2. HAZARD IDENTIFICATION AND STATEWIDE RISK ASSESSMENT

This section assesses various hazard risks Louisiana faces in order to identify a strategy for mitigation. Having identified the categories of hazards, emergencies, disasters, and catastrophes, this section details the major climatological and natural/human-influenced hazards by (1) defining them, (2) explaining how they are measured, (3) describing their geographic extent, (4) surveying their previous occurrences, and (5) evaluating their future likelihood of occurrence. First, we profile the state in terms of its geography, climate, and history, and then proceed to identify and assess the major hazards that threaten it.

LOCAL RISK ASSESSMENTS

As part of the hazard identification and risk assessment process, parish plans were reviewed to identify profiled hazards that were consistent with the SHMPC's evaluation of the most serious natural hazard threats to the state. Some hazards identified in parish and municipal plans are not directly addressed in the Plan Update. Generally, these hazards appear in a small number of parish and municipal plans and were not consistent with the SHMPC's evaluation of the most serious natural hazard threats to the state.

Members from the SHMPC and the LSU Advisory Team reviewed each of the 64 parish plans that are current in the State to identify the hazards that were profiled in each plan in order to (1) determine the frequency with which each was addressed and (2) to determine if sufficient consistency between the local plans existed to systematically integrate the data, methods, and results into the Plan Update. Table 2.1 lists the hazards profiled in the existing 64 parish plans for each of the hazards (or sub-hazard) included in this Plan Update. The hazard most often addressed by parish plans was tropical cyclones, with 62 of the 64 parishes including them in the hazard profile. None of the existing parish plans profiled sinkhole hazards and only two parish plans profiled sea level rise as a hazard. Of the 20 hazards (or sub-hazards) included in this plan update, parish plans included 11 of these on average. The Iberville Parish plan considers the fewest of the hazards profiled in this plan update (4 hazards), while five parish plans (Assumption, Claiborne, Lincoln, Orleans, and Red River) consider 15 of the 20 hazards profiled in this plan.

Overall, the parish plans and the Plan Update were found to be consistent in identifying natural hazards that affect areas of the state. Although the identified hazards were largely consistent, the parish plans vary widely in key characteristics, including hazard identification definitions, risk assessment data, risk assessment methodologies, and economic loss estimation. The primary commonality among the plans is the inclusion of Hazus Level 1 analyses. This Update includes Level 1 flood, wind, and combined wind and flood model results. Thus, the risk assessments for these very prevalent hazards are consistent among the parish and state plans.

Table 2.1. Summary of hazards included in the State Plan Update that are profiled in current parish plans.

HAZARDS INCLUDED IN STATE PLAN UPDATE PROFILED IN PARISH PLANS																				
Parish	Coastal Erosion	Dam Failure	Drought	Earthquake	Extreme Heat	Flooding	Hail	High Wind	Tropical Cyclones	Lightning	Levee Failure	Saltwater Intrusion	Sea Level Rise	Sinkholes	Storm Surge	Subsidence	Thunderstorm	Tornadoes	Wildfire	Winter Weather
Acadia			X			X	X	X	X	X						X	X	X		X
Allen		X				X		X	X	X							X	X	X	X
Ascension						X		X	X	X	X				X		X	X		
Assumption		X	X			X	X	X	X	X	X		X		X	X	X	X	X	X
Avoyelles		X				X		X	X		X							X		
Beauregard		X	X		X	X	X		X								X	X	X	
Bienville		X	X	X	X	X	X		X	X								X	X	X
Bossier		X	X	X	X	X	X	X	X	X	X						X	X	X	X
Caddo		X	X	X	X	X	X	X	X	X	X						X	X	X	X
Calcasieu		X	X		X	X	X	X	X	X	X						X	X	X	X
Caldwell		X	X	X		X	X		X		X						X	X	X	X
Cameron	X		X			X	X	X	X						X	X	X	X	X	
Catahoula		X	X			X	X	X		X	X						X	X		X
Claiborne		X	X	X	X	X	X	X	X	X	X				X		X	X	X	X
Concordia		X	X	X	X	X	X	X	X	X	X						X	X	X	
De Soto		X	X	X	X	X	X	X	X	X	X						X	X	X	X
East Baton Rouge		X	X	X		X	X	X	X	X	X					X	X	X	X	X
East Carroll		X	X	X		X	X		X		X						X	X	X	X
East Feliciana		X	X	X		X	X		X	X	X					X	X	X	X	X
Evangeline						X		X	X	X							X	X		X
Franklin		X	X		X	X	X	X	X	X	X						X	X		X
Grant		X	X			X	X	X	X	X	X						X	X	X	X
Iberia	X	X	X			X	X	X	X	X	X				X		X	X		
Iberville						X			X		X								X	
Jackson		X	X	X	X	X	X	X	X	X	X						X	X	X	X
Jefferson	X		X	X		X	X	X	X	X					X	X		X	X	X
Jefferson Davis	X		X	X		X	X		X	X	X				X		X	X	X	
La Salle		X	X			X	X		X	X	X						X	X	X	X
Lafayette		X	X	X		X	X	X	X	X	X					X	X	X	X	X
Lafourche	X								X		X					X		X		
Lincoln		X	X	X	X	X	X	X	X	X	X	X					X	X	X	X
Livingston						X			X						X			X	X	
Madison						X	X		X		X							X		X
Morehouse		X	X	X	X	X	X	X	X	X	X						X	X	X	X
Natchitoches		X	X			X	X	X	X	X	X						X	X	X	X
Orleans	X	X	X			X	X	X	X	X	X		X		X	X	X	X		X
Ouachita		X	X	X	X	X	X	X	X	X	X						X	X	X	X
Plaquemines	X					X		X	X		X	X			X			X		
Pointe Coupee	X	X	X	X		X	X		X		X						X	X	X	X

HAZARDS INCLUDED IN STATE PLAN UPDATE PROFILED IN PARISH PLANS																				
Parish	Coastal Erosion	Dam Failure	Drought	Earthquake	Extreme Heat	Flooding	Hail	High Wind	Tropical Cyclones	Lightning	Levee Failure	Saltwater Intrusion	Sea Level Rise	Sinkholes	Storm Surge	Subsidence	Thunderstorm	Tornadoes	Wildfire	Winter Weather
Rapides		X	X	X	X	X	X	X	X	X	X						X	X	X	X
Red River		X	X	X	X	X	X	X	X	X	X					X	X	X	X	X
Richland		X	X			X	X		X		X						X	X		X
Sabine		X	X	X	X	X	X	X	X	X	X						X	X	X	X
St. Bernard						X	X	X	X	X	X	X			X	X	X	X	X	
St. Charles	X		X		X	X	X	X	X		X	X				X	X	X		X
St. Helena			X			X	X	X	X	X							X	X	X	X
St. James		X	X			X	X	X	X	X	X				X	X	X	X	X	X
St. John the Baptist		X	X		X	X	X	X	X	X	X					X	X	X		X
St. Landry			X			X	X	X	X	X						X	X	X	X	X
St. Martin						X		X	X		X							X		
St. Mary	X					X		X	X		X				X			X		
St. Tammany		X	X	X		X	X	X	X		X					X		X	X	X
Tangipahoa			X		X	X	X	X	X	X		X				X	X	X	X	X
Tensas		X	X	X	X	X	X	X	X	X	X						X	X	X	X
Terrebonne						X		X	X		X	X			X	X		X		
Union		X	X	X		X	X	X	X		X						X	X	X	X
Vermilion	X					X		X	X		X				X			X		
Vernon		X	X	X	X	X	X	X	X	X	X						X	X	X	X
Washington		X	X		X	X		X	X	X	X					X	X	X	X	X
Webster		X	X	X	X	X	X	X	X	X	X						X	X	X	X
West Baton Rouge			X	X	X	X	X	X	X	X	X					X	X	X	X	X
West Carroll		X	X			X	X		X	X	X						X			X
West Feliciana		X				X	X	X	X	X	X					X	X	X	X	X
Winn			X			X		X		X							X	X	X	
TOTALS	**11**	**42**	**49**	**27**	**24**	**63**	**50**	**50**	**62**	**45**	**52**	**6**	**2**	**0**	**15**	**21**	**51**	**62**	**45**	**47**

GOHSEP considers the risk assessment included in this Plan Update to be more complete and detailed than many parish plans because of the technical expertise and input of the SHMPC, the SHMPC LSU Advisory Team, and the SHMP Agencies. Parishes generally have not had the means or capability to provide detailed analysis, and methodologies differ widely. As a means to facilitate adoption of common methodologies to define and measure the hazards, describe their geographical extents, document previous occurrences, and evaluate the future likelihood of occurrence, mapping methodologies utilized in the Update are provided in Appendix C.

The variations in data and methodologies were noted in the 2011 update and continue to make comparative analysis of parish plans difficult. As a result, the Plan Update relies primarily on consistent national and statewide datasets for hazard identification and risk assessment,

although parish-specific data were utilized for more localized hazards (e.g. sinkholes). The majority of parish plans rely on hazard information from the NCDC database. This Plan Update primarily utilizes the SHELDUS dataset, which is considered an improvement over parish plan data, as SHELDUS integrates data from NCDC with additional data from the NOAA Storm Prediction Center, National Hurricane Center, and U.S. Fire Administration.

GOHSEP and the SHMT are committed to meaningfully incorporate the results of parish hazard mitigation plans into the State Plan. Therefore, this Plan Update is intended to serve as a framework that will facilitate parish and municipal updates and provide a degree of uniformity across jurisdictions. Such updates will be implemented between October 2014 and December 2017, when the 64 parish plans are due for updating and approval. Thus, it is the intent of GOHSEP that all plans will use similar, appropriate data sources and data processing steps to facilitate more effective integration for future plan updates. This coordination will enable comparisons between parishes for the first time, which will foster more consistent mitigation planning within the state.

Additionally, to address the data format, collection, and processing inconsistencies that to date have precluded integration of local plans with the State Plan, a currently funded project through the CEO program will provide a mechanism for state planners to collect and exchange hazard and risk data. GOHSEP is partnering with University of Louisiana at Lafayette's NIMSAT Institute to develop a web-based, password-protected risk data collection portal. NIMSAT will collect and ground truth hazard and risk data from parishes and municipalities, then filter and return the data to local communities for concurrence. As the project progresses, these data will be made available for updating risk assessment in both the state and local mitigation plans. The NIMSAT project will help make data from local plans in the future more practical through the development of:

- a validated database of historical disasters, indexed by address, zip code, and/or census tract;
    - a statewide "Risk Index" based upon the above data and valid, uniform risk assessment methodologies;
    - a web portal offering general public and business-level access;
    - a secure-access web portal for governmental stakeholders (development version); and
    - ongoing support including communications, data management, tutorials, and web-hosting.

STATE PROFILE

Geographically, climatologically, and historically, Louisiana (Map 2.1) is one of the most complicated states in the United States.

GEOGRAPHY

The state is situated entirely within the Gulf Coastal Plain, and as such, vertical relief is subtle across its distance. Although the divisions are not always very distinct, the state has three major physiographic regions: hills, terraces, and lowlands. And while it is flush with numerous waterways of a diverse nature, including an extensive alluvial region along the Mississippi and other major rivers, Louisiana is also largely composed of forested regions. These regions are not mutually exclusive.

As the vertical relief topography of Map 2.1 reveals, the state's hill country is mostly located north and west of a line running roughly from the western Sabine River border to Monroe. Elevations there are the highest in the state (topping 500 ft. in a few places). The lower, shallower terraces that meet Louisiana's waters sit south of its hills, the more recent formations resulting from alluvial deposits. Louisiana has two major terrace zones, the first in the Florida Parishes, the other across southwestern Louisiana, just inland from the Gulf of Mexico.

One of the more pronounced characteristics of the state, as Map 2.1 illustrates, is its extensive water and marsh region in the southern-most parishes. These lowlands are comprised of river floodplains and marsh lying south of the terraces. They include two major components: (1) the Chenier Plain of southwestern Louisiana, and (2) the Deltaic Plain, which includes the Atchafalaya Basin and almost everything south and east of metropolitan Baton Rouge, including metropolitan New Orleans and Houma/Thibodaux. Except along natural or artificial river levees, vertical relief is subtle in the lowlands, with absolute elevations rarely surpassing 20 ft.

In the metropolitan New Orleans area, elevations are even below sea level. As a result, flooding in this part of the state can inundate much of the coastal area, although one specific cause cannot be identified due to varying combinations of riverine and coastal effects—including overflow (or backwater) flooding from the Mississippi and Atchafalaya Rivers, their tributaries, and other waterways throughout the state, as well as high tides and storm surges from tropical storms in the Gulf of Mexico. Ultimately, this diversity of geography has sometimes been responsible for the state's tumultuous economic, political, cultural, and climatological history.

Map 2.1. Natural land covers of Louisiana (map by East Tennessee State University [ETSU] student Hannah Miltier).[i]

CLIMATE

Given its proximity to the Gulf of Mexico, in addition to its subtropical latitude and low elevations, Louisiana's warm and humid climate contributes significantly to its inclination to disaster. Average annual temperatures range from the mid- to upper-60°s F across the state, and its precipitation average (approximately 58 in.) is the highest among the 48 conterminous states. During the spring, temperatures warm faster over Louisiana than in inland areas, creating surface fronts that spawn frequent rain and severe thunderstorms, which can include high winds, hail, lightning, and tornadoes. Rainfall totals can exceed 10 in. over a short period of days. Moreover, soils tend to be near saturation at this time of year, and thus spring is typically the period of maximum streamflow. The highest precipitation totals are in the southeastern part of the state, where the lowlands also leave the state most vulnerable to flooding. Moreover, due to the large number of tributaries that feed the Mississippi, which in turn are affected by the snowmelt and precipitation in the central region of the country, the state's vulnerability to flooding is increased by certain climatological factors independent of the state itself. In fact, Louisiana itself contributes virtually nothing to the Mississippi flow. In fact, on average, 70% of the volume along the Lower Mississippi comes from drainage from the Ohio River.[ii] Snowmelt from winters with unusually high snowfall in the Ohio River Basin leads to significant increases in streamflow in the Lower Mississippi.

In the summer months, warm and moist air from the Gulf results in a relatively consistent climate regime. Daily maximum temperatures generally range from 85° F to 95° F, but they may increase over the next century. Frontal systems are infrequent, but the steady inflow of moist, unstable Gulf air masses promotes frequent development of showers and thundershowers, particularly across the southern parishes. Nevertheless, severe weather events tend to be somewhat less frequent and less violent than in spring. For instance, tornado activity is diminished, particularly over the southern half of the state. Drought is possible in the summer, as subsiding air from weak high pressure and associated upper-level ridges locked in place over the central United States can inhibit the development of convective showers for weeks. Most significantly, summer marks the start of the Atlantic tropical cyclone (hurricane and tropical storm) season, and Louisiana is susceptible to such systems fueled by the warm Gulf waters.

Autumn is a period of moderating temperatures, but tropical cyclone activity also reaches its peak at this time. Fortunately, the duration of such events tends to only be a few days. In the periods between such tropical storms, daytime humidity tends to be somewhat lower than other times of the year. Continental and Gulf air masses confront each other minimally in the autumn, resulting in weak frontal activity, which produces little or no rainfall. Thus, autumn is the driest season of the year for Louisiana.

Winters in Louisiana are characterized by a strong thermal gradient across the state. On average, northern Louisiana is 10 F° colder than its southern counterpart. Cold Canadian air can reach into the state, and at least one hard freeze per season is typical, except on the extreme coastal margins. Such freezing events seldom last for longer than a week, even in northern Louisiana. Most precipitation arrives as rain, but modest accumulations of snow do occur,

particularly in the north. Despite its relative infrequency, freezing rain and ice storms can create significant problems across the state.

History

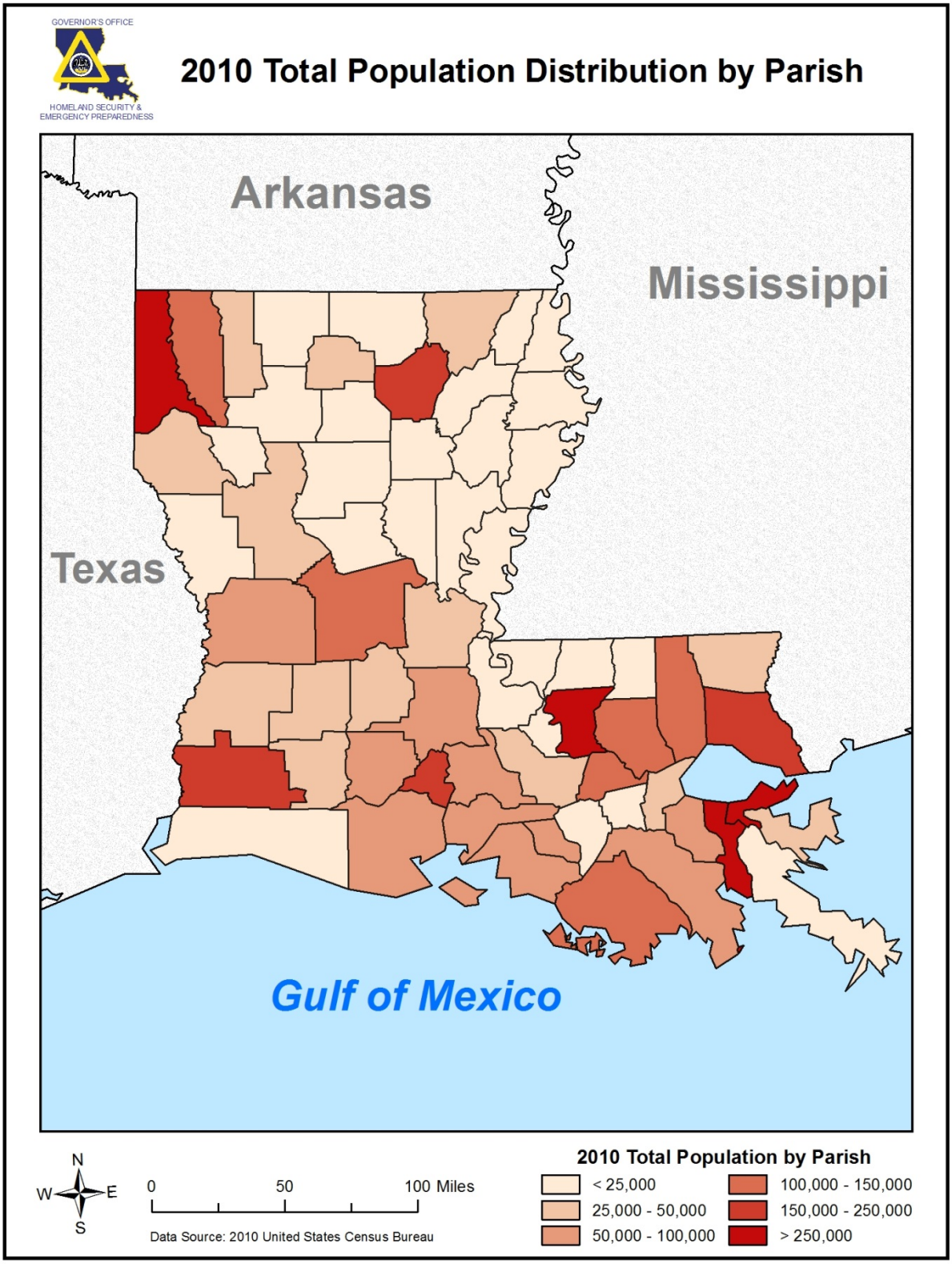
Like the rest of the United States, Native Americans inhabited Louisiana prior to the arrival of the Europeans. According to the 2010 census, roughly 55,000 American Indians still reside in Louisiana, but ubiquitous testaments to their presence survive through the state's many historical burial mounds (such as the Watson Brake site and Poverty Point), but also through the names of various places, including parishes (e.g., Caddo, Calcasieu, Tangipahoa, and Natchitoches) and the state's capital (Baton Rouge).

Louisiana was explored by a succession of European powers, beginning with the Spanish in the sixteenth century, followed by the French in the seventeenth century. The explorer Robert Cavalier de La Salle gave the area its current name in honor of King Louis XIV, but it also included parts or all of present-day Mississippi, Arkansas, Oklahoma, Missouri, Kansas, Nebraska, Iowa, Illinois, Indiana, Michigan, Wisconsin, Colorado, Wyoming, Montana, Minnesota, North Dakota, South Dakota, and New Mexico. Over time, New Orleans became the default capital of the region, due to its control of the strategically significant mouth of the Mississippi River. Having already ceded more eastern territory to Great Britain in the French and Indian War—and following a period of about 40 years of Spanish rule ended by Napoleon—the French sold the remainder of Louisiana to the newly formed United States in 1803. Its sale doubled the size of the young nation overnight.

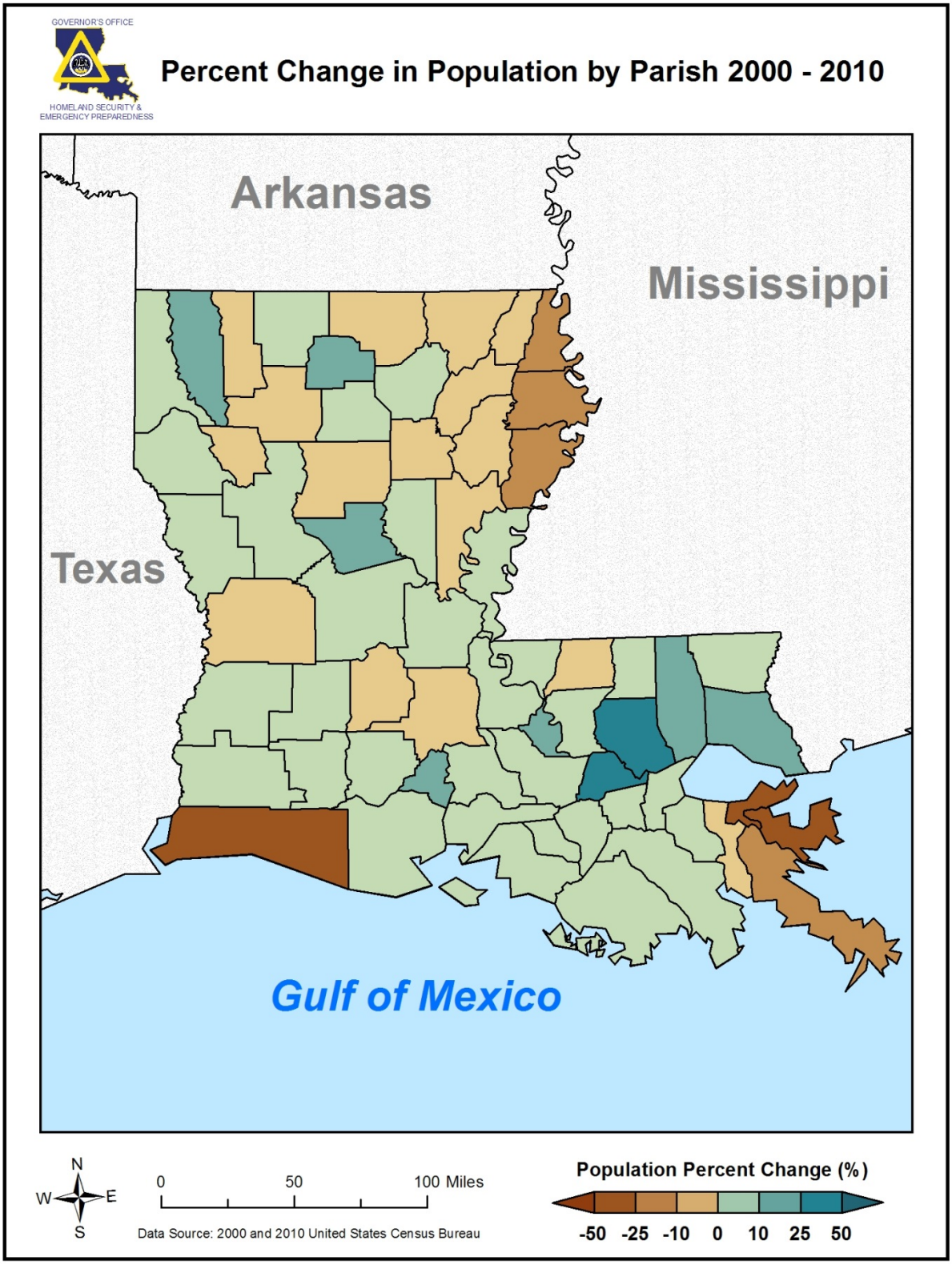
At present, roughly 4.6 million residents populate Louisiana, of whom 60.3% are non-Hispanic white American, 32% black American, and 2.3% white Hispanic.[iii] A variety of other races and ethnicities—the largest portion including Native Americans, multiracial Americans, and a number of Asian ethnicities—comprise the remaining 5.4%. Map 2.2 illustrates the state's current population density, while Map 2.3 illustrates the changes in population from 2000 to 2010. The greatest concentration of people in Louisiana still reside in the southern, lowland regions of the state (those areas most vulnerable to flooding and hurricane disaster), but significant, isolated population concentrations can be found in central and northern Louisiana. There was a slight overall population increase from 2000 to 2010.

Although this fact seems irrelevant at first, as of 2011, 49% of Louisianians under the age of one are non-white, indicating drastic shifts in the demographics of the state.[iv] Such demographic changes must be used with relation to hazard mitigation. The University of South Carolina's Hazards and Vulnerability Research Institute (HVRI) has established a Social Vulnerability Index (SoVI®) that (1) maps variations in vulnerable populations and (2) acts as an indicator to determine variations in recovery through a combination of thirty socioeconomic factors, which social research suggests contribute to a community's ability to "prepare for, respond to, and recover from hazards." Ultimately, seven factors (race and poverty; wealth; elderly

residents; Hispanic ethnicity; special needs individuals; Native American ethnicity; and service industry employment) explain 72% of the variance in the data, which reveal uneven capacities



Map 2.2. 2010 population density of Louisiana by parish (source: United States Census Bureau).



Map 2.3. Percent change in population from 2000 to 2010 (map from United States Census Bureau).

for preparedness and response, and thus indicate where resources can be used more effectively to reduce pre-existing vulnerability. Three important implications of SoVI® data should be noted. First, social vulnerability can shift drastically in a relatively short amount of time. Second, the social vulnerability in regions that suffer greater economic losses due to environmental hazards should be monitored closely for even more rapid shifts in vulnerability. Map 2.4 demonstrates the particular vulnerability of the coastal parishes in this respect through economic loss since that region of the state has suffered considerably between 1960 and 2009. Last, SoVI® data only provides data at the county or parish level, even though social vulnerability can vary greatly even within a single neighborhood. Since the state's overall population is shifting toward a larger minority population, which is often more vulnerable to environmental hazards according to the SoVI®, any mitigation of hazards in present-date Louisiana should account for the increasing vulnerability of the state's population. The changing racial and ethnic demographics of the state have already played a significant role historically both in the management of major disasters and in their aftermath and must be considered in terms of mitigation.

Given past experience and present data, social vulnerability should play a significantly greater role in mitigation in future plans. In 2011, the *Journal of Homeland Security and Emergency Management* published an article by a number of authors from the Center for Disease Control that describes the use of the SoVI® for emergency management, specifically exploring Hurricane Katrina's impact on Louisiana's population as an example of the necessity of including social vulnerability in hazard mitigation and preparation.[v]

Historically, a relatively high percentage of the people of Louisiana have tended to work in jobs related to the state's natural resources and geographic location, including mining (leading the nation in salt and sulfur production), drilling (with major production of crude petroleum and natural gas), agriculture of a wide variety (such as sweet potatoes, rice, and sugarcane), fishing (including shrimp and oysters), fur-trapping, and transportation (with the major national ports of New Orleans, Baton Rouge, Lake Charles, Plaquemines, and South Louisiana, which is along the Mississippi River between Baton Rouge and New Orleans). In recent years, tourism has become a larger portion of the state's economy, as has the income related to the film industry's increasing use of the state due to its recent generous tax credits.

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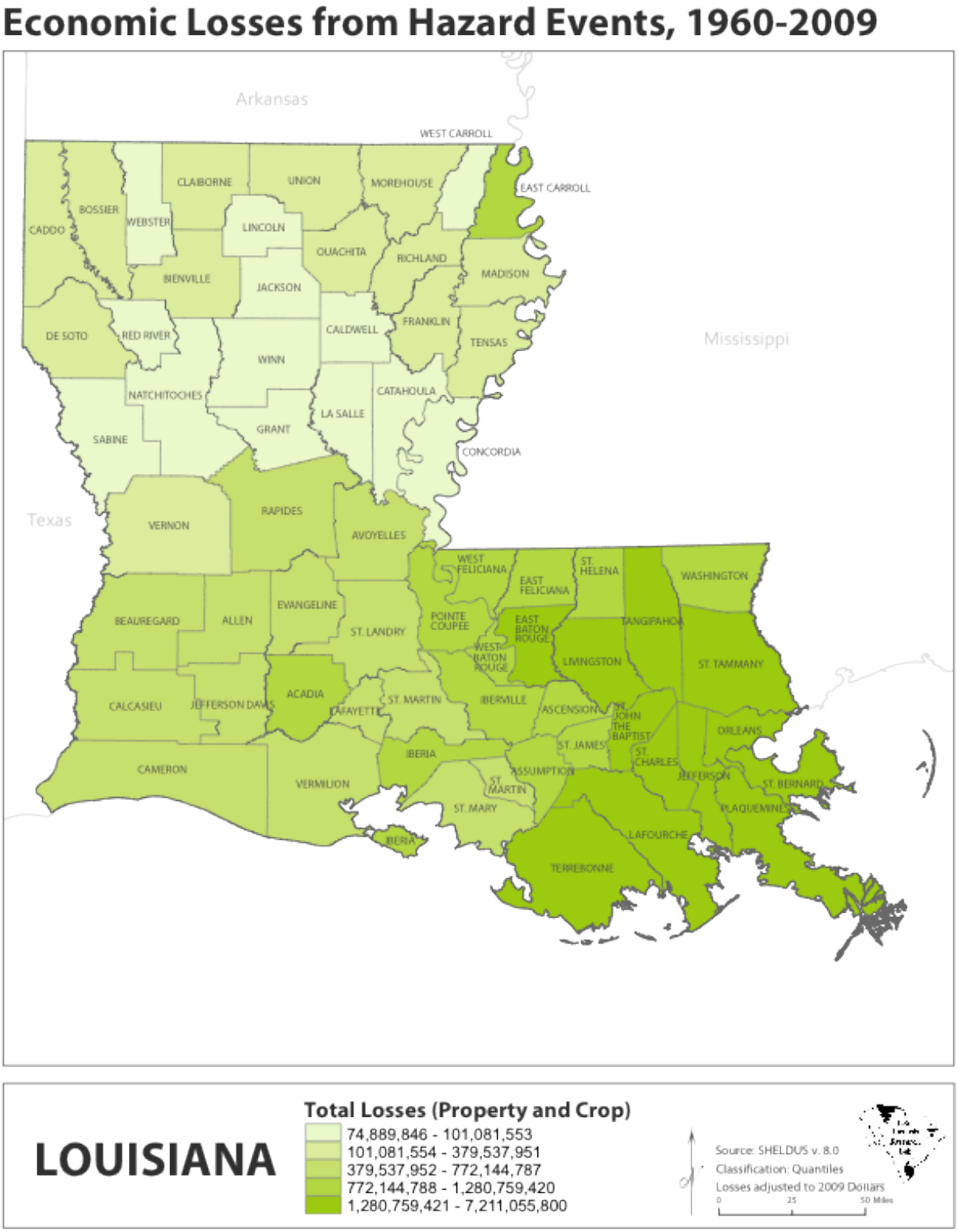

Map 2.4. Cumulative economic (property and crop) losses from 1960 to 2009 (source: HVRI).

Changes in Development Through Land Cover Change Detection

Land cover change detection provides a powerful method to evaluate several changes in development that influence hazard prone areas. Land cover has changed in many areas throughout the state over the past two decades (Map 2.5), but the reasons for these changes vary greatly. In high population growth parishes including Ascension, Livingston, Tangipahoa, and St. Tammany (refer to Map 2.3), most land cover change is related to new construction and development. These parishes, along with every other parish in Louisiana, are part of the National Flood Insurance Program (NFIP) and new development must meet NFIP standards. Consequently, new growth and development occurs above base flood elevation (BFE), but some development does encroach on areas that are adjacent to wetlands or areas that often flood. This potentially increases the flood risks for new developments, while simultaneously altering the flood risks for other surrounding areas since the topography and hydrology of the area may be altered. Some new construction occurs in areas that are below BFE and must be "filled-in." New construction standards require a net zero change in elevation across a development and retention ponds or wetlands are constructed to offset this imbalance.

Elsewhere in the state where population changes have not occurred at as rapid a pace as in the areas north and northwest of Lake Pontchartrain, land cover change can mostly be attributed to agricultural and/or forestry changes. Many of these areas in western and northern Louisiana are areas of heavy timber harvesting and agricultural production, thus the land cover is in a constant state of flux as it transitions between crops and between forest and cut-over/open land.

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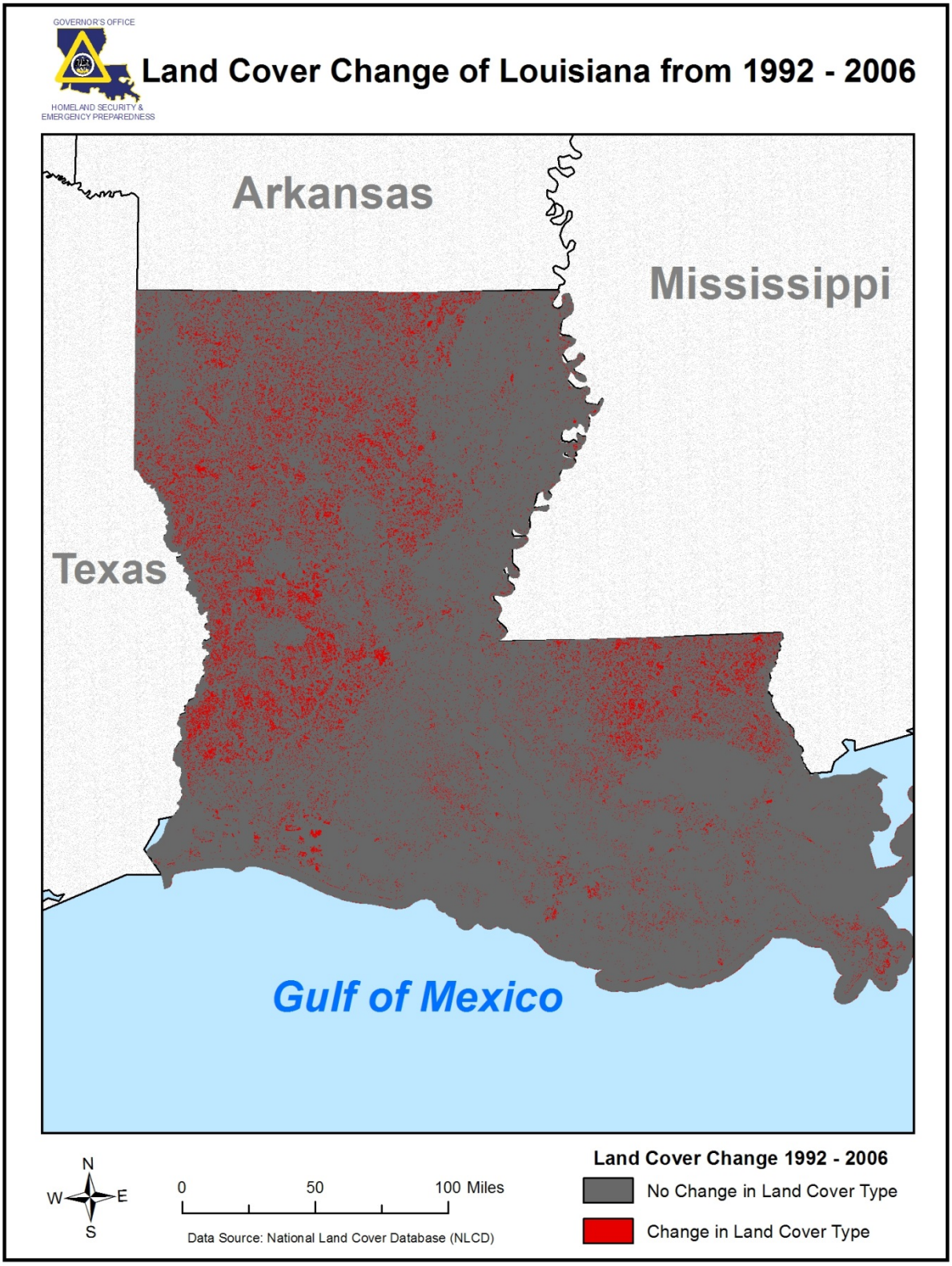


Map 2.5. Land cover change of Louisiana from 1992 to 2006.

CLIMATOLOGICAL HAZARDS

Louisiana has endured significant losses to life and property from disasters throughout its history. Moreover, the state profile (page 2-5) indicates that the worst of these disasters have affected largely the lowland areas of the state—although this plan will also specify the ways in which the rest of the state has suffered climatological, geographic, and human-influenced hazards. Thus, in accordance with federal requirements,[vi] the hazards identified and assessed for the Louisiana State Hazard Mitigation Plan are organized into two categories: **climatological hazards** and **geological/human-influenced hazards**. The categories are comprised by the following disasters:

- Climatological Hazards
  - Droughts
  - Extreme Heat
  - Flooding (including Riverine, Flash, Backwater, and Urban, as well as Ponding)
  - Thunderstorms (Hail, High Wind, and Lightning)
  - Tornadoes
  - Tropical Cyclones (i.e., Hurricanes and Tropical Storms, including Storm Surges)
  - Wildfires
  - Winter Weather (including Extreme Cold, Ice Storms, and Snow)
- Geological/Human-Influenced Hazards
  - Coastal Hazards
    - Coastal Erosion
    - Saltwater Intrusion
    - Sea Level Rise
    - Subsidence
  - Dam Failure
  - Earthquake
  - Levee Failure
  - Sinkhole

The remainder of this section will describe the previous occurrences of these disasters, their location and extent, and their annual likelihood of recurrence. Likelihood is measured as **Low**, **Medium**, or **High** through a percentage scale (0–30%, 31–70%, 71–100%, respectively) based on previous occurrences over the past 25 years. A relatable, everyday comparison will also be included for all likelihood measurements. So if a hazard occurs 20 times over the course of 25 years, its likelihood is measured at 80% (**High**), which translates to an occurrence of once every 15 months. Unless otherwise specified, only hazards with **Medium** or **High** likelihood will be considered for vulnerability analysis, which will follow immediately. In each of those risk analyses, this Plan Update describes the vulnerability of the state in terms of those jurisdictions most threatened by the hazard profiled. The data are evaluated for consideration of vulnerability in each local jurisdiction (i.e. the parish) by the following criteria: (1) number of hazard events; (2) economic damage; (3) human injuries; (4) human fatalities; (5) probability of

future occurrence; and (6) previously damaged state assets. This Plan Update also relies on FEMA's Hazus-MH 2.1 software to estimate potential losses from disasters. Hazus is a national, standard methodology using models to estimate potential losses from earthquakes, floods, and hurricanes. It relies on Geographic Information Systems (GIS) technology to estimate the physical, economic, and social impacts of disasters by visualizing the spatial relationship between high-risk disaster locations and nearby populations.

In determining future likelihood, recent trends in global climate information must also be taken into account. Temperature and precipitation averages always fluctuate with time, but in recent years both have tended to increase. For instance, the historical record shows that since the mid-1970s there have been fewer days per year (between 4–7 days) than the long-term average when the temperature has been below freezing in the Southeast region. Some parts of western Louisiana have experienced more than 20 fewer freezing days. This upward trend is expected to continue, and will have significant impacts on weather-related hazards in Louisiana.[vii] Of vital importance, then, is understanding as fully as possible the state's climatological system in order to optimize efforts in mitigating the hazards it produces. As such, climate change amplification is a new addition to this Plan Update, and it will be incorporated in the profiles and risk assessments.

In Louisiana, natural hazards tend to follow seasonal and spatial patterns. In the winter and early spring, the state experiences frequent cold frontal passages, bringing considerable rainfall as well as occasional winter storms (including ice and snowfall) and tornadoes. In the summer, Louisiana is prone to afternoon thunderstorms, ranging from brief, weak storms to violent multi-day occurrences. Among the biggest threats to the state are tropical cyclones, flooding, and tornadoes. We will profile first the climatological hazards, then the geological/human-influenced hazards, proceeding alphabetically through each category.

DROUGHT

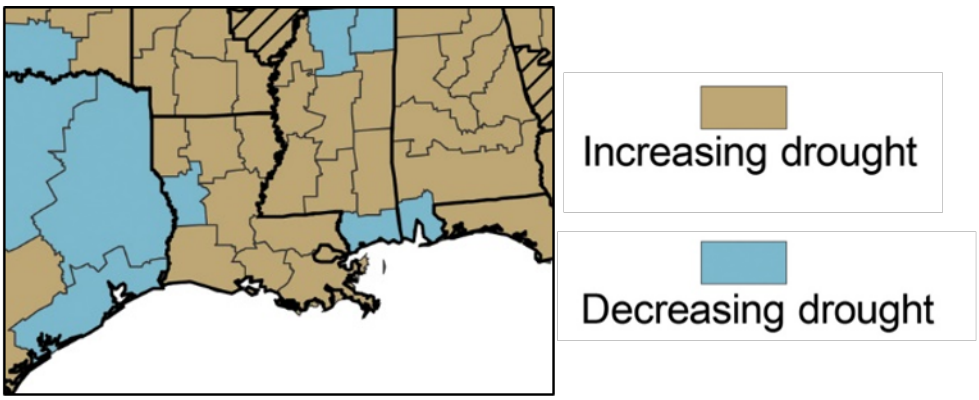
A drought is a deficiency in water availability over an extended period of time, caused by precipitation totals and soil water storages that do not satisfy the environmental demand for water either by evaporation or transpiration through plant leaves. It is important to note that the lack of precipitation alone does not constitute drought; the season during which the precipitation is lacking has a major impact on whether drought occurs. For example, a week of no precipitation in July, when the solar energy to evaporate water and vegetation's need for water to carry on photosynthesis are both high, may trigger a drought, while a week of no precipitation in January may not initiate a drought.

Drought is a unique and insidious hazard. Unlike other natural hazards, no specific threshold of "dryness" exists for declaring a drought. In addition, the definition of drought depends on stakeholder needs. For instance, the onset (and demise) of agricultural drought is quick, as crops need water every few days; once they get rainfall, they improve. But hydrologic drought sets in (and is alleviated) only over longer time periods. A few dry days will not drain a reservoir, but a few rain showers cannot replenish it, either. Moreover, different geographical regions define drought differently based on the deviation from local, normal precipitation. And drought can occur anywhere, triggered by changes in the local-to-regional-scale atmospheric circulation over an area or by broader-scale circulation variations such as the expansion of semi-permanent oceanic high-pressure systems or the stalling of an upper-level atmospheric ridge in place over a region. The severity of a drought depends upon the degree and duration of moisture deficiency, as well as the size of the affected area. Periods of drought tend to be associated with other hazards such as wildfires and/or heat waves as well. Lastly, drought is a slow onset event, causing less direct—but tremendous indirect—damage. Depletion of aquifers, crop loss, and livestock and wildlife mortality rates are examples of direct impacts. Since the groundwater found in aquifers is the source of about 38% of all county and city water supplied to households (and comprises 97% of the water for all rural populations that are not already supplied by cities and counties), droughts can potentially have direct, disastrous effects on human populations.[viii] The indirect consequences of drought such as unemployment, reduced tax revenues, increased food prices, reduced outdoor recreation opportunities, higher energy costs as water levels in reservoirs decrease and consumption increases, and water rationing are not often fully known. This complex web of impacts causes drought to affect people and economies well beyond the area physically experiencing the drought.

This hazard is often measured using the Palmer Drought Severity Index (PDSI, also known operationally as the Palmer Drought Index). The PDSI, first developed by Wayne Palmer in a 1965 paper for the U.S. Weather Bureau, measures drought through recent precipitation and temperature data with regard to a basic supply-and-demand model of soil moisture. It is most effective in long-term calculations. Three other indices used to measure drought are the Palmer Hydrologic Drought Index (PHDI); the Crop Moisture Index (CMI), which is derived from the PDSI; and the Keetch-Byram Drought Index (KBDI), created by John Keetch and George Byram in 1968 for the U.S. Forest Service. The KBDI is used mainly for predicting likelihood of wildfire outbreaks and will be discussed further with regard to that hazard. As a compromise, the PDSI

is used most often for droughts since it is a medium-response drought indicator. Due to the varying types and severities of drought that rely on different indicators, great caution should be exercised in interpreting and inferring from the results of the PDSI maps shown here.

As Map 2.6 shows, results from the PDSI indicate that the drought risk across most of Louisiana increased, although not significantly from a statistical perspective, between 1958 and 2007. The PDSI best measures the duration and intensity of drought-inducing circulation patterns at a somewhat long-term time scale, although not as long term as the PHDI. Long-term drought is cumulative, so the intensity of drought during the current month is dependent on the current weather patterns plus the effects of cumulative patterns of previous months—or longer. Based on Map 2.6, the entire state, with the exception of a small portion below Shreveport, has experienced increasing drought conditions since 1958.



Trends in end-of-summer drought as measured by the Palmer Drought Severity Index from 1958 to 2007 in each of 344 U.S. climate divisions. Hatching indicates significant trends. Image Reference: Guttman, N. B., and R. G. Quayle. "A Historical Perspective of U.S. Climate Divisions." Bulletin of the American Meteorological Society 77, no. 2 (1996): 293-303.

Map 2.6. Observed drought trends between 1958 and 2007. Source: *Global Climate Change Impacts in the United States* (U.S. Global Change Research Program).

Although weather patterns can change almost literally overnight from a long-term drought pattern to a long-term wet pattern, as a medium-response indicator, the PDSI responds relatively rapidly.[ix] Map 2.7 indicates the severity of drought conditions in Louisiana at the time this Plan went to publication using data compiled by the National Drought Mitigation Center.

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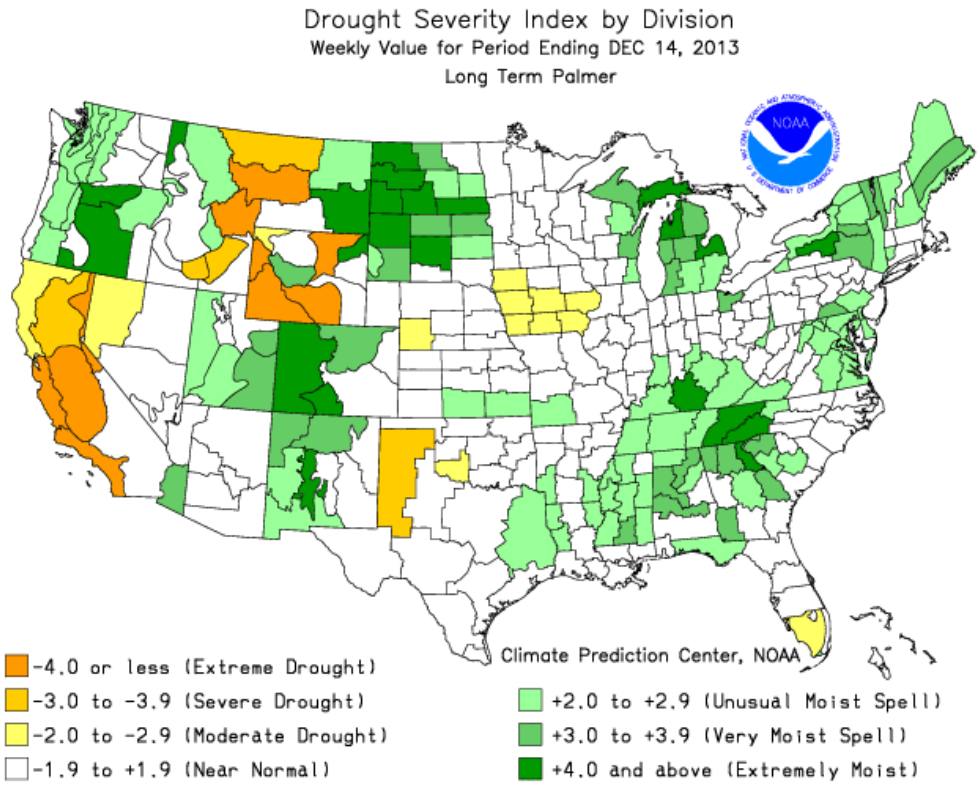

Map 2.7. Palmer Drought Severity Index and categories by climate division, December 14, 2013 (source: National Drought Mitigation Center).

The experimental "Long-Term Blend" (shown in Map 2.8) approximates drought-related impacts (such as reservoir stores, irrigated agriculture, groundwater levels, and well water depth) that respond to precipitation on time scales ranging from several months to a few years by blending data from those time scales. Map 2.8 also details the data input used and the percentile at which they are used for the indicator.

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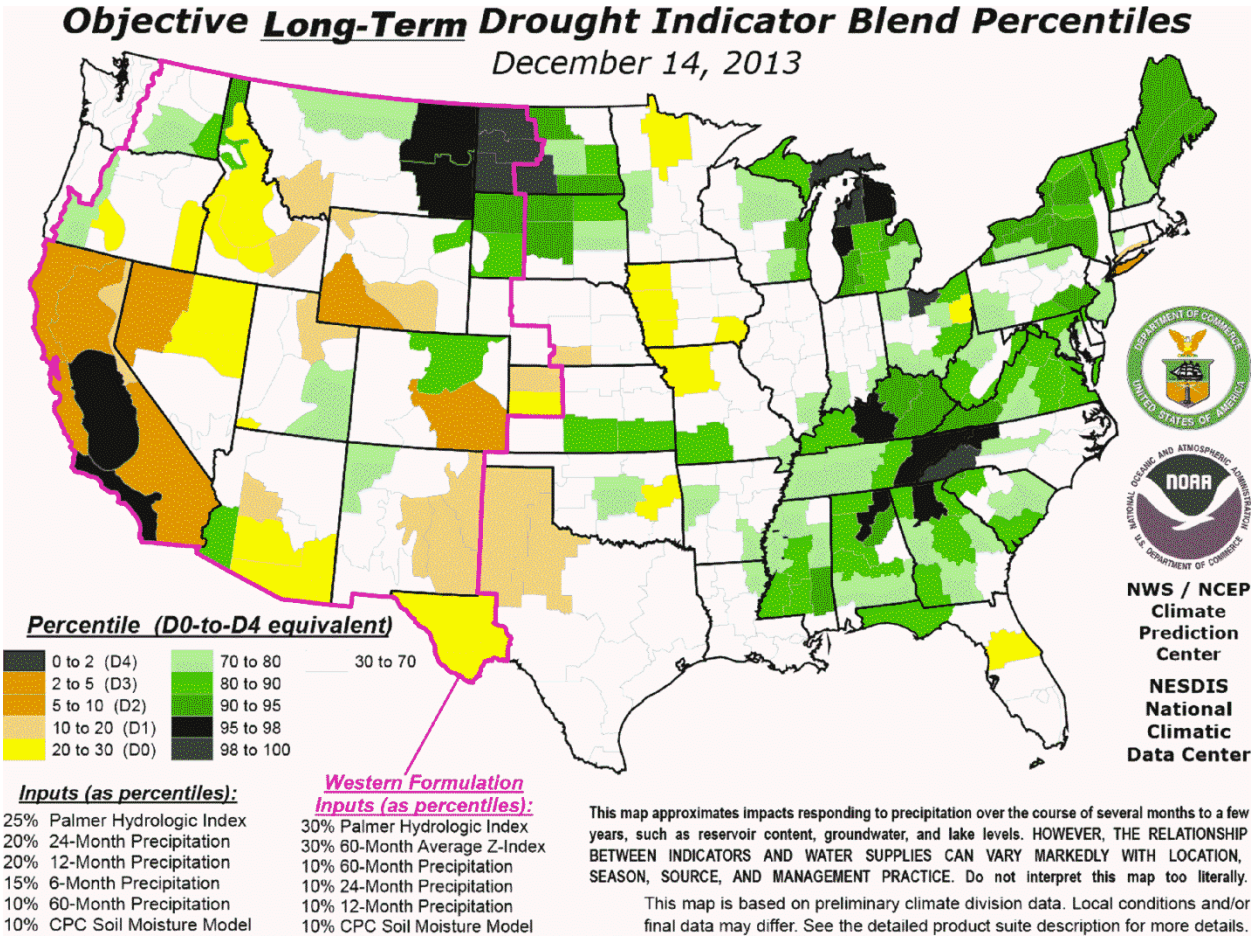

Map 2.8. Long-term drought prediction by climate division.

