts.

Table 3.23 Historical Hail Storms in Alabama with Significant Economic Damage (1955 – 2017)

Date	Location	Estimated Property Damage (2017 dollars)	Estimated Crop Damage (2017 dollars)	Description
June 9, 1994	Lauderdale County	$0	$82,500	Hail severely damaged a cotton crop in the Bluewater Creek area about seven miles west of Rogersville. The hail was described as large and stripped cotton plants to the stem.
May 15, 1995	Cullman County	$1,046,500	$0	Hail up to softball-size was reported in the area from southern Cullman to Hanceville. Numerous cars sustained damage in the hail including one Chevrolet dealership where every car sustained hail damage.
May 6, 1998	Bibb County, Perry County	$75,000	$75,000	Four to five trailers in Bibb County had their windows knocked out by Hen Egg sized hail along SR 219. Twenty-three acres of timber was damaged due to the hail. The hail damage continued into Perry County along SR 219 where mostly tree damage occurred.
April 25, 2003	Central Alabama	$5,088,580	$0	Several steady-state, rotating thunderstorms, referred to as supercells, cut swaths of damage through twelve counties Alabama. Large hail caused widespread damage to automobiles and homes and was accompanied by damaging winds. Hail sizes ranged from penny to softball size.
May 2, 2003	Northwestern Alabama	$3,192,000	$0	Several severe thunderstorms moved through the northwestern part of the state and generally affected the counties from Jefferson to Cherokee. Dime to golf ball size hail fell in many locations, causing damage to homes and cars. Two automobile dealerships in Chatom sustained major damage to their automobile inventory.

Date	Location	Estimated Property Damage (2017 dollars)	Estimated Crop Damage (2017 dollars)	Description
March 26, 2011	Walker County, Winston County	$1,728,540	$0	Hailstones up to two inches wide caused extensive damage to vehicles and homes. In the city of Jasper, hundreds of cars in the city were damaged, with many car dealerships sustaining damage to every car on the lot. Hundreds of homes sustained roof damage. Hailstones also caused widespread damage to buildings and vehicles in the city of Hayleyville.
April 15, 2011	Choctaw County	$1,404,000	$0	Numerous supercell thunderstorms crossed southwestern Alabama, producing tornadoes and hail mostly in rural areas. Baseball size hail caused damage to the Georgia Pacific Paper Plant northeast of Pennington. Numerous automobiles around the facility suffered significant damage.
March 19, 2018	Northern Alabama	N/A	$0	A cluster of supercell thunderstorms moved through norther Alabama, producing tornadoes and damaging hail. Hail growth was boosted by strong updrafts with vertical wind speeds of up to 185 mph, and the hail ranged from baseball to grapefruit-sized. The hail caused extensive damage to vehicles and other property and formed small craters in the grassy areas where it landed.

3.2.6.4 Probability of Hail Storms in Alabama

Reported hailstorms have historically affected northern counties more frequently than southern counties (Figure 3.23). It is important to note, however, that the distribution of reported hail events reflects both where hail events occurred, and where people were located to observe and report these events. In other words, there is reporting bias in the Storm Events Database. This reporting bias probably contributes to the high frequency of observed hail events in Jefferson and Madison counties.

3.2.6.4.1 Future Probability

The probability of hail events is directly tied to the probability of severe thunderstorms. According to the Southeast Regional Report prepared for the Third US National Climate Assessment, the effect of climate change on the future probability of severe thunderstorms is unclear.[64] Although scientists have seen a significant increase in the number of severe thunderstorm reports since 1950, this increase appears to be related to better detection and reporting systems. Future projections generated by climate simulations are also unclear. One of the building blocks for severe thunderstorms is the atmospheric instability that results when warm, moist air near the Earth's surface rises and interacts with cooler and drier air higher in the atmosphere. While the frequency of unstable conditions is expected to increase throughout the twenty-first century, global climate models predict significant variability from one year to the next.

3.2.6.4.2 Risk and Vulnerability

A community's vulnerability to loss from hailstorms is a function of the probability of severe hailstorms, the exposure of property and crops to hailstorms, and the susceptibility of property and crops to hail impact. In Alabama, high hail frequency and high property exposure intersect in the northern metropolitan areas of Huntsville and Birmingham. Based on the record of past damages, cars exposed to the elements (such as those on dealership lots) tend to be particularly susceptible to hail damage. Car dealerships tend to be located in areas with higher population densities. Based on these factors, the counties in northern Alabama are most vulnerable to property damage from hail. Many of the state's northern counties are also among the leading agricultural counties in terms of acres of cropland. The counties of Lauderdale, Limestone, Madison, Jackson, DeKalb, Cherokee, Lawrence, Morgan, and Cullman all had more than 65,000 acres of cropland in 2007.[65] These counties are therefore more vulnerable to crop damage from hail.

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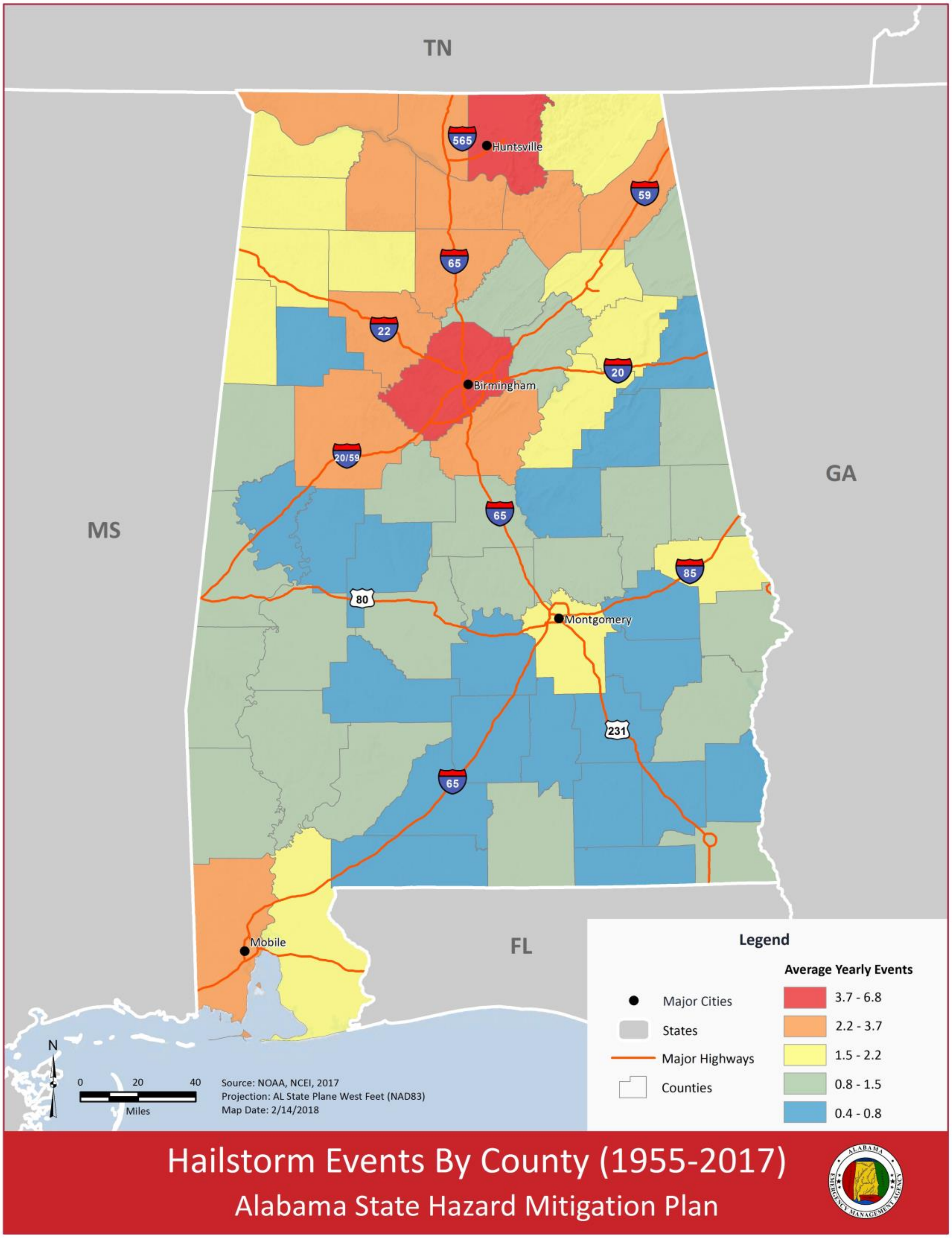
[64] Ingram, K., K. Dow, L. Carter, J. Anderson, eds. 2013. Climate of the Southeast US: Variability, change, impacts, and vulnerability. Washington DC: Island Press.
[65] The University of Alabama, Department of Geography. Alabama Maps. Retrieved at http://alabamamaps.ua.edu/contemporarymaps/alabama/agriculture/index.html

Figure 3.23 Annual Hail Reports by County, 1955-2017 (NOAA, 2012)



3.2.7 High Winds

3.2.7.1 Description

High winds are one of the most destructive natural hazards that affect the US. Each year, this hazard claims lives, causes injuries, and results in billions of dollars in property damage.[66] High winds are generally associated with three weather phenomena: tornadoes, thunderstorms, and tropical cyclones. Because these three phenomena often overlap (hurricanes, for example, can spawn tornadoes and generate severe thunderstorms), this section addresses the high winds associated with all these phenomena. Flooding and storm surge hazards related to hurricanes and severe storms are discussed in Section 3.2.5.

Tornadoes are nature's most violent storms and can strike with little or no warning. These storms can produce internal winds exceeding 300 mph and can lift and move very large objects (including entire buildings). Tornadoes are localized events, with path widths of less than 0.6 miles, and lengths ranging from less than a mile to tens of miles. Tornado speeds along their path length range from 30 to 125 mph, and their lifespans are generally less than 30 minutes.[67] Since tornadoes are related to large vortex formations, clusters of tornadoes often occur in thunderstorms and in the right forward quadrant of hurricanes.

The magnitude of a tornado is measured in terms of the maximum wind speed as estimated based on observed damage. The two most widely-used scales for tornado magnitude are the Fujita Tornado Scale (or F-scale, developed in 1971 by Theodore Fujita of the University of Chicago), and the Enhanced Fujita Tornado Scale (or EF-scale, implemented by the National Weather Service in 2007).[68] Both scales use observed damage to estimate wind speeds, but the EF-scale takes more variables into account than the F-scale, and generally estimates lower speeds. 5.1.1.1.1.1.1Table 3.24 shows the wind speeds (expressed as 3-second gust speeds) and expected damage corresponding to the ratings on the EF-scale. 5.1.1.1.1.1.1Table 3.24Figure 3.24 shows how the EF-scale in use today compares to the F-scale used before 2007. The historical databases maintained by the NWS continue to report the F-scale ratings for historic events.

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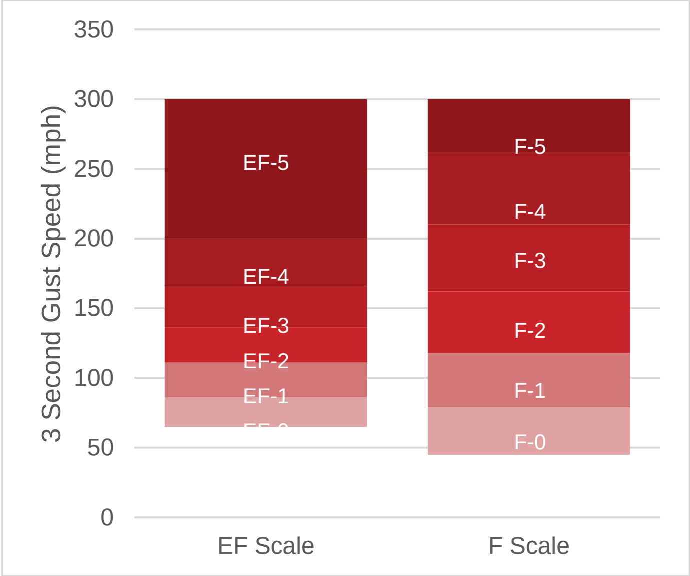
[66] National Windstorm Impact Reduction Program, 2015. Biennial Report to Congress for Fiscal Years 2013 and 2014. Retrieved at: https://www.nist.gov/sites/default/files/documents/el/nwirp/NWIRP-FY2013-2014-Biennial-Report-to-Congress-2.pdf
[67] Federal Emergency Management Agency, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library/assets/documents/7251
[68] National Oceanic and Atmospheric Administration, Storm Prediction Center, 2018. Enhanced F Scale for Tornado Damage. Retrieved at: http://www.spc.noaa.gov/faq/tornado/ef-scale.html

Table 3.24 Enhanced Fujita (EF) Scale for Tornado Magnitude (NWS, 2018)[69]

EF Rating	3 Second Gust Speed (mph)	Expected Damage
EF-0	65 - 85	'Minor' damage: shingles blown off or parts of a roof peeled off, damage to gutters/siding, branches broken off trees, shallow rooted trees toppled.
EF-1	86 - 110	'Moderate' damage: more significant roof damage, windows broken, exterior doors damaged or lost, mobile homes overturned or badly damaged.
EF-2	111 - 135	'Considerable' damage: roofs torn off well-constructed homes, homes shifted off their foundation, mobile homes destroyed, large trees snapped or uprooted, cars can be tossed.
EF-3	136 - 165	'Severe' damage: entire stories of well-constructed homes destroyed, significant damage done to large buildings, homes with weak foundations can be blown away, trees begin to lose their bark.
EF-4	166 - 200	'Extreme' damage: Well-constructed homes are leveled, cars are thrown significant distances, top story exterior walls of masonry buildings would likely collapse.
EF-5	Over 200	'Massive/incredible' damage: Well-constructed homes are swept away, steel-reinforced concrete structures are critically damaged, high-rise buildings sustain severe structural damage, trees are usually completely debarked, stripped of branches, and snapped.

69 National Oceanic and Atmospheric Administration, National Weather Service, 2018. Explanation of EF-Scale Ratings. Retrieved at: https://www.weather.gov/hun/efscale_explanation

Figure 3.24 Comparison of EF-Scale and F-Scale for Tornado Magnitude (NOAA, 2016)



Thunderstorms are local storms, usually of short duration, that are accompanied by lightning and thunder. The average thunderstorm in the US is about 15 miles in diameter and lasts less than 30 minutes in any one location.[70] Most thunderstorm winds that cause severe damage result from the spreading out of downbursts and microbursts. Downburst winds are strong straight-line winds that can reach speeds of 125 mph, while microburst winds are more concentrated winds affecting a smaller area that can reach speeds of 150 mph.[71] According to the National Weather Service (NWS), damage from severe thunderstorm winds accounts for half of all severe weather reports in the continental US and is more common than damage from tornadoes.[72]

A tropical cyclone is "a low-pressure area of closed circulation winds that originates over tropical waters."[73] The four building blocks for a tropical cyclone are: 1) a low-pressure disturbance, 2) warm sea surface temperature, 3) rotational force from the rotation of the earth, and 4) the absence of wind shear in the lowest 50,000 feet of the atmosphere. Tropical cyclones are often classified according to their wind speeds. Storms with wind speeds between 25 and 38 mph are known as tropical depressions, storms with wind speeds of 39 to 73 mph are known as tropical

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[70] Federal Emergency Management Agency, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library/assets/documents/7251
[71] Ibid.
[72] National Oceanic and Atmospheric Administration, The National Severe Storms Laboratory, 2018. Severe Weather 101. https://www.nssl.noaa.gov/education/svrwx101/wind/
[73] Federal Emergency Management Agency, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library/assets/documents/7251

storms, and storms with wind speeds of 74 mph or more are known as hurricanes. This section describes the high wind hazards associated with hurricanes.

Hurricanes are intense tropical cyclones with maximum sustained winds over water of 74 mph or higher. These storms are much larger than thunderstorms or tornadoes. The eye of a hurricane typically ranges from 10 to 30 nautical miles in diameter, and the surrounding storm may be 100 to 500 nautical miles in diameter.[74] These storms can cause extensive loss of life and property through several related hazards, including high winds, storm surge, flooding, coastal erosion, and lightning. This section, however, addresses only high wind. Flooding and storm surge hazards related to hurricanes and severe storms are discussed in Section 3.2.5.

In the US, the Atlantic coast is most prone to tropical cyclones, and the communities along the Gulf Coast are most prone to landfall by a hurricane.[75] The hurricanes that strike this region originate as tropical storms in the warm waters of the Gulf of Mexico, Caribbean Sea, or tropical Atlantic, then gain in intensify as they traverse the ocean. Atlantic hurricanes can occur from June through November, but hurricane activity is most intense in August and September. Since 1900, the US has experienced an average of 1.7 landfalling hurricanes per year.

The Saffir-Simpson scale is used to classify hurricanes according to their strength and expected damages. The scale uses information on central pressure, wind speed, storm surge height, and damage potential to assign each storm to one of five categories. It is important to note that the measure of wind speed used to classify hurricanes is different than the measure of wind speed used in the EF tornado scale and in engineering standards. While the Saffir-Simpson scale uses 1-minute sustained wind speeds over water, the EF tornado scale and engineering standards use the 3-second gust wind speed over land. 5.1.1.1.1.1.1Table 3.25 shows both the sustained wind speeds and level of damage corresponding to each Saffir-Simpson hurricane category, and the 3-second gust speeds that correspond to the sustained wind speeds.

Table 3.25 Saffir-Simpson Scale for Hurricane Magnitude (NWS, 2018)[76]

Saffir-Simpson Hurricane Category	Sustained Wind Speed over Water (mph)	3-Second Gust Wind Speed over Land (mph)	Damage Level
Category 1	74 - 95	82 - 108	Minimal
Category 2	96 - 110	109 - 130	Moderate
Category 3	111-130	131 - 156	Extensive

[74] Federal Emergency Management Agency, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library/assets/documents/7251
[75] Ibid.
[76] National Oceanic and Atmospheric Administration, National Weather Service, 2018. Explanation of EF-Scale Ratings. Retrieved at: https://www.weather.gov/hun/efscale_explanation

Saffir-Simpson Hurricane Category	Sustained Wind Speed over Water (mph)	3-Second Gust Wind Speed over Land (mph)	Damage Level
Category 4	131-155	157 - 191	Extreme
Category 5	>155	>191	Catastrophic

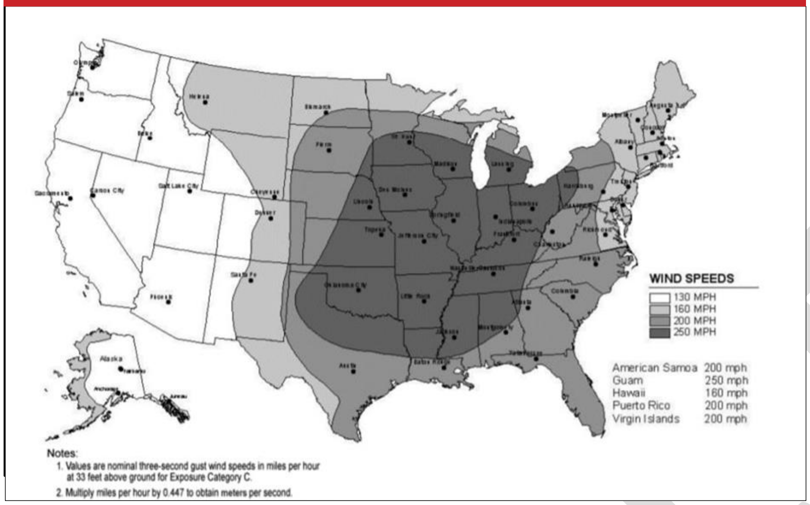
3.2.7.2 Nature of the Hazard in Alabama

High winds from thunderstorms, tornadoes, and hurricanes are the largest loss-producing natural hazard in Alabama. According to NOAA's Storm Events Database, high winds caused nearly 700 fatalities between 1950 and 2017 and more than $15 billion in direct economic losses (adjusted to 2017 dollars). The most damaging events were tornadoes, which accounted for 92% of the wind-related fatalities and 66% of direct economic losses. Thunderstorm winds were also deadly, accounting for 7% of wind-related fatalities. While hurricane winds were less deadly, they were costlier in terms of economic loss. Between 1950 and 2017, hurricanes accounted for more than $5 billion in direct damage to property and crops.

Tornado frequency and intensity varies across Alabama, but is generally associated with the frequency and intensity of thunderstorms. The non-coastal regions of Alabama have a disproportionately high frequency of intense thunderstorms, and thus a disproportionately high frequency of strong tornadoes. Although tornadoes are most common between March and August, they can occur at any time.

The best protection against tornadoes is provided by a safe room built to the FEMA recommended criteria in FEMA P-361 or the ICC Standard for the Design and Construction of Storm Shelters (ICC 500-2014). The ICC Standard provides criteria for the design, construction, and installation of shelters from high winds. For tornado safe rooms, the standard divides the US into four zones based on tornado threat and establishes a design wind speed for each zone (5.1.1.1.1.1.1Table 3.25Figure 3.25). The design wind speeds range from 250 mph for the zone determined to have the greatest tornado threat, to 130 mph for the zone determined to have the least tornado threat. The entire state of Alabama falls into the highest and second highest tornado wind speed zones. While the state's coastal region lies in the 200-mph design wind speed zone, the non-coastal region lies in the 250-mph design wind speed zone.

Figure 3.25 Tornado Safe Room Design Wind Speeds (ICC 500-214)

ICC 500-2014 Reference Map	Alabama Detail
	

Alabama's coastal region is subject to the highest risk from hurricane winds. Wind speeds tend to decrease significantly within 12 hours of landfall, as drier and cooler air begins to power the eyewall. Depending on a hurricane's strength and forward motion, however, hurricane force winds (winds greater than or equal to 74 mph) can extend well inland. NOAA scientists developed the Inland Wind Model to estimate the maximum sustained surface wind as a storm moves inland. Model results show that hurricane force winds can extend inland under a range of conditions (5.1.1.1.1.1.1.1Table 3.25Figure 3.26 and 5.1.1.1.1.1.1.1Table 3.25Figure 3.27). A Category 4 Hurricane with 24 knots of forward motion, for example, could produce hurricane force winds as far north as Birmingham.

Figure 3.26 Maximum Envelop of Winds for Category 2 Hurricane at 16 Knots (Inland Wind Model)

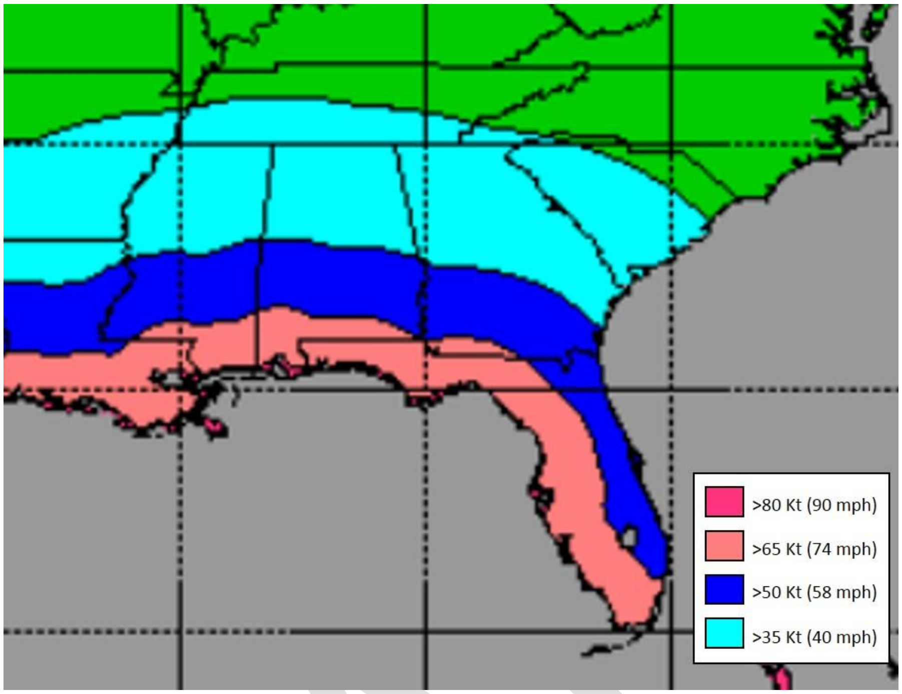
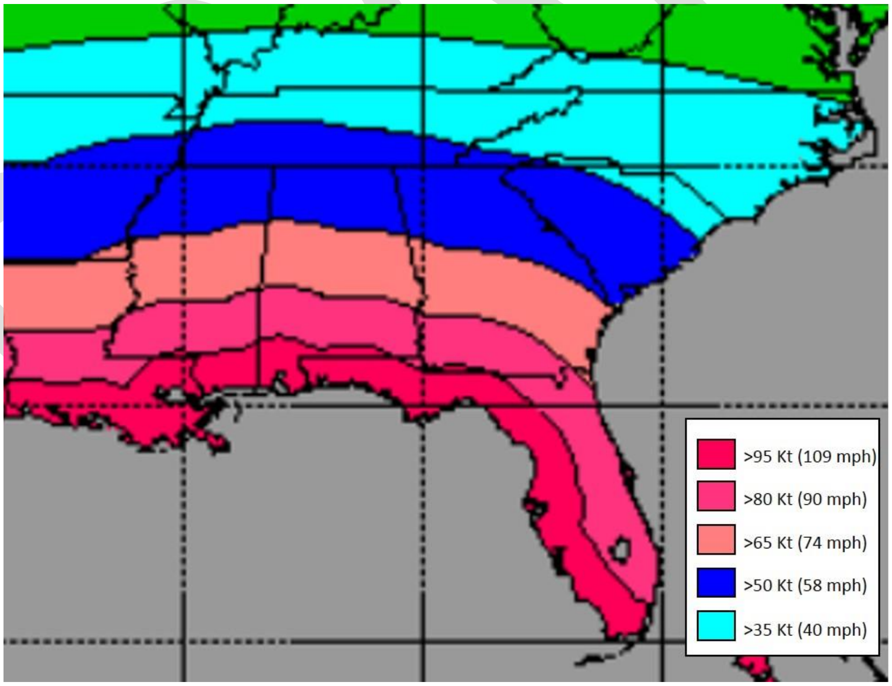


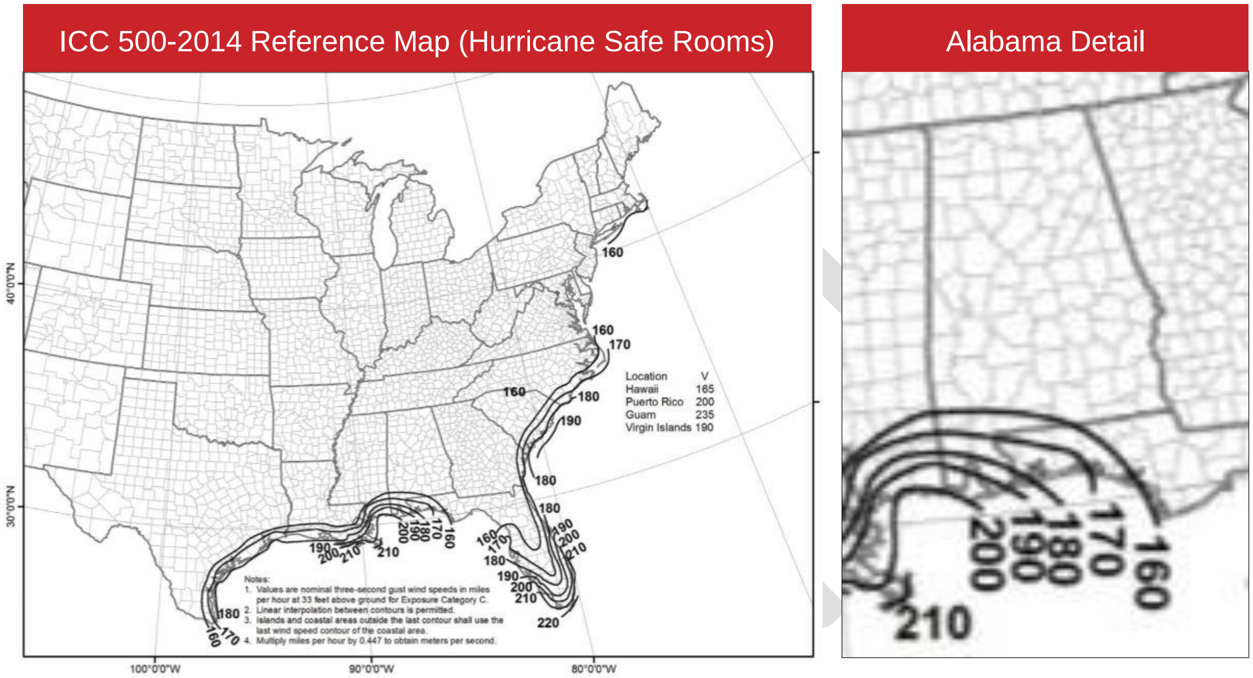
Figure 3.27 Maximum Envelop of Winds for Category 4 Hurricane at 24 Knots (Inland Wind Model)



As with tornadoes, the best protection from extreme hurricane winds is provided by a safe room built to the FEMA or ICC standards. For hurricane safe rooms, the design wind speed at a given

location is the wind speed with a 0.5% probability of exceedance in 50 years (5.1.1.1.1.1.1.1Table 3.25Figure 3.28). The design wind speeds range from 220 mph for the southern Florida coast, to 150 mph for interior regions. Most of Alabama falls into the lowest design wind speed zones for hurricane safe rooms, with only the coastal counties having higher design wind speeds.

Figure 3.28 Hurricane Safe Room Design Wind Speeds (ICC 500-214)

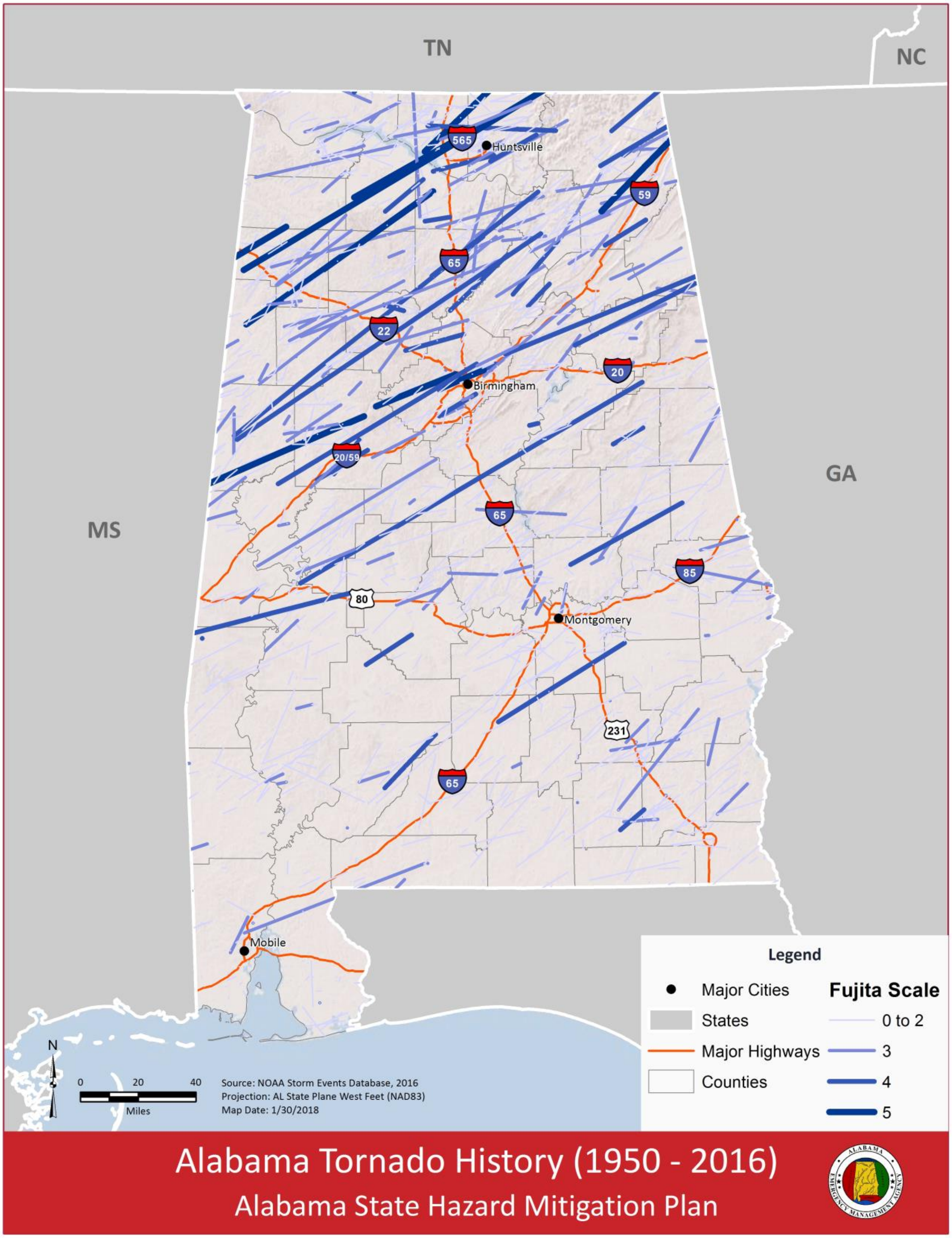


3.2.7.3 High Wind History in Alabama

3.2.7.3.1 Tornado Related High Wind History in Alabama

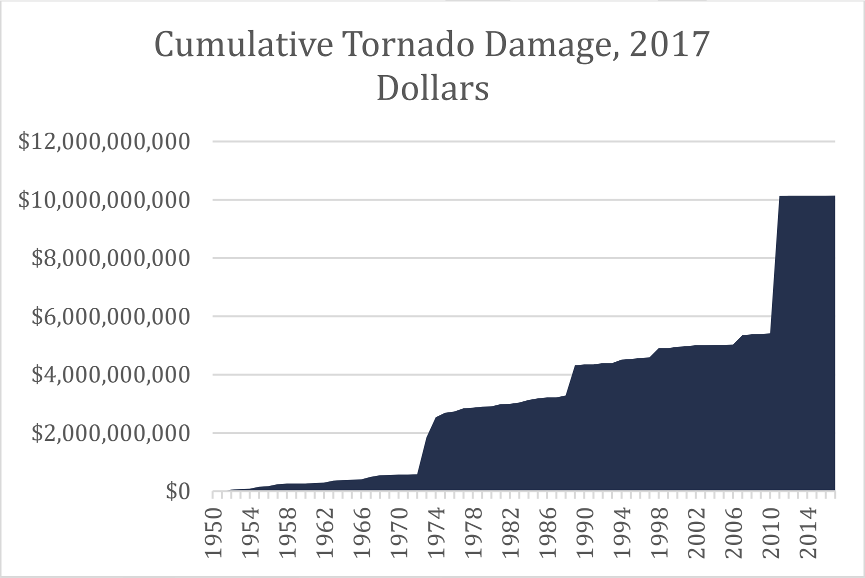
Between 1950 and 2017, the NWS Storm Events Database recorded 2,454 tornadoes in Alabama. Most of these were less damaging tornadoes measuring between F-0 and F-2 on the Fujita Scale and EF-0 to EF-2 on the Enhanced Fujita Scale, but 277 were more damaging tornadoes measuring greater than F-3 or EF-3 (5.1.1.1.1.1.1.1Table 3.25Figure 3.29). The months of March and April had the highest frequency of strong tornadoes (with 43 and 109 tornadoes measuring 3 or greater, respectively), followed by the months of November and December (with 38 and 18 tornadoes measuring 3 or greater, respectively). Note that these counts reflect the number of observed tornadoes, rather than the number of tornadoes that occurred throughout the state. Note also that counting tornadoes is complicated by the occurrence of clusters of tornadoes that strike at about the same time, and by tornadoes that cross political boundaries.

Figure 3.29 Tornado History in Alabama (NOAA, 2016)



NOAA's Storm Events Database has collected data on tornado events since 1950. Between 1950 and 2017, tornadoes in Alabama caused at least $10.1 billion dollars in direct property damage, 629 deaths, and 8,132 injuries (5.1.1.1.1.1.1Table 3.25Figure 3.30 and 5.1.1.1.1.1.1Table 3.25Figure 3.31). Fourteen of the most significant tornadoes to strike Alabama, as defined by the damage reported in the Storm Events Database, are described below. As discussed in the Introduction, property damage estimates from the Storm Events Database come with some limitations. The damage estimates are collected from diverse sources by staff with little or no training in damage estimation and are not compared with actual costs. In addition, the damage estimates only include direct physical damage to property, crops, and public infrastructure. Although damage estimates for individual events may be quite inaccurate, as estimates from many events are added together the errors become progressively smaller.[77]

Figure 3.30 Cumulative Property Damage (NOAA, 2017)



[77] Downton, M., Miller, Z., and Pielke, R., 2005. Reanalysis of US National Weather Service Flood Loss Database. Natural Hazards Review, Vol. 6, No. 1.

Figure 3.31 Cumulative Deaths and Injuries (NOAA, 2017)

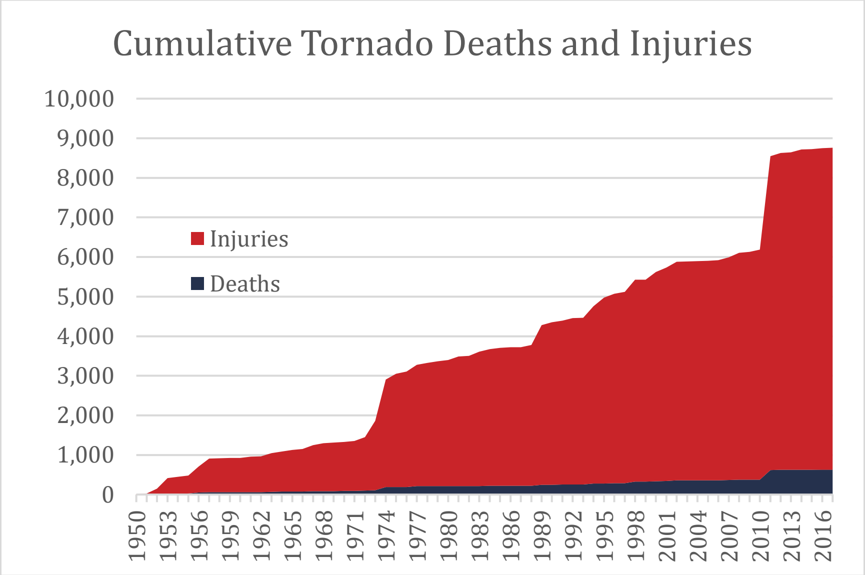


Table 3.26 Historical Tornado Events in Alabama (NWS, 2017)

Year	Location	Description
1932	Central and Northeastern Alabama	On March 21, 1932, seven tornadoes ripped through a dozen central and northeastern Alabama counties, leaving 268 people dead and 1,834 injured.
1974	Northwestern Alabama	A “Super Outbreak” occurred on April 3, 1974, between 3 and 9 p.m. At least seven tornadoes killed 86 people and injured 938. The following day, April 4, 1974, 20 counties were declared federal disaster areas.
1994	Northern Alabama	On March 30, 1994, the President declared seven counties in north Alabama major disaster areas resulting from tornadoes, flooding, and severe storms that struck the region on March 27, 1994. The storms moved across northeast Alabama to the Georgia state line, spawning tornadoes, flooding, and straight-line winds. These events were responsible for 22 deaths, over 150 injuries, and caused extensive property damage. The 50-mile long tornado path of the Cherokee County storm places it among the longest tornado tracks ever recorded in Alabama.
1995	Northern Alabama	Severe storms that began on February 15 and continued through February 20, 1995, produced high winds, rain, and tornadoes across north Alabama. The National Weather Service confirmed three tornadoes, one of which was an F3 event that passed through the northern part of the state. On April 21, 1995, President Clinton issued a major disaster declaration for the five Alabama counties of Cullman, DeKalb, Marion, Marshall, and Winston. In the community of Arab, five people died as a result of the storms. Across the five counties, more than 30 people were injured and close to 300 homes and farm buildings were damaged.
2007	Throughout Alabama, including Wilcox and Coffee counties	On March 1, 2007, 12 tornadoes touched down throughout the State of Alabama, two of which were rated EF-4. The first EF-4 tornado occurred in Wilcox County causing one death and significant damage to about 70 residential properties. The second developed near the Enterprise Municipal Airport in Coffee County, causing 8 deaths, 121 injuries, and damage to at least 370 houses.
2007	Southern Alabama	On April 14, 2007, an EF-1 tornado struck parts of Bullock, Conecuh, Crenshaw, Dale, and Monroe counties. The tornado damaged residences, churches, and a poultry farm and left trees uprooted along its path. Property damage from this event totaled $1.26 million ($1.46 million in 2017 dollars).