Drought Profile

Louisiana contains a diversity of landscapes heavily reliant on its abundant water supply. Consequently, droughts have the potential to cause economic losses to water-intensive sectors of the economy, including agriculture, ranching, forestry, and fisheries. While data from SHELDUS do not show a history of extreme droughts in Louisiana, a severe drought would affect those industries appreciably. However, drought is an expected and anticipated hazard in those industries, and those susceptible continuously take steps to prepare for and mitigate against its effects. Crop insurance assures that should drought negatively affect those industries, they have effective means to recover.

Drought can affect every jurisdiction of Louisiana, but the SHELDUS dataset shows that it has caused no fatalities, no injuries, and no property damage in the past 25 years. In fact, a federal disaster declaration due to drought has only occurred once—in association with the Great Western Drought of 1977. Even then, Louisiana did not experience the same levels of drought as many states west of the Mississippi. Between 1987 and 2012, no Louisiana parish has

experienced more than seven discrete drought events, leading to a future likelihood of roughly one drought every four years. Future likelihood for droughts is thus considered **Low**. Based on the results of the hazard profiling for this Plan Update, drought is not considered significant by the SHMPC in comparison to the other profiled hazards. Therefore, a technical risk assessment is not included.

Although drought is not a significant threat at this time, it should be noted that future changes in rainfall totals for the southeastern region of the United States, including Louisiana, are still highly uncertain.[x] It is projected that the amount of total available water will decline, perhaps even if precipitation increases.

Extreme Heat

In the same way that there is no single operational drought threshold, there is no operational definition for defining heat or a heat wave. Heat waves are the consequence of the same weather pattern as drought and therefore both hazards often occur concurrently. A heat wave is an extended period of oppressive and above normal temperatures over a given period of time. The World Meteorological Organization recommends the declaration of a heat wave when the daily maximum temperature exceeds the average maximum temperatures by 9 F° and lasts for a period of at least five days.

However, temperature alone is insufficient to describe the stress placed on humans (as well as flora and fauna) in hot weather. It is crucial to consider the effect of relative humidity since it is essential to the body's ability to perspire and cool. Once air temperature reaches 95° F, perspiration becomes a very significant biophysical mechanism to ensure heat loss. Perspiration is ineffective as a cooling mechanism if the water cannot evaporate (i.e., sweating in high relative humidity is reduced as compared to during dry conditions). To communicate this relationship between temperature and humidity, the National Weather Service (NWS) developed the Heat Index (HI), which provides a warning system based on a combination of air temperature and relative humidity. The HI is presented in Table 2.2. The NWS devised the index for shady, light wind conditions, and thus advises that the HI value can be increased by as much as 15 F° if a person is in direct sunlight, and that strong winds of hot, dry air can be extremely hazardous.[xi]

Table 2.2. Heat Index advisory based on air temperature (° F) and relative humidity (source: National Weather Service).

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution | Extreme Caution | Danger | Extreme Danger

Most heat disorders (e.g., sunburn, heat cramps, heat exhaustion, and heat stroke) occur because the victim has been overexposed to heat or has over-exercised considering age and physical condition. Other circumstances that can induce heat-related illnesses include stagnant atmospheric conditions and poor air quality. Seniors and children are most at risk from adverse heat effects. Extreme heat can also damage roads, bridges, pipelines, utilities, and railroads. High temperatures can be partially responsible for deflection of rails and related railroad accidents.

Extreme Heat Profile

According to NOAA, extreme heat is the leading weather-related cause of deaths in the United States.[xii] And while heat-related deaths in Louisiana are not common, due in part to the consistency and predictability of high seasonal temperatures, they do occur, and are still very intense and dangerous. Such deaths happen in a variety of circumstances, often in ways that are not easily categorized because they are unexpected. For instance, although exposure to heat is higher at the beach than usual, NOAA does not track heat-related deaths there because such deaths happen infrequently. Instead, heat-related deaths are characterized by highly individual circumstances. In June of 2010, the *Beauregard Daily News* reported that a two year-old boy died of heat exhaustion in Hineston after he climbed into an unlocked car and became trapped for less than one hour in the afternoon. The heat index in the area (recorded at Alexandria International Airport) had a value of 110° F, given a high of 99° F and a dew point of 72° F. In August of 2011, a roof worker in Houma was overcome by heat and died in a heat index near 105° F. In September of 2012, with temperatures in the mid-90°s F across southeastern Louisiana and power outages there from Hurricane Isaac, several cases of heat exhaustion were reported, causing at least one fatality from heat stroke.

Although all of Louisiana is vulnerable to extreme heat, summer temperatures can often exceed 100° F in the northern parishes, particularly during dry spells when clear skies allow increased solar radiation to reach the surface; afternoon highs there have occasionally reached 110° F, with an all-time extreme of 114° F recorded in Plain Dealing (Bossier Parish) on August 10, 1936, during the 1936 North American Heat Wave.[xiii] Extreme heat events tend to affect the northern parishes with greater severity due to a reduced moderation of temperatures by the Gulf (see Map 2.9 for average July maximum daily temperatures in the state by parish). Moreover, temperatures are actually recorded at a height of 1.5 meters, in a “Stevenson screen.” Thus, certain conditions—such as beneath heat-absorbent clothing or on large, sunlight-exposed surfaces—undoubtedly lead to higher actual temperatures.

One of the worst extreme heat events occurred in 1998, with 27 days of temperatures over 100° F, causing 20 deaths. According to the United States Global Change Research Program[xiv], assuming that fossil fuel emissions increase temporally, Louisiana can expect a significant increase in the number of days per year with peak temperature over 90° F over the next decades. Furthermore, the number of very hot days is predicted to rise at a greater rate than the average temperature.[xv] See Map 2.10 for a comparison of the number of days over 90° F

between the recent past (1961–1979) and 70–80 years from now. The average annual temperature in the Southeast is likely to increase by 4–8 F°. Temperatures in inland areas will likely increase more than those along the coast by 1–2 F°.[xvi] The increasing frequency of very hot days can have serious consequences for human health, drought, available water, energy production, and wildfires, among other things. Overall, between 1995 and 2008, 47 deaths occurred in the state as a result of extreme heat.[xvii]

Based on historical record and projections for the future, the probability of future occurrences of extreme heat is **High**. However, high temperatures and extreme heat are such a pervasive fact of life in Louisiana that their hazardous potential is rarely overestimated. The state's citizens are habituated to heat and its negative effects and have developed lifestyles to accommodate its omnipresence. Moreover, everyone has access to a building equipped with air conditioning units since all public buildings have them, and most private buildings have long been equipped with them as well. Based on the results of the hazard profiling for this plan update, as well as the population's relative readiness to handle this hazard, extreme heat is not considered significant by the SHMPC in comparison to the other profiled hazards. Therefore, a technical risk assessment is not included. Nevertheless, other agencies and private stakeholders should take any action possible to minimize the negative effects of extreme heat.

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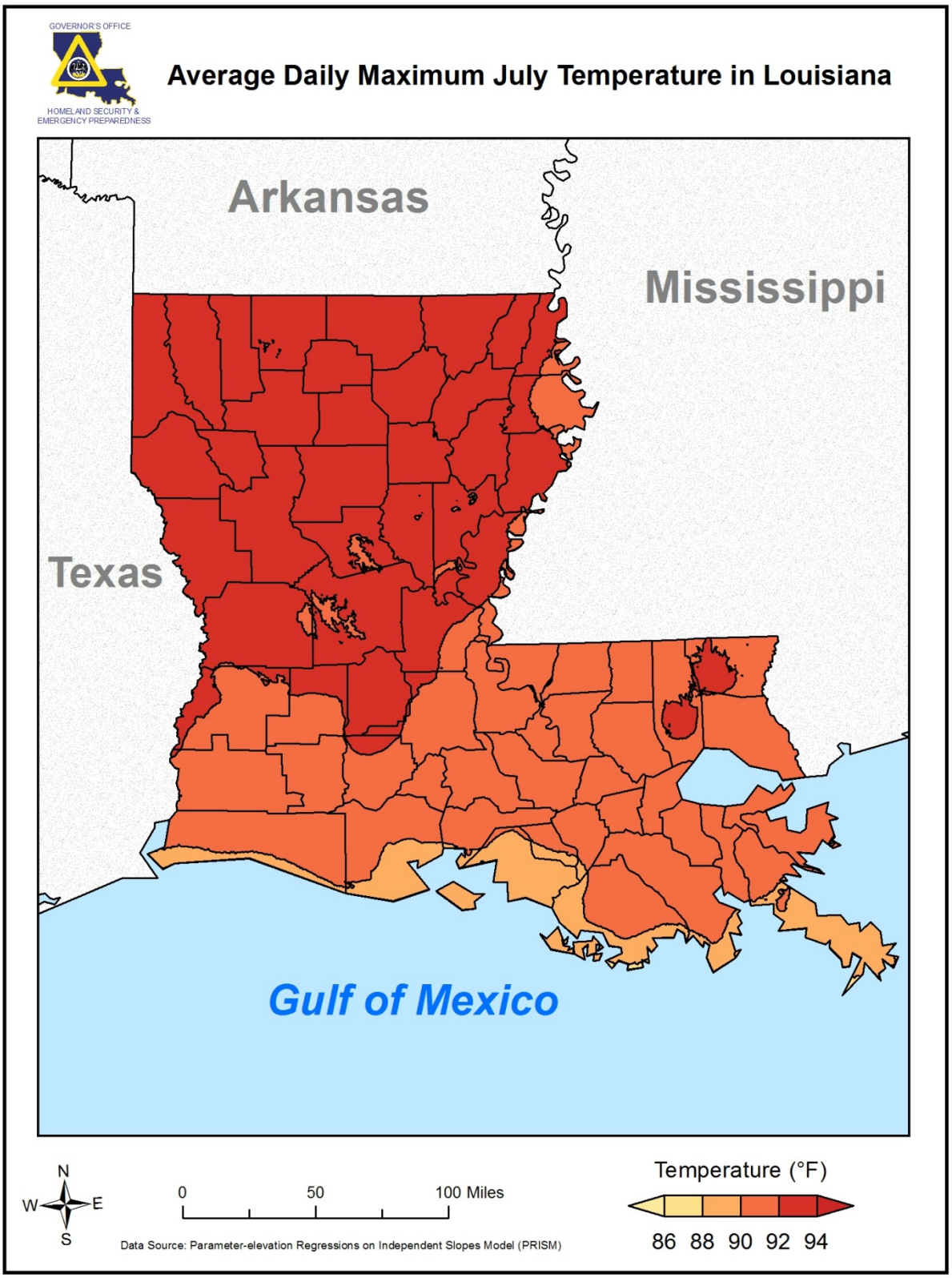
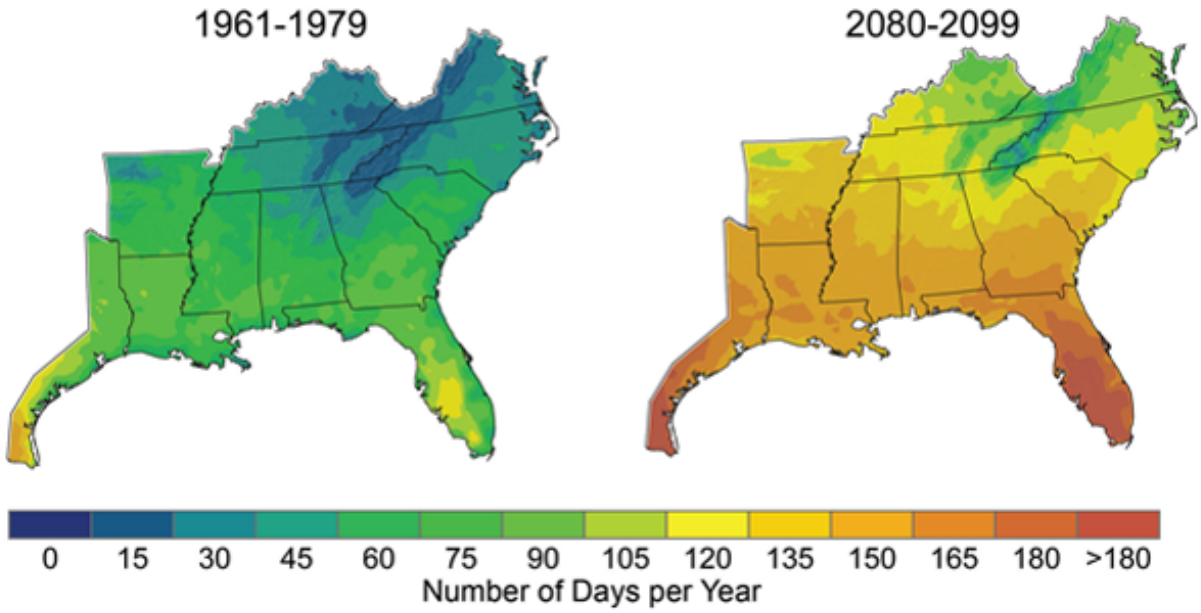


Map 2.9. Average daily maximum temperature in July in Louisiana, by parish.



Map 2.10. Number of days per year with peak temperatures over 90° F, under higher emissions scenario (map courtesy of Global Climate Change 2009 Report).

FLOODING

A flood is the overflow of water onto land that is usually not inundated. The National Flood Insurance Program defines a flood as follows:

> [A] general and temporary condition of partial or complete inundation of two or more acres of normally dry land area or of two or more properties from overflow of inland or tidal waves, unusual and rapid accumulation or runoff of surface waters from any source, mudflow, or collapse or subsidence of land along the shore of a lake or similar body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels that result in a flood as defined above.[xviii]

Factors influencing the type and severity of flooding include natural variables such as precipitation, topography, vegetation, soil texture, and seasonality, as well as anthropogenic factors such as urbanization (extent of impervious surfaces), land use (e.g., agricultural and forestry tend to remove native vegetation and accelerate soil erosion), and the presence of flood-control structures such as levees and dams.

Excess precipitation, produced from thunderstorms or hurricanes, is often the major initiating condition for flooding, and Louisiana can have high rainfall totals at any time of day or year. During the cooler months, slow-moving frontal weather systems produce heavy rainfalls, while the summer and autumn seasons produce major precipitation in isolated thunderstorm events (often on warm afternoons) that may lead to localized flooding. During these warmer seasons, floods are more overwhelmingly of the flash flood variety, as opposed to the slower-developing river floods caused by heavy streamflow during the cooler months.

In those months, particularly in the spring, Louisiana is in peak season for severe thunderstorms. The fronts that cause these thunderstorms often stall while passing over the state, occasionally producing rainfall totals exceeding 10 in. within a period of a few days. Since soil tends to be nearly saturated at this time (due to relatively low overall evaporation rates), spring typically becomes the period of maximum streamflow across the state. Together, then, these characteristics increase the potential for high water; low-lying, poorly drained areas are particularly prone to flooding during these months.[xix]

In Louisiana, five specific types of floods are of main concern: riverine, flash, ponding, backwater, and urban.

- **Riverine flooding** occurs along a river or smaller stream. It is the result of runoff from heavy rainfall or intensive snow or ice melt. The speed with which riverine flood levels rise and fall depends not only on the amount of rainfall, but even more on the capacity of the river itself and the shape and land cover of its drainage basin. The smaller the river, the faster water levels rise and fall. Thus, the Mississippi River levels rise and fall slowly due to its large bankfull capacity. Generally, elongated and intensely-developed

drainage basins will reach faster peak discharges and faster falls than circular-shaped and forested basins of the same area.

- **Flash flooding** occurs when a locally intense precipitation inundates an area in a short amount of time, resulting in local streamflow and drainage capacity being overwhelmed.
- **Ponding** occurs when concave areas (e.g., parking lots, roads, and clay-lined natural low areas) collect water and are unable to drain.
- **Backwater flooding** occurs when water slowly rises from a normally unexpected direction where protection has not been provided. A model example is the flooding that occurred in LaPlace during Hurricane Isaac. Although the town was protected by a levee on the side facing the Mississippi, floodwaters from Lake Maurepas crept into the community on the side of town *opposite* the Mississippi River.
- **Urban flooding** is similar to flash flooding but is specific to urbanized areas. It takes place when storm water drainage systems cannot keep pace with heavy precipitation, and water accumulates on the surface. Most urban flooding is caused by slow-moving thunderstorms or torrential rainfall.
- **Coastal flooding** can appear similar to any of the other flood types, depending on its cause. It occurs when normally dry coastal land is flooded by sea water, but may be caused by direct inundation (when the sea level exceeds the elevation of the land), overtopping of a natural or artificial barrier, or the breaching of a natural or artificial barrier (i.e., when the barrier is broken down by the sea water). These direct causes come from storm surges, tsunami, and gradual sea level rise.

Based on stream gauge levels and precipitation forecasts, the NWS posts flood statements watches and warnings. The NWS issues the following weather statements with regard to floods[xx]:

- Flood Categories
    - Minor Flooding - minimal or no property damage, but possibly some public threat.
    - Moderate Flooding - some inundation of structures and roads near streams. Some evacuations of people and/or transfer of property to higher elevations.
    - Major Flooding - extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations.
    - Record Flooding - flooding which equals or exceeds the highest stage or discharge at a given site during the period of record keeping.
- Flood Warning
    - Issued along larger streams when there is a serious threat to life or property.
- Flood Watch
    - Issued when current and developing hydrometeorological conditions are such that there is a threat of flooding, but the occurrence is neither certain nor imminent.

Floods are measured mainly by probability of occurrence. A 10-yr flood event, for example, is an event of small magnitude (in terms of streamflow or precipitation) but with a relatively high annual probability of recurrence (10%). A 100-yr flood event is larger in magnitude, but it has a smaller chance of recurrence (1%). A 500-yr flood is significantly larger than both a 100-yr event and a 10-yr event, but it has a lower probability than both to occur in any given year (0.2%). It is important to understand that an *x*-yr flood event does not mean an event of that magnitude occurs only once in *x* years. Instead, it just means that *on average*, we can expect a flood event of that magnitude to occur once every x years. Given that such statistical probability terms are inherently difficult for the lay population to understand, the Association of State Floodplain Managers (ASFPM) promotes the use of more tangible expressions of flood probability. As such, the ASFPM also expresses the 100-yr flood event has having a 25% chance of occurring over the life of a 30-yr mortgage.[xxi]

It is essential to understand that the magnitude of an *x*-yr flood event for a particular area depends on the source of flooding and the area's location. The size of a specific flood event is defined through historic data of precipitation, flow, and discharge rates. Consequently, different 100-yr flood events can have very different impacts. The 100-yr flood events in two separate locations have the same likelihood to occur, but they do not necessarily have the same magnitude. For example, a 100-yr event for the Mississippi River means something completely different in terms of discharge values (ft^3/s) than, for example, for the Amite River. Not only are the magnitudes of 100-yr events different between rivers, they can be different along any given river. A 100-yr event upstream is different from one downstream since river characteristics (volume, discharge, and topography) change. As a result, the definition of what constitutes a 100-yr flood event is specific to each location, river, and time, since floodplain and river characteristics change over time. Finally, it is important to note that each flood event is unique. Two hypothetical events at the same location, given the same magnitude of streamflow, may still produce substantially different impacts, if there were different antecedent moisture characteristics, different times of day of occurrence (which indicates the population's probable activities at the flood's onset), or other characteristic differences.

The 100-yr event is of particular significance since it is the regulatory standard that determines the obligation or lack thereof to purchase flood insurance. Flood insurance premiums are set depending on the flood zone as modeled by National Flood Insurance (NFIP) Rate Maps. The NFIP and FEMA suggest insurance rates based on special flood hazard areas (SFHAs), as diagrammed in Figure 2.1.

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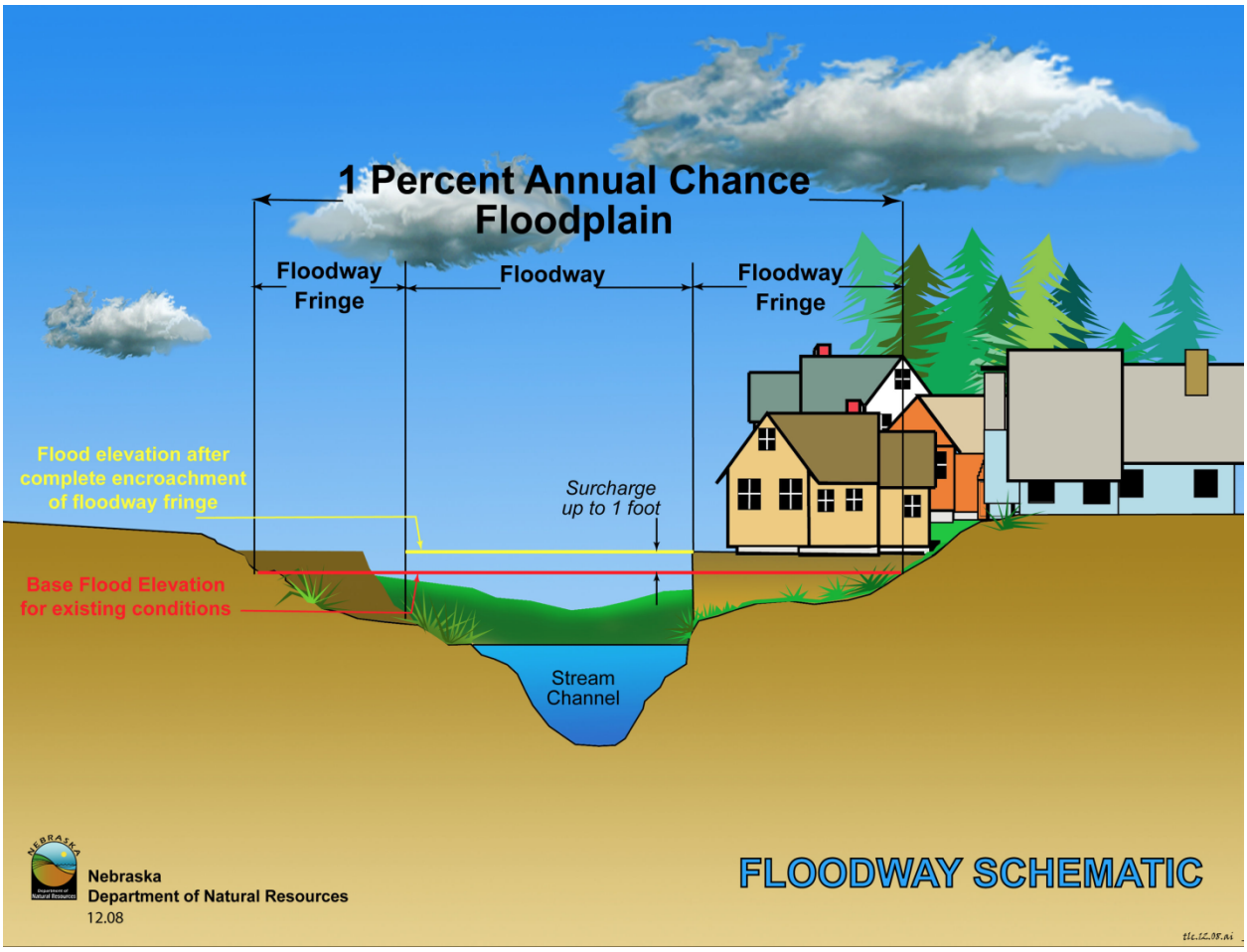


Figure 2.1. Schematic of 100-yr floodplain. The special flood hazard area (SFHA) extends to the end of the floodway fringe (source: Nebraska Department of Natural Resources Desk Reference).

A SFHA is the land area covered by the floodwaters of the base flood (the red line), where the NFIP's floodplain management regulations must be enforced and the area where the mandatory purchase of flood insurance applies.[xxii]

Flooding Profile

Louisiana has experienced significant flooding in its history and can expect more in the future with the effects of climate change and coastal erosion.[xxiii] In recent years, Louisiana has experienced major flooding, often due to the tropical cyclones that have affected the state. Rainfall has contributed significantly, too. The past decade alone has experienced the most days of heavy precipitation per year than any decade in the past century.[xxiv] For instance, just a bit over a decade ago, Tropical Storm Allison caused severe flooding throughout the state in 2001, inundating thousands of homes and streets with rain, reaching levels of 30 in. in some places. The Bogue Falaya, Amite, and Comite Rivers all reached record and near-record flood levels.

Damage from the flooding resulted in losses around $30 million with disaster declarations in 27 parishes. The flooding effects of Hurricane Katrina (2005) were extremely deadly, but as they largely resulted from levee breaching, that kind of disaster will be covered in the Levee Failure Risk Assessment.

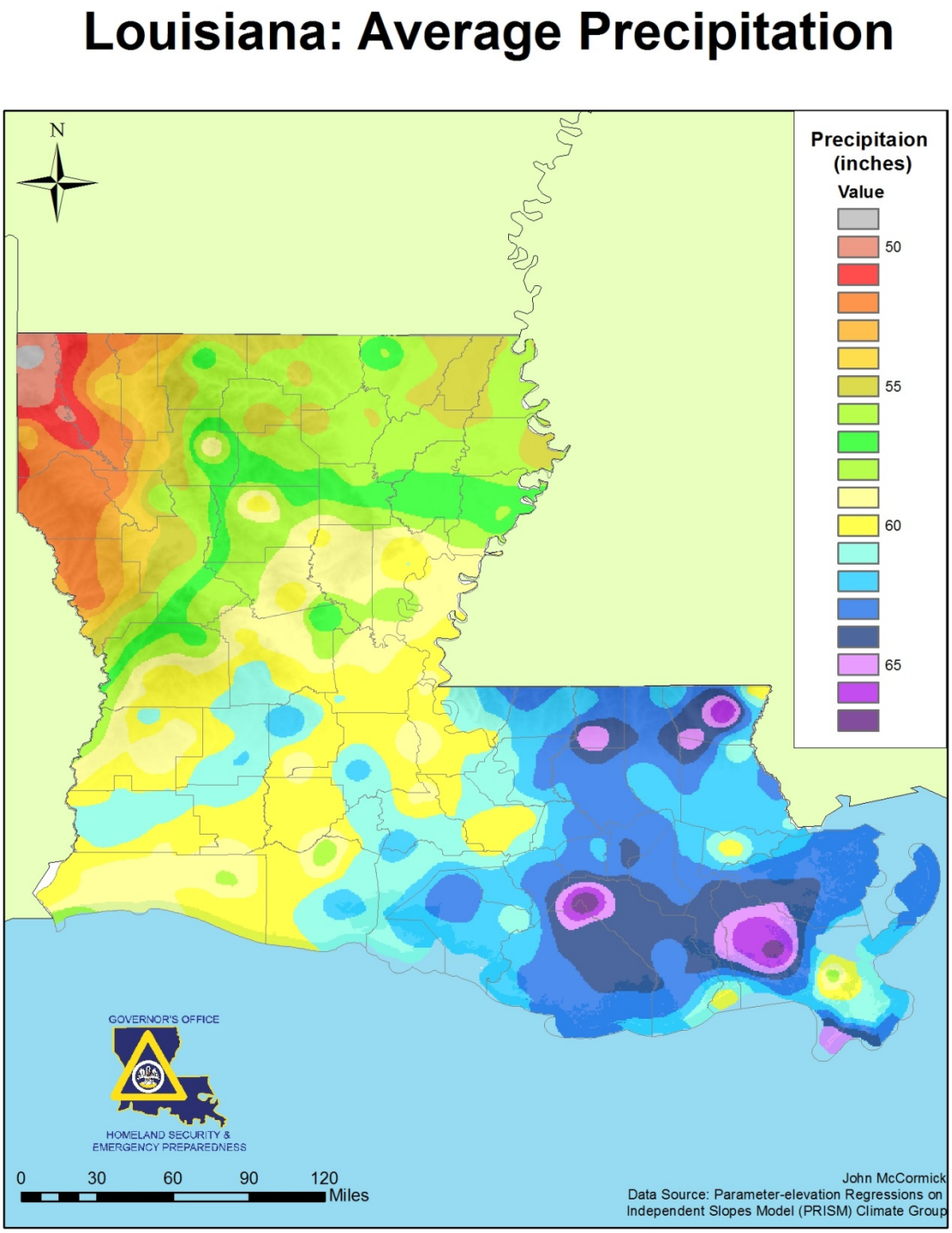
Louisiana has of course experienced disastrous flooding through non-cyclone-initiated floods, most of which have occurred along the Mississippi River. Table 2.3 details years that experienced major floods along the Lower Mississippi. Such floods are so significant due to the great size of the river. And as indicated in the CLIMATE overview of this section, since there is virtually no contribution to the Mississippi River from Louisiana itself, the effects from precipitation and snowmelt from the Ohio and Missouri Rivers have a significant impact on the Mississippi's streamflow throughout Louisiana.

Table 2.3. Years with major Lower Mississippi River flooding from 1700-2013 (source: Vega, Grymes, Rohli 136).

YEARS OF MAJOR FLOODS ON THE LOWER MISSISSIPPI (1700-PRESENT)	
1700s	1718, 1735, 1770, 1782, 1785, 1791, 1796, 1799
1800s	1809, 1811, 1813, 1815, 1816, 1823, 1824, 1828, 1844, 1849, 1850, 1851, 1858, 1859, 1892, 1893
1900s	1903, 1907, 1908, 1912, 1913, 1916, 1920, 1922, 1923, 1927, 1929, 1932, 1936, 1937, 1945, 1950, 1957, 1958, 1973, 1974, 1975, 1979, 1983, 1984, 1993, 1997
2000s	2011

While Table 2.3 indicates one year of historic Mississippi flooding in the past decade, Louisiana has certainly experienced other kinds of major floods in that time. In December 2009, for instance, nine Louisiana parishes received a FEMA Disaster Declaration for flooding, tornadoes, and severe storms. Most of these parishes were in northern and central Louisiana. A series of heavy rainfall events and severe storms throughout the state led to rivers and creeks overflowing their banks, causing widespread flood damages. Map 2.11 shows the average annual precipitation totals in Louisiana (using data from 1961 to 1990), indicating where the most rainfall tends to occur.

The floods of the 2011 water year—which extends from October 1 of the previous calendar year to the following September 30—were indeed historic. The NWS reported in its 2011 Flood Loss Report that direct flood damages that year totaled $8.73 billion (2013 USD), with 108 flood-related deaths (61 were vehicle related and 71 were flash-flood related). Many of the nation's largest rivers (Missouri, Ohio, and Mississippi) experienced record flood events. The most significant instigating factor was the meltwater from heavy snow in 2010, which caused unavoidable flooding throughout the Mississippi River basin. Record spring rainfalls from Tulsa to Cincinnati contributed to the snowmelt-induced flooding. Nearly half of the annual damages came from Ohio and Lower Mississippi River flooding.[xxv] Of this damage, Louisiana experienced



Map 2.11. Average annual precipitation totals, 1981-2010 (map by ETSU undergraduate John McCormick).

one direct fatality and about $3.5 billion in damages. Louisiana's population and (still significant) economic losses due to the historic flooding were probably mitigated mainly by the opening of the Morganza Spillway to avoid levee breaching and further flooding in Baton Rouge and New Orleans. Louisiana experienced a relatively major flood event recently, in early January 2013, when a stalled frontal boundary produced an extended period of rainfall, thunderstorms, and a few tornadoes. Massive flooding occurred along the Mermentau River, where rainfall exceeded 1 ft. in some locations.[xxvi]

Although general flooding can happen anywhere in the state, areas along the major rivers and in the coastal region are at the greatest risk of flooding. Map 2.12 shows the extent of 100-yr floodplains—and thus FEMA's flood zones. Map 2.13 reveals that a much greater percentage of the southern parishes than the northern parishes are located in Flood Insurance Rate Map (FIRM) flood zones, and Map 2.14 shows that larger percentages of parish populations are located in flood zones in those parishes. Floods along the lower half of the major north–south flood axis along the Mississippi and Atchafalaya Rivers in Map 2.12 (i.e., from southwestern corner of Mississippi to the Gulf of Mexico) more often result from upstream runoff (riverine floods) rather than local rainfall (flash floods).[xxvii] Flooding in this region can have significant economic and emergency response impacts. The combination of major ports there—the Ports of New Orleans, Baton Rouge, Plaquemines, and South Louisiana—also increases boating activity, including casinos, and may have repercussions for emergency response operations. Flooding that triggers emergency response may have to be adjusted to allow additional time for responders to deal with additional traffic, potential property damage, and at-risk tourist population. Frequent flooding of any kind is of particular concern in areas of active real estate growth and development. Additionally, even if a developer accounts for flooding in planning and provides adequate drainage for a home, newly developed land upstream might make the initially adequate drainage insufficient, through no fault of the developer or homeowner.

In all, the primary focus in Louisiana for flood mitigation is on repetitive losses (RLs). The National Flood Insurance Act (NFIA) defines RLs as properties that are currently insured under the NFIP and have had two or more claims greater than $1,000 paid by the NFIP within any 10-yr period. The NFIA defines severe repetitive flood loss properties (SRLs) as a subset of repetitive loss properties that have experienced even greater damage. They have had at least four claims payments of over $5,000 paid by the NFIP with at least two occurring within a ten-yr period, the cumulative amount exceeding $20,000, or with at least two separate claims that exceed the value of the home when combined.[xxviii] The State of Louisiana has a defined process for maintaining up-to-date repetitive flood loss data; GOHSEP receives an updated listing of RLs and SRLs from FEMA Region VI on a monthly basis. These data are stored following very specific protocols to ensure that the most recent data are consistently available and that Privacy Act regulations are followed.

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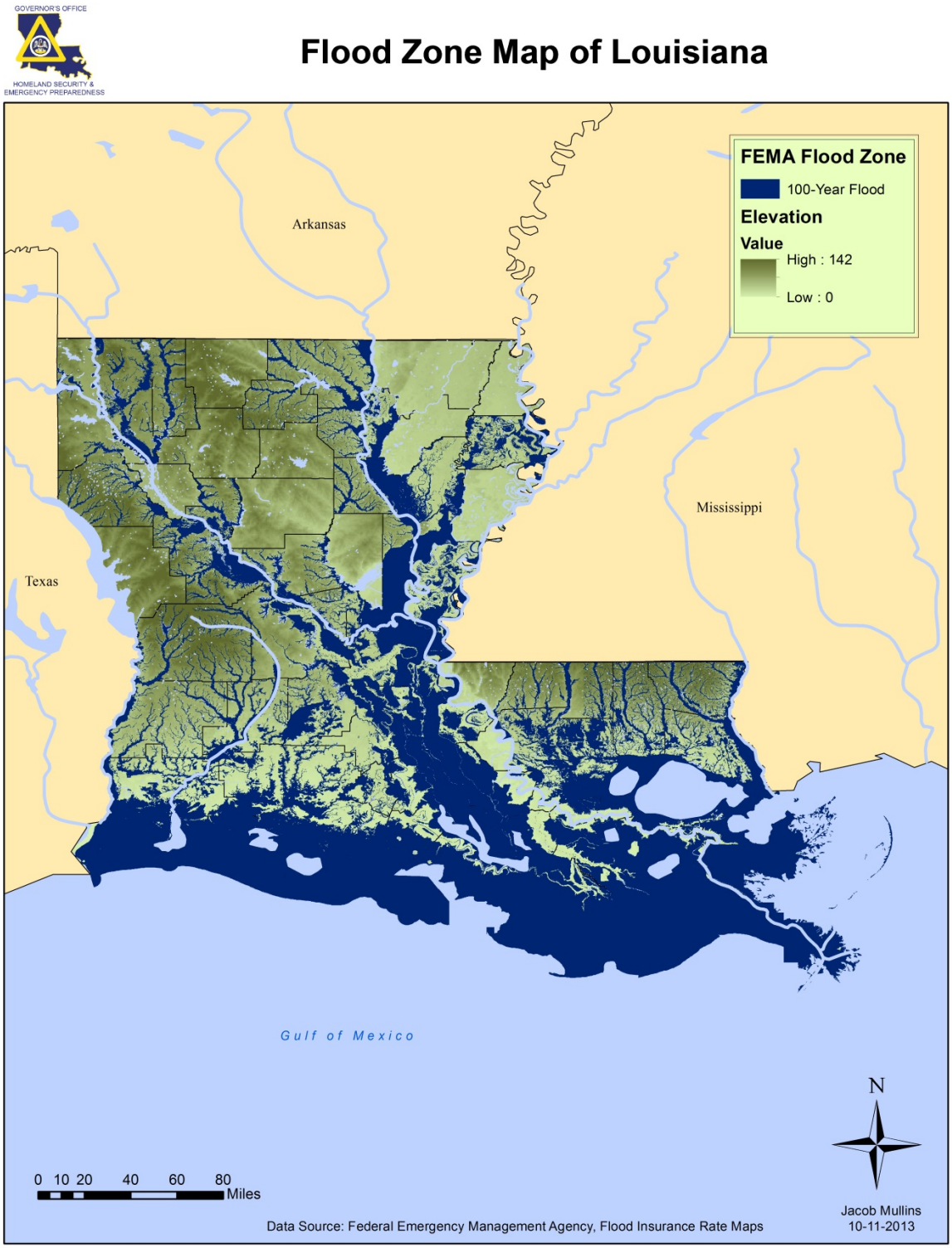
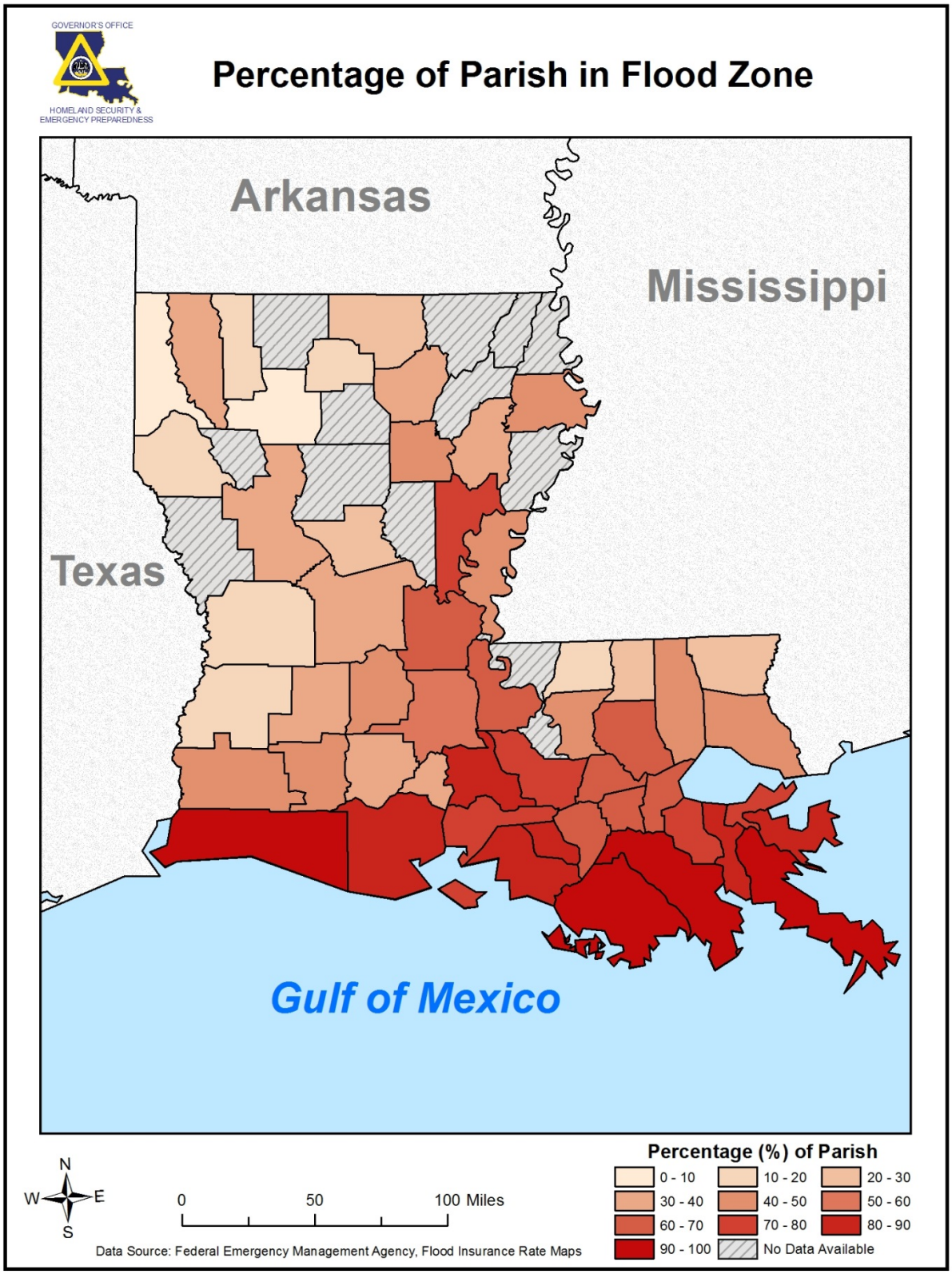
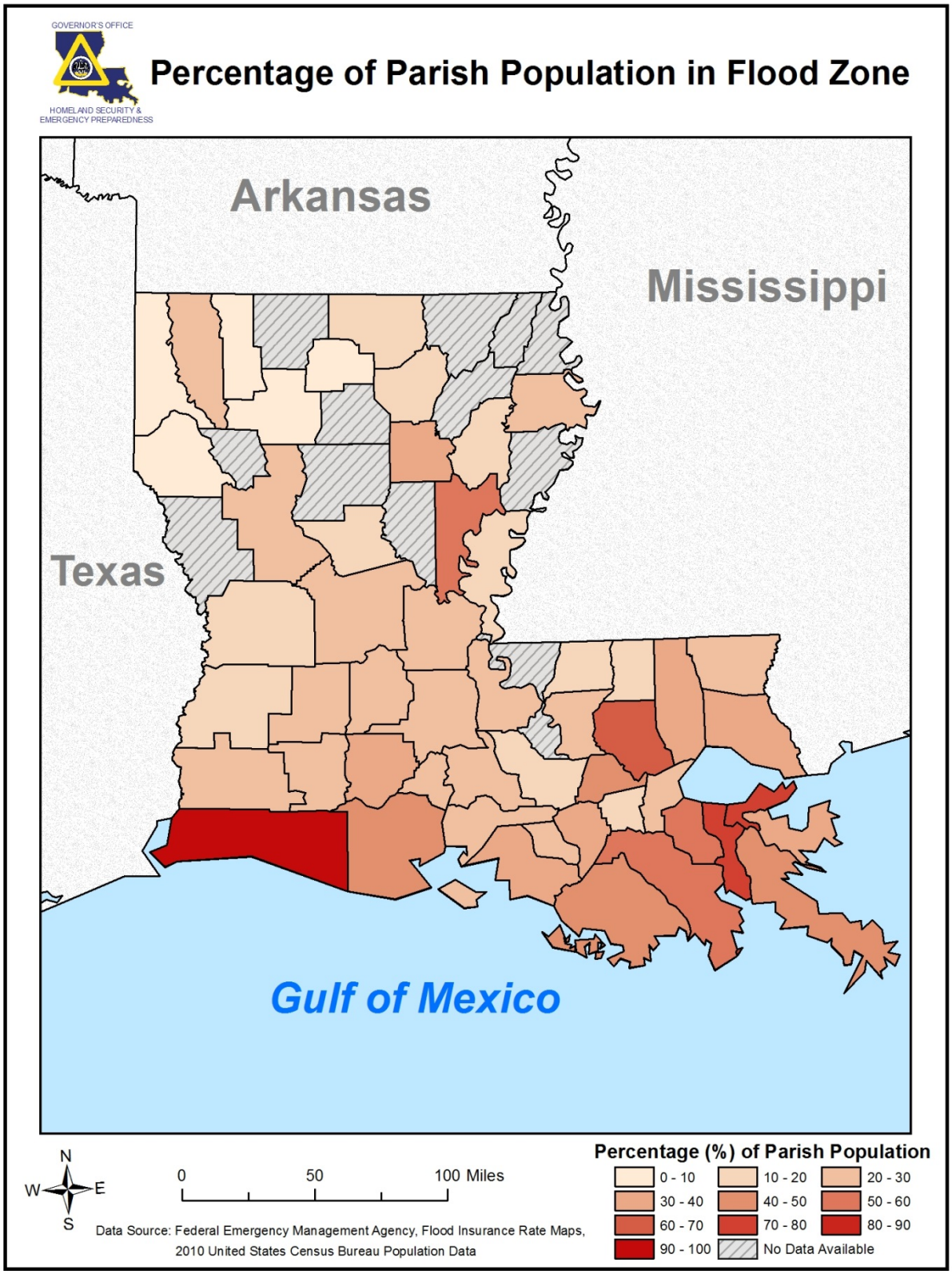


Map 2.12. Extent of 100-yr floodplains (areas with 1% chance on average of being inundated in any given year) in Louisiana (map by ETSU undergraduate Jacob Mullins).



Map 2.13. Percentage of Louisiana parishes located in Flood Insurance Rate Map (FIRM) flood zones.



Map 2.14. Percentage of population located in Flood Insurance Rate Map (FIRM) flood zones, by Louisiana parish.

Livingston, Tangipahoa, and St. Tammany parishes are at high risk (greater than 2.0 composite risk score) to flooding and have experienced significant population increases of more than 10% since 2000 with Livingston parish experiencing a greater than 20% increase in population (see Map 2.3). As a result, the vulnerability of these parishes to flooding has increased. No parishes that are at high risk to flooding experienced a significant population decrease of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability to flooding has not decreased measurably in any part of the state.

Flood studies identify floodplain areas and associate possible flood elevations in the floodplains with probabilities of occurrence. But it should be noted that the Advisory Base Flood Elevations (ABFEs) released for southeastern Louisiana do not fully account for the possibility of catastrophic flooding as a result of levee failure. Instead, they represent a compromise between projected flood levels based on stormwater drainage and the inundation levels reached following Hurricane Katrina. Other areas of the state have outdated ABFEs that do not take into account significant changes in drainage patterns due to development. Additionally, FIRMs are only estimates of flood levels. Floodwaters rarely stop exactly at the line drawn on the map.

Flooding Risk Assessment

Generally, floods with higher flood stages have lower chances of occurring. Minor flooding is virtually a yearly occurrence for a number of rivers and tributaries, and major floods occur regularly in Louisiana. Since one-third of Louisiana's parishes have experienced floods on average more than once every 20 months (60% likelihood)—with other parishes experiencing them on average more than once every six months—the probability of flooding in Louisiana is **High**, and are thus subject in this Plan to vulnerability and impact analyses. Map 2.15 suggests the probability of future occurrence based on past data. While the whole state is subject to flooding at least once every couple of years, Calcasieu and Beauregard Parishes, along with Caddo, Morehouse, and Rapides Parishes, suggest the greatest probability of more extensive future flooding: about 1–2 times per year.

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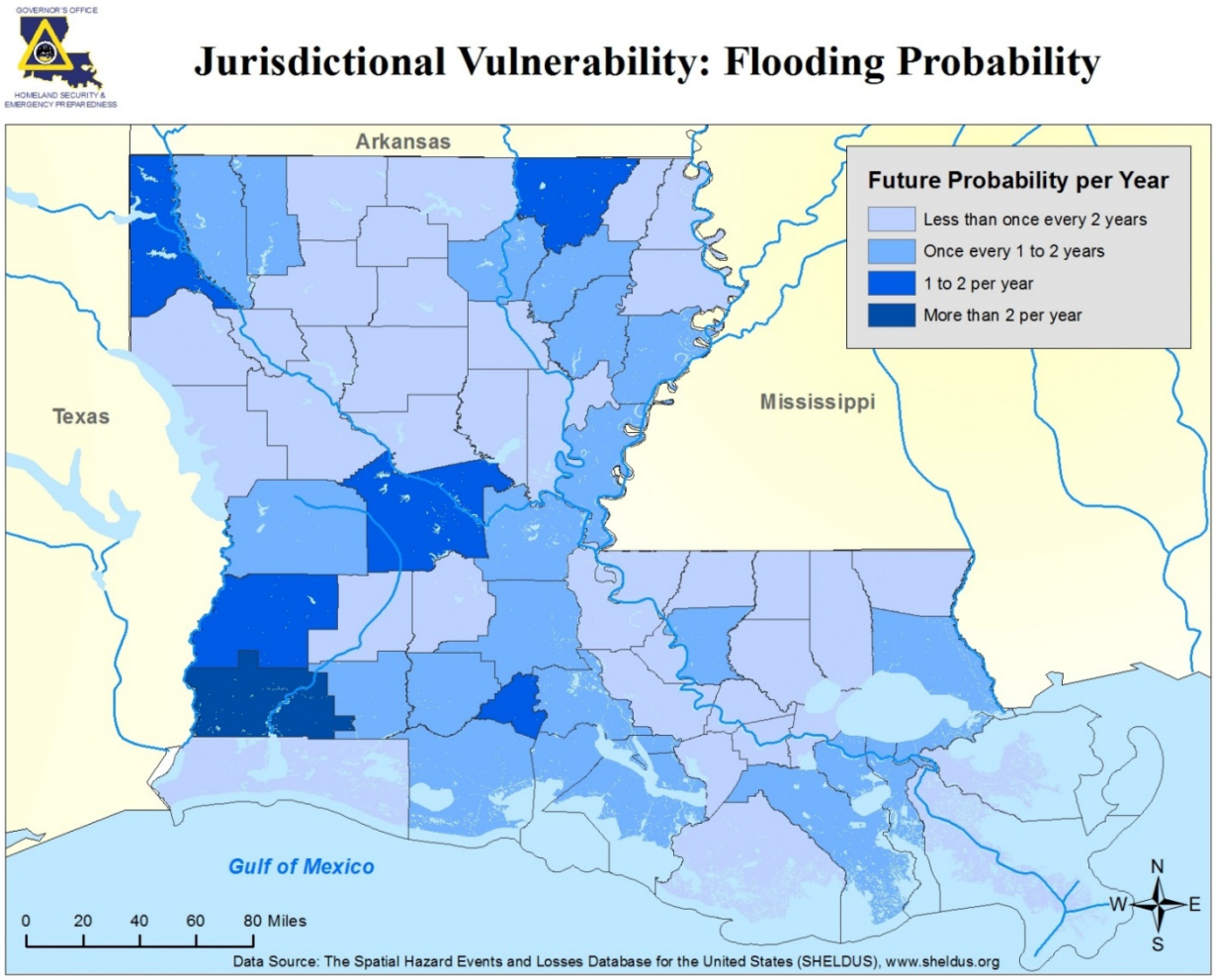
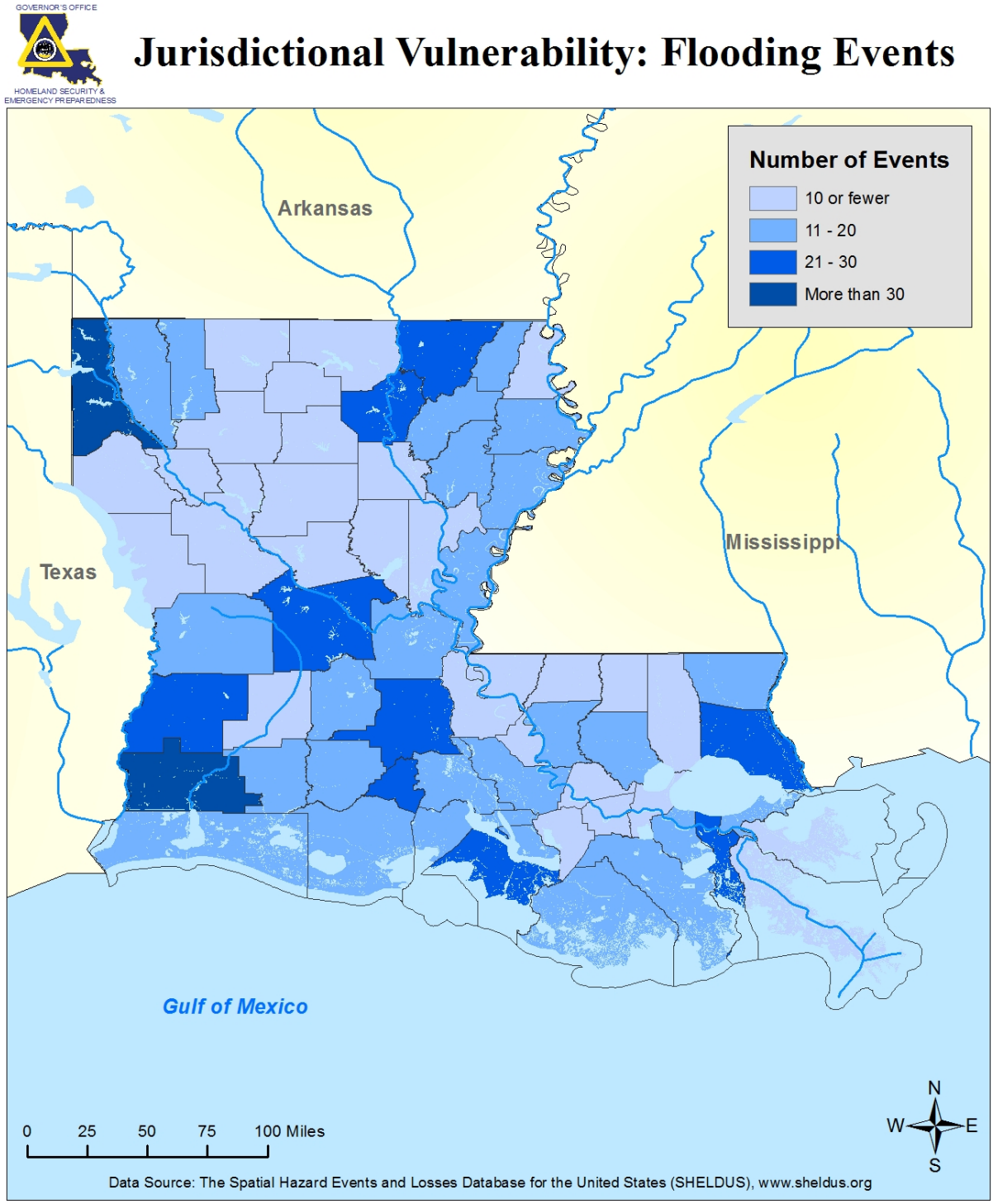


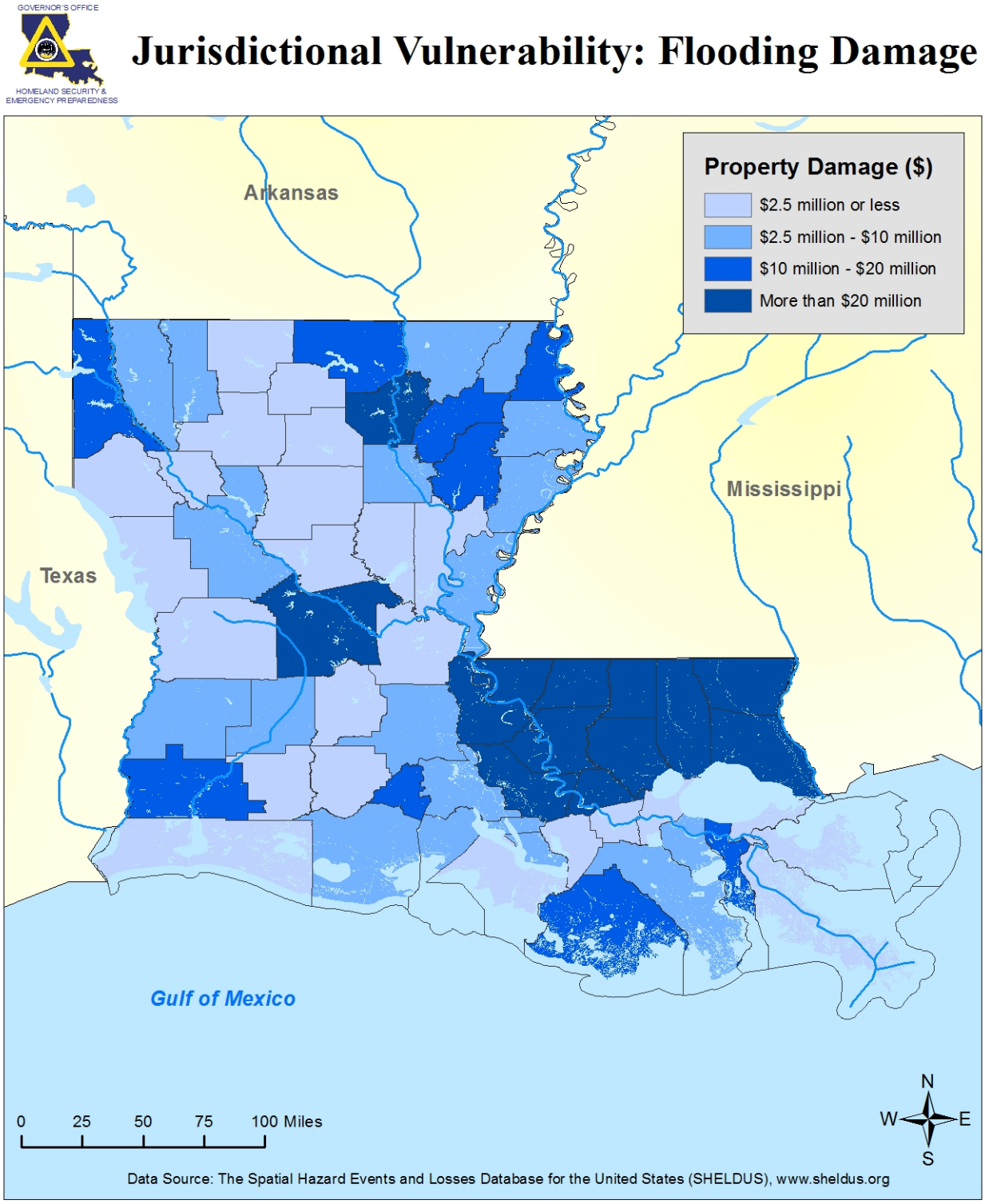
Map 2.15. Probability of flooding in Louisiana by parish based on data from 1987–2012.