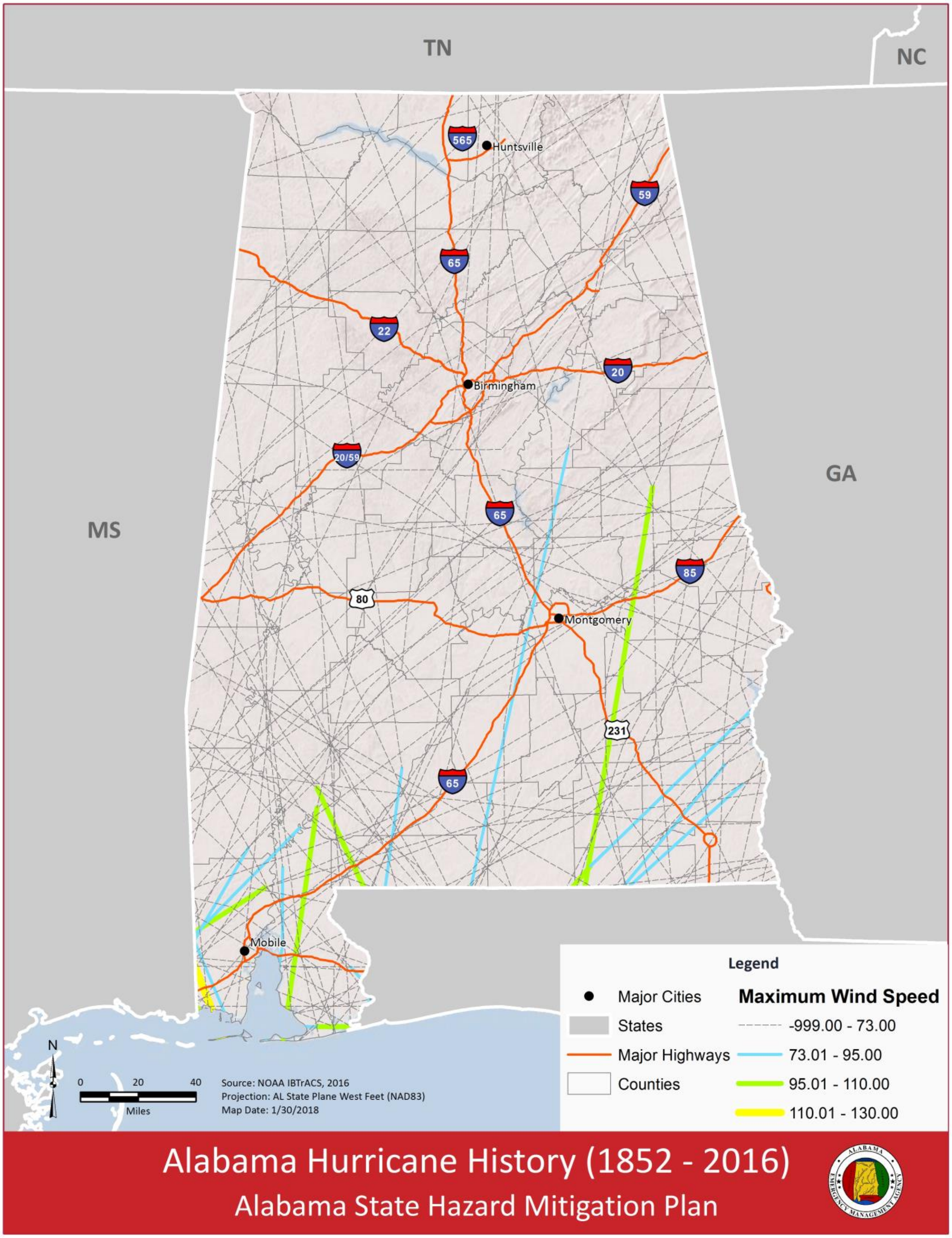
Year	Location	Description
2008	Northern Alabama	On February 6, 2008, the Weather Forecast Office (WFO) for the Huntsville County Warning Area experienced a tornado outbreak. While most of the tornadoes were minor EF-0 and EF-1 tornadoes, two EF-4 tornadoes were reported. The EF-4 tornadoes caused five fatalities and dozens of injuries in Walker, Lawrence, and Jackson counties. Property damage was estimated at $525,000 ($583,000 in 2012 dollars).
2008	Central Alabama	A long-lived supercell moved through Florida and into Alabama on February 17, 2008, producing a tornado outbreak along with hail and wind damage. The most significant tornado damage was associated with an EF-3 tornado in Autauga County, where an estimated 200 residences and 40 businesses were damaged or destroyed, and 50 people reported injuries. Property damages were estimated at $12.3 million ($13.9 million in 2017 dollars), with $10 million ($11.2 million in 2017 dollars) attributed to Autauga County alone.
2009	Northwestern Alabama	On April 19, 2009, supercells erupted across northwest Alabama. Initially, these storms were large hail producers, with up to baseball-sized hail reported in Franklin County. As the early evening progressed, this supercell tracked into Lawrence and Morgan counties producing wind damage and at least six tornadoes (the most severe measuring EF-2) as it moved east. The tornadoes caused two fatalities and produced property damage of $1.162 million ($1.27 million in 2017 dollars).
2010	Northeast Alabama	At least eight tornadoes hit northeast Alabama on the evening of April 24, 2010. Marshall County and DeKalb County were hardest hit. Some of the tracks were several miles long and reached EF-4 strength. No fatalities were reported but damage was severe including $15.8 million (2017 dollars) in property damage and over ninety-three homes destroyed in Marshall County alone.
2011	Central and Southwest Alabama	A strong line of thunderstorms produced several tornadoes in Central and Southwest Alabama on April 15, 2011. A total of forty tornadoes were recorded in the state, thirty of which touched down in Central Alabama. This set a (short-lived) record of tornadoes within the state from one event. Several injuries were reported as well as three fatalities in Washington County. These tornadoes largely spared populated areas, but damaged rural homes and timber holdings. According to the Alabama Forestry Commission, the tornadoes produced nearly $7.3 million (2017 dollars) in timber losses.

Year	Location	Description
2011	Throughout Alabama	The tornado events of April 27, 2011 impacted the most populous areas in the state and are the worst recorded in Alabama history. A total of 62 confirmed tornadoes were reported, with magnitudes ranging from EF-1 to EF-5. The tornadoes caused 248 fatalities and 2,219 injuries throughout the state. In all, thirty-five of Alabama's sixty-seven counties had damage, though the overall events (which also included straight-lines winds, severe storms, and flooding) led to disaster declarations in forty-three of the counties. AEMA estimates damage at $1.2 billion (2017 dollars), though the Storm Events Database estimates damage as high as 4.6 billion (2017 dollars). According to the Insurance Information Institute, almost $3 billion of the $3.2 billion that Alabama insurers paid out for catastrophe losses in 2011 can be traced directly to the tornadoes, hail, and thunderstorms associated with this super outbreak. The April 25-28th, 2011 super outbreak was the largest single-system tornado outbreak ever recorded and the second deadliest tornado outbreak in US history.
2014	Northern and Eastern Alabama	The deadly tornado outbreak of April 28-29, 2014 produced EF-3 tornadoes in four Alabama counties: Limestone, Cullman, Etowah, and Lee. These counties reported a total of 6 fatalities and 39 injuries. The outbreak was part of a larger storm system that generated 84 tornadoes over a period of 4 days, collectively causing 35 fatalities and over 300 injuries.
2016	Central Alabama	From November 29-30, 2016, a slow-moving weather system produced tornadoes, damaging winds, and some hail across Central Alabama. EF-3 tornadoes were reported in Morgan and Dekalb counties and were responsible for one death and nine injuries.
2018	Northern Alabama	On March 19, 2018, a powerful severe weather system produced a broken line of supercell thunderstorms and affected areas near and north of I-20. Fifteen tornado touchdowns were confirmed across the state, ranging in magnitude from EF-0 to EF-3. The most intense damage was located near and north of I-20, and near and east of I-65, but damage also occurred in the northwest sections of the state.

3.2.7.3.2 Hurricane Related High Wind History in Alabama

Between 1852 and 2016, NOAA recorded 120 tropical cyclone tracks in Alabama. Most of these tropical cyclones had maximum sustained wind speeds below 64 knots, but 18 struck the Alabama coast with hurricane force winds (5.1.1.1.1.1.1Table 3.26Figure 3.32). The hurricanes that struck Alabama included one Category 3 hurricane (Frederic in 1979, which crossed the western end of Dauphin Island as a Category 4 hurricane), and nine Category 2 hurricanes (including Eloise in 1975, Opal in 1995, Ivan in 2004, and Dennis in 2005).

Figure 3.32 Hurricane History in Alabama (NOAA, 2016)



NOAA's Storm Events Database has collected data on hurricane events since 1996. Before summarizing this data, it is important to understand the way the Storm Events Database defines different hazard categories. Hurricanes are complicated events that involve multiple hazards, including storm surge, flooding, high winds, and tornadoes. To prevent double-counting of damages, the National Weather Service instructs its field offices to separate damages caused by different hazards, and to assign only wind-related damages to the hurricane category. The National Weather Service also advises its field offices to choose the hazard category based on the strength of the storm at their location. As hurricanes move inland and weaken, wind-related damages may therefore be assigned to other hazard categories (such as Tropical Storm or Strong/High Wind). Between 1996 and 2017, hurricane winds caused more than $5 billion dollars in direct economic losses in Alabama and two deaths. According to the Storm Events Database, the two hurricane seasons in which hurricane winds caused the most direct damage were 2004 ($3.25 million) and 2005 ($1 million). Six of the most significant hurricanes to affect Alabama, as defined by the estimated damage, are described below:

Table 3.27 Historical Hurricane Events in Alabama (NWS, 2017)

Year	Estimated Damage (2017 dollars)	Description
1979	$7.7 billion	One of Alabama's costliest hurricanes was Hurricane Frederic, a Category 3 event that resulted in widespread damage in south and southwest Alabama. Frederic came ashore on September 12, 1979, and caused enormous damage to parts of Alabama, Florida, and Mississippi. With winds reaching 145 miles per hour, Hurricane Frederic moved over Dauphin Island (near the mouth of Mobile Bay) and inland just west of Mobile, Alabama. The damage estimate of Frederic was $2.3 billion ($7.7 billion in 2017 dollars). Based on information from emergency preparedness officials, 250,000 people were safely evacuated in advance of Frederic. Eleven counties were included in the federal disaster declaration: Baldwin, Choctaw, Clarke, Conecuh, Covington, Escambia, Geneva, Marengo, Mobile, Monroe, and Washington. The hurricane impact area comprised 20.5 percent of the total land area of the State of Alabama. AEMA reports that more than 250 deaths were caused by the storm.
1997	$92.6 million	Hurricane Danny came ashore through Mobile Bay beginning during the evening of July 18 and continuing through the morning of July 19, 1997. Danny had sustained winds of approximately 85 miles per hour. The most severe wind damage was concentrated in the Fort Morgan and West Beach areas of Gulf Shores and Dauphin Island. Most of the damage to residential and commercial buildings was roof and water damage and broken windows. Most of the businesses were able to reopen within a day or two after the storm with the exception of some condominiums and hotels. As a result of the storm, three counties were declared disaster areas and received federal assistance to help aid in repairs.

Year	Estimated Damage (2017 dollars)	Description
1998	$269 million	Hurricane Georges made landfall near Biloxi Mississippi on September 28, 1998, and then weakened to a tropical depression before drifting to the east. In coastal Alabama, heavy rainfall and strong waves caused extensive property damage. Further inland, high winds downed power lines and trees, leaving 177,000 people without power after the storm. 17 shelters housed 4,977 people in the aftermath of the storm. Damage to the buildings was minimal to non-existent, with the only direct effect from the hurricane being a brief interruption of electricity. The damage estimate for Hurricane Georges reflects damage caused by storm surge as well as high winds.
2004	$3.26 billion	Hurricane Ivan made landfall on September 16, 2004, near Gulf Shores in Baldwin County as a strong Category 3 hurricane. In Baldwin County, the coastal areas from Fort Morgan to Gulf Shores to Orange Beach saw the worst damage from a hurricane in over a hundred years. Fallen trees caused extensive structural damage and power outages over inland areas. Agriculture interests also suffered major losses with significant damages to the cotton, soybean, and pecan crops. In fact, the soybean and pecan crops were nearly destroyed. Seven deaths in Alabama were attributed to Hurricane Ivan in Alabama, with six due to high storm surge levels and one due to a fallen tree. The entire state was declared a federal disaster area. Property damage was estimated at more than $3.2 billion, and the crop damage at more than $32 million, in 2017 dollars.
2005	$1.25 billion	Hurricane Katrina made landfall along the Louisiana and Mississippi Gulf Coasts on August 29, 2005, as a strong Category 3 hurricane before moving inland along the Mississippi-Alabama border. Katrina's winds had impacts that were widespread across western and central Alabama. Thousands of trees and power lines were brought down, minor to major structural damage occurred, and power outages were lengthy and widespread. Several locations remained without power for over a week. Six tornadoes occurred across central Alabama in association with Katrina (four F-0s and two F-1s). Alabama Power reported that this was the worst event in their history for damage and power outages statewide. Twenty-two counties in the western half of the state were declared a federal disaster area.
2017	Not yet available	The unusually active 2017 hurricane season saw Hurricane Nate striking the northern Gulf Coast on October 7-8. Hurricane Nate made two landfalls as a Category 1 hurricane, first in southeast Louisiana and then near Biloxi, Mississippi. The storm then tracked inland, spawning several tornadoes and causing tree damage, structural damage, and power outages across Alabama.

3.2.7.4 Probability of High Winds in Alabama

The best available guide to the probability of high winds in Alabama is the design wind speed maps produced for the ASCE standard on *Minimum Design Loads for Buildings and Other Structures*. ASCE standards provide technical guidelines for promoting safety and reliability in civil engineering, and are updated or reaffirmed at least every five years. The standard on *Minimum Design Loads for Buildings and Other Structures* was last updated in coordination with the ASCE Structural Engineering Institute (SEI) in 2016 and is generally referred to as ASCE/SEI 7-16. Chapters 26 through 31 of ASCE/SEI 7-16 address the design of buildings and other structures to resists wind loads.

The ASCE/SEI 7-16 standard includes wind speed maps for three probabilities of occurrence: the 300-year event (15% probability of exceedance in 50 years), the 700-year event (7% probability of exceedance in 50 years) and the 1,700-year event (3% probability of exceedance in 50 years). These frequencies reflect the average design life of a building (50 years) and the different levels of risk tolerance for different types of buildings. The highest level of risk (300-year event) is appropriate for buildings whose failure poses a low hazard to human life (e.g., agricultural facilities and minor storage facilities), while the lowest level of risk (1,700-year event) is appropriate for essential facilities (e.g., fire stations, police stations, and emergency shelters). It is important to note that the design wind speed maps do incorporate hurricane hazard data, but do not incorporate tornado hazard data. These maps can therefore be used to assess the threat of high winds from hurricanes, tropical storms, or thunderstorms, but cannot be used to assess the threat from tornadoes.

5.1.1.1.1.1.1Table 3.27Figure 3.33 shows the ASCE/SEI 7-16 design wind speeds in Alabama with a recurrence interval of 700 years (7% probability of exceedance in 50 years). Wind speeds are estimated as 3-second gust wind speeds at a height of 33 feet (or 10 meters). The coastal counties have the highest probability of high winds from hurricanes, tropical storms, or thunderstorms.

Modeling and mapping the probability of tornado wind hazards is complicated by the lack of available data. The information available on tornadoes is limited by shorter periods of record, lower data archival requirements, and the inability to accurately measure tornado wind speeds. Furthermore, because the area of land directly affected by tornadoes is relatively small, tornado-related winds have a significantly lower probability of occurrence at any given point than the high winds associated with other meteorological events. A general understanding of the probability of tornado wind hazards, however, can be derived from the record of historic tornado events maintained by the NWS Storm Events Database. 5.1.1.1.1.1.1Table 3.27Figure 3.34 shows the number of tornado touchdowns per 100 square miles by county between 1950 and 2016. The counties with the highest density of touchdowns are Limestone and Cullman counties. Note that the density of observed tornadoes reflects both the spatial distribution of the hazard, and the spatial distribution of monitoring and reporting capabilities.

Figure 3.33 Alabama High Winds with a Recurrence Interval of 700 Years (ASCE/SEI 7-16, 2016)

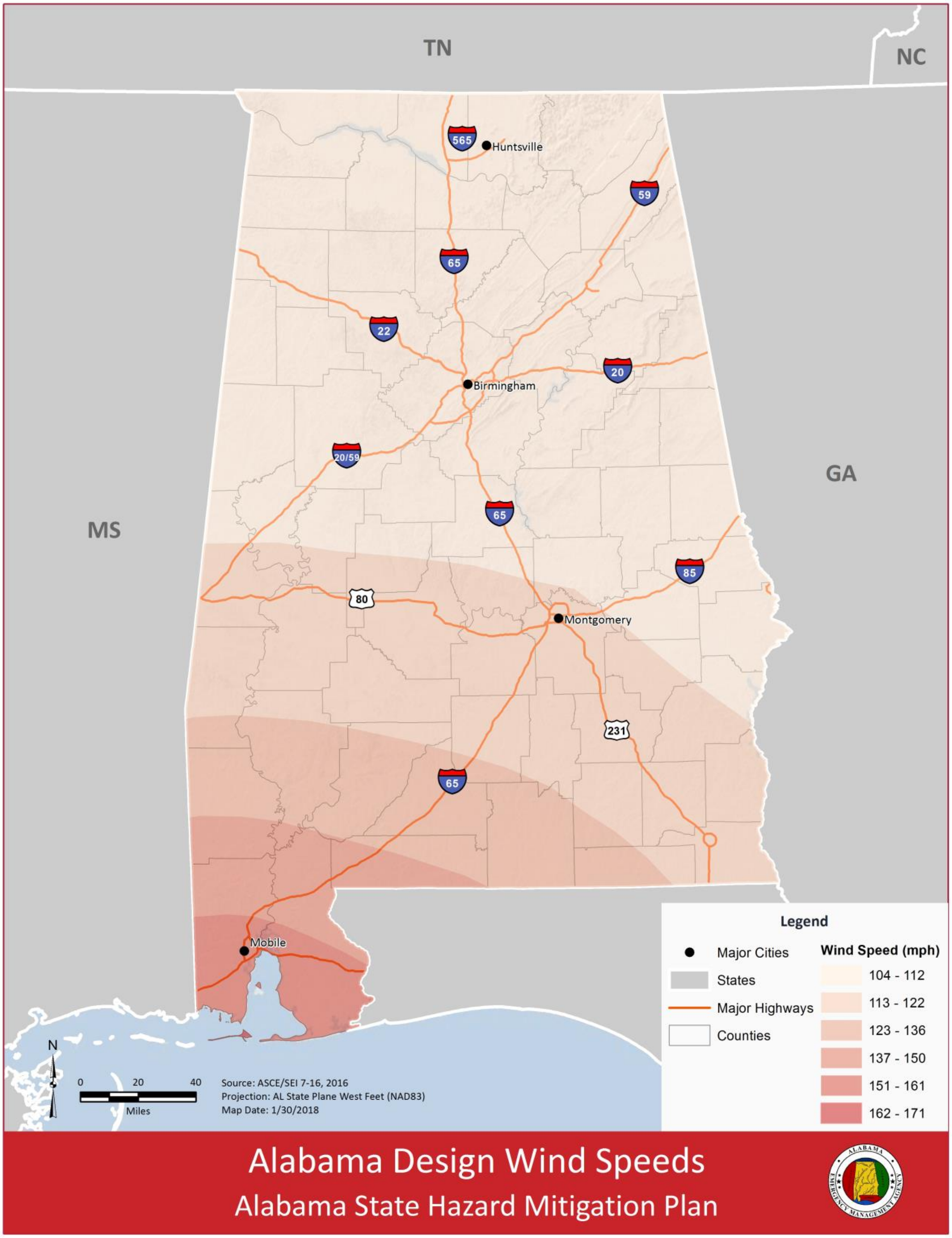
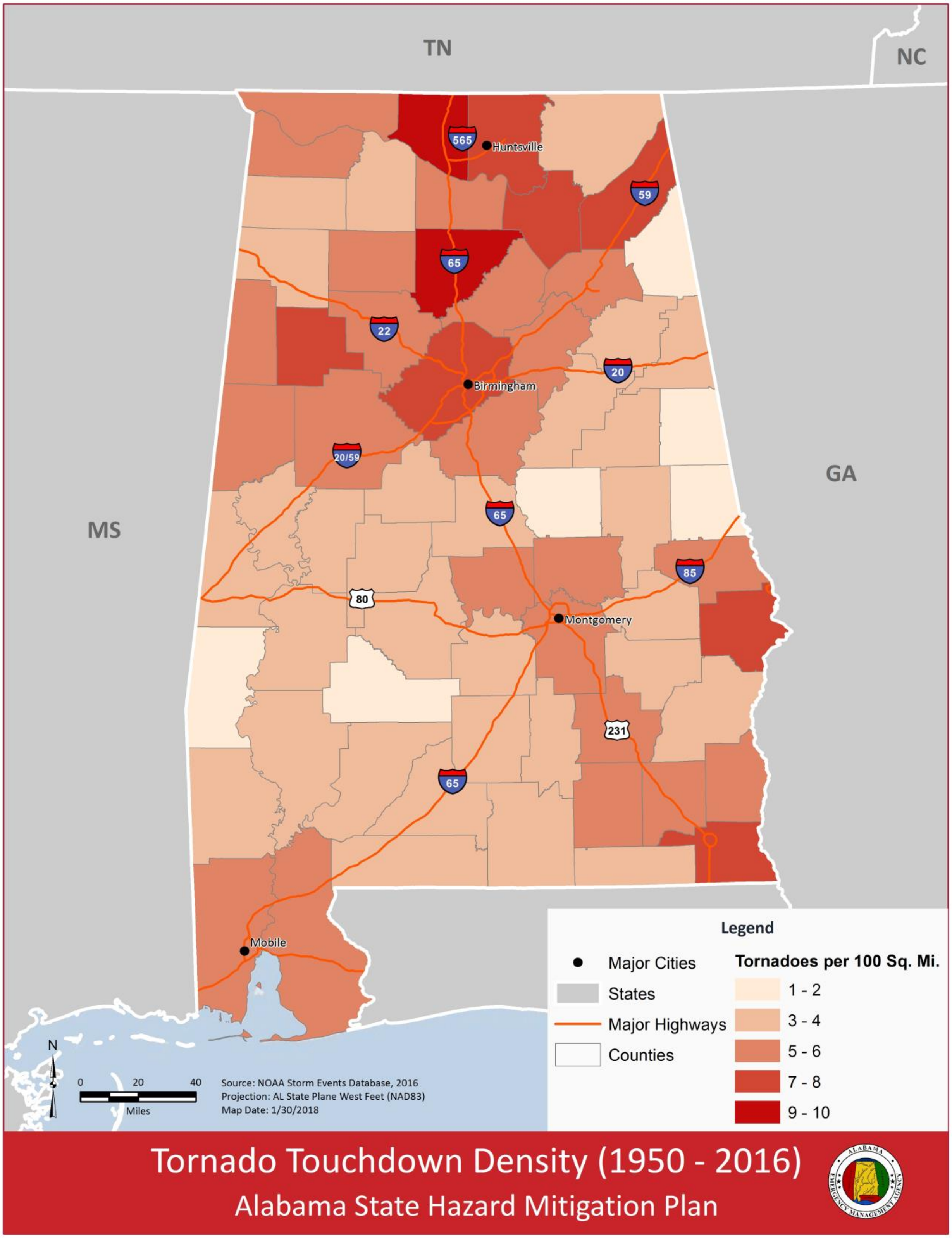


Figure 3.34 Alabama Tornado Touchdowns by County (NOAA, 2016)



3.2.7.4.1 Future Probability

The Federal Emergency Management Agency's (FEMA) State Plan Review Guide requires states to consider changes to climate conditions that may affect their vulnerability to natural hazards. A review of the literature suggests that hurricane hazards in Alabama are likely to increase, while changes in tornado hazards remain uncertain.

The building blocks for tornadoes are atmospheric instability and wind shear. Atmospheric instability results when warm, moist air near the Earth's surface rises and interacts with cooler and drier air higher in the atmosphere. While the frequency of unstable conditions is expected to increase throughout the twenty-first century, global climate models suggest significant variability from one year to the next. In addition to atmospheric instability, tornadoes need strong vertical wind shear to provide a rotational source. While some studies anticipate a decrease in vertical wind shear due to a weakening of the pole-to-equator temperature gradient, other studies anticipate an increase in wind shear on days with high atmospheric instability.[78,79] Adding to these uncertainties, available tornado records are not long or reliable enough to detect long-term trends, and tornadoes are too small to be simulated by climate models. Until scientists develop a better understanding of historic trends and/or projected changes in the physical processes that drive tornadoes, the impact of climate change on tornado hazards will remain uncertain.

In contrast to the uncertainty regarding tornado hazards, hurricane hazards are generally expected to increase through the twenty-first century. The measures of hurricane activity include intensity, frequency, and duration. Since high-quality satellite data first became available in the early 1980s, scientists have observed a substantial increase in all of these measures of hurricane activity for North Atlantic hurricanes, as well as an increase in the frequency of the strongest (Category 4 and 5) hurricanes.[80] Although simulations of future hurricane activity span a range of possible outcomes, on average the models project an increase in the annual number of Category 4 and 5 hurricanes by the late twenty-first century, as well as a slight decrease in the number of tropical cyclones.[81] Changes in the storm tracks of North Atlantic hurricanes are less well understood. The storm tracks of North Atlantic hurricanes are shaped by both atmospheric

[78] Emrich C. T., Morath D. P., Bowser G. C., and Reeves R. (2014). Climate-Sensitive Hazards in Florida: Identifying and Prioritizing Threats to Building Resilience against Climate Effects. University of South Carolina, Hazards and Vulnerability Research Institute. Retrieved from http://www.floridahealth.gov/environmental-health/climate-and-health/vulnerability/index.html
[79] Diffenbaugh, N. S., Scherer, M., and Trapp R. J. (2013) Robust increases in severe thunderstorm environments in response to greenhouse forcing. Proceedings of the National Academy of Sciences 110(41) 16361 – 16366.
[80] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the US: The Third National Climate Assessment. US Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.
[81] *Ibid.*

dynamics and ocean circulation, and projected changes in ocean circulation remain poorly constrained.[82]

In short, emergency managers in Alabama can expect the probability of damaging high winds associated with hurricanes to increase through the twenty-first century and should adopt mitigation measures accordingly.

3.2.7.4.2 Risk and Vulnerability

A detailed assessment of vulnerability to high winds in Alabama is provided in Section 5.3.

[82] Woolings, T., Gregory, J. M., Pinto, J. G., Reyers, M., and Brayshaw, D. J. (2012). Response of the North Atlantic storm track to climate change shaped by ocean–atmosphere coupling. Nature Geoscience volume 5, pages 313–317.

3.2.8 Landslides

3.2.8.1 Description

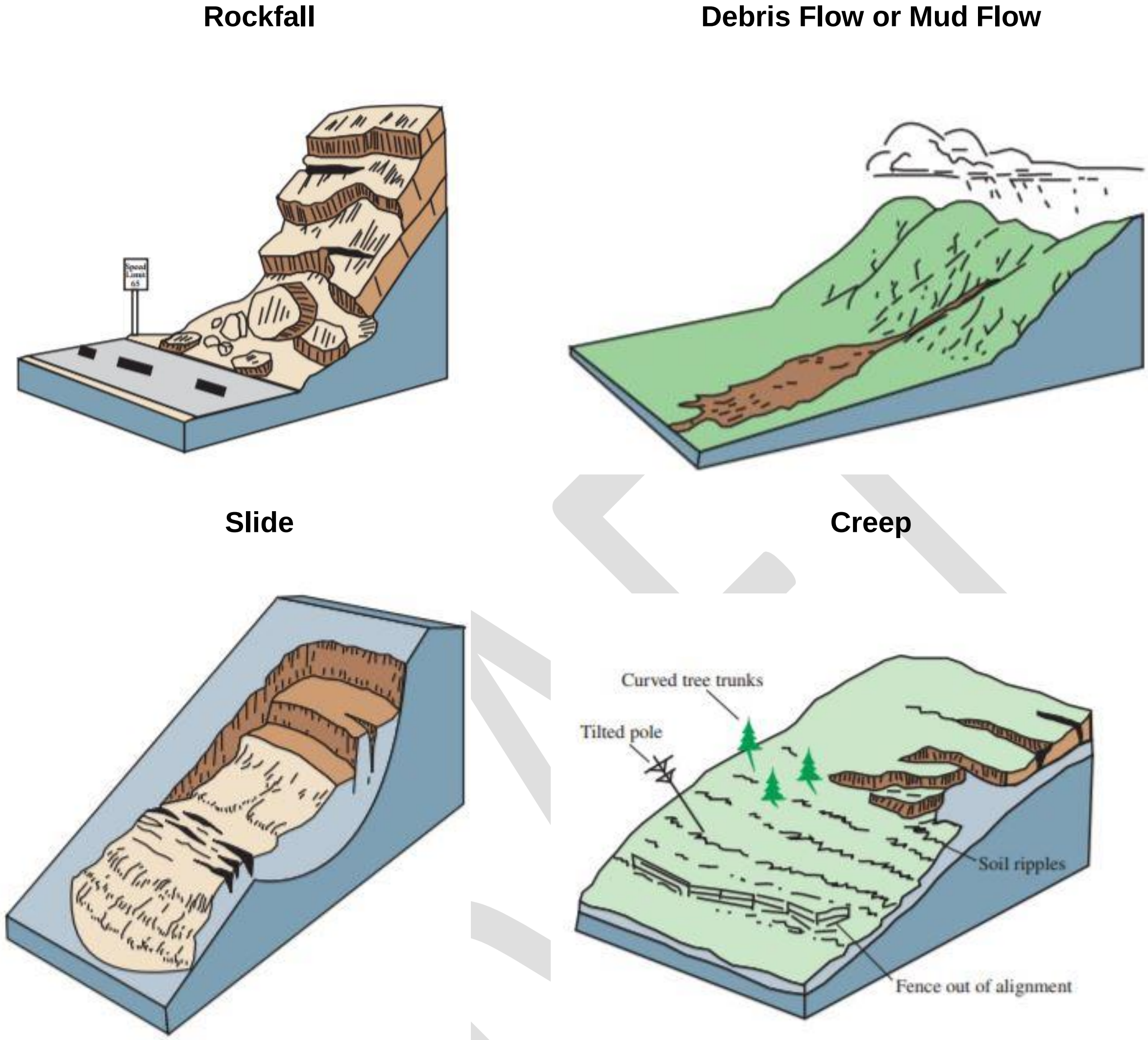
"Landslide" is a general term that refers to the "downward and outward movement of slope-forming soil, rock, and vegetation under the influence of gravity."[83] There are many types of landslides, but some of the most common are rock falls, debris flows, mud flows, slides, and creep. 5.1.1.1.1.1.1Table 3.28 defines these types of landslides in terms of their material type, movement velocity, and movement character, and shows schematic diagrams developed by the USGS to illustrate each landslide type[84]. Debris flows are considered one of the most dangerous forms of landslides. This type of landslide usually starts on steep slopes during heavy rainfall, and often follows roadway drainage networks and streams. Because debris flows move rapidly and with great force, they can destroy almost everything in their path. Debris flows and mud flows differ only in the materials that flow downslope and are depicted by the same schematic.

Table 3.28 Landslide Types

Landslide Type	Material	Movement Velocity	Movement Character
Rock Fall	Masses of rock	Varies	Material falls freely
Debris Flow	Loose soil, rock, and organic matter combined with water	Rapid	Material flows like a viscous fluid
Mud Flow	Slurry of water and fine sediment	Rapid	Material flows like a viscous fluid
Slide	Intact masses of soil or rock	Varies, generally moderate	Material slides downslope as a coherent unit
Creep	Masses of soil or rock	Very slow, generally imperceptible	Material moves slowly downslope, often causing leaning utility poles, trees, and retaining walls along the slope

[83] Geological Survey of Alabama, 2018. Geologic Hazards: Landslide Science and Types. Website accessed at: https://www.gsa.state.al.us/gsa/geologic/hazards/landslides
[84] US Geological Survey, 2004. Landslide Types and Processes. Fact Sheet 2004-3072. Retrieved at: https://pubs.usgs.gov/fs/2004/3072/pdf/fs2004-3072.pdf

Figure 3.35 Landslide Types (USGS, 2004)



Landslides pose a risk to both property and life. They can damage or destroy homes, roads, infrastructure, forests, and farms. Because landslides are often triggered or exacerbated by other natural hazards, including flooding, earthquakes, and wildfires, the damage they cause is often attributed to the triggering events. In addition, landslides can contribute to other hazards, such as dam failure.

Landslides happen when areas that are landslide-prone are subject to natural and/or human-induced changes in the environment. Landslide-prone areas can be identified based on rock strength, slope, land cover, and known historical landslides. In general, landslides are more likely in areas with steeper slopes, weaker rocks, and sparser vegetation. Future landslides are also more likely to occur in areas with known historical landslides. Although landslides are most common in mountainous regions, they can also occur in areas with low relief as well, particularly

when natural or human-induced triggers are present. The environmental changes that can trigger a landslide include:[85]

- High precipitation
- Changes in groundwater level
- Seismic activity
- Construction or mining activity
- Over-steepening of slopes
- Changes in surface water runoff
- Heavy loads on slopes

It is important to emphasize that the likelihood of landslides is enhanced when slopes are destabilized by construction or erosion. Road cuts and other excavated areas are particularly susceptible to landslides.

3.2.8.2 Nature of the Hazard in Alabama

The geologic units that are most prone to landslides are those characterized by strongly cemented rocks and very steep slopes (more than thirty degrees); weakly cemented rocks and moderately steep slopes (more than fifteen degrees); and shales, clayey soils, or poorly compacted fills and slightly steep slopes (more than ten degrees). The GSA has developed a map of landslide susceptibility based on state data on Alabama rock types and USGS data on topography (5.1.1.1.1.1.1Table 3.28Figure 3.35). Much of the state is underlain by weak rocks and shallows slopes, and the many of the geologic provinces with steeper slopes are also characterized by stronger rocks. Areas of steeper slopes tend to be concentrated in the Piedmont Upland, Valley and Ridge, and Cumberland Plateau geologic provinces located in the northeastern part of the state, as well as along river bluffs and roadcuts throughout the state. Areas of strongly cemented rock tend to be concentrated in the Piedmont Upland geologic province in the eastern part of the state and the Highland Rim geologic province in the northern part of the state. The GSA map shows how the interaction of geology and slope throughout the state produces highly localized areas of landslide susceptibility. In addition to geology and slope, mapping known historical landslides helps assess where landslides are likely to occur in the future. Points on the map show the incidence of past landslides as determined from historic topographic maps by Pomeroy (1982), Rheams (1982), and Thomas (1979, 1982). Notable geologic units with a documented history of landslides include (but are not limited to): the Tuscaloosa Group, Pottsville Formation, Parkwood Formation, Pennington Formation, Bangor Limestone, and Pride Mountain Formation. For details on the soil, clays, shales, slopes, and fractures of these units and how these factors contribute to slide susceptibility, see USGS Bulletin 1649.[86]

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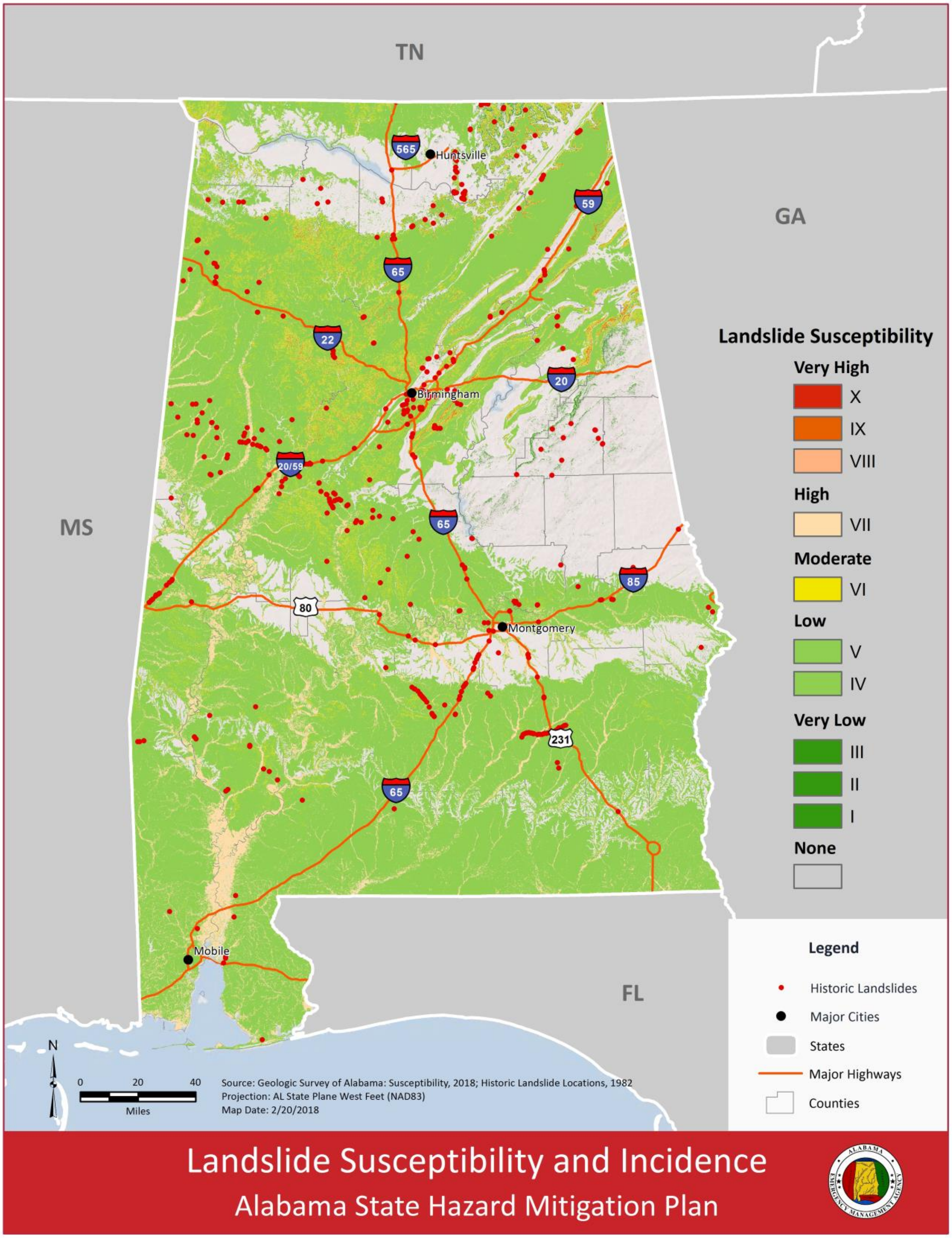
[85] Geological Survey of Alabama, 2018. Geologic Hazards: Landslide Science and Types. Website accessed at: https://www.gsa.state.al.us/gsa/geologic/hazards/landslides
[86] John S. Pomeroy and Roger E. Thomas, 1985, Geologic Relationships of Slope Movement in Northern Alabama, US Geological Survey Bulletin 1649.

Landslides become more likely during heavy rainfall. Annual rainfall averages indicate that the southwestern part of Alabama receives the most rainfall.

Figure 3.36 Landslide Incidence and Susceptibility (GSA, 2018)



3.2.8.3 Landslide History in Alabama

Alabama does not maintain a statewide real-time or near real-time record or reporting system of landslide events throughout the state. In the late 1970s and early 1980s, however, scientists at the GSA developed a map of historical landslide events based on historic topographic maps. Historical landslide events were identified by examining the contour lines in the 1:24,000-scale topographic maps published by the US Geological Survey through 1982 and identifying all features with curvatures characteristic of landslide events. The location of these historical landslides is shown in 5.1.1.1.1.1.1Table 3.28Figure 3.36.

To illustrate the potential impacts of landslides, 5.1.1.1.1.1.1Table 3.29 describes several historical events in Alabama that were reported to be geologically significant or to cause property damage. Images were available for the 1998 DeKalb County landslide and the 1998 Madison County landslide and are reproduced below the table (5.1.1.1.1.1.1Table 3.29Figure 3.37). No new major landslide events were reported by the GSA for the 2018 plan update. Landslides reported in local newspapers were added to the table.

Table 3.29 Landslide History in Alabama

Date	Location	Description
Ancient	Hokes Bluff Etowah County	In 1996, geologists discovered the remnant of an ancient landslide at Hokes Bluff which formed a 140-foot hill. This massive landslide once ripped apart Colvin Mountain and sent millions of tons of rock sliding down into the valley floor.
1886	Bogan Mountain Cherokee County	The largest landslide in Alabama to be documented by the press was a large landslide (reported to be 1 mile long) along the side of Bogan Mountain that temporarily dammed up the Chattooga River. This landslide was described in an article in The New York Times on January 30, 1886. While the slide is not apparent on the topographic maps, the mountain does have steep slopes with a relatively high landslide susceptibility.
1972	North of Gadsen Etowah County	In 1972, the southbound lane of Interstate 59 slid from its perch on a mountainside down into the valley below. The landslide resulted in $1.3 million in repairs ($7.6 million in 2017 dollars) and prolonged disruption of traffic.
1988	Birmingham Jefferson County	In 1988, a landslide destroyed apartment buildings during the construction of an adjacent Festival Center. Estimated damages were over $10 million ($20.7 million in 2017 dollars).
1997 and 1998	Monte Sano Mountain Madison County	In 1997, 400,000 pounds of rock broke away from Monte Sano Mountain and crashed into Governors Drive. In 1998, extensive rainfall associated with a hurricane resulted in a major landslide with large fissures on Monte Sano Mountain. The slide, about 750 feet long and 200 feet wide, began near the top of the mountain in a relatively new neighborhood and threatened to wipe out an older residential area at the base of the mountain. Extensive dewatering and eventual removal of the affected rock prevented a major disaster.
1998	Lookout Mountain DeKalb County	In 1998, a landslide in DeKalb County wiped out County Highway 81 on Lookout Mountain. The landslide moved more than 117,000 cubic yards of rock and cost $1.7 million to repair ($2.5 million in 2017 dollars). Another landslide on Highway 35 between Rainsville and Fort Payne cost between $1-2 million to repair ($1.5 to $3 million in 2017 dollars).

Date	Location	Description
2005	Near Prattville Autauga County	In 2005, County Road 47 was closed by a landslide. The problem stemmed from unconsolidated sediments that move underneath the road when it rains. A temporary repair was implemented which cost between $150,000 and $200,000 ($184,000 and $246,000 in 2017 dollars). The Alabama Department of Transportation has since completed a permanent repair for a cost of approximately $1.5 million (according to the 2015 proposal).
March 2009	City of Alexander Tallapoosa	Rain-soaked ground led to the failure of an embankment on Morgan Street in Alexander City. The mudslide caused a portion of building to collapse, leaving large holes in the exterior walls of two businesses. Rain and mud then entered the businesses, heavily damaging or destroying much of the merchandise, and covering the floor with a layer of mud. The estimated property damage was $114,000 (or $130,000 in 2017 dollars).
January 2010	City of Daphne, Baldwin County	Daphne Police report a mudslide on the by-pass in Spanish Fort. The west bound lanes were blocked. The mudslide was caused by excessive heavy rainfall.
September 2011	City of Cordova, Walker County	Due to persistent, heavy rainfall from the remnants of Tropical Storm Lee, a mudslide occurred along River Road, northeast of Cordova. The road was closed until the debris could be removed. River Road and the surrounding area sustained extensive damage from two tornadoes on April 27, 2011, which stripped the land of most of the vegetation.
September 2011	Near Leeds Jefferson County	Rainfall amounts of 6 inches occurred near Leeds, causing a landslide to occur. Several large rocks blocked Dunnavant Road.
November 2011	Town of Section, Jackson County	A landslide along State Highway 35 occurred near the town of Section on the side of Sand Mountain in the early morning hours. At least two large boulders, one the size of a pickup truck, along with a large quantity of smaller rocks, dirt and trees slid into the road. A car was trapped under the landslide, and rescue crews were able to get the driver out unharmed. The road was not cleared and reopened until the afternoon.

Date	Location	Description
February 2012	City of Hartselle Morgan County	A landslide along I-65 closed the northbound lanes of the interstate between Hartselle and Priceville for about two weeks. Officials with the Alabama Department of Transportation first noticed the landslide encroaching on the shoulder of the road when they were repairing a sinkhole in the area. Traffic was detoured for two weeks while crews worked round the clock on the repair project.
April 2014	City of Vestavia Hills Jefferson County	Soil from a hillside slumped onto US 31 during heavy rains. The landslide buried a section of the highway near Brookwood Hospital under trees, mud and rock, blocking the highway's northbound lanes. Repairs were complete within a day.
December 2015	City of Attalla, Etowah County	A landslide along US 431 occurred near the city of Attalla, shutting down traffic in two lanes. The landslide occurred in the evening when a 50-foot section of rock, brush, tree limbs and soil came tumbling down the mountainside and covered two lanes of southbound traffic. No injuries were reported, but some cars were damaged by falling rocks.

Figure 3.37 Historical Landslides that Caused Property Damage

1998 DeKalb County Landslide

Source: GSA, 2018

1998 Madison County Landslide

Source: Alabama HMP, 2013

3.2.8.4 Probability of Landslides in Alabama

The probability of landslides cannot be expressed in terms of specific frequencies or return periods. These events are the culmination of multiple naturally-occurring and human-induced geological processes that play out over a range of timescales and can be highly localized. Areas

that are more landslide-prone can be identified, however, based on geologic characteristics and historic landslide events (5.1.1.1.1.1.1Table 3.28Figure 3.36).

3.2.8.4.1 Future Probability

Some of the processes that increase the likelihood of landslides may be impacted by future climate change. These include high precipitation and changes in groundwater levels. If rainfall events become more intense in the future, the incidence of landslides in Alabama may increase. At the same time, more prolonged and intense drought events could lead to more groundwater withdrawals and the lowering of some water tables. In some instances, this effect could reduce the likelihood of landslides.

3.2.8.4.2 Risk and Vulnerability

A community's vulnerability to loss from landslides is a function of the probability of landslides, the exposure of structures to landslides, and the susceptibility of structures to landslides. In Alabama, landslide risk is highly site-specific and difficult to generalize. To the extent that new development takes place near steep slopes, drainage ways, or natural erosion valleys, it will be more vulnerable to loss from landslides. In addition, roadways are particularly vulnerable to disruption from landslides. Roadway systems with more redundancy will be more resilient to temporary closures.

3.2.9 Lightning

3.2.9.1 Description

Lightning is a discharge of electricity in the atmosphere that occurs between clouds, the air, or the ground. While lightning can occur during such events as volcanic eruptions, intense forest fires, and large hurricanes, lightning most typically occurs during a thunderstorm. In a thunderstorm, rising and descending air separates positive and negative charges. Additionally, the presence of water and ice particles may also affect this distribution of the electrical charge. The subsequent discharge of energy between these positive and negative charge areas results in lightning (see 5.1.1.1.1.1.1Table 3.29Figure 3.38). Thunder is a by-product of lightning. In only a few millionths of a second, the air surrounding a lightning strike is heated to 50,000°F, a temperature five times hotter than the surface of the sun.[87] Thunder is the result of this rapid heating and cooling of air near the lightning that causes a shock wave.[88]

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[87] National Oceanic and Atmospheric Administration, The National Severe Storms Laboratory. Severe Weather 101 – Lightning. Retrieved at https://www.nssl.noaa.gov/education/svrwx101/lightning/basics/

[88] Federal Emergency Management Agency, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library-data/20130726-1545-20490-4487/mhira_in.pdf

Figure 3.38 Formation of Lightning (University Corporation for Atmospheric Research (UCAR))

The risk posed by lightning is often underestimated by people in the vicinity. High winds, rainfall, and a darkening cloud cover are the warning signs for possible cloud-to-ground lightning strikes. While many lightning casualties happen at the beginning of an approaching storm, a significant number of lightning deaths occur after a thunderstorm has passed. Although the lightning threat diminishes after the last sound of thunder, the threat may persist for more than 30 minutes after the storm.[89] When thunderstorms are in the area, but not overhead, the lightning threat may still exist. Lightning can strike outward of ten miles from the storm.[90] Additionally, although most lightning-related deaths and injuries have occurred during the summer season, weather conditions conducive to thunderstorms and lightning can occur throughout the year.[91]

According to the NWS, there are approximately 25 million cloud-to-ground flashes detected every year in the US. However, approximately half of all cloud-to-ground lightning flashes have more than one ground strike point, resulting in at least 30 million points on the ground struck on average each year. In addition, there are roughly five to ten times as many cloud-to-cloud flashes as there are to cloud-to-ground flashes.[92] Although cloud-to-cloud lightning occurs more frequently, cloud-to-ground lightning flashes are those that pose a threat to human life.

Cloud-to-ground lightning can kill or injure people through a direct or indirect strike. Although not as common, a direct strike is potentially the most deadly. However, a portion of lightning current

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[89] National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS). Lightning Safety for You and Your Family. Retrieved at http://www.lightningsafety.noaa.gov/resources/Lightning-Brochure17.pdf

[90] National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS). Understanding Lightning Science. Retrieved at http://www.lightningsafety.noaa.gov/science/science-overview.shtml

[91] National Oceanic and Atmospheric Administration (NOAA), The National Severe Storms Laboratory. Severe Weather 101 – Lightning. Retrieved at https://www.nssl.noaa.gov/education/svrwx101/lightning/faq/

[92] National Oceanic and Atmospheric Administration (NOAA), The National Severe Storms Laboratory. Severe Weather 101 – Lightning. Retrieved at https://www.nssl.noaa.gov/education/svrwx101/lightning/faq/

that has struck a taller object, such as a tree or pole, can branch off to a nearby person, generally within two feet of the object. In addition, electrical current from a lightning strike may be conducted through the ground to a person after striking a nearby object. Lightning current may also travel longer distances through power lines or plumbing pipes to a person who is in contact with an electric appliance or plumbing fixture; this is known as conduction. Lightning may also directly and indirectly damage property through similar processes and may result in an explosion, fire, or destruction.[93]

Lightning is a significant cause of weather-related deaths in the US. Between 1987 and 2016, there was an average of 47 reported lightning fatalities per year in the US according to the NWS Storm Data. This number has decreased more recently to an annual average of 30 reported lightning fatalities between 2000 and 2016. However, only approximately ten percent of people struck by lightning are killed. Therefore, the total number of people struck by lightning in the US on average is approximately 300 per year. Those that are struck by lightning, but do not suffer fatal injuries, may sustain long-term injuries.[94]

3.2.9.2 Nature of the Hazard in Alabama

Although lightning can occur anywhere throughout the US, lightning is more likely to occur in areas with conditions conducive to thunderstorm cloud formation. This happens when a large amount of moisture is present low within the atmosphere, surface temperatures are higher, and there is sufficient upward air movement.[95] These conditions are often met along the Gulf of Mexico, which has high frequencies of cloud-to-ground lightning flashes with Florida having the greatest annual average cloud-to-ground flashes per square mile (20.8 flashes per square mile). Alabama, in close proximity to the Gulf of Mexico, ranks seventh of the 48 continental states in annual average cloud-to-ground flashes per square mile (14 flashes per square mile).[96]

Between 1959 and 2016, Alabama ranked twelfth in the US in the number of deaths from lightning; when weighted by population, Alabama ranked fifteenth. In the past decade, between 2007 and 2016, Alabama has ranked in the top ten in terms of number of deaths per lightning including

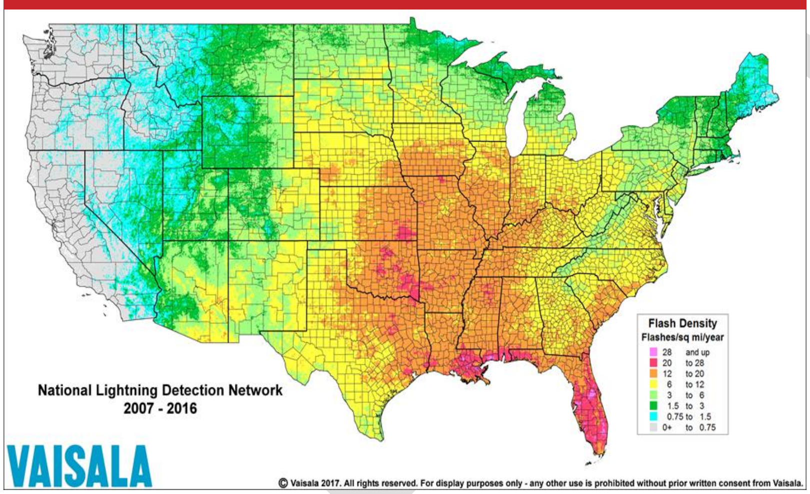
[93] National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS). Lightning Science: Five Ways Lightning Strikes People. Retrieved at http://www.lightningsafety.noaa.gov/struck.shtml
[94] National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS). How Dangerous is Lightning? Retrieved at http://www.nws.noaa.gov/om/lightning/odds.shtml
[95] FEMA, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library-data/20130726-1545-20490-4487/mhira_in.pdf
[96] Vaisala Inc. Number of Cloud-To-Ground Flashes by State from 2007 to 2016 and Rank of Cloud-To-Ground Flash Densities by State from 2007 To 2016, March 2017. Retrieved at http://www.lightningsafety.noaa.gov/stats/07-16_Flash_Density_State.pdf

when weighted by population.[97] In 2017, there were 16 lightning-related deaths in the US, three of which occurred in Alabama, which was had second highest number after Florida.[98]

The frequency and duration of thunderstorms are the main factors that influence the frequency of lightning strikes. Based on historic data collected by the National Weather Service (NWS), southern counties near the Gulf of Mexico have the highest frequency of thunderstorms in the state. These counties include Baldwin, Mobile, Washington, and Escambia. While the remainder of the state also experiences high frequencies of thunderstorms, counties located in the northern half of the state have more frequent thunderstorms than counties that are centrally located. Unlike thunderstorm frequency, thunderstorm duration is generally uniform throughout the state.[99] In addition to thunderstorm frequency and duration, past lightning strikes can help determine where lighting is more likely to occur in the future. According to the National Lightning Detection Network (NLDN), between 2007 and 2016, the average annual density of lightning flashes, expressed as flashes per square mile, was highest in the southern-most counties of the state, specifically in Mobile and Baldwin Counties. 5.1.1.1.1.1.1Table 3.29Figure 3.39 provides a map of average annual density of lightning flashes in the US. As illustrated in 5.1.1.1.1.1.1Table 3.29Figure 3.39, the southern and western portions of the state have high densities of lightning flashes. Lightning density decreases in the eastern portion of the state approaching the border with Georgia.

Figure 3.39 Average Annual Density of Lightning Flashes (Vaisala, 2018)

Vaisala Reference Map



Alabama Detail

[97] Vaisala Inc. Lightning Fatalities by State. April 2017. Retrieved at http://www.lightningsafety.noaa.gov/stats/07-16_State_Ltg_Fatality_Fatality_Rate_Maps.pdf
[98] National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS). Lightning Fatalities 2017 by State. http://www.lightningsafety.noaa.gov/fatalities/fatalities17.shtml
[99] Federal Emergency Management Agency, 1997. Multihazard Identification and Risk Assessment: A Cornerstone of the National Mitigation Strategy. Retrieved at: https://www.fema.gov/media-library-data/20130726-1545-20490-4487/mhira_in.pdf

3.2.9.3 Lightning History in Alabama

NOAA's National Centers for Environmental Information (NCEI) maintains the Storm Events Database that records storms occurrences and other severe weather events including lightning strikes that have led to casualties, injuries, property damage, and/or disruption to commerce. According the NOAA's Storm Events Database, between 1996 and August 2017, there were 651 lightning strikes reported in Alabama that resulted in 33 fatalities and 164 injuries. Additionally, lightning caused nearly $29 million in property damages and more than $25,000 in damages to crops. More than 87 percent of the lightning events recorded in the State between 1996 and 2017 occurred during the six-month period between March and August. Further, more than 60 percent of the events occurred in the summer months between June and August.

To illustrate the impacts of lightning events, 5.1.1.1.1.1.1.1Table 3.30 provides select incidents of lightning strikes that have resulted in death, injuries, and/or property damage in the state. The information in the table includes the date and location of the strike, the number of fatalities and/or injuries, the value of property damage adjusted for inflation, and a brief description of the impact. This information was obtained from NCEI's Storm Events Database. These select incidents show the severity and potential widespread damage resulting from a lightning strike.

Table 3.30 Select Past Occurrences of Lightning Events in Alabama

Date	Location	Fatalities	Injuries	Property Damage (in 2017 dollars)	Event Details
March 2001	Beatrice, Monroe County	0	0	$690,000	Lightning struck a tree near Beatrice Elementary School just before school opened. The lightning ran through the roots of a tree causing the gymnasium to catch on fire, which was destroyed. The remainder of the school suffered only minor damage from the fire.
June 2002	Hamilton, Marion County	3	4	$54,400	Lightning was believed to be responsible for a fire in a mobile home, resulting in the death of three children and two adults, two other children were injured in the fire. The State Fire Marshall said the preliminary investigation indicated the fire started in the general area of the living room around the television. A burn at the base of the utility box outside the residence indicated that lightning could have been involved in starting the fire.
July 2005	Etowah County	0	0	$137,500	An auto body shop in Attalla was struck by lightning. The ensuing fire destroyed the entire business. Another lightning strike hit a clothes drier in a home in Gadsden. The residents were able to extinguish the fire after it caused minor damage.
April 2006	Semmes, Mobile County	0	0	$960,000	Lightning struck an elementary school just north of Semmes. The lightning struck the roof starting a fire in the ceiling. It took several hours to put the fire out. Most of the damage was confined to the roof and ceiling area.
August 2006	Mount Vernon, Mobile County	0	0	$600,000	Lightning struck a church in the Mount Vernon area in Mobile County. The strike started a fire and the church was destroyed by the blaze.

Date	Location	Fatalities	Injuries	Property Damage (in 2017 dollars)	Event Details
June 2007	Hueytown, Jefferson County	0	6	0	Lightning struck a drilling rig at the Shoal Creek Mine in western Jefferson County. The lightning ignited methane gas in the mine and six miners were injured by the subsequent fire.
February 2008	DeKalb, Jackson, and Marshall Counties	0	0	0	A lightning strike knocked out the main switching facility of Farmer Telecommunications Cooperative, resulting in loss of phone service over much of DeKalb, Jackson, and Marshall counties. The general manager was quoted as saying this was the worst severe weather-related damage to the main switch in 30 years.
July 2009	Atmore, Escambia County	1	0	0	A woman was struck and seriously injured while taking out the garbage at her residence on the morning of July 6th. She later died on July 8th.
July 2010	Cottonville, Marshall County	1	4	0	Five people including a 15-year old were struck by lightning from a thunderstorm at a campground along Lake Guntersville. A fifteen-year-old from this group was killed and four were injured. They were swimming near the water's edge. The storm also knocked down some trees and produced intense lightning.
April 2011	Pumpkin Center, Morgan County	0	0	$540,000	Lightning sparked a fire at the Bellview Baptist Church on Old Moulton Road. The fire destroyed the education building and fellowship hall.

Date	Location	Fatalities	Injuries	Property Damage (in 2017 dollars)	Event Details
March 2012	Morgan County	0	1	$21,400	Lightning struck a female who was taking photos with a cell phone of a storm with her arm outside the home through a doorway. The female felt a surge of electricity through her arm, into her neck and out her wrist which appeared bruised. She then suffered a seizure for several minutes. She was hospitalized overnight. The Morgan County emergency manager reported at least 3 fires sparked by lightning the county.
August 2013	Jasper, Walker County	0	0	$813,750	Lightning struck the First Church of the Nazarene, causing a fire that destroyed the building.
June 2015	Covington County	2	0	0	A male and female were struck and killed by lightning as they were attempting to cover a chicken coup which was by a tree.
July 2016	Madison County	1	3	0	Lightning killed a man working outdoors at Redstone Arsenal in Huntsville with minor injuries to three others.
August 2017	Gulf Shores, Baldwin County	1	5	0	A group of 6 men were struck by lightning on the beach in Gulf Shores. There were 5 injuries and 1 died.

3.2.9.4 Probability of Lightning in Alabama

Areas that have a high density of cloud-to-ground lightning strikes are at a greater risk for potential property damage, injuries, or fatalities. Between 2007 and 2016, an average of 726,033 cloud-to-ground flashes occurred in the state each year, which is a density of 14 flashes per square mile. As discussed above, Alabama ranked seventh of the 48 continental states in terms of the average annual density of cloud-to-ground flashes.[100] Therefore, the probability of a cloud-to-ground lightning strike and the potential for lightning to result in damage are relatively high in the state of Alabama.

As discussed above and as shown in 5.1.1.1.1.1.1Table 3.29Figure 3.39, Alabama's southern-most counties have the highest average annual densities of lightning flashes in the state. Therefore, the probability of a cloud-to-ground lightning strike is likely highest in Mobile and Baldwin Counties. However, other counties near the southern border of the state and counties located in the western half of the state also have high densities of lightning flashes and have a higher probability of a lightning strike than those in the eastern portion of the state where lightning flash densities diminish.

However, because the impacts of a lightning strike are so localized, the site-specific incidence of a lightning strike occurring is considered very low. For example, while on average over one-quarter of a million cloud-to-ground lightning strikes are recorded annually, between 1996 and 2017, only approximately 30 lightning occurrences each year were reported to result in property damage, fatalities, or injuries according to NCEI's Storm Events Database.

3.2.9.4.1 Future Probability

Since the probability of a lightning event is influenced by the probability of a severe thunderstorm occurrence, potential future changes in climate and weather conditions may impact the future probability of cloud-to-ground lightning strikes. However, future projections in the severity and frequency of thunderstorms are uncertain in the Southeast US. Although the number of severe thunderstorms reported in this region has increased in the last 50 years, it has largely been attributed to advancement in reporting technologies.[101] Further, the future probability of lightning activity is not forecasted as lightning strikes are frequent and widespread. Additionally, forecasters' understanding of the cloud electrification process is incomplete.[102]

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[100] Vaisala Inc. Number of Cloud-To-Ground Flashes by State from 2007 to 2016 and Rank of Cloud-To-Ground Flash Densities by State from 2007 To 2016, March 2017. Retrieved at http://www.lightningsafety.noaa.gov/stats/07-16_Flash_Density_State.pdf

[101] Ingram, K., K. Dow, L. Carter, J. Anderson, eds. 2013. Climate of the Southeast US: Variability, change, impacts, and vulnerability. Washington DC: Island Press.

[102] National Oceanic and Atmospheric Administration (NOAA), The National Severe Storms Laboratory. Severe Weather 101 – Lightning. Retrieved at https://www.nssl.noaa.gov/education/svrwx101/lightning/forecasting/

3.2.9.4.2 Risk and Vulnerability

A community's vulnerability to loss from lightning strikes is a function of the probability of lightning strikes, the exposure of structures and people to the hazard, and the susceptibility of structures and infrastructure to the hazard. Although the southern and western portions of the state have the highest probability of cloud-to-ground lightning flashes, the large percentage of plans that recognize lightning as a significant hazard indicates that the risk of lightning is high throughout the state. People and property throughout the state are vulnerable to loss of life, injury, or property damage from lightning. The people who are most susceptible to death or injury from lighting strikes are those who are engaged in outdoor activities and/or exposed to the outdoors. Therefore, vulnerability at the individual level is influenced by the ability to seek suitable shelter and the level of understanding of lightning safety procedures.

3.2.10 Sea Level Rise and Coastal Land Change

3.2.10.1 Description

Sea level rise is a global phenomenon with varying local impacts. At the global scale, climate change is driving the rising seas. Warming oceans are causing ocean waters to expand, and the melting of land-based ice (glaciers and ice sheets) is causing ocean volumes to rise.[103] At the local scale, however, a range of local factors can hasten or slow the rate of sea level rise seen by communities. Depending on the direction and magnitude of these local factors, local sea level can be observed to rise faster or slower than the global average and can even be observed to fall.[104]

In the US, observed rates of sea level rise range from an average increase of 9.65 mm/year at Eugene Island, Louisiana to an average decrease of 17.53 mm/year at Skagway, Alaska.[105] Figure 3.40 shows local sea level trends across the US, with the arrows representing the direction and magnitude of change. The highest rates of sea level rise are seen along the Texas and Louisiana coastlines.

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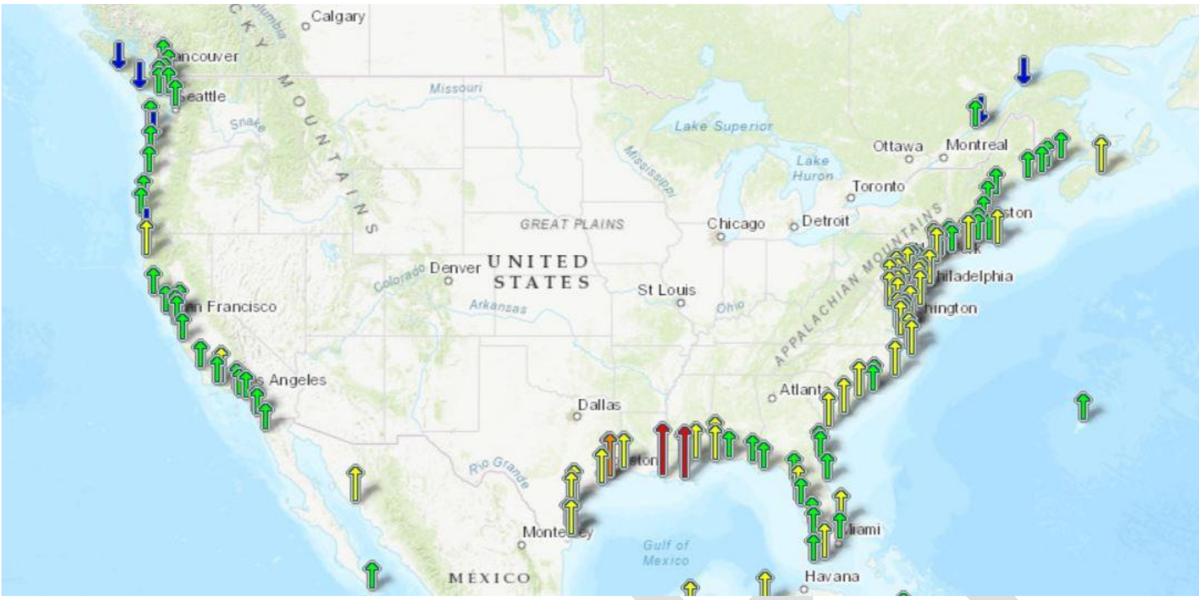
[103] National Oceanic and Atmospheric Administration, 2018. Is sea level rising? Website accessed at: https://oceanservice.noaa.gov/facts/sealevel.html

[104] National Oceanic and Atmospheric Administration, 2018. What is the difference between local sea level and global sea level? Website accessed at: https://oceanservice.noaa.gov/facts/sealevel-global-local.html

[105] National Oceanic and Atmospheric Administration, 2018. US Linear Relative Sea Level (RSL) trends. Website accessed at: https://tidesandcurrents.noaa.gov/sltrends/mslUSTrendsTable.htm

Figure 3.40 Local Sea Level Trends (NOAA, 2018)



The local factors that shape the height of water along a coast include regional ocean currents and regional changes in ground elevation (i.e., land subsidence or uplift). Regional changes in ground elevation can be caused by many different natural processes and human activities. The most common natural causes are fault processes, sediment compaction, sediment loading, and glacial isostatic adjustment, while the most common human causes are fluid withdrawal (i.e., the extraction of oil, gas, and groundwater) and surface water drainage. Table 3.31 provides a brief summary of each of these processes.[106]

Table 3.31 Causes of Vertical Land Movement in Coastal Environments

Process	Typical Location	Description
Fault Processes	Faults	The movement of the earth's crust along faults can cause changes in land elevation. This process can cause either land subsidence or uplift.
Sediment Compaction	River deltas	River deltas are landforms created over time by the deposition of river sediments. As these sediments settle, their volume is reduced and the land surface sinks.
Sediment Loading	River deltas, lakes, valleys	In places where large sediment loads are deposited over a relatively small area, the weight of the sediment load can deform the earth's crust. If the bending of the underlying crust is not balanced by the accumulation of new sediment deposits, the land surface will sink.

[106] Yuill, B., Lavoie, D., and Reed, J., 2009. Understanding Subsidence Processes in Coastal Louisiana. Journal of Coastal Research, Special Issue No. 54.

Process	Typical Location	Description
Glacial Isostatic Adjustment	Glaciated and forebulge areas	During the last Ice Age, glaciers covered much of the northern half of North America. Even though these glaciers retreated long ago, the earth's crust is still adjusting to the removal of their weight. Similar to a soft mattress, the areas that were once beneath the glaciers are slowly rising, while the areas that were once pressed up around the edges (the forebulge areas) are slowly sinking.
Fluid Withdrawal	Areas mined for hydrocarbons or groundwater	The extraction of water, oil, and natural gas removes the support provided by the fluid and can cause the ground to sink.
Surface Water Drainage	Areas dewatered with subsurface drainage systems	When organic soils are dewatered, their volume is reduced and the land surface sinks.

Local sea level rise will fundamentally change coastal environments in the US, exacerbating existing flooding hazards and creating new coastal change hazards. While Section 5.2.5 discusses the acute but episodic hazards posed by the flooding impacts of sea level rise, this section discusses the slow-moving but enduring hazards posed by the coastal change impacts of sea level rise. Some overlap is inevitable, but the goal of this section is to highlight the profound and irreversible impacts of local sea level rise on coastal environments and to highlight where communities can intervene to interrupt positive feedback loops and preserve coastal resources.

As local sea levels rise, changes in the form and function of coastal environments will lead to more and more property damage and economic disruption. The physical effects of local sea level rise will progress from more frequent and extensive "nuisance flooding," to chronic inundation, to coastal land loss (these terms will be defined in the subsections below). Along the way, the coastal ecosystems that communities depend on for critical ecosystem services will also be transformed. These effects will be felt by a large share of the nation's population. Nearly 40 percent of Americans live in densely populated coastal areas.[107]

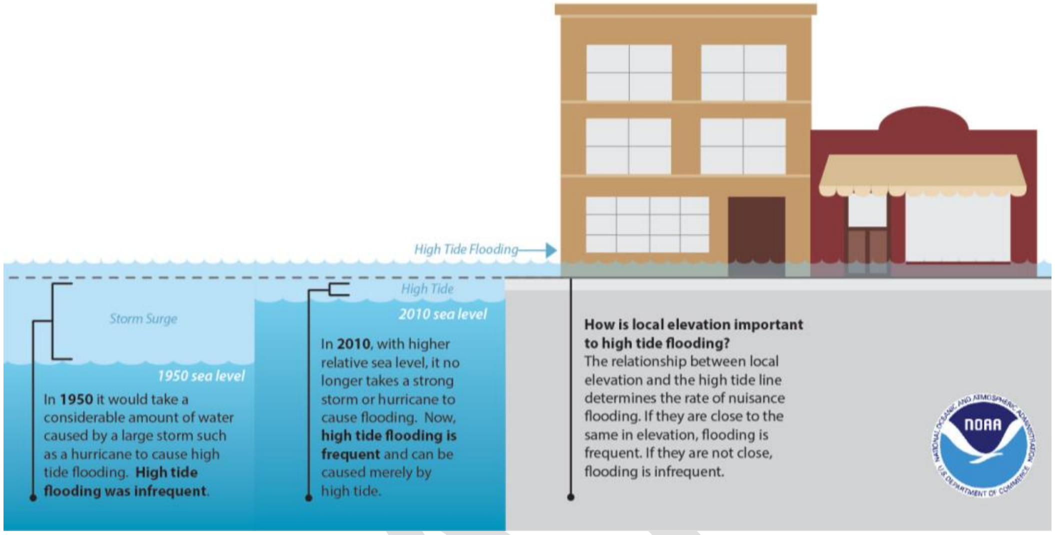
3.2.10.1.1 Nuisance Flooding

Nuisance flooding refers to shallow coastal flooding that causes significant public inconvenience, but generally does not cause significant structural damage to buildings. The impacts of nuisance flooding include temporary road and business closures, overwhelmed stormwater systems, damage to transportation infrastructure, and coastal erosion. Figure 3.41 illustrates how local sea level rise leads to more nuisance flooding. In the past, the gap between mean sea level and nuisance water levels was larger, and it would take an extreme event such as a tropical storm coinciding with high tide to produce nuisance flooding. As local sea levels rise, however, the gap

[107] National Oceanic and Atmospheric Administration, 2018. Is sea level rising? Website accessed at: https://oceanservice.noaa.gov/facts/sealevel.html

between mean sea level and nuisance water levels is shrinking. This means that now less extreme events, such as the extreme high tides that occur every year when the Earth is nearest the sun (or "king tides"), can also cause nuisance flooding.

Figure 3.41 Sea Level and Nuisance Flooding (NOAA, 2018)



Since 1950, communities across the US have seen a significant and accelerating increase in the frequency of nuisance flooding. Whereas in 1950 events causing nuisance flooding typically had return periods of 1 to 5 years, in 2008 these events had return periods of less than three months at most NOAA gauges.[108]

3.2.10.1.2 Chronic Inundation

Chronic inundation is a term coined by the Union of Concerned Scientists (UCS) to refer to episodic coastal flooding that is so frequent it makes normal routines impossible. UCS defines "chronic inundation" as flooding that occurs, on average, once every other week, and defines a "chronically inundated community" as any coastal community that experiences this frequency of flooding over 10 percent of its area or more.[109] Chronic inundation is more than an inconvenience, and causes significant disruption to people's routines, livelihoods, homes, and communities.[110] The effects of chronic inundation depend on the character and density of exposed communities. For more urban communities, impacts may include lower home values and inaccessible business districts. For more rural communities, in contrast, impacts may include lower farm productivity and homes that are isolated from emergency services.

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[108] National Oceanic and Atmospheric Administration, 2014. Sea Level Rise and Nuisance Flood Frequency Changes around the US. NOAA Technical Report NOS CO-OPS 073.
[109] Union of Concerned Scientists, 2017. When Rising Seas Hit Home.
[110] Ibid.

Based on an analysis of three different sea level rise scenarios developed for the Third National Climate Assessment (the Intermediate-Low, Intermediate-High, and High scenarios), UCS determined that the number of coastal communities exposed to chronic inundation could increase by two-fold in the next twenty years, and by more than seven-fold by the end of the century. Table 3.32 shows the estimated number of communities that would be exposed to chronic inundation under the Intermediate-High and High sea level rise scenarios.

Table 3.32 US Communities Exposed to Chronic Inundation with Sea Level Rise (UCS, 2017)

Scenario/Year	Today	2035	2060	2100
Intermediate-High	90	167	272	489
High	90	180	360	668

3.2.10.1.3 Coastal Land Loss

Coastal land loss refers to the permanent loss of low-lying coastal land and is the final step in the transition from dry land to open water. Local sea level rise is a contributor to coastal land loss, but it is not the only factor that determines the location and extent of this transition. Coastal environments are complex and dynamic systems shaped by interacting natural and human factors, and many of these factors play a role in coastal land loss. The natural factors at play include erosion, reductions in sediment supply, and wetland deterioration, while the human factors include sediment excavation, river modification, and coastal construction. According to the USGS, “the exact causes of land loss are uncertain,” so predicting future change requires an understanding of all the causes of land loss.[111]

Coastal land loss can have devastating social and economic impacts, from destroying homes to reshaping regional economies. At the household level, coastal land loss can destroy properties located near the waterfront. Based on Zillow research, a 6-foot rise in sea levels could submerge 1.9 million homes by 2100. This loss would account for 1.8 percent of the nation’s housing stock, representing a value of $916 billion.[112] At the regional level, coastal land loss can expose areas further inland to flooding and erosion hazards. This is because wetlands and barrier islands act as natural buffers to storm surge and wave impacts, and the loss of these buffers exposes more upland areas. Coastal land loss also can compromise critical regional lifelines, such as water supply, energy infrastructure, and evacuation routes. Water-dependent infrastructure, including port facilities, thermal power plants, and bridges, is particularly vulnerable to coastal land loss. At the national level, coastal land loss can impact the national economy through its impacts on

[111] US Geological Survey, 2003. An Overview of Coastal Land Loss: With Emphasis on the Southeastern US. Open File Report 03-337.
[112] Zillow Research, 2017. Climate Change and Homes: Who Would Lose the Most to a Rising Tide. Retrieved at: https://www.zillow.com/research/climate-change-underwater-homes-2-16928/.

nationally-important port assets and economic activity. In 2010, for example, more than $1.9 trillion in imports came through US ports, providing 90% of consumer goods and supporting more than 13 million jobs.[113]

In Alabama, the Port of Mobile is an important driver of the state and regional economy. Located on the western shore of Mobile Bay, at the confluence of several rivers flowing into the Gulf of Mexico, the port has both inland waterway and ocean access. Major commodities handled at the port include coal, petroleum products, iron and steel, paper, aluminum, and some perishable foodstuffs. In 2016, more than 10,000 vessels called at the Port of Mobile, and the cargo throughput exceeded 58 million short tons.[114] According to the Alabama State Port Authority, the port has a total economic value of $19.4 billion, supports 124,328 direct and indirect jobs, and has a direct and indirect tax impact of more than $459 million.[115]

3.2.10.1.4 Coastal Ecosystem Transformation

Coastal ecosystems provide many valuable ecosystem services, from supporting recreation and tourism to protecting the built environment from storm surge and waves. Human activities are already placing significant stresses on these ecosystems and their services and rising local sea levels will exacerbate these stresses.[116] Consider salt marsh systems, for example. As the local sea level rises, the marsh will begin to migrate landward. If the uplands are developed, however, and not available for migration, the marsh may drown. The loss of coastal ecosystems represents not only an aesthetic and cultural loss, but an important economic loss as well. In many coastal communities, commercial fisheries, recreation, and tourism are important components of the local economy – and Alabama is no exception.

Every year the National Oceanic and Atmospheric Administration (NOAA) publishes a report on the Fisheries Economics of the United States, providing a detailed look at the economic performance of commercial and recreational fisheries on a state, regional, and national basis. According to the 2016 report, fishing and seafood industries are a strong part of the Alabama economy. Alabama fishermen harvested more than 25 million pounds of finfish and shellfish in 2014, earning $68.8 million for their catch. In the report, the seafood industry is defined as the commercial harvest sector, seafood processors and dealers, seafood wholesalers and

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113 Moser, S. C., M. A. Davidson, P. Kirshen, P. Mulvaney, J. F. Murley, J. E. Neumann, L. Petes, and D. Reed, 2014: Ch. 25: Coastal Zone Development and Ecosystems. Climate Change Impacts in the US: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., US Global Change Research Program, 579-618.

114 US Department of Transportation, 2017. Port Performance Freight Statistics Program: Annual Report to Congress. Retrieved at: https://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/port-performance/216906/port-performance-2017-revised-2-12-18.pdf

115 Alabama State Port Authority, 2018. Port Facts. Retrieved at: http://www.asdd.com/portfacts.html

116 Moser, S. C., M. A. Davidson, P. Kirshen, P. Mulvaney, J. F. Murley, J. E. Neumann, L. Petes, and D. Reed, 2014: Ch. 25: Coastal Zone Development and Ecosystems. Climate Change Impacts in the US: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., US Global Change Research Program, 579-618.

distributors, importers, and seafood retailers. In 2014, the Alabama seafood industry supported 15,059 full- and part-time jobs and generated $661 million in sales, $252 million in income, and $333 million in value-added impacts. In the same year, approximately 853,000 recreational saltwater anglers took 2.2 million saltwater fishing trips in Alabama. These anglers spent $141 million on fishing trips and $1.3 billion on durable fishing-related equipment. These expenditures contributed $1.1 billion in sales impacts to the state economy, generated $828 million in value-added impacts, and supported approximately 14,124 jobs.[117] Artificial reefs are an important part of the recreational fishing economy in Alabama. To date, Alabama's artificial reef program has included an estimated 15,000 artificial reefs offshore of Alabama, and 33 inshore reefs in the Mississippi Sound, Mobile Bay, and Perdido/Wolf Bay. These artificial reefs proved to be valuable to the fishing industry, increasing habitat complexity and promoting oyster production.[118]

Figure 3.42 Coastal Ecosystem Services (NOAA, 2018)

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[117] National Marine Fisheries Service. 2016. Fisheries Economics of the United States, 2014. U.S. Dept. of Commerce, NOAA Tech. Memo. NMFS-F/SPO-163, 237p.
[118] Alabama Marine Resources Division, 2018. Alabama's Artificial Reef Plan. Retrieved at: http://www.alreefs.com/resources/submitted_plan.pdf

3.2.10.2 Nature of the Hazard in Alabama

Alabama has approximately 607 miles of Gulf Coast shoreline, including the state's offshore islands and the tidal shorelines of Mobile and Baldwin counties.[119] Local sea level rise along the Gulf Coast is occurring more quickly than the global average because of relatively high rates of land subsidence. The best-understood cause of land subsidence along the Gulf Coast is the long-term rebound of the earth's crust following the retreat of the glaciers. This phenomenon is known as glacial isostatic adjustment and is described in Table 3.31. Throughout the Gulf of Mexico, glacial isostatic adjustment is driving land subsidence at a rate of at least 0.4 mm/year.[120]

Other causes of land subsidence on the Gulf Coast may include growth faulting and fluid extraction, but "the relative importance of these processes is still poorly understood because of their spatial and temporal variability."[121] Fluid extraction is most likely to be a contributor to land subsidence in areas where the density of oil and gas wells is highest and where the geotechnical properties of the substrate are most conducive to compaction. To show the areas in Alabama where fluid extraction is most likely to be a contributor to land subsidence, Figure 3.43 maps the location of oil and gas wells relative to the location of substrates prone to compaction. The location of substrates prone to compaction was derived from a 2004 USGS karst map depicting the location of thick, unconsolidated sediments with signs of subsidence.[122] Based on this overlay, the southern portions of Baldwin County are most likely to experience land subsidence caused by fluid extraction.