Maps 2.16, 2.17, 2.18, 2.19 identify how floods have affected the parishes of Louisiana from 1987 to 2012 in terms of total events, economic damage, injuries, and fatalities, respectively. Based on the data represented, each section of the state has its own riverine hazards associated with flooding. In the northeastern parishes, the Ouachita River and the rivers feeding with it and the Tensas River down into the Atchafalaya seem to threaten the most flooding. In the northwestern region, the Red River and its tributaries are a major threat, contributing significantly to the state's fatalities and damages from flooding. In the southwestern parishes, the area around the Calcasieu River and the tributaries that feed into Calcasieu Lake, along with the Sabine River on the Texas border, are associated with that region's flooding. In the southeastern parishes, where flooding is rampant and especially destructive, the Mississippi, Tangipahoa, and Bogue Chitto Rivers as they flow into the wetlands and Gulf seem to cause that region's major flooding. Livingston, Tangipahoa, and St. Tammany Parishes are at high risk (greater than 2.0 composite risk score) to flooding and have experienced significant population increases of more than 10% since 2000 with Livingston parish experiencing a greater than 20% increase in population (see Map 2.3). As a result, the vulnerability of these parishes to flooding has increased. No parishes that are at high risk to

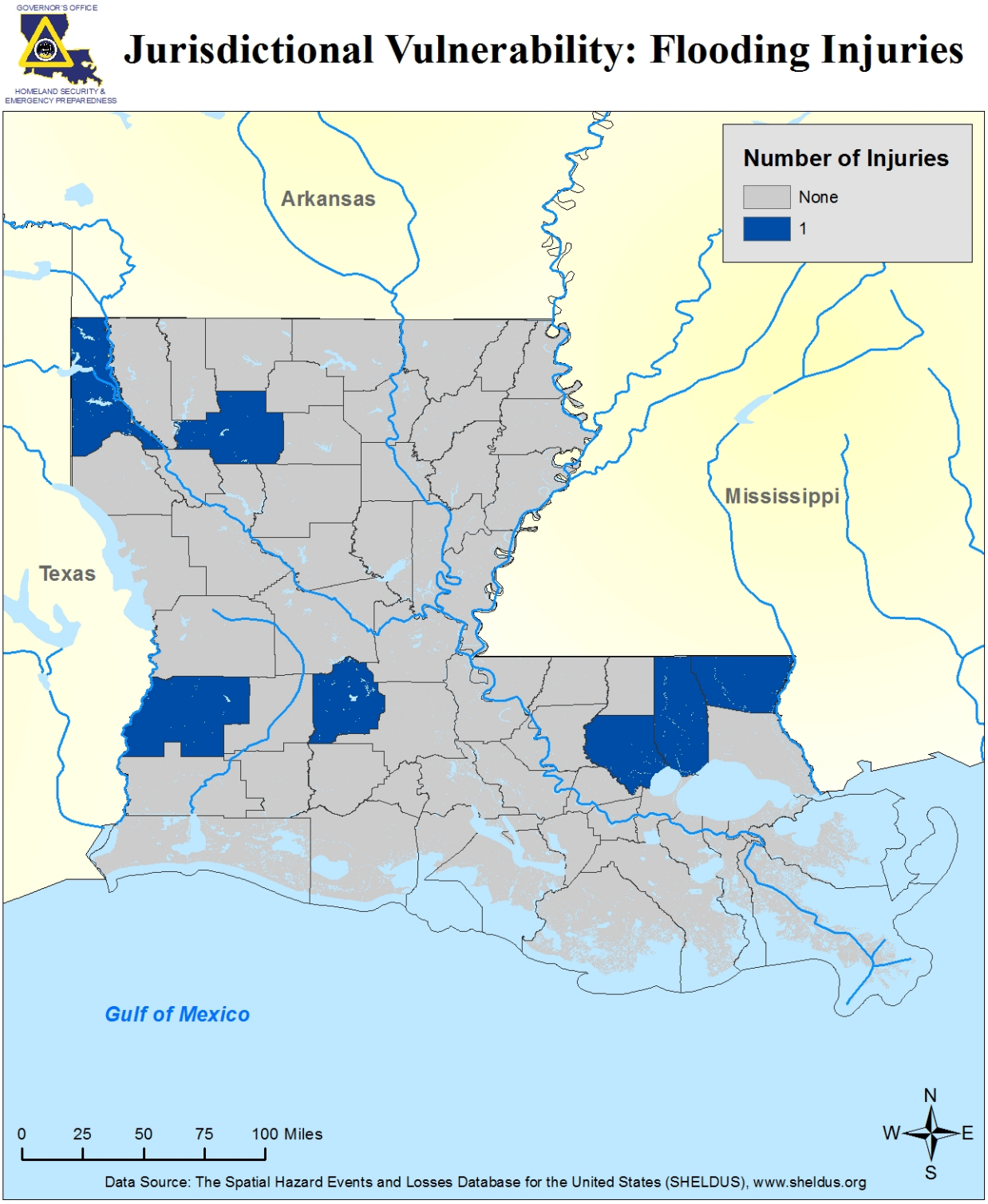
flooding experienced a significant population decrease of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability to flooding has not decreased measurably in any part of the state.



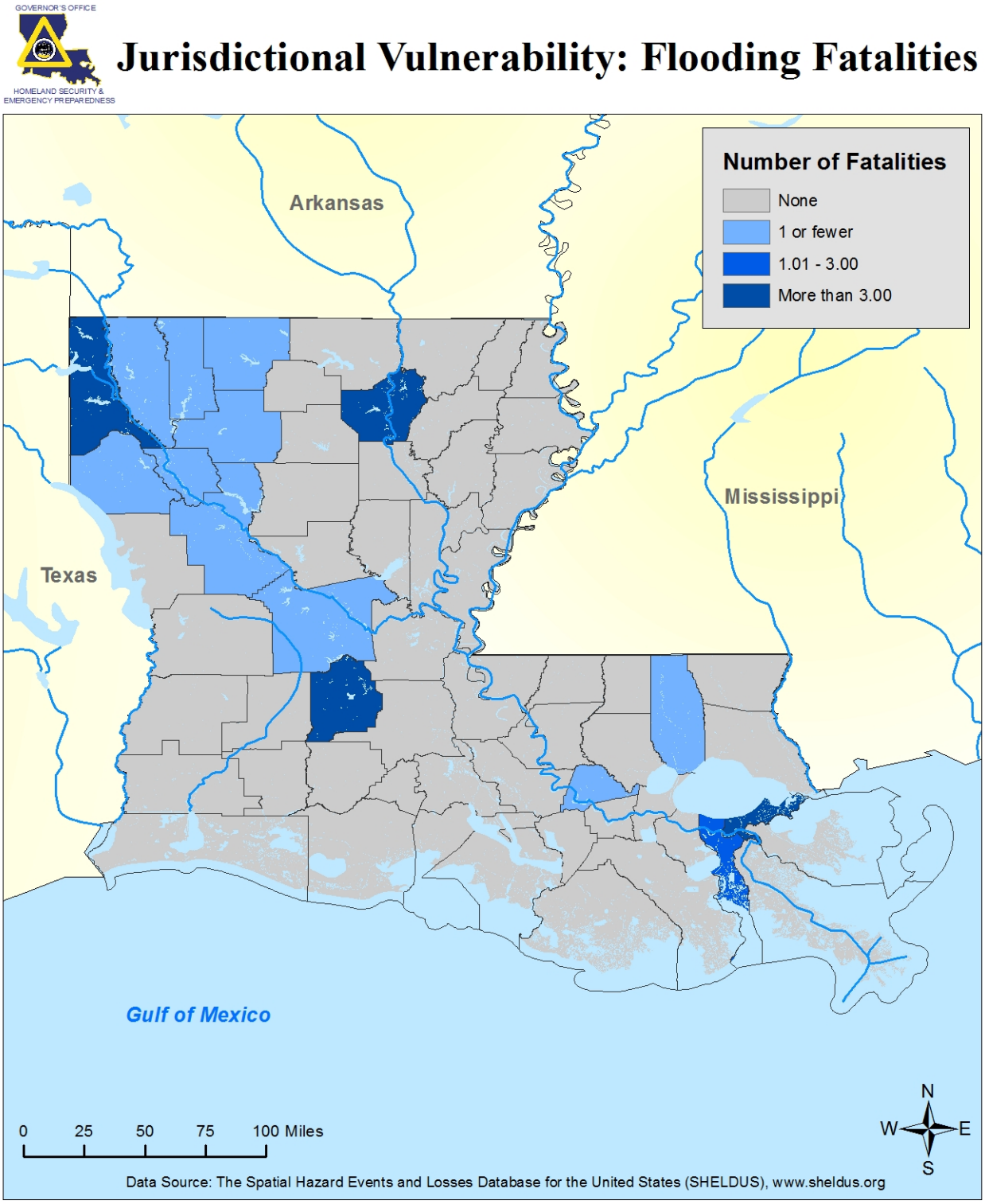
Map 2.16. Louisiana jurisdictional vulnerability for flooding events based on data from 1987–2012.



Map 2.17. Louisiana jurisdictional vulnerability for damage from flooding based on data from 1987–2012.



Map 2.18. Louisiana jurisdictional vulnerability for injury from flooding based on data from 1987–2012.



Map 2.19. Louisiana jurisdictional vulnerability for fatalities from flooding based on data from 1987–2012.

Map 2.20 locates Louisiana's state assets previously damaged by floods in terms of the state's 100-yr flood zones. State-owned critical facilities located in areas affected by flooding are of the following types: hospitals, shelters, Emergency Operation Centers, data processing centers, and state police troop offices.

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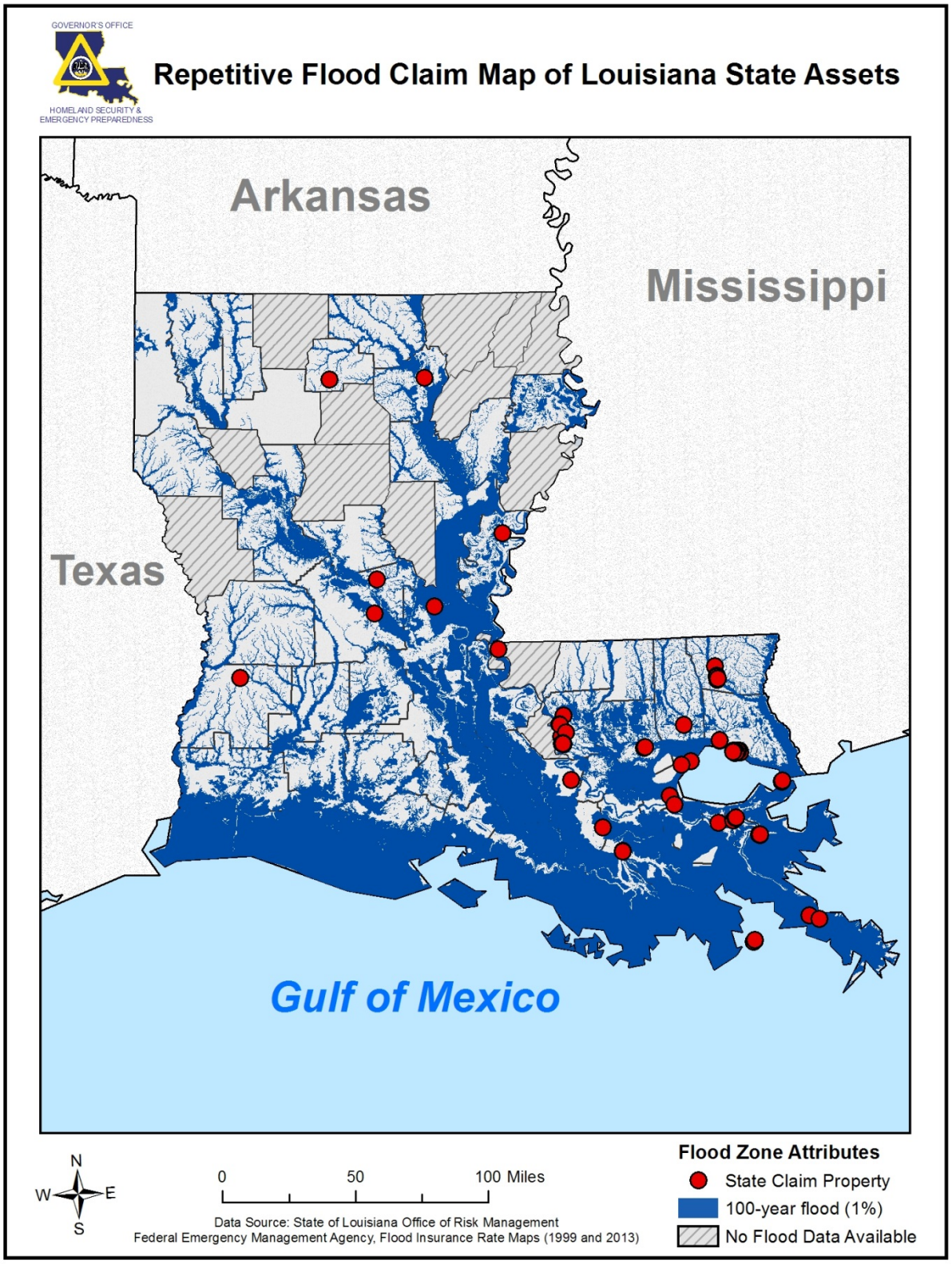

Map 2.20. Louisiana state assets with paid repetitive claims for flooding.

Tables 2.4 and 2.5 list the top 10 flood-damaged assets, without and within a leveed area, respectively.

Table 2.4. Top 10 paid claims for flood-damaged state assets not in a leveed area.[xxix]

Top 10 Paid Claims for Flood-Damaged State Assets Not in a Leveed Area				
Building ID	Building Name	Location	Net Paid	Total Number of Claims (Flood)
S12850	New Orleans Center for the Creative Arts - Building C	New Orleans	$93,663	1
S07952	McCall Dining Hall - Grambling University	Grambling	$76,339	1
S03525	Armory Building	Franklinton	$57,096	1
S12852	New Orleans Center for the Creative Arts - Building E	New Orleans	$52,739	1
S08887	Malone Football Stadium - University of Louisiana-Monroe	Monroe	$32,340	1
S02145	Sewage Pump #2 - Southern University	Baton Rouge	$19,016	1
S00910	Bath House - Fontainebleau State Park	Mandeville	$18,586	2
S02009	New State Capitol	Baton Rouge	$16,635	1
S22026	Area 1 Meeting Room - Fontainebleau State Park	Mandeville	$15,486	2
S22030	Area 1 Dorm 1 - Fontainebleau State Park	Mandeville	$15,199	1

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Table 2.5. Top 10 paid claims for flood-damaged state assets in a leveed area (source: Louisiana Office of Risk Management).

Top 10 Paid Claims for Flood-Damaged State Assets in a Leveed Area				
Building ID	Building Name	Location	Net Paid	Total Number of Claims (Flood)
S12850	New Orleans Center for the Creative Arts - Building C	New Orleans	$93,663	1
S12852	New Orleans Center for the Creative Arts - Building E	New Orleans	$52,739	1
S08887	University of Louisiana-Monroe - Auxiliary Services	Monroe	$35,340	1
S02009	New State Capitol	Baton Rouge	$16,635	1
S14331	Southeastern Louisiana University - General Operations	Hammond	$7,119	1
S04453	Southeastern Louisiana University - Turtle Cove Guest House	Hammond	$5,697	1
S11984	Board of Medical Examiners - Eli Lily Building	New Orleans	$2,199	1
S10015	LSU Alexandria (Abrams Hall & Student Center)	Alexandria	$492	2
S04283	Nicholls State University - Peltier Hall	Thibodaux	$423	1
S12849	New Orleans Center for the Creative Arts - Building B	New Orleans	$65	3

Map 2.21 shows the composite jurisdictional risk for Louisiana based on the preceding data. Livingston, Tangipahoa, Washington, Evangeline, and Caddo Parishes have the greatest risk of flood events (very high).

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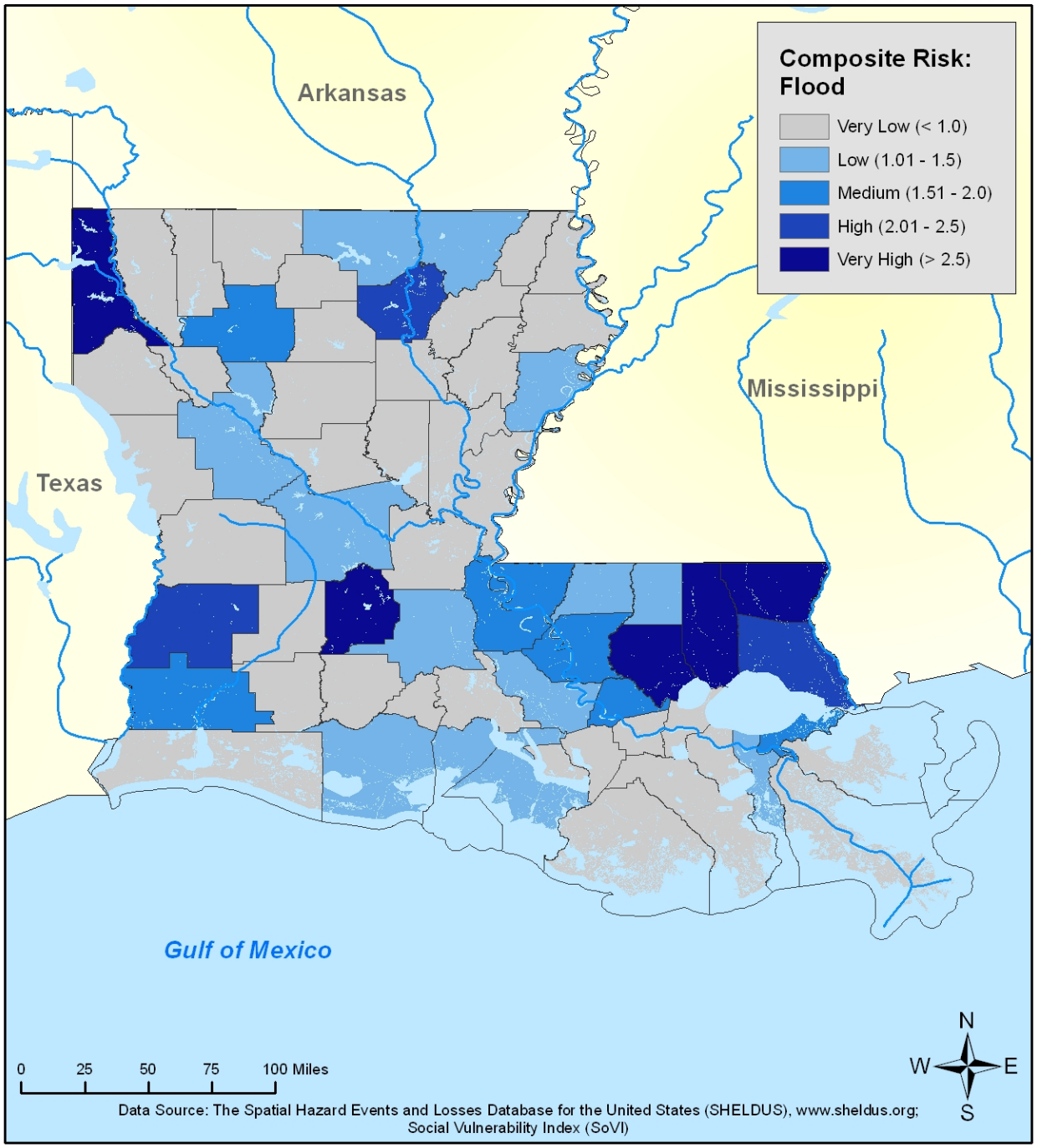

Map 2.21. Composite risk map for flood events showing parishes with the highest historical and highest potential risks.

POTENTIAL ECONOMIC LOSS

Because Digital Flood Insurance Rate Maps (DFIRMs) are not yet available for the entire State of Louisiana, and many are pending adoption, FEMA's Hazus-MH flood model was used to generate the 100-yr flood depth grid and boundary files based on USGS 30-m digital elevation model (DEM) data. A Level 1 Hazus analysis was performed using default inventory datasets for General Building Stock and Essential Facilities. Hazus hydrologic and hydraulic analyses were performed using 40 mi^2 areas for the majority of the state. For locations where riverine analyses could not be completed, further refinement of the stream network was performed, using 1 mi^2 analysis. Some errors were encountered during the flood analysis, including poor definition of the stream network in the Atchafalaya Basin and coastal wetland areas, and failure of the software to complete analysis of the Mississippi River corridor from Baton Rouge to South Pass. Because of the complexity of the state's riverine network and limited vertical relief, it is recommended that Level 2 Hazus analysis be conducted to refine the analysis results. Level 2 analysis incorporates improved elevation data and refined building stock dataset, beyond a standard Level 1 analysis.

Table 2.6 summarizes the economic loss results of the 100-yr Hazus flood analysis by parish, including the modeled population (based on 2000 census data), total building exposure (in thousands), total economic loss (in thousands), total number of damaged buildings, total building loss (in thousands), short-term shelter needs, and economic loss resulting from damage to the transportation infrastructure. All transportation losses estimated by Hazus were the result of economic losses to bridges.

Table 2.6. Summary results of 100-yr Hazus flood analysis by parish. Includes modeled population (based on 2000 census data), total building exposure (in thousands), total economic loss (in thousands), total number of damaged buildings, total building loss (in thousands), short-term shelter needs, and transportation losses.

SUMMARY OF HAZUS FLOOD MODEL FOR 100-YR FLOOD IN LOUISIANA BY PARISH							
Parish	Hazus Modeled Population (2000)	Total Building Exposure ($1,000)	Total Economic Loss ($1,000)	Total Damaged Buildings	Building Loss ($1,000)	Short Term Shelter Needs	Transportation Infrastructure Economic Loss ($)
Acadia	58,861	3,359,777	87,240	397	47,811	2,198	29,515
Allen	25,440	1,295,592	95,485	644	53,820	1,793	44,784
Ascension	76,627	4,898,707	201,846	1,544	112,467	6,075	98,220
Assumption	23,388	1,253,610	19,227	199	11,359	1,182	12,757
Avoyelles	41,481	2,131,433	163,285	1,172	82,461	5,159	1,851
Beauregard	32,986	1,864,083	82,055	409	46,161	1,219	25,714
Bienville	15,752	861,313	20,316	125	11,126	305	14,888
Bossier	98,310	6,454,615	261,099	1,374	127,726	5,340	758
Caddo	252,161	16,833,151	266,510	850	106,386	4,869	8,305

Summary of Hazus Flood Model for 100-yr Flood in Louisiana by Parish							
Parish	Hazus Modeled Population (2000)	Total Building Exposure ($1,000)	Total Economic Loss ($1,000)	Total Damaged Buildings	Building Loss ($1,000)	Short Term Shelter Needs	Transportation Infrastructure Economic Loss ($)
Calcasieu	183,577	11,927,017	317,406	1,904	165,353	8,056	57,550
Caldwell	10,560	566,360	41,221	213	21,942	774	6,978
Cameron	9,991	746,172	42,522	233	18,045	1,515	10,358
Catahoula	10,920	548,174	70,533	467	33,266	2,647	76,371
Claiborne	16,851	889,712	15,138	119	8,502	173	10,943
Concordia	20,247	1,085,572	25,606	200	14,355	623	14,416
De Soto	25,494	1,316,230	24,664	93	12,755	322	1,352
East Baton Rouge	412,852	32,382,054	805,850	4,669	421,628	22,721	41,762
East Carroll	9,421	400,903	645	1	348	13	19,904
East Feliciana	21,360	1,713,143	32,267	154	16,944	488	3,888
Evangeline	35,434	1,755,144	53,178	212	26,330	890	0
Franklin	21,263	1,086,076	15,617	30	5,563	445	2,242
Grant	18,698	944,365	48,009	242	26,123	663	31,988
Iberia	73,266	4,405,058	85,893	383	39,325	2,411	0
Iberville	33,320	1,800,313	145,475	1,007	66,635	6,866	0
Jackson	15,397	963,397	15,119	74	8,175	226	6,510
Jefferson	455,466	35,684,176	65	1	41	1	0
Jefferson Davis	31,435	1,842,635	82,800	519	46,160	1,803	0
La Salle	190,503	772,883	25,679	870	103,563	680	5,755
Lafayette	89,974	14,227,704	218,440	275	15,781	4,749	17,226
Lafourche	14,282	5,730,667	29,542	145	14,357	5,842	55,540
Lincoln	42,509	2,539,621	9,560	28	5,385	74	58,682
Livingston	91,814	5,245,226	352,345	2,246	195,753	8,195	65,787
Madison	13,728	675,033	7,758	27	3,916	85	7,986
Morehouse	31,021	1,606,460	8,104	12	3,963	182	56,239
Natchitoches	39,080	2,224,690	46,482	177	24,090	567	0
Orleans	484,674	35,117,466	260	1	156	6	15,568
Ouachita	147,250	9,717,268	667,897	2,981	276,063	13,924	17,956
Plaquemines	26,757	1,714,703	28,492	195	13,362	1,851	43,366
Pointe Coupee	22,763	1,392,561	46,006	311	23,058	1,089	14,483
Rapides	126,337	8,380,764	1,516,137	6,817	645,810	26,495	875
Red River	9,622	461,984	23,938	137	13,197	634	12,705
Richland	20,981	1,045,694	5,609	15	2,877	139	7,939
Sabine	23,459	1,411,859	16,532	46	7,641	146	16,304
St. Bernard	67,229	4,449,262	629	10	397	57	3,369
St. Charles	48,072	3,434,466	11,147	85	5,344	510	42,340

SUMMARY OF HAZUS FLOOD MODEL FOR 100-YR FLOOD IN LOUISIANA BY PARISH							
Parish	Hazus Modeled Population (2000)	Total Building Exposure ($1,000)	Total Economic Loss ($1,000)	Total Damaged Buildings	Building Loss ($1,000)	Short Term Shelter Needs	Transportation Infrastructure Economic Loss ($)
St. Helena	10,525	496,825	36,412	178	19,167	498	68,667
St. James	21,216	1,235,643	5,324	55	3,046	367	24,357
St. John the Baptist	43,044	2,793,689	4,484	40	2,513	213	15,338
St. Landry	87,700	4,540,764	234,539	1,757	123,364	6,870	0
St. Martin	48,583	2,641,889	139,804	1,131	77,221	5,195	61,047
St. Mary	53,500	3,287,539	1,090,524	293	518,073	19,843	12,633
St. Tammany	191,268	13,611,715	614,121	2,994	314,480	11,922	26,235
Tangipahoa	100,588	5,311,687	193,966	1,172	103,431	5,115	28,935
Tensas	6,618	405,232	2,283	4	1,079	0	16,413
Terrebonne	104,503	7,275,577	144,295	513	50,395	8,877	33,200
Union	22,803	1,245,082	69,729	370	40,458	1,039	3,979
Vermilion	53,807	3,173,547	108,995	423	49,640	3,345	26,398
Vernon	52,531	2,774,419	52,917	174	28,225	760	9,969
Washington	43,926	2,182,384	99,848	533	47,911	1,717	28,247
Webster	41,831	2,325,744	36,233	182	20,197	612	15,156
West Baton Rouge	21,601	1,401,587	9,107	8	2,881	188	47,985
West Carroll	12,314	639,035	1,104	1	592	3	14,640
West Feliciana	15,111	692,252	31,097	122	14,989	1,822	5,495
Winn	16,894	886,087	35,756	181	19,730	530	14,165
TOTALS	**4,468,976**	**296,077,790**	**8,944,166**	**41,741**	**4,322,912**	**212,918**	**1,416,033**

Table 2.7 summarizes the counts of essential facilities damaged by the 100-yr flood.

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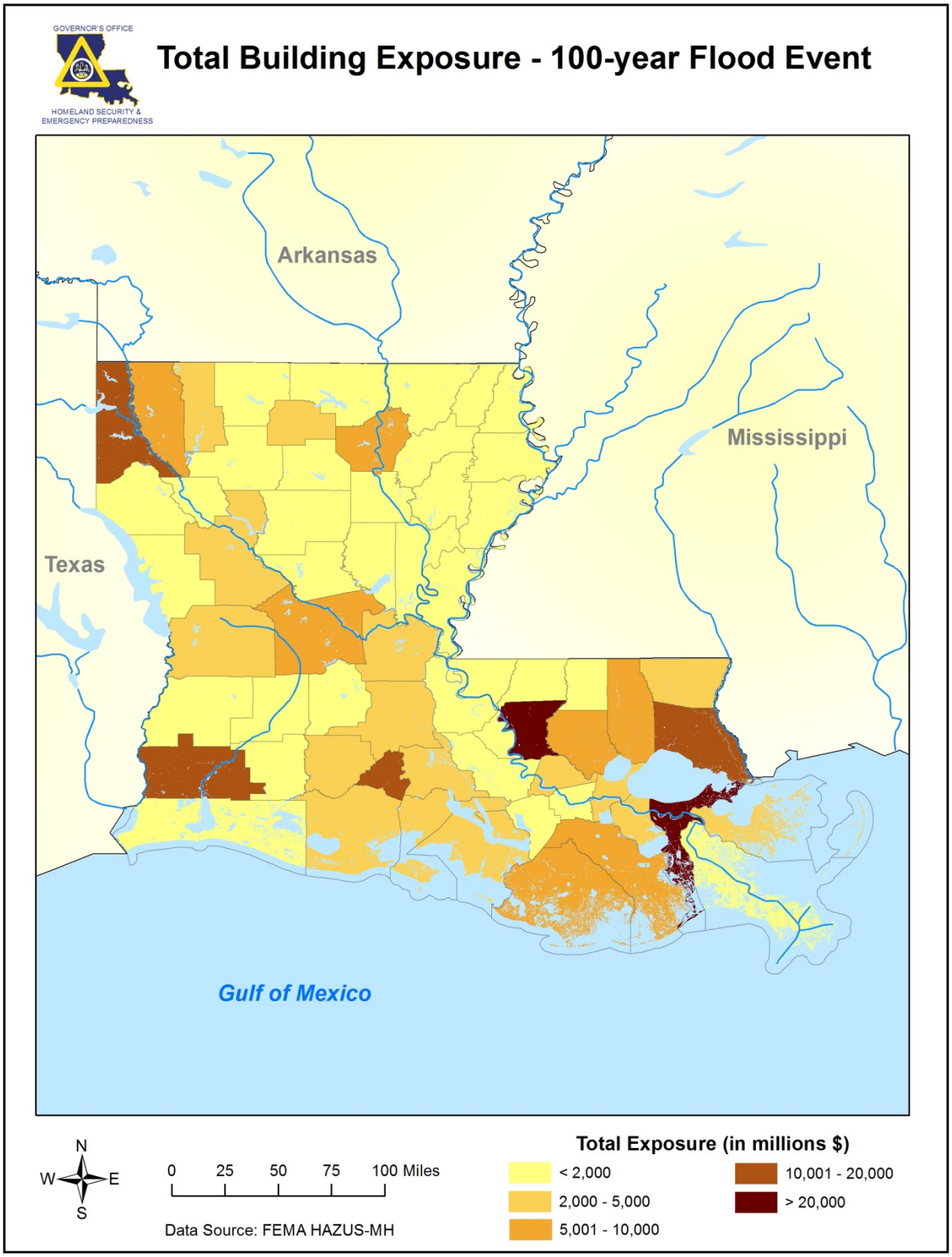
Table 2.7. Total essential buildings damaged by 100-yr flood.

Counts of Essential Facilities Damaged by the 100-year Flood					
Parish	Damaged Essential Facilities by Parish				
	Fire Stations	Police Stations	Hospitals	Schools	Total Facilities
Acadia	0	2	0	1	3
Allen	0	0	0	0	0
Ascension	0	0	0	0	0
Assumption	0	0	0	0	0
Avoyelles	1	1	0	1	3
Beauregard	0	0	0	0	0
Bienville	1	0	0	0	1
Bossier	0	0	0	2	2
Caddo	0	1	0	1	2
Calcasieu	0	0	0	1	1
Caldwell	0	0	0	0	0
Cameron	0	3	0	2	5
Catahoula	1	0	0	5	6
Claiborne	1	0	0	1	2
Concordia	0	1	0	0	1
De Soto	0	0	0	0	0
East Baton Rouge	2	0	0	4	6
East Carroll	0	0	0	0	0
East Feliciana	0	0	0	0	0
Evangeline	0	0	0	0	0
Franklin	0	0	0	0	0
Grant	0	1	0	0	1
Iberia	0	0	0	0	0
Iberville	1	0	0	2	3
Jackson	0	0	0	0	0
Jefferson	0	0	0	0	0
Jefferson Davis	1	0	0	1	2
Lafayette	0	0	0	0	0
Lafourche	0	1	0	1	2
La Salle	0	0	0	0	0
Lincoln	0	0	0	0	0
Livingston	1	0	0	3	4
Madison	0	0	0	0	0
Morehouse	0	0	0	0	0
Natchitoches	1	0	0	0	1
Orleans	0	0	0	0	0
Ouachita	1	5	1	10	17

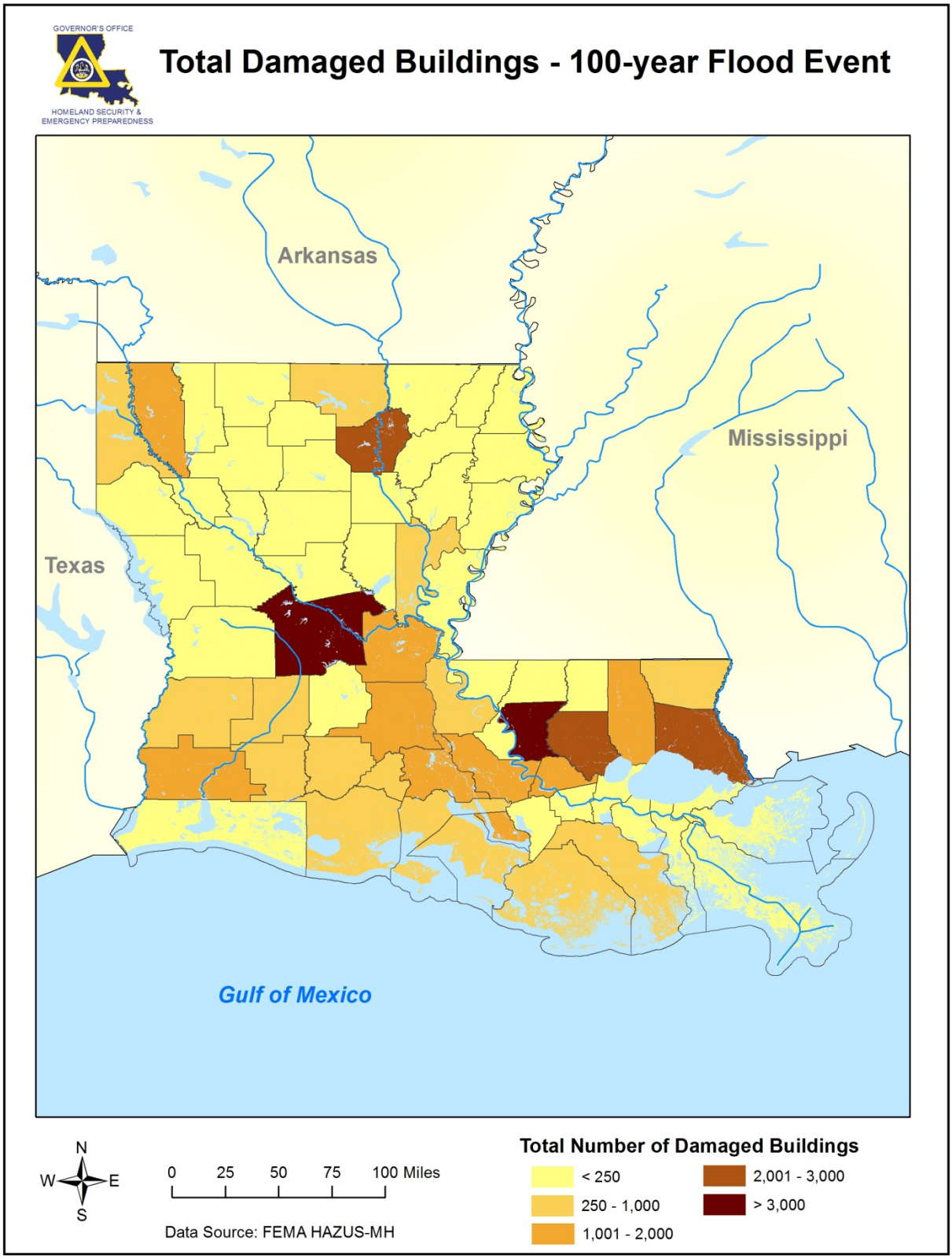
Counts of Essential Facilities Damaged by the 100-year Flood					
Parish	Damaged Essential Facilities by Parish				
	Fire Stations	Police Stations	Hospitals	Schools	Total Facilities
Plaquemines	0	0	0	1	1
Pointe Coupee	0	1	0	0	1
Rapides	2	12	2	18	34
Red River	0	0	0	0	0
Richland	0	0	0	0	0
Sabine	0	0	0	0	0
St. Bernard	0	0	0	0	0
St. Charles	0	0	0	0	0
St. Helena	0	0	0	0	0
St. James	0	0	0	0	0
St. John the Baptist	0	0	0	0	0
St. Landry	0	4	0	6	10
St. Martin	0	1	0	1	2
St. Mary	4	8	1	17	30
St. Tammany	2	3	0	3	8
Tangipahoa	0	1	0	0	1
Tensas	0	0	0	0	0
Terrebonne	1	1	0	1	3
Union	0	0	0	0	0
Vermilion	0	0	0	1	1
Vernon	0	1	0	0	1
Washington	0	1	0	1	2
Webster	0	0	0	0	0
West Baton Rouge	0	0	0	0	0
West Carroll	0	0	0	0	0
West Feliciana	0	0	0	0	0
Winn	0	0	0	0	0
TOTALS	**20**	**48**	**4**	**84**	**156**

Maps 2.22 through 2.29 provide information regarding 100-yr flood events in Louisiana as modeled using Hazus-MH 2.1. Map 2.22 models flood depth in relation to digitized elevation in Louisiana. Map 2.23 shows the ratio of total economic loss to total building exposure by parish. Map 2.24 shows estimated building loss by parish, while Maps 2.25 and 2.26 reveal total estimated economic losses by parish and by census block group. Maps 2.27 and 2.28 illustrates the estimated displaced population and shelter needs by parish, and Map 2.29 locates the density of damaged essential facilities by parish.

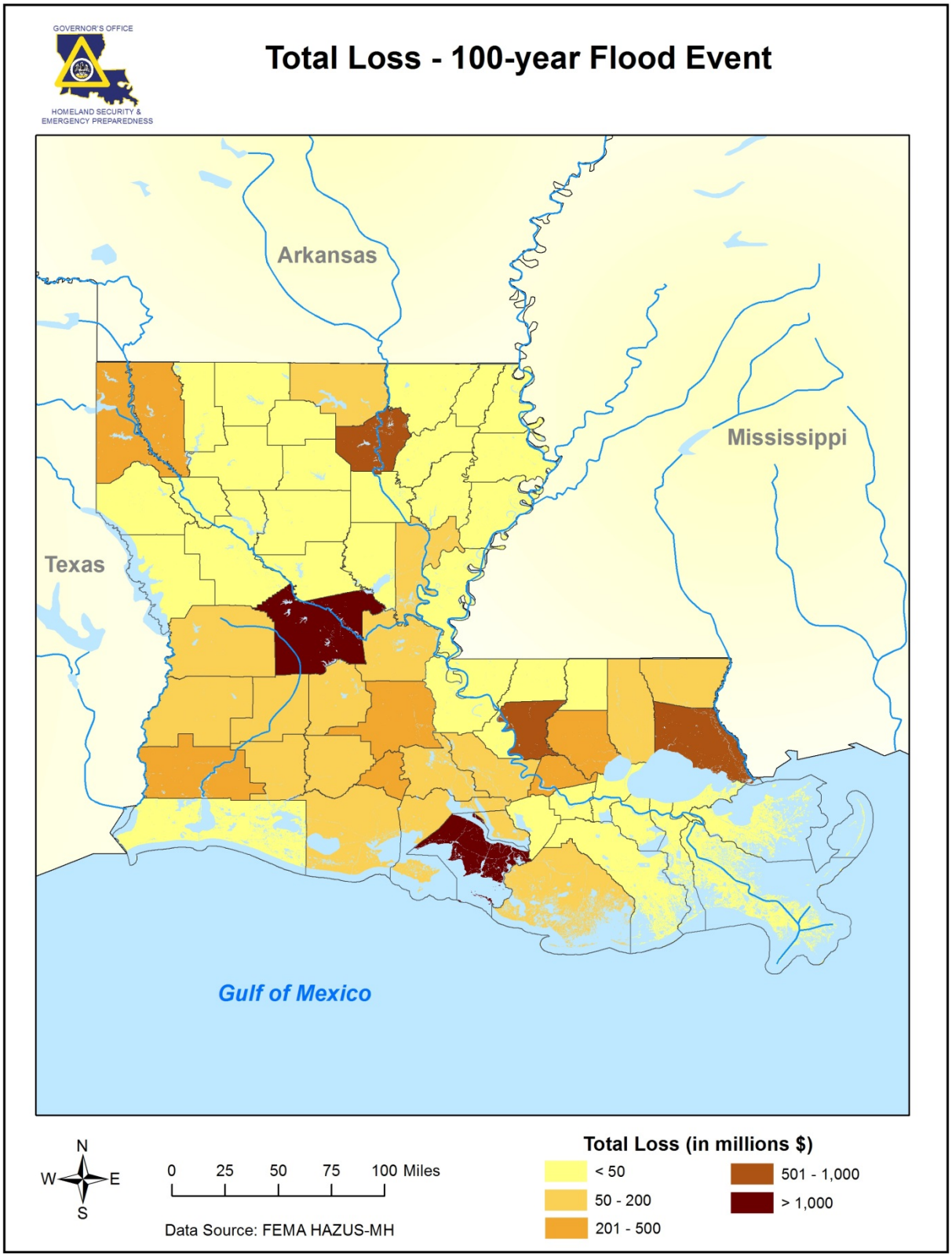
Map 2.22. 100-yr flood depth surface (from Hazus), overlain on study area digital elevation model.



Map 2.23. Total building exposure by parish (in millions) from default Hazus database.

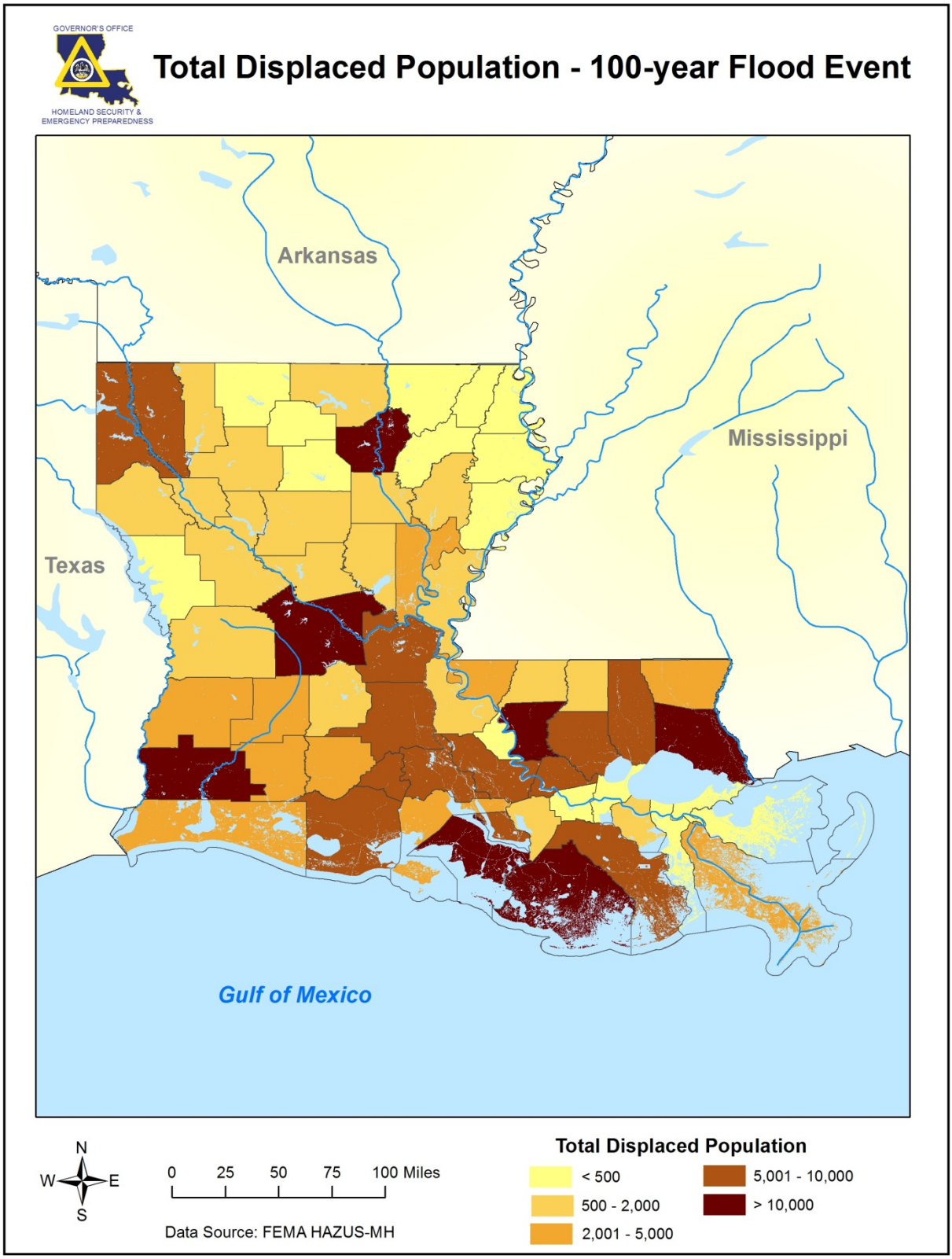


Map 2.24. Total damaged buildings by 100-yr flood event per parish.

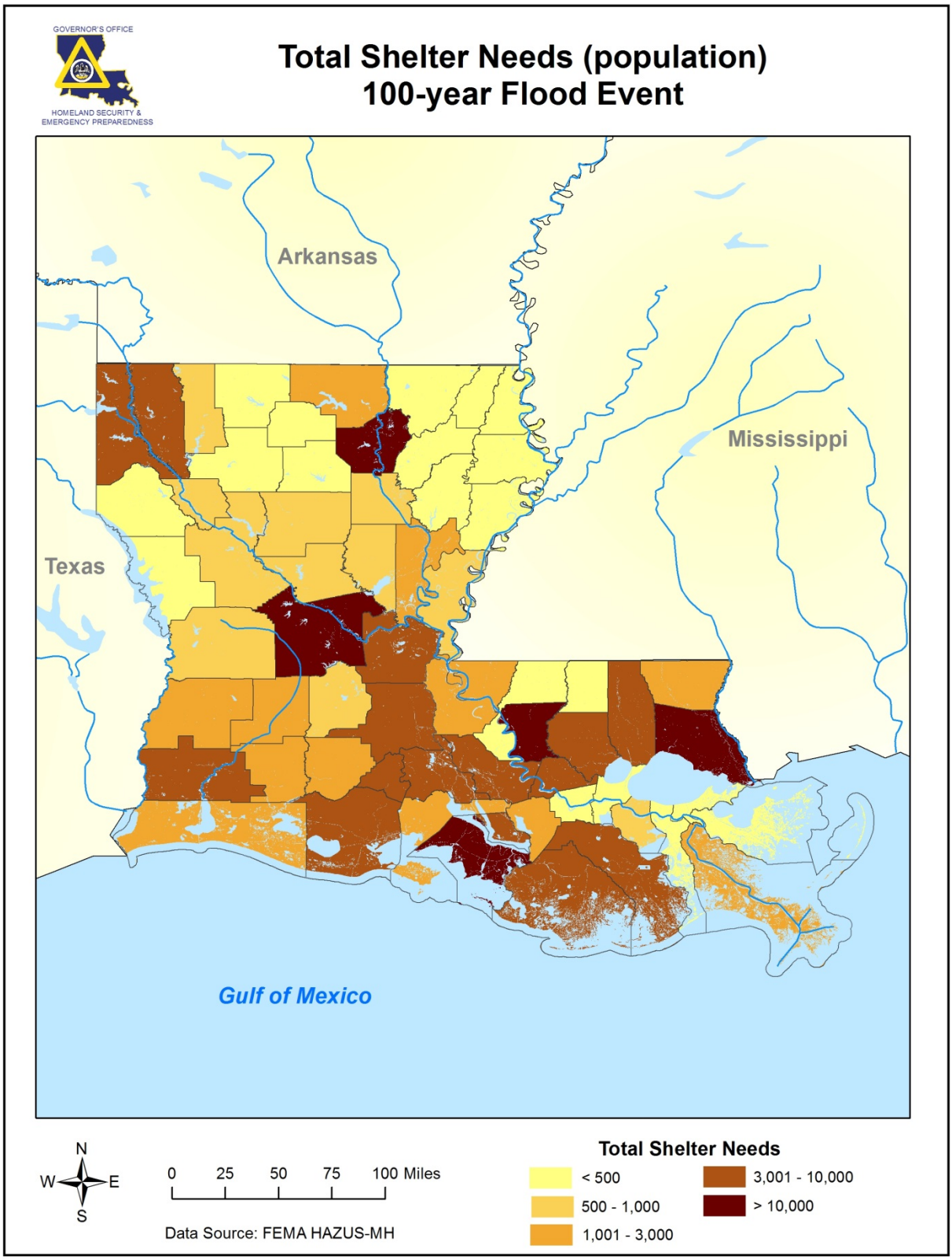


Map 2.25. Total economic loss by parish (in millions) resulting from a 100-yr flood event.