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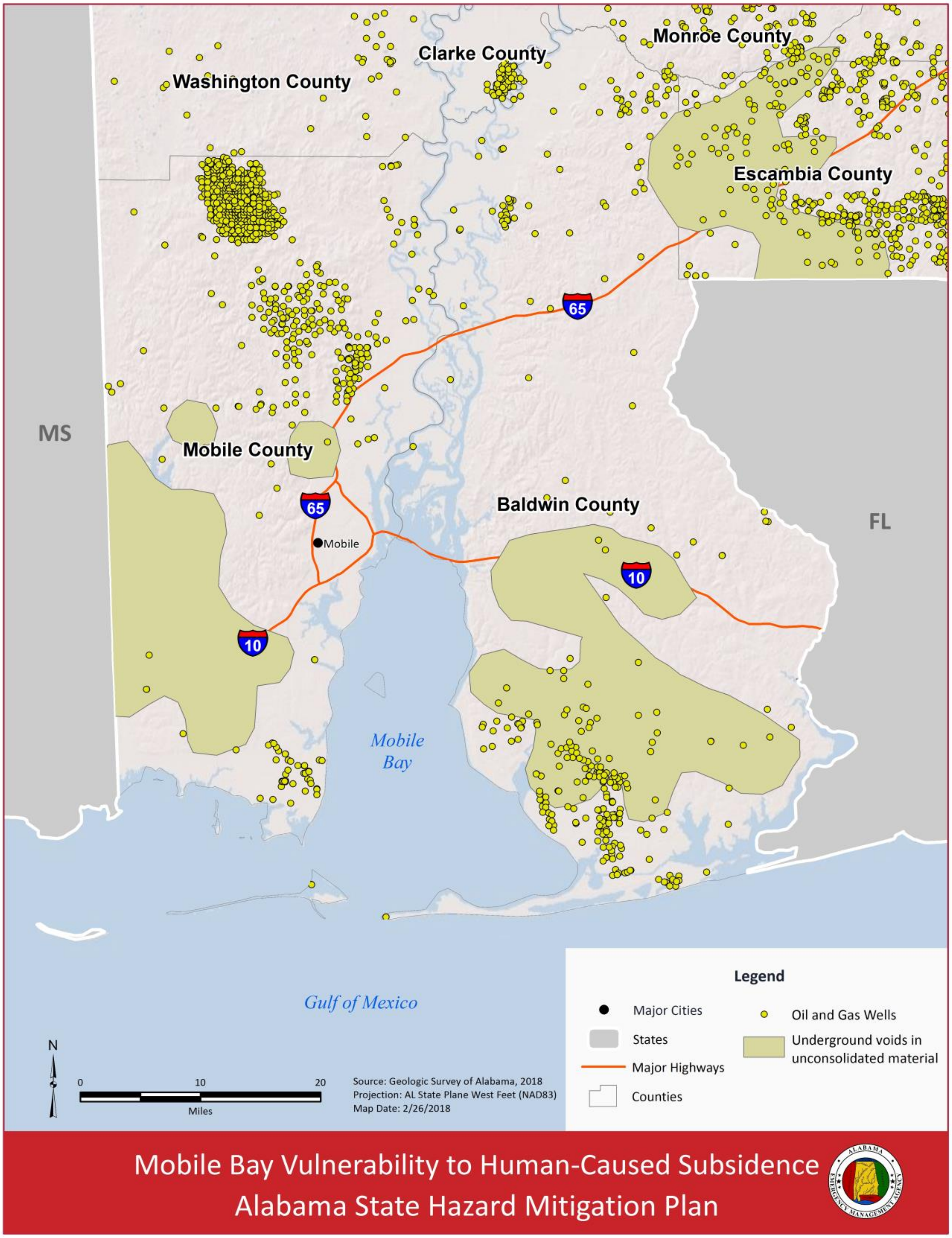
[119] National Oceanic and Atmospheric Administration, 2018. Shoreline Mileage of the US. Retrieved at: https://coast.noaa.gov/data/docs/states/shorelines.pdf
[120] US Geological Survey, 2016. Subsidence and Coastal Geomorphic Change in South-Central Louisiana. Retrieved at: https://coastal.er.usgs.gov/geo-evo/research/la-subsidence.html
[121] Ibid.
[122] US Geological Survey, 2004. Engineering aspects of karst. Open-File Report 2004-1352, Retrieved at: https://pubs.usgs.gov/of/2004/1352/data/USA_karst.pdf

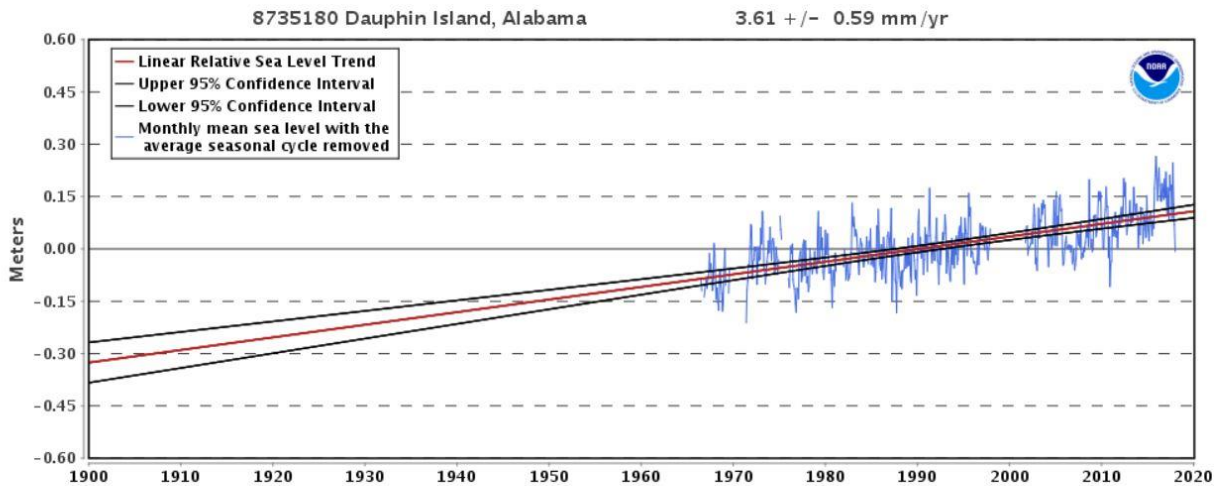
Figure 3.43 Vulnerability to Human-Caused Coastal Subsidence (GSA, 2018 and USGS, 2004)



3.2.10.3 Sea Level Rise History in Alabama

NOAA tracks local sea level rise through its National Water Level Observation Network (NWLON). This network includes nine tide stations in Alabama. Only the Dauphin Island and Mobile State Docks, however, have records long enough to detect long-term trends in local sea level. Figure 3.44 shows the long-term trend in mean sea level measured by the station at Dauphin Island.

Figure 3.44 Dauphin Island Sea Leve Trend (NOAA, 2018)



Based on a comprehensive analysis of observed sea levels, NOAA determined that local sea levels at Dauphin Island are rising at an average rate of 3.61 mm/year (with a 95% confidence interval of +/- 0.59 mm/year), while local sea levels at the Mobile State Docks are rising at an average rate of 3.45 mm/year (with a 95% confidence interval of +/- 1.62 mm/year).[123] These local trends exceed the global average of 1.7 mm/year, but are lower than some of the local trends observed in Louisiana and Texas. By separating the various components of local sea level rise, NOAA has also developed estimates of the rate of vertical land motion for the tide stations with the longest records. Based on data collected between 1966 and 2006, the land surface at the Dauphin Island station was estimated to be subsiding at an average rate of 1.22 mm/year.[124]

3.2.10.4 Probability of Sea Level Rise in Alabama

Sea level rise is a certainty along the Alabama coast. The important questions in assessing the hazards posed by local sea level rise are:

- How quickly is local sea level expected to rise, and

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[123] National Oceanic and Atmospheric Administration, 2018. Sea Level Trends, Retrieved at: https://tidesandcurrents.noaa.gov/sltrends/

[124] National Oceanic and Atmospheric Administration, 2013. Estimating Vertical Land Motion from Long-Term Tide Gauge Records. Technical Report NOS CO-OPS 065. Retrieved at: https://tidesandcurrents.noaa.gov/publications/Technical_Report_NOS_CO-OPS_065.pdf

- How much time do coastal communities have to prepare for the different levels of coastal change (i.e., nuisance flooding, chronic inundation, and coastal land loss)

The future rate of local sea level rise along a particular coast will depend on the future rate of global sea level rise, as well as the future rate of local land subsidence. Each of these rates could follow a range of trajectories, depending on what stresses human activities exert on natural systems and how those systems respond. Key determinants of the rate of global sea level rise include how aggressively greenhouse gas emissions are reduced and how quickly land-based glaciers and ice sheets melt. Key determinants of the rate of local subsidence include how aggressively underground oil, gas, and water resources are extracted and how quickly regional land elevations fall.

To help communities plan for and adapt to the risk of rising sea levels, NOAA has developed local sea level rise scenarios for tide stations across the US. These local scenarios begin in the year 2000 and account for global sea level rise, changes in regional ocean circulation, and local vertical land motion.[125] Six scenarios were developed to reflect the many possible futures that could result from human interaction with the global climate system – Low, Intermediate-Low, Intermediate, Intermediate-High, High, and Extreme. While each scenario is designed to be scientifically plausible, each has a different probability of being equaled or exceeded. Table 3.33 presents the probabilities for each NOAA scenario and shows how those probabilities differ under two different greenhouse gas emissions scenarios: a moderate and a high emissions scenario.[126] The moderate scenario assumes that moderate greenhouse gas mitigation policies are put in place through the rest of the century, limiting greenhouse gas emissions through the year 2100. The high scenario assumes an upper bound of business-as-usual greenhouse gas emissions through the rest of the century with no additional greenhouse gas mitigation policies put in place.

Table 3.33 Probability of exceeding Global Mean Sea Level Rise scenarios in 2100

NOAA Sea Level Rise Scenario	Moderate Emissions Scenario (RCP 4.5)	High Emissions Scenario (RCP 8.5)
Low	98%	100%
Intermediate-Low	73%	96%
Intermediate	3%	17%
Intermediate-High	0.5%	1.3%
High	0.1%	0.3%
Extreme	0.05%	0.1%

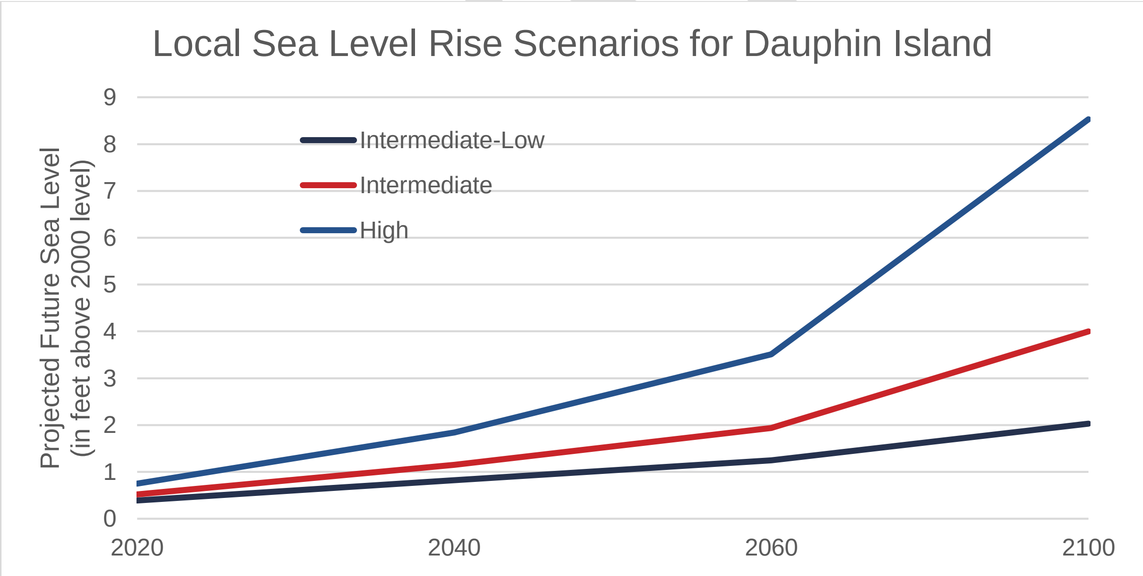
[125] Sweet, W. V., Kopp, R. E., Weaver, C. P., Obeysekera, J., Horton, R. M., Thieler, E. R., & Zervas, C. (2017). Global and regional sea level rise scenarios for the US. NOAA Technical Report NOS CO-OPS 083. NOAA/NOS Center for Operational Oceanographic Products and Services.
[126] Kopp, R.E., Horton, R.M., Little, C.M., Mitrovica, J.X., Oppenheimer, M., Rasmussen, D.J., Strauss, B.H., and Tebaldi, C. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future, v. 2, p. 383–406.

For the purposes of this plan update, the Intermediate-Low, Intermediate, and High sea level rise scenarios were selected for further analysis. As shown in Table 3.33, these scenarios span a range of probabilities under business-as-usual greenhouse gas emissions. While the Intermediate-Low sea level rise scenario has a 96% chance of being equaled or exceeded, the Intermediate scenario has a 17% chance of being equaled or exceeded, and the High scenario has a 0.3% chance. In Alabama, NOAA developed local sea level rise projections for the tide station located on Dauphin Island. Table 3.34 and Table 3.34Figure 3.45 show the local sea level rise projections for Dauphin Island in both a table and chart format. Note that NOAA also provides guidelines to help decision-makers choose sea level rise scenarios that are compatible with local priorities and risk tolerances. These guidelines can be found in Section 6 of the 2017 NOAA technical report: Usage of Scenarios within a Risk-Based Context.[127]

Table 3.34 Sea Level Rise Scenarios for Dauphin Island (in feet above 2000 level) (NOAA, 2017)

Scenario/Year	2020	2040	2060	2100
Intermediate-Low	0.39	0.82	1.25	2.03
Intermediate	0.52	1.15	1.94	4.00
High	0.75	1.84	3.51	8.53

Figure 3.45 Sea Level Rise Scenarios for Dauphin Island (NOAA, 2017)



In all scenarios, local sea levels are expected to rise to one foot above the 2000 level in the relatively near future (between 2025 and 2045). More divergence is seen among the scenarios, however, with time. According to the three selected scenarios, two feet of sea level rise could

[127] Sweet, W. V., Kopp, R. E., Weaver, C. P., Obeysekera, J., Horton, R. M., Thieler, E. R., & Zervas, C. (2017). Global and regional sea level rise scenarios for the US. NOAA Technical Report NOS CO-OPS 083. NOAA/NOS Center for Operational Oceanographic Products and Services.

occur between 2040 and 2100, and three feet of sea level rise could occur between 2055 and well past 2100.

Translating the rate of local sea level rise in Alabama into the amount of time that coastal communities must prepare for different levels of coastal change would require complex, high-resolution analyses that are beyond the scope of this hazard mitigation plan. To illustrate the extent of the communities that will be affected by sea level rise, however, Figure 3.46 shows the land area that would be permanently submerged by one, three, and six feet of local sea level rise. The darker the color, the smaller the rise in sea level that is necessary to submerge the area, and the sooner the area will be impacted.

It is important to remember that permanent submergence is the final step in a progression of increasingly costly and disruptive impacts. Consider the areas shown as submerged with six feet of local sea level rise—while permanent inundation may not occur until 2100, the interim effects of nuisance flooding and chronic inundation will occur well before that time.

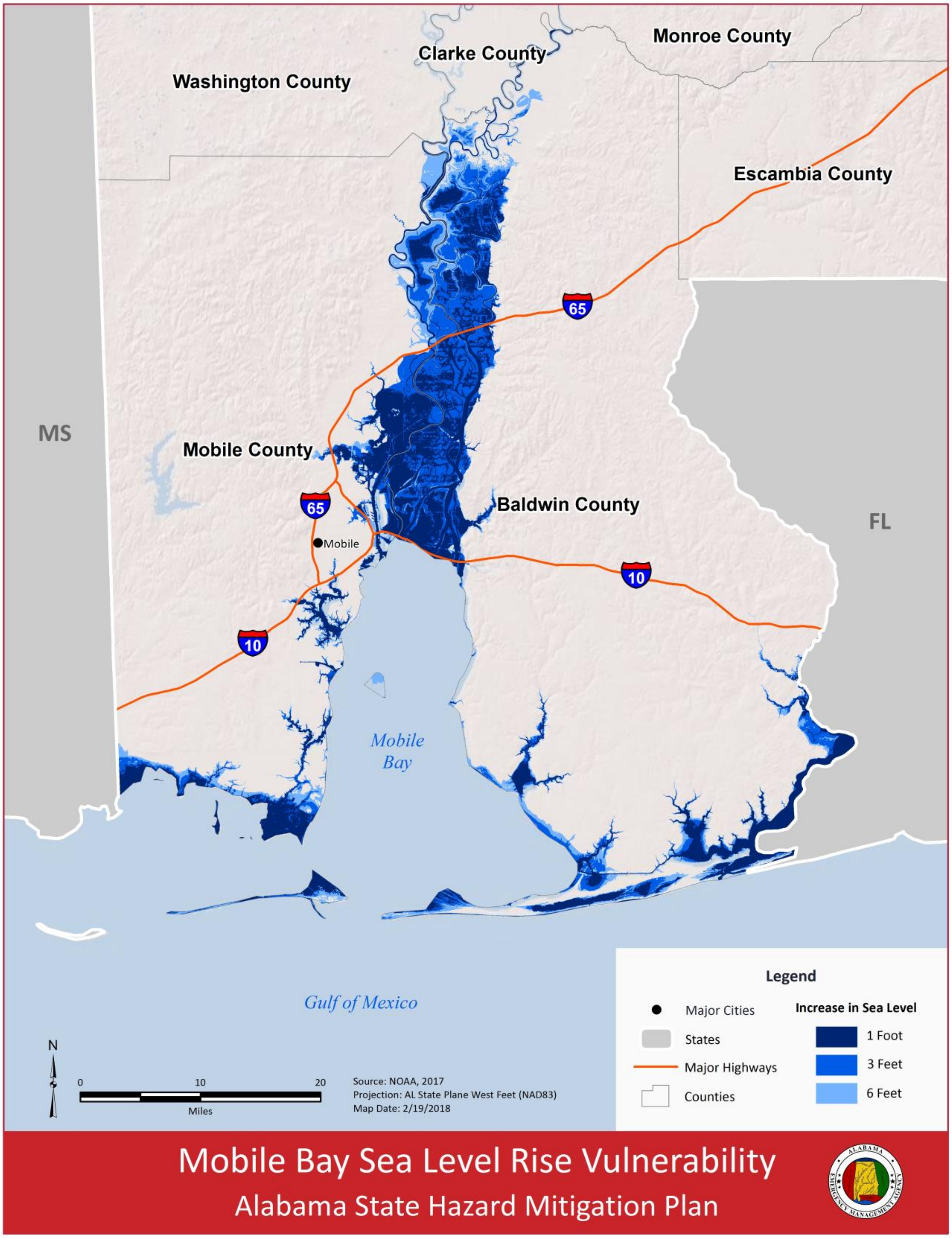
3.2.10.4.1 Future Probability

Sea level rise differs from the other hazards profiled in this plan update in that the hazard is a gradual process moving forward over time, as opposed to a discrete and episodic event. The concept of future change is therefore embedded in this hazard, and a discussion of its future probability would be redundant.

3.2.10.4.2 Risk and Vulnerability

A detailed assessment of vulnerability to sea level rise in Alabama is provided in Section 5.3

Figure 3.46 Alabama Sea Level Rise Scenarios (NOAA, 2017)



3.2.11 Sinkholes and Land Subsidence

3.2.11.1 Description

Land subsidence is the loss of surface elevation due to the removal of subsurface support. This geologic hazard can be caused by many different natural processes and human activities, and ranges from slow, regional lowering of the land surface to sudden, localized collapse. 5.1.1.1.1.1.1Table 3.35 summarizes the nature and causes of several types of land subsidence.

Table 3.35 Types of Land Subsidence

Subsidence Type	Nature	Cause	Description
Sinkhole	Sudden or slow-growing sinkhole or collapse	Naturally-occurring	Collapse of surficial material into underground voids usually created by the dissolution of soluble bedrock. Most of the sinkhole-related subsidence in the US is associated with areas underlain by carbonates such as limestone. These areas are also known as karst areas.
Mining	Sudden, local collapse	Human-induced	Collapse of surficial material into underground voids created by abandoned mines. Most of the mining-related subsidence in the US is associated with coal mines.
Underground Fluid Withdrawal	Broad, regional lowering	Human-induced	Sediment compaction caused by the removal of fluid from an underground reservoir. This type of subsidence is commonly associated with the extraction of groundwater and petroleum.
Natural Compaction	Broad, regional lowering	Naturally-occurring	Sediment compaction that occurs as older sediment is buried by younger sediment. In the US, this type of subsidence is occurring most rapidly in the Mississippi River Delta area.
Draining of Organic Soils	Broad, regional lowering	Human-induced	Elevation loss caused by the dewatering of organic soils, which then lose their volume. In the US, this type of subsidence is occurring most rapidly in the greater New Orleans area, the Everglades, and the Sacramento-San Joaquin River Delta area.

Subsidence poses a greater risk to property than to life. Local collapse can damage or destroy buildings, roads, or utilities and can remove land from productive use. Broad, regional lowering

can aggravate flood risk in an area or even permanently inundate an area. Damage can also include business and personal losses that accrue during periods of repair.

This section addresses the localized subsidence associated with mining and sinkholes (see Section 3.2.10 for additional information on subsidence in coastal areas). The potential for sinkholes is highest in areas with a type of terrain known by geologists as karst. The USGS defines karst as "distinctive surficial and subterranean features . . . characterized by closed depressions, sinking streams, and cavern openings."[128] Karst terrain usually occurs where the surface is underlain by rocks that are easily dissolved by water, such as carbonates, sulfates, and halides. Karst terrain can also develop, however, through processes other than the dissolution of rocks that create underground voids.

The underground voids in karst range in size from small fissures and tubes to large caves and caverns. For underground voids caused by the dissolution of soluble rock, the number and size of solution features tends to be larger at lower latitudes and in younger rocks. The underground voids in karst terrain give rise to many problems for structural and civil engineers. Large caves increase the potential for sinkhole collapse and gradual subsidence; solution tubes can lead to subsidence, flooding of excavations, leaks in reservoirs, and weakening of retaining walls; and solution fissures can lead to leaks in reservoirs and instability in cuts, bridge abutments, piers, and dam foundations and abutments.

While sinkholes are a naturally occurring geologic process, the rate of sinkhole growth can be increased in populated areas where groundwater conditions are altered by excessive pumping or subsurface drainage systems (such as tile drainage systems on farms). The lowering of the water table removes the support provided by the hydrostatic pressure of water, and the loss of support can result in the collapse of the surface into underground voids. Drought, excessive rainfall, and construction activities can also create conditions favorable to sinkhole development.

3.2.11.2 Nature of the Hazard in Alabama

Alabama, in particular the north and northeastern part of Alabama, is part of the well-known Tennessee-Alabama-Georgia area of caves and sinkholes (TAG area). The TAG area is one of the densest karst areas of the US. The karst areas in Alabama most prone to sinkhole formation are concentrated in four physiographic sections: the Highland Rim, with the greatest sinkhole density in a West-to-East band associated with the geologic unit Tuscumbia Limestone; the Cumberland Plateau, with the greatest density in the northern plateau and Northeast to Southwest trending units of the Bangor Limestone and Knox Group; parts of the Alabama Valley and Ridge, with greatest density in the Knox Group, Chepultepec Dolomite, and Copper Ridge Dolomite; and the southern part of the Coastal Plain, including residuum of the Eocene-Oligocene units, Miocene Series, and parts of the Citronelle Formation.

[128] US Geological Survey, 2004. A GIS version of Davies, W.E., Simpson, J.H., Ohlmacher, G.C., Kirk, W.S., and Newton, E.G., 1984, Engineering aspects of karst. Open-File Report 2004-1352.

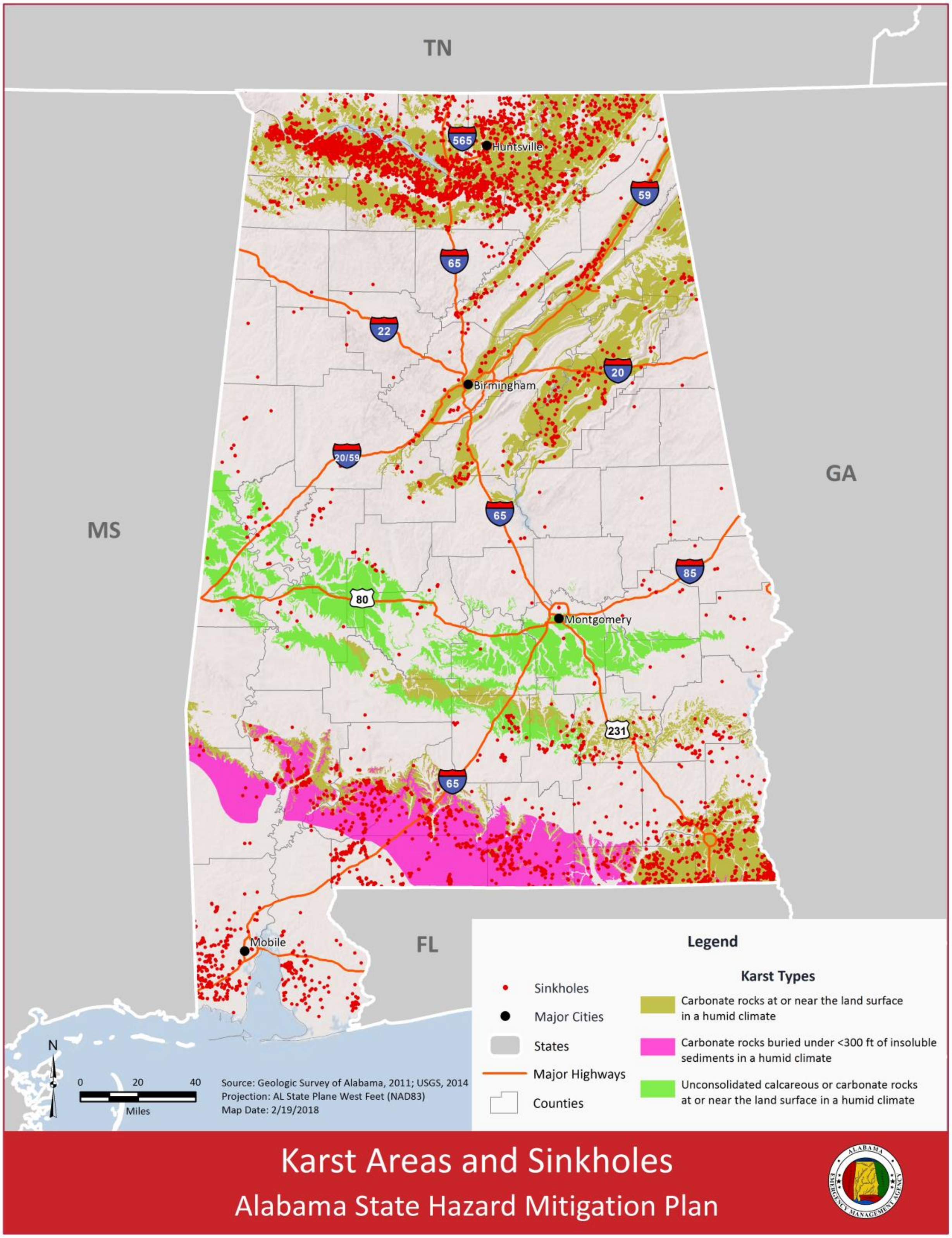
5.1.1.1.1.1.1Table 3.35Figure 3.47 shows the distribution of karst areas and sinkhole incidence in Alabama. The karst areas are shaded according to the type of underlying rock. The band of karst areas in the center of the state consists mostly of unconsolidated calcareous or carbonate rocks and tends to be least prone to sinkhole development. The karst areas in the Coastal Plains consist mostly of carbonate rock buried deeply beneath insoluble sediments. These areas are prone to broad, slowly-developing, shallow sinkholes. The karst areas in the northern part of the state can be prone to sudden sinkhole collapse. In the Valley and Ridge and Cumberland Plateau physiographic sections, sinkholes are often related to carbonate geology with and without complex structures and faults. In the Highland Rim and northern Cumberland Plateau physiographic sections, cave density and sinkhole density are well correlated, with some sinkholes being connected to caves in deep vertical shafts. The northern tier of Alabama includes some of the state's most populous areas (including Huntsville), and is among the most intensely developed karst areas in the US.

Localized subsidence is also common in those areas of the state underlain by abandoned coal and iron mines. Pillars left for roof support in the mines generally deteriorate over time and eventually collapse, removing support. This is particularly a problem where mines underlie more recently developed residential areas and roads. Abandoned coal mines in Alabama are concentrated in the northeast and central Alabama, especially in areas underlain by the Pottsville Formation geologic unit.

Groundwater withdrawal is an important driver of sinkhole development in Alabama. Geologists estimate that more than 4,000 human-induced sinkholes and areas of subsidence have occurred in Alabama since 1900. Most have occurred since 1950, and most have resulted from a decline in the water table associated with groundwater withdrawals. Sinkholes related to wells tend to be located within 150 meters of the site of withdrawal, while sinkholes related to quarry operations tend to be located within 600 meters of the site of withdrawal. Recent sinkholes associated with groundwater withdrawal have ranged from 1 to 90 meters in diameter, and from 0.3 to 30 meters in depth.[129]

[129] Poland, J. F., & International Hydrological Programme. (1984). Guidebook to studies of land subsidence due to ground-water withdrawal. Paris: Unesco.

Figure 3.47 Karst Terrain and Active Sinkholes (USGS, 2014)



3.2.11.3 Sinkholes and Land Subsidence History in Alabama

Sinkholes are becoming an increasing problem in Alabama as the population encroaches on scenic rural valleys underlain by limestone in the Valley and Ridge province, and as large metropolitan areas in the Cumberland Plateau of north Alabama continue to expand. In addition, as water demand for agricultural production continues to increase, the state is seeing more sinkhole growth associated with groundwater withdrawals. Recent years have seen sinkholes reported throughout the state, and periods of drought have aggravated the problem.

Alabama does not maintain a statewide real-time or near real-time record or reporting system of sinkhole events throughout the state. The GSA has, however, developed a map of sinkholes. This map was prepared by examining the 1:24,000-scale topographic maps published by the US Geological Survey between 1938 and 1987 and identifying all topographic depressions that were likely produced by naturally-occurring sinkholes. The location of these historical sinkholes is shown in 5.1.1.1.1.1.1Table 3.35Figure 3.47.

Despite the lack of a real-time reporting system, sinkholes in Alabama are known to cause costly damage and accidents. Collapses have occurred beneath highways, streets, railroads, buildings, sewers, gas pipelines, and vehicles.[130] The cost of road repairs related to sinkhole development demonstrate the considerable damage that sinkholes can cause. In 2013, a sinkhole affecting the northbound lane of Interstate 65 in Morgan County cost $1.2 million to repair. Other sinkholes costing hundreds of thousands of dollars to repair have occurred along Interstate 59 in Birmingham, near Regions Field in Birmingham, and along Weaver Road in Anniston.

To illustrate the potential impacts of sinkholes in Alabama, 5.1.1.1.1.1.1Table 3.36 describes several of the most widely-reported sinkhole events throughout the state. Images are available for two of the sinkholes and are reproduced below the table. Since 2012, the GSA has received over 164 requests for information on sinkholes. Of these, 135 pertained to sinkholes on personal property that sustained damage (this includes damage to land as well as structures).

[130] Poland, J. F., & International Hydrological Programme. (1984). Guidebook to studies of land subsidence due to ground-water withdrawal. Paris: Unesco.

Table 3.36 Historical Sinkhole Events

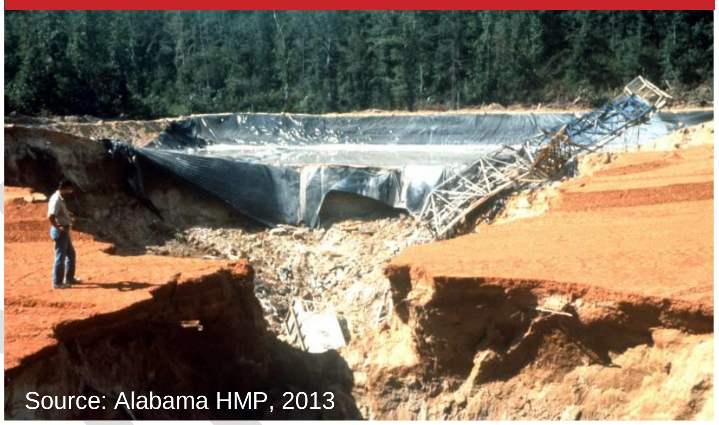
Date	Location	Description
1972	City of Calera Shelby County	A large sinkhole developed near Calera in a matter of seconds in December 1972. The sinkhole is about 425 feet long, 350 feet wide and 150 feet deep. Called the "December Giant" or the "Golly Hole," the sinkhole is the largest on record in the US. This sinkhole occurred during a drought when the water table was much lower than normal. It was found by hunters two days after someone reported hearing a roaring noise, trees breaking, and his house shaking.
1990	Hale County	In 1990, a sinkhole was formed in Hale County. An oil and gas drill rig had reached a depth of 755 feet when the drilling fluid was lost in the hole. In a period of two hours, unconsolidated sediments overlying carbonate rock sunk into subsurface cavities, carrying the drill rig downward with them. The weight of the fluids in the adjacent mud pit facilitated the rapid downward movement of the sediments. Another well was successfully drilled across the road to a total depth of 12,000 feet.
Late 1990s	City of Trussville Jefferson County	Trussville provides a prime example of the impact sinkholes can have on a growing community where land and groundwater are both in great demand. Sinkholes first formed beneath and around the Trussville Middle School, forcing closure and rebuilding of the school at another site. Sinkholes continued to develop in a nearby park and neighborhood and emptied a pond. Damage has been estimated to be millions of dollars.
2007	City of Madison Madison County	During an extreme drought in northern Alabama, a sinkhole formed beneath the corner of a house in a new subdivision, and the house tipped into the depression. More than $100,000 was spent to repair the house and protect it from future impacts.
2008	City of Birmingham Jefferson County	In January 2008, a Bush Hills homeowner lost his house when it was swallowed by a massive sinkhole. The sinkhole was 75 feet wide at its widest and 30 feet deep.
2013	City of Hartselle, Morgan County	A sinkhole measuring 4 feet deep and 3 feet wide developed in the southbound lane of Interstate 65. An emergency lane closure was implemented while crews repaired the highway. Road closures for sinkhole repair are not uncommon in northern Alabama.

Figure 3.48 Widely-Reported Sinkholes

1972 Calera Sinkhole (“Golly Hole”)

Source: Time Magazine, 1973

1990 Hale County Sinkhole



Source: Alabama HMP, 2013

2008 Birmingham Sinkhole

Source: Birmingham News, 2008

3.2.11.4 Probability of Sinkholes and Land Subsidence in Alabama

The probability of sinkholes and land subsidence cannot be expressed in terms of specific frequencies or return periods. These events are the culmination of multiple naturally-occurring and human-induced geological processes that play out over a range of timescales and can be highly localized. Areas that are more sinkhole-prone can be identified, however, based on geologic characteristics and historic sinkhole events (5.1.1.1.1.1.1Table 3.35Figure 3.47). As discussed above, the karst areas in the northern part of the state, in the Valley and Ridge and Cumberland Plateau provinces, are most prone to sinkholes.

3.2.11.4.1 Future Probability

Some of the processes that tend to accelerate sinkhole development may be impacted by future climate change. These include drought conditions and groundwater withdrawals, both of which can remove the support provided by water pressure and lead to the collapse of underground voids. If drought periods become more intense and prolonged in the future, the incidence of sinkholes in Alabama may increase, particularly in the state's northern counties.

3.2.11.4.2 Risk and Vulnerability

A community's vulnerability to sinkhole loss is a function of the probability of sinkholes, the exposure of structures to sinkholes, and the susceptibility of structures to sinkholes. In Alabama, the communities in the greater Huntsville area and the greater Birmingham area are more vulnerable to loss from sinkholes due, in part, to larger populations. However, other populations mentioned in section 5.2.11.2 and shown in figure 5.44 are also vulnerable.

Another important consideration is the environmental risk posed by sinkholes. Groundwater is the main water resource for 44% of the state's population, including several large cities and many smaller towns. Since sinkholes are direct conduits to the state's groundwater supply, dumping in sinkholes and spills in karst areas have the potential to contaminate the public's water supply. this makes them (and the public's water supply) highly vulnerable to contamination. Recognizing the potential for contamination, Alabama has a state law that prohibits dumping in sinkholes.

3.2.12 Tsunamis

3.2.12.1 Description

A tsunami is a series of long waves generated in the ocean by a sudden displacement of a large volume of water. Underwater earthquakes, landslides, volcanic eruptions, meteor impacts, or onshore slope failures can cause this displacement. Most tsunamis originate in the Pacific "Ring of Fire," the area of the Pacific bounded by the eastern coasts of Asia and Australia and the western coasts of North America and South America, which is the most active seismic feature on earth. Tsunami waves can travel at speeds averaging 450 to 600 miles per hour. As a tsunami nears the coastline, its speed diminishes, its wavelength decreases, and its height increases greatly. Unusual heights have been known to be over 100 feet high. However, waves that are 10 to 20 feet high can be very destructive and cause many deaths and injuries.

After a major earthquake or other tsunami-inducing activity occurs, a tsunami could reach the shore within a few minutes. From the source of the tsunami-generating event, waves travel outward in all directions in ripples. As these waves approach coastal areas, the time between successive wave crests varies from 5 to 90 minutes. The first wave is usually not the largest in the series of waves, nor is it the most significant. One coastal community may experience no damaging waves while another may experience destructive deadly waves. Some low-lying areas could experience severe inland inundation of water and deposition of debris of more than 1,000 feet inland.

Along the West Coast, the Cascadia Subduction Zone threatens California, Oregon, and Washington with devastating local tsunamis. Earthquakes of magnitude of 8 or more have happened in the zone, and there is a 35 percent chance that an earthquake of this magnitude could occur before 2045 (estimated between the years 1995 and 2045).

3.2.12.2 Nature of the Hazard in Alabama

According to the US States and Territories National Tsunami Hazard Assessment, tsunami risk on the US Gulf Coast is Very Low.[131] Since the Gulf Coast is not near an active tectonic plate boundary, the chance of an underground earthquake causing a tsunami is minimal. Geologic studies indicate that a submarine landslide is the region's most likely tsunami source. Large submarine landslides occurred throughout the Gulf of Mexico more than 7,500 years ago. 5.1.1.1.1.1.1Table 3.36Figure 3.49 shows the locations of submarine landslides that occurred in the Gulf of Mexico during the Quaternary period (the last 2.588 million years). Landslide deposits are marked in red, and the dashed lines indicate geologic provinces.

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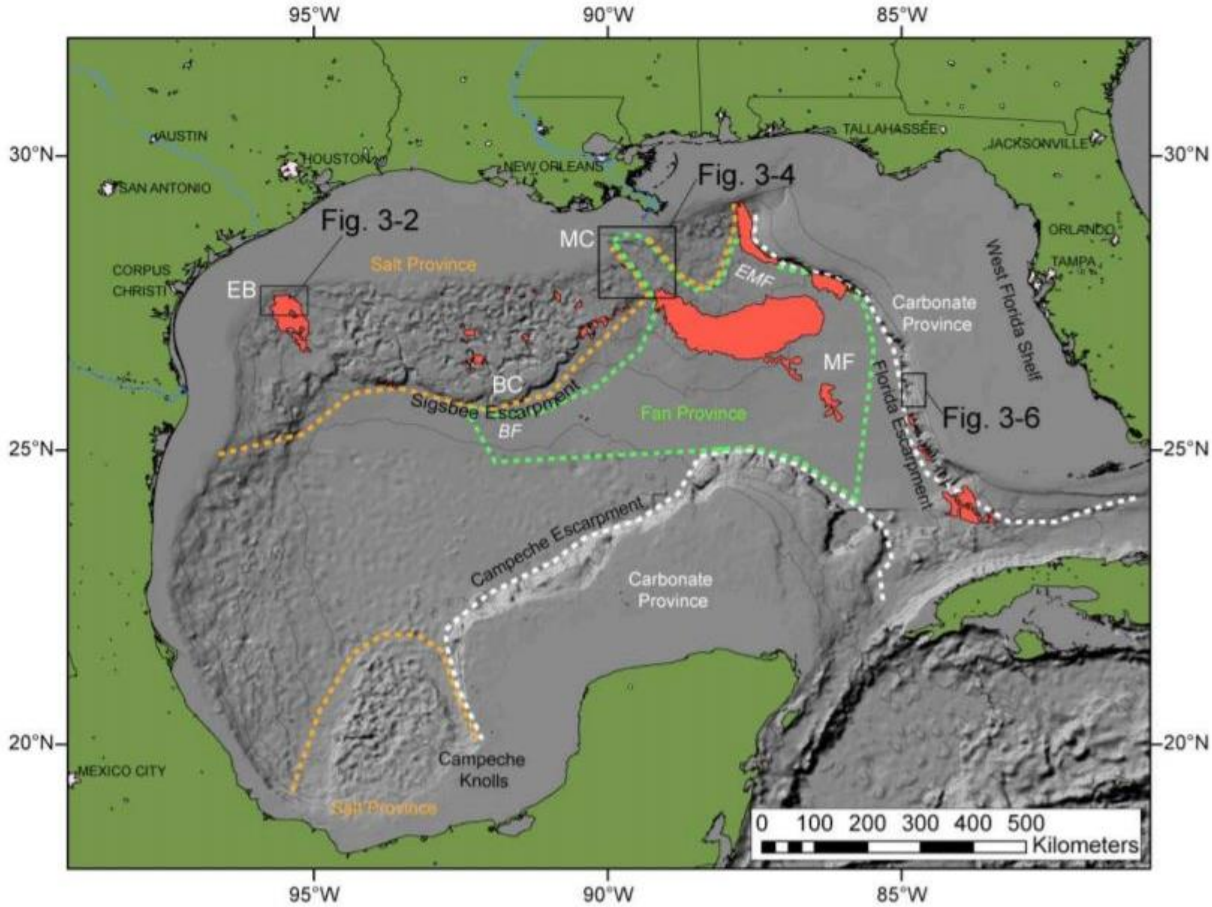
[131] National Oceanic and Atmospheric Administration and US Geological Survey, 2015. US and Territories National Tsunami Hazard Assessment: Historical Record and Sources for Waves – Update. Retrieved at: http://nws.weather.gov/nthmp/documents/Tsunami_Assessment_2016Update.pdf

Figure 3.49 Large Submarine Landslides in the Gulf of Mexico (USGS, 2008)



Although the tsunami risk in Alabama is low, the consequences would be significant. If a tsunami were to reach Alabama, the state's relatively shallow shoreline relief and densely populated coastal areas would expose coastal communities to significant losses. In addition, rare tsunami events must be considered in long-range planning, such as in the placement of nuclear power plants. Scientists are continuing to study the threat of landslide-generated tsunamis along the Gulf Coast, and future hazard mitigation plans should be updated to reflect their findings.

3.2.12.3 Tsunami History in Alabama

No tsunamis are recorded as occurring in Alabama. Along the Gulf Coast, the only confirmed tsunami observation is from an aftershock of the 1918 Mona Passage earthquake. The Mona Passage connects the Atlantic Ocean and the Caribbean Sea, separating the islands of Puerto Rico and Hispaniola. This earthquake generated a small tsunami that was recorded by a tide gauge at Galveston, Texas.

3.2.12.4 Probability of Tsunamis in Alabama

Landslide tsunamis represent the most significant tsunami hazard to the Gulf Coast. The likelihood of a landslide tsunami in the Gulf Coast, however, is very small. Scientists studying

Quaternary landslides in the Gulf of Mexico have determined that the large landslides have not been active for more than 7,500 years.[132]

3.2.12.4.1 Future Probability

The future probability of tsunamis in Alabama is not expected to change with climate change.

3.2.12.4.2 Risk and Vulnerability

A community's vulnerability to tsunamis is a function of the probability of the hazard, the exposure of people and structures to the hazard, and the susceptibility of people and structure to tsunamis. In Alabama, the coastal communities of Mobile and Baldwin counties are most vulnerable to loss from tsunamis.

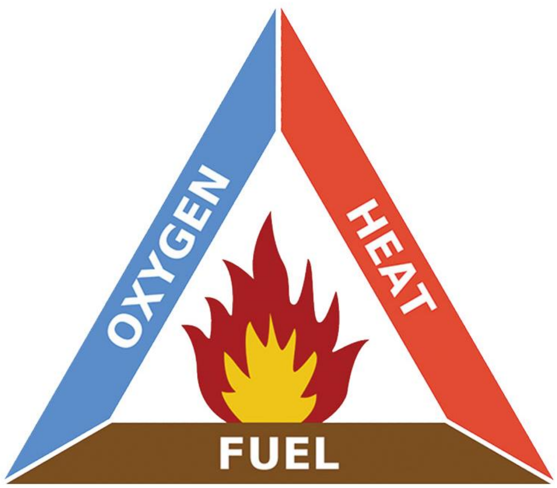
[132] National Oceanic and Atmospheric Administration and US Geological Survey, 2015. US and Territories National Tsunami Hazard Assessment: Historical Record and Sources for Waves – Update. Retrieved at: http://nws.weather.gov/nthmp/documents/Tsunami_Assessment_2016Update.pdf

3.2.13 Wildfire

3.2.13.1 Description

A wildfire can be defined as any non-structural fire that occurs in the wild. Wildfires are uncontrolled blazes fueled by weather, wind, and dry underbrush that have the ability to burn a significant amount of land in a very short period of time. Three conditions need to be present for a wildfire to burn: fuel, oxygen, and a heat source.[133] 5.1.1.1.1.1.1Table 3.36Figure 3.50 illustrates these three required conditions referred to as the fire triangle.

Figure 3.50 The Fire Triangle (Sonoma County Gazette, 2017)



Wildfires have a significant impact on the US. Over 100,000 wildfires clear up to 5 million acres of US land every year. Wildfires have the ability to destroy everything in their path. Three distinct types of wildland fires have been defined and include: naturally occurring wildfire, human-caused wildfire, and prescribed fire. Wildfires are typically human-caused, which distinguishes them from other natural disasters.[134]

The US Department of Agriculture Fire Service has adopted a National Fire Danger Rating System. The purpose of the system is to help prevent human-caused wildfires from occurring. This system allows fire managers to express the level of fire danger in an area (and the need for fire protection) in terms of qualitative or numeric indices. Knowledge of the fire danger level in an area can help people make decisions on whether it is safe to have a campfire, burn debris,

[133] National Geographic, 2018. Learn More About Wildfires. Retrieved at: https://www.nationalgeographic.com/environment/natural-disasters/wildfires/
[134] National Geographic, 2018. Learn More About Wildfires. Retrieved at: https://www.nationalgeographic.com/environment/natural-disasters/wildfires/

etc. If the fire danger level is very extreme, the National Forest has the ability to restrict certain activities. 5.1.1.1.1.1.1Table 3.37 provides an explanation of the different danger levels established by the National Fire Danger Rating System.[135]

Table 3.37 National Fire Danger Rating System (USDA Forest Service)

Fire Danger Rating and Color Code	Description
Low	Fuels do not ignite easily from small embers, but a more intense heat source, such as lightning, may start fires in duff or dry rotten wood. Fires in open, dry grasslands may burn easily a few hours after a rain, but most wood fires will spread slowly, creeping or smoldering. Control of fires is generally easy.
Moderate	Fires can start from most accidental causes, but the number of fire starts is usually pretty low. If a fire does start in an open, dry grassland, it will burn and spread quickly on windy days. Most wood fires will spread slowly to moderately. Average fire intensity will be moderate except in heavy concentrations of fuel, which may burn hot. Fires are still not likely to become serious and are often easy to control.
High	Fires can start easily from most causes and small fuels (such as grasses and needles) will ignite readily. Unattended campfires and brush fires are likely to escape. Fires will spread easily, with some areas of high-intensity burning on slopes or concentrated fuels. Fires can become serious and difficult to control unless they are put out while they are still small.
Very High	Fires will start easily from most causes. The fires will spread rapidly and have a quick increase in intensity, right after ignition. Small fires can quickly become large fires and exhibit extreme fire intensity, such as long-distance spotting and fire whirls. These fires can be difficult to control and will often become much larger and longer-lasting fires.
Extreme	Fires of all types start quickly and burn intensely. All fires are potentially serious and can spread very quickly with intense burning. Small fires become big fires much faster than at the "very high" level. Spot fires are probable, with long-distance spotting likely. These fires are very difficult to fight and may become very dangerous and often last for several days.

The occurrence of wildfires is monitored and reported by many different state and federal agencies. To consistently report the size of wildfires, all federal agencies use a fire size classification system developed by the National Wildfire Coordinating Group. This system assigns fires to one of several ranges of fire size based on the number of acres within the final

[135] US Department of Agriculture, Forest Service, 2018. National Fire Rating System. Retrieved at: https://www.fs.usda.gov/detail/inyo/home/?cid=stelprdb5173311

perimeter. The largest fires are assigned to Class D (100 to 300 acres), Class E (300 to 1,000 acres), Class F (1,000 to 5,000 acres), or Class G (5,000 acres or more).

3.2.13.2 Nature of the Hazard in Alabama

Approximately 71 percent of Alabama's land area is forestland, and 85 percent of this forestland is owned by nonindustrial private landowners.[136] Therefore, the vast majority of wildland fires in Alabama occur on privately owned lands. Additionally, the majority of the wildland fires in Alabama occur in areas where residential properties or other structures are endangered. Areas where homes are built near or among lands prone to wildland fire are known as the wildland-urban interface. As more people move into natural areas for their privacy, beauty, recreational opportunities, and affordable real estate, the wildland-urban interface in Alabama is growing and now faces the risk of major losses from wildfires. In Alabama, most wildland-urban interface areas are considered "intermixed." Instead of large forest areas surrounding an isolated town, the pattern of development in Alabama is characterized by many scattered residences and farms distributed throughout the forest areas. The state's extensive wildland-urban interface is shown in 5.1.1.1.1.1.1Table 3.37Figure 3.51.

Based on an analysis by the Alabama Forestry Commission, there are 1,350 potential wildland-urban interface communities at risk of wildfire damage in Alabama, and the number of these communities is projected to increase with time.[137] 5.1.1.1.1.1.1Table 3.37Figure 3.52 illustrates how housing density in Alabama has changed since 1990 and how it is expected to change through 2030. Decentralized growth patterns around Decatur and Huntsville in the state's north; Birmingham, Tuscaloosa, Montgomery, and Auburn in the state's center; and Mobile and Dothan in the state's south have led to the spread of urban areas throughout the state's rural landscapes. Much of this development is encroaching into forest lands, particularly in the northeastern portion of the state where the Appalachians extend into Alabama. This decentralized growth is driving the growth of the wildland-urban interface and increasing the risk of loss from wildfires.

[136] Alabama Cooperative Extension System, 2014. Meet the Neighbors: Understanding Who Owns Alabama's Woodlands. Retrieved at: https://www.researchgate.net/publication/278020431_Meet_the_Neighbors_Understanding_Who_Owns_Alabama's_Woodlands

[137] Southern Group of State Foresters, 2008. Fire in the South 2: The Southern Wildfire Risk Assessment. Retrieved at: http://www.southernforests.org/resources/publications/fire-in-the-south-2-pdf/view

Figure 3.51 Wildland-Urban Interface in Alabama (Alabama Forestry Commission)

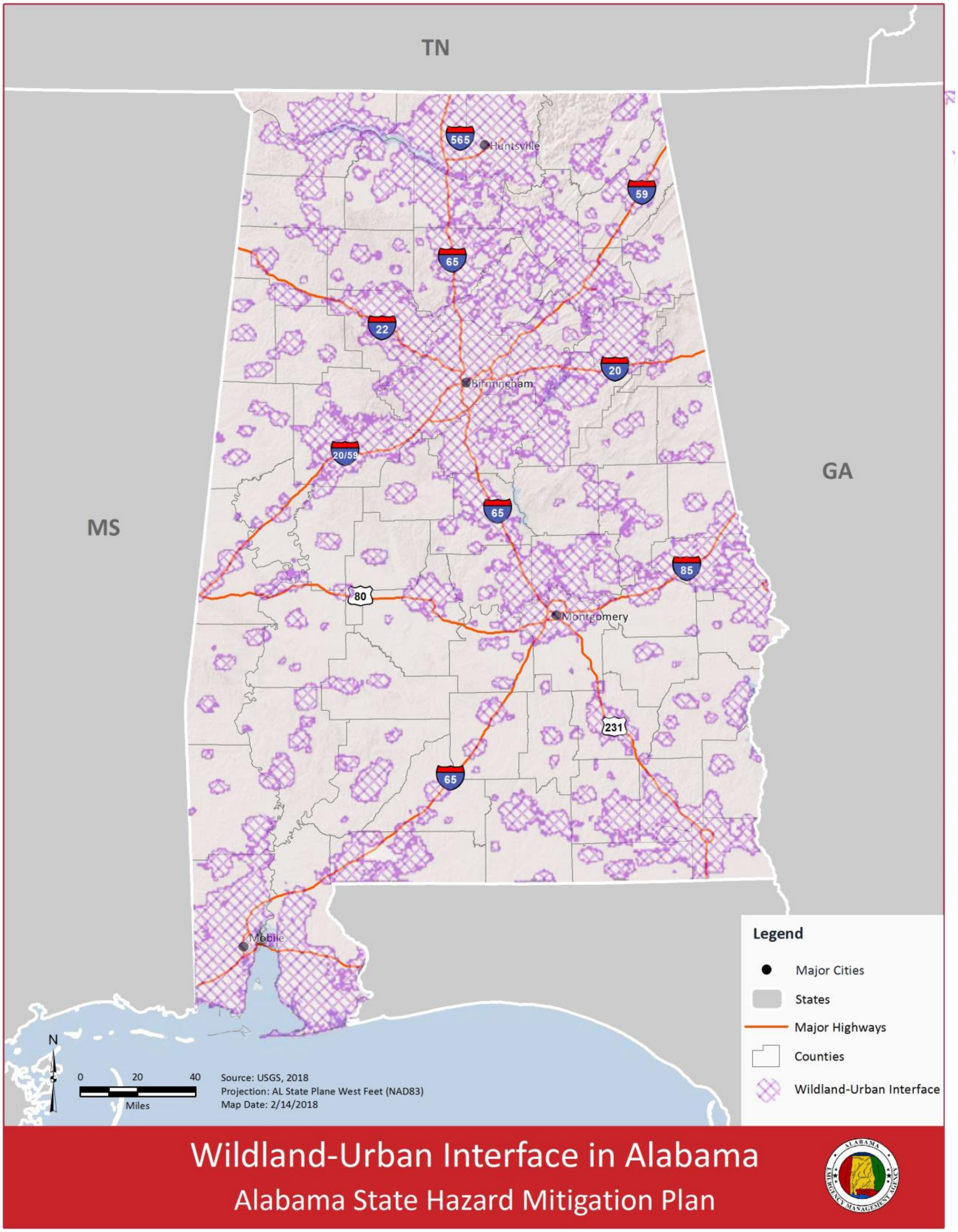
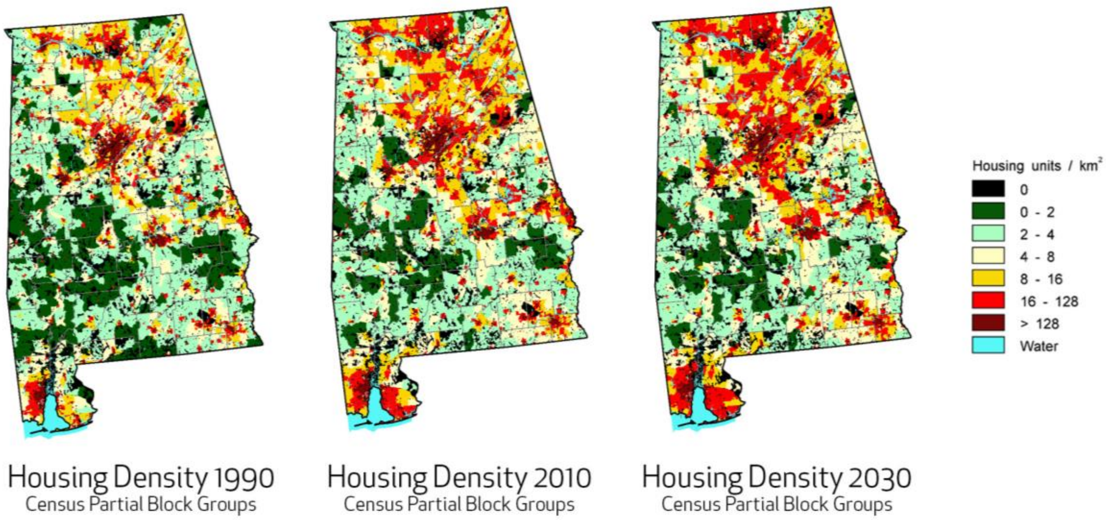


Figure 3.52 Alabama Housing Density Over Time (Hammer and Radeloff, 2005)



The following two factors contribute significantly to wildfire behavior in Alabama:

1. **Fuel:** The type of fuel and the fuel loading (measured in tons of vegetative matter per acre) have a direct impact on fire behavior. Fuel types vary from light fuels (grass) to moderate fuels (Southern Rough, or flammable evergreen shrubs) to heavy fuels (slash, or woody debris). The type of fuel and the fuel load determines the potential intensity of the wildfire and how much effort must be expended to contain and control it.
2. **Weather:** The most variable factor affecting wildfire behavior is weather. Important weather variables are precipitation, humidity, and wind. Weather events ranging in scale from localized thunderstorms to large cold fronts can have major effects on wildfire occurrence and behavior. Extreme weather, such as extended drought and low humidity can lead to extreme wildfire activity.

In addition to affecting people, wildfires may severely impact livestock. Wildfires often destroy food crops and supplies which inflicts severe economic losses on farmers. The forest resources of Alabama also supply one of the main industries of the state. Timber loss to fire creates an economic loss to both the private landowner and the state's economy. The forestry industry in Alabama directly creates 70,000 jobs, and another 100,000 jobs are associated with the industry. In total the industry adds about $12.2 billion to the economy each year.[138] Therefore, wildfires can potentially have a significant economic impact on the economy of the state.

[138] Southern Group of State Foresters, 2008. Fire in the South 2: The Southern Wildfire Risk Assessment. Retrieved at: http://www.southernforests.org/resources/publications/fire-in-the-south-2-pdf/view

Wildfires in Alabama generally are moderate in intensity, resulting in destruction of undergrowth and some timber. With Alabama's long growing season, the soil surface layer of the forest recovers quickly, minimizing erosion and water quality impacts.

3.2.13.3 Wildfire History in Alabama

The frequency and severity of wildfires is dependent on weather and on human activity. 5.1.1.1.1.1.1Table 3.38 shows the number of fires and acres burned from January 2009 through February 2018 recorded by the Alabama Forestry Commission. Alabama had a total of 18,807 fires during this 10-year period, affecting a total of 287,237 acres.[139] 5.1.1.1.1.1.1Table 3.39 shows data on wildfire size and cause for wildfires that occurred in Alabama between 1980 and 2016. This data was collected from fire records from the US Fish and Wildlife Service, the National Park Service and the US Forest Service within the US Department of Interior, and the US Department of Agriculture.[140] Nearly all wildfires in Alabama are human-caused. If not promptly controlled, wildfires may grow into an emergency or disaster. During a series of severe fire situations between 1999 and 2001, nine wildfires in Alabama were declared fire disaster emergencies by FEMA.[141] Even small fires, however, can threaten lives, damage forest resources, and destroy structures.

In Alabama, there are an average of 4,000 wildfires that burn 40,000 acres a year. On average, wildfires destroy 46 homes, 114 structures, and 1,100 vehicles per year.[142] The Alabama Forestry Commission's Annual Reports provide a wide variety of statistics related to wildfire occurrence and prevention. According to the Alabama Forestry Commission Annual Report for Fiscal Year 2016, between October 2015 and September 2016 1,793 wildfires burned 22,252 acres in Alabama. This caused the destruction or damage of 33 homes, 3,404 other structures, and 107 vehicles. However, about 1,265 homes were saved as a direct result of firefighter response.

The Forestry Commission is also heavily involved in mitigation activities. During the 2016 Fiscal Year, The Forestry Commission completed 27,492 acres in prescribed burns. Furthermore, the commission administered $1,042,810 in grant money appropriated by the Alabama Legislature. This grant money was used, among other things, to provide and maintain county-wide communication systems for volunteer fire departments in 37 counties and assisted in federal fire and in-state responses.[143]

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[139] Alabama Forestry Commission, 2018. Wildfire Information by Date Range. Retrieved at: http://www.forestry.alabama.gov/fire_totals_date_range.aspx?bv=1&s=4
[140] Department of the Interior, 2017. Federal Fire Occurrence Website. Retrieved at: https://wildfire.cr.usgs.gov/firehistory/about.html
[141] Federal Emergency Management Agency, 2018. FEMA Disaster Declarations Summary. Retrieved at: https://www.fema.gov/media-library/assets/documents/28318
[142] The Southern Group of State Foresters. Fire in the South. http://www.forestry.alabama.gov/PDFs/fire_in_the_south.pdf
[143] Alabama Forestry Commission, 2016. 2016 Annual Report. Retrieved at: http://www.forestry.state.al.us/PDFs/AFCAnnualReport2016.pdf

Table 3.38 Wildfires in Alabama, 2009 to 2018 (Alabama Forestry Commission, 2018)

County	Number of Fires	Acres Affected
Autauga County	217	1,673
Baldwin County	1,230	22,031
Barbour County	214	2,940
Bibb County	231	2,405
Blount County	209	4,055
Bullock County	137	2,615
Butler County	367	3,461
Calhoun County	314	11,259
Chambers County	250	2,144
Cherokee County	392	14,430
Chilton County	436	2,752
Choctaw County	317	2,202
Clarke County	259	2,216
Clay County	224	2,979
Cleburne County	328	9,515
Coffee County	134	1,291
Colbert County	202	1,611
Conecuh County	404	5,614
Coosa County	246	3,785
Covington County	241	2,973
Crenshaw County	168	963
Cullman County	237	4,391
Dale County	94	408
Dallas County	242	1,561
DeKalb County	625	6,725
Elmore County	114	1,376
Escambia County	478	9,687
Etowah County	153	2,449
Fayette County	164	1,450
Franklin County	176	3,265
Geneva County	155	1,593
Greene County	160	1,422
Hale County	234	1,072
Henry County	157	1,166

County	Number of Fires	Acres Affected
Houston County	122	855
Jackson County	205	3,009
Jefferson County	404	10,832
Lamar County	138	1,145
Lauderdale County	186	2,947
Lawrence County	135	3,386
Lee County	171	2,735
Limestone County	117	736
Lowndes County	169	1,847
Macon County	444	10,966
Madison County	57	209
Marengo County	214	2,146
Marion County	383	3,271
Marshall County	173	1,536
Mobile County	1,038	29,027
Monroe County	256	2,057
Montgomery County	157	1,669
Morgan County	157	1,443
Perry County	282	2,259
Pickens County	153	1,615
Pike County	152	1,351
Randolph County	225	1,846
Russell County	333	7,972
Saint Clair County	223	4,432
Shelby County	273	2,798
Sumter County	80	881
Talladega County	619	8,773
Tallapoosa County	314	3,534
Tuscaloosa County	326	3,634
Walker County	651	11,240
Washington County	640	12,750
Wilcox County	320	3,295
Winston County	181	1,570
Total	**18,807**	**287,237**

5.1.1.1.1.1.1Table 3.39 shows the fire size, total acres burned, and cause of fire for wildfires that occurred in Alabama from 1980 to 2016, and 5.1.1.1.1.1.1Table 3.38Figure 3.53 displays the location of the largest recorded events. The largest recorded events were defined as those with fire size classes of D, E, or F. The data used for this analysis is a collection of fire records from the US Fish and Wildlife Service, the National Park Service, the Bureau of Indian Affairs, the Bureau of Land Management, and the US Forest Service within the US Department of Interior and the US Department of Agriculture. Because these agencies only complete fire records when they participate in the fire response, this data represents a sample of all the fires that have occurred in Alabama. This sample, however, provides insight into the location and extent of past fires.[144]

[144] Department of the Interior, 2017. Federal Fire Occurrence Website. Retrieved at: https://wildfire.cr.usgs.gov/firehistory/about.html

Figure 3.53 Major Wildfire Occurrences (USGS, 2018)

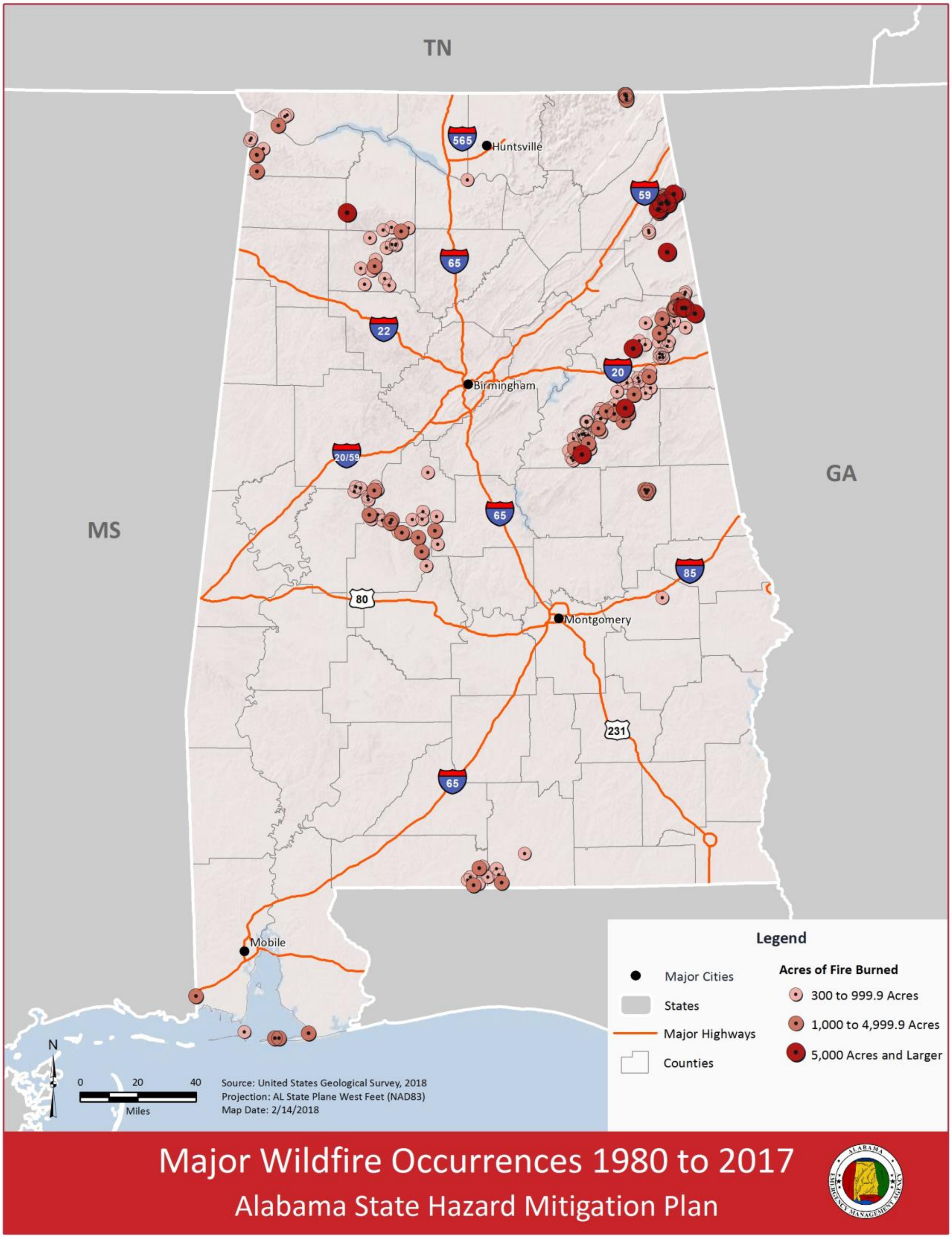

Table 3.39 Wildfire Size and Cause (USGS, 2018)

Fire Size Class	Class Description	Total Fires	Total Acres Burned	Percent Naturally Caused	Percent Human Caused
A	0.1 to 0.2 Acres	396	46	6%	94%
B	0.3 to 9.9 Acres	1,620	4,780	9%	91%
C	10.0 to 99.9 Acres	904	28,703	12%	88%
D	100.0 to 299.9 Acres	143	24,643	11%	89%
E	300.0 to 999.9 Acres	67	32,277	9%	91%
F	5,000.0 Acres and Larger	13	22,652	0%	100%
Not Rated	Not Reported	6	1,892	0%	100%
Total	**All Classes Combined**	**3,150**	**114,993**	**10%**	**90%**

3.2.13.4 Probability of Wildfires in Alabama

Unlike other natural hazards, the probability of wildfires cannot be expressed in terms of specific frequencies or return periods. These events are the culmination of multiple natural and human-caused factors that play out over a range of timescales and can be highly localized. Regions that are more prone to wildfires can be identified, however, based on historic wildfire events. Analysis of these events indicates that the counties that are more likely to experience wildfires include Cherokee, Calhoun, Cleburne, Clay, Talladega, Bibb, Hale, Winston, Escambia, Covington, Baldwin and Mobile Counties. 5.1.1.1.1.1.1Table 3.39Figure 3.54 shows the number of acres burned by wildfires from 2009 to 2018 by county, and 5.1.1.1.1.1.1Table 3.39Figure 3.55 maps the frequency of wildfire events that have triggered a federal response. In 5.1.1.1.1.1.1Table 3.39Figure 3.54, frequency of fire occurrences is determined based on geospatial analysis of the density of occurrences. Even though shaded areas may not have experienced an event, these areas are located in regions where events are frequent. Refer to 5.1.1.1.1.1.1Table 3.38Figure 3.53 for the location and extent of the large-scale events included in this analysis.

3.2.13.4.1 Future Probability

As with most natural hazards, wildfires are strongly influenced by weather phenomena. As the climate changes, Alabama is projected to become more prone to wildfire occurrences. Alabama is at risk of facing considerable increasing threat levels from wildfire between now and 2050. According to research conducted by Climate Central and ICF, by 2050 the average number of

days with high wildfire potential is projected to double from 25 to 50 days a year.[145] Therefore, Alabama should anticipate that the probability of wildfires occurring will increase in the future.

3.2.13.4.2 Risk and Vulnerability

A community's vulnerability to fire loss is a function of the probability of wildfires, the exposure of structures and assets to wildfires, and the susceptibility of structures and assets to wildfires. The state of Alabama is highly vulnerable to losses from wildfires. The southern US often leads the nation in the number of wildfires that occur each year. In Alabama, the high vulnerability to wildfires is driven by the state's extremely hot summers, extensive forest cover, and large and growing wildland-urban interface.[146] As population growth and development continue to gravitate towards more remote and rural landscapes, more of Alabama's people, infrastructure and assets will become vulnerable to loss from wildfires.[147]

Wildfires also pose a risk to Alabama's forestry industry, which represents the second largest sector of the state's economy. Alabama's forestry industry provides over 122,000 jobs in timber production and processing and contributes over $21 billion to the state's economy each year. This industry is supported by 23 million acres of timberland (about 69 percent of the total land area in the state) managed by 440,000 forestland owners.[148] Wildfires pose a risk not only to the assets of these forestland owners, but to a principal sector of the state's economy.

Based on the drivers of wildfire risk and loss, wildfire vulnerability in Alabama is likely to grow most in the state's northeast and in its coastal region. While Northeast Alabama is likely to become more vulnerable due to its high growth rates, decentralized development patterns, and growing wildland-urban interface, coastal Alabama is likely to become more vulnerable due to its very hot climate and the more severe impacts that climate change may have on the region. Although vulnerability may grow most in these two regions, the risk of wildfire loss is expected to grow throughout the state.

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[145] Climate Central, 2018. States at Risk Alabama Report Card. Retrieved at: http://assets.statesatrisk.org/summaries/Alabama_report.pdf
[146] The Southern Group of State Foresters. Fire in the South. http://www.forestry.alabama.gov/PDFs/fire_in_the_south.pdf
[147] Alabama Forestry Commission, 2010. 50 Ways to Make Your Woodland Home Firewise. http://www.forestry.alabama.gov/PDFs/50_Ways_to_Protect_Your_home.pdf
[148] Alabama Forestry Commission, 2016. 2016 Annual Report. Retrieved at: http://www.forestry.state.al.us/PDFs/AFCAnnualReport2016.pdf

Figure 3.54 Acres Burned by Wildfire by County 2009 to 2018 (Alabama Forestry Commission)

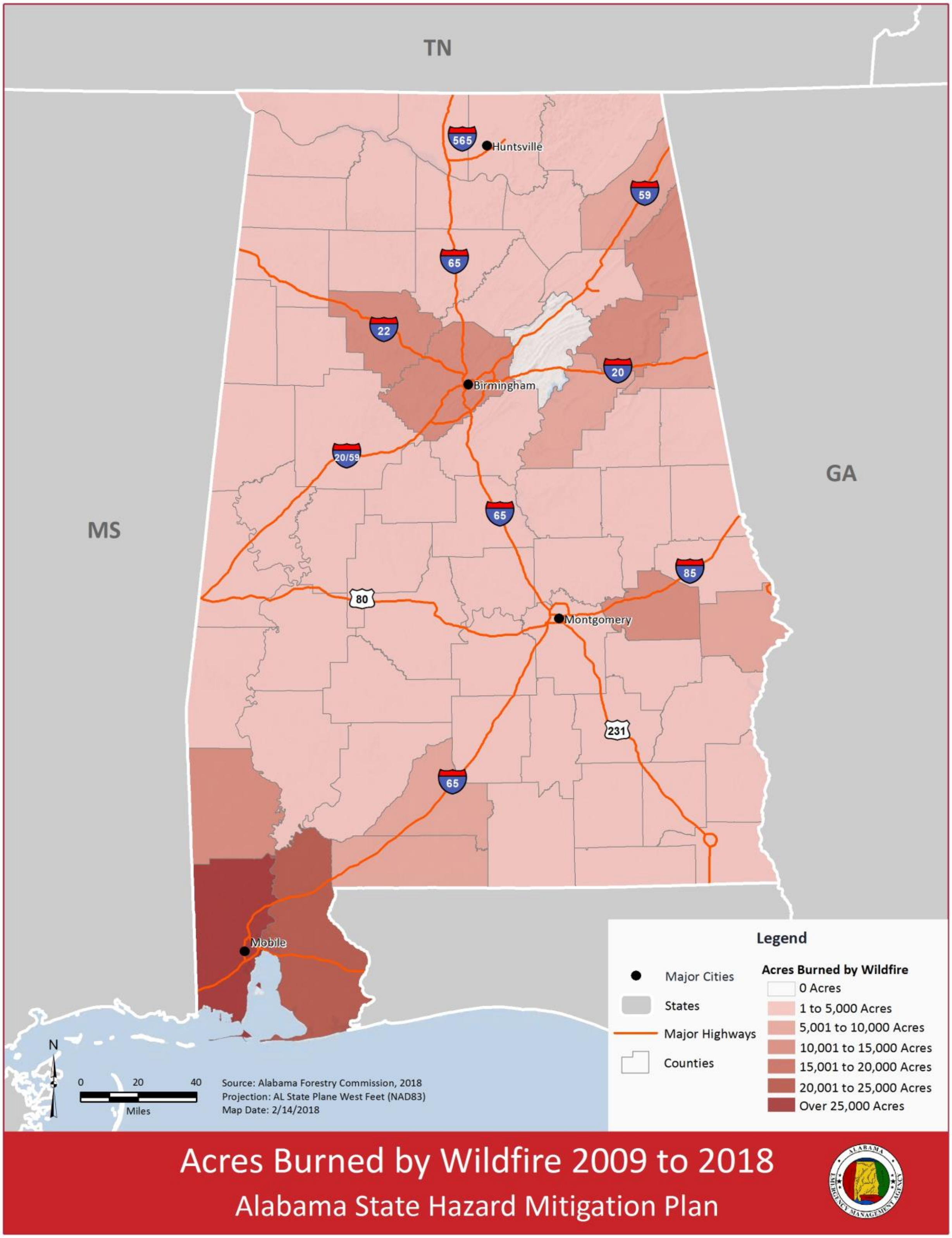
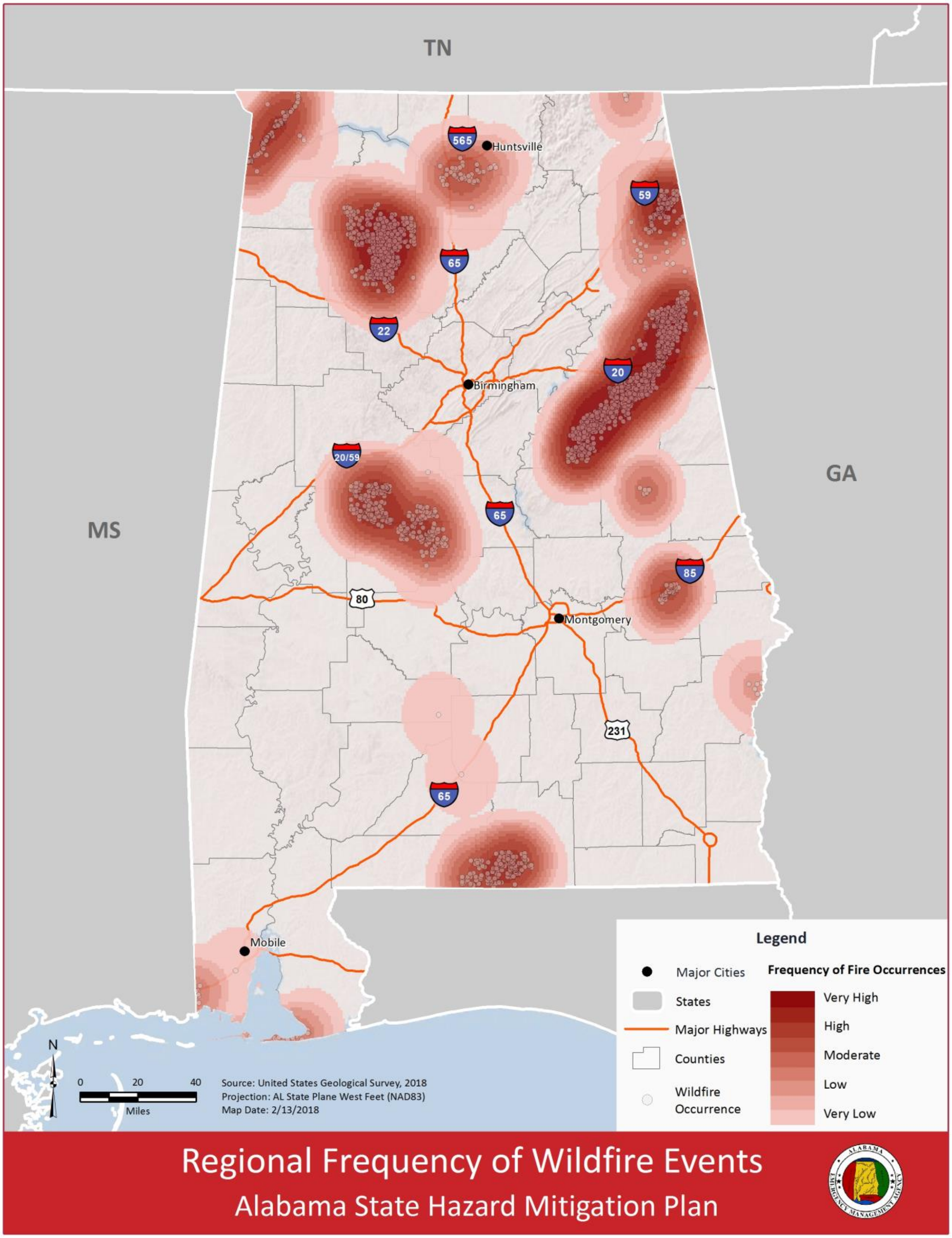


Figure 3.55 Frequency of Wildfire Occurrences that Warranted Federal Response (USGS, 2018)



3.2.14 Winter Storms

3.2.14.1 Description

Winter storms are storm events characterized by extreme cold and precipitation in the form of snow, ice, and/or sleet (5.1.1.1.1.1.1Table 3.40). Winter storms can also spawn other natural hazards, such as coastal flooding and erosion, severe thunderstorms and tornados, and extreme winds. These storm events can have significant impacts in terms of human life, economic loss, and disruption of transportation and commerce. Accumulations of snow and ice can lead to vehicle and pedestrian accidents, collapsed roofs, and felled trees or other debris that impact utility systems and transportation routes.