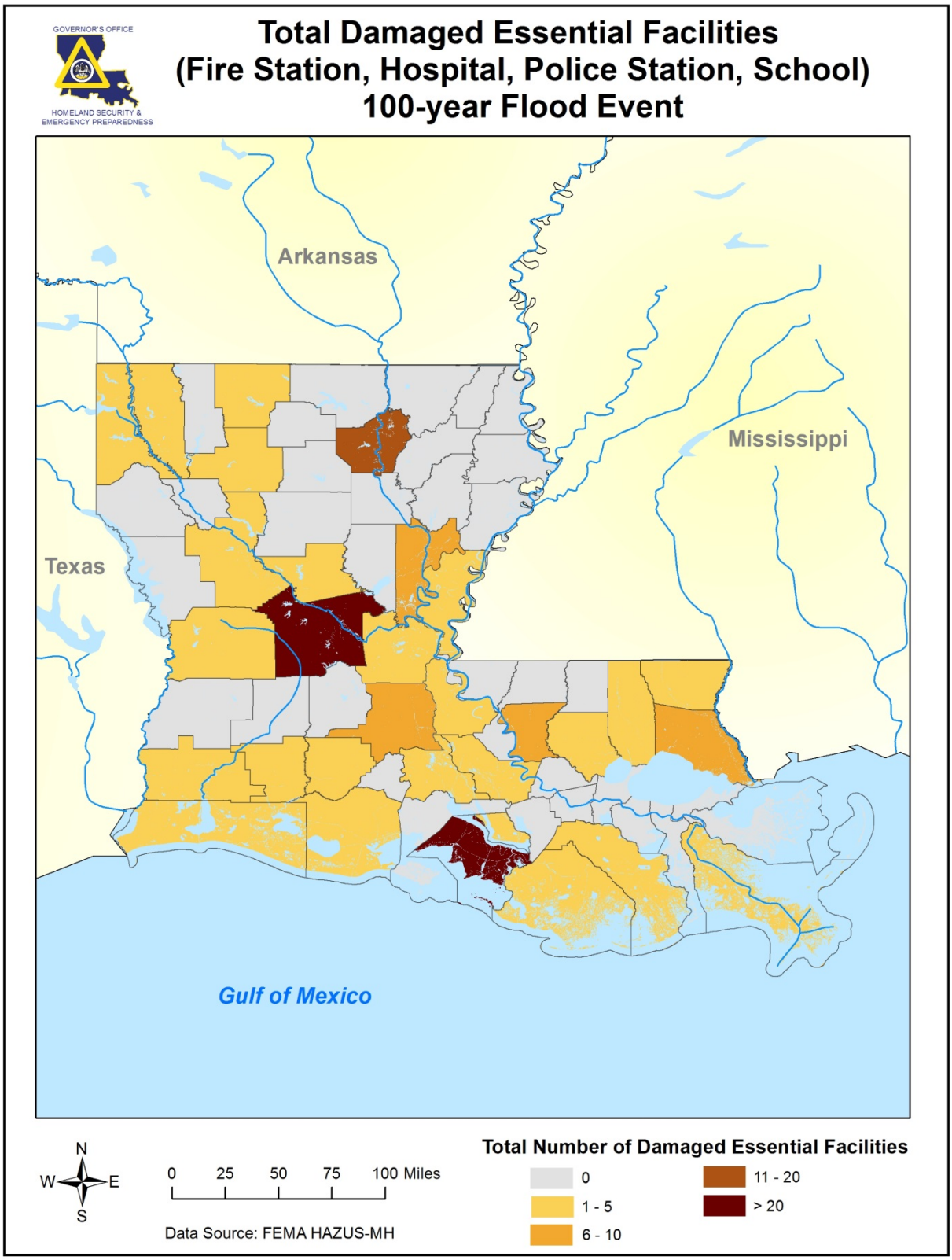
Map 2.26. Total economic loss by census block group (in millions) resulting from a 100-yr flood event.



Map 2.27. Total displaced population by parish resulting from a 100-yr flood event.



Map 2.28. Total shelter needs by parish resulting from a 100-yr flood event.



Map 2.29. Total damaged essential facilities by parish resulting from a 100-yr flood event.

To determine potential loss estimates from flooding, the available historical loss data was annualized to determine future loss potential (see Map 2.30). As shown, parishes with the largest populations are predicted to have the highest potential annualized losses.

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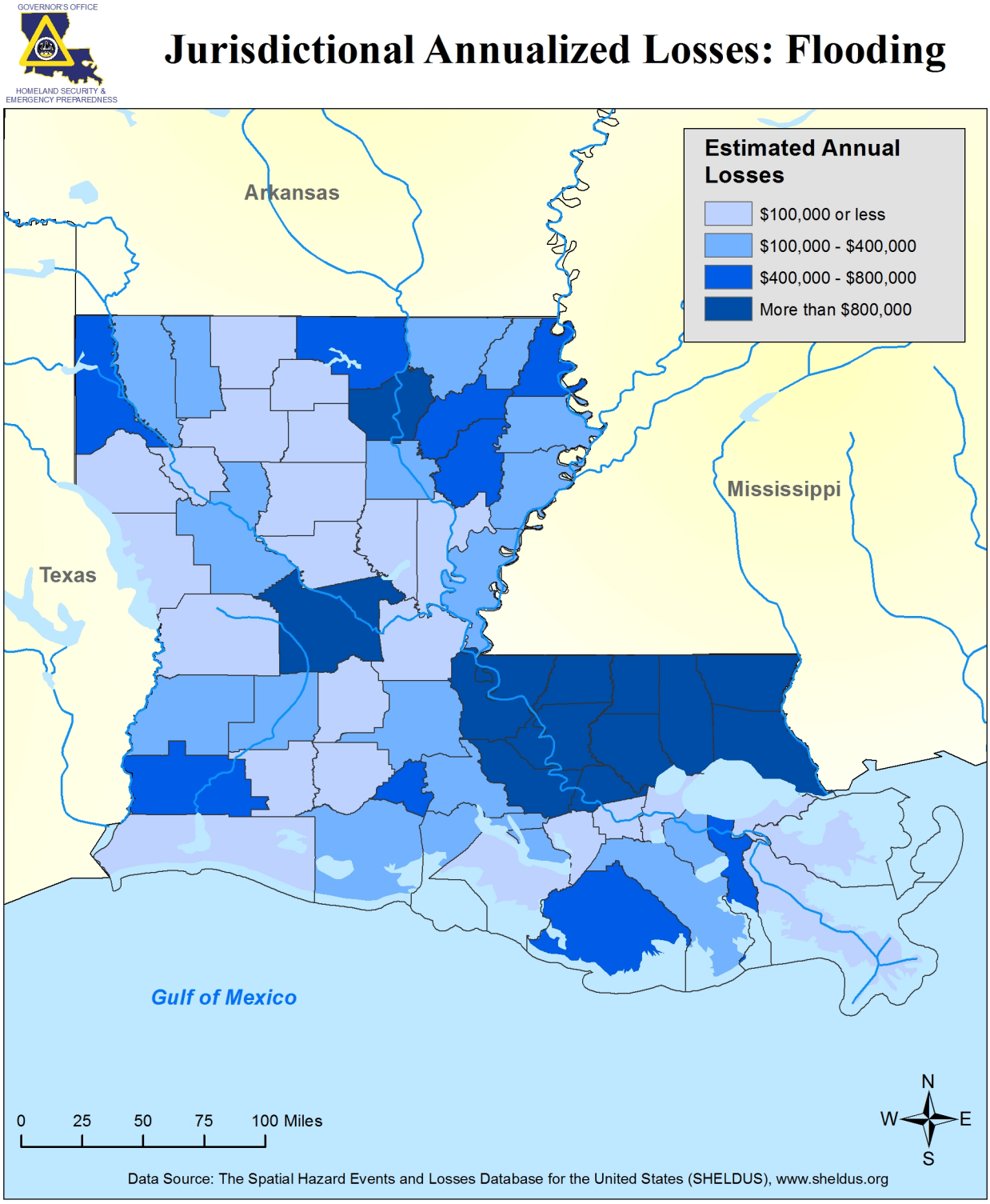


Map 2.30. Jurisdictional annualized loss due to flooding.

Potential Losses by Jurisdiction

Overview & Analysis of Potential Losses: Flooding occurs throughout the state, but Livingston, Tangipahoa, Washington, Evangeline, and Caddo Parishes have the greatest risk of flood events (very high). Most parishes are vulnerable to riverine flooding, but coastal (southern) parishes are confronted with the additional risk of various types of coastal flooding.

Changes in jurisdictional population levels impact each parish across the state disparately. In the parishes where flood vulnerability has increased because of increases in population (Livingston, Tangipahoa, and St. Tammany), concomitant changes in development have impacted loss estimates and will cause an increase in future losses due to increased levels of exposure in areas that are already impacted by both riverine and coastal flooding. Since all parishes participate in the National Flood Insurance Program (NFIP), new development must meet base flood elevations (BFE) and wetlands that are in-filled to meet the BFE are offset elsewhere in new developments through the construction of retention ponds and other projects that create a net-zero topographic change. Consequently, changes in new development may impact previously built areas elsewhere.

Of all assessed hazards, flooding is most impacted by changes in development and flooding will be greatly exacerbated in parishes where populations have substantially increased. No high-risk parishes for flooding experienced a significant decrease in population and, consequently, no other parishes will experience a measurable change in loss estimates based on development trends.

Potential Losses of State Facilities

The flood hazard vulnerability assessment of state-owned buildings was based on the parish-level composite risk score, which incorporates the total number of flooding events, injuries, fatalities, and property damages as well as the social vulnerability of impacted parishes. The criteria used to determine specific vulnerability rankings for each building and the results of applying this ranking to the state-owned buildings are shown in Table 2.8.

Table 2.8. Flood Vulnerability Criteria and Ranking Results.

Flood Vulnerability Criteria and Ranking	
Ranking	Criteria
High	Composite risk score greater than 2.0
Medium	Composite risk score between 1.5 and 2.0
Low	Composite risk score less than 1.5
None	Insufficient data

The flood loss estimate ranges are derived from the 2011 state hazard mitigation plan and inflation-adjusted to 2013 dollars. The January 2014 state facilities database was used to obtain accurate building numbers for each loss estimate range. Loss estimates of state-owned buildings in Louisiana involved an analysis of the following parameters:

- Flood Hazard Vulnerability Ranking
- Average Flood Depth
- Average Building Type
- Depth-Damage Functions

Table 2.9. Flood Loss Estimate Ranges and Ranking Results.

FLOOD LOSS ESTIMATE RANGES AND RANKING		
Ranking	Total Loss Estimate Ranges	Number of Buildings
High	$21,376 - $160,320,000	1219
Medium	$268 - $21,376	2664
Low	$0 - $267 (including facilities with insufficient data	4802

THUNDERSTORMS

The term "thunderstorm" is usually used as a catch-all term for several kinds of storms. Here "thunderstorm" is defined to include any precipitation event in which thunder is heard or lightning is seen. Thunderstorms are often accompanied by heavy rain and strong winds and, depending on conditions, occasionally by hail or snow. Consequently, hail, lightning, and high winds will be profiled and defined in the thunderstorm section. Thunderstorms form when humid air masses are heated, which causes them to become convectively unstable and therefore rise. Upon rising, the air masses' water vapor condenses into liquid water and/or deposits directly into ice when they rise sufficiently to cool to the dew-point temperature.

Thunderstorms are classified into four main types (single-cell, multicell, squall line, and supercell), depending on the degree of atmospheric instability, the change in wind speed with height (called *wind shear*), and the degree to which the storm's internal dynamics are coordinated with those of adjacent storms. There is no such interaction for single-cell thunderstorms, but there is significant interaction with clusters of adjacent thunderstorms in multicell thunderstorms and with a linear "chain" of adjacent storms in squall line thunderstorms. Though supercell storms have no significant interactions with other storms, they have very well-organized and self-sustaining internal dynamics, which allows them to be the longest-lived and most severe of all thunderstorms.

Thunderstorms are common all year in Louisiana, but occur more frequently in the summer months because intense sunshine heats the Earth's surface more frequently and powerfully. Fortunately, even though single-cell storms are the most common thunderstorm type everywhere, Louisiana has an even more disproportionate share of its thunderstorms as single-cell thunderstorms than most places. As a result, even though Louisiana experiences frequent severe weather, the non-tropical severe weather that does occur is seldom of record-breaking proportions, such as the recent tornado outbreaks in Tuscaloosa, Alabama; Joplin, Missouri; and Moore, Oklahoma; though record-breaking severe weather outbreaks certainly are possible in Louisiana.

The life of a thunderstorm proceeds through three stages: the **developing** (or cumulus) stage, the **mature** stage, and the **dissipation** stage. Figure 2.2 depicts these three stages and indicates their major characteristics. During the **developing stage**, the unstable air mass is lifted as an *updraft* into the atmosphere. This sudden lift rapidly cools the moisture in the air mass, releasing latent heat as condensation and/or deposition occurs, and warming the surrounding environment, thus making it less dense than the surrounding air. This process intensifies the updraft and creates a localized lateral rush of air from all directions into the area beneath the thunderstorm to feed continued updrafts. At the **mature stage**, the rising air is accompanied by *downdrafts* caused by the shear of falling rain (if melted completely), or hail, freezing rain, sleet, or snow (if not melted completely). The **dissipation stage** is characterized by the dominating presence of the downdraft as the hot surface that gave the updrafts their buoyancy is cooled by precipitation. During the dissipation stage, the moisture in the air mass largely empties out.

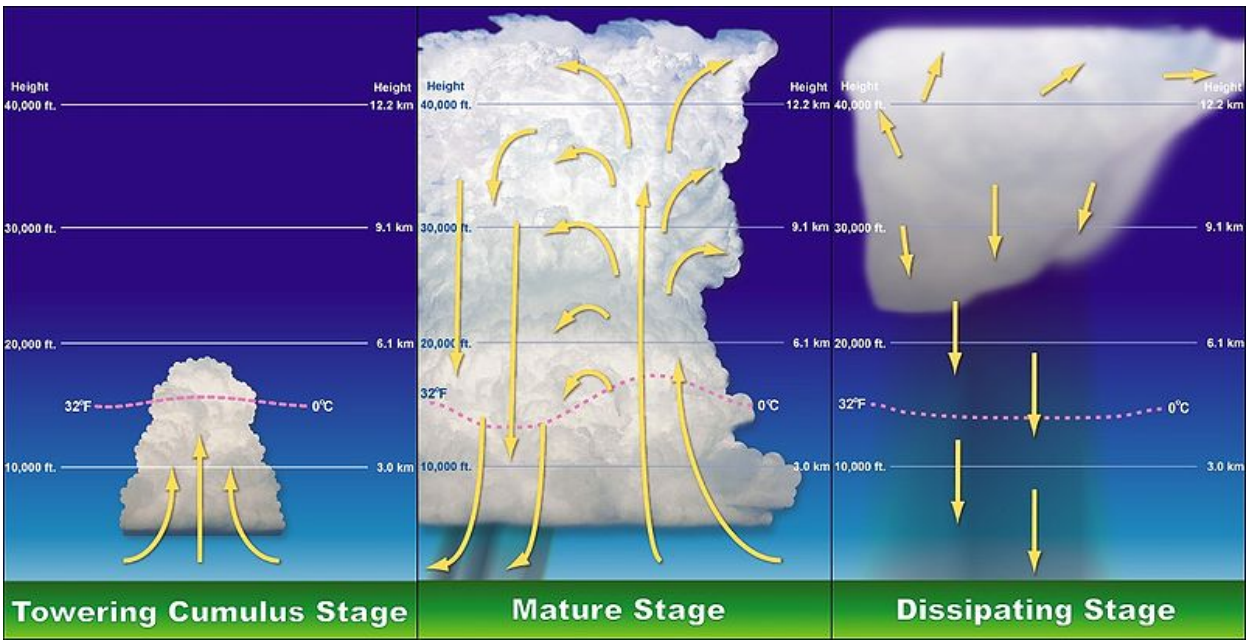


Figure 2.2. Figure illustrating the three stages of a basic thunderstorm (map from Vega, Grymes, and Rohli; source: NOAA).

THUNDERSTORM PROFILE

A variety of hazards might be produced by thunderstorms, including lightning, hail, tornadoes or waterspouts, flash floods, and high-speed winds called *downbursts*. Nevertheless, given all of these criteria, NOAA characterizes a thunderstorm as *severe* when it produces one or more of the following:

- **hail** of 1 in. in diameter or larger
- **wind gusts** to 58 mph or greater
- one or more **tornadoes**

Lightning and heavy rain can be devastating, but their ubiquitous presence in thunderstorms precludes their use in *distinguishing* among types of thunderstorms. For the purpose of profiling this hazard, this plan focuses on three hazards that occur in thunderstorms: hail, high wind, and lightning. These hazards are defined below and each given a risk assessment in the Thunderstorm Risk Assessment. Flooding and tornadoes will be considered as separate hazards.

Hailstorms are severe thunderstorms in which balls or chunks of ice fall along with rain. Hail develops in the upper atmosphere initially as ice crystals that are bounced about by high-velocity updraft winds. The ice crystals grow through deposition of water vapor onto their surface, fall partially to a level in the cloud where the temperature exceeds the freezing point, melt partially, get caught in another updraft whereupon re-freezing and deposition grows another concentric layer of ice, and fall after developing enough weight, sometimes after

several trips up and down the cloud. The size of hailstones varies depending on the severity and size of the thunderstorm. Higher surface temperatures generally mean stronger updrafts, which allows more massive hailstones to be supported by updrafts, leaving them suspended longer. This longer time means larger hailstone sizes. Table 2.10 displays a spectrum of hailstone diameters and their everyday equivalents.

Because of this cycle, hailstorms generally occur more frequently during the late spring and early summer—a period of extreme variation between ground surface temperatures and upper atmospheric temperatures. Hailstorms can cause widespread damage to homes and other structures, automobiles, and crops. While the damage to individual structures or vehicles is often minor, the cumulative cost to communities, especially across large metropolitan areas, can be quite significant. Hailstorms can also be devastating to crops. Thus, the severity of hailstorms depends on the size of the hailstones, the length of time the storm lasts, and where it occurs.

Table 2.10. Spectrum of hailstone diameters and their everyday description (source: NWS).

Spectrum of Hailstone Diameters	
Hail Diameter Size	Description
1/4"	Pea
1/2"	Plain M&M
3/4"	Penny
7/8"	Nickel
1" **(severe)**	Quarter
1 1/4"	Half Dollar
1 1/2"	Ping Pong Ball / Walnut
1 3/4"	Golf Ball
2"	Hen Egg / Lime
2 1/2"	Tennis Ball
2 3/4"	Baseball
3"	Teacup / Large Apple
4"	Softball
4 1/2"	Grapefruit
4 3/4"- 5"	Computer CD-DVD

In general, high winds can occur in a number of different ways, within and without thunderstorms. FEMA distinguishes these as shown in Table 2.11.

The only high winds of present concern are **thunderstorm winds** and **downbursts**. Straight-line winds are common but are a relatively insignificant hazard (on land) compared to other high winds. Downslope winds are common but relatively insignificant in the mountainous areas where they occur. Nor'easters are cyclonic events that have at most a peripheral effect on Louisiana, and none associated with high winds. Winds associated with hurricanes and

tornadoes will be considered in their respective sections. Table 2.12 presents the Beaufort Wind Scale, first developed in 1805 by Sir Francis Beaufort, which aids in determining relative force and wind speed based on the appearance of wind effects.

Map 2.31 reveals that Louisiana is located mainly in two distinct FEMA Wind Zones: Zones III and IV. Zone III (with peak winds up to 200 mph) includes southern Louisiana and the other hurricane-susceptible regions of the country. Northern Louisiana is in Zone IV, described by an area of the United States that can experience sustained winds of up to 250 mph. This area is highly susceptible to tornadoes.

Louisiana's wind-zone location indicates the severity that such storms can produce. Major damage can occur especially when downdrafts become constricted during the dissipation phase of a thunderstorm.[xxx] Constriction of a downdraft increases pressure within the storm by preventing any pressure release outside the system. Such downbursts can cause damage that is similar to a tornado, even leading to some classification confusion between the two when damage due to a thunderstorm is assessed.

Table 2.11. High winds categorized by source, frequency, and duration (source: *Making Critical Facilities Safe from High Wind*, FEMA).

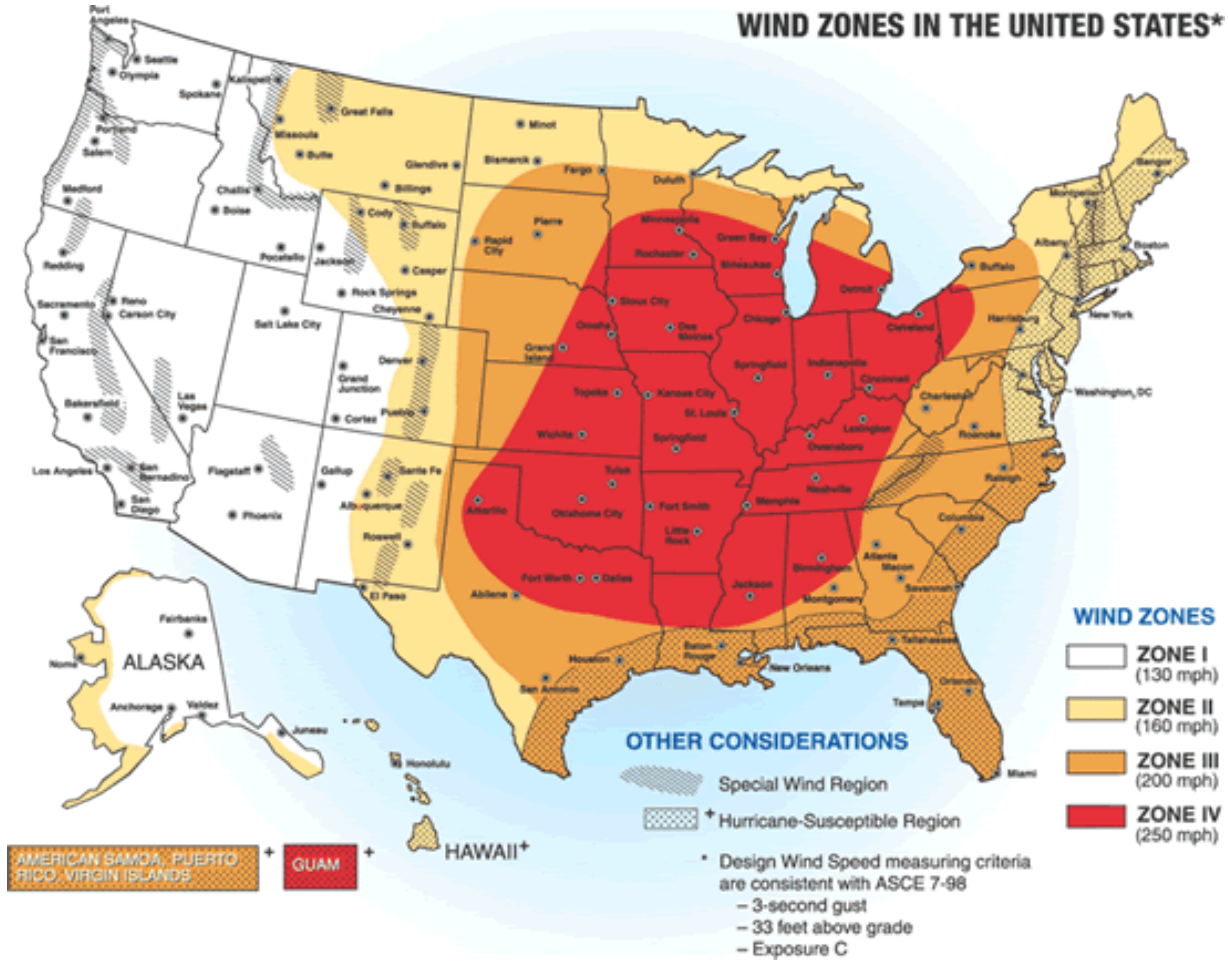
High Winds Categories			
High Wind Type	Description	Relative Frequency in Louisiana	Relative Maximum Duration in Louisiana
Straight-line Winds	Wind blowing in straight line; usually associated with intense low-pressure area	**High**	Few minutes–1 day
Downslope Winds	Wind blowing down the slope of a mountain; associated with temperature and pressure gradients	**N/A** (high in mountainous regions)	N/A (continuous in mountainous regions)
Thunderstorm Winds	Wind blowing due to thunderstorms, and thus associated with temperature and pressure gradients	**High** (especially in the spring and summer)	~Few minutes–several hours
Downbursts	Sudden wind blowing down due to downdraft in a thunderstorm; spreads out horizontally at the ground, possibly forming horizontal vortex rings around the downdraft	**Medium-to-High** (~5% of all thunderstorms)	~15–20 minutes
Northeaster (nor'easter)	Wind blowing due to cyclonic storm off the east coast of North America; associated with	**N/A** (medium along east	N/A (several days along

High Winds Categories			
High Wind Type	Description	Relative Frequency in Louisiana	Relative Maximum Duration in Louisiana
Winds	temperature and pressure gradients between the Atlantic and land	coast of U.S.)	coast)
Hurricane Winds	Wind blowing in spirals, converging with increasing speed toward eye; associated with temperature and pressure gradients between the Atlantic and Gulf and land	**Low-to-Medium**	Several days
Tornado Winds	Violently rotating column of air from base of a thunderstorm to the ground with rapidly decreasing winds at greater distances from center; associated with extreme temperature gradient	**Low-to-Medium**	Few minutes–few hours

Table 2.12. Beaufort Wind Scale, indicating relative destruction appearance on land for a spectrum of wind speeds (source: NOAA's SPC).[xxxi]

Beaufort Wind Scale			
Force	Wind (MPH)	WMO Classification	Appearance of Wind Effects On Land
			Calm, smoke rises vertically
1	*1-3*	Light Air	Smoke drift indicates wind direction, still wind vanes
2	*4-7*	Light Breeze	Wind felt on face, leaves rustle, vanes begin to move
3	*8-12*	Gentle Breeze	Leaves and small twigs constantly moving, light flags extended
4	*13-17*	Moderate Breeze	Dust, leaves, and loose paper lifted, small tree branches move
5	*18-24*	Fresh Breeze	Small trees in leaf begin to sway
6	*25-30*	Strong Breeze	Larger tree branches moving, whistling in wires
7	*31-38*	Near Gale	Whole trees moving, resistance felt walking against wind
8	*39-46*	Gale	Twigs breaking off trees, generally impedes progress
9	*47-54*	Strong Gale	Slight structural damage occurs, slate blows off roofs
10	*55-63*	Storm	Seldom experienced on land, trees broken or uprooted, "considerable structural damage"
11	*64-73*	Violent Storm	
12	*74+*	Hurricane	

Although major damage directly due to thunderstorm winds is relatively rare, minor damage is common and pervasive, and most noticeable when it contributes to power outages. These power outages can have major negative impacts, including health risks for those requiring electric medical equipment and/or air conditioning; increased tendency for traffic accidents; loss of revenue for businesses; increased vulnerability to fire; food spoilage; and other losses that might be sustained by a loss of power. Since much of Louisiana falls within FEMA's special hurricane zone, these wind speeds are specifically for the hurricane wind zones and do not necessarily relate to potential thunderstorm or tornado wind speeds.



Map 2.31. Wind zone map from FEMA.

The action of rising and descending air in a thunderstorm, and the presence of ice particles in high parts of clouds and liquid water in others, cause a separation of positively and negatively charged ions, with lightning resulting from the discharge of current between positive and negative charge areas. In only a few millionths of a second, the air near a lightning strike is heated to an estimated 50,000° F, a temperature much hotter than the surface of the Sun.

Thunder is the sound of air colliding after the very rapid expansion of the heated air near the lightning strike creates a momentary vacuum.

An average of 20 million cloud-to-ground flashes are detected annually in the continental United States, about half of which have more than one ground-strike point. Cloud-to-cloud flashes are estimated to occur nearly five to ten times more frequently than cloud-to-ground flashes.[xxxii] Given its energy and extent, lightning is one of the most frequent causes of death by natural hazard, along with extreme heat and flooding. Reportedly, around 100 deaths and 500 injuries occur annually due to lightning, though the number could be much higher since many lightning deaths and injuries probably go unreported as current travels through numerous other paths, including power lines, telephone lines, and electric appliances. Moreover, it often starts fires, which may cause death and injury not ultimately attributed to lightning. On a national scale, the Louisiana is second only to Florida in terms of "flash density"—the number of lightning flashes per area per year—and is 12th in the nation in terms of lightning fatalities per capita.[xxxiii] A map of the density of lightning strikes accompanies the Thunderstorm Risk Assessment section.

Thunderstorm Risk Assessment

Thunderstorms occur throughout Louisiana at all times of the year, although the types and severity of those storms vary greatly, depending on a wide variety of atmospheric conditions. Due to the high potential for significant personal injury and property damage for the state, and due to insufficient data to determine future likelihood, this hazard is included in the Risk Assessments and is addressed in the Mitigation Action Plan. For the purposes of hazard mitigation, this plan is considering the April 26, 2011, severe thunderstorm that affected 16 parishes in Louisiana as its bellwether for the largest likely extent of future damages from this hazard. The storm produced straight-line winds up to 111 mph and spawned multiple weak-to-moderate tornadoes. Hail was reported in a number of parishes, ranging up to 2.75 in. in diameter. In all, the storm resulted in 2 deaths, 2 injuries, and $16.6 million in damages (2013 USD).[xxxiv]

In assessing the state's vulnerability by jurisdiction, this Plan examines the hazards of hail, high winds, and lightning as parts of the thunderstorm category. Each hazard will still be given thorough risk assessment. Maps 2.32, 2.33, and 2.34 illustrate the jurisdictional probability of hail, high wind, and lightning (respectively).

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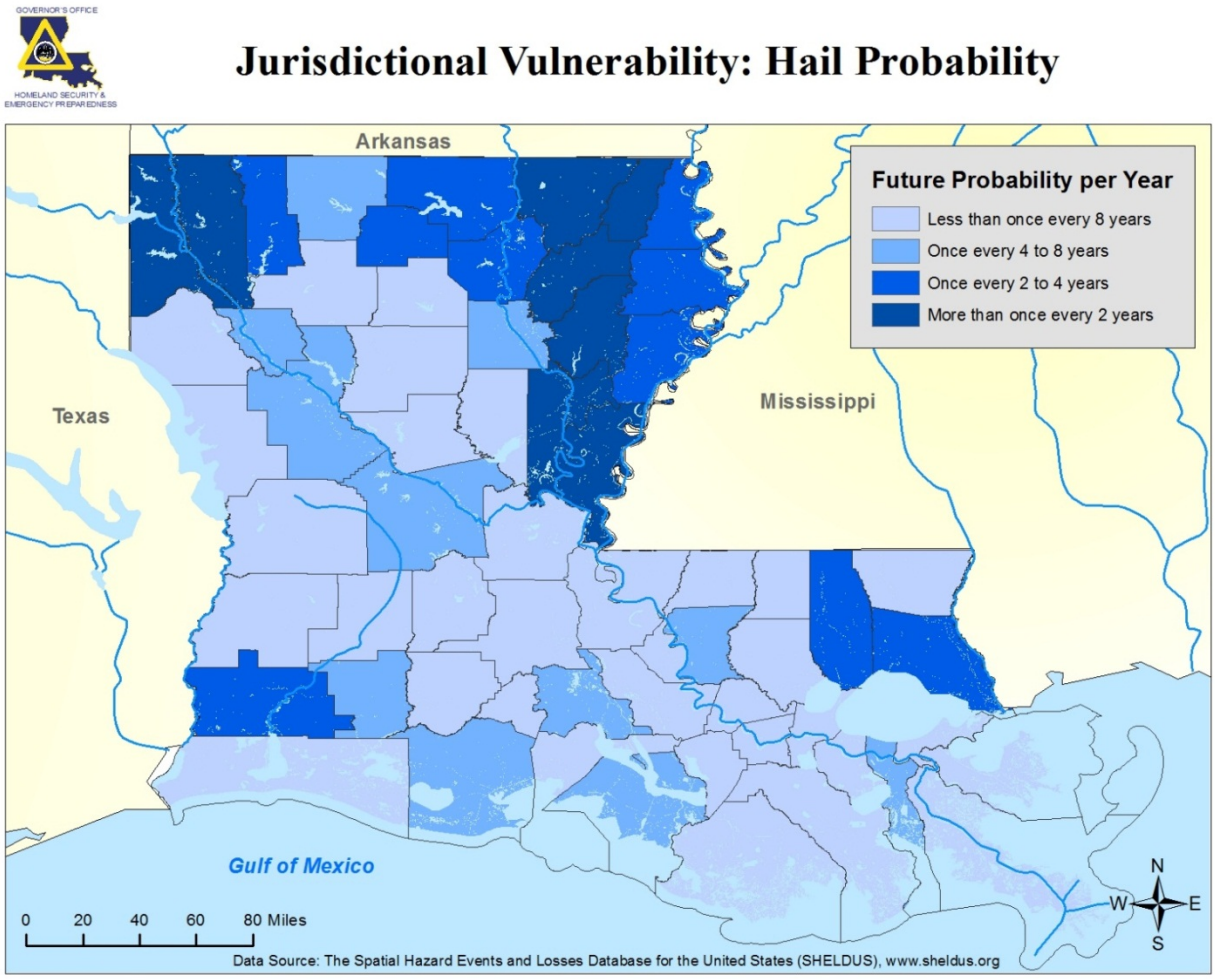

Map 2.32. Probability of hail in Louisiana by parish based on data from 1987–2012.

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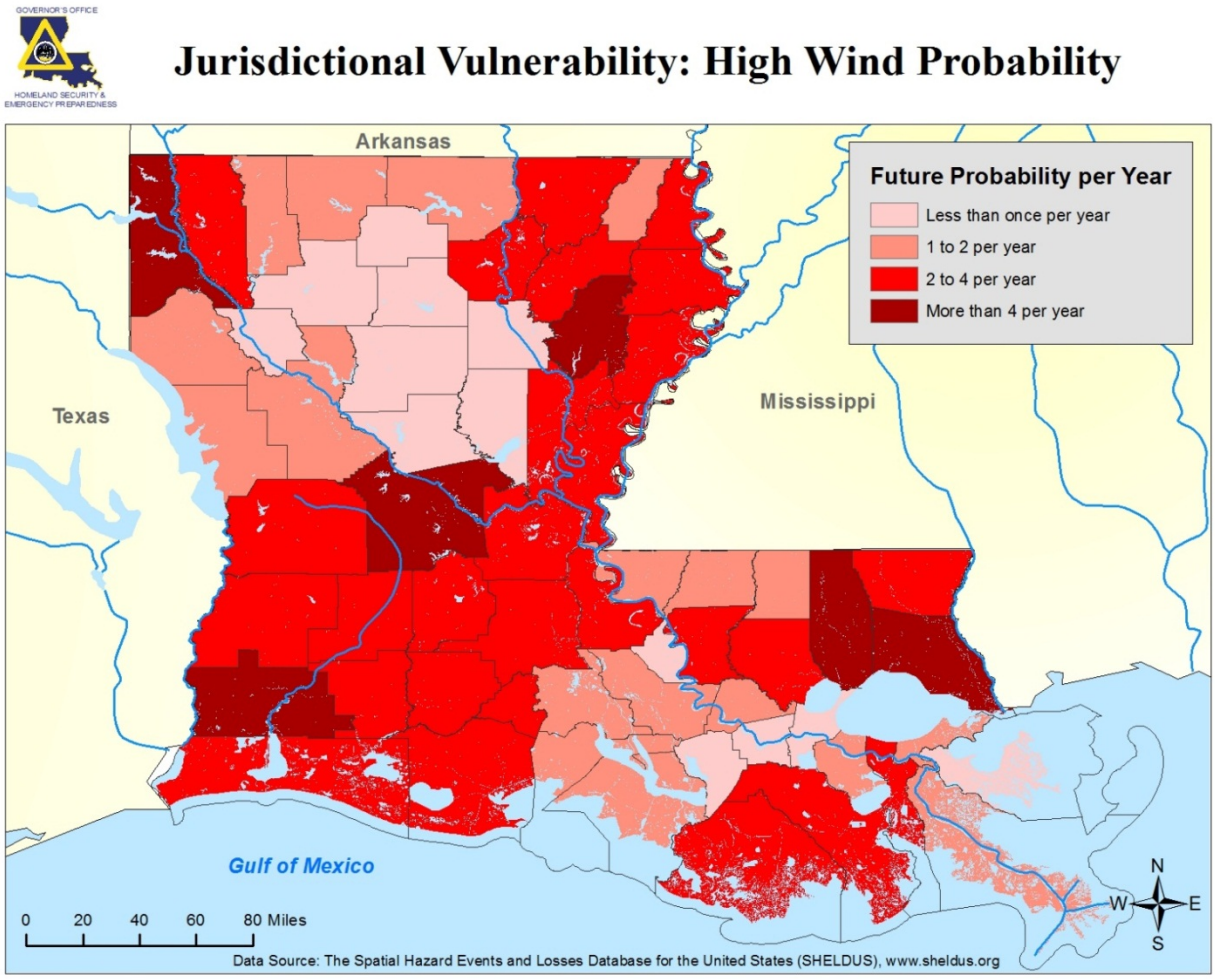

Map 2.33. Probability of high winds in Louisiana by parish based on data from 1987–2012.

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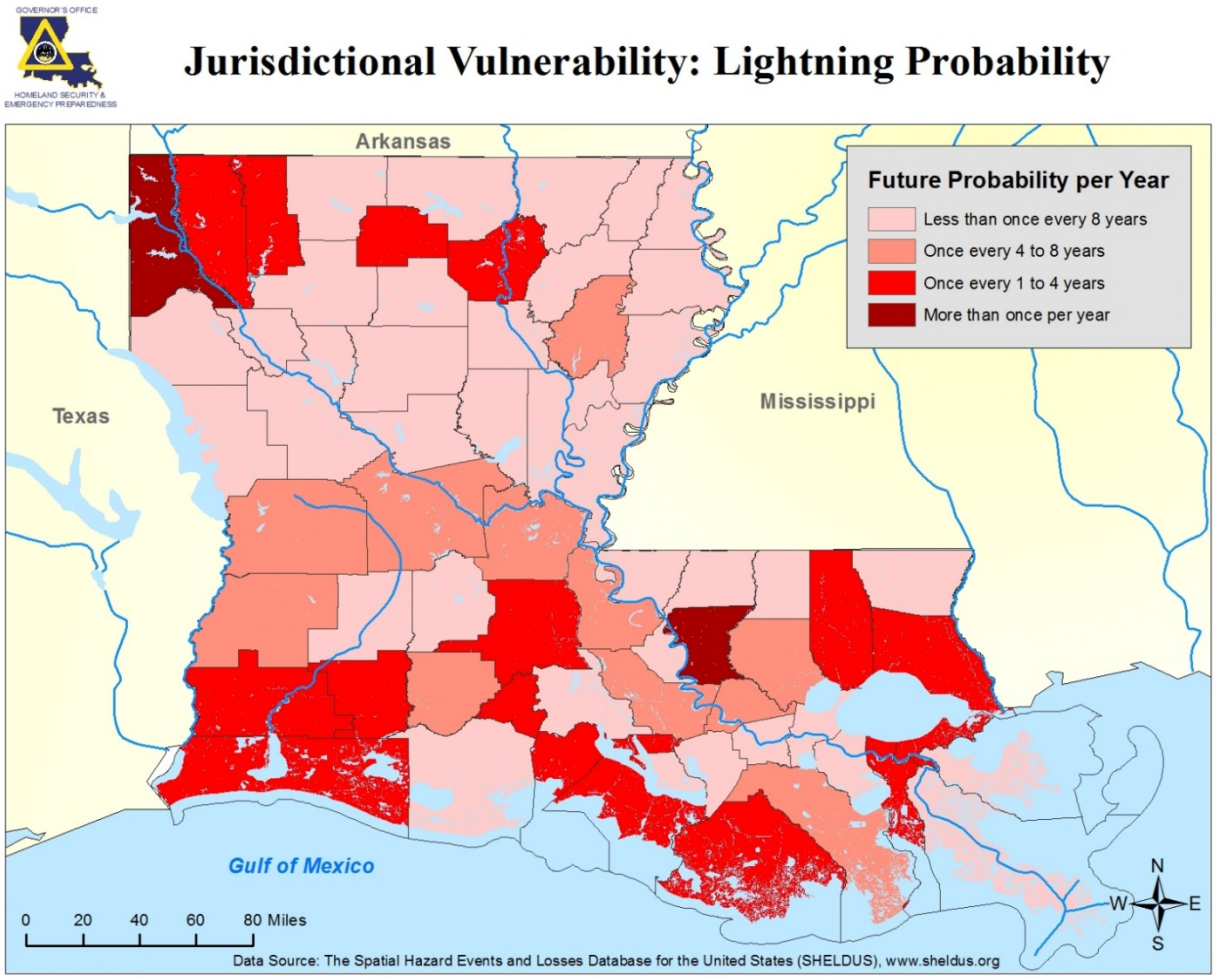

Map 2.34. Probability of lightning strikes in Louisiana by parish based on data from 1987–2012.

HAIL

Compared to other states, Louisiana has a moderate frequency of hailstorms. Between 1955 and 2009, Louisiana experienced a total of 4,469 recorded hailstorm events, with a maximum hail size of 4.5 in. These events vary widely in terms of damage. On May 12, 2007, 4-in. hail was reported in Sterlington (Ouachita Parish), although the event did not cause any significant damage or injuries. On March 27, 2009, in Reeves (Allen Parish), hail was again measured at 4 in. in diameter, causing $10,000 in property damages. On April 22, 1995, however, the Shreveport metropolitan area experienced a hailstorm with hailstones as large as 4.5 in. in diameter, resulting in $50 million in property damages.

According to the University of Louisiana at Monroe, and based on past occurrence of hailstorm events, Louisiana parishes experience between 2 and 29 hail events per year per 1000 mi^2.[xxxv] Map 2.35 illustrates the relative density of hail events based on various diameters of hailstones.

The map suggests a high occurrence of hailstorm events near Shreveport (81% of reported events), but the reason for this anomaly is uncertain. This uncertainty renders any estimates of probability based upon the data suspect. Better data collection on hailstorms would significantly improve the probability of mitigation of those storms.

Hail seems to be most probable and destructive among the northern parishes, particularly on the western and eastern sides of the state. Still, it can affect the whole state and has had a notable impact on the coastal parish of Vermilion. Maps 2.36, 2.37, 2.38, and 2.39 indicate the total events, economic damage, injuries, and fatalities (which were none) associated with hailstorms. Bossier Parish is at high risk (greater than 2.0 composite risk score) to hail events and has experienced a significant population increase of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability of Bossier parish to hail has increased. No parishes that are at high risk to hail experienced a significant population decrease of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability to hail has not decreased measurably in any part of the state.

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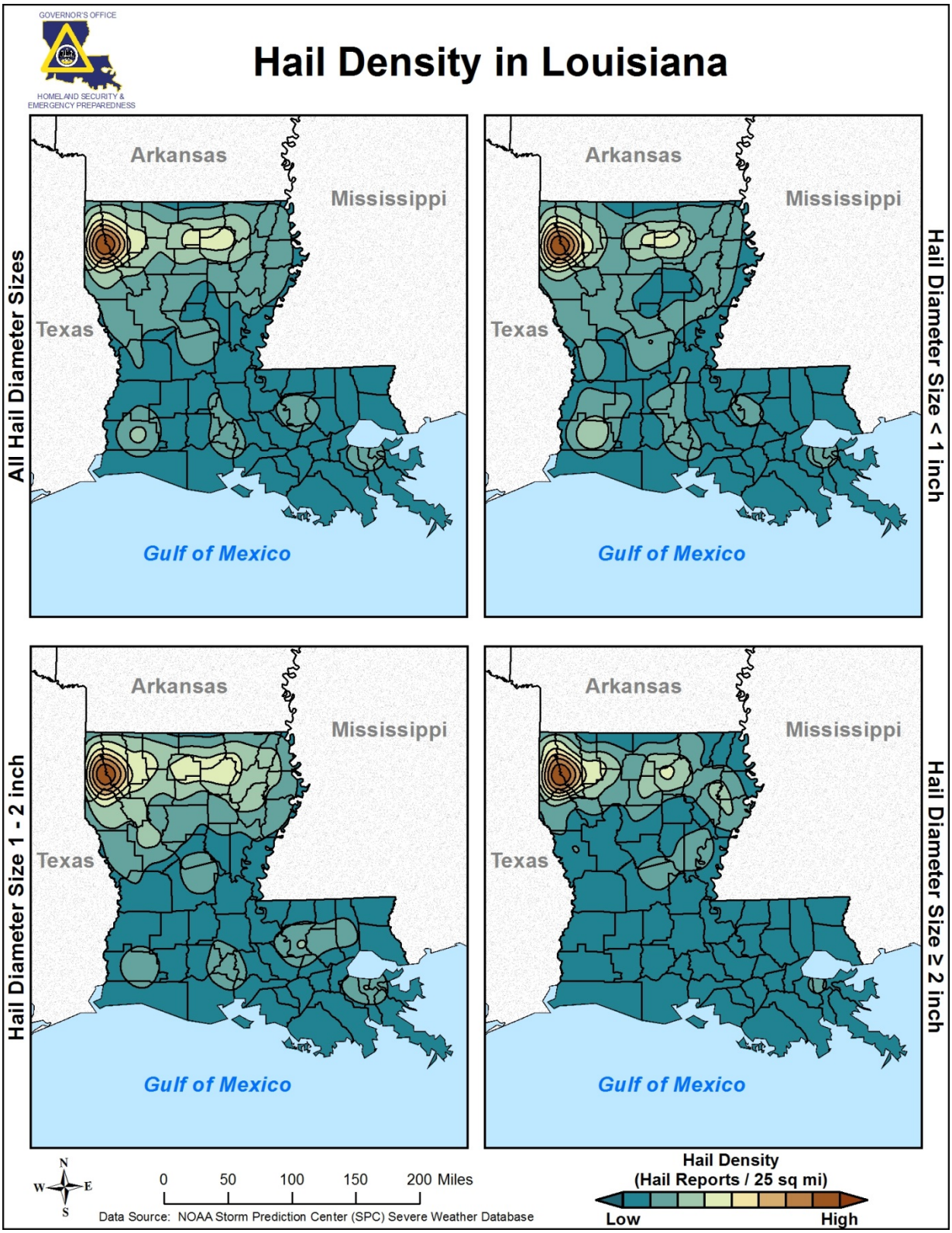
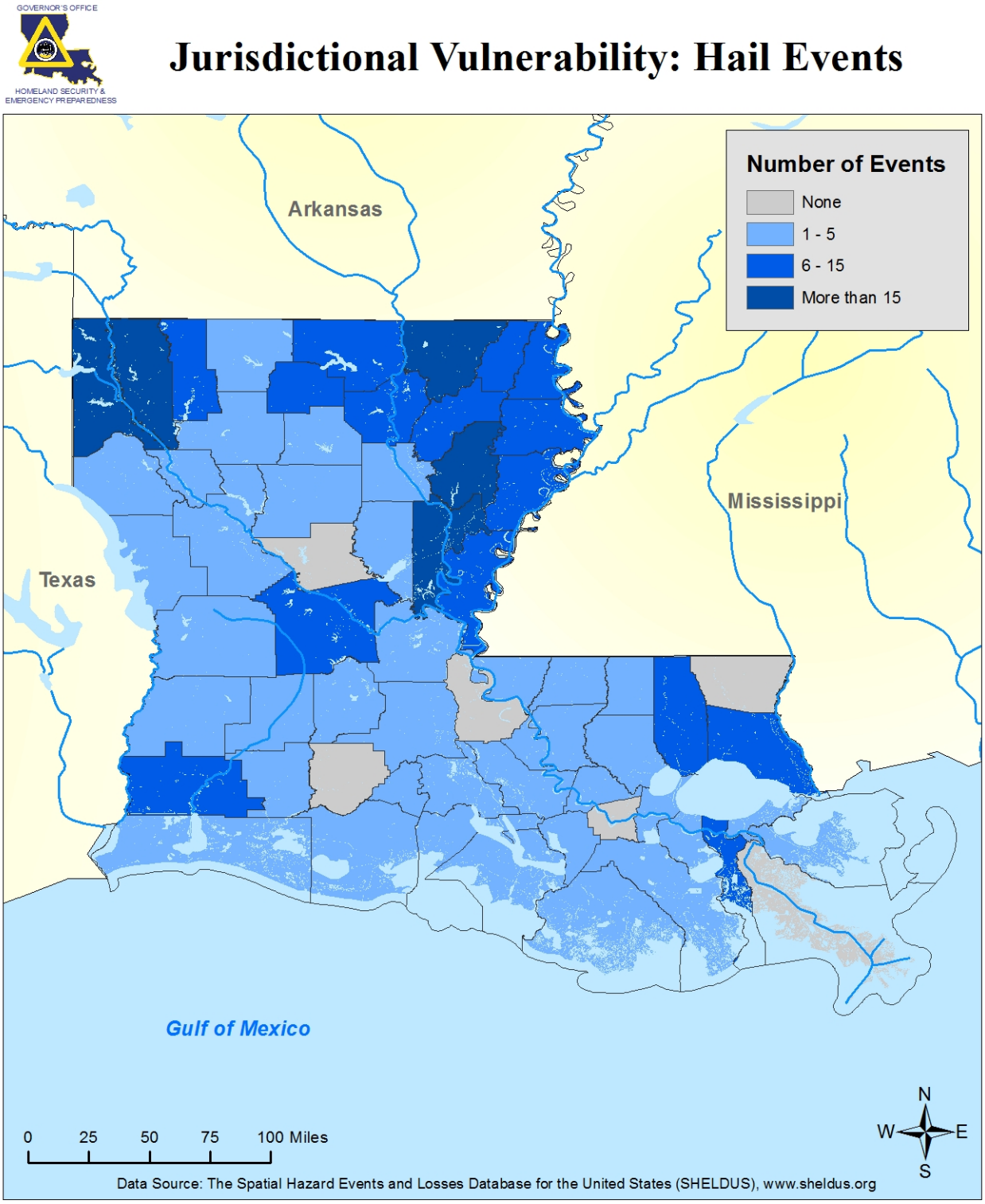
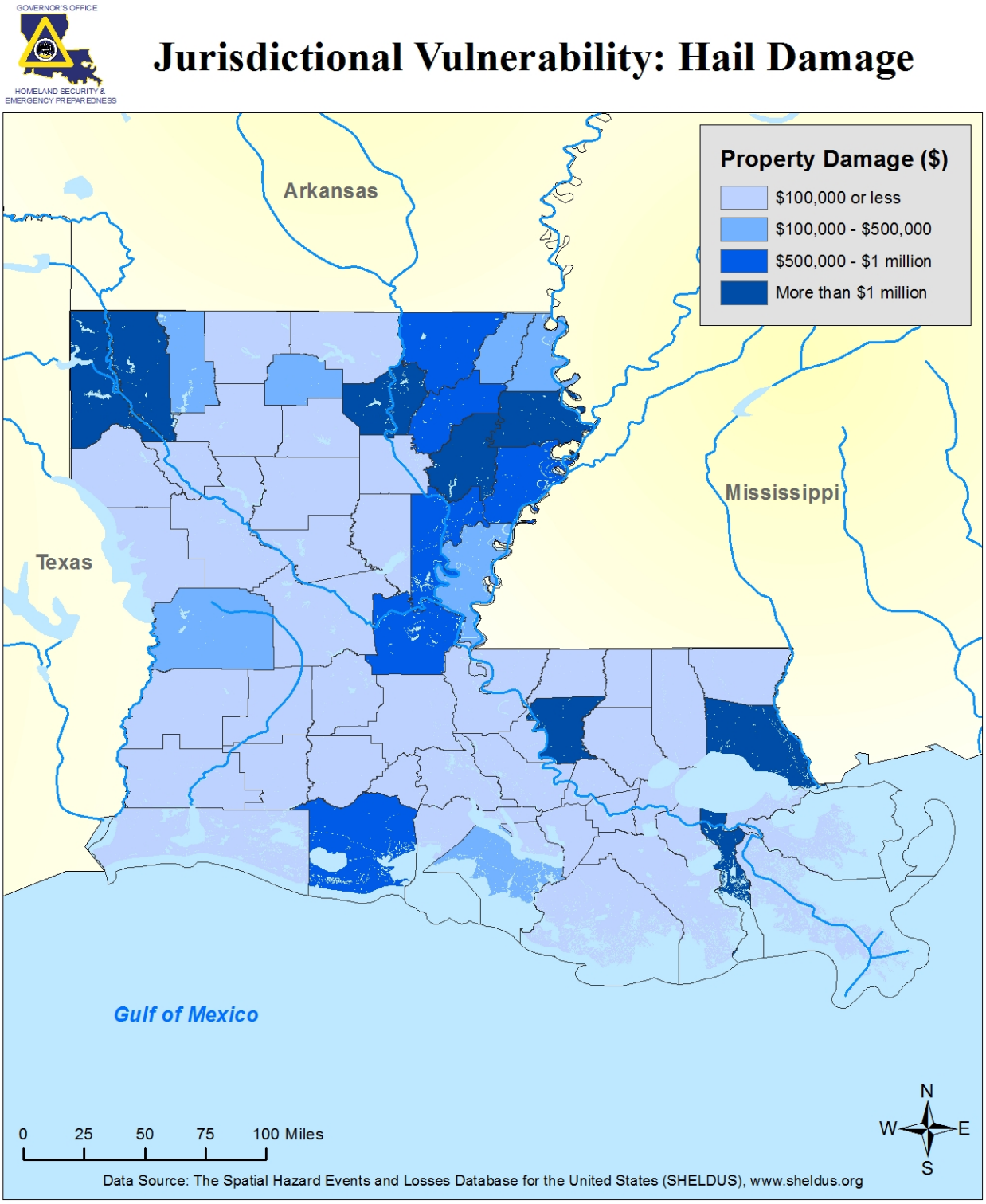


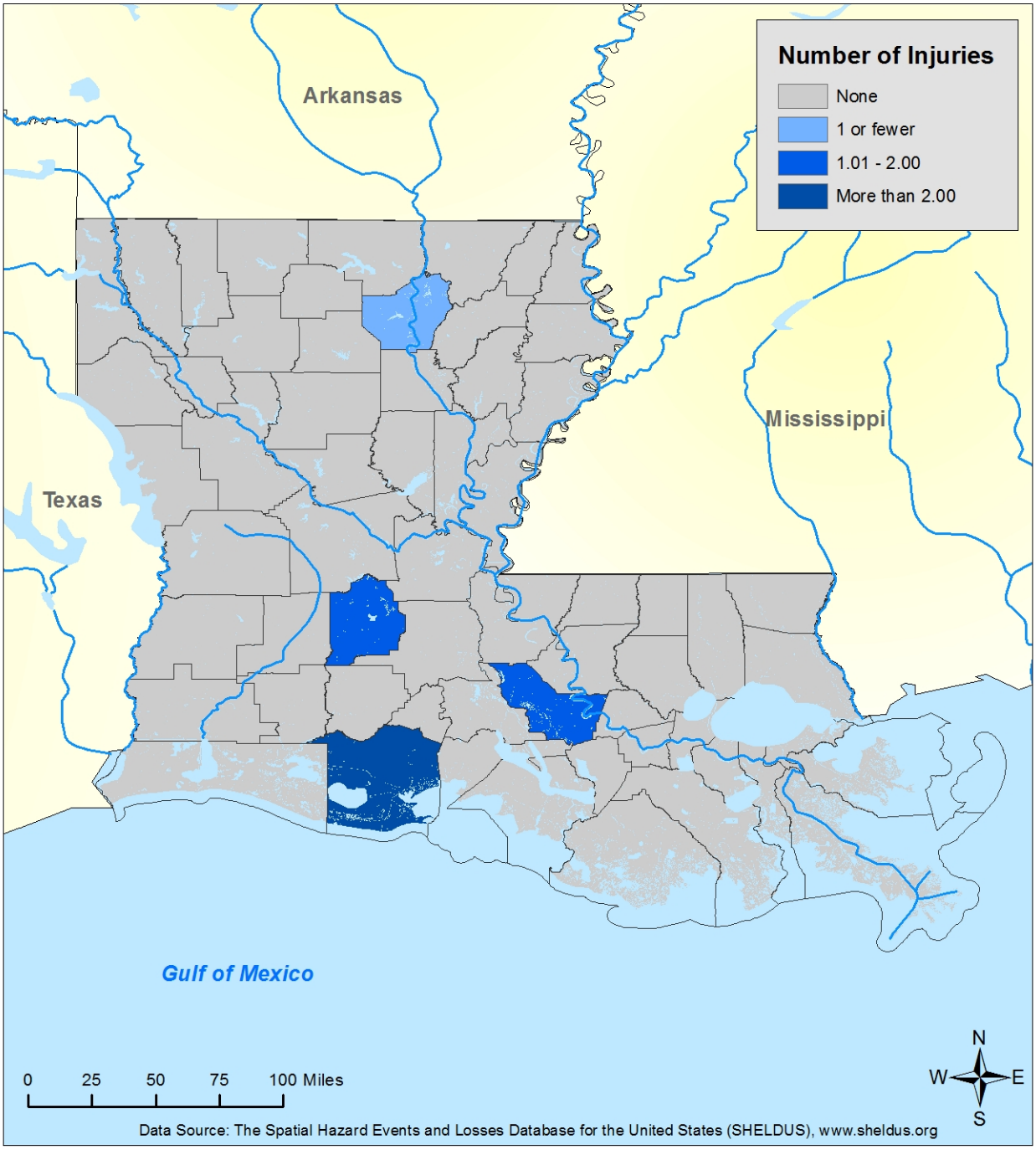
Map 2.35. Hail density across Louisiana for hail of (a) all diameters (top left), (b) < 1 in. in diameter (top right), (c) 1-2 in. in diameter (bottom left), (d) and ≥ 2 in. in diameter (bottom right).