Table 3.40 Winter Storm Precipitation Types

Precipitation Type	Description
Snow	Snow occurs when the temperature remains at or below 32°F from the cloud base to the ground. Snow reaches the ground as soft, white flakes.
Ice Storm	An ice storm (or freezing rain) occurs when snowflakes completely melt as they fall through a layer of warm air, then enter a shallow layer of cold air near the surface. The water droplets reach the ground as supercooled liquid then re-freeze on contact, creating a glaze of ice on the ground, trees, and power lines.
Sleet	Sleet occurs when snowflakes partially melt as they fall through a shallow layer of warm air, then refreeze as they fall through a deep layer of freezing air above the surface. Sleet reaches the ground as frozen rain drops that bounce on impact.

The disruption caused by a winter storm depends on the amount of precipitation, the affected population, and the regional climatology. Areas where winter storms are rare, such as the southeastern US, tend to be less prepared for these events and therefore tend to experience greater disruption.

3.2.14.2 Nature of the Hazard in Alabama

Winter storms in Alabama are not as severe or common as winter storms in the northern states. Typically, a winter storm in Alabama consists of freezing rain or a few inches of snow that may or may not be accompanied by frozen roadways. Because Alabama is not accustomed to these events, however, winter storms tend to be very disruptive to transportation and commerce. The local warning criteria established by the Mobile, AL and New York, NY Weather Forecast Offices illustrate how the amount of snow or ice that poses a risk to life and property varies from state to state (5.1.1.1.1.1.1Table 3.41). While expected snow accumulation of 2 inches in 24 hours is enough to trigger a warning in Mobile, snow accumulation of 6 inches in 12 hours is required to trigger a warning in New York.

Table 3.41 Local Warning Criteria for Winter Storms

Warning Type	New York, NY Warning Criteria	Mobile, AL Warning Criteria
Winter Storm	Snow accumulation of 6 inches in a 12-hour period or 8 inches in a 24-hour period; Ice accumulation of 1/2 inch or more	Snow accumulation of 2 inches in a 12-hour period; Sleet/ice pellet accumulation of 1/2 inch or more
Ice Storm	Freezing rain with ice accumulations of 1/2 inch or more	Freezing rain with ice accumulations of 1/4 inch or more

Ice storms pose a particularly great risk to life and property. Trees, cars, roads, and other surfaces develop a coating or glaze of ice, making even small accumulations of ice extremely hazardous to motorists and pedestrians. The most prevalent impacts of heavy accumulations of ice are slippery roads and walkways that lead to vehicle and pedestrian accidents; collapsed roofs from fallen trees and limbs and heavy ice and snow loads; and felled trees, telephone poles and lines, electrical wires, and communication towers. Because of severe ice storms, telecommunications and power can be disrupted for days. Such storms can also cause exceptionally high rainfall that persists for days, resulting in heavy flooding.

3.2.14.3 Winter Storm History in Alabama

Winter storms in Alabama are moderate loss-producing atmospheric hazards. According to NOAA's Storm Events Database, winter storms caused more than $32 million in direct economic losses (adjusted to 2017 dollars) between 1996 and 2017. The most damaging events were ice storms, which accounted for nearly $28 million in direct economic losses, followed by winter storms with a mix of precipitation types, which accounted for nearly $5 million. Between 1996 and 2017, the most frequently recorded events were winter storms with a mix of precipitation (23 events), heavy snow (13 events), and ice storms (10 events).

Since the Storm Events Database began collecting data on winter storms in 1996, Alabama has had five winter storms that were reported to cause more than $1 million in estimated damage (adjusted to 2017 dollars). In addition, Alabama had one federal emergency declaration for severe snowfall in 1993. 5.1.1.1.1.1.1Table 3.42 summarizes these historical storms and their reported impacts.

Table 3.42 Historical Winter Storms with Damage Exceeding $1 million (1993 – 2017)

Date	Type	Estimated Damage (2017 dollars)	Description
March 12, 1993	Snow Storm	$85 to $170 million	A winter storm described as the worst in Alabama history struck on March 12, 1993 and lasted through mid-day March 13, 1993. Snow accumulated to 6 to 12 inches over North Alabama and 2 to 4 inches over the Gulf Coast. A 40-mile-wide band of 12 to 20 inches fell from the Birmingham area northeastward to DeKalb and Cherokee counties, generally following the Appalachian Mountains. It was estimated that 400,000 residences were without electricity, and many remained so for several days. Compounding the snow and power problems, temperatures fell well into the single digits and teens across much of the state. There were at least 14 deaths associated with exposure or stress due to the storm. The entire state was declared a federal disaster area.
December 23, 1998	Ice Storm	$21.6 million	A winter storm brought a mixture of freezing rain, sleet, and rain to the northern half of Alabama. The northwestern quarter of Alabama was especially hard hit. The northwestern quarter of the state saw temperatures at or below freezing for the majority of the event, as well as significant ice accumulations of one half to one inch. Numerous trees were down across every county. Significant power outages were encountered in all counties and many locations did not return to service until the 26th or 27th. The National Guard was activated in a few northwestern counties to help with the cleanup duties. Numerous roads were closed during the event which included Interstate 65 and 565 in the Huntsville area. One fatality occurred in Huntsville when a homeless man died of exposure. Numerous multiple vehicle and single automobile accidents occurred due to the icy road conditions. These accidents resulted in at least 5 fatalities and numerous minor injuries.

Date	Type	Estimated Damage (2017 dollars)	Description
January 22, 2000	Ice Storm	$3.8 million	A light mixture of rain, freezing rain, sleet, and snow fell on the morning of the 22nd. Several bridges became ice covered and numerous trees received a glaze of ice. Several trees and tree limbs started breaking and falling on roads by the evening, causing scattered power outages. In the early morning of the 23rd, temperatures cooled off to the point where significant icing began taking place. Numerous locations received icing up to at least one inch. Trees and power lines were downed throughout the area and many downed trees blocked roads. Numerous roads were closed, especially at higher elevations. The Alabama National Guard was activated and dispatched to northeast Alabama to help in tree removal and cleanup. Thousands of customers were without power for several days. Numerous homes and automobiles were damaged by falling trees. An Alabama man was killed when he drove his car into a large mass of tree limbs covering SR 71 near Rosalie. Numerous other traffic accidents were reported, and several people had minor injuries.
January 28, 2000	Ice Storm	$1.6 million	Very light precipitation started falling early in the morning of the 28th. The precipitation was initially a mix of rain, sleet, and snow. Little to no accumulation of snow occurred across the area. As the day progressed, the precipitation changed to light freezing rain and lasted until the afternoon of the 29th. Significant accumulation of ice occurred on trees and bridges mainly in the higher elevations. Most of this same area was hit very hard by an ice storm on the 22nd and 23th and had not recovered yet. Numerous trees and power lines went down across the area and several homes and automobiles were damaged by the falling trees. Many roads were impassable and closed. A young man was killed in Dekalb County when a car slid into him while he was riding a four-wheeler. Thousands of people were without power for several hours.

Date	Type	Estimated Damage (2017 dollars)	Description
January 28, 2014	Winter Storm	$1.0 million	A mixture of winter precipitation fell across Central Alabama beginning on January 28th. Travel conditions quickly deteriorated as snow, sleet, and ice began to accumulate. Brief periods of freezing rain resulted in a light glaze of ice on area roadways and bridges at the onset of precipitation. As precipitation transitioned to all snow, it melted and refroze quickly on area roadways, further deteriorating travel conditions. In many locations across Central Alabama, snow accumulated on top of a layer of ice. Hundreds of wrecks and hazardous road conditions left thousands of people stranded in their vehicles on area roadways for hours; many remained there overnight. Many others abandoned their vehicles in favor of walking to nearby shelters. As temperatures remained below freezing through January 30th, there was only slight improvement in icy road conditions. Seven fatalities (indirect) were attributed to vehicle accidents on icy roads in Central Alabama. One fatality (indirect) resulted from a male slipping on ice outside his home. One fatality (direct) resulted from severe hypothermia. Due to the high number of vehicle accidents and vehicles abandoned in favor of walking to shelters, there were likely unreported indirect injuries numbering in the dozens across the affected area.

3.2.14.4 Probability of Winter Storms in Alabama

Winter storms have historically affected northern counties more frequently than southern counties (5.1.1.1.1.1.1Table 3.42Figure 3.56). Because winter temperatures in Alabama are primarily a function of latitude, this pattern is expected to continue in the future.

3.2.14.4.1 Future Probability

According to the Southeast Regional Report prepared for the Third US National Climate Assessment, average annual snowfall totals across the northern tier of the southeastern states have fallen at a rate of about 1% per year since the late 1930s.[149] At the same time, snowstorms exceeding 6 inches have declined in frequency. These two trends have accompanied a trend towards warmer winters in the second half of the twentieth century. These declines in snowfall stand in contrast to positive trends in snowfall across the northeastern and midwestern regions of the US. The frequency of days with freezing rain, however, has shown little overall change since the middle of the 20th century. If these trends continue, Alabama can expect the probability of hazardous ice storms to remain relatively constant, and the probability of hazardous snow storms to fall.

3.2.14.4.2 Risk and Vulnerability

A community's vulnerability to winter storms is a function of the probability of winter storms; the exposure of transportation, energy, and telecommunication infrastructure to winter storms; and the susceptibility of this infrastructure to winter storms. In Alabama, the northern counties are most likely to experience severe winter storms, and the population centers in these counties have the highest density of exposed infrastructure. The susceptibility of infrastructure systems to disruption is a complex property, however, that must be modeled at the community level. Relevant characteristics include the availability of alternate routes or connections, and the availability of substitutes (such as public transportation in the case of roadways, or generators in the case of power lines).[150]

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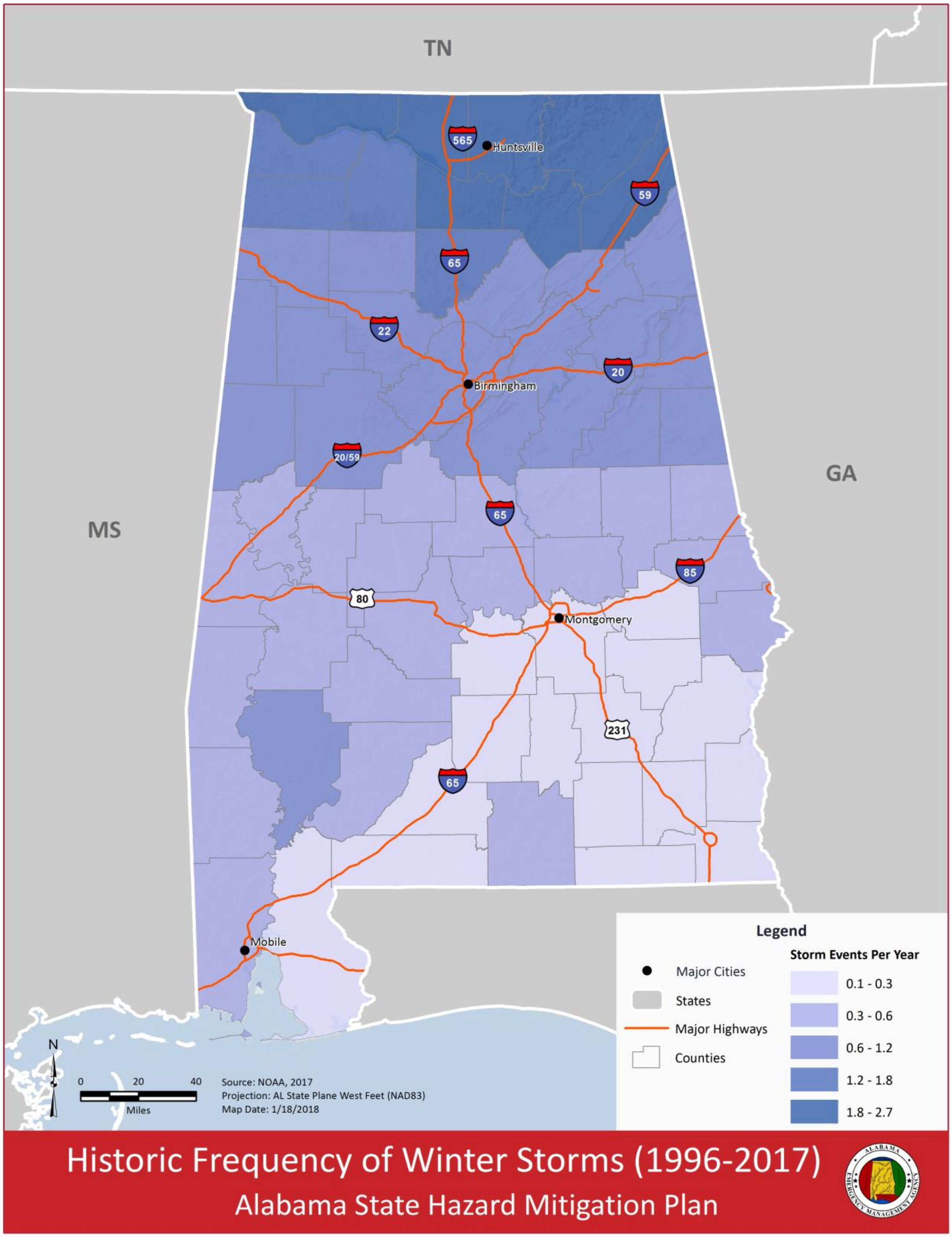
[149] Ingram, K., K. Dow, L. Carter, J. Anderson, eds. 2013. Climate of the Southeast US: Variability, change, impacts, and vulnerability. Washington DC: Island Press.
[150] Ganin, A., Kitsak, M., Marchese, D., Keisler, J., Seater, T., and Linkov, I., 2017. Resilience and efficiency in transportation networks. Science Advances 3(12). Retrieved at: http://advances.sciencemag.org/content/3/12/e1701079.full

Figure 3.56 Historic Frequency of Winter Storms (NOAA, 2017)



3.3 Vulnerability Assessment & Loss Estimation

3.3.1 Methodology

Vulnerability assessment is the process of evaluating the potential loss to a community from natural hazards. As discussed above, vulnerability depends on the probability of occurrence of a hazard event, the exposure of people and property to the hazard, and the susceptibility of people and property to the hazard. Different methodologies exist for assessing the risk posed by natural hazard events, ranging from qualitative to quantitative. In this section, quantitative methodologies are applied to the four hazards identified by the SHMT as having a high probability, high mitigation potential, and/or well-developed assessment methodology.

As in previous plans, floods and high winds were selected for further analysis based on their high probability of occurrence and high ease of mitigation, while earthquakes were selected based on the well-developed Hazus loss estimation methodology. Unlike in previous plans, sea level rise was also selected for further analysis. In developing this plan update, the SHMT determined that sea level rise has a high probability of occurrence in Alabama and a high ease of mitigation through planning and design approaches. Quantitative methodologies were applied to determine the vulnerability of both state assets and local jurisdictions.

3.3.1.1 Methodology for State Assets

According to FEMA guidance, state assets "may include state-owned or operated buildings, infrastructure, and critical facilities" and critical facilities are those "structures that the state determines must continue to operate before, during, and after an emergency."[151] After discussing the FEMA guidance with partners in state agencies, the SHMT decided to assess the vulnerability of two types of state assets: state-insured facilities and state-identified Critical Infrastructure and Key Resources (CIKR). CIKR refers to assets that are essential to the nation's security, public health and safety, economic vitality, and way of life. These assets are mostly privately-owned and operated, and include facilities such as power grids and water filtration plants; national monuments and government facilities; telecommunications and transportation systems; and chemical facilities.

An inventory of state-insured facilities was obtained from the Alabama Division of Risk Management (DORM). This inventory includes 12,144 structures and contains information on structure type, name, location, and replacement value. 5.1.1.1.1.1.1Table 3.43 shows the number and value of the different types of structures in the inventory of state-insured facilities.

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[151] Federal Emergency Management Agency, 2015. State Mitigation Plan Review Guide.

Table 3.43 State-Insured Facilities (DORM, 2018)

Type	Number	Replacement Value
Agriculture	20	$34,156,212
Transportation	545	$321,675,019
Education	8,917	$20,436,058,471
Government	243	$2,331,312,345
Healthcare	304	$767,790,626
Military	102	$340,088,064
Parks & Recreation	1,224	$350,486,368
Port Authority	168	$348,956,567
Public Safety	621	$766,604,173
Total	**12,144**	**$25,697,127,845**

An inventory of CIKR was obtained from the Alabama Law Enforcement Agency (ALEA). This inventory includes 150 facilities and contains information on structure type, name, and location. 5.1.1.1.1.1.1Table 3.44 shows the number of each type of facilities in the inventory of CIKR.

Table 3.44 Critical Infrastructure and Key Resources (ALEA, 2018)

Type	Number
Agriculture & Food	6
Banking & Finance	11
Chemical	17
Commercial	35
Critical Manufacturing	6
Dams	18
Defense Industrial Base	2
Emergency Services	2
Energy	7
Government Facilities	12
Healthcare & Public Health	13
Information Technology	1
National Monuments & Icons	4
Nuclear Reactors, Materials, & Waste	2
Transportation Systems	12
Water	2
Total	**150**

The quantitative methodology for assessing the vulnerability of state assets consisted of geocoding all inventoried assets and performing a Geographic Information System (GIS) analysis. For each hazard, the methodology mapped the magnitude of the largest event expected to occur within the design life of a building, identified the areas where the magnitude of this event would cause significant damage, and intersected this area with the location of state assets.

3.3.1.2 Methodology for Local Jurisdictions

According to State Mitigation Plan Review Guide, state hazard mitigation plans “must provide a current summary of the most vulnerable jurisdictions,” and vulnerability should be analysed in terms of “damage and loss…related to populations and assets”.[152] To meet these criteria, the SHMT decided to apply FEMA’s Hazus loss estimation software. Hazus (Hazard US) is an integrated GIS-based simulation system that was designed to promote more consistent and standardized assessments of vulnerability, and more transparent and effective approaches to setting local and state priorities.

The methodology embedded in the Hazus software divides the loss estimation process into three phases. The first phase is the hazard analysis phase. In this phase, the model analyses the physical processes that determine loss. In the case of flood hazards, for example, the model would determine the depth and velocity of flooding associated with different flood frequencies.

The second phase is the damage estimation phase. In this phase, the model overlays the hazard layer with an inventory layer to identify the buildings and infrastructure exposed to the hazard, then uses vulnerability curves to estimate the extent of structural damage. Each of the Hazus analyses conducted for Alabama used the default Hazus inventory. This inventory includes information on 1) the general building stock (the number and characteristics of residential, commercial, industrial, agricultural, and other buildings), 2) essential facilities (e.g., police stations), 3) high potential loss facilities (e.g., dams), and 4) selected transportation and utility systems (e.g., highway bridges and water treatment plants). Hazus uses census data to determine the distribution of residential structures, and Dun & Bradstreet data to determine the distribution of non-residential structures. The version of Hazus applied for this plan update uses data from the 2010 Census.

The third phase is the loss estimation phase. In this phase, the model quantifies the economic losses caused by the estimated structural damage. Each of the Hazus analyses conducted for Alabama used the damage estimates to calculate two kinds of economic losses: 1) immediate losses related to the damage to structures and their contents (building loss, content loss, and business inventory loss); and 2) business interruption losses related to how long businesses remain inoperable (relocation loss, wage loss, income loss, and rental income loss. Note that income loss refers to business owners' income). The spatial resolution of the modelled losses depends on the modelled hazard. While losses related to flooding and high winds are calculated at the census block level (the smallest census geography), losses related to earthquakes are

[152] Federal Emergency Management Agency, 2015. State Mitigation Plan Review Guide.

calculated at the census tract level. The frequency of the modelled losses can also vary depending on the available data. When data is available on the extent of the natural hazard at different probability levels, it is common to present loss estimates in terms of the average annualized loss (AAL). This value condenses the estimated losses at each modelled probability level into a single value representing the average annual loss. Only two of the three Hazus analyses conducted for Alabama present the loss estimates in terms of average annualized loss – the earthquake analysis and the high winds analysis. While data for these hazards was available at a series of probability levels, data for flood hazards was only available for the 1%-annual-chance flood. Loss estimates for flood hazards are therefore presented for only the 1%-annual-chance event.

3.3.2 Earthquakes

Seismic risk is a function of the probability and frequency of the earthquake hazard, exposure, and susceptibility. While the probability and frequency of earthquake hazards is essentially constant on human timescales, the vulnerability to damage and loss can increase with population growth and development. The following sections summarize potential earthquake impacts to both state assets and jurisdictions throughout Alabama.

3.3.2.1 Vulnerability of State Assets

To assess the vulnerability of state-insured facilities and critical infrastructure to earthquakes, all structures located in areas characterized by high earthquake hazard and high susceptibility to liquefaction were identified. Relative earthquake hazard was derived from the 2014 USGS National Seismic Hazard Map for the shaking event with a recurrence interval of 2,500 years (2% probability of exceedance in 50 years) (5.1.1.1.1.1.1Table 3.11Figure 3.11). As described above, PGA is expressed as a percentage of the force of gravity, or %g, and damage to buildings of poor construction generally begins at a PGA of 10% g. Relative susceptibility to liquefaction was derived from the GSA modeling study (5.1.1.1.1.1.1Table 3.11Figure 3.9). As described above, liquefaction is one of several secondary hazards that can increase the impact of an earthquake. While the GSA has recommended projects to study additional secondary hazards in Alabama, the distribution of other secondary hazards in Alabama is not currently available. Vulnerable assets were defined as those assets located in areas with a PGA exceeding 10% g, and a high or very high susceptibility to liquefaction.

Of the more than 12,000 state-insured facilities, 557 are located in areas with a relatively high probability of strong ground shaking and a high susceptibility to ground failure through liquefaction (5.1.1.1.1.1.1Table 3.45). These facilities have a combined replacement value of more than $1 billion, or approximately 4% of the value of all state-insured facilities.

Table 3.45 State-Insured Facilities Vulnerable to Earthquake Hazard

Facility Type	# of Vulnerable Structures	% of Total Structures for Facility Type	Replacement Value	% of Total Value for Facility Type
Education	416	3.4%	$869,298,236	3.4%
Government	4	0.03%	$12,439,604	0.05%
Healthcare	26	0.2%	$152,728,695	0.6%
Military	8	0.1%	$19,700,722	0.1%
Parks/Recreation	47	0.4%	$12,724,178	0.05%
Port Authority	2	0.02%	$247,097	0.001%
Public Safety	40	0.3%	$46,938,393	0.2%
Transportation	14	0.1%	$3,935,358	0.02%
Total	**557**	**4.6%**	**$1,118,012,283**	**4.4%**

Of the 150 structures identified as critical infrastructure by the state, 16 are located in areas with a relatively high probability of strong ground shaking and a high susceptibility to ground failure through liquefaction (5.1.1.1.1.1.1Table 3.46). Most of these facilities are dams.

Table 3.46 Critical Infrastructure Vulnerable to Earthquake Hazard

Facility Type	# of Vulnerable Structures
Chemical	2
Dams	11
Energy	1
Healthcare & Public Health	1
Nuclear Reactors, Materials, & Waste	1
Total	**16**

3.3.2.2 Vulnerability of Jurisdictions

FEMA's Hazus software version 3.2 was used to estimate seismic vulnerability across the state. The methodology uses Hazus default data on seismic hazards along with state-wide building stock data (based on 2010 US Census data) and the software's standard algorithms. The calculation algorithms quantify the potential losses associated with seismic hazards using information about shake probabilities, soil characteristics, and other parameters. As discussed in Section 3.3.1, Hazus was used to calculate two kinds of economic losses: 1) immediate losses related to the damage to structures and their contents, and 2) business interruption losses related to how long businesses remain inoperable.

The tables below show the average annualized earthquake losses for Alabama aggregated to the county scale. While 5.1.1.1.1.1.1.1Table 3.47 shows immediate economic losses (building loss, contents loss, and business inventory loss), 5.1.1.1.1.1.1.1Table 3.48 shows business interruption losses (relocation costs, income loss, rental loss, and wage loss). 5.1.1.1.1.1.1.1Table 3.48Figure 3.57 shows the spatial distribution of the total average annualized losses (the sum of immediate losses and business interruption losses). Note that losses are shown at the census tract level. While the county-level tables show the highest annualized losses in Jefferson and Madison counties, the census-tract level map shows the highest annualized losses in census tracts located in Madison, Morgan, Colbert, and Lauderdale counties.

Table 3.47 Potential Immediate Losses from Earthquake Hazards (AAL)

County	Building Loss	Content Loss	Inventory Loss	Total Immediate Losses
Jefferson County	$4,290,101	$1,352,500	$41,661	$5,684,262
Madison County	$2,344,360	$663,410	$22,258	$3,030,028
Tuscaloosa County	$1,007,327	$299,523	$10,992	$1,317,841
Shelby County	$961,436	$301,031	$9,498	$1,271,966
Lauderdale County	$879,092	$254,376	$10,492	$1,143,960
Morgan County	$763,510	$224,569	$11,980	$1,000,059
Colbert County	$545,717	$164,295	$9,152	$719,164
Dekalb County	$458,350	$151,462	$12,486	$622,299
Etowah County	$455,049	$137,793	$5,549	$598,391
Marshall County	$444,723	$130,903	$7,126	$582,751
Limestone County	$443,752	$117,813	$4,241	$565,806
Cullman County	$425,070	$122,152	$7,557	$554,779
Calhoun County	$421,389	$120,947	$5,280	$547,617
Walker County	$360,179	$102,977	$4,327	$467,482
Jackson County	$338,489	$104,383	$5,593	$448,465
St. Clair County	$286,090	$77,650	$3,139	$366,879
Talladega County	$280,486	$80,784	$5,041	$366,311
Montgomery County	$277,706	$66,404	$2,594	$346,705
Franklin County	$228,858	$66,209	$3,910	$298,977
Marion County	$220,657	$62,729	$4,734	$288,121
Blount County	$212,105	$58,301	$1,988	$272,393
Lawrence County	$184,519	$47,566	$1,507	$233,591
Winston County	$172,190	$50,597	$4,798	$227,586
Cherokee County	$167,867	$47,564	$2,451	$217,881
Mobile County	$164,183	$34,563	$1,414	$200,159
Lee County	$127,229	$26,715	$1,076	$155,020
Chilton County	$105,654	$27,117	$1,079	$133,851
Fayette County	$91,904	$26,993	$1,920	$120,817
Elmore County	$88,413	$20,026	$556	$108,995

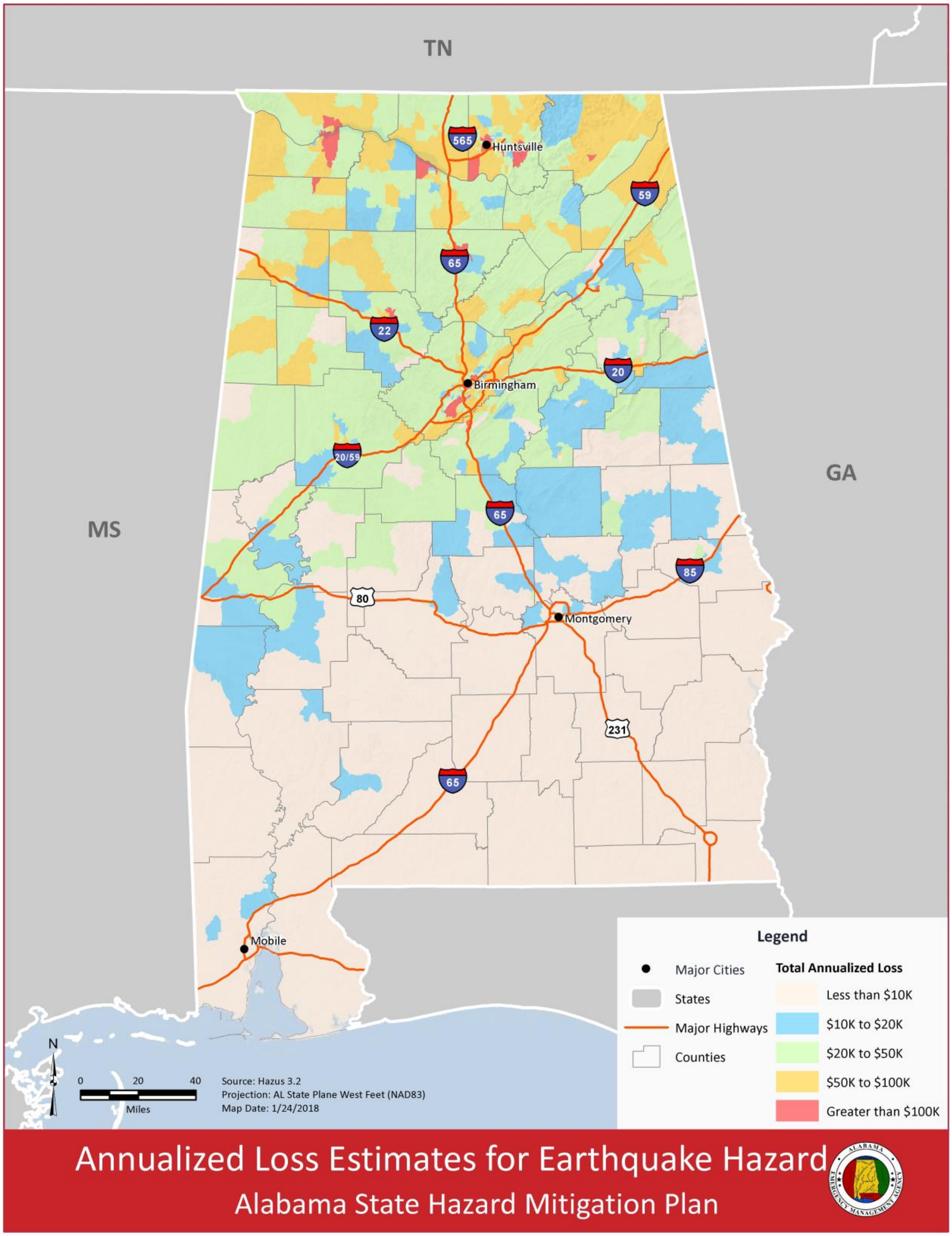
County	Building Loss	Content Loss	Inventory Loss	Total Immediate Losses
Lamar County	$75,288	$21,056	$1,371	$97,715
Tallapoosa County	$70,500	$16,773	$629	$87,903
Pickens County	$69,047	$17,399	$554	$86,999
Bibb County	$67,872	$18,324	$464	$86,661
Dallas County	$66,273	$16,867	$703	$83,843
Autauga County	$62,373	$14,372	$503	$77,247
Baldwin County	$62,547	$12,293	$344	$75,183
Hale County	$40,744	$10,306	$485	$51,535
Randolph County	$41,192	$9,615	$354	$51,160
Chambers County	$38,974	$9,294	$656	$48,924
Clay County	$36,284	$10,331	$1,028	$47,643
Marengo County	$36,750	$9,027	$279	$46,056
Cleburne County	$33,988	$8,663	$372	$43,022
Sumter County	$33,053	$7,547	$296	$40,896
Russell County	$32,429	$6,734	$268	$39,431
Houston County	$32,270	$5,916	$214	$38,399
Greene County	$24,850	$6,264	$254	$31,368
Perry County	$23,249	$5,805	$166	$29,220
Coosa County	$22,962	$5,426	$203	$28,591
Clarke County	$21,582	$4,755	$171	$26,508
Choctaw County	$19,424	$4,610	$325	$24,359
Macon County	$17,462	$3,534	$134	$21,130
Escambia County	$15,772	$3,397	$196	$19,365
Pike County	$15,830	$2,934	$113	$18,877
Coffee County	$15,925	$2,808	$82	$18,815
Dale County	$15,900	$2,630	$86	$18,616
Covington County	$13,905	$2,607	$101	$16,613
Monroe County	$13,569	$2,819	$101	$16,488
Barbour County	$12,705	$2,431	$153	$15,289
Butler County	$11,960	$2,427	$101	$14,488
Washington County	$10,133	$2,105	$54	$12,293
Wilcox County	$9,635	$2,034	$99	$11,768
Lowndes County	$8,681	$1,820	$88	$10,588
Crenshaw County	$6,526	$1,184	$48	$7,758
Geneva County	$6,077	$941	$22	$7,040
Conecuh County	$5,688	$1,096	$48	$6,833
Bullock County	$5,574	$1,044	$45	$6,663
Henry County	$5,509	$899	$32	$6,441
Total	**$17,848,907**	**$5,199,436**	**$215,539**	**$23,263,882**

Table 3.48 Potential Business Interruption Losses from Earthquake Hazards (AAL)

County	Income Loss	Relocation Loss	Rental Income Loss	Wage Loss	Total Business Interruption Losses
Jefferson County	$383,743	$683,622	$352,124	$521,650	$1,941,140
Madison County	$204,151	$347,810	$184,169	$252,787	$988,917
Tuscaloosa County	$84,367	$158,261	$81,587	$114,925	$439,141
Lauderdale County	$77,392	$142,471	$66,753	$107,303	$393,919
Morgan County	$69,312	$127,787	$61,005	$102,652	$360,756
Shelby County	$66,318	$129,978	$61,934	$83,744	$341,973
Colbert County	$50,199	$90,079	$40,855	$66,686	$247,817
Etowah County	$42,761	$80,209	$35,720	$63,891	$222,580
Marshall County	$40,005	$77,853	$34,298	$53,278	$205,435
Calhoun County	$34,551	$73,722	$33,396	$50,031	$191,700
Dekalb County	$30,191	$79,564	$31,426	$47,726	$188,906
Cullman County	$33,179	$72,979	$29,556	$51,302	$187,016
Limestone County	$28,965	$72,591	$31,639	$35,075	$168,271
Walker County	$28,044	$67,344	$26,533	$41,432	$163,352
Montgomery County	$28,120	$51,932	$28,300	$38,258	$146,610
Jackson County	$20,969	$56,299	$21,233	$31,012	$129,512
Talladega County	$20,078	$51,916	$18,843	$31,084	$121,920
Franklin County	$20,812	$39,698	$16,540	$29,350	$106,400
St. Clair County	$15,828	$48,150	$16,899	$22,091	$102,968
Marion County	$18,624	$37,454	$16,988	$28,589	$101,654
Blount County	$12,996	$35,483	$13,212	$17,570	$79,261
Mobile County	$13,655	$30,921	$15,666	$18,809	$79,050
Lawrence County	$13,223	$34,246	$12,069	$18,022	$77,560
Winston County	$9,612	$28,639	$10,555	$14,661	$63,467
Cherokee County	$8,794	$29,754	$9,853	$13,561	$61,961
Lee County	$10,053	$24,932	$11,775	$12,812	$59,572
Chilton County	$7,814	$19,714	$7,104	$12,724	$47,355
Fayette County	$6,626	$16,277	$6,334	$10,656	$39,893
Dallas County	$6,168	$15,936	$6,041	$9,136	$37,281
Tallapoosa County	$5,768	$14,467	$5,977	$8,946	$35,158
Elmore County	$5,109	$15,767	$6,581	$6,845	$34,302
Lamar County	$4,898	$13,652	$5,497	$7,447	$31,493
Pickens County	$3,937	$13,379	$4,956	$7,144	$29,416
Baldwin County	$4,442	$11,202	$5,615	$6,002	$27,261
Bibb County	$3,779	$12,112	$4,371	$5,549	$25,811
Autauga County	$3,826	$11,366	$4,110	$5,062	$24,364
Houston County	$3,646	$7,472	$3,724	$5,531	$20,372
Chambers County	$3,216	$8,005	$3,104	$4,947	$19,271

County	Income Loss	Relocation Loss	Rental Income Loss	Wage Loss	Total Business Interruption Losses
Marengo County	$3,106	$8,376	$3,008	$4,770	$19,260
Randolph County	$2,304	$8,679	$2,885	$4,110	$17,978
Hale County	$2,331	$8,620	$2,690	$3,817	$17,458
Sumter County	$2,656	$7,115	$2,837	$4,034	$16,641
Russell County	$2,600	$7,171	$2,927	$3,901	$16,599
Clay County	$1,896	$6,621	$2,311	$3,378	$14,207
Cleburne County	$1,741	$6,685	$2,155	$2,896	$13,477
Clarke County	$1,673	$4,889	$1,969	$2,676	$11,206
Greene County	$1,575	$4,941	$1,576	$2,246	$10,338
Perry County	$1,404	$4,575	$2,183	$2,041	$10,203
Choctaw County	$1,429	$4,200	$1,456	$2,465	$9,549
Macon County	$1,357	$3,811	$1,779	$1,885	$8,832
Escambia County	$1,406	$3,637	$1,547	$2,201	$8,791
Pike County	$1,360	$3,528	$1,707	$1,949	$8,544
Dale County	$1,277	$3,196	$1,662	$2,124	$8,259
Coffee County	$1,236	$3,348	$1,504	$1,820	$7,908
Covington County	$1,100	$3,069	$1,290	$1,806	$7,265
Coosa County	$665	$4,326	$1,079	$1,185	$7,254
Monroe County	$1,050	$3,217	$1,169	$1,740	$7,175
Barbour County	$1,031	$2,965	$1,302	$1,607	$6,905
Butler County	$1,045	$2,567	$1,154	$1,561	$6,327
Wilcox County	$644	$2,339	$775	$1,170	$4,927
Washington County	$407	$1,989	$646	$685	$3,726
Lowndes County	$345	$2,100	$651	$614	$3,710
Geneva County	$307	$1,413	$524	$475	$2,719
Bullock County	$374	$1,216	$511	$619	$2,719
Crenshaw County	$273	$1,397	$487	$480	$2,638
Conecuh County	$297	$1,274	$425	$466	$2,463
Henry County	$227	$1,193	$414	$319	$2,154
Total	**$1,462,283**	**$2,951,494**	**$1,370,958**	**$2,017,329**	**$7,802,062**

Figure 3.57 Total Potential Losses for Earthquake Hazard (Average Annualized Loss)



3.3.3 Flooding

The risk of damage and loss from flooding is a function of the flood hazard; the exposure of people, buildings and infrastructure; and the susceptibility of the exposed communities and structures. As discussed in Section 3.2.5, the probability of both riverine and coastal flooding will likely increase with climate change. The precise amount by which the probability of high winds will increase, however, is uncertain. This section therefore summarizes the potential impacts of flooding on state assets and jurisdictions under present conditions.

3.3.3.1 Vulnerability of State Assets

The vulnerability of state assets to flooding was determined based on the flood zones mapped by FEMA's Risk MAP program. As discussed in Section 3.2.5, the flood zones delineated by the Risk MAP program include areas with a 1%-annual-chance of flooding, areas with a 0.2%-annual-chance of flooding, and Coastal High Hazard Areas. Coastal High Hazard Areas are areas with a 1%-annual-chance of flooding that are subject to additional hazards associated with storm-induced waves.

Of the more than 12,000 state-insured facilities, 547 are located within the 1%-annual-chance floodplain and 672 are located within the 0.2%-annual-chance floodplain (5.1.1.1.1.1.1Table 3.49 and 5.1.1.1.1.1.1Table 3.50). These facilities consist mostly of park and recreation facilities, education facilities, and port facilities, and have a combined replacement value of more than $610 million for the 1%-annual-chance flood, and more than $860 million for the 0.2% annual chance flood. Only 94 state-insured facilities are located within the Coastal High Hazard Area, all of which are park and recreation facilities.