Map 2.36. Louisiana jurisdictional vulnerability for hail events based on data from 1987–2012.



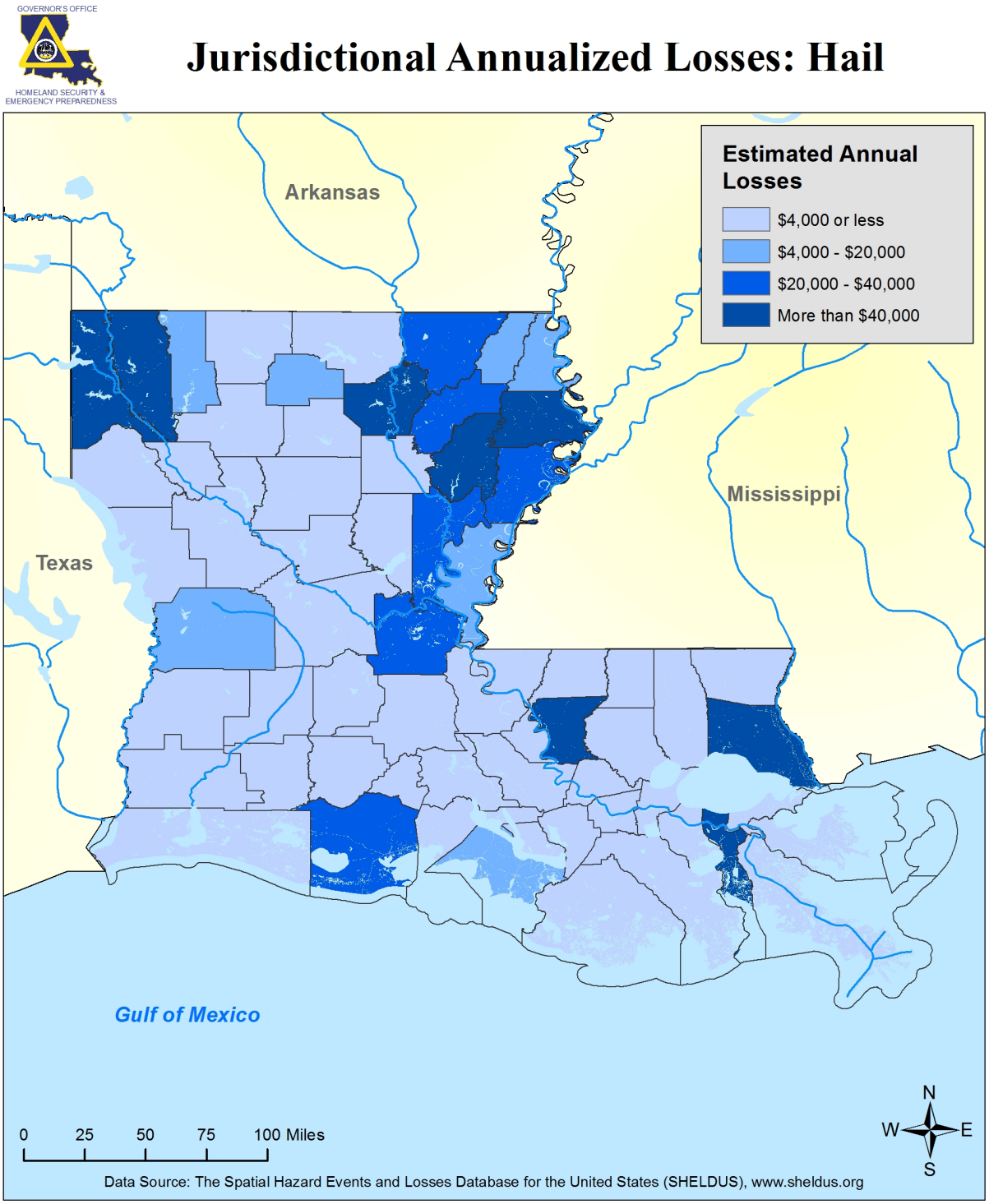
Map 2.37. Louisiana jurisdictional vulnerability for damage from hail based on data from 1987–2012.



Map 2.38. Louisiana jurisdictional vulnerability for injury from hail based on data from 1987–2012.

Map 2.39. Louisiana jurisdictional vulnerability for fatalities from hail based on data from 1987–2012.

To determine potential loss estimates from hail, the available historical loss data was annualized to determine future loss potential (see Map 2.40). As shown, parishes with the largest populations are predicted to have the highest potential annualized losses.



Map 2.40. Jurisdictional annualized loss due to hail.

Earlier, Map 2.32 suggested the future likelihood of hailstorms in Louisiana, which is somewhat low. At most, records from the northern parishes indicate that hailstorm events may happen more than once every two years, while the rest of Louisiana might expect it no more than once every two to four years, and likely much less often. The top 10 state assets damaged by hail are profiled at the end of the high winds subsection.

High Winds

Maps 2.41, 2.42, 2.43, 2.44 show the number of high wind events along with the economic damage, injuries, and fatalities associated with them. Since severe thunderstorms affect the whole state, the effects of dangerous high winds have been extensive, although such effects have been comparatively minimal in the central parishes between the Red River and the Ouachita River. Similarly, as Map 2.33 indicated earlier, the future likelihood of high wind events is quite high, but is at its lowest (one per year) in those central parishes. The parishes at high risk (greater than 2.0 composite risk score) to high wind events (Washington, Calcasieu, and East Baton Rouge) did not experience significant population increases or decreases of more than 10% since 2000 (see Map 2.3). As a result, vulnerability to high wind has not changed measurably across the state.

Map 2.45 shows Louisiana's state assets that have had repetitive claims for both hail and high wind events. Table 2.13 lists the top 10 wind and hail-damaged state asset properties that were paid toward loss claims. State-owned critical facilities located in areas affected by hail and high winds are of the following types: hospitals, shelters, Emergency Operation Centers, data processing centers, and state police troop offices.

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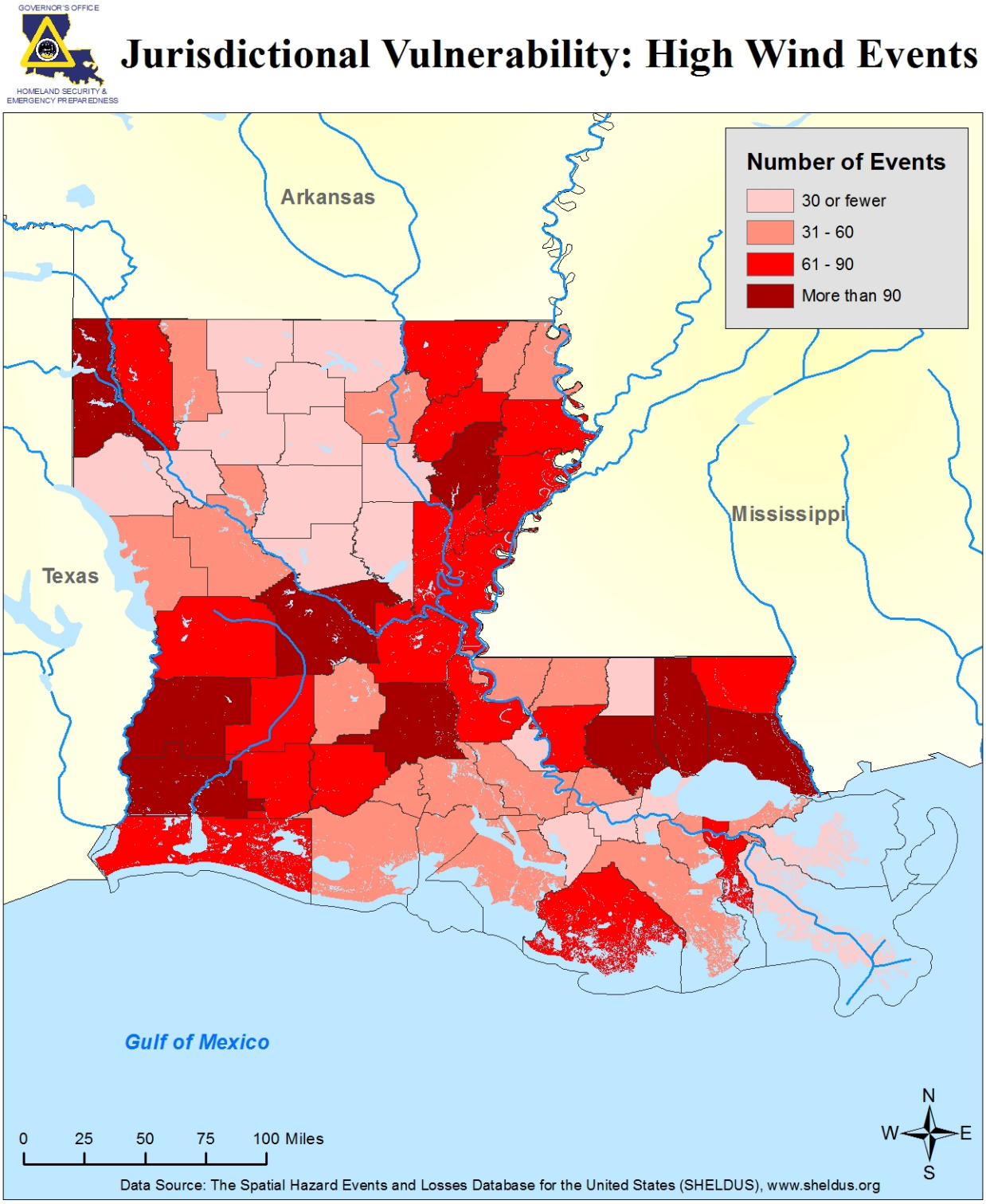
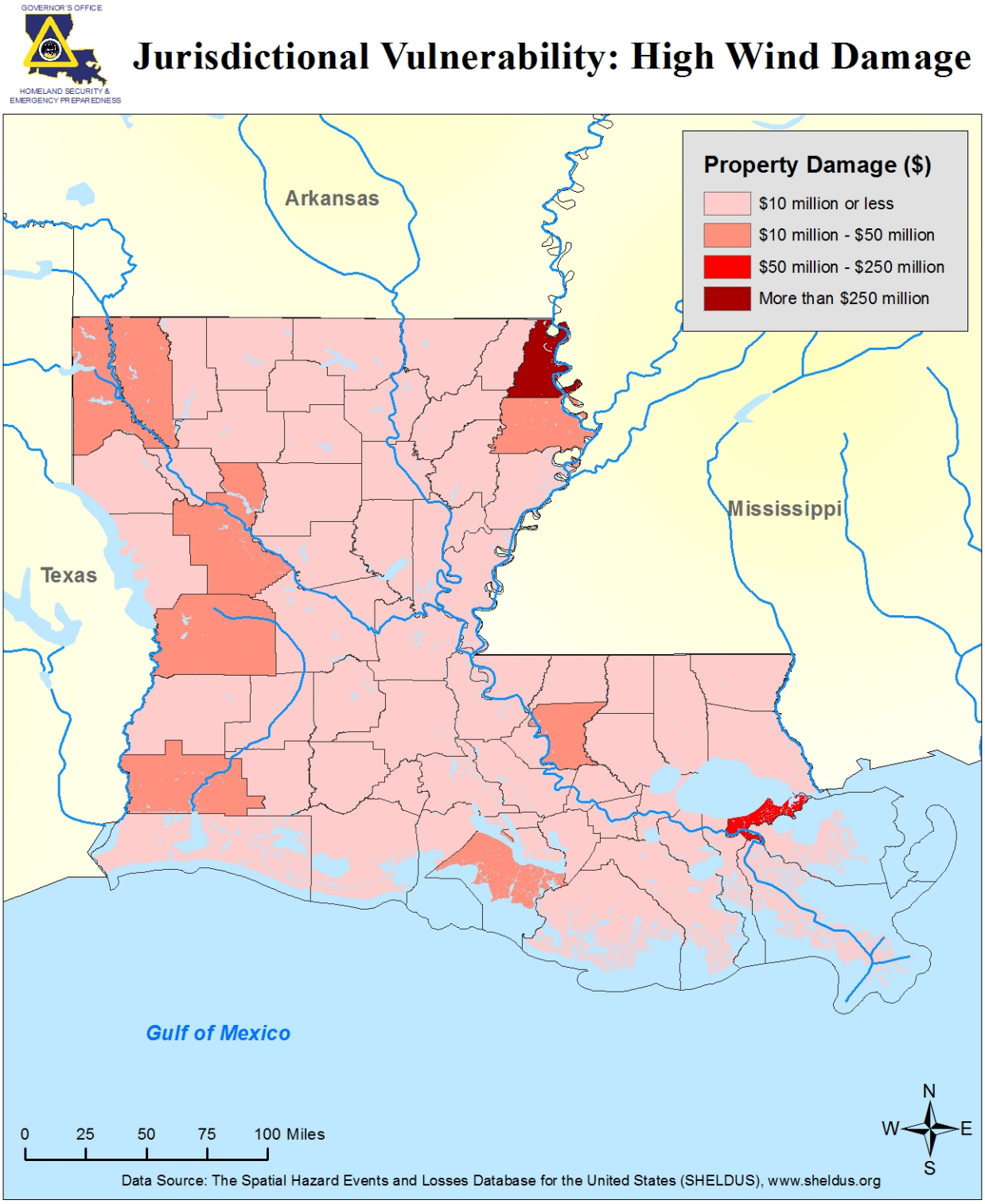
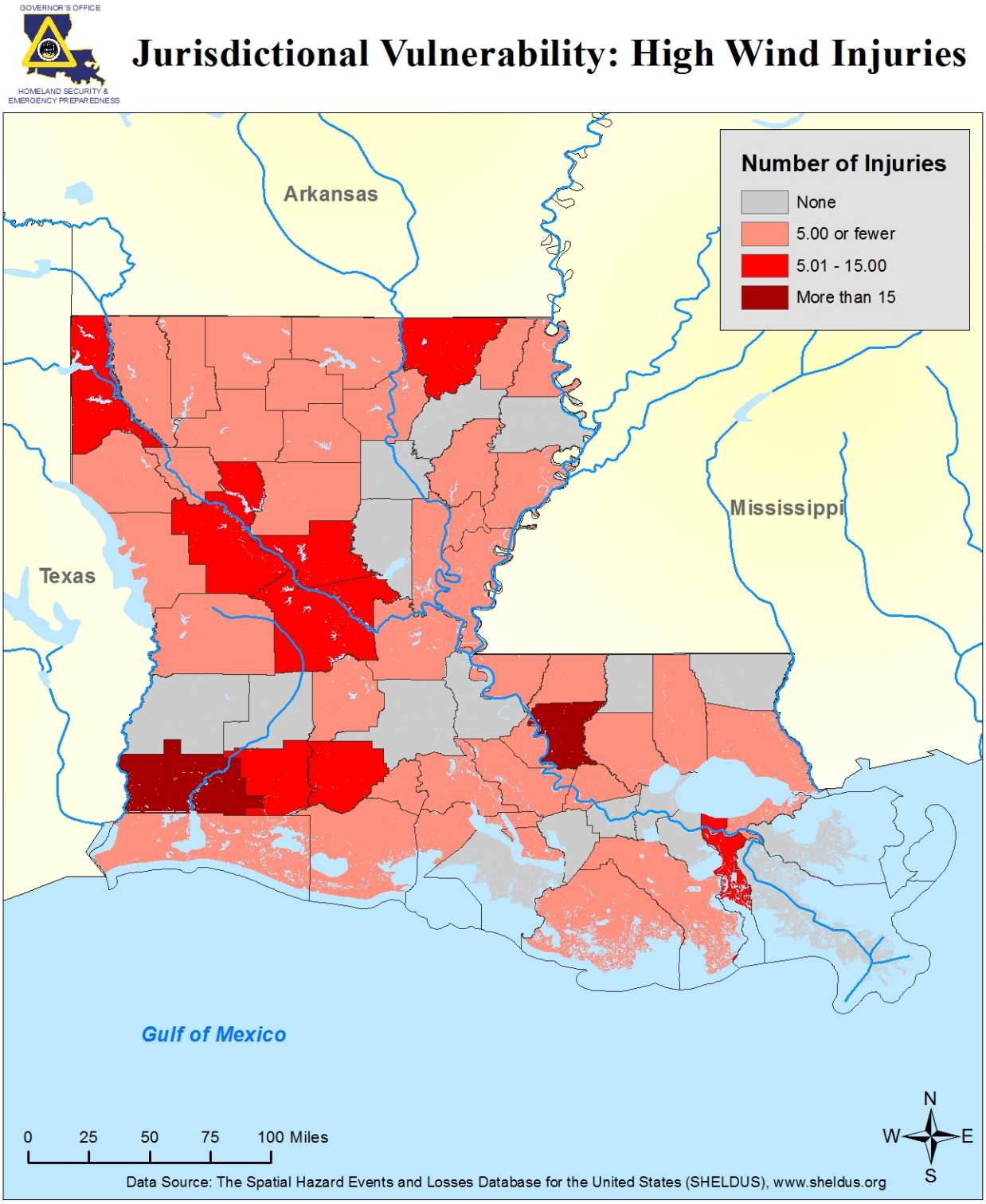


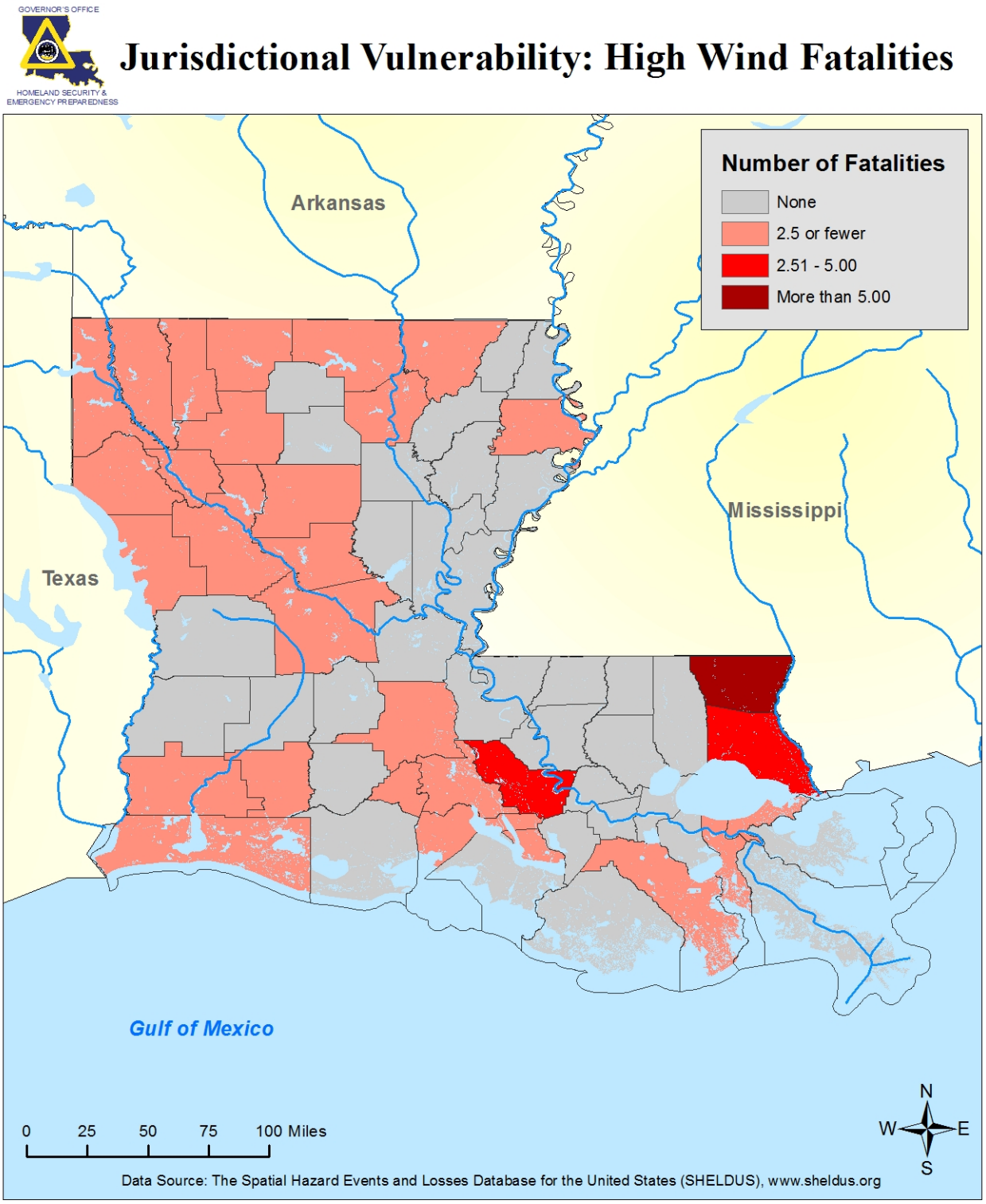
Map 2.41. Louisiana jurisdictional vulnerability for high wind events based on data from 1987–2012.



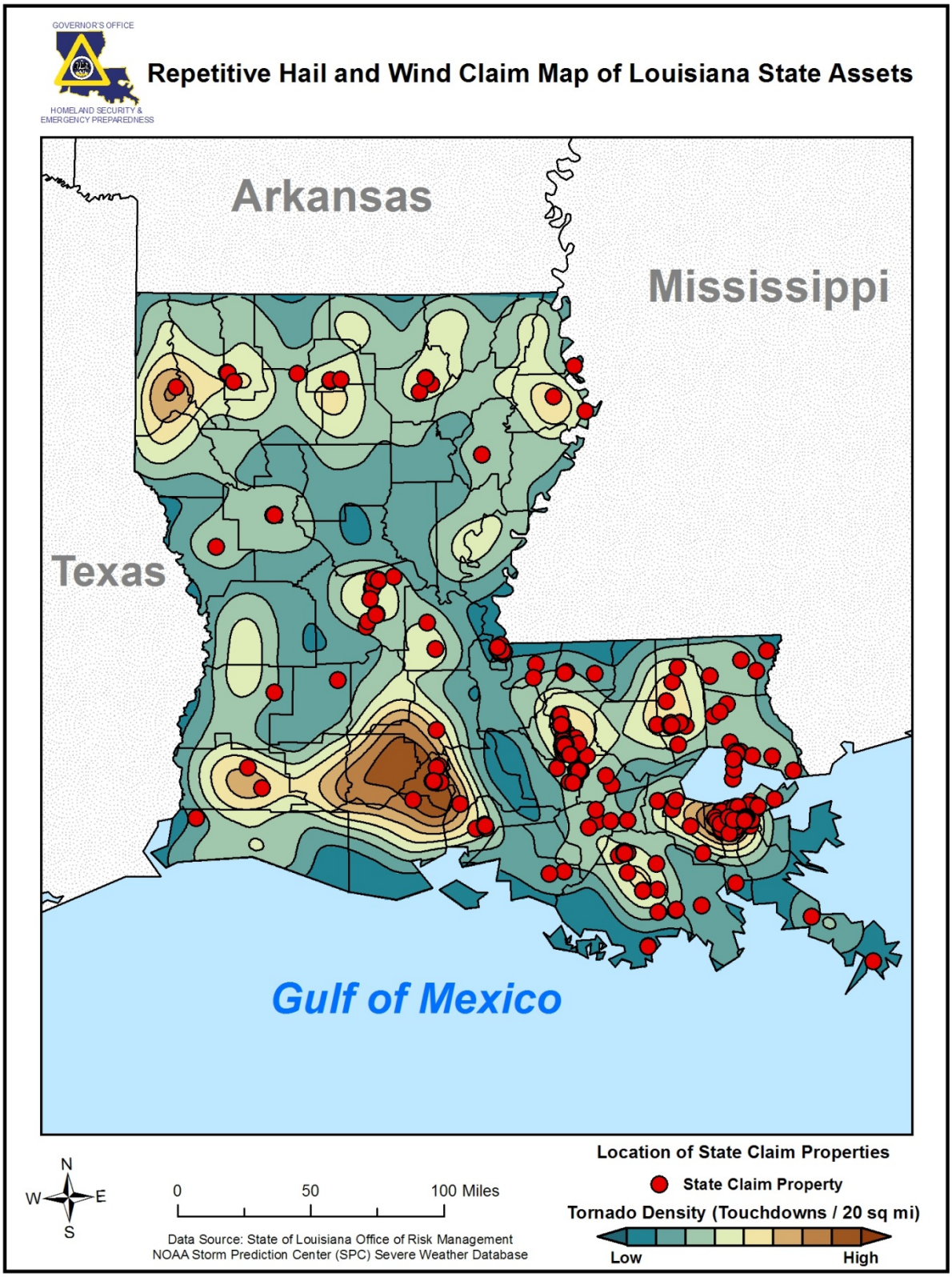
Map 2.42. Louisiana jurisdictional vulnerability for damage from high winds based on data from 1987–2012.



Map 2.43. Louisiana jurisdictional vulnerability for injuries from high winds based on data from 1987–2012.



Map 2.44. Louisiana jurisdictional vulnerability for fatalities from high winds based on data from 1987–2012.



Map 2.45. State assets with repetitive claims for hail and wind damage.

Table 2.13. Top 10 paid claims for wind- and hail-damaged state assets (source: Louisiana Office of Risk Management).

Top 10 Paid Claims for Wind- and Hail-Damaged State Assets				
Building ID	Building Name	Location	Net Paid	Total Number of Claims (Wind/Hail)
L13850	Pride Hall - Southeastern University	Hammond	$84,549	1
L14162	Central Mechanical Plant - Baton Rouge Community College	Baton Rouge	$127,760	1
L14648	Albert Wicker Elementary	New Orleans	$102,222	1
S00519	The Louisiana Superdome	New Orleans	$91,598	1
S12595	Jefferson Baseball Stadium	Metairie	$321,196	1
S12799	LaSalle Building	Baton Rouge	$37,204	1
S12851	New Orleans Center for the Creative Arts - Building F	New Orleans	$45,791	1
S12852	New Orleans Center for the Creative Arts - Building E	New Orleans	$40,243	1
S13487	State Printing and Forms Management	Baton Rouge	$86,830	1
S13692	Visitor Processing Center - LA State Penitentiary	Angola	$443,340	1

To determine potential loss estimates from high wind, the available historical loss data was annualized to determine future loss potential (see Map 2.46). As shown, parishes with the largest populations are predicted to have the highest potential annualized losses.

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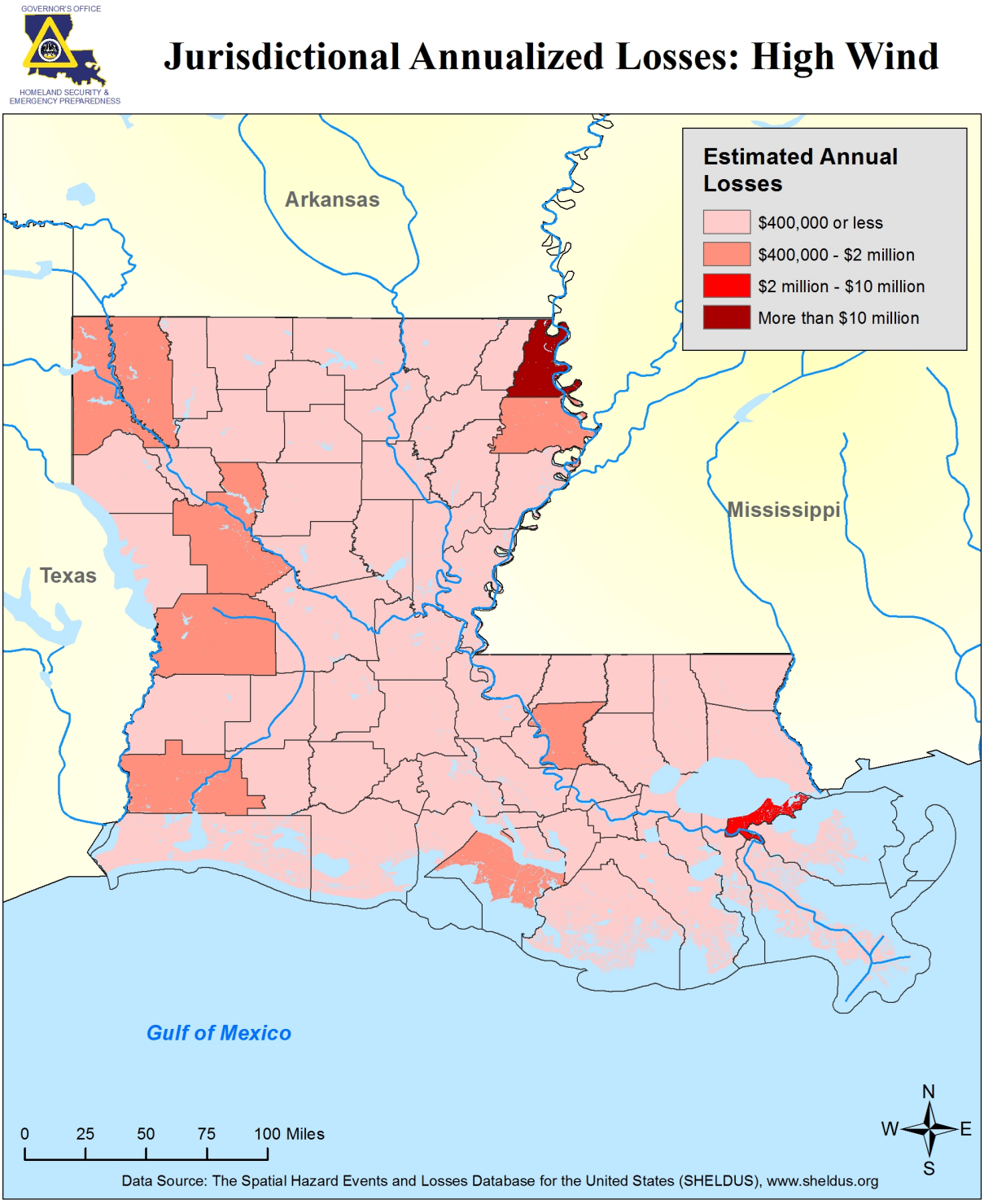

Map 2.46. Jurisdictional annualized loss due to high wind.

LIGHTNING

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, more than half of lightning deaths occur *after* a thunderstorm has passed. The lightning threat diminishes after the last sound of thunder, but still may persist for more than 30 minutes. When thunderstorms are in the area, but not overhead, the lightning threat can exist when skies are clear. Lightning has been known to strike more than ten mi. from the storm in an area with clear sky above.

Due to the frequency and geographic scope of lightning strikes in Louisiana, the probability of future events is 100%. Lightning strikes most frequently between June and August, with 70% of all lightning fatalities occurring in those months. July alone contains 35% of all fatalities. Most deaths and injuries from lightning occur in the afternoon, and mostly on the weekend. This is the case because many more people are spending time outside, involved in leisure activities that make them vulnerable to lightning strikes.[xxxvi] Map 2.47 shows the density of lightning flashes (per mi^2 per year) in Louisiana.

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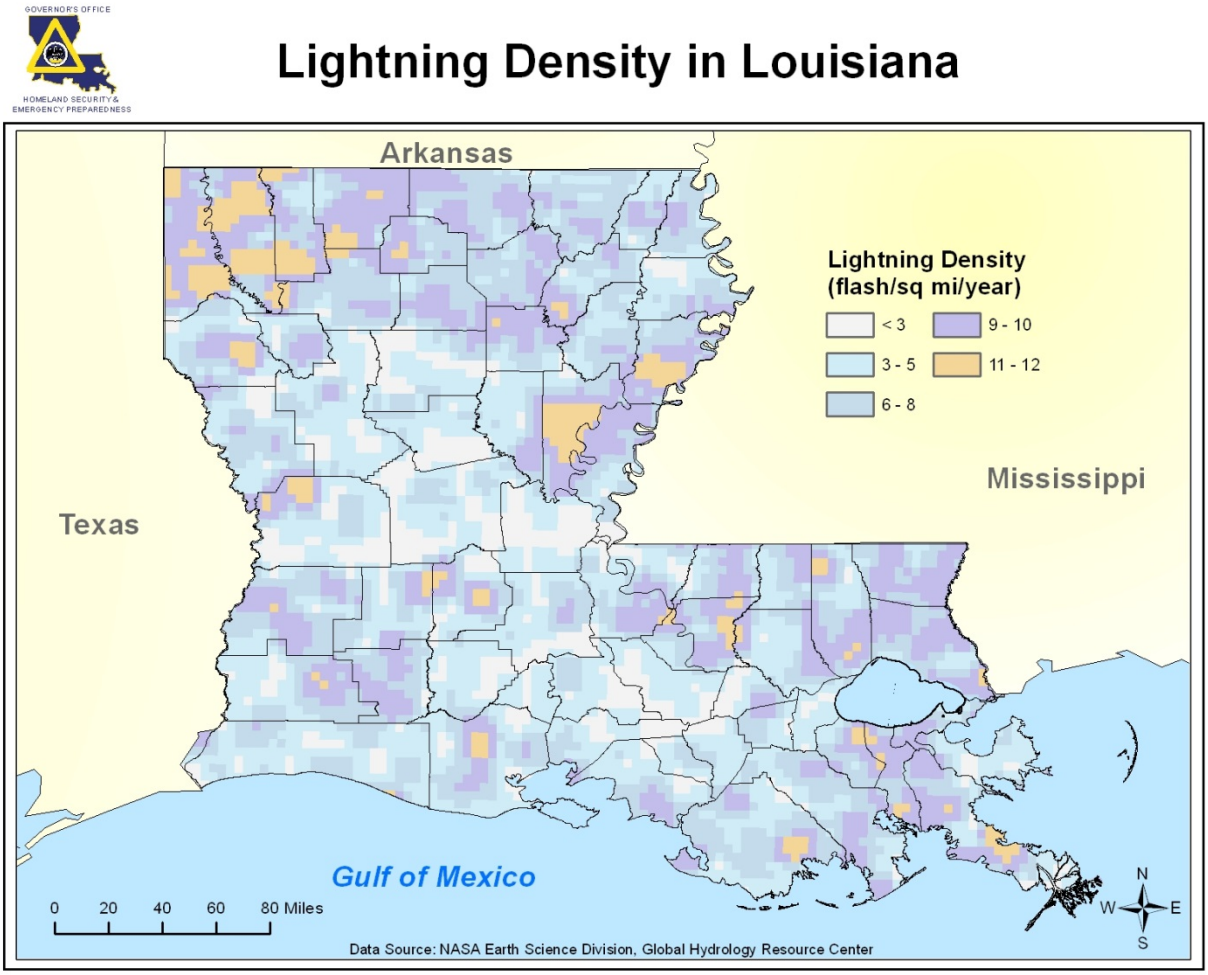
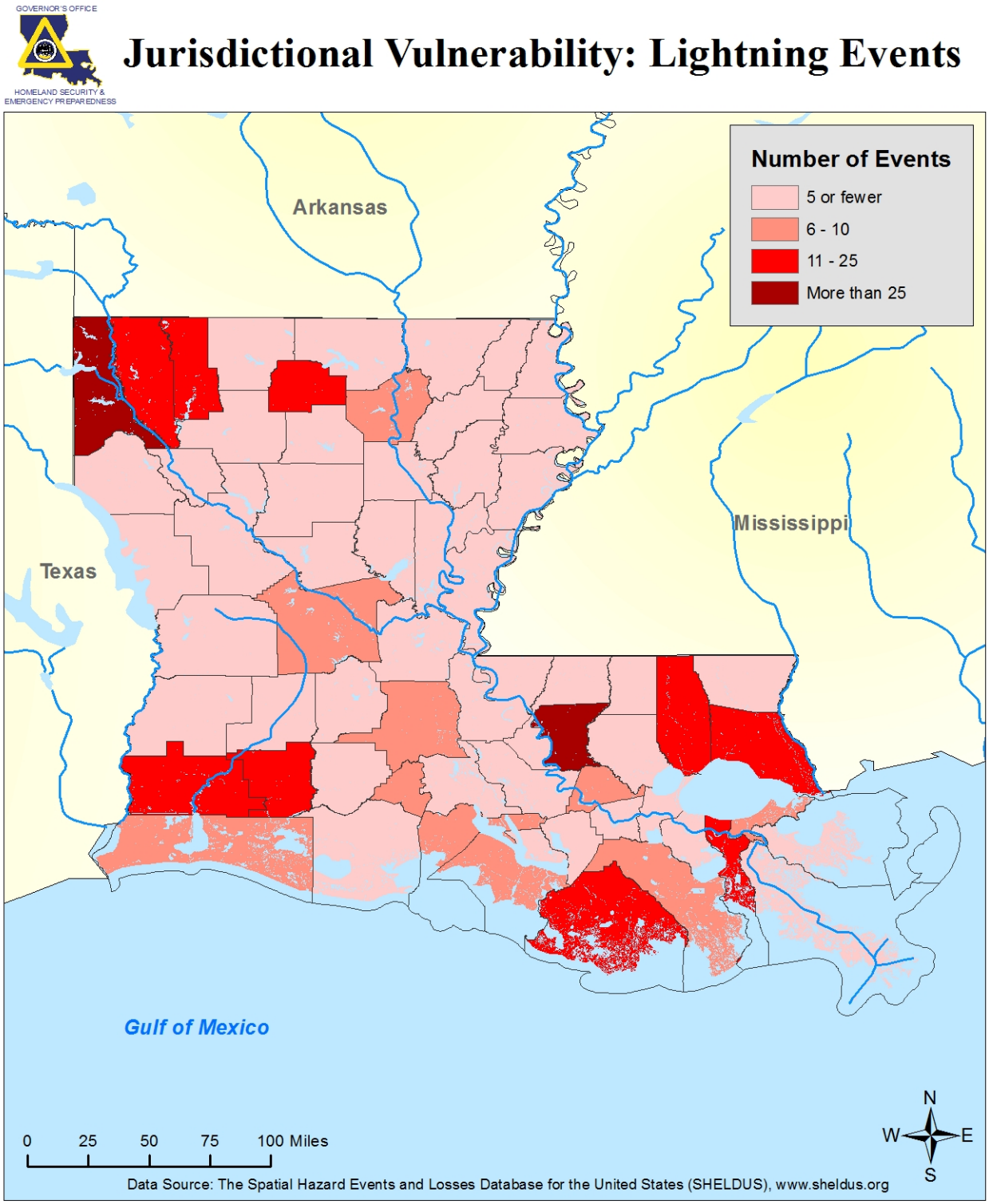
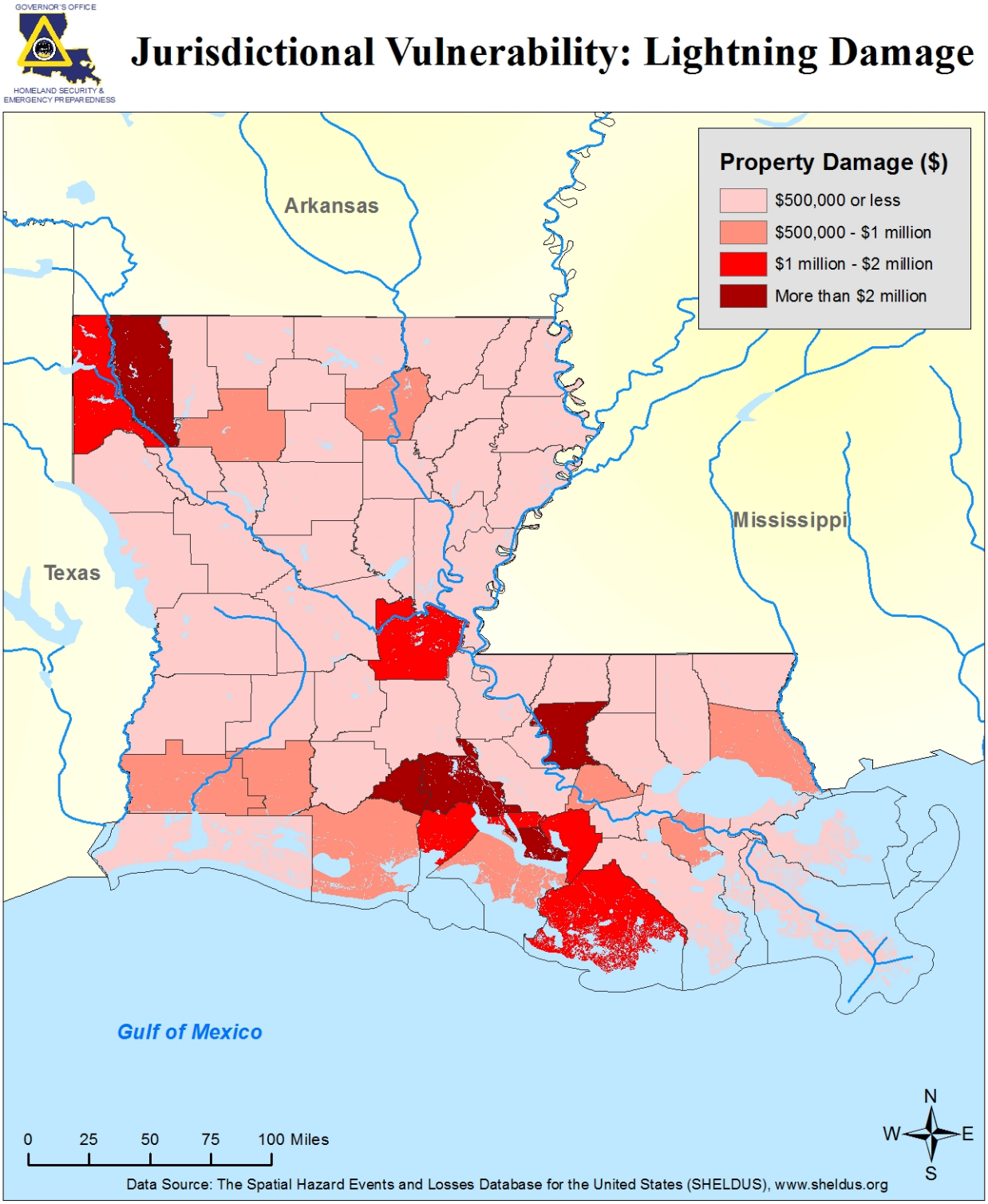


Map 2.47. Density of lightning strikes in Louisiana parishes by flash per square mile per year.

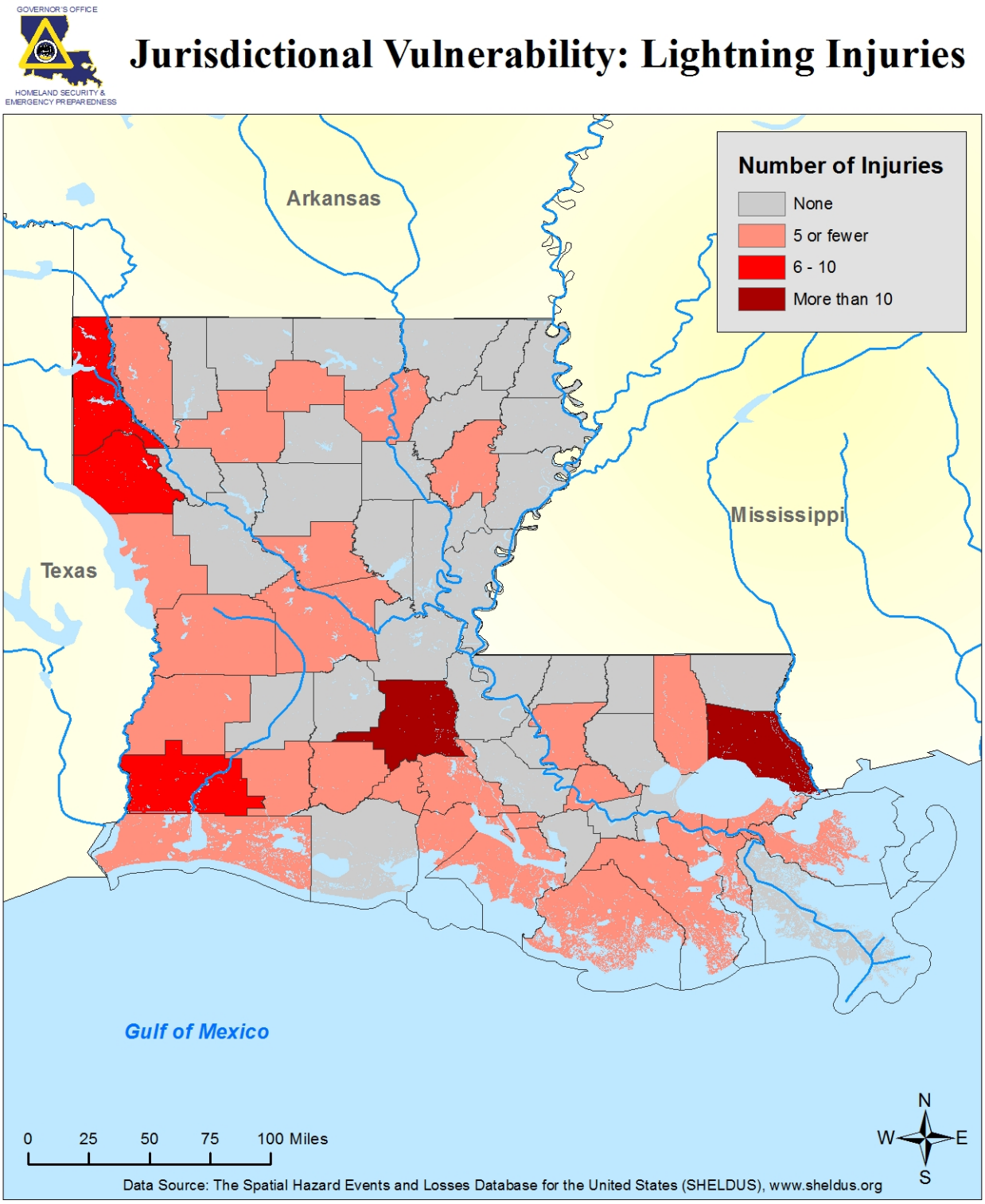
The state's vulnerability to lightning is illustrated through Maps 2.48, 2.49, 2.50, and 2.51, which indicate the total lightning events, as well as the damages, injuries, and fatalities attributed to lightning. Although lightning can strike anywhere, the data reported for lightning will generally reflect a greater incidence of lightning events in (1) areas with higher population densities and (2) areas located in close proximity to the Gulf. Thus, Caddo and East Baton Rouge Parishes have a greater number of events than many other parishes, and all of the parishes along the Gulf have a relatively high probability of future occurrence. Nevertheless, certain areas had unusual damage, injury, and death due to a high incidence of lightning. Terrebonne Parish, while sparsely populated areas of the state, even while located along the Gulf, still seemed to have a higher incidence of lightning strikes, along with the damage and personal injury and death associated with such strikes. Most notably, Terrebonne Parish, which has a population of 111,860 people over 2,080 mi^2.[xxxvii] Two reasons for the relatively high incidence of lightning strikes in Terrebonne are its proximity to the Gulf (and its subsequent vulnerability to more thunderstorms) and its large land mass (it is the second largest parish in area in Louisiana).



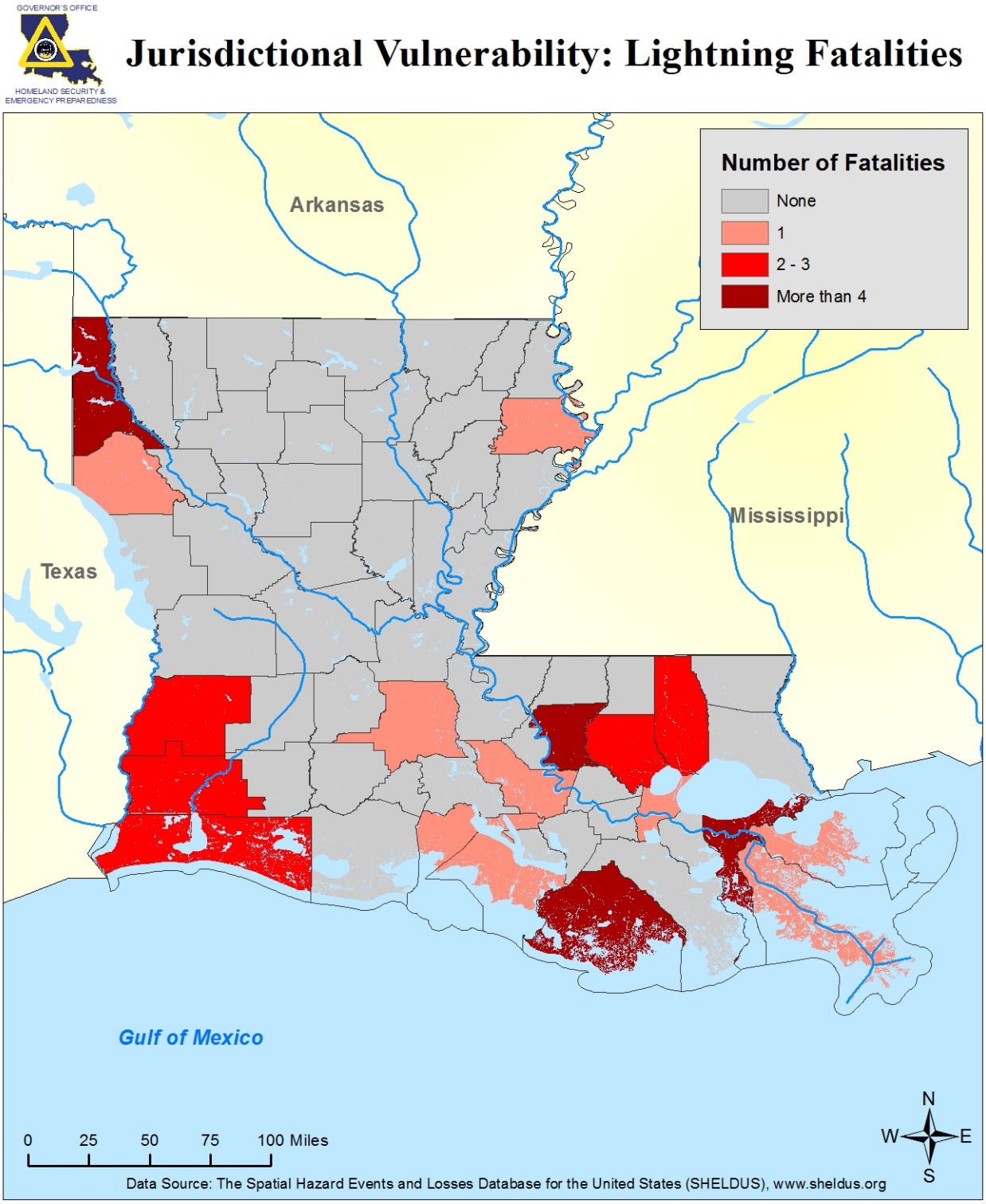
Map 2.48. Louisiana jurisdictional vulnerability for lightning strikes based on data from 1987–2012.



Map 2.49. Louisiana jurisdictional vulnerability for damage from lightning strikes based on data from 1987–2012.



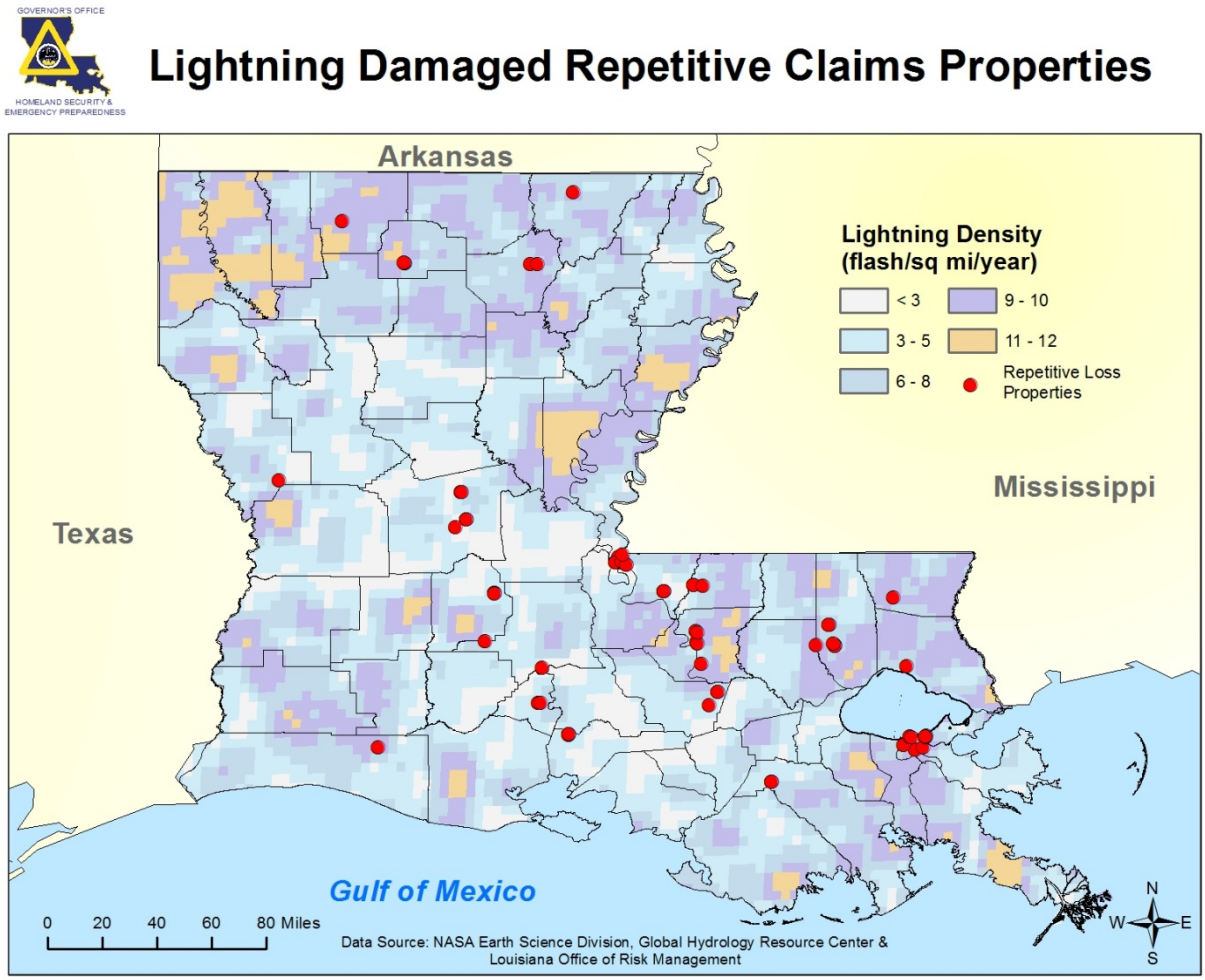
Map 2.50. Louisiana jurisdictional vulnerability for injury from lightning strikes based on data from 1987–2012.



Map 2.51. Louisiana jurisdictional vulnerability for fatalities from lightning strikes based on data from 1987–2012.

Earlier, Map 2.34 indicated the future probability of lightning strikes in Louisiana by parish, suggesting that parishes with urban areas were in greater danger than more rural parishes. Again, lightning strikes tend to be reported more frequently in heavily populated areas and along the Gulf Coast where thunderstorms are more prevalent.

Map 2.52 locates previously damaged state asset properties against the density of lightning strikes over the past 25 years. Table 2.14 lists the top 10 lightning-damaged state asset properties. State-owned critical facilities located in areas affected by lightning are of the following types: hospitals, shelters, Emergency Operation Centers, data processing centers, and state police troop offices.



Map 2.52. State assets with repetitive claims for lightning damage.

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Table 2.14. Top 10 paid claims for lightning-damaged state assets (source: Louisiana Office of Risk Management).

Top 10 Paid Claims for Lightning-Damaged State Assets				
Building ID	Building Name	Location	Net Paid	Total Number of Claims (Lightning)
L22008	Millennium Apartment Buildings - Southern University	Baton Rouge	$78,998	1
S02553	Center Building - Eastern LA Mental Health System	Jackson	$48,028	1
S03160	Main Hospital - Lallie Kemp Regional Medical Center	Independence	$33,806	1
S03186	Generator Room - Lallie Kemp Regional Medical Center	Independence	$46,291	1
S08879	Walker Hall - University of Louisiana-Monroe	Monroe	$1,738,587	1
S10101	Utilities Plant - Louisiana State University-Alexandria	Alexandria	$23,582	1
S12282	Building 34 - University of Louisiana-Lafayette	New Iberia	$42,472	1
S14400	Building 52 - University of Louisiana-Lafayette	New Iberia	$27,255	1
S14401	Building 53 - University of Louisiana-Lafayette	New Iberia	$26,255	1
S16016	Farm Services Building - Southern University	Baker	$43,914	1

Maps 2.53, 2.54, and 2.55 show the composite jurisdictional risk for hail, high winds, and lightning in Louisiana based on the preceding data. Caddo and Bossier Parishes have the greatest risk of hail events (high); East Baton Rouge, Calcasieu, and Washington Parishes have the greatest risk of high wind events (high); and East Baton Rouge and Caddo Parishes have the greatest risk of lightning events (very high and high, respectively). The parishes at high risk (greater than 2.0 composite risk score) to lightning (Caddo and East Baton Rouge) did not experience significant population increases or decreases of more than 10% since 2000 (see Map 2.3). As a result, vulnerability to lightning has not changed measurably across the state.

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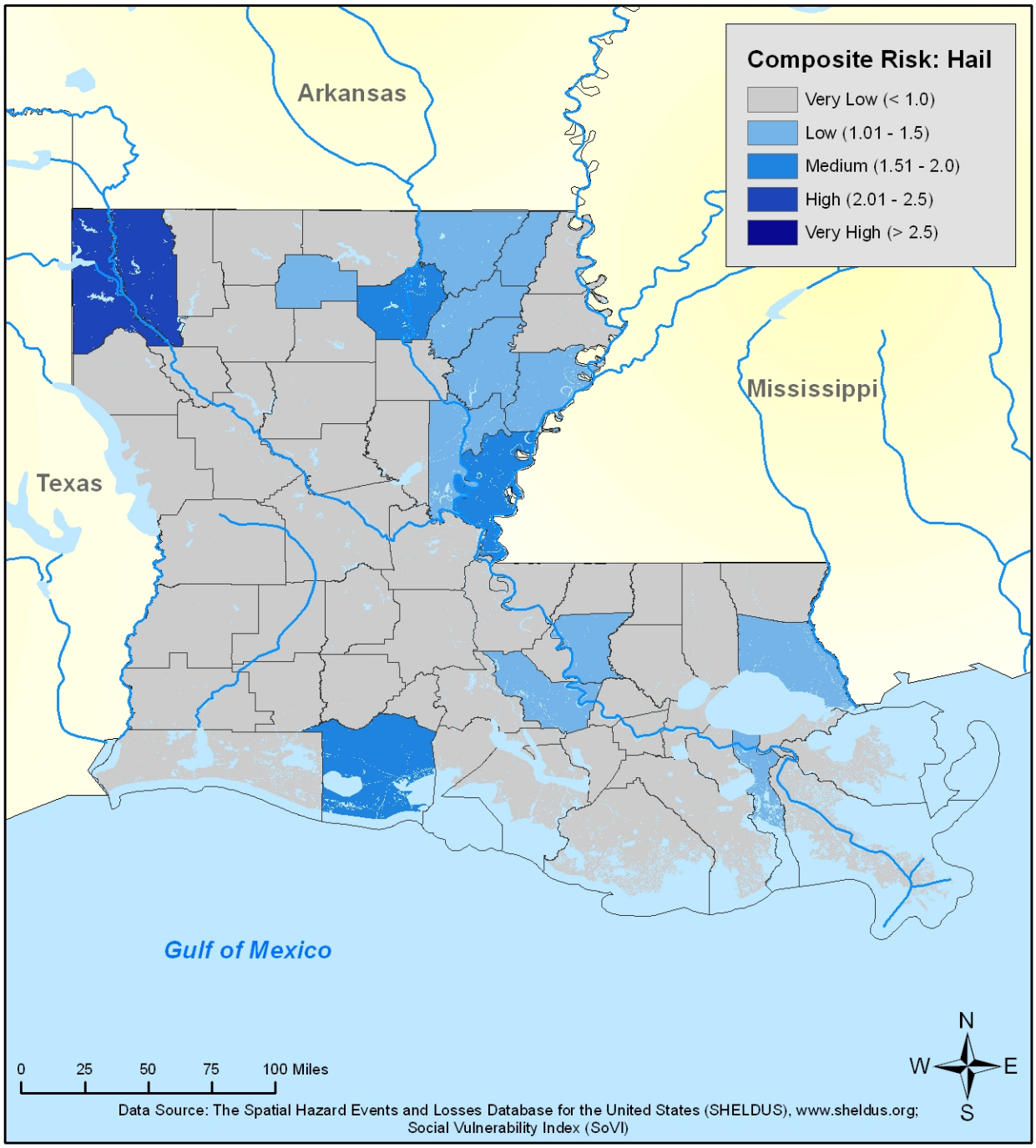
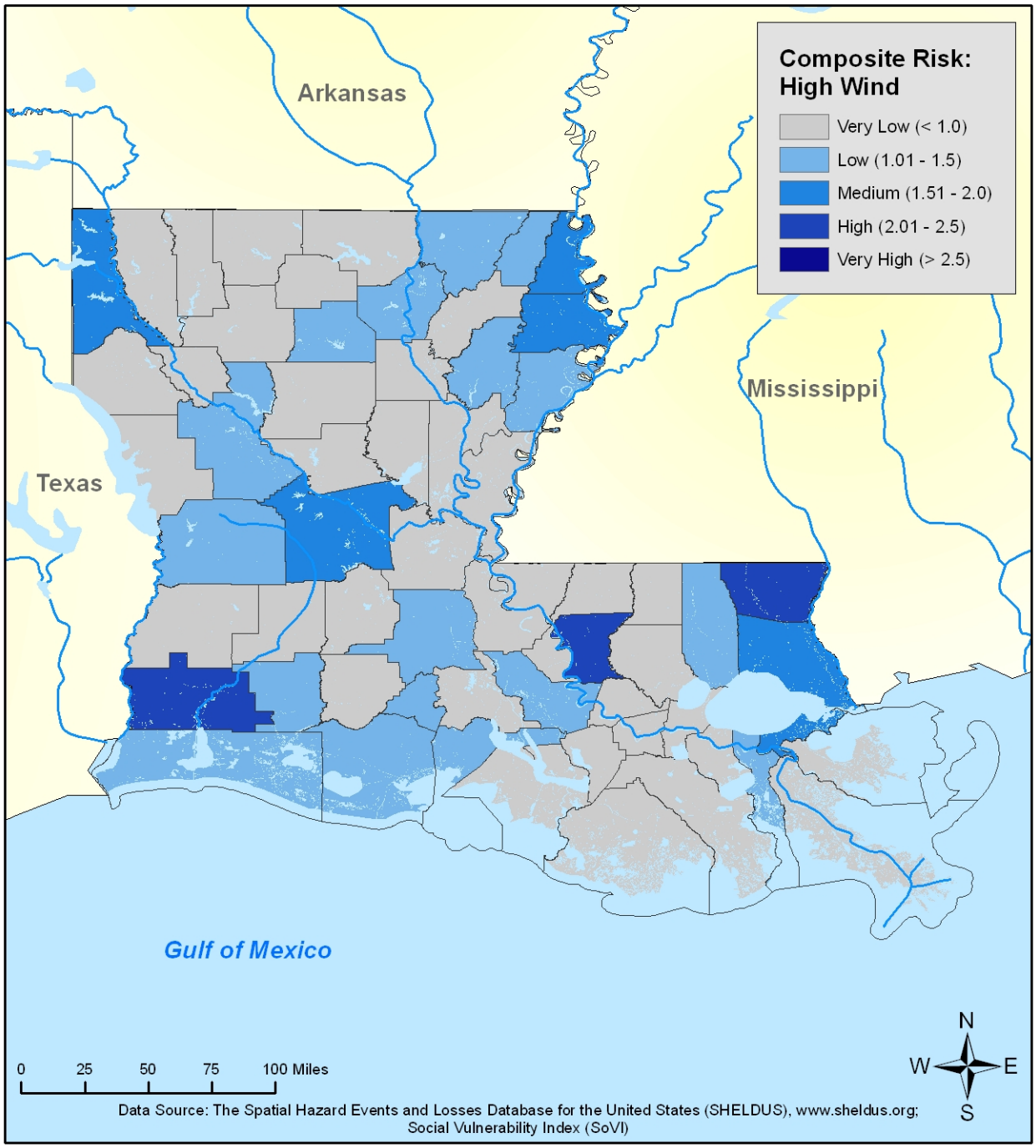
Jurisdictional Vulnerability: Hail Composite Risk

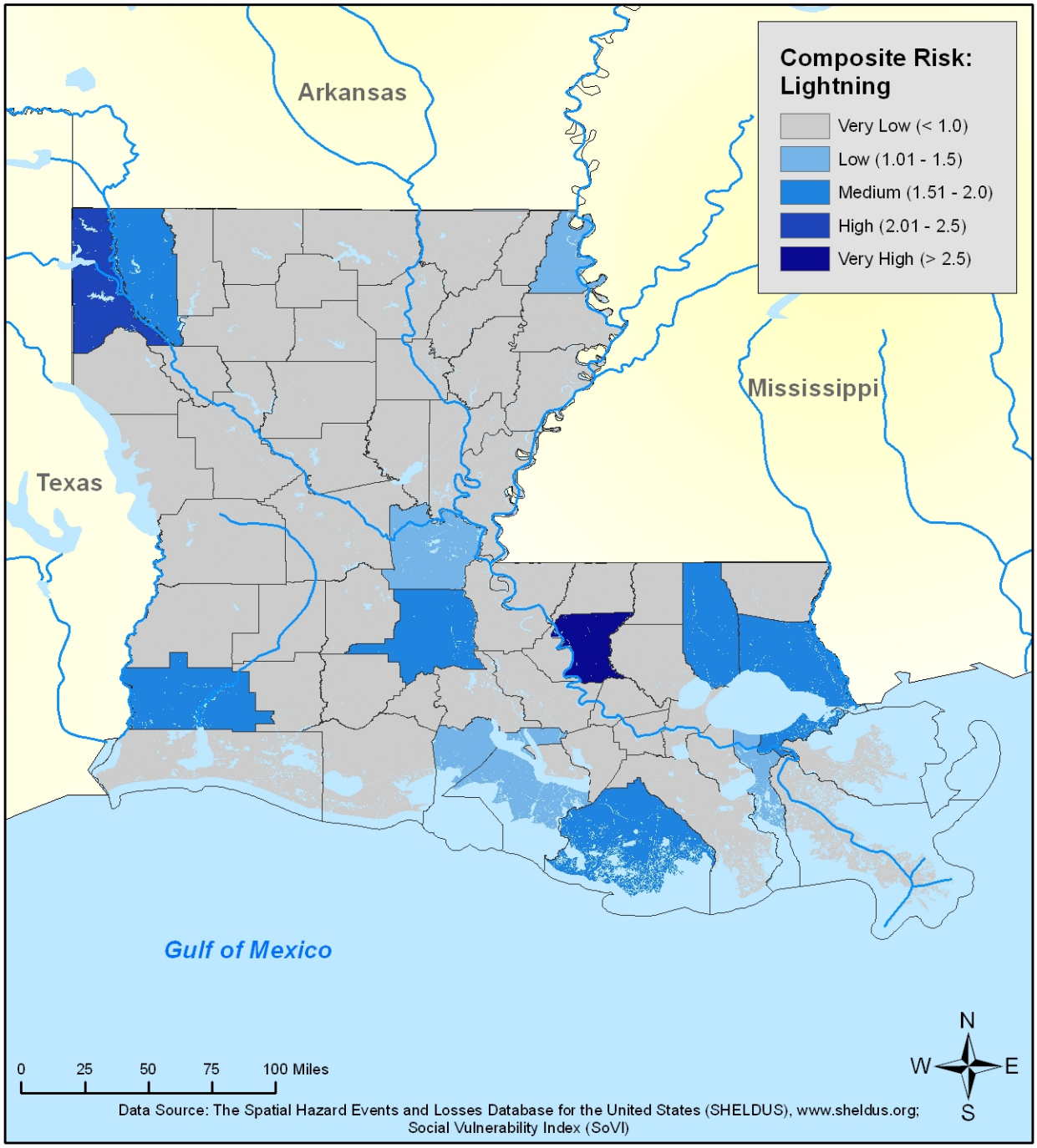


Map 2.53. Composite risk map for hail events showing parishes with the highest historical and highest potential risks mostly in northern Louisiana.

Jurisdictional Vulnerability: High Wind Composite Risk

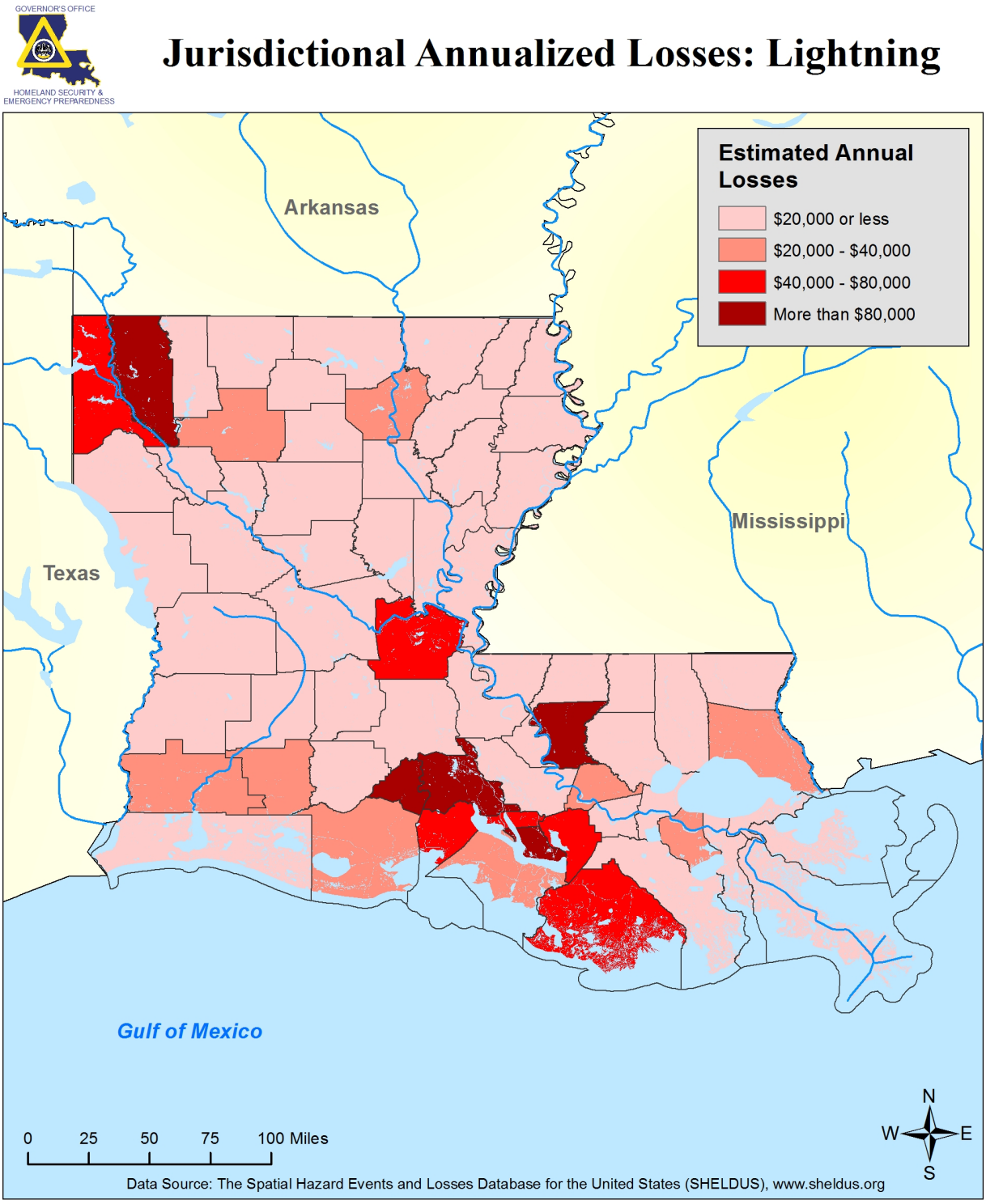


Map 2.54. Composite risk map for high wind events showing parishes with the highest historical and highest potential risks scattered across Louisiana.



Map 2.55. Composite risk map for lightning events showing parishes with the highest historical and highest potential risks scattered across Louisiana.

To determine potential loss estimates from lightning, the available historical loss data was annualized to determine future loss potential (Map 2.56). As shown, parishes with the largest populations are predicted to have the highest potential annualized losses.



Map 2.56. Jurisdictional annualized loss due to lightning.

Potential Economic Loss

Based on multiple sources (e.g., SHELDUS, NOAA, NCDC), the following parishes are most likely to be affected by thunderstorms: Bossier, Caddo, Calcasieu, Cameron, Catahoula, Concordia, East Baton Rouge, East Carroll, Franklin, Jefferson, Jefferson Davis, Madison, Morehouse, Orleans, Ouachita, Richland, St. Tammany, Tangipahoa, Tensas, Washington, and West Carroll. Among these parishes, Bossier, Caddo, Calcasieu, East Baton Rouge, Jefferson, Orleans, Ouachita, St. Tammany, and Tangipahoa Parishes have populations of over 80,000 and have the highest infrastructure dollar exposures within Louisiana. These nine parishes are considered to have the highest vulnerability to thunderstorms within the state.

Table 2.15 shows the overall exposure for high-risk parishes based on Hazus-MH 2.1 inventory databases and the percentage of residences comprising mobile home structures in each parish. Similar to their vulnerability to tornadoes (although not as extreme), mobile home structures are vulnerable to the various hazards associated with thunderstorms and particularly to high wind since they are not built to withstand high wind speeds.

Table 2.15. Overall exposure for high-risk parishes.

Exposure Data for Parishes with Highest Thunderstorm Risk			
Parish	Population (2010)	Total Exposure ($1,000)	Mobile Homes (%)
Bossier	116,979	$16,148,468	15.5
Caddo	254,969	$34,345,146	9.3
Calcasieu	192,768	$21,704,525	16.1
Cameron	6,839	$5,497,935	36.0
Catahoula	10,407	$4,153,475	25.3
Concordia	20,822	$3,928,603	22.6
East Baton Rouge	440,171	$62,537,076	3.2
East Carroll	7,759	$2,430,145	18.3
Franklin	20,767	$3,818,331	18.7
Jefferson	432,552	$68,890,600	1.6
Jefferson Davis	31,594	$8,082,036	18.4
Madison	12,093	$2,712,688	14.4
Morehouse	27,979	$6,391,012	16.9
Orleans	343,829	$71,111,981	1.6
Ouachita	153,720	$19,349,689	13.7
Richland	20,725	$4,905,466	17.7
St. Tammany	233,740	$31,411,675	8.6
Tangipahoa	121,097	$13,106,990	22.4
Tensas	5,252	$2,158,271	10.0
Washington	47,168	$6,658,683	22.6
West Carroll	11,604	$2,412,695	24.0
TOTALS	**2,512,834**	**$391,755,490**	**16.0 (Average)**

Based on the geographic extents determined in the hazard profile and the jurisdictional vulnerability assessments, the parishes in blue in Map 2.57 have the highest risk factor with respect to thunderstorms. The corridors outlined in red mark the extent of each high-risk area.

This Plan Update also utilizes Hazus-MH 2.1 for the analysis of building exposure in each of the most vulnerable parishes by general occupancy type, which is detailed in Table 2.16.

Table 2.16. Building exposure for thunderstorms in most vulnerable parishes by general occupancy type.

Building Exposure in Most Vulnerable Parishes for Thunderstorms							
Parish	Exposure Type ($1,000)						
	Residential	Commercial	Industrial	Agricultural	Religion	Government	Education
Bossier	11,891,551	2,709,321	761,501	59,494	432,384	192,803	101,414
Caddo	24,028,899	6,808,440	1,781,362	103,056	1,140,772	226,850	255,767
Calcasieu	15,879,101	3,805,841	1,011,908	58,492	576,612	150,541	222,030
Cameron	4,209,736	691,929	393,622	37,564	90,194	38,602	36,288
Catahoula	3,057,422	629,752	138,779	63,292	153,556	57,673	53,001
Concordia	2,901,139	621,577	96,944	55,674	151,576	51,342	50,351
East Baton Rouge	44,435,690	12,153,263	2,615,210	137,030	1,511,136	960,722	724,025
East Carroll	1,686,708	359,608	121,147	56,672	127,054	39,850	39,106
Franklin	2,797,175	530,282	139,622	72,966	183,488	48,884	45,914
Jefferson	50,104,392	13,418,248	3,024,142	114,922	1,204,366	437,819	586,711
Jefferson Davis	6,364,838	911,215	320,585	64,622	239,620	75,342	105,814
Madison	1,993,179	379,309	109,226	59,224	118,460	25,696	27,594
Morehouse	4,880,603	788,741	239,143	83,610	272,078	61,893	64,944
Orleans	50,691,672	12,784,835	2,595,764	77,762	1,980,374	984,070	1,997,504
Ouachita	12,968,015	4,382,733	938,805	80,576	616,220	181,698	181,642
Richland	3,420,917	774,645	265,348	90,184	234,316	67,130	52,926
St. Tammany	23,583,443	5,750,413	927,918	111,050	565,620	246,405	226,826
Tangipahoa	9,581,467	2,226,918	520,534	67,496	435,132	101,324	174,119
Tensas	1,490,623	421,817	63,506	52,738	70,438	30,406	28,743
Washington	5,129,019	819,489	254,003	64,838	266,440	55,916	68,978
West Carroll	1,722,320	287,341	107,687	76,142	144,518	41,231	33,456
TOTALS	**282,817,909**	**71,255,717**	**16,426,756**	**1,587,404**	**10,514,354**	**4,076,197**	**5,077,153**

Map 2.57. High risk areas for thunderstorms with specific sub-hazard types listed.

Based on the baseline Hazus-MH 2.1 inventory database, the Louisiana Digital Map GIS database (via LOSCO), and the U.S. Census Bureau, regional vulnerability to thunderstorms is listed in Table 2.17.

Table 2.17. Regional vulnerability to thunderstorms.

Regional Vulnerability to Thunderstorms	
Vulnerable Locations	Number of Records
Louisiana Parishes	21
Dams	297
Airports	59
Communication Towers/Facilities	266
Electricity Providers/Facilities	48
Emergency Response Centers	15
Fire Stations	321
Hospitals	127
Nuclear Plants	0
Police Stations	443
Elementary/Secondary Schools	1341
Universities/Colleges	28

Louisiana has a very high frequency of thunderstorms annually. Collectively, the three thunderstorm-associated sub-hazards of hail, high wind, and lightning cause hundreds of thousands of dollars of damage to property every year. All forms of occupancy types are susceptible to thunderstorms and a severe storm can have many of the same effects as tornadoes including the disruption of traffic flow and the impediment of police, fire, and medical personnel during response and recovery efforts. Power outages are commonly caused by high winds that cause downed trees and power lines and can impact entire communities and jurisdictions for long periods of time depending on the severity. Hail can cause widespread damage, especially to homes and automobiles. Lightning can disrupt communication towers, start fires, and harm technology-intensive devices.

Substantial damage could be incurred by state, local, and federal facilities. The damage to infrastructure could be widespread with lost power, water, sewer, gas, and communications. Road and technology (e.g., internet, communications) networks can be severely impacted by thunderstorms. And people who work outdoors are most susceptible to the multi-pronged impacts of thunderstorms. Lightning, hail, and high wind have been the cause of multiple injuries and fatalities in Louisiana, with lightning being a major cause of fatality.

Potential Losses by Jurisdiction

Overview & Analysis of Potential Losses: Overall, most of Louisiana is vulnerable to thunderstorms, but there are certain parishes that are more vulnerable to specific thunderstorm sub-hazards than others. High wind and lightning are major concerns in south Louisiana, while hail appears to be a bigger issue in northern parishes. Similarly with tornadoes, poorly constructed or older homes and mobile home parks are at highest risk of sustaining the greatest damage during thunderstorms.

Changes in development are expected to impact loss estimates for thunderstorms since any new development represents an increase in the number of structures that are vulnerable to the effects of thunderstorms. Areas of increased population growth and development, especially those in the parishes of southeast Louisiana, will experience an increase in losses from thunderstorms (i.e., hail, high winds, and lightning).

Changes in jurisdictional population levels impact each parish across the state disparately. In Bossier parish where hail vulnerability has increased because of an increase in population, concomitant changes in development have impacted loss estimates and will cause an increase in future losses due to increased levels of exposure. No high-risk parishes for hail experienced a significant decrease in population and, consequently, no other parishes will experience a measurable change in loss estimates based on development trends.

When considering high wind, no high-risk parishes experienced a significant increase or decrease in population and, consequently, minimal changes in development are expected. Loss estimates for high wind will not experience a measurable change based on development trends.

When considering lightning, no high-risk parishes experienced a significant increase or decrease in population and, consequently, minimal changes in development are expected. Loss estimates for lightning will not experience a measurable change based on development trends.

Potential Losses of State Facilities

The thunderstorm hazard vulnerability assessment of state-owned buildings was based on the parish-level composite risk scores for all three thunderstorm-related hazards, which incorporate the total number of hail, lightning, and high wind events, injuries, fatalities, and property damages as well as the social vulnerability of impacted parishes. The criteria used to determine specific vulnerability rankings for each building and the results of applying this ranking to the state-owned buildings are shown in Tables 2.18 and 2.19.

Table 2.18. Thunderstorm Vulnerability Criteria and Ranking Results.

THUNDERSTORM VULNERABILITY CRITERIA AND RANKING	
Ranking	Criteria
High	Composite risk score greater than 2.0 for one or more thunderstorm-related hazard
Medium	Composite risk score between 1.5 and 2.0 for one or more thunderstorm-related hazard
Low	Composite risk score less than 1.5 for one or more thunderstorm-related hazard

The thunderstorm loss-estimate ranges are derived from the 2011 state hazard mitigation plan and inflation-adjusted to 2013 dollars. The January 2014 state facilities database was used to obtain accurate building numbers for each loss estimate range. Loss estimates of state-owned buildings in Louisiana involved an analysis of the following parameters:

- Hailstorm, Lightning, and High Wind Hazard Vulnerability
- Average Building Type
- Hailstorm Damage Functions

Table 2.19. Thunderstorm Loss Estimate Ranges and Ranking Results.

THUNDERSTORM LOSS ESTIMATE RANGES AND RANKING		
Ranking	Total Loss Estimate Ranges	Number of Buildings
High	$5,344 to $53,440	1876
Medium	$535 to $5,344	2574
Low	$0 to $534	4235

TORNADOES

Tornadoes (also called twisters and cyclones) are rapidly rotating funnels of wind extending between storm clouds and the ground. For their size, tornadoes are the most severe storms, and 70% of the world's reported tornadoes occur within the continental United States, making them one of the most significant hazards Americans face.[xxxviii] When they exist over water, they are considered waterspouts.[xxxix] Tornadoes and waterspouts form during severe weather events, such as thunderstorms and hurricanes, when cold air overrides a layer of warm air, causing the warm air to rise rapidly, which usually occurs in a counterclockwise direction in the northern hemisphere. The updraft of air in tornadoes always rotates because of *wind shear* (differing speeds of moving air at various heights), and it can rotate in either a clockwise or counterclockwise direction; clockwise rotations (in the northern hemisphere) will always result in near-immediate demise, but counterclockwise rotations (in the northern hemisphere) will sustain the system, at least until other forces cause it to die seconds to minutes later.

Since February 1, 2007, the Enhanced Fujita (EF) Scale has been used to classify tornadoes. The EF Scale classifies **tornadoes based on their damage pattern, not wind speed;** wind speed is then derived and estimated. This contrasts with the Saffir-Simpson scale used for hurricane classification, which is based on measured wind speed. Table 2.20 shows the EF Scale in comparison with the old Fujita (F) Scale, which was used prior to February 1, 2007. When discussing past tornadoes, the scale used at the time of the hazard will be used. Adjustment to the EF Scale can be made using Table 2.20.

Table 2.20. Comparison of Fujita (F) Scale to Enhanced Fujita (EF) Scale.

ENHANCED FUJITA SCALE						
	EF0	***EF1***	***EF2***	***EF3***	***EF4***	***EF5***
Winds	**65-85 mph**	**86-110 mph**	**111-135 mph**	**136-165 mph**	**166-200 mph**	**>200 mph**
(Old Fujita Scale)	***F0***	***F1***	***F2***	***F3***	***F4***	***F5***
	<73 mph	**73-112 mph**	**113-157 mph**	**158-206 mph**	**207-260 mph**	**>261 mph**

TORNADO PROFILE

From data over the past 60 years, Louisiana ranks 11th among the states in frequency of tornado occurrences, 13th for tornado-related deaths, 16th for tornado-related injuries, and 15th for damage costs. When considering total tornado frequency per mi^2, Louisiana ranks 5th in frequency, 11th in deaths, 12th in injuries, and 10th for costs. The very high frequency per unit area is compensated somewhat by the fact that an even higher percentage of Louisiana's tornadoes have been EF0 and EF1s than in other states.[xl] Since 1900, Louisiana has suffered through eight days in which 10 or more people have died in tornadoes.

Table 2.21 details the dates and locations of observed tornadoes in Louisiana that resulted in more than three deaths. Tornadoes also cause a significant amount of property damage. According to the National Climatic Data Center, the average annual economic loss due to tornadoes in Louisiana is $38.8 million, but in 1953, 1971, and 1983, that figure topped $209 million each (in 2013 USD).[xli]

Table 2.21. Louisiana tornadoes resulting in >3 deaths (source: Vega, Grymes, Rohli 171; data provided by NOAA/Storm Prediction Center (SPC))

MOST FATAL LOUISIANA TORNADOES			
Date/Time	Location	Deaths	Injuries
24 April 1908 (5 a.m.)	Concordia Parish	39	150
24 April 1908 (11:45 a.m.)	Amite Parish	47	270
13 May 1908 (5:30 a.m.)	Caddo (Gilliam), Bossier Parishes	49	135
4 April 1923 (6 p.m.)	Alexandria and Pineville	15	150
1 May 1933 (4 p.m.)	Minden	28	400
17 February 1938 (9:40 p.m.)	Rodessa	21	50
31 December 1947 (4 p.m.)	Shreveport, Cotton Valley	18	225
3 December 1953 (4:30 a.m.)	Vernon (Leander), Rapides, Grant Parishes	7	50
22 January 1957 (10:50 a.m.)	Bossier Parish, Princeton	3	9
7 November 1957 (8:55 p.m.)	Alexandria, Boyce	3	35
7 November 1957 (9:30 a.m.)	Acadia Parish	4	12
12 September 1961 (1 p.m.)	Hodge (from Hurricane Carla)	5	37
3 October 1964 (6:30 a.m.)	Larose (from Hurricane Hilda)	22	165
21 February 1971 (2:50 p.m.)	Madison Parish	10	400
8 April 1993 (1:20 p.m.)	Grand Isle (from waterspout)	3	39
3 April 1999 (4:03 p.m.)	Benton	7	90

Two Louisiana tornadoes are among the ten deadliest tornadoes in American history. On May 7, 1840, the second-deadliest tornado in United States history struck Concordia Parish before moving into neighboring Adams County, Mississippi, resulting in 317 deaths and 109 injuries. On April 24, 1908, another tornado moved through Louisiana and Mississippi, killing 143 people and injuring 770 in Amite Parish, as well as Pine and Purvis Counties in Mississippi.[xlii]

In recent years, Louisiana has continued to experience numerous devastating tornado events. On April 3, 1999, several F3 and F4 tornadoes touched down in Bossier, Caddo, Claiborne, and DeSoto Parishes, killing seven people, injuring 103, and causing more than $12 million in damages, resulting in a Presidential Disaster Declaration. In February 2006 and 2007, several F2 tornadoes struck Orleans and Jefferson Parishes, touching down in Westwego, New Orleans, and Gentilly. The 2007 tornadoes cause over $5 million in damages, hitting areas still devastated from Hurricanes Katrina and Rita.

The 2008 and 2009 tornado seasons proved to be as deadly and as costly as in previous years, producing approximately 164 recorded tornadoes in Louisiana that resulted in 6 deaths, 32 injuries and $41.6 million in damages. Over the past three years, residents across 56 parishes in Louisiana have observed 107 tornadoes, resulting in 1 death, 47 injuries, $87.5 million in property damage, and $1.5 million in crop damage in the course of a total of 58 days.[xliii] On April 24, 2010, a long-track tornado touched down west of Tallulah (Madison Parish) and crossed into Mississippi where it became the 4th-longest-track tornado in Mississippi history, traveling 149 mi. The tornado produced mainly EF3 and EF2 damage across Madison Parish with maximum winds around 155 mph. On March 5, 2011, one supercell thunderstorm produced four tornadoes in Jefferson Davis and Acadia Parishes, ultimately causing one fatality and 11 injuries. According to the Louisiana State Fire Marshal's Office, 42 houses were destroyed; 48 sustained major damage, 79 sustained moderate damage, and another 514 sustained minor damage. Louisiana experienced a total of $15 million in property damage.

Despite the fact that Louisiana is now generally better prepared for tornadoes than in previous years, the state has experienced an increase in the rate of tornado touchdowns over the past 40 years. However, this increase could be due to improved observation techniques and increases in population density.[xliv] Tornadoes have been observed in every parish of Louisiana (indeed, they have been witnessed in every state in the United States). Map 2.58 shows the densities of tornado touchdowns in Louisiana from 1950 to 2012. The highest densities of tornado touchdowns are in urban areas (specifically, Lafayette, New Orleans, Shreveport), with the highest occurrences in Crowley (near Lafayette). This bias is typical since higher population densities ensure a greater likelihood of tornado observation. Despite these densities, however, the length of the tracks of these tornadoes is not similarly distributed. Map 2.59 shows the density of the longest tornado tracks in Louisiana from 1950–2012, where higher density reflects a higher concentration of longer-track tornadoes. Map 2.60 reveals the tracks of the EF/F3, EF/F4, and EF/F5 tornadoes that have struck the state from 1950 to 2012. Both Map 2.59 and Map 2.60 indicate that long-track tornadoes are more frequent near Shreveport. Furthermore, most long-track tornadoes tend to move from southwest to northeast, which is presumed to be along the pre-cold frontal squall line, a location particularly prone to severe weather.

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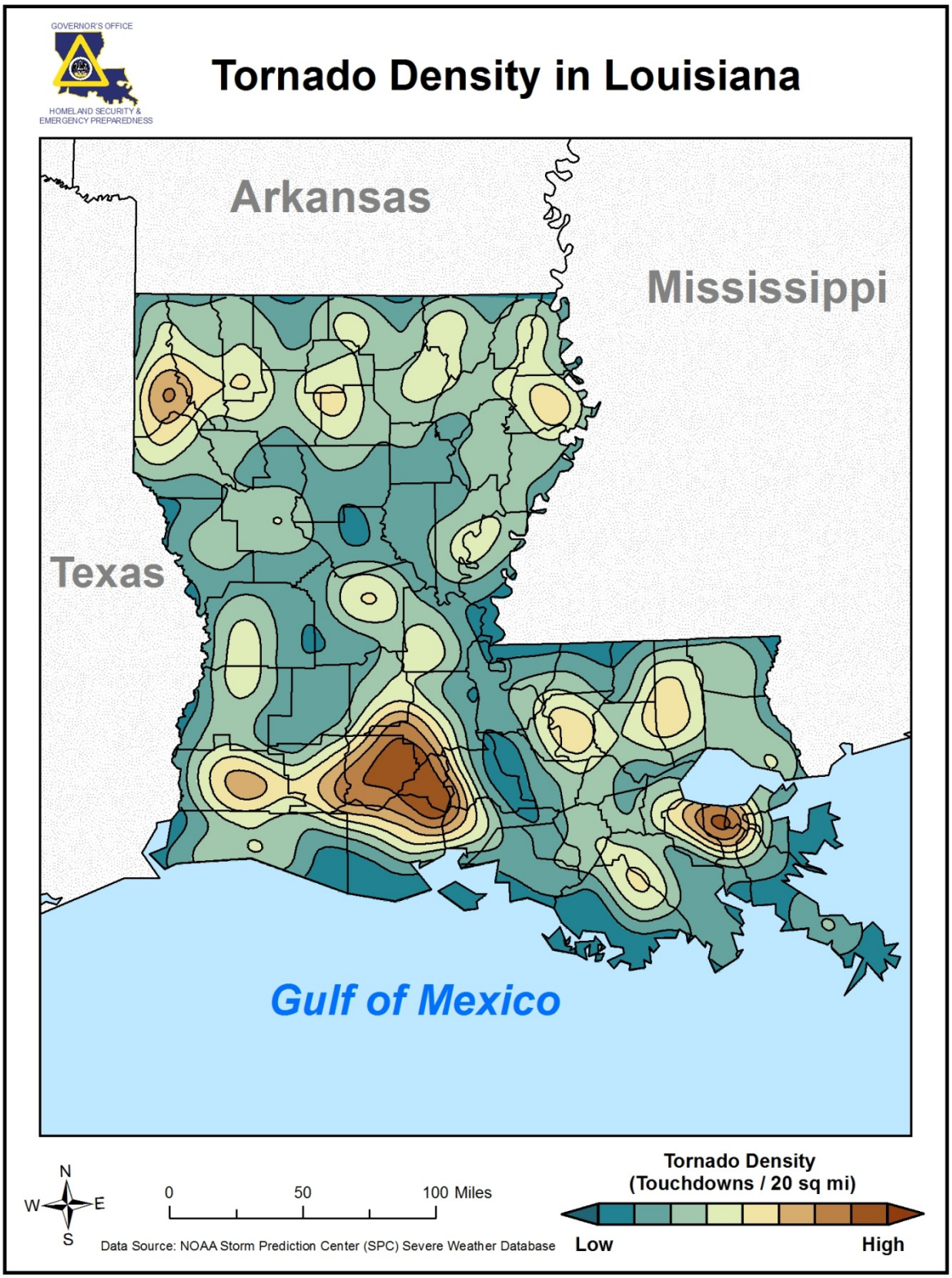
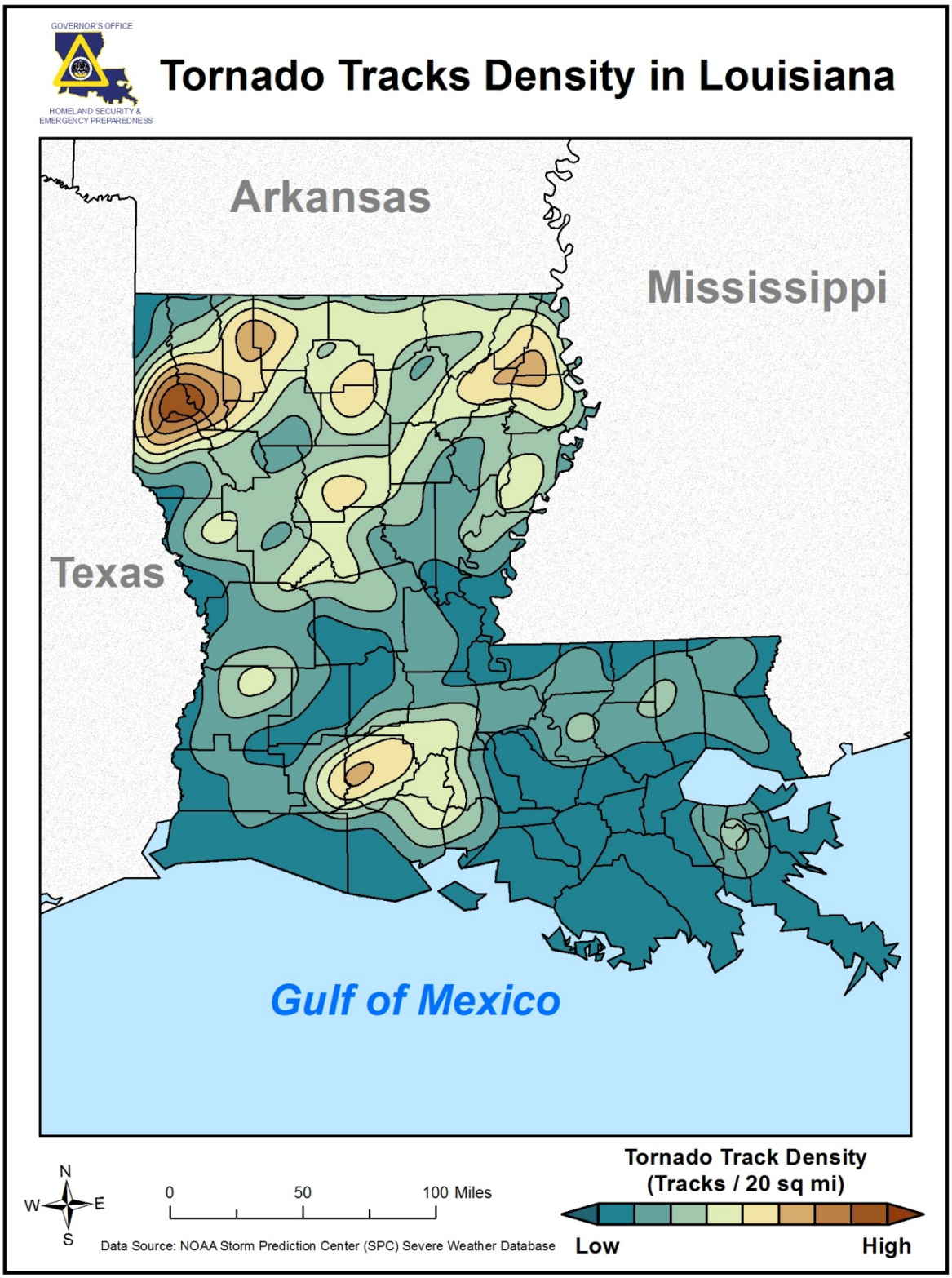
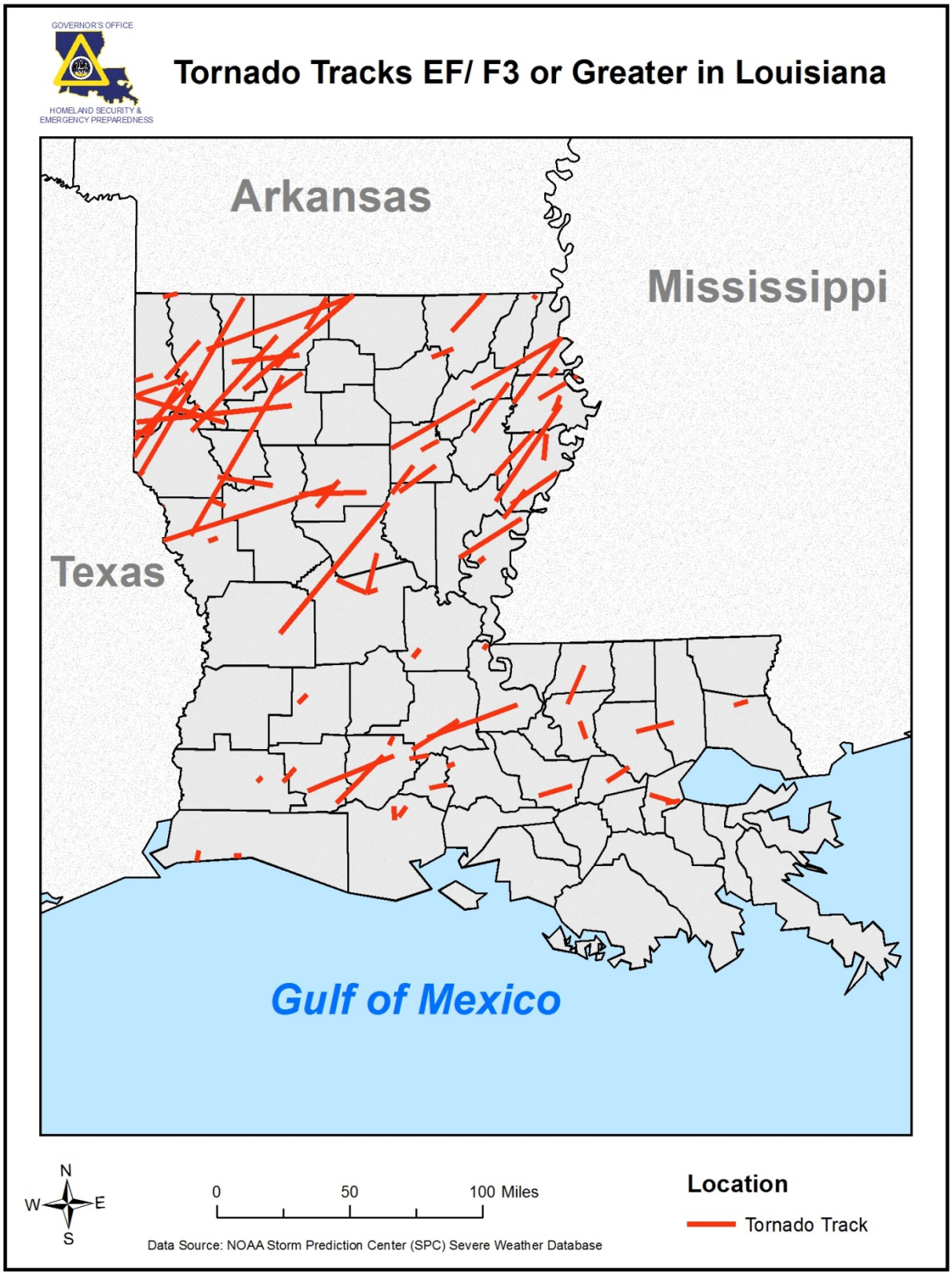


Map 2.58. Density of tornado touchdowns in Louisiana from 1950–2012 (source: NOAA/SPC Severe Weather Database).



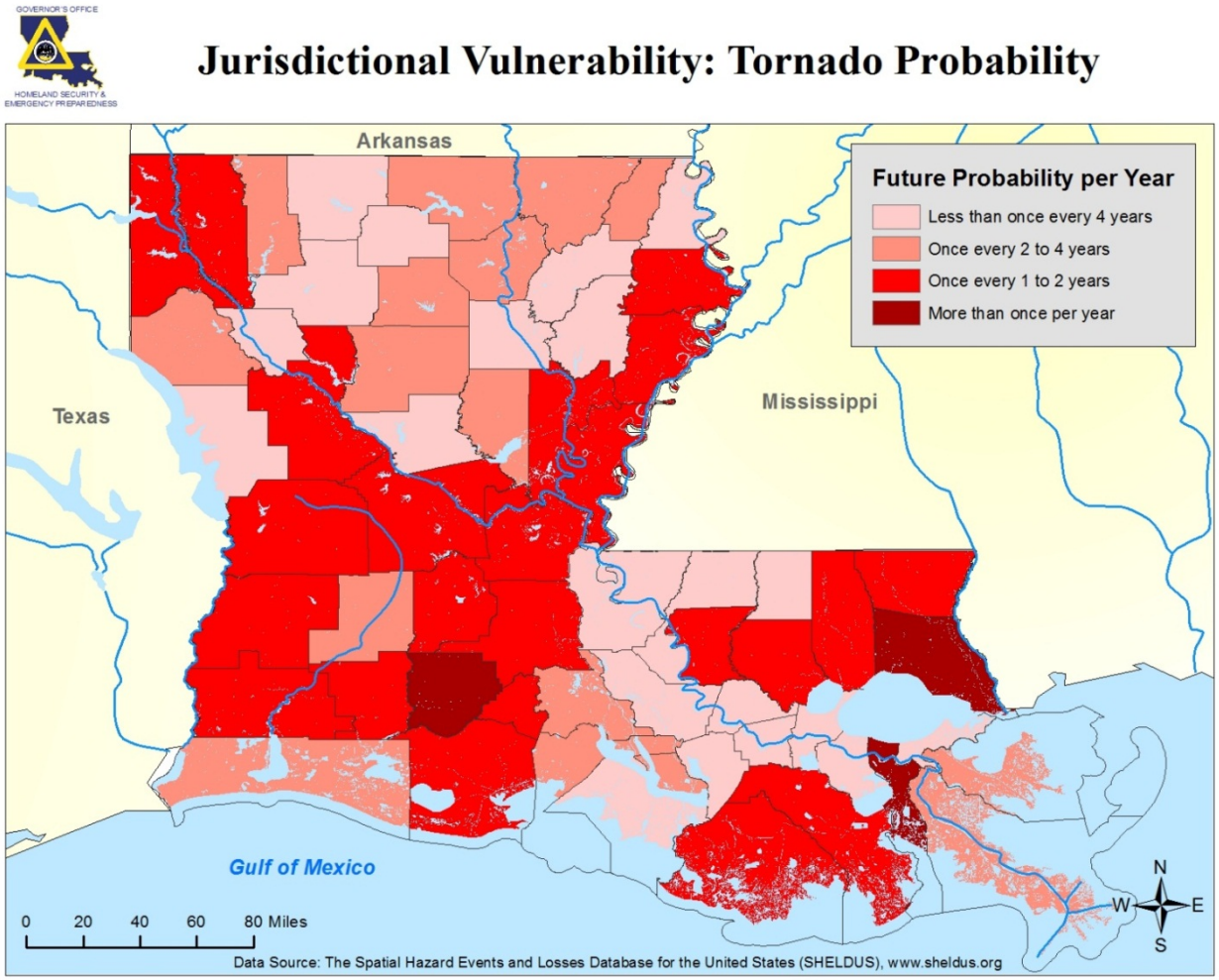
Map 2.59. Density of longest tornado tracks in Louisiana from 1950–2012. Higher density reflects a higher concentration of longer tracks (source: SPC Severe Weather Database).



Map 2.60. Tracks of EF/F3 tornadoes in Louisiana, 1950–2012 (source: SPC Severe Weather Database).

TORNADO RISK ASSESSMENT

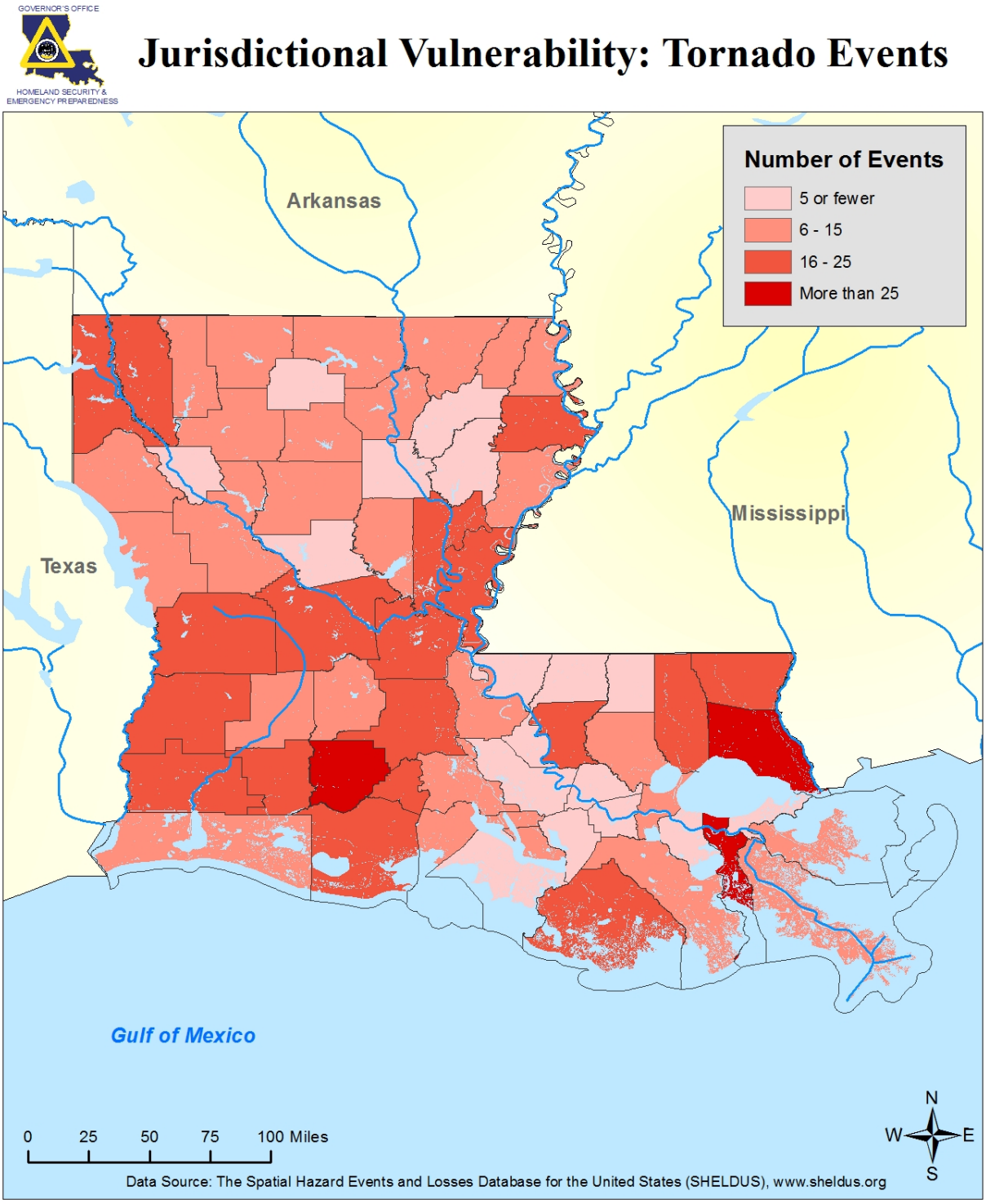
Peak tornado activity in Louisiana occurs during the spring, as it does in the rest of the United States. Nearly one-third of observed tornadoes in the U.S. occur during April and May. About half of those in Louisiana, including many of the strongest, occur between March and June. Fall and winter tornadoes are less frequent, but the distribution of tornadoes throughout the year is more uniform in Louisiana than in locations farther north. Based on historical record, illustrated in Map 2.61, the probability of future occurrence of tornadoes is **High**, and so this Plan Update provides a Risk Assessment of this hazard.



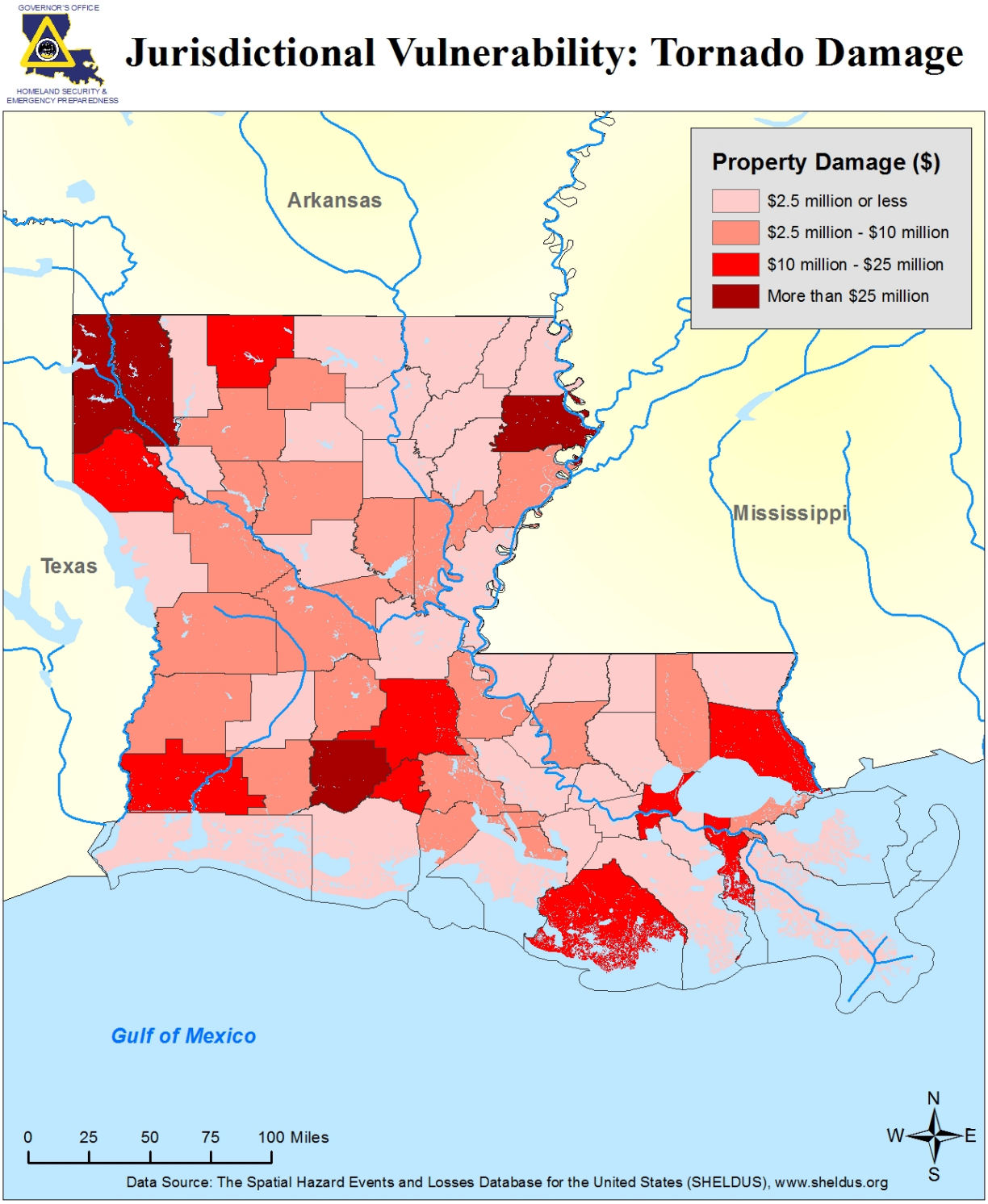
Map 2.61. Probability of tornado events in Louisiana by parish based on data from 1987–2012.

Maps 2.62, 2.63, 2.64, and 2.65 illustrate the tornado events, along with the damage, injuries, and fatalities they caused, between 1987 and 2012. Bossier Parish is at high risk (greater than 2.0 composite risk score) to tornadoes and has experienced a significant population increase of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability of Bossier Parish to tornadoes has increased. Madison Parish is at a high risk to tornadoes, but has experienced a

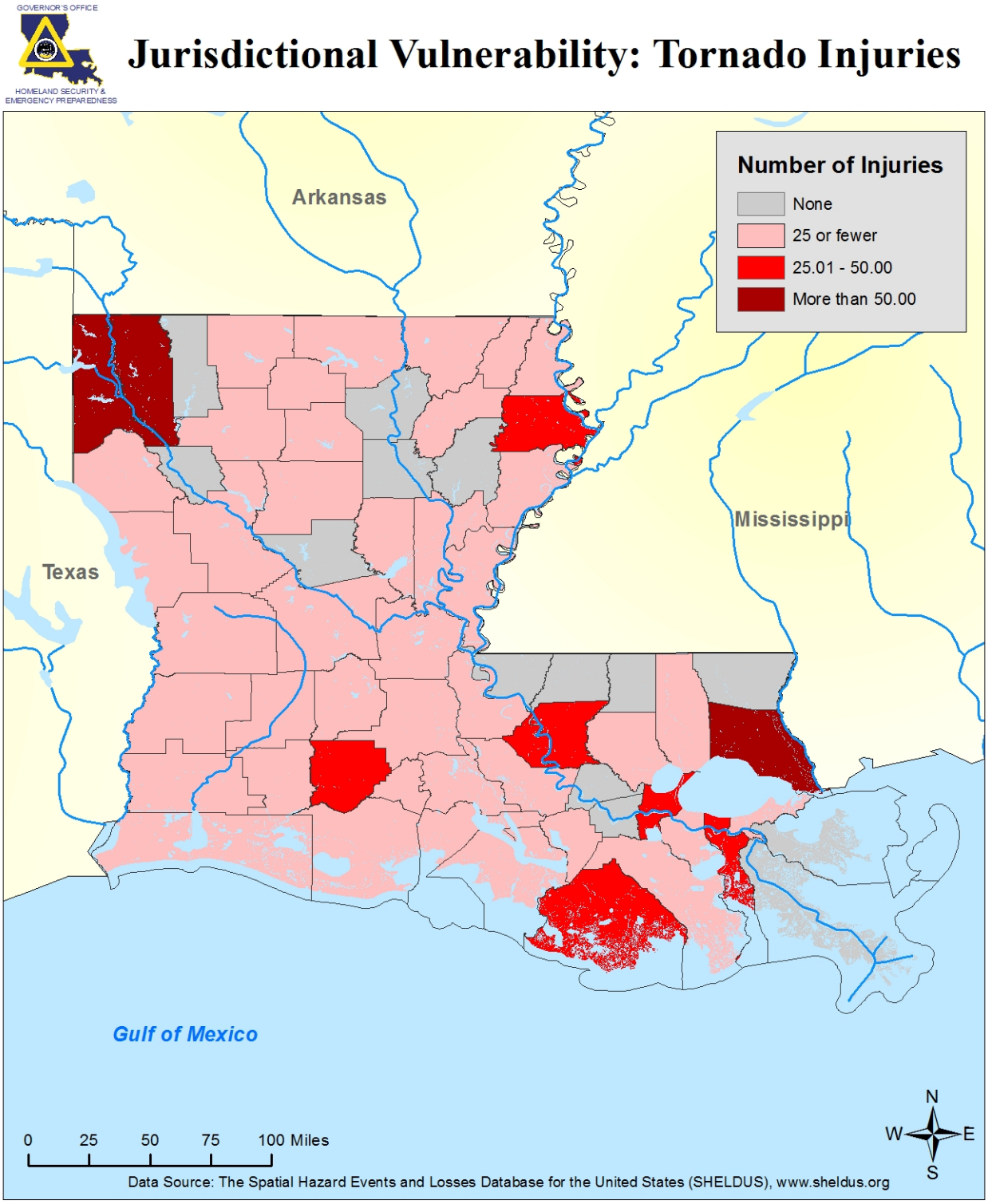
significant population decrease of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability of Madison Parish to tornadoes has decreased.



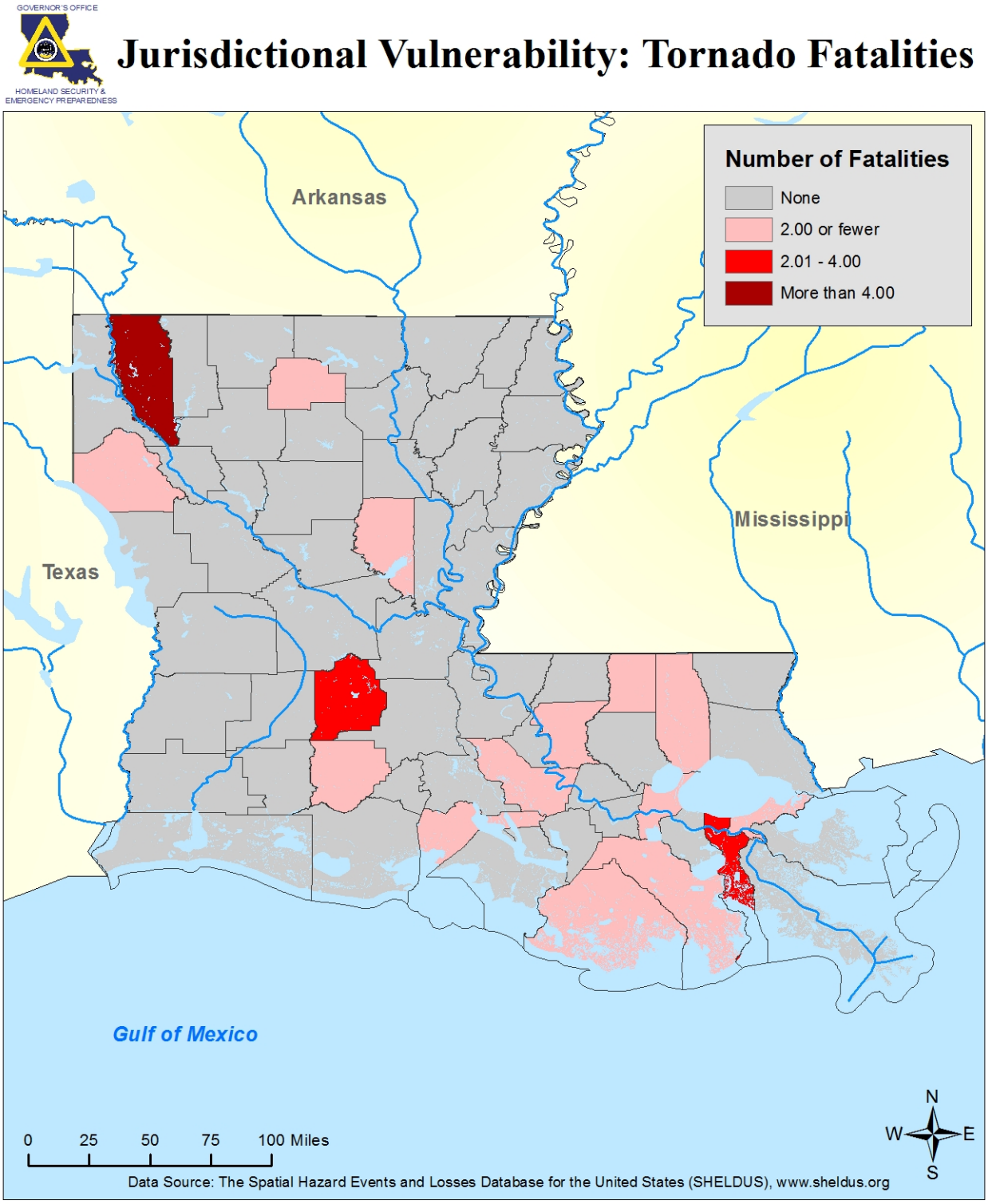
Map 2.62. Louisiana jurisdictional vulnerability for tornado events based on data from 1987–2012.



Map 2.63. Louisiana jurisdictional vulnerability for damage from tornadoes based on data from 1987–2012.



Map 2.64. Louisiana jurisdictional vulnerability for injuries from hail based on data from 1987–2012.



Map 2.65. Louisiana jurisdictional vulnerability for fatalities from hail based on data from 1987–2012.

Map 2.66 indicates the composite jurisdictional risk of tornadoes in Louisiana based on the preceding data. Much of the state is vulnerable, with tornadoes likely to recur at least once every two to four years in most parishes. In Acadia, Bossier, St. Tammany, Caddo, and Jefferson Parishes, past occurrence suggests tornadoes may recur more than once per year.

Table 2.22 details the top 10 state asset properties paid for claims from potential tornado damage. These data are based on the wind/hail-damaged claims listed earlier. State-owned critical facilities located in areas affected by tornadoes are of the following types: hospitals, shelters, Emergency Operation Centers, data processing centers, and state police troop offices.

Table 2.22. Top 10 paid claims for tornado-damaged state assets (source: Louisiana Office of Risk Management).

Top 10 Paid Claims for Tornado-Damaged State Assets				
Building ID	Building Name	Location	Net Paid	Total Number of Claims (Wind/Hail)
S12595	Jefferson Baseball Stadium	Metairie	$321,196	1
L14648	Albert Wicker Elementary	New Orleans	$102,222	1
S00519	The Louisiana Superdome	New Orleans	$91,598	1
S12851	New Orleans Center for the Creative Arts - Building F	New Orleans	$45,791	1
S12852	New Orleans Center for the Creative Arts - Building E	New Orleans	$40,243	1
S12816	Alario Center	Westwego	$37,106	1
S12088	Crescent City Connection Bridge	New Orleans	$16,664	1
S10958	LSU Health Services Center - Boiler	New Orleans	$12,977	1
S11071	LSU Health Services Center - Physical Plant	New Orleans	$10,859	2
L16375	Lord Beaconsfield Landry High School	Algiers	$9,587	1

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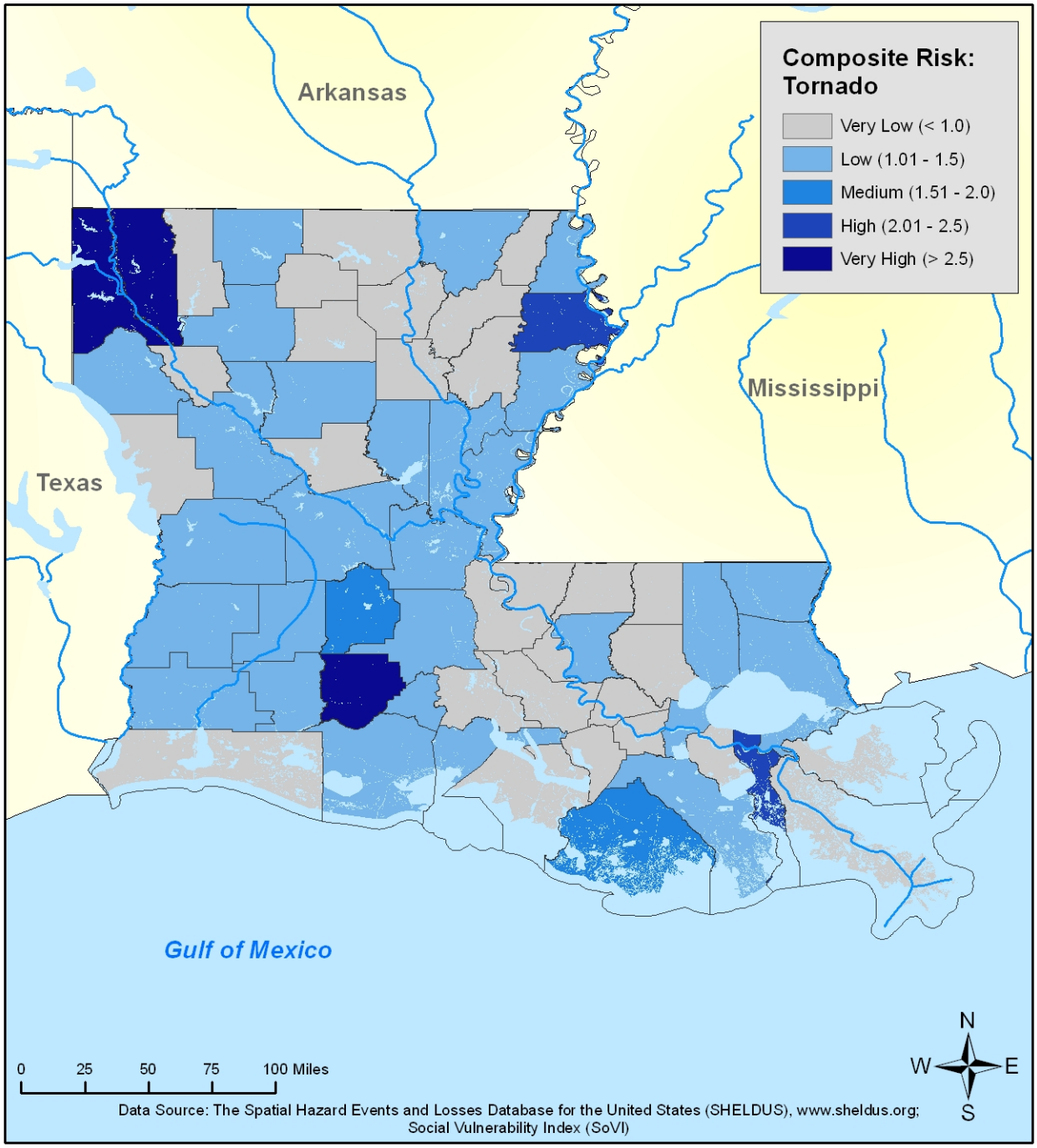
Jurisdictional Vulnerability: Tornado Composite Risk



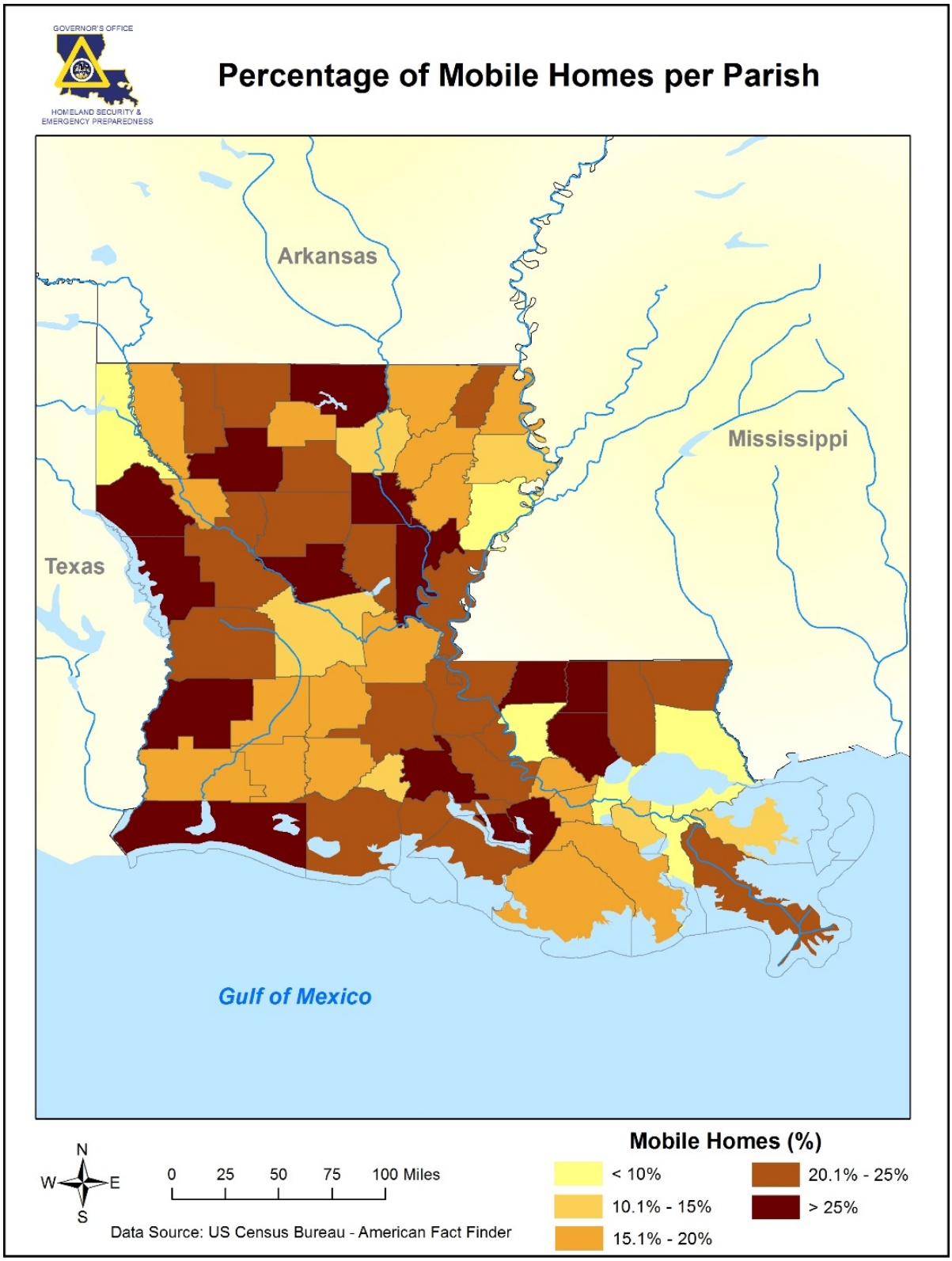
Map 2.66. Composite risk map for tornadoes showing parishes with the highest historical and highest potential risks across Louisiana.

Table 2.23 shows the overall exposure for high-risk parishes based on the Hazus-MH 2.1 inventory database, and the percentage of residences comprising mobile home structures in each parish. Mobile home structures are particularly vulnerable to tornadoes since they often lack a foundation and can be more easily moved and destroyed by high wind since they are not built to withstand high wind speeds.

Table 2.23. Exposure data for high-risk parishes.

EXPOSURE DATA FOR PARISHES WITH HIGHEST TORNADO RISK			
Parish	Population (2010)	Total Exposure ($1,000)	Mobile Homes (%)
Acadia	61,773	$10,551,833	17.7
Bossier	116,979	$16,148,468	15.5
Caddo	254,969	$34,345,146	9.3
Calcasieu	192,768	$21,704,525	16.1
Cameron	6,839	$5,497,935	36.0
De Soto	26,656	$5,177,055	30.0
East Baton Rouge	440,171	$62,537,076	3.2
East Carroll	7,759	$2,430,145	18.3
Jackson	16,274	$6,573,859	22.5
Jefferson	432,552	$68,890,600	1.6
Jefferson Davis	31,594	$8,082,036	18.4
Lafayette	221,578	$30,145,227	11.3
Lincoln	46,735	$7,424,222	17.6
Madison	12,093	$2,712,688	14.4
Morehouse	27,979	$6,391,012	16.9
Orleans	343,829	$71,111,981	1.6
Ouachita	153,720	$19,349,689	13.7
Plaquemines	23,042	$9,583,932	24.1
Richland	20,725	$4,905,466	17.7
St. Bernard	35,897	$9,052,282	11.3
St. Charles	52,780	$11,391,140	10.1
St. Landry	83,384	$14,242,451	21.0
Tangipahoa	121,097	$13,106,990	22.4
Union	22,721	$5,591,013	27.1
Vermilion	57,999	$10,828,531	22.6
Webster	41,207	$7,109,218	20.5
West Carroll	11,604	$2,412,695	24.0
TOTALS	**2,864,724**	**$467,297,215**	**17.2 (Average)**

Map 2.67 shows the percentage of building stock comprising mobile homes by parish. Since mobile homes lead to an increase in structural vulnerability to tornadoes, greater density of mobile homes in a parish lead to an increase in jurisdictional vulnerability.



Map 2.67. Mobile homes as a percentage of homes, by parish.

Table 2.24 presents a list of parishes with more than a quarter (25%) of their building stock comprised of mobile homes.

Table 2.24. Percentage of parish buildings that are mobile homes.

PERCENTAGE (>25%) OF PARISH BUILDING STOCK COMPRISING MOBILE HOMES	
Parish	Mobile Homes (%)
Catahoula	25.3
Bienville	25.6
Grant	25.9
St. Martin	26.9
Union	27.1
Beauregard	28.4
Livingston	28.6
East Feliciana	29.6
De Soto	30.0
Caldwell	30.5
Assumption	31.4
Cameron	36.0
St. Helena	38.3
Sabine	39.7

Based on the geographic extents determined in the hazard profile and the jurisdictional vulnerability assessments, the parishes in blue in Map 2.68 have the highest risk factor with respect to tornadoes. The corridors outlined in red indicate the extent of each high risk area.

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Map 2.68. High risk areas for tornadoes.

This Plan Update also utilizes Hazus-MH 2.1 for the analysis of building exposure in each of the most vulnerable parishes by general occupancy type, detailed in Table 2.25.

Table 2.25. Building exposure by occupancy type for tornadoes.

BUILDING EXPOSURE BY GENERAL OCCUPANCY TYPE FOR TORNADOES							
Parish	Exposure Type ($1,000)						
	Residential	Commercial	Industrial	Agricultural	Religion	Government	Education
Acadia	7,979,614	1,419,342	563,874	148,772	237,546	56,573	146,112
Bossier	11,891,551	2,709,321	761,501	59,494	432,384	192,803	101,414
Caddo	24,028,899	6,808,440	1,781,362	103,056	1,140,772	226,850	255,767
Calcasieu	15,879,101	3,805,841	1,011,908	58,492	576,612	150,541	222,030
Cameron	4,209,736	691,929	393,622	37,564	90,194	38,602	36,288
De Soto	4,099,351	547,708	210,562	28,702	199,404	45,114	46,214
East Baton Rouge	44,435,690	12,153,263	2,615,210	137,030	1,511,136	960,722	724,025
East Carroll	1,686,708	359,608	121,147	56,672	127,054	39,850	39,106
Jackson	5,186,884	670,191	304,068	29,986	256,162	37,219	89,349
Jefferson	50,104,392	13,418,248	3,024,142	114,922	1,204,366	437,819	586,711
Jefferson Davis	6,364,838	911,215	320,585	64,622	239,620	75,342	105,814
Lafayette	20,352,559	6,720,522	2,019,583	101,370	430,730	219,274	301,189
Lincoln	5,441,177	1,083,517	388,514	45,284	275,472	45,226	145,032
Madison	1,993,179	379,309	109,226	59,224	118,460	25,696	27,594
Morehouse	4,880,603	788,741	239,143	83,610	272,078	61,893	64,944
Orleans	50,691,672	12,784,835	2,595,764	77,762	1,980,374	984,070	1,997,504
Ouachita	12,968,015	4,382,733	938,805	80,576	616,220	181,698	181,642
Plaquemines	7,797,736	1,087,148	385,252	20,648	170,950	52,157	70,041
Richland	3,420,917	774,645	265,348	90,184	234,316	67,130	52,926
St. Bernard	7,159,720	1,160,684	438,162	13,074	149,344	51,617	79,681
St. Charles	8,318,110	1,948,898	717,882	25,498	204,072	96,946	79,734
St. Landry	11,074,652	1,981,588	525,532	84,532	312,906	112,478	150,763
Tangipahoa	9,581,467	2,226,918	520,534	67,496	435,132	101,324	174,119
Union	4,533,455	594,390	197,758	32,350	166,228	26,885	39,947
Vermilion	8,196,283	1,596,191	631,852	69,528	161,172	57,631	115,874
Webster	5,530,603	790,119	376,432	29,676	271,698	41,297	69,393
West Carroll	1,722,320	287,341	107,687	76,142	144,518	41,231	33,456
TOTALS	**339,529,232**	**82,082,685**	**21,565,455**	**1,796,266**	**11,958,920**	**4,427,988**	**5,936,669**

Using the baseline Hazus-MH 2.1 inventory database, the Louisiana Digital Map GIS database (via LOSCO), and the U.S. Census Bureau, regional vulnerability to tornadoes was chronicled in Table 2.26.

Table 2.26. Regional vulnerability to tornadoes.

Regional Vulnerability to Tornadoes	
Vulnerable Locations	Number of Records
Louisiana Parishes	27
Dams	369
Airports	84
Communication Towers/Facilities	355
Electricity Providers/Facilities	74
Emergency Response Centers	13
Fire Stations	384
Hospitals	147
Nuclear Plants	1
Police Stations	517
Elementary/Secondary Schools	1624
Universities/Colleges	34

Louisiana has a relatively high frequency of tornadoes annually. Tornadoes cause hundreds of thousands of dollars of damage to property per year. Houses, businesses, and government infrastructure often suffer extensive damage many fatalities can be attributed to tornadoes. Disruption of traffic flow occurs not only for citizen's day-to-day traffic but also critical services such as emergency police, fire, and medical. School bus and mail routes are also disrupted due to damaged or destroyed roads and bridges. Power outages impede response and recovery times and also cause sanitation issues for communities. Schools, hospitals, grocery stores, and other critically needed and economically important facilities are damaged and closed for extended periods. Employment can also be impacted in various ways due to tornado damage.

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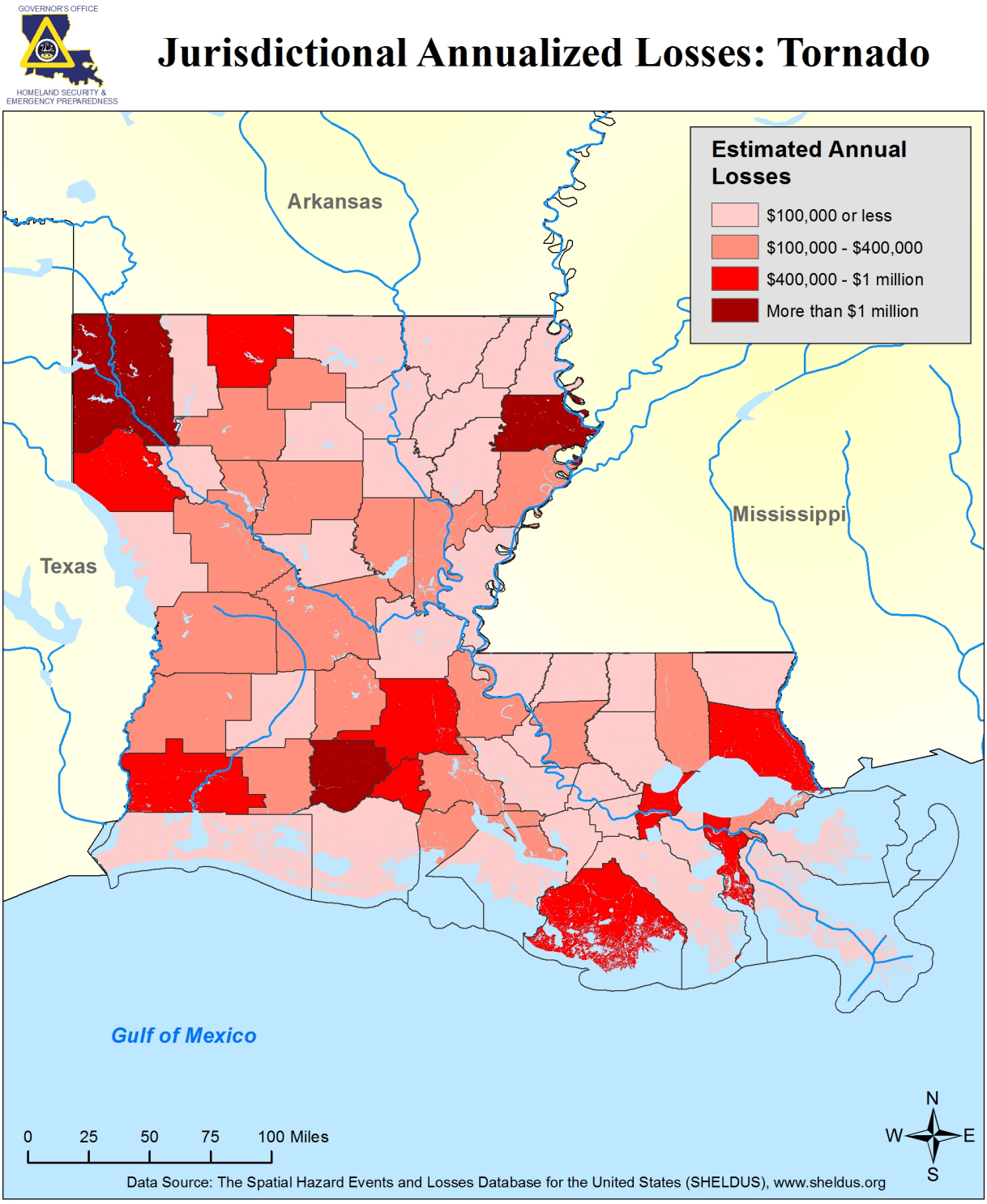
To determine potential loss estimates from tornadoes, the available historical loss data was annualized to determine future loss potential (see Map 2.69). As shown, parishes with the largest populations are predicted to have the highest potential annualized losses.



Map 2.69. Jurisdictional annualized loss due to tornadoes.

Even with advances in meteorology, warning times may be short or sometimes not possible. Overall, all of Louisiana is vulnerable to tornadoes, but northern and southwestern parishes experience the most tornadoes, while southeast Louisiana also experiences several tornadoes per year.

Poorly constructed or older homes and mobile home parks are at highest risk to sustain the greatest damage during a tornado. The direct impact of a very strong (EF3 or higher) tornado hitting a major metropolitan area could be catastrophic (as in the cases of Joplin, Missouri, and Tuscaloosa, Alabama).

Substantial damage could be incurred by state, local, and federal facilities. The damage to infrastructure would be enormous with lost power, water, sewer, gas, and communications. Roads and bridges could be damaged or at the least blocked and cluttered with debris. Continuity of government could be severely limited and emergency response would be greatly hindered. Many people could lose their homes and be displaced from their primary residence with high numbers of injuries and fatalities possible.

Potential Losses by Jurisdiction

Overview & Analysis of Potential Losses: Overall, all of Louisiana is vulnerable to tornadoes, but certain parishes are more vulnerable than others. Based on multiple sources (e.g., SHELDUS, NOAA, NCDC), the following parishes are most likely to be affected by tornadoes: Acadia, Bossier, Caddo, Calcasieu, Cameron, De Soto, East Baton Rouge, East Carroll, Jackson, Jefferson, Jefferson Davis, Lafayette, Lincoln, Madison, Morehouse, Orleans, Ouachita, Plaquemines, Richland, St. Bernard, St. Charles, St. Landry, Tangipahoa, Union, Vermilion, Webster, and West Carroll.

Among these parishes, Bossier, Caddo, Calcasieu, East Baton Rouge, Jefferson, Lafayette, Orleans, Ouachita, St. Landry, and Tangipahoa Parishes all have populations of over 80,000 and have the highest infrastructure dollar exposures within Louisiana. These ten parishes are considered to have the highest vulnerability to tornadoes within the state.

Changes in development are expected to impact loss estimates for tornadoes since any new development represents an increase in the number of structures that are vulnerable to the effects of tornadoes. Changes in jurisdictional population levels impact each parish across the state disparately. Areas of increased population growth and development, especially those in the parishes of southeast Louisiana, will experience an increase in losses from tornadoes. Although southeast Louisiana has seen the most population growth, any parish with population increases will experience greater loss. For instance, in Bossier parish, where tornado vulnerability has increased because of an increase in population, concomitant changes in development have impacted loss estimates and will cause an increase in future losses due to increased levels of exposure. In Madison parish, where tornado vulnerability has decreased

because of a decrease in population, concomitant changes in development have impacted loss estimates and will cause decrease in future losses due to decreased levels of exposure.

Potential Losses of State Facilities

The tornado wind hazard vulnerability assessment of state-owned buildings was based on the parish-level composite risk scores from Map 2.62. The criteria used to determine specific vulnerability rankings for each parish are shown in Table 2.27.

Table 2.27. High Wind Vulnerability Criteria and Ranking Results.

High Wind Vulnerability Criteria and Ranking		
Ranking	Criteria	Number of Parishes
High	Map 2.62 Composite Ranking of 2.0+	5
Medium	Map 2.62 Composite Ranking of 1.0-2.0	30
Low	Map 2.62 Composite Ranking of <1.0	29

The tornado loss estimate ranges are derived from a ratio based on the expected annual losses in parishes with high, medium, and low vulnerability rankings. The January 2014 state facilities database was used to obtain accurate building numbers for each loss estimate range. Loss estimates of State-owned buildings in Louisiana involved an analysis of the following parameters:

- Tornado Wind Hazard Vulnerability
- Previous Losses and Annual Loss Estimations

Table 2.28. Tornado Loss Estimate Ranges and Ranking Results.

Tornado Loss Estimate Ranges and Ranking		
Ranking	Total Loss Estimate Ranges	Number of Buildings
High	$37,500 to $375,000	611
Medium	$3,750 to $37,500	89
Low	$0 to $3,750	7985

Tropical Cyclones

Tropical cyclones are among the worst hazards Louisiana faces. These spinning, low-pressure air masses draw surface air into their centers and attain strength ranging from weak tropical waves to the most intense hurricanes. Usually, these storms begin as clusters of oceanic thunderstorms off the western coast of Africa, moving westward in the trade wind flow.[xlv] The spinning of these thunderstorm clusters begins because of the formation of low pressure in a perturbation in the westerly motion of the storms associated with differential impacts of the Earth's rotation. The west-moving, counterclockwise-spinning collection of storms—now called a tropical disturbance—may then gather strength as it draws humid air toward its low-pressure center, forming a tropical depression (defined when the maximum sustained surface wind speed is 38 mph or less), then a tropical storm (when the maximum sustained surface wind speed ranges from 39 mph to 73 mph), and finally a hurricane (when the maximum sustained surface wind speeds exceed 73 mph). Table 2.29 presents the Saffir–Simpson Hurricane Wind Scale, which categorizes tropical cyclones based on sustained winds.

Many associated hazards can occur during a hurricane, including heavy rain, flooding, high winds, and tornadoes.[xlvi] A general rule of thumb in coastal Louisiana is that the number of inches of rainfall to be expected from a tropical cyclone is approximately 100 divided by the forward velocity of the storm in mph; so a fast-moving storm (20 mph) might be expected to drop 5 in. of rain while a slow-moving (5 mph) storm could produce totals of around 20 in. However, no two storms are alike, and such generalizations have limited utility for planning purposes. Hurricane Beulah, which struck Texas in 1967, spawned 115 confirmed tornadoes. In recent years, extensive coastal development has increased the *storm surge* resulting from these storms so much that this has become the greatest natural hazard threat to property and loss of life in the state. Storm surge is a temporary rise in sea level generally caused by reduced air pressure and strong onshore winds associated with a storm system near the coast. Although storm surge can technically occur at any time of the year in Louisiana, surges caused by hurricanes can be particularly deadly and destructive. Such storm surge events are often accompanied by large, destructive waves exceeding 10 m in some places that can inflict high numbers of fatalities and economic losses. In 2005 Hurricane Katrina clearly demonstrated the destructive potential of this hazard, as it produced the highest modern-day storm surge levels in the state of Louisiana, reaching up to 18.7 ft. in St. Bernard Parish, near Alluvial City.[xlvii]

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Table 2.29. Saffir–Simpson Hurricane Wind Scale.

SAFFIR–SIMPSON HURRICANE WIND SCALE			
Category	Sustained Winds	Pressure	Types of Damage Due to Hurricane Winds
Tropical Depression	< 39 mph	N/A	
Tropical Storm	39-73 mph	N/A	
1	74-95 mph	> 14.2 psi	**Very dangerous winds will produce some damage:** Well-constructed frame homes could have damage to roof, shingles, vinyl siding, and gutters. Large branches of trees will snap and shallow-rooted trees may be toppled, especially after the soil becomes waterlogged. Extensive damage to power lines and poles likely will result in power outages that could last several days.
2	96-110 mph	14–14.2 psi	**Extremely dangerous winds will cause extensive damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallow-rooted trees will be snapped or uprooted, especially after the soil becomes waterlogged, and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3 (major)	111-129 mph	13.7–14 psi	**Devastating damage will occur:** Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, especially after the soil becomes waterlogged, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	130-156 mph	13.3–13.7 psi	**Catastrophic damage will occur:** Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted especially after the soil becomes waterlogged, and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (major)	157 mph or higher	< 13.7 psi	**Catastrophic damage will occur:** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

TROPICAL CYCLONE PROFILE

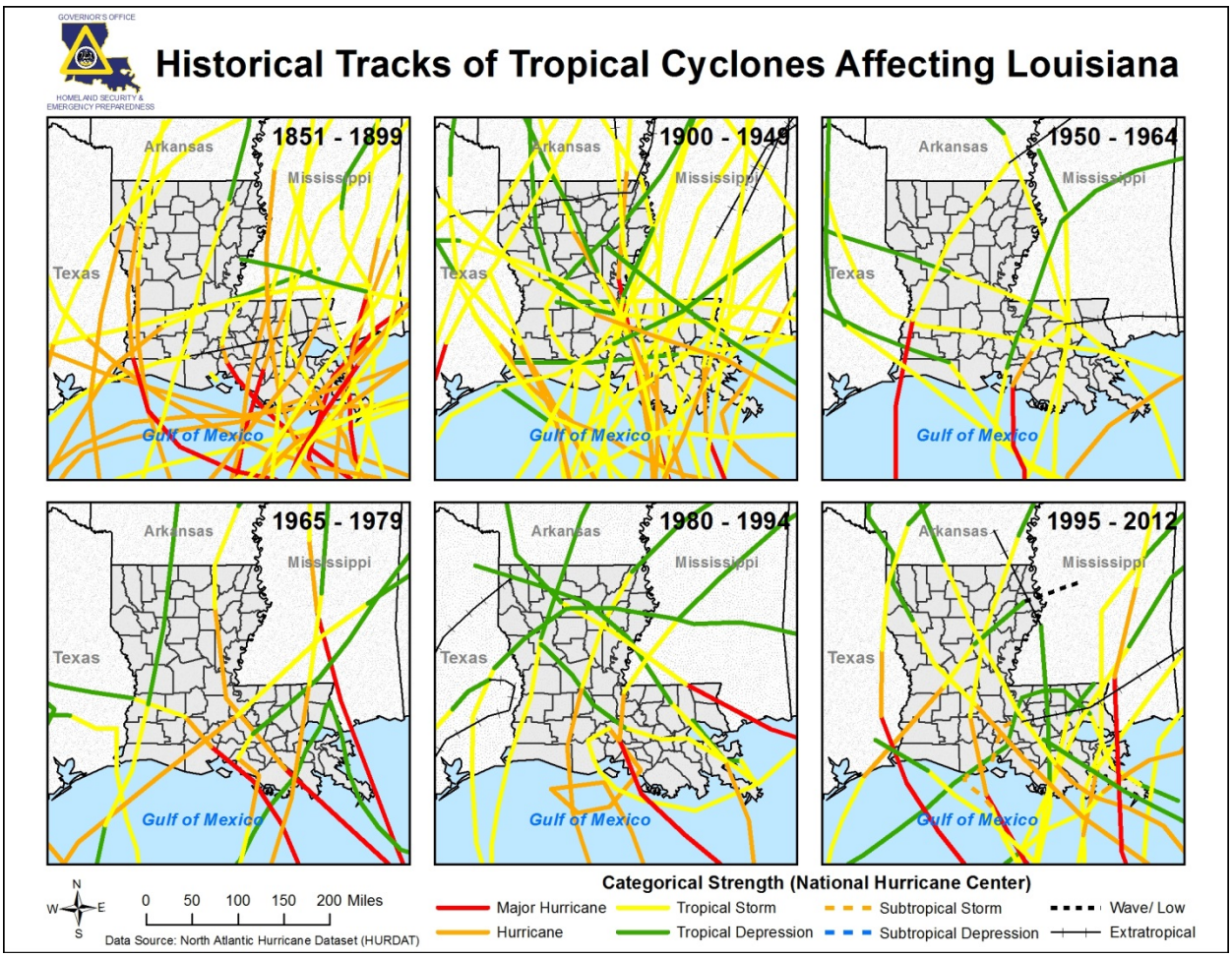
The central Gulf of Mexico coastline is among the most hurricane-prone locations in the United States, and hurricanes can affect every part of the state. Table 2.30 presents the total landfalls by tropical cyclones in Louisiana since 1900.