Table 3.49 State-Insured Facilities Vulnerable to 1%-Annual-Chance Flood

Facility Type	# of Vulnerable Structures	% of Total Structures for Facility Type	Replacement Value	% of Total Value for Facility Type
Agriculture	0	0.0%	$0	0.0%
Education	138	1.5%	$200,667,785	1.0%
Government	5	2.1%	$13,887,883	0.6%
Healthcare	9	3.0%	$7,481,032	1.0%
Military	0	0.0%	$0	0.0%
Parks/Recreation	227	18.5%	$65,586,581	18.7%
Port Authority	136	81.0%	$309,870,329	88.8%
Public Safety	32	5.2%	$16,277,829	2.1%
Transportation	21	3.9%	$9,530,477	3.0%
Total	**547**	**4.7%**	**$613,771,439**	**2.4%**

Table 3.50 State-Insured Facilities Vulnerable to 0.2%-Annual-Chance Flood

Facility Type	# of Vulnerable Structures	% of Total Structures for Facility Type	Replacement Value	% of Total Value for Facility Type
Agriculture	1	5.0%	$53,900	0.2%
Education	216	2.4%	$407,301,142	2.0%
Government	14	5.8%	$22,119,211	0.9%
Healthcare	14	4.6%	$15,279,243	2.0%
Military	0	0.0%	$0	0.0%
Parks/Recreation	241	19.7%	$71,481,920	20.4%
Port Authority	152	90.5%	$328,076,621	94.0%
Public Safety	34	5.5%	$17,651,279	2.3%
Transportation	26	4.8%	$12,340,424	3.8%
Total	**672**	**5.8%**	**$861,963,316**	**3.4%**

Of the 150 structures identified as critical infrastructure by the state, 32 are located within the 1%-annual-chance floodplain, and 36 are within the 0.2%-annual-chance floodplain (5.1.1.1.1.1.1Table 3.51 and 5.1.1.1.1.1.1Table 3.52). Most of these facilities are dams, transportation systems, or commercial facilities.

Table 3.51 Critical Infrastructure Vulnerable to 1%-Annual-Chance Flood

Facility Type	# of Vulnerable Structures
Agriculture & Food	0
Banking & Finance	0
Chemical	1
Commercial	7
Critical Manufacturing	0
Dams	14
Defense Industrial Base	0
Emergency Services	0
Energy	1
Government Facilities	0
Healthcare & Public Health	1
Information Technology	0
National Monuments & Icons	1
Nuclear Reactors, Materials, & Waste	0
Transportation Systems	7
Water	0

Facility Type	# of Vulnerable Structures
Total	**32**

Table 3.52 Critical Infrastructure Vulnerable to 1%-Annual-Chance Flood

Facility Type	# of Vulnerable Structures
Agriculture & Food	0
Banking & Finance	1
Chemical	1
Commercial	8
Critical Manufacturing	0
Dams	14
Defense Industrial Base	1
Emergency Services	0
Energy	2
Government Facilities	0
Healthcare & Public Health	1
Information Technology	0
National Monuments & Icons	1
Nuclear Reactors, Materials, & Waste	0
Transportation Systems	7
Water	0
Total	**36**

3.3.3.2 Vulnerability of Jurisdictions

The relative vulnerability of jurisdictions to flood hazards can be estimated based on both historic losses and Hazus modeling of potential losses. As discussed in Section 3.2.5, the NFIP is a program established by the federal government to reduce and insure flood losses. Through this program, the Federal Emergency Management Agency (FEMA) collects extensive data on the location of NFIP insurance claims. In addition to tracking the location of claims and the value of payments for building and contents losses, FEMA tracks the number of repetitive loss properties, and the number of repetitive loss claims associated with them. The distribution of NFIP claims and repetitive loss claims indicates where the historical vulnerability to flood events was greatest.

5.1.1.1.1.1.1Table 3.52Figure 3.58, 5.1.1.1.1.1.1Table 3.52Figure 3.59, 5.1.1.1.1.1.1Table 3.52Figure 3.60, and 5.1.1.1.1.1.1Table 3.52Figure 3.61 show the distribution of NFIP claims, NFIP repetitive loss claims, NFIP claims per 1,000 persons, and NFIP repetitive loss claims per 1,000 persons. The first two figures in the series highlight that all the major metropolitan areas have seen high numbers of insurance claims, but the coastal counties and the counties in the

greater Birmingham area have seen the highest numbers of repetitive loss claims. The third and fourth figures in the series take population density into account and show the counties where the number of per capita claims is highest. These figures reveal that per capita losses are particularly high in Greene and Coffee counties.

Figure 3.58 Distribution of NFIP Claims (1978-2017)

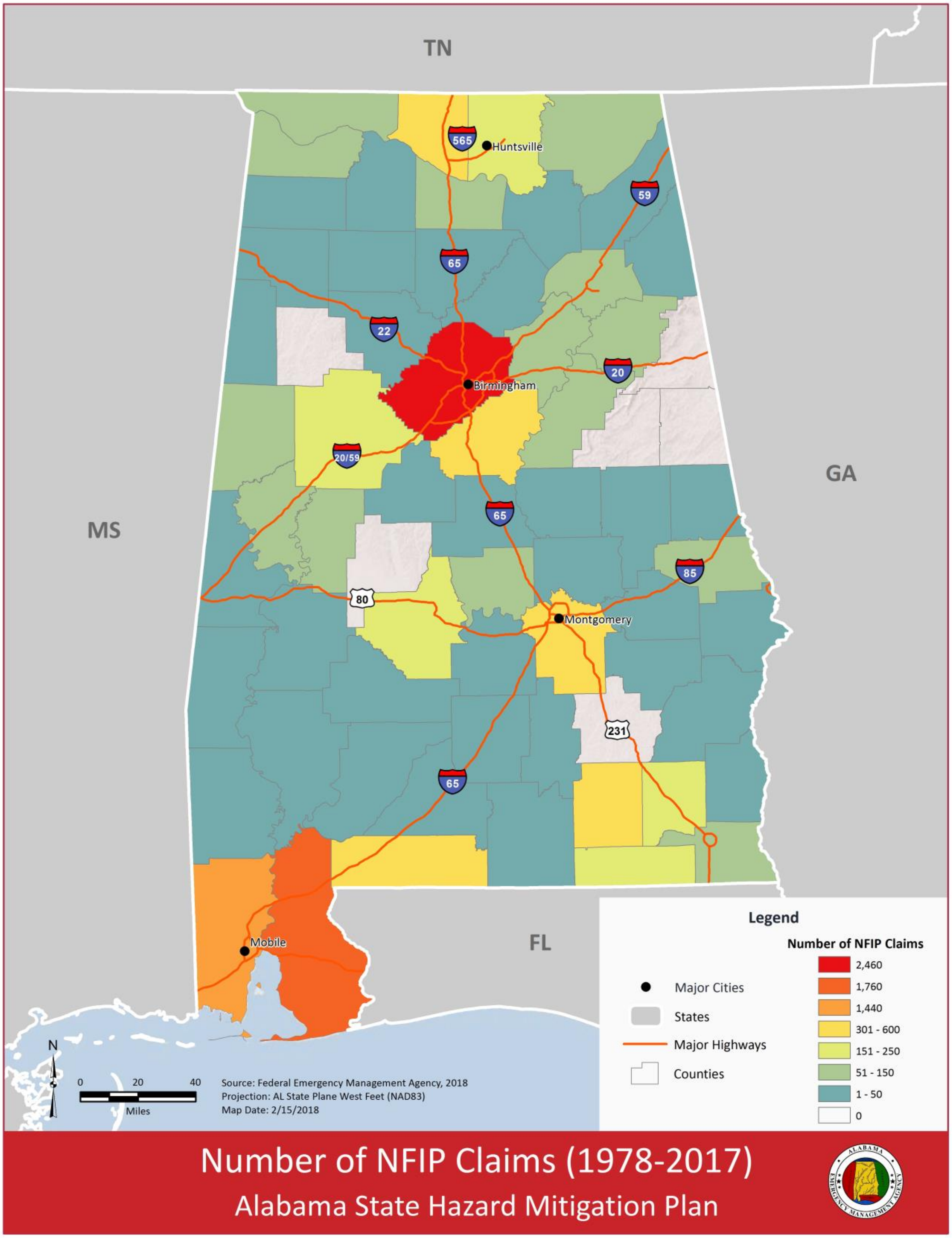


Figure 3.59 Distribution of NFIP Repetitive Loss Claims (1978-2017)

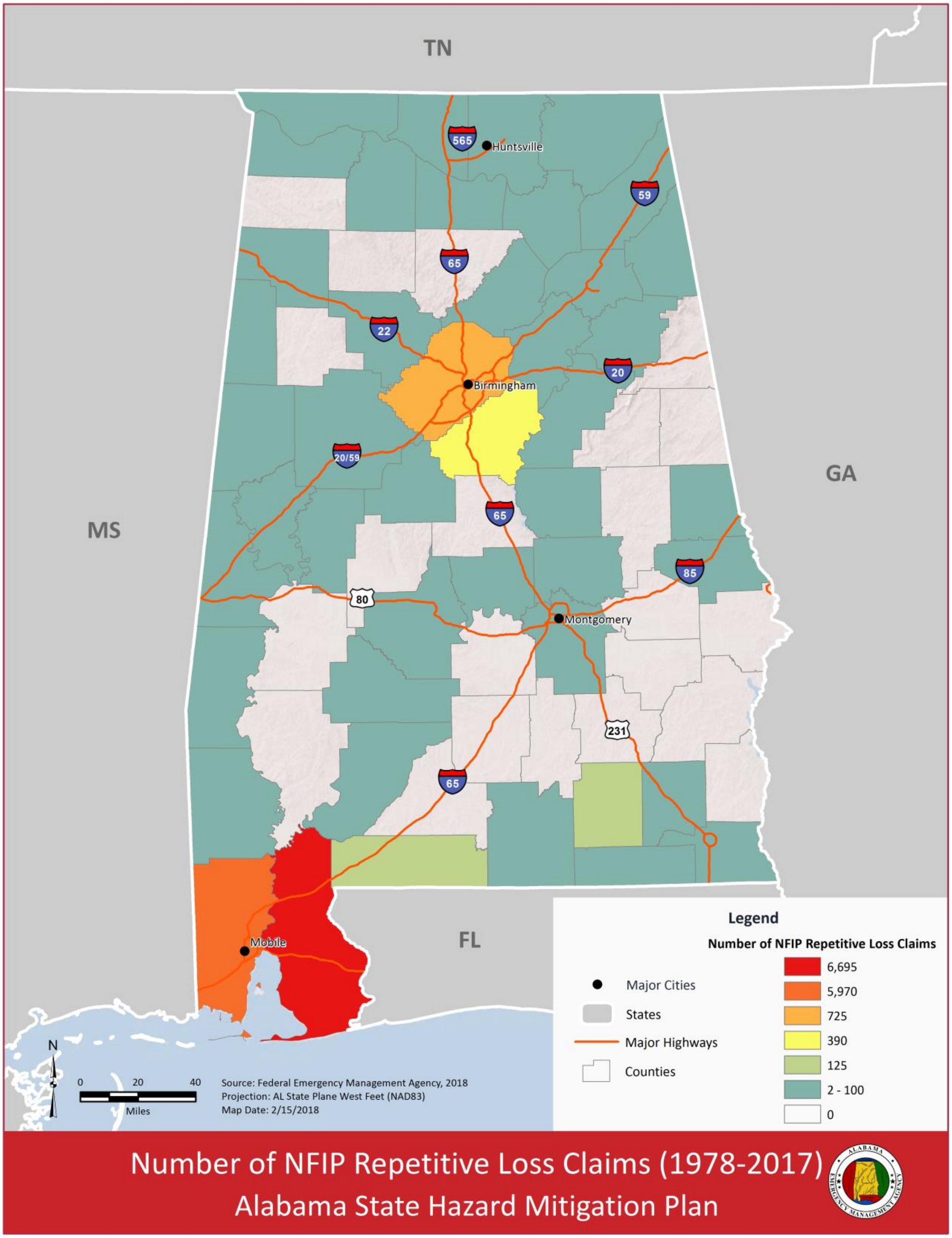


Figure 3.60 Distribution of NFIP Claims per 1,000 Persons (1978-2017)

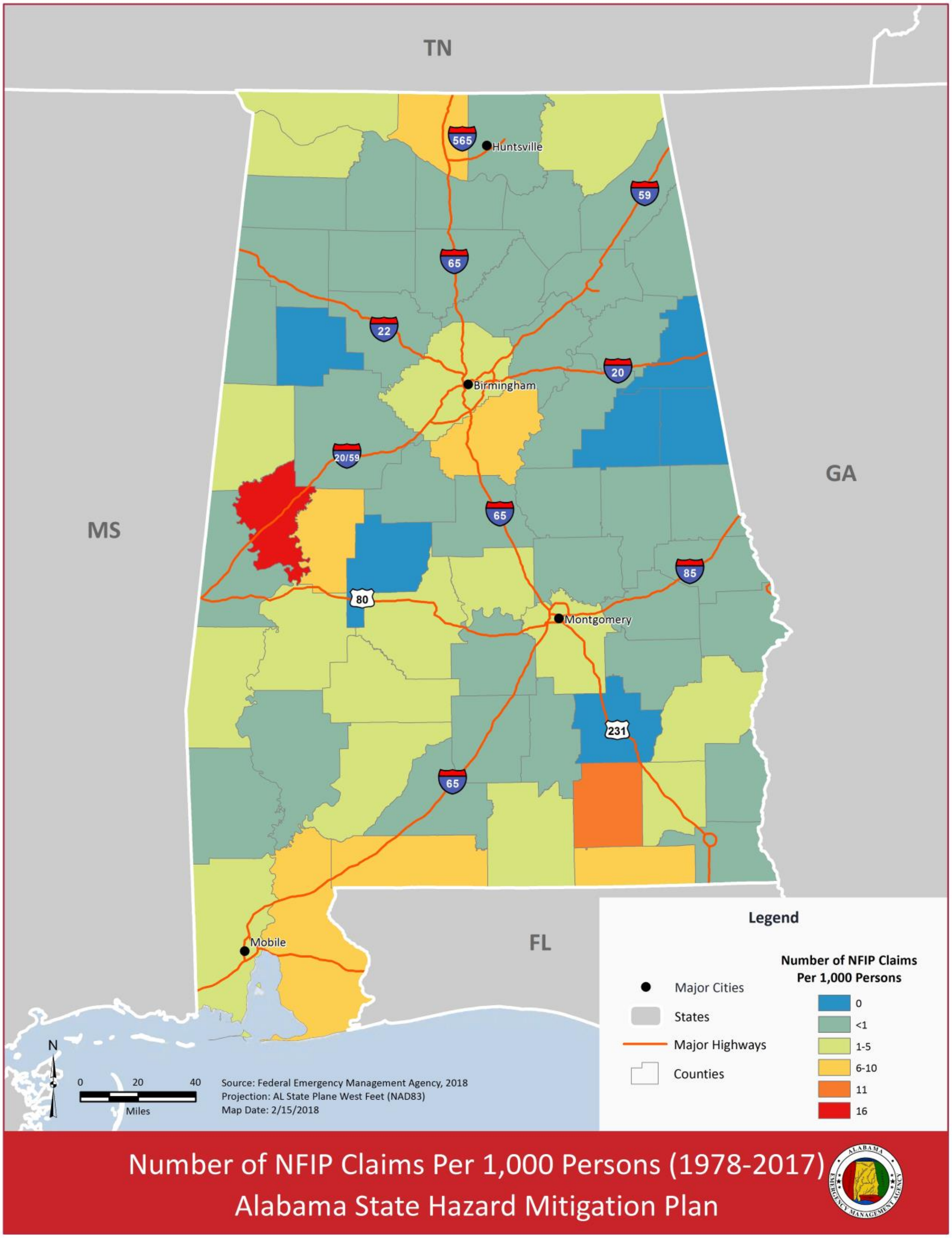
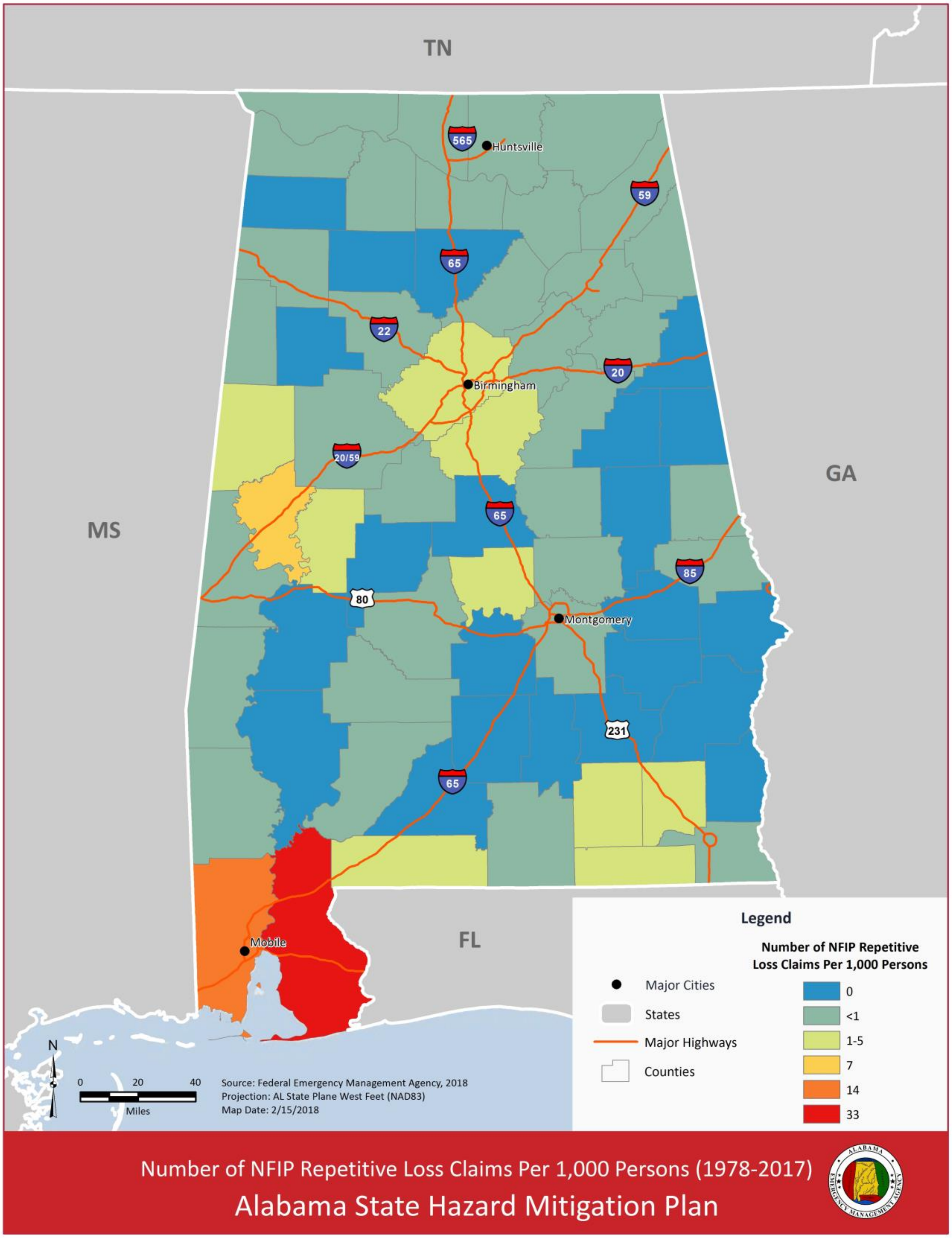


Figure 3.61 Distribution of NFIP Repetitive Loss Claims per 1,000 Persons (1978-2017)



FEMA's Hazus software version 3.2 was also used to estimate potential flood losses across the state. The methodology used a Level II analysis for riverine flooding. The latest available FEMA flood maps and the best available ground elevation data were used to derive local flood depths. This data was combined with the default Hazus inventory data and the default depth-damage curves to estimate damages and associated losses. As discussed in Section 3.3.1, Hazus was used to calculate two kinds of economic losses: 1) immediate losses related to the damage to structures and their contents, and 2) business interruption losses related to how long businesses remain inoperable.

The tables below show the flood losses associated with the 1%-annual-chance flood event aggregated to the county scale. As discussed in Section 3.3.1, flood depth data was not available for multiple flood frequencies, and the average annualized loss therefore could not be calculated. While 5.1.1.1.1.1.1Table 3.53 shows immediate economic losses (building loss, contents loss, and business inventory loss), 5.1.1.1.1.1.1Table 3.53 shows business interruption losses (relocation costs, income loss, rental loss, and wage loss). The estimated immediate losses for the 1%-annual-chance flood are highest for Baldwin, Madison, and Jefferson counties, while the estimated business interruption losses are highest for Mobile, Jefferson, and Madison counties.

5.1.1.1.1.1.1Table 3.54Figure 3.62 shows the spatial distribution of the total average annualized losses (the sum of immediate losses and business interruption losses). Note that losses are shown at the census tract level. The census tracts with the highest estimated losses are located in the coastal areas of Mobile and Baldwin counties and in the western part of the greater Montgomery area.

Table 3.53 Potential Immediate Losses from Flood Hazards (1%-Annual-Chance Flood)

County	Building Loss	Content Loss	Inventory Loss	Total Immediate Losses
Baldwin County	$696,401,000	$547,000,000	$6,745,000	$1,250,146,000
Madison County	$445,387,000	$516,059,000	$14,023,000	$975,469,000
Jefferson County	$438,565,000	$499,846,000	$15,375,000	$953,786,000
Mobile County	$388,880,000	$505,967,000	$17,469,000	$912,316,000
Montgomery County	$294,327,000	$343,971,000	$16,145,000	$654,443,000
Shelby County	$179,183,000	$188,123,000	$6,088,000	$373,394,000
Tuscaloosa County	$151,093,000	$158,182,000	$9,853,000	$319,128,000
Talladega County	$151,788,000	$153,406,000	$6,955,000	$312,149,000
Calhoun County	$128,546,000	$137,830,000	$7,390,000	$273,766,000
Morgan County	$110,951,000	$105,795,000	$4,580,000	$221,326,000
Cherokee County	$106,628,000	$72,555,000	$1,799,000	$180,982,000
Dallas County	$86,770,000	$82,292,000	$3,852,000	$172,914,000
St. Clair County	$89,338,000	$71,970,000	$1,384,000	$162,692,000
Lauderdale County	$81,602,000	$63,042,000	$2,146,000	$146,790,000
Jackson County	$62,544,000	$77,880,000	$2,419,000	$142,843,000
Elmore County	$67,016,000	$64,018,000	$2,496,000	$133,530,000

County	Building Loss	Content Loss	Inventory Loss	Total Immediate Losses
Etowah County	$61,655,000	$67,206,000	$2,690,000	$131,551,000
Escambia County	$49,245,000	$69,803,000	$8,149,000	$127,197,000
Choctaw County	$67,251,000	$55,861,000	$1,683,000	$124,795,000
Russell County	$44,628,000	$67,057,000	$702,000	$112,387,000
Dekalb County	$40,687,000	$60,755,000	$5,220,000	$106,662,000
Colbert County	$46,816,000	$54,815,000	$1,847,000	$103,478,000
Limestone County	$50,223,000	$44,877,000	$1,432,000	$96,532,000
Autauga County	$45,749,000	$42,087,000	$3,289,000	$91,125,000
Lee County	$52,703,000	$37,145,000	$943,000	$90,791,000
Hale County	$48,513,000	$32,599,000	$367,000	$81,479,000
Houston County	$35,579,000	$35,155,000	$1,369,000	$72,103,000
Marengo County	$35,965,000	$31,760,000	$806,000	$68,531,000
Cleburne County	$37,984,000	$26,744,000	$944,000	$65,672,000
Lowndes County	$32,222,000	$32,009,000	$846,000	$65,077,000
Marion County	$28,395,000	$33,678,000	$2,258,000	$64,331,000
Marshall County	$34,658,000	$28,694,000	$688,000	$64,040,000
Walker County	$35,572,000	$26,841,000	$860,000	$63,273,000
Greene County	$38,325,000	$22,911,000	$128,000	$61,364,000
Blount County	$33,875,000	$26,156,000	$362,000	$60,393,000
Bibb County	$33,312,000	$26,249,000	$479,000	$60,040,000
Coffee County	$29,134,000	$26,686,000	$1,560,000	$57,380,000
Sumter County	$30,373,000	$26,104,000	$615,000	$57,092,000
Pickens County	$26,260,000	$25,331,000	$685,000	$52,276,000
Lawrence County	$28,440,000	$23,113,000	$580,000	$52,133,000
Chilton County	$23,745,000	$23,882,000	$1,004,000	$48,631,000
Wilcox County	$24,840,000	$20,774,000	$1,611,000	$47,225,000
Tallapoosa County	$26,843,000	$19,832,000	$218,000	$46,893,000
Chambers County	$21,642,000	$23,398,000	$769,000	$45,809,000
Franklin County	$20,351,000	$22,540,000	$1,237,000	$44,128,000
Cullman County	$24,124,000	$19,078,000	$582,000	$43,784,000
Randolph County	$23,335,000	$18,049,000	$755,000	$42,139,000
Lamar County	$21,033,000	$18,842,000	$642,000	$40,517,000
Covington County	$20,254,000	$14,902,000	$181,000	$35,337,000
Washington County	$20,679,000	$13,610,000	$150,000	$34,439,000
Coosa County	$19,857,000	$13,667,000	$275,000	$33,799,000
Macon County	$18,641,000	$14,785,000	$273,000	$33,699,000
Geneva County	$19,361,000	$12,924,000	$198,000	$32,483,000
Fayette County	$16,159,000	$14,220,000	$420,000	$30,799,000
Clay County	$16,926,000	$12,416,000	$423,000	$29,765,000
Barbour County	$12,096,000	$13,946,000	$745,000	$26,787,000
Clarke County	$17,214,000	$9,284,000	$56,000	$26,554,000

County	Building Loss	Content Loss	Inventory Loss	Total Immediate Losses
Dale County	$12,322,000	$9,993,000	$291,000	$22,606,000
Monroe County	$13,468,000	$8,236,000	$78,000	$21,782,000
Perry County	$8,898,000	$10,371,000	$319,000	$19,588,000
Butler County	$7,428,000	$9,215,000	$137,000	$16,780,000
Bullock County	$6,736,000	$5,931,000	$185,000	$12,852,000
Henry County	$6,167,000	$5,617,000	$187,000	$11,971,000
Pike County	$7,060,000	$4,789,000	$62,000	$11,911,000
Winston County	$6,525,000	$4,572,000	$134,000	$11,231,000
Crenshaw County	$5,504,000	$4,306,000	$114,000	$9,924,000
Conecuh County	$3,035,000	$2,287,000	$65,000	$5,387,000
Total	**$4,870,826,000**	**$4,863,038,000**	**$168,332,000**	**$9,902,196,000**

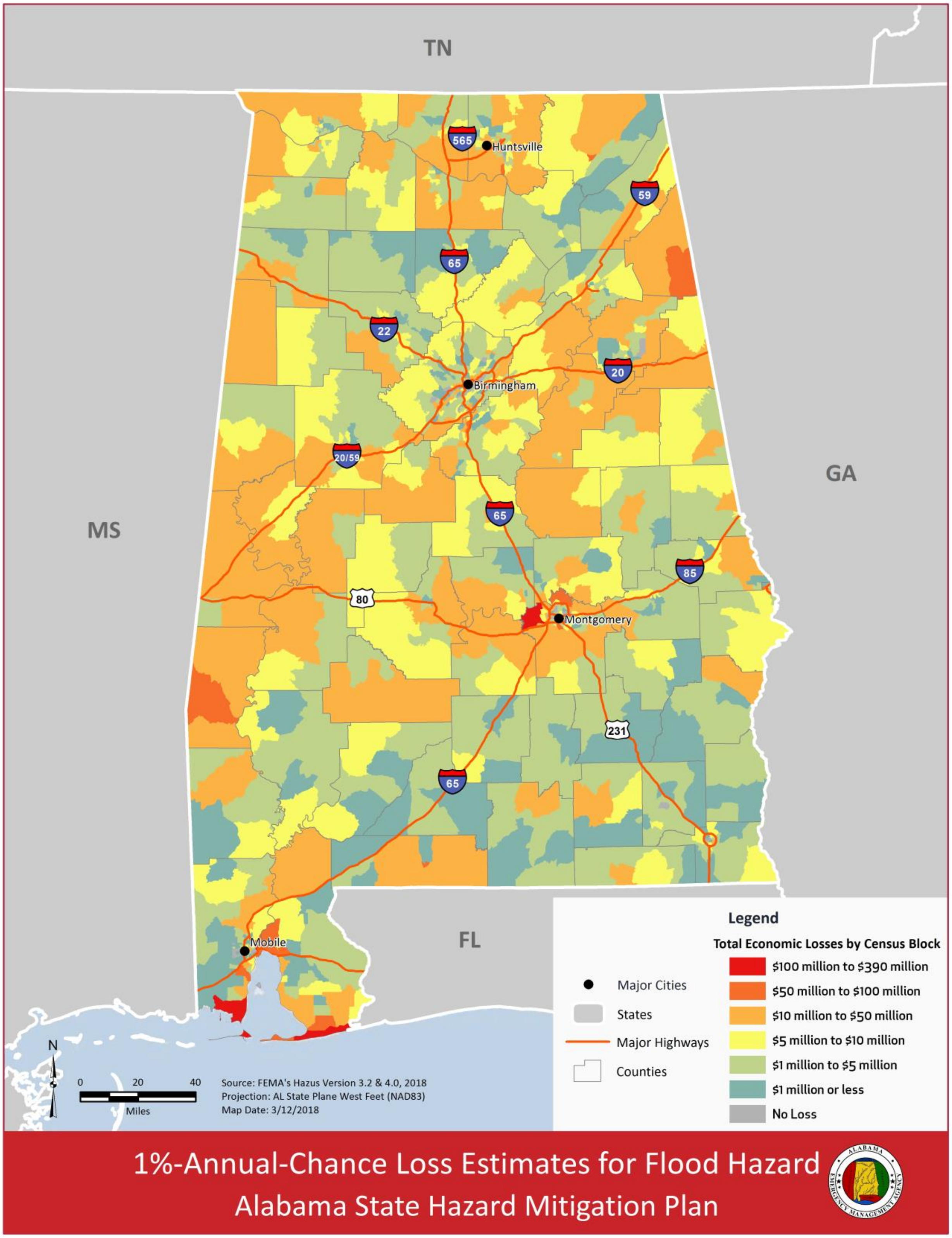
Table 3.54 Potential Business Interruption Losses from Flood Hazards (1%-Annual-Chance Flood)

County	Income Loss	Relocation Loss	Rental Income Loss	Wage Loss	Total Business Interruption Losses
Mobile County	$1,724,000	$949,000	$340,000	$4,835,000	$7,848,000
Jefferson County	$2,030,000	$856,000	$330,000	$3,778,000	$6,994,000
Madison County	$1,446,000	$739,000	$280,000	$2,906,000	$5,371,000
Baldwin County	$1,195,000	$1,423,000	$858,000	$1,561,000	$5,037,000
Montgomery County	$917,000	$499,000	$228,000	$1,523,000	$3,167,000
Shelby County	$385,000	$216,000	$59,000	$670,000	$1,330,000
Talladega County	$230,000	$143,000	$31,000	$656,000	$1,060,000
Russell County	$131,000	$69,000	$8,000	$757,000	$965,000
Calhoun County	$226,000	$112,000	$34,000	$522,000	$894,000
Morgan County	$124,000	$114,000	$27,000	$598,000	$863,000
Tuscaloosa County	$195,000	$131,000	$47,000	$394,000	$767,000
Choctaw County	$51,000	$47,000	$10,000	$626,000	$734,000
Cherokee County	$38,000	$119,000	$15,000	$519,000	$691,000
Dallas County	$132,000	$121,000	$21,000	$410,000	$684,000
Hale County	$19,000	$62,000	$4,000	$489,000	$574,000
Jackson County	$170,000	$55,000	$21,000	$322,000	$568,000
Elmore County	$79,000	$55,000	$5,000	$315,000	$454,000
Escambia County	$82,000	$42,000	$12,000	$316,000	$452,000
Etowah County	$107,000	$39,000	$17,000	$285,000	$448,000
Fayette County	$20,000	$5,000	$1,000	$416,000	$442,000
Colbert County	$153,000	$34,000	$9,000	$236,000	$432,000
Dekalb County	$100,000	$29,000	$8,000	$239,000	$376,000
St. Clair County	$54,000	$67,000	$8,000	$239,000	$368,000

County	Income Loss	Relocation Loss	Rental Income Loss	Wage Loss	Total Business Interruption Losses
Sumter County	$34,000	$12,000	$8,000	$314,000	$368,000
Lowndes County	$33,000	$44,000	$5,000	$278,000	$360,000
Marengo County	$39,000	$27,000	$2,000	$233,000	$301,000
Limestone County	$66,000	$48,000	$10,000	$171,000	$295,000
Marion County	$99,000	$25,000	$16,000	$136,000	$276,000
Lauderdale County	$50,000	$40,000	$6,000	$176,000	$272,000
Greene County	$20,000	$40,000	$3,000	$201,000	$264,000
Autauga County	$38,000	$39,000	$3,000	$172,000	$252,000
Tallapoosa County	$20,000	$14,000	$3,000	$158,000	$195,000
Washington County	$1,000	$10,000	$0	$172,000	$183,000
Barbour County	$9,000	$6,000	$0	$158,000	$173,000
Lawrence County	$23,000	$10,000	$1,000	$131,000	$165,000
Houston County	$33,000	$22,000	$8,000	$88,000	$151,000
Butler County	$6,000	$0	$1,000	$132,000	$139,000
Chambers County	$36,000	$14,000	$1,000	$87,000	$138,000
Bibb County	$12,000	$5,000	$0	$120,000	$137,000
Pickens County	$47,000	$18,000	$4,000	$62,000	$131,000
Lee County	$27,000	$50,000	$8,000	$45,000	$130,000
Coffee County	$25,000	$17,000	$2,000	$78,000	$122,000
Blount County	$26,000	$13,000	$3,000	$66,000	$108,000
Walker County	$8,000	$12,000	$2,000	$78,000	$100,000
Marshall County	$16,000	$16,000	$3,000	$62,000	$97,000
Chilton County	$18,000	$12,000	$3,000	$54,000	$87,000
Franklin County	$30,000	$7,000	$1,000	$46,000	$84,000
Randolph County	$11,000	$9,000	$1,000	$62,000	$83,000
Clay County	$3,000	$2,000	$0	$73,000	$78,000
Cullman County	$7,000	$9,000	$2,000	$58,000	$76,000
Wilcox County	$10,000	$15,000	$0	$51,000	$76,000
Covington County	$6,000	$8,000	$6,000	$50,000	$70,000
Macon County	$9,000	$5,000	$1,000	$54,000	$69,000
Perry County	$22,000	$9,000	$3,000	$30,000	$64,000
Bullock County	$0	$2,000	$0	$53,000	$55,000
Monroe County	$7,000	$14,000	$3,000	$27,000	$51,000
Coosa County	$8,000	$5,000	$1,000	$32,000	$46,000
Crenshaw County	$2,000	$0	$0	$44,000	$46,000
Henry County	$6,000	$5,000	$1,000	$34,000	$46,000
Lamar County	$9,000	$3,000	$3,000	$29,000	$44,000
Cleburne County	$5,000	$7,000	$0	$30,000	$42,000
Geneva County	$12,000	$10,000	$0	$18,000	$40,000
Dale County	$12,000	$5,000	$0	$20,000	$37,000

County	Income Loss	Relocation Loss	Rental Income Loss	Wage Loss	Total Business Interruption Losses
Clarke County	$3,000	$8,000	$1,000	$21,000	$33,000
Pike County	$4,000	$0	$0	$5,000	$9,000
Winston County	$2,000	$0	$0	$7,000	$9,000
Conecuh County	$0	$0	$0	$4,000	$4,000
Total	**$10,462,000**	**$6,543,000**	**$2,488,000**	**$26,532,000**	**$46,025,000**

Figure 3.62 Total Potential Losses for Flood Hazard (1%-Annual-Chance Flood)



3.3.4 High Winds

The risk of damage and loss from high winds is a function of the high wind hazard; the exposure of people, buildings and infrastructure; and the susceptibility of the exposed communities and structures. As discussed in Section 3.2.7, the probability of damaging high winds will likely increase with climate change. The precise amount by which the probability of high winds will increase, however, is uncertain. This section therefore summarizes the potential impacts of high winds on state assets and jurisdictions under present conditions.

3.3.4.1 Vulnerability of State Assets

The vulnerability of state assets to high winds was determined based on the design wind speed maps published in ASCE/SEI 7-16. As discussed in Section 3.2.7, ASC3.2.7E/SEI 7-16 reflects the wind hazard posed by all storm events except tornadoes and shows the distribution of wind speeds at three probabilities of occurrence. The 700-year wind event (or the wind event with a 7% probability of exceedance in 50 years) was determined to be most appropriate for this analysis. This is the design wind event recommended for structures whose failure would pose a moderate risk to life and safety. Within the 700-year design wind speed map, all locations with wind speeds exceeding 137 mph were selected for further analysis. According to the Enhanced Fujita Tornado Scale, wind speeds of 137 mph or more can cause severe damage, destroying entire stories of well-constructed houses, lifting heavy cars off the ground, and blowing away structures with weak foundations.

Of the more than 12,000 state-insured facilities, 1,741 were located in areas with a 700-year design wind speed exceeding 137 mph (5.1.1.1.1.1.1Table 3.55). These facilities consist mostly of education facilities and have a combined replacement value of more than $3 billion, or 12% of the value of all state-insured facilities.

Table 3.55 State-Insured Facilities Vulnerable to High Wind Hazard

Facility Type	# of Vulnerable Structures	% of Total Structures for Facility Type	Replacement Value	% of Total Value for Facility Type
Agriculture	3	15.0%	$882,917	2.6%
Education	1,183	13.3%	$2,499,710,321	12.2%
Government	22	9.1%	$18,650,346	0.8%
Healthcare	64	21.1%	$117,519,947	15.3%
Military	9	8.8%	$39,228,539	11.5%
Parks/Recreation	193	15.8%	$70,903,674	20.2%
Port Authority	151	89.9%	$339,159,167	97.2%
Public Safety	71	11.4%	$79,509,213	10.4%
Transportation	45	8.3%	$30,406,270	9.5%
Total	**1,741**	**14.3%**	**$3,195,970,394**	**12.4%**

Of the 150 structures identified as critical infrastructure by the state, 37 are located in areas with a 700-year design wind speed exceeding 137 mph (5.1.1.1.1.1.1Table 3.56). Most of these facilities are commercial or chemical facilities.

Table 3.56 Critical Infrastructure Vulnerable to High Wind Hazard

Facility Type	# of Vulnerable Structures
Agriculture & Food	1
Banking & Finance	1
Chemical	8
Commercial	11
Critical Manufacturing	2
Defense Industrial Base	1
Energy	3
Government Facilities	1
Healthcare & Public Health	3
Transportation Systems	6
Total	**37**

3.3.4.2 Vulnerability of Jurisdictions

FEMA's Hazus software version 3.2 was used to estimate high wind vulnerability across the state. The methodology uses Hazus default data on high wind hazards along with state-wide building stock data (based on 2010 US Census data) and the software's standard algorithms. The calculation algorithms quantify the potential losses associated with hurricane using information about sea surface temperature, central pressure, translation speed, and surface roughness. As discussed in Section 3.3.1, Hazus was used to calculate two kinds of economic losses: 1) immediate losses related to the damage to structures and their contents, and 2) business interruption losses related to how long businesses remain inoperable.

The tables below show the average annualized hurricane wind losses for Alabama aggregated to the county scale. While 5.1.1.1.1.1.1Table 3.57 shows immediate economic losses (building loss, contents loss, and business inventory loss), 5.1.1.1.1.1.1Table 3.58 shows business interruption losses (relocation costs, income loss, rental loss, and wage loss). 5.1.1.1.1.1.1Table 3.58Figure 3.63 shows the spatial distribution of the total average annualized losses (the sum of immediate losses and business interruption losses). Note that losses are shown at the census tract level. Both the county-level tables and the census-tract level map show the highest annualized losses in Mobile and Baldwin counties.

It is instructive to compare the magnitude of average annualized losses for earthquake hazards and high wind hazards. While the potential immediate losses across the state of Alabama total

more than half a trillion dollars for high wind hazards, they total slightly more than $20 million for earthquake hazards. This finding reflects the lower probability of earthquake hazards discussed in the Section 3.2.3.