Table 2.30. Frequency of Louisiana Tropical Cyclones by Saffir-Simpson Category, 1900–2012 (source: NOAA/National Hurricane Center).

Total Number of Tropical Cyclones Affecting Louisiana (1900–2012)		
Strength	Coastal Landfalls	Inland Strikes[xlviii]
Tropical Storm	47	3
Category 1	18	—
Category 2	6	—
Category 3	12	—
Category 4	1	—
Category 5	1	—

Map 2.70 illustrates the tracks of tropical cyclones from 1851 to the present through a series of maps that breaks down the tracks by various periods in Louisiana history: 1851–1899, 1900–1945, 1950–1964, 1965–1979, 1980–1994, and 1995–2012. Because the time periods are not all even, trends in cyclone activity are not immediately apparent. Louisiana experienced a very active period between 1851 and 1899, illustrated by the number of major hurricanes (red lines) that tracked across the state. The period from 1900 to 1945 was much less active. While the period from 1950 to 1994 was more active than the first 50 years of the twentieth century, the second half was still a relatively quiet period of tropical cyclone activity. During the twentieth century, the state experienced a time of greater coastal development, somewhat buoyed by the fact that the coast was experiencing fewer cyclones than before or after. The period between 1995 and 2012, though, had a relatively active—and severe—period of cyclone activity in Louisiana, and coastal development sustained severe damage. As Map 2.70 illustrates, Louisiana has experienced significant tropical cyclone activity over the past 25 years. Table 2.31 lists the major storms that have affected the state from 1988 to 2002.

In the past ten years, though, Louisiana has experienced truly paradigm-shifting storms. Before discussing the storms of 2005 that have changed how the United States approaches disaster management, a review of some of the other major storms from the past ten years is warranted. Early in the hurricane season of 2003, Tropical Storm Bill made landfall near Cocodrie (Terrebonne Parish), causing widespread but minor damage, with losses reaching $38 million (2013 USD). In 2004, both Hurricane Ivan and Tropical Storm Matthew struck the state, the first in September, the second in October. Ivan was a major storm, reaching Category 5 before landfall, but dying down to a tropical depression when it made first landfall in Alabama. However, Ivan looped back into the Gulf and strengthened into a tropical storm before landing near Cameron, Louisiana (Cameron Parish). Overall, the storm caused 25 deaths in the United States and resulted in $16 billion (2013 USD) in damages. Perhaps most significantly, Ivan was a precursor of the catastrophes that occurred during the 2005 hurricane season. Roughly one-third of New Orleans' residents evacuated before Ivan struck, with major traffic jams blocking the few routes out of the city.



Map 2.70. Tropical cyclone paths across Louisiana by sub-periods from 1851 to 2012.

In September 2007, Hurricane Humberto formed quickly over the northwestern Gulf of Mexico, becoming the fastest-forming hurricane ever. Although Humberto made official landfall in Texas, his wind field was expansive enough that he delivered hurricane-force winds across southwestern Louisiana, although he ultimately caused relatively little damage. In 2008, a series of significant storms struck Louisiana. The season began with the smaller Tropical Storm Edouard, which caused some storm surge activity in Cameron Parish. In late August, though, Hurricane Gustav made landfall near Cocodrie as a strong Category 2 hurricane, spurring millions of residents to evacuate. He tracked northwest across the state, leaving significant wind damage and heavy rain (see Maps 2.73 and 2.74 for the geographic extent of precipitation totals and wind speeds, respectively). The high winds caused three deaths and spawned tornadoes in the state, and storm surge was a major problem. Indeed, for many communities across the state, including Baton Rouge, Gustav was the most severe hurricane in memory. Ultimately, 48 deaths were attributed to the storm.

Table 2.31. Features of Louisiana's major tropical cyclones: 1988-2012 (source: David Roth's *Louisiana Hurricane History* [Camp Springs, MD: National Weather Service, 2010], http://www.hpc.ncep.noaa.gov/research/lahur.pdf).

INFORMATION ON TROPICAL CYCLONES AFFECTING LOUISIANA (1988–2012)				
Tropical Cyclone Name	Date	Highest Category	Louisiana Deaths[xlix]	Louisiana Damages (2013 USD)
Hurricane Florence	9 Sept. 1988	1	0	~$5 million
Hurricane Andrew	26 Aug. 1992	5	2	~$1.6 billion
Hurricane Opal	4 Oct. 1995	4	0	~$307,000
Tropical Storm Josephine	5–8 Oct. 1996	Tropical Storm	0	~$8.2 million
Hurricane Danny	18 July 1997	1	0	~$2.2 million
Hurricane Earl	31 Aug.–3 Sept. 1998	2	0	~$170,000
Tropical Storm Frances	8–13 Sept. 1998	Tropical Storm	1	~$712 million
Hurricane Georges	15 Sept.–1 Oct. 1998	4	0	~$25 million
Tropical Storm Allison	5–17 June 2001	Tropical Storm	1	~86 million
Tropical Storm Bertha	4–9 Aug. 2002	Tropical Storm	0	~$195,000
Hurricane Isidore	14–27 Sept. 2002	3	1	~$429 million
Hurricane Lili	21 Sept.–4 Oct. 2002	4	2	~$1 billion

Just after Gustav struck, Hurricane Ike affected Louisiana in a unique but important way: he never made landfall in Louisiana, but had a severe impact on the state from his widespread winds, intense rainfall, and extensive storm surge (see Maps 2.73 and 2.74 for the geographic extent of precipitation totals and wind speeds, respectively). In fact, Ike is the only hurricane on record to have produced storm surge for every coastal parish in the state. Moreover, Ike re-flooded a number of areas that had only recently been flooded by Gustav. A year after Gustav and Ike, Hurricane Ida closed out a quiet 2009 hurricane season, barely reaching Louisiana and only peripherally affecting the state, but still making history as the first tropical storm on record to affect Louisiana in November.

As disastrous as the storms of 2008 were, the tropical cyclones of 2005 have had an even more significant and lasting legacy on national views on disaster management. Of course, the risks of natural and human-caused disasters that could create catastrophic incidents in Louisiana were well known prior to 2005, but the impact of that hurricane season on the Gulf Coast brought about a new level of planning and engagement related to disaster response, recovery, and hazard mitigation, perhaps akin to the Great Mississippi Flood of 1927. Actually, the whole 2005 North Atlantic hurricane season was historic, as it produced more tropical storms and hurricanes than any in recorded history.[l] In terms of the state, though, the season confirmed

fears about Louisiana's extreme exposure to natural disasters and the compounding effects of engineered flood-protection solutions. Moreover, Hurricanes Katrina and Rita hit three weeks apart, together causing damage estimated between $104 and $162 billion (2013 USD), making the two events the first and third costliest natural disasters in U.S. history, respectively.[li] Nearly 1600 individuals in and around New Orleans perished when area levees and floodwalls failed. Officially, 1836 deaths in states affected by the storm have been attributed to Katrina, and 705 others remain missing. On the second anniversary of Katrina, New Orleans' population remained one-third lower than before the storm and more than 200,000 people remained displaced.[lii] Like Katrina, Rita was also a truly catastrophic event, and the two storms highlighted a hurricane season that was unparalleled in U.S. history.

For Louisiana, the season actually began in early July with Hurricane Cindy, a storm that was originally classified as a tropical storm on landfall, but later upgraded to a Category 1 hurricane for a brief period through post-seasonal analysis.[liii] Cindy landed near Grand Isle (Jefferson Parish) and tracked across southeastern Louisiana, Mississippi, and Alabama, finally moving up the Atlantic coast. The worst discomfort for most Louisianians in the path of Cindy was flooding and an extended blackout in New Orleans.

In late August, Hurricane Katrina began as a broad area of low pressure and became a Category 1 hurricane moving across southern Florida. She weakened over Florida, but once in the Gulf waters, she strengthened quickly. The storm reached Category 3 status by the 27th, having also grown in size. This change resulted in slower wind speeds, which consequently led to a lower internal pressure. Early in the hours of the 28th, Katrina was upgraded to Category 4 and was upgraded again only hours later to Category 5. A mandatory evacuation of New Orleans was ordered—the first in history.[liv]

Katrina made landfall on the morning of the 29th, moving in as a weak Category 4 storm.[lv] Storm surges were recorded as being between 18 and 22 ft., with some regions experiencing surges up to 28 ft. See Map 2.71 for the geographic extent and qualitative reach of peak wind gusts and surge depth during Katrina, and see Map 2.72 for estimated losses due to both wind gusts and storm surge by census block group.

It was after the storm veered away from the city that levees began to breach around the city, leaving 80% of the city under water. In addition to the tragic loss of human life, the extensive mixing of water with raw sewage, bacteria, metal, pesticides, and other chemicals has led to ecosystem damage in the New Orleans area that could last for decades.[lvi]

Only six weeks later, Hurricane Rita tracked into the Gulf, quickly achieving Category 5 status. She had dropped to a Category 3 as she neared landfall in Louisiana. Nevertheless, the storm surges Rita produced reached 15 ft. in Cameron and around 8 ft. at Grand Lake and Calcasieu Lake (all in Cameron Parish). Such surges occurred even farther inland, in Vermilion, Iberia, and St. Mary Parishes—areas that had recently been flooded by Katrina. In Jefferson, Terrebonne, and Orleans Parishes, levees were overtopped; in New Orleans, several levees that were damaged by (but had survived) Katrina finally succumbed to storm-surge stress, keeping most

of the city flooded until early October.[lvii] The extensive surge damage was exacerbated by winds of 105–115 mph (and some ninety tornadoes), as well as rainfall amounting to 9–15 in. all across the southern parishes (see Maps 2.73 and 2.74 for the geographic extent of the precipitation totals and wind speeds). Due to great evacuation efforts and the fact that the hardest-hit regions were sparsely populated, the storm only resulted in seven deaths. Economic losses amounted to about $12 billion (2013 USD).[lviii]

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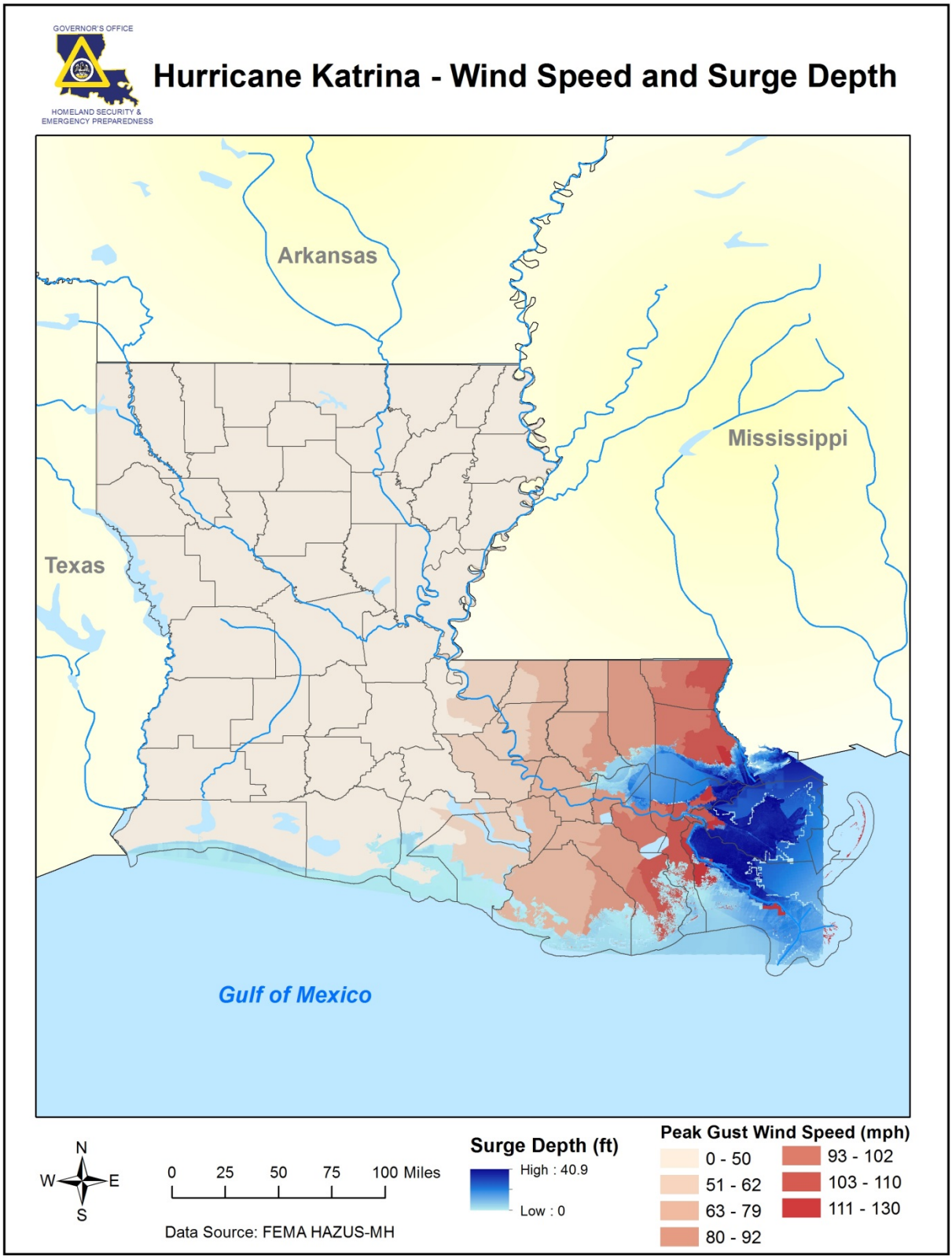
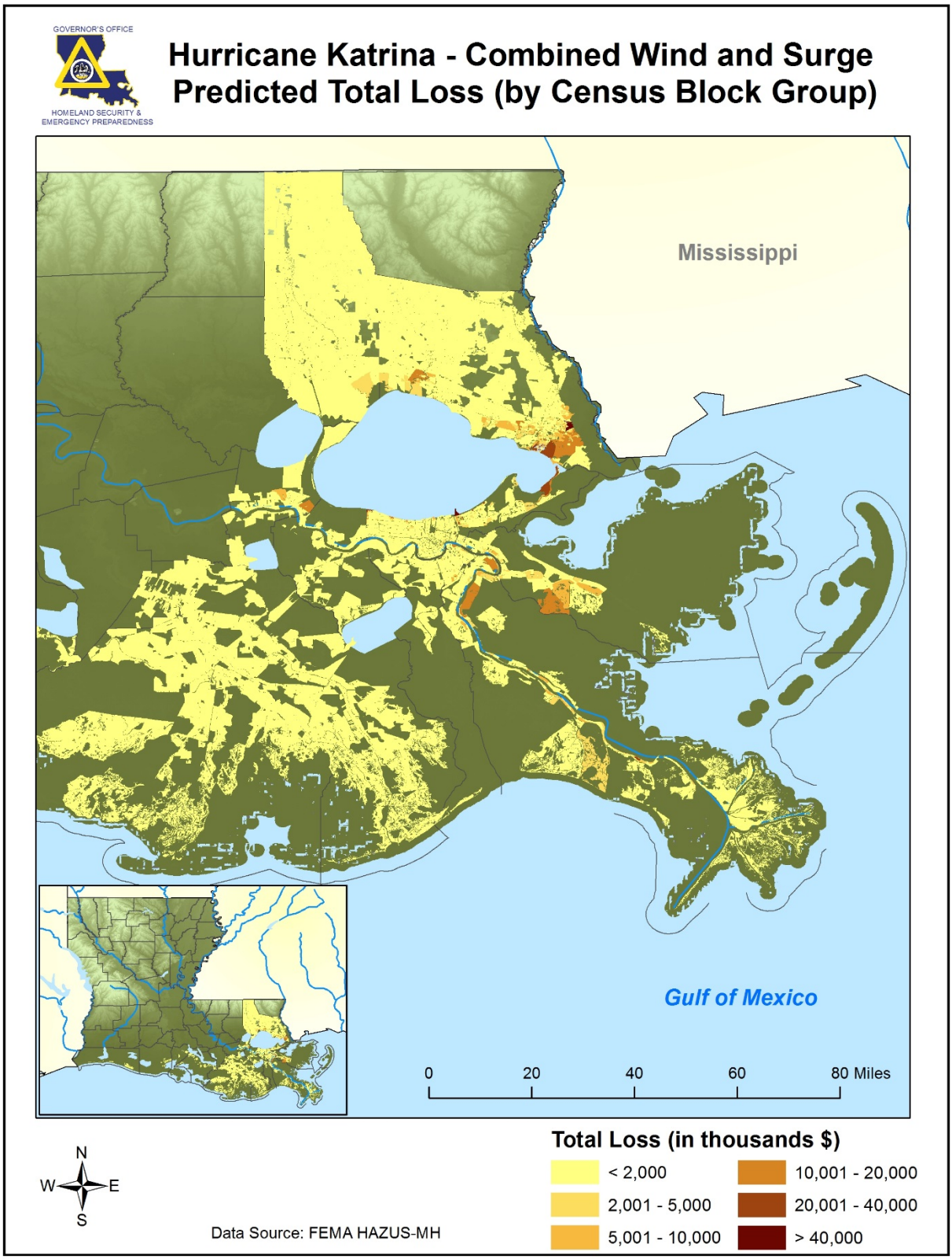
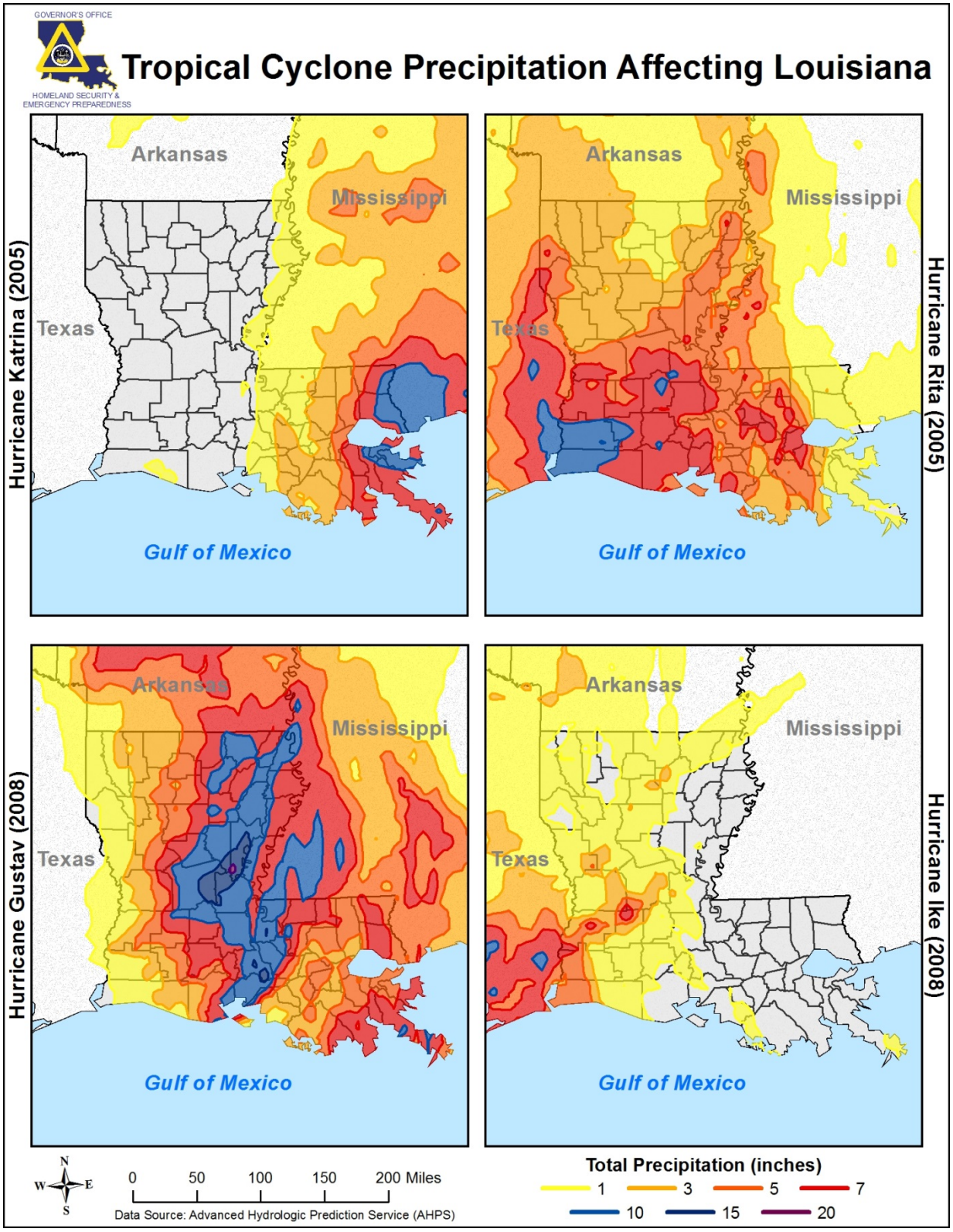


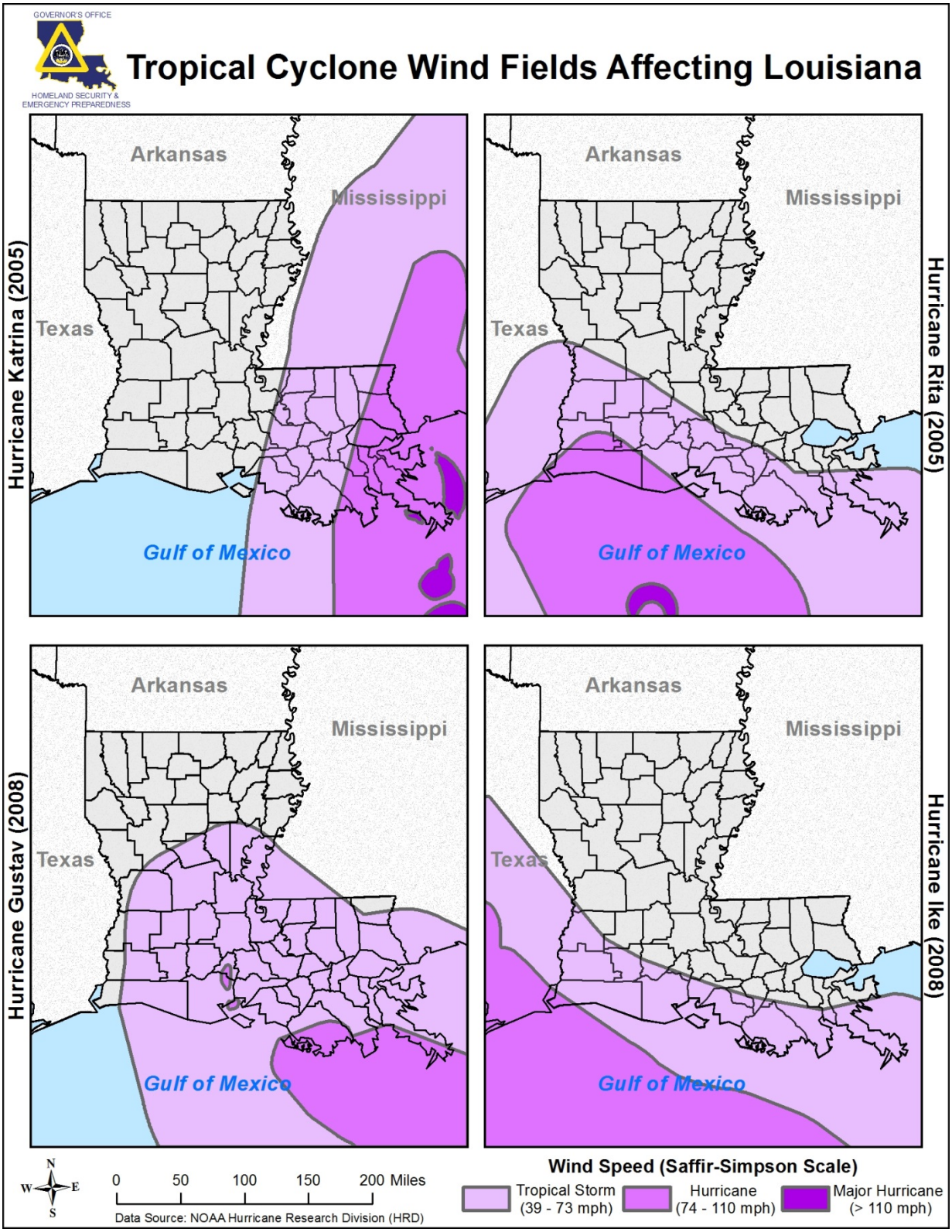
Map 2.71. Peak gust wind speeds and maximum storm surge depths for Hurricane Katrina; modeled using Hazus Combined Wind and Coastal Flooding Model.



Map 2.72. Combined wind and storm surge losses for areas affected by *both* wind and storm surge (by census block group) during Hurricane Katrina; calculated using the Hazus Wind and Coastal Flood Model.



Map 2.73. Precipitation totals due to major hurricanes, 2003–2013.



Map 2.74. Wind speeds due to major hurricanes, 2003–2013.

Tropical Cyclone Risk Assessment

While the 2005 hurricane season dwarfs most seasons (even 2008) in every category, Louisiana has continued to experience memorable storms over the past three years. While 2010's Tropical Storm Bonnie was a relatively weak system, it still caused enough destruction to total $867,000 (2013 USD) in damages to the state from flooding and wind damage.[lix] Tropical Storm Lee dumped rain of 1–5 in. across most of Louisiana, with up to 10–15 in. in some southern parishes.[lx] The storm's effect in Texas, as well as the mid-Atlantic and northeastern United States, helpfully illustrates the strange interrelation of environmental hazards across disparate geographic regions. Lee's rains did not end up mitigating the drought conditions in Texas, but his high winds ironically contributed to major wildfire outbreaks. Furthermore, in a number of northern and mid-Atlantic states (Pennsylvania, New York, New Jersey, Connecticut, Virginia, and Maryland), Lee caused extensive, disastrous, unexpected flooding. In all, Lee caused 21 deaths and $1.35 billion in damages throughout the whole United States.[lxi]

One of the most unusual hurricanes for Louisiana in recent memory was the slow-moving Hurricane Isaac, which resulted in five deaths and $622 million (2013 USD).[lxii] The storm produced very large storm surges, leading to three of the total deaths attributed to the storm. Rainfall was extensive, peaking at 23 in., and leading to flash and riverine flooding (see Maps 2.75 and 2.76 for the geographic extent of precipitation totals and wind speeds from the storm).

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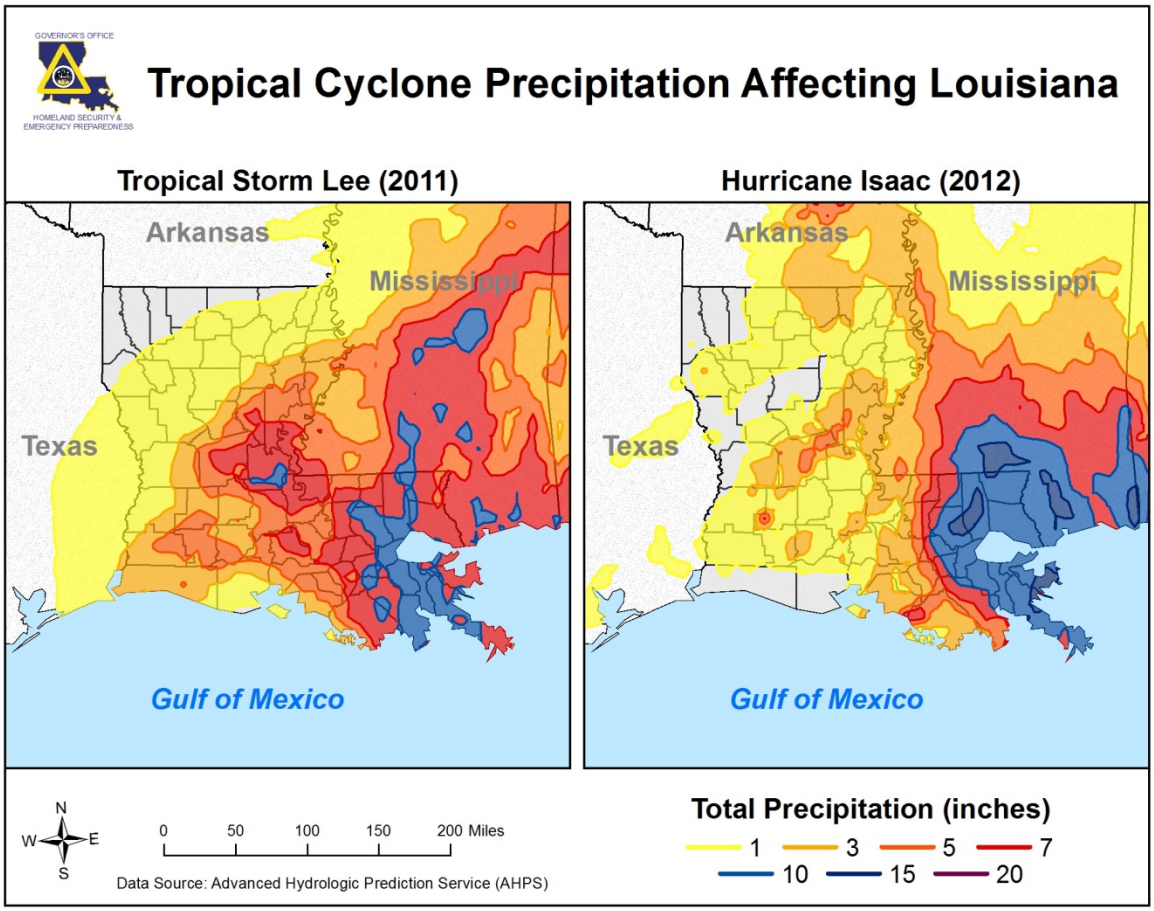

Map 2.75. Precipitation totals from Tropical Storm Lee and Hurricane Isaac.

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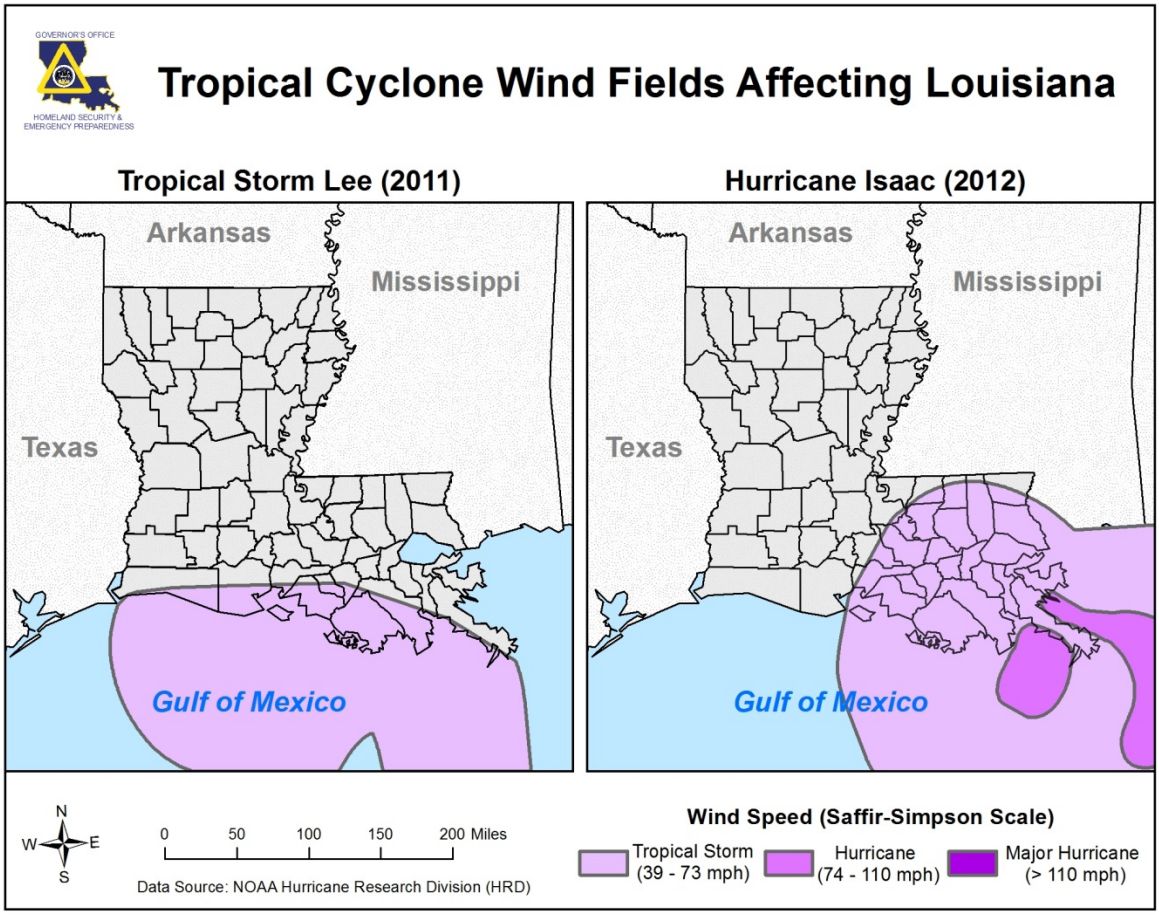

Map 2.76. Wind speeds from Tropical Storm Lee and Hurricane Isaac.

Based on previous occurrences, and as Map 2.77 indicates, the probability of future likelihood for a hurricane hitting Louisiana is **Medium**, however, the impacts can be catastrophic, as this section has shown.

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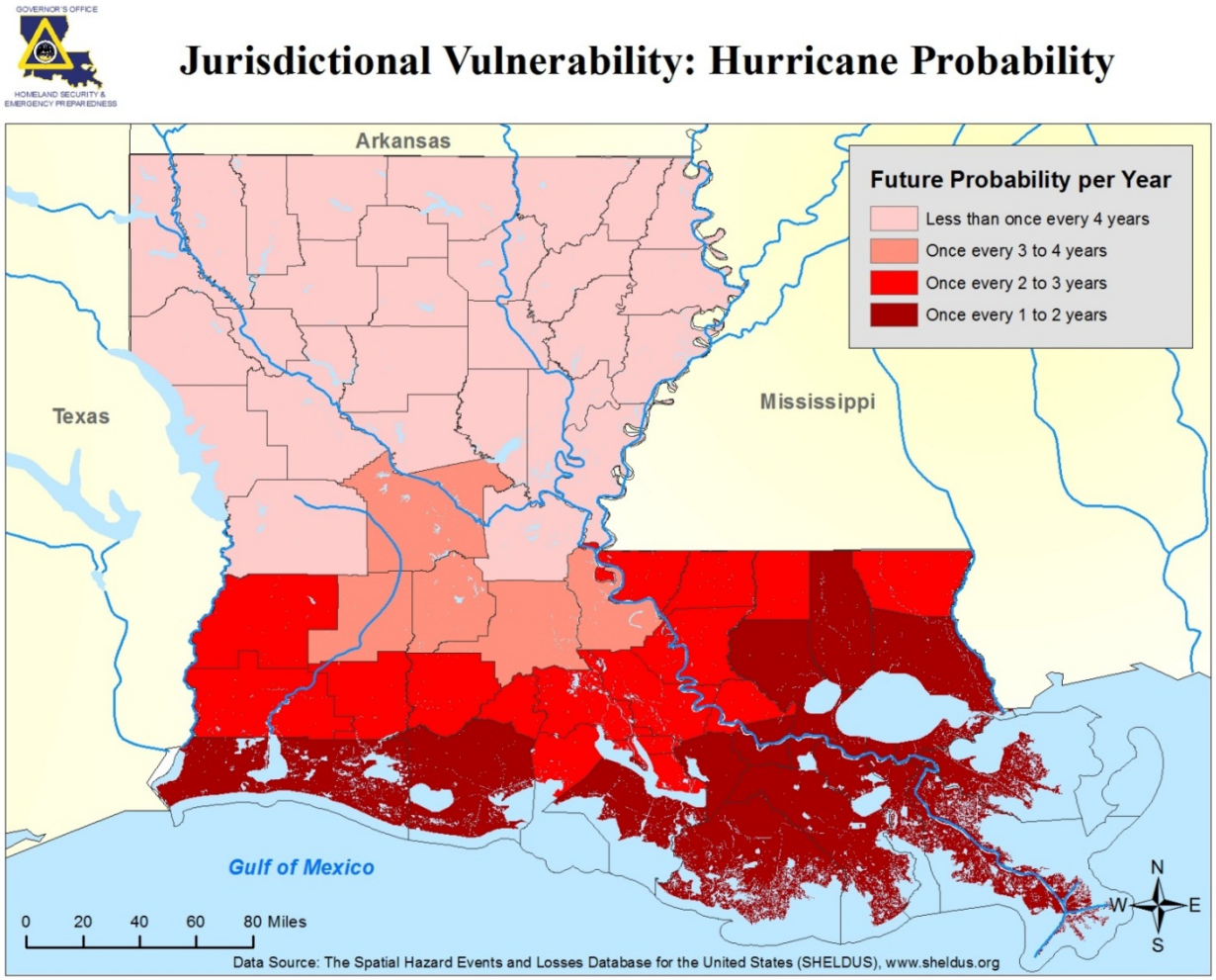

Map 2.77. Probability of future tropical cyclone events in Louisiana by parish based on data from 1987–2012.

Potential Economic Loss

To estimate damage and economic loss for the state of Louisiana due to tropical cyclones, this Plan draws on data from a level 1 analysis using FEMA's Hazus-MH 2.1 economic loss modeling software in order to evaluate both historical record and probability of future occurrence. The analysis uses the default "general building stock" and "essential facility" databases that are built into the model. These databases are derived from national-level data sources for (1) building square footage, (2) building value, (3) population characteristics, (4) costs of building repair, and (5) economic data. Direct economic and social losses associated with the general building stock are computed, as are estimates of essential facility functionality, short-term shelter need, and debris. Damages and economic loss are modeled by building type and occupancy for Hurricanes Katrina and Isaac, and Tropical Storm Lee. Hazus-MH 2.1 estimates losses of approximately $3.559 billion for Katrina, $446.3 million for Isaac, and $105.6 million for Lee. Table 2.32 details these estimations.

Table 2.32. Direct economic loss for residential buildings modeled with Hazus-MH.

DIRECT ECONOMIC LOSSES BY RESIDENTIAL BUILDINGS FROM RECENT TROPICAL CYCLONES								
Event	Total Loss	Building Damage Loss	Content Damage Loss	Inventory Loss	Relocation Loss	Coastal Related Loss	Wages Loss	Rental Income Loss
Katrina	$3,559,050,000	$2,441,778,000	$603,803,000	$4,831,000	$274,090,000	$32,190,000	$56,223,000	$146,134,000
Isaac	$446,344,000	$353,128,000	$69,301,000	$15,000	$11,950,000	$1,267,000	$989,000	$9,694,000
Lee	$105,691,000	$81,673,000	$23,689,000	$0	$148,000	$0	$0	$181,000

Wind speed, extent of damage, impacted critical facilities, and total building losses can be generated using the analysis results for each hurricane. Maps 2.78 and 2.79 show peak wind gusts and total residential building losses (in thousands of dollars) after Hurricane Katrina, as given by the Hazus analysis results. Maps 2.80 and 2.81 show peak wind gusts and total residential building losses after Hurricane Isaac, and Maps 2.82 and 2.83 show peak wind gusts and total residential building losses after Tropical Storm Lee.

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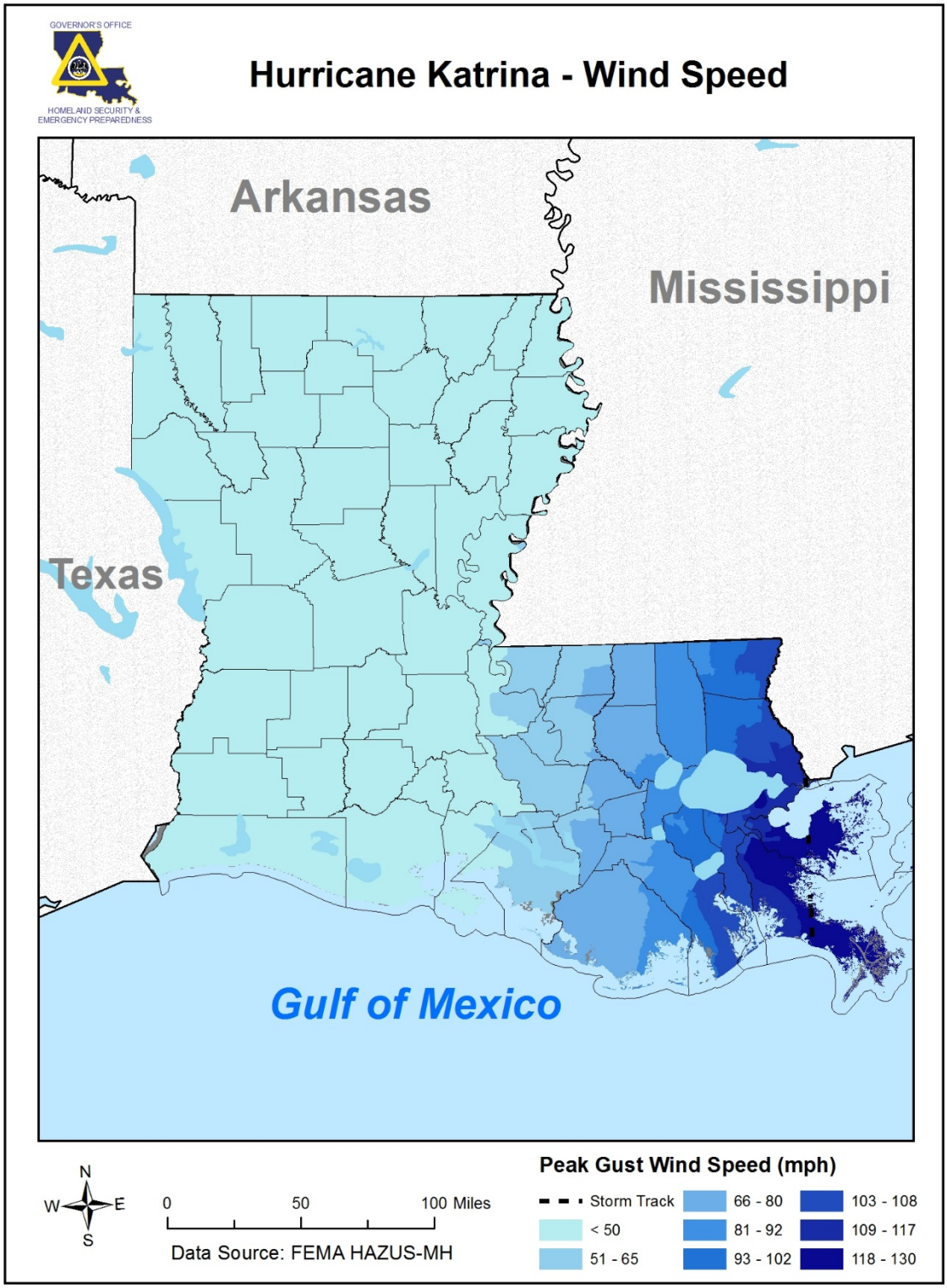
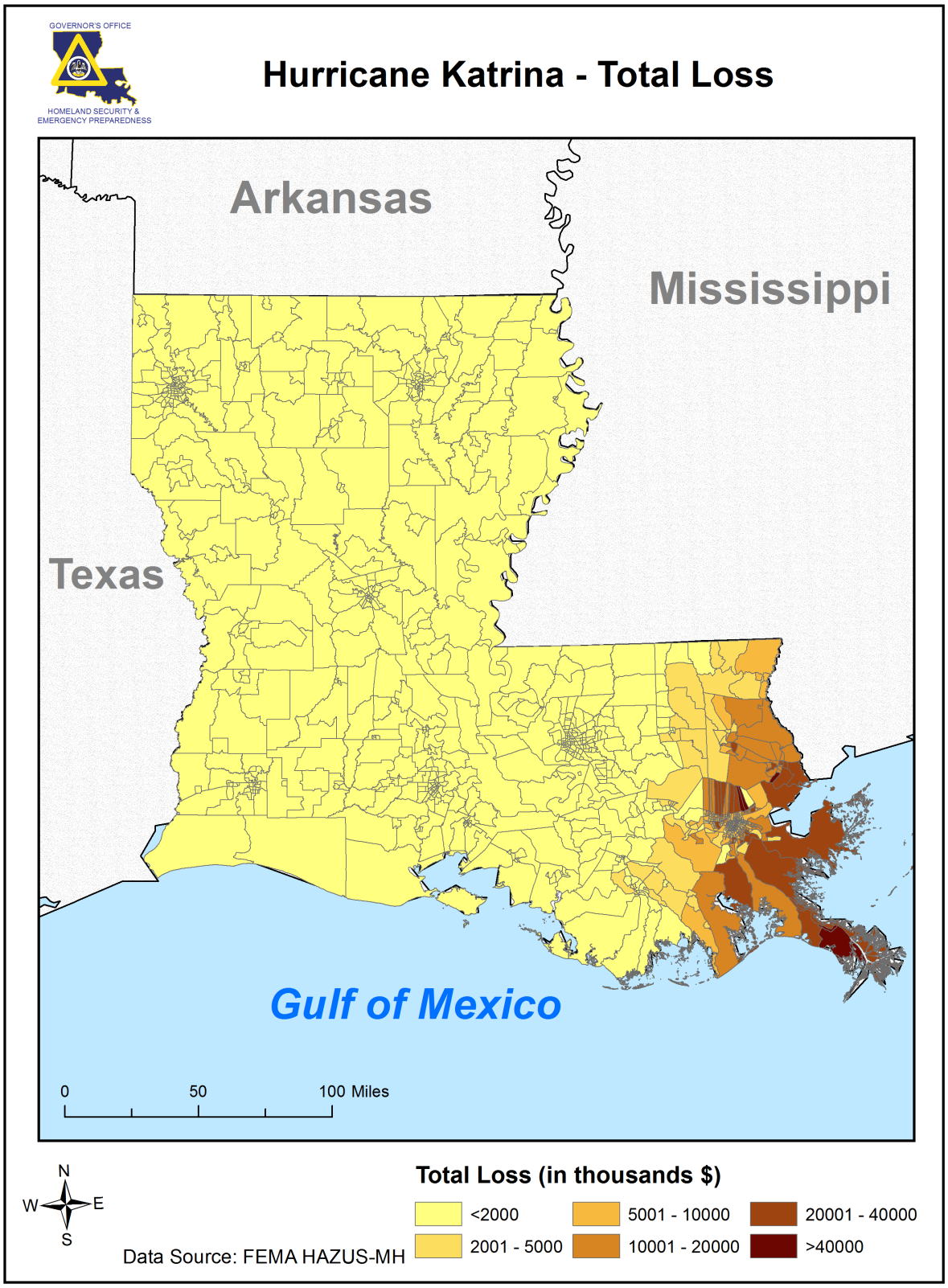
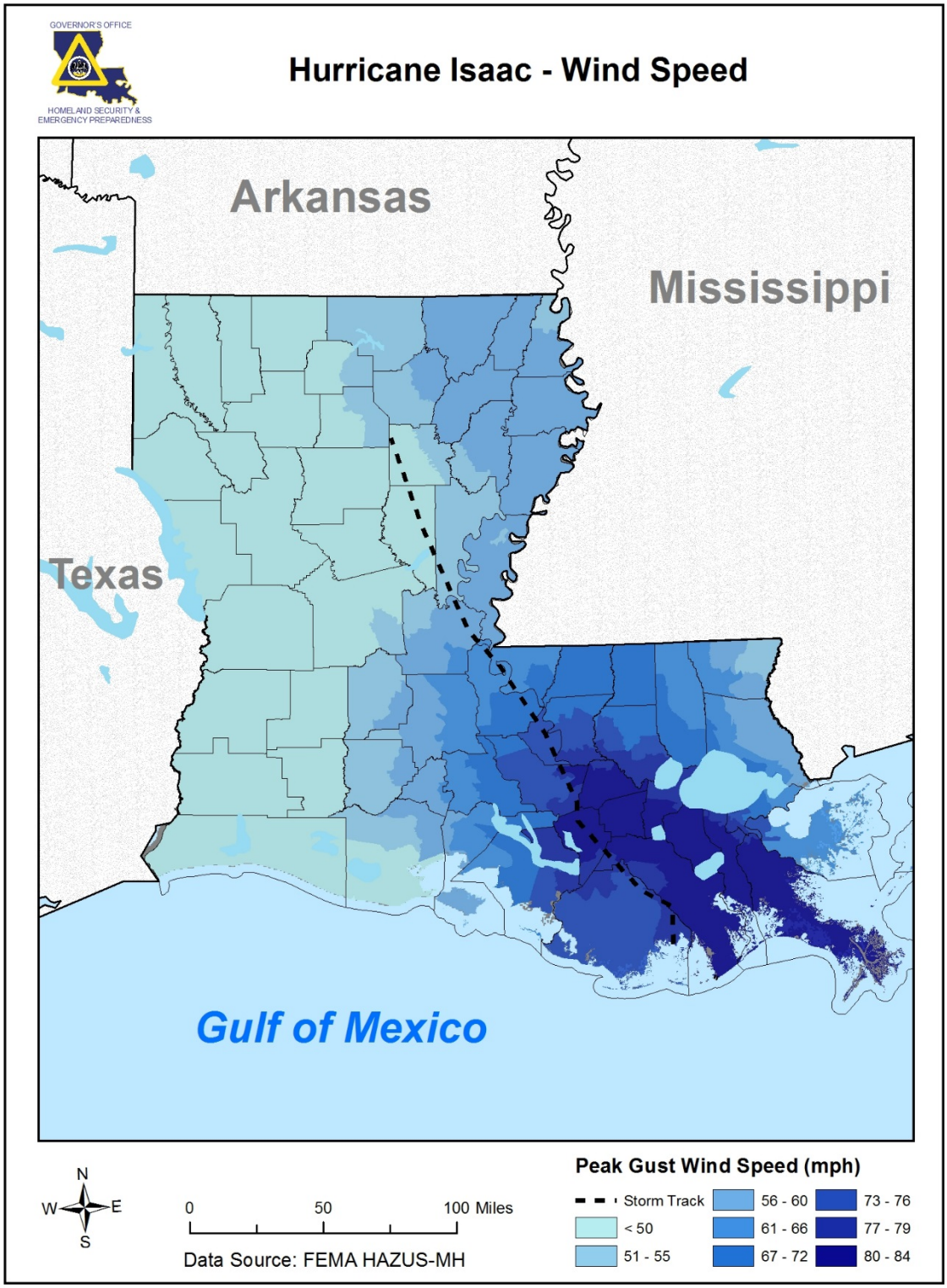