Table 3.57 Potential Immediate Losses from High Wind Hazards (AAL)

County	Building Loss	Contents Loss	Business Inventory Loss	Total Immediate Losses
Mobile County	$196,582,066	$88,212,640	$1,385,249	$286,179,954
Baldwin County	$119,042,397	$49,264,936	$527,422	$168,834,756
Escambia County	$4,300,417	$1,692,897	$43,174	$6,036,488
Montgomery County	$3,412,464	$975,674	$6,262	$4,394,400
Jefferson County	$3,149,302	$1,061,238	$2,605	$4,213,145
Houston County	$3,193,780	$1,007,426	$10,203	$4,211,409
Covington County	$2,320,227	$914,451	$9,754	$3,244,432
Coffee County	$1,963,972	$775,056	$4,205	$2,743,233
Dale County	$1,405,434	$517,485	$3,684	$1,926,603
Geneva County	$1,336,960	$486,258	$3,199	$1,826,417
Washington County	$1,282,189	$514,268	$2,216	$1,798,673
Shelby County	$1,276,801	$385,100	$1,110	$1,663,011
Monroe County	$1,240,029	$398,968	$5,116	$1,644,114
Tuscaloosa County	$1,184,358	$390,524	$1,531	$1,576,413
Lee County	$1,074,127	$421,158	$1,728	$1,497,012
Clarke County	$1,017,491	$366,554	$3,275	$1,387,320
Elmore County	$908,142	$367,870	$715	$1,276,727
Conecuh County	$686,509	$262,398	$2,139	$951,046
Autauga County	$670,383	$199,782	$1,139	$871,303
Madison County	$712,526	$153,554	$415	$866,495
Butler County	$520,401	$197,788	$1,347	$719,536
Pike County	$528,973	$149,904	$1,581	$680,458
Dallas County	$462,005	$141,958	$1,059	$605,022
Crenshaw County	$349,699	$135,659	$737	$486,095
Henry County	$381,497	$89,404	$1,006	$471,908
Russell County	$336,849	$116,034	$796	$453,679
Calhoun County	$350,761	$100,870	$468	$452,099
Tallapoosa County	$315,030	$127,818	$218	$443,066
Talladega County	$326,124	$111,570	$762	$438,456
Choctaw County	$320,496	$104,242	$964	$425,701
Etowah County	$293,765	$122,839	$232	$416,835
Chilton County	$310,242	$100,167	$462	$410,871
Barbour County	$292,423	$98,902	$1,239	$392,564
St. Clair County	$278,852	$110,450	$200	$389,502
Marengo County	$301,471	$85,097	$476	$387,044
Morgan County	$236,816	$68,430	$178	$305,424

County	Building Loss	Contents Loss	Business Inventory Loss	Total Immediate Losses
Wilcox County	$220,909	$80,266	$514	$301,689
Cullman County	$204,546	$59,165	$343	$264,053
Walker County	$192,786	$63,979	$182	$256,946
Chambers County	$176,045	$53,932	$681	$230,658
Limestone County	$174,818	$52,165	$110	$227,093
Macon County	$157,763	$55,774	$278	$213,814
Hale County	$146,681	$64,024	$241	$210,946
Blount County	$155,855	$50,927	$84	$206,866
Marshall County	$163,163	$38,289	$233	$201,686
Bibb County	$126,913	$51,370	$94	$178,376
Sumter County	$131,562	$45,669	$318	$177,548
Lauderdale County	$137,404	$19,156	$120	$156,681
Bullock County	$105,196	$43,346	$239	$148,782
Randolph County	$105,347	$41,194	$101	$146,642
Lowndes County	$121,239	$23,709	$362	$145,310
Perry County	$90,072	$30,082	$77	$120,231
Pickens County	$86,824	$32,386	$67	$119,277
Dekalb County	$99,834	$16,393	$312	$116,540
Coosa County	$80,978	$32,625	$57	$113,659
Colbert County	$93,508	$17,511	$168	$111,186
Jackson County	$79,975	$28,246	$84	$108,305
Marion County	$78,804	$28,800	$154	$107,757
Cherokee County	$77,804	$26,490	$113	$104,406
Greene County	$63,338	$21,224	$66	$84,628
Lawrence County	$66,509	$17,380	$34	$83,923
Lamar County	$52,570	$27,241	$71	$79,881
Fayette County	$57,536	$21,532	$130	$79,197
Winston County	$59,846	$16,096	$178	$76,120
Clay County	$52,907	$19,340	$230	$72,477
Franklin County	$50,722	$11,356	$73	$62,151
Cleburne County	$40,092	$16,801	$29	$56,922
Total	**$355,816,521**	**$151,335,832**	**$2,032,609**	**$509,184,962**

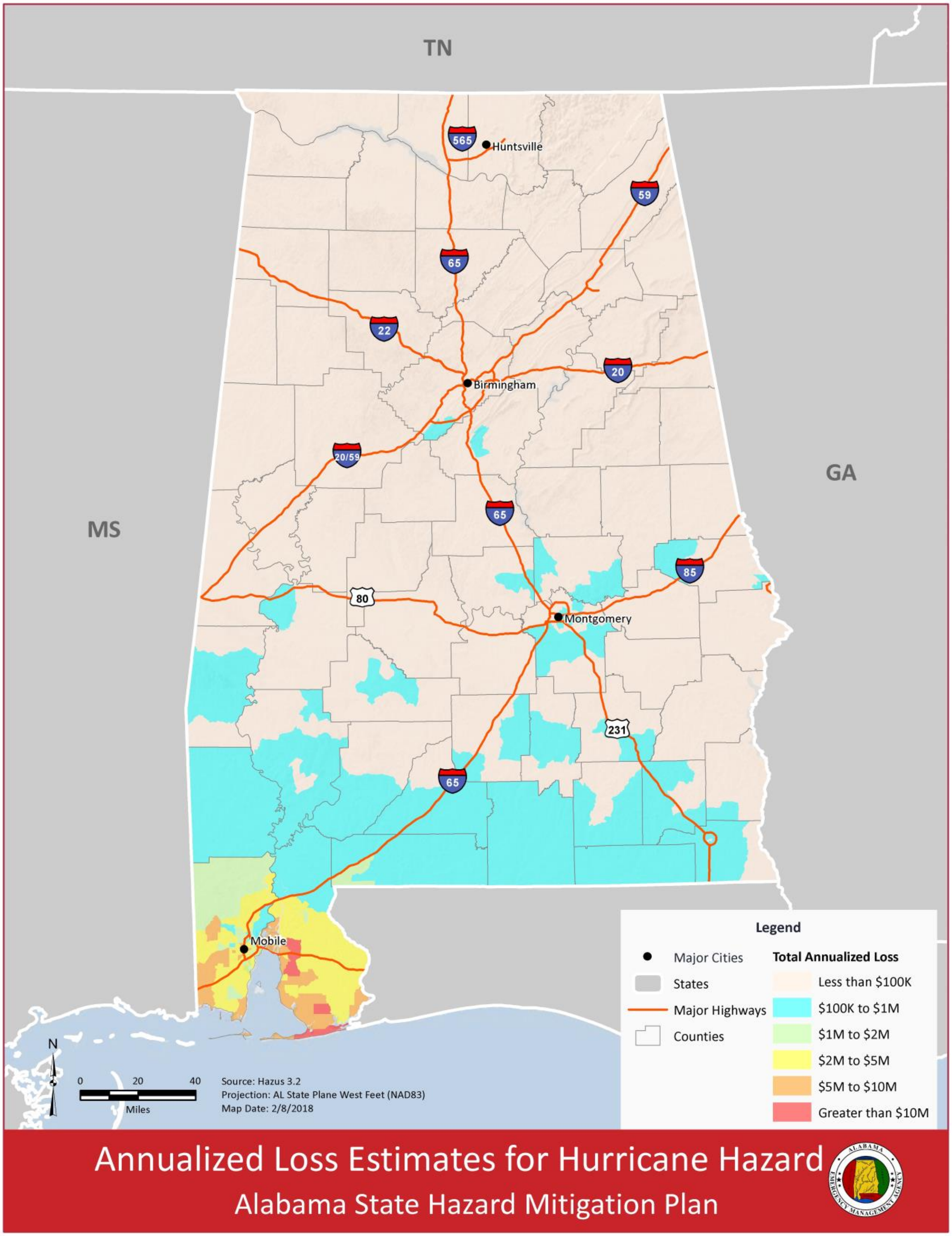
Table 3.58 Potential Business Interruption Losses from High Wind Hazards (AAL)

County	Relocation Loss	Income Loss	Rental Income Loss	Wage Loss	Total Business Interruption Losses
Mobile County	$25,144,094	$3,697,339	$9,488,505	$4,663,572	$42,993,510
Baldwin County	$13,630,220	$1,770,962	$5,682,085	$2,179,425	$23,262,691

County	Relocation Loss	Income Loss	Rental Income Loss	Wage Loss	Total Business Interruption Losses
Escambia County	$533,627	$66,437	$191,257	$100,323	$891,643
Houston County	$275,866	$34,377	$112,069	$52,575	$474,888
Covington County	$220,217	$19,331	$76,496	$33,158	$349,202
Montgomery County	$187,566	$24,321	$97,637	$31,472	$340,996
Coffee County	$150,925	$12,939	$55,936	$18,041	$237,841
Monroe County	$141,633	$11,998	$47,172	$23,829	$224,633
Geneva County	$136,265	$8,505	$44,493	$15,238	$204,501
Jefferson County	$109,601	$13,547	$46,031	$15,925	$185,104
Washington County	$120,291	$5,681	$36,367	$16,017	$178,356
Dale County	$97,411	$7,337	$40,178	$11,799	$156,725
Clarke County	$85,363	$6,908	$30,520	$15,168	$137,959
Conecuh County	$58,369	$3,228	$19,450	$6,382	$87,429
Tuscaloosa County	$47,926	$4,500	$20,264	$5,613	$78,303
Lee County	$48,149	$3,597	$19,025	$4,595	$75,366
Pike County	$39,779	$3,991	$17,395	$6,030	$67,195
Shelby County	$40,672	$2,638	$13,881	$2,934	$60,124
Elmore County	$40,040	$2,429	$13,493	$3,516	$59,477
Butler County	$34,282	$3,253	$14,661	$5,403	$57,600
Dallas County	$31,896	$4,314	$13,683	$7,499	$57,392
Henry County	$35,607	$2,270	$11,587	$3,265	$52,730
Autauga County	$34,722	$2,061	$11,371	$2,875	$51,029
Choctaw County	$23,067	$1,802	$7,649	$5,740	$38,258
Crenshaw County	$23,280	$1,326	$8,012	$3,016	$35,634
Barbour County	$19,488	$2,020	$8,533	$4,193	$34,235
Marengo County	$21,206	$1,968	$7,353	$3,314	$33,840
Russell County	$20,592	$1,422	$7,129	$2,771	$31,913
Madison County	$19,721	$2,005	$7,604	$1,999	$31,330
Wilcox County	$14,764	$1,103	$5,601	$2,747	$24,215
Chilton County	$15,646	$996	$4,669	$1,853	$23,165
Talladega County	$13,717	$1,055	$4,626	$1,662	$21,060
Calhoun County	$13,470	$1,072	$4,917	$1,496	$20,954
Tallapoosa County	$10,716	$654	$3,533	$1,150	$16,054
Sumter County	$8,902	$812	$3,289	$2,202	$15,206
Lowndes County	$9,688	$606	$2,979	$1,285	$14,559
Macon County	$8,848	$688	$3,336	$1,295	$14,167
Etowah County	$8,219	$706	$2,969	$1,045	$12,938
Chambers County	$8,270	$516	$2,764	$927	$12,476
Hale County	$7,765	$467	$2,346	$1,305	$11,882
St. Clair County	$8,150	$372	$2,565	$540	$11,627
Walker County	$7,469	$484	$2,400	$763	$11,115

County	Relocation Loss	Income Loss	Rental Income Loss	Wage Loss	Total Business Interruption Losses
Cullman County	$6,900	$485	$2,225	$907	$10,517
Morgan County	$6,368	$602	$2,290	$653	$9,912
Bullock County	$5,813	$394	$1,947	$781	$8,935
Marshall County	$5,747	$442	$1,918	$628	$8,735
Limestone County	$5,734	$373	$1,826	$423	$8,356
Perry County	$5,330	$355	$1,888	$622	$8,196
Lauderdale County	$5,224	$410	$1,884	$568	$8,086
Bibb County	$5,171	$298	$1,683	$558	$7,711
Blount County	$4,542	$257	$1,383	$299	$6,481
Dekalb County	$4,045	$284	$1,239	$870	$6,438
Randolph County	$4,189	$212	$1,297	$610	$6,308
Colbert County	$4,072	$314	$1,408	$419	$6,213
Pickens County	$3,734	$167	$1,249	$424	$5,574
Greene County	$3,426	$122	$1,092	$447	$5,087
Cherokee County	$2,844	$144	$817	$289	$4,093
Marion County	$2,497	$198	$889	$362	$3,946
Coosa County	$2,822	$63	$798	$214	$3,897
Lawrence County	$2,479	$136	$727	$251	$3,592
Winston County	$2,459	$97	$750	$184	$3,490
Franklin County	$2,159	$132	$719	$215	$3,224
Jackson County	$2,105	$132	$655	$185	$3,077
Fayette County	$1,921	$98	$644	$278	$2,941
Clay County	$1,868	$101	$620	$248	$2,837
Lamar County	$1,616	$90	$524	$182	$2,412
Cleburne County	$1,312	$44	$397	$147	$1,900
Total	**$41,601,875**	**$5,737,986**	**$16,226,700**	**$7,274,723**	**$70,841,284**

Figure 3.63 Total Potential Losses for High Wind Hazard (Average Annualized Loss)



As discussed in Section 3.2.7, modeling and mapping the probability of tornado wind hazards is complicated by the lack of available data. In the absence of accurate models of tornado hazard, it is not possible to model the future vulnerability of people and property across Alabama counties. Historic vulnerability to tornado hazards, however, can be used as a rough guide to future vulnerability. 5.1.1.1.1.1.1Table 3.59 shows the tornado-related property damage sustained be each county in Alabama between 1950-2017, as recorded in the Storm Events Database. It is important to note that the damage estimates in the Storm Events Database are collected from diverse sources by staff with little or no training in damage estimation, and that these estimates are often not compared with actual costs. Nevertheless, this dataset represents the most complete and consistent available record of tornado damage in the US. Based on their historical vulnerability, the counties of Tuscaloosa, Jefferson, Limestone, and Madison are likely to be the most vulnerable to tornado damage and loss.

Table 3.59 Historical Tornado Damage by County, 2017 Dollars

County	Property Damage	Crop Damage	Total Damage
Tuscaloosa County	$1,926,382,495	$1,000,710	$1,927,383,205
Jefferson County	$1,426,772,700	$3,300,000	$1,430,072,700
Limestone County	$1,136,279,350	$76,500	$1,136,355,850
Madison County	$1,088,373,665	$0	$1,088,373,665
St. Clair County	$383,918,555	$27,507,500	$411,426,055
Coffee County	$369,128,263	$82,500	$369,210,763
Walker County	$298,507,265	$120,000	$298,627,265
Cullman County	$297,430,748	$64,830	$297,495,578
Marion County	$204,230,125	$0	$204,230,125
Calhoun County	$153,017,336	$27,530,000	$180,547,336
Hale County	$168,315,635	$0	$168,315,635
Perry County	$163,519,160	$39,000	$163,558,160
Shelby County	$161,491,258	$0	$161,491,258
Bibb County	$155,738,533	$0	$155,738,533
Pickens County	$153,921,040	$22,500	$153,943,540
Talladega County	$152,051,615	$0	$152,051,615
Fayette County	$143,804,610	$0	$143,804,610
Clay County	$143,322,305	$3,990	$143,326,295
Tallapoosa County	$131,198,639	$65,520	$131,264,159
Dale County	$119,194,900	$0	$119,194,900
Elmore County	$86,187,192	$156,000	$86,343,192
Marshall County	$75,850,993	$82,830	$75,933,823
Russell County	$74,440,665	$3,000	$74,443,665

County	Property Damage	Crop Damage	Total Damage
Morgan County	$69,869,103	$0	$69,869,103
Dekalb County	$63,043,875	$45,300	$63,089,175
Blount County	$62,250,890	$81,410	$62,332,300
Franklin County	$59,674,600	$0	$59,674,600
Cherokee County	$26,420,800	$27,500,000	$53,920,800
Lawrence County	$51,665,395	$12,240	$51,677,635
Lee County	$50,775,135	$0	$50,775,135
Henry County	$46,771,350	$805	$46,772,155
Etowah County	$41,338,933	$109,020	$41,447,953
Montgomery County	$40,463,945	$0	$40,463,945
Jackson County	$40,395,810	$7,650	$40,403,460
Dallas County	$39,886,735	$93,600	$39,980,335
Marengo County	$31,530,450	$0	$31,530,450
Autauga County	$30,424,631	$0	$30,424,631
Baldwin County	$28,462,027	$0	$28,462,027
Chilton County	$24,712,440	$7,800	$24,720,240
Winston County	$24,280,898	$34,320	$24,315,218
Sumter County	$23,166,828	$0	$23,166,828
Coosa County	$19,943,928	$31,200	$19,975,128
Colbert County	$19,813,893	$7,650	$19,821,543
Monroe County	$19,137,123	$0	$19,137,123
Houston County	$19,019,453	$0	$19,019,453
Choctaw County	$18,951,640	$0	$18,951,640
Mobile County	$17,267,667	$0	$17,267,667
Covington County	$16,960,238	$0	$16,960,238
Greene County	$13,369,209	$0	$13,369,209
Pike County	$12,559,335	$15,000	$12,574,335
Randolph County	$12,541,300	$0	$12,541,300
Chambers County	$10,293,420	$82,500	$10,375,920
Lamar County	$10,059,100	$67,500	$10,126,600
Escambia County	$9,917,135	$0	$9,917,135
Clarke County	$6,194,790	$3,240,000	$9,434,790
Lauderdale County	$9,316,818	$0	$9,316,818
Conecuh County	$8,740,120	$0	$8,740,120
Crenshaw County	$8,542,950	$0	$8,542,950

County	Property Damage	Crop Damage	Total Damage
Barbour County	$8,324,045	$5,550	$8,329,595
Lowndes County	$7,892,180	$45,000	$7,937,180
Washington County	$7,693,933	$0	$7,693,933
Butler County	$7,139,969	$0	$7,139,969
Geneva County	$5,983,715	$0	$5,983,715
Cleburne County	$5,615,350	$23,760	$5,639,110
Wilcox County	$3,319,325	$0	$3,319,325
Macon County	$3,280,875	$0	$3,280,875
Bullock County	$2,832,670	$13,500	$2,846,170
Total	**$10,052,921,067**	**$91,478,685**	**$10,144,399,752**

3.3.5 Sea Level Rise and Coastal Land Change

The risk of damage and loss from sea level rise is a function of the hazard; the exposure of people, buildings and infrastructure; and the susceptibility of the exposed communities and structures. As discussed in Section 3.2.10, sea level rise is a certainty in Alabama, but its rate could increase or decrease depending on human activities and the response of natural systems. To inform coastal planning, scientists have developed a range of sea level rise scenarios. This section examines the impacts of a one-foot, three-foot, and six-foot rise in local sea levels to illustrate the range of possible impacts. The only jurisdictions vulnerable to sea level rise are Mobile and Baldwin counties.[153]

3.3.5.1 Vulnerability of State Assets

Of the more than 12,000 state-insured facilities, 5 would be vulnerable to a 1-foot rise in local sea level, 94 would be vulnerable to a 3-foot rise, and 125 would be vulnerable to a 6-foot rise (5.1.1.1.1.1.1Table 3.60, 5.1.1.1.1.1.1Table 3.61, and 5.1.1.1.1.1.1Table 3.62). These facilities consist mostly of park and recreation facilities and port facilities and have a combined replacement value of more than $7 million for a 1-foot rise in local sea level, more than $25 million for a 3-foot rise, and more than $74 million for a 6-foot rise.

[153] Due to limitations in the floodplain mapping data available, sea level rise products have only been produced for Mobile and Baldwin counties and are not currently available for other counties near the coast. The availability of data in other counties does not mean that these counties do not face risk from sea-level risk.

Table 3.60 State-Insured Facilities Vulnerable to 1-Foot Local Sea Level Rise

Facility Type	# of Vulnerable Structures	% of Total Structures for Facility Type	Replacement Value	% of Total Value for Facility Type
Agriculture	0	0.0%	$0	0.0%
Education	3	0.0%	$7,056,445	0.0%
Government	0	0.0%	$0	0.0%
Healthcare	0	0.0%	$0	0.0%
Military	0	0.0%	$0	0.0%
Parks/Recreation	1	0.1%	$285,242	0.1%
Port Authority	1	0.6%	$33,117	0.0%
Public Safety	0	0.0%	$0	0.0%
Transportation	0	0.0%	$0	0.0%
Total	**5**	**0.0%**	**$7,374,804**	**0.0%**

Table 3.61 State-Insured Facilities Vulnerable to 3-Foot Local Sea Level Rise

Facility Type	# of Vulnerable Structures	% of Total Structures for Facility Type	Replacement Value	% of Total Value for Facility Type
Agriculture	0	0.0%	$0	0.0%
Education	3	0.0%	$7,056,445	0.0%
Government	0	0.0%	$0	0.0%
Healthcare	0	0.0%	$0	0.0%
Military	0	0.0%	$0	0.0%
Parks/Recreation	87	7.1%	$16,765,186	4.8%
Port Authority	2	1.2%	$559,849	0.2%
Public Safety	2	0.3%	$639,477	0.1%
Transportation	0	0.0%	$0	0.0%
Total	**94**	**0.8%**	**$25,020,957**	**0.1%**

Table 3.62 State-Insured Facilities Vulnerable to 6-Foot Local Sea Level Rise

Facility Type	# of Vulnerable Structures	% of Total Structures for Facility Type	Replacement Value	% of Total Value for Facility Type
Agriculture	0	0.0%	$0	0.0%
Education	6	0.1%	$8,390,383	0.0%
Government	0	0.0%	$0	0.0%
Healthcare	0	0.0%	$0	0.0%
Military	0	0.0%	$0	0.0%
Parks/Recreation	104	8.5%	$19,913,037	5.7%

Facility Type	# of Vulnerable Structures	% of Total Structures for Facility Type	Replacement Value	% of Total Value for Facility Type
Port Authority	13	7.7%	$45,883,729	13.1%
Public Safety	2	0.3%	$639,477	0.1%
Transportation	0	0.0%	$0	0.0%
Total	**125**	**1.1%**	**$74,826,626**	**0.3%**

Very few critical facilities are located in areas that would be inundated by local sea level rise. No critical facilities would be submerged by a 1- or 3- foot rise in sea level, and only two commercial facilities would be submerged by a 6-foot rise in local sea level. Recall, however, that state assets and critical facilities could face severe impacts well before they become submerged, from the amplified coastal flooding and storm surge discussed in Section 3.2.5, to the increasing frequency and extent of episodic tidal flooding discussed in Section 3.2.10.

3.4 Impacts of Development Trends on Vulnerability

As discussed in Section 5.1, the structure of the risk assessment chapter is intended to support the development of effective mitigation strategies and to demonstrate compliance with federal regulations and policy. While Sections 5.2 and 5.3 profile the hazards that affect Alabama, assess the vulnerability of the state and its counties, and provide loss estimates, this section discusses the impacts of development trends on vulnerability.

3.4.1 Population and Development Trends

When a hazard strikes, the characteristics of the people, property, and infrastructure exposed to the hazard event are key determinants of the extent of damage and loss. High growth in high-risk areas can increase Alabama's vulnerability to hazards, while appropriately-sited and designed growth can reduce future losses.

This plan recognizes that development patterns change over time, and that state and local planning processes must monitor and adapt to these changes. The series of maps below illustrate the distribution of people and land uses across the state today and show how this distribution is projected to change in the future. The most densely populated counties in Alabama are those surrounding the major metropolitan areas of Birmingham, Huntsville, and Mobile (5.1.1.1.1.1.1Table 3.62Figure 3.64 and 5.1.1.1.1.1.1Table 3.62Figure 3.66). While these counties have more urbanized area than other parts of the state, they still have significant amounts of forest and farm lands and are characterized by decentralized development patterns that extend the built environment into rural areas (5.1.1.1.1.1.1Table 3.62Figure 3.65).

In the next twenty to thirty years, population growth rates are expected to vary widely across the state. Decentralized growth patterns, however, are expected to continue to prevail. The counties adjacent to the state's largest cities are expected to experience the highest growth rates, while the counties encompassing these cities are expected to experience only moderate growth. The one exception to this trend is Huntsville, where high growth rates are expected in both Madison and Limestone counties.

Figure 3.64 Current Population Density (US Census, 2016)

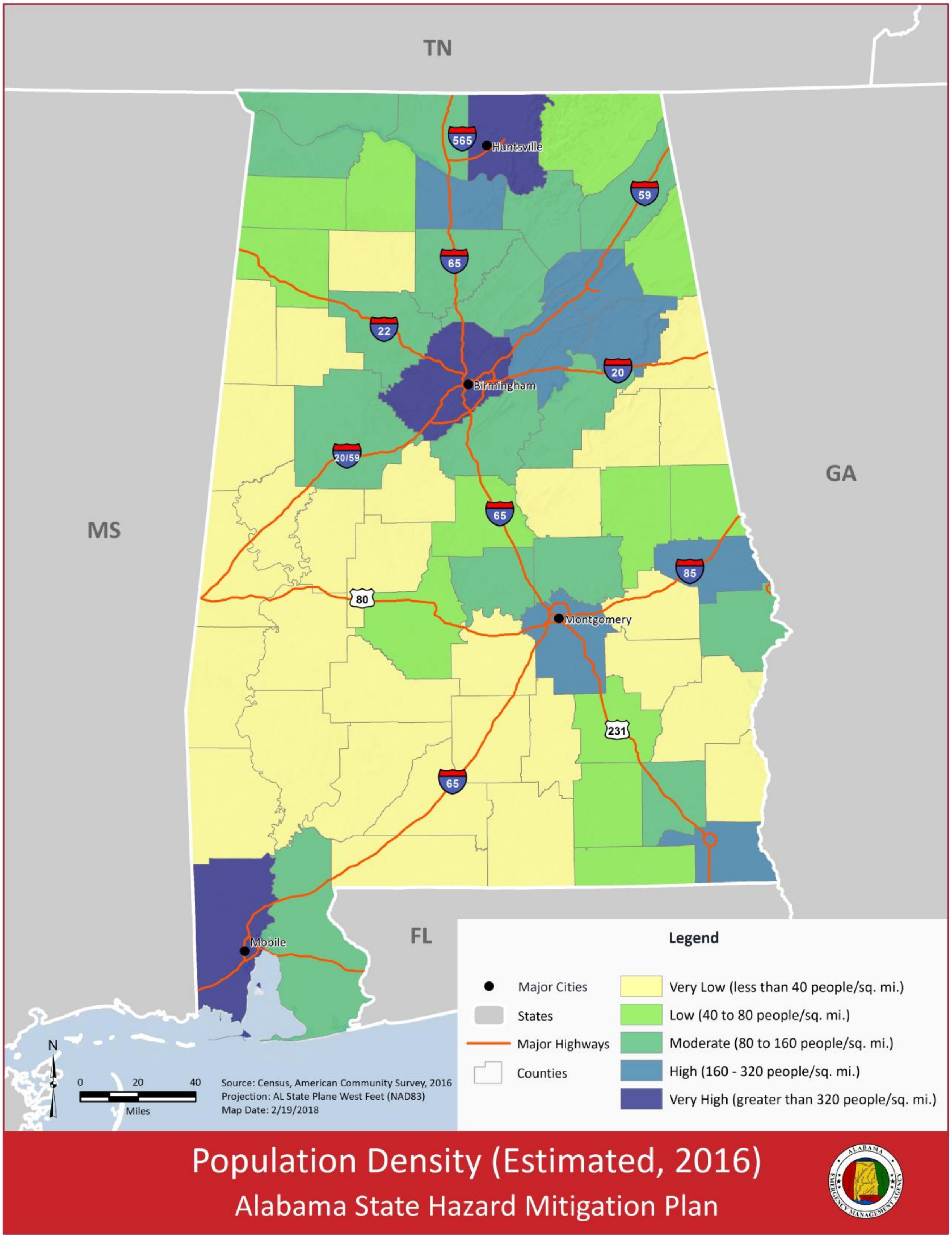


Figure 3.65 Current Land Use (NLCD, 2011)

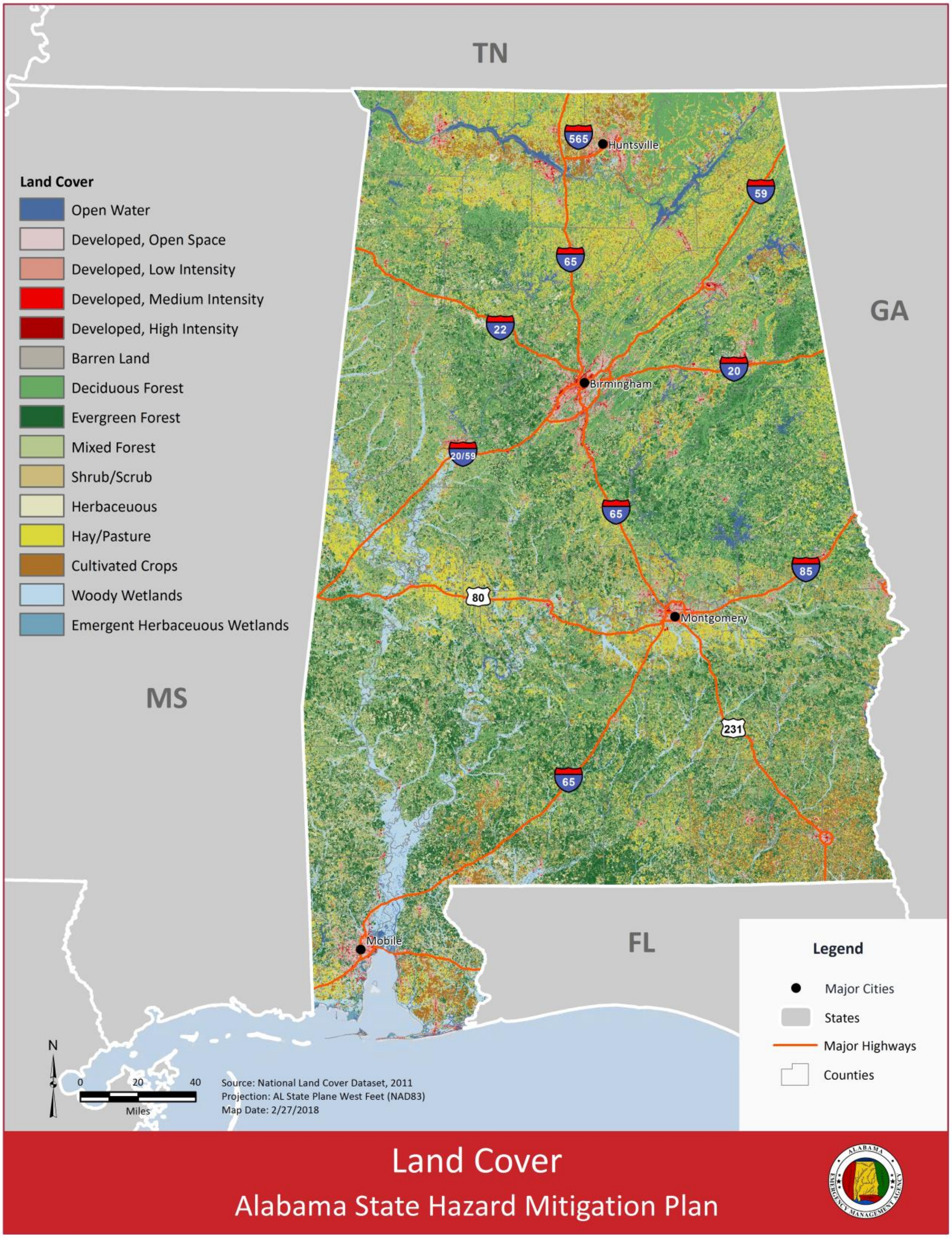


Figure 3.66 Major Metropolitan Areas

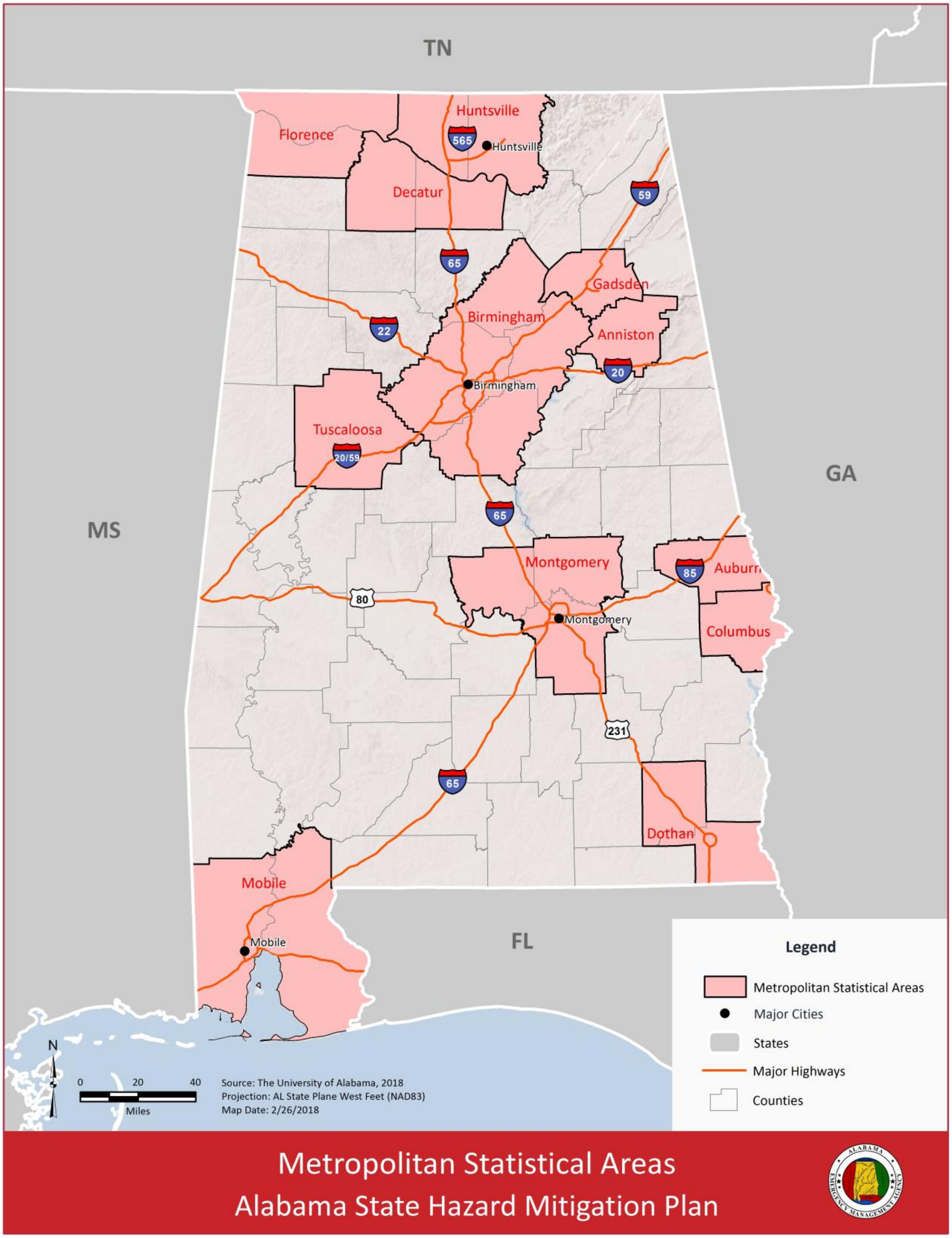
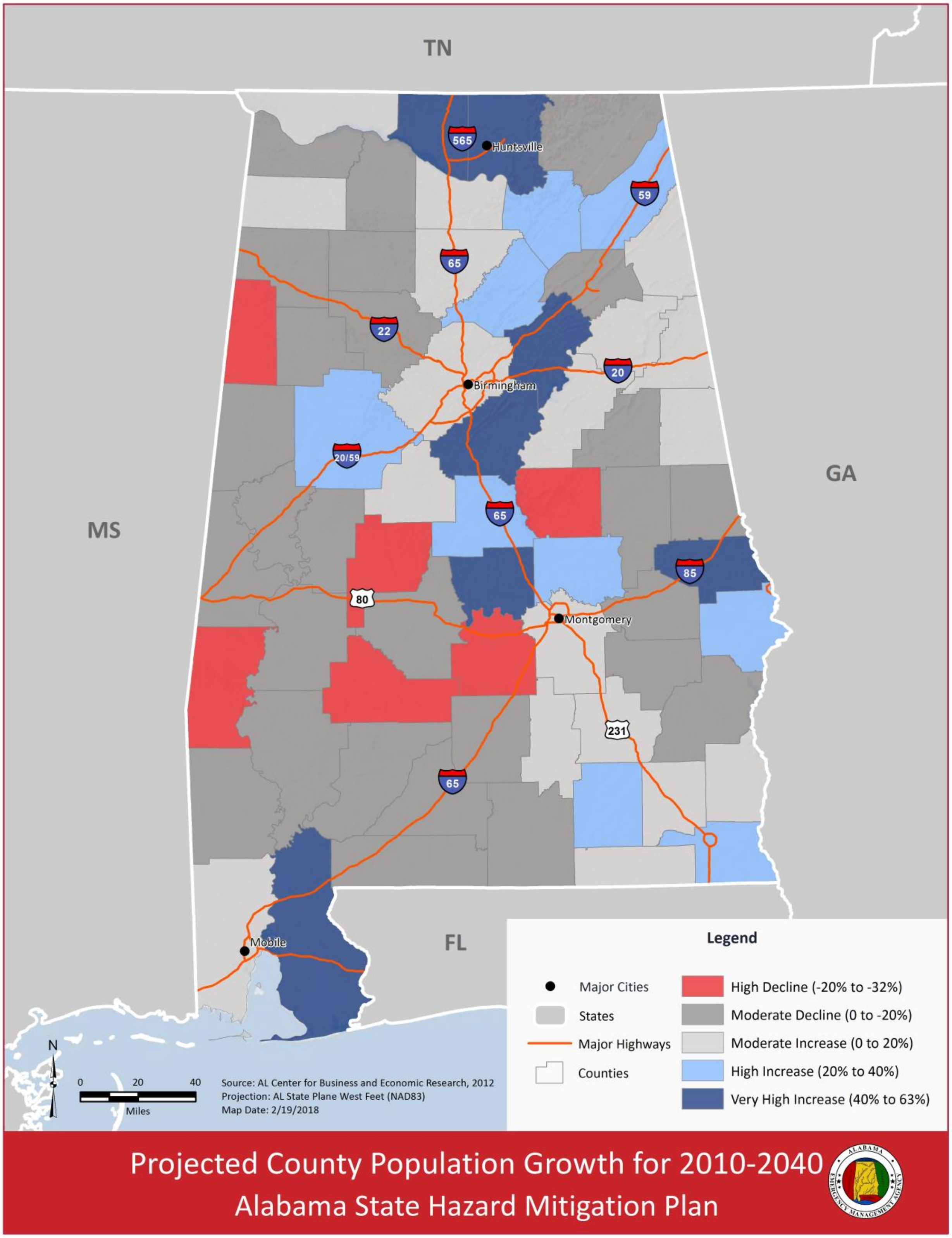


Figure 3.67 Projected Population Growth Rates



3.4.2 Intersections between High Growth Areas and High-Risk Areas

The growth patterns projected for Alabama are likely to intersect with high risk areas throughout the state, placing more people and property at risk. Some aspects of the projected trends in population and development that can be expected to exacerbate future losses include the following:

- New population growth is often concentrated along economically desirable coastal areas that are at high risk of coastal flooding, storm surge, and wind damages;
- New development and associated parking, roads, and other impervious surfaces can increase urban runoff, exacerbating flooding hazards;
- New construction in previously rural areas can expand the wildland urban interface, increasing exposure to wildfires;
- Population growth across the unconsolidated aquifers of the Coastal Plan can increase the demand for limited water resources in times of drought;
- Ongoing beach development and construction can increase risk of beach erosion; and
- More development in the state's karst areas, particularly in the Huntsville area, can increase the probability of property and infrastructure damages.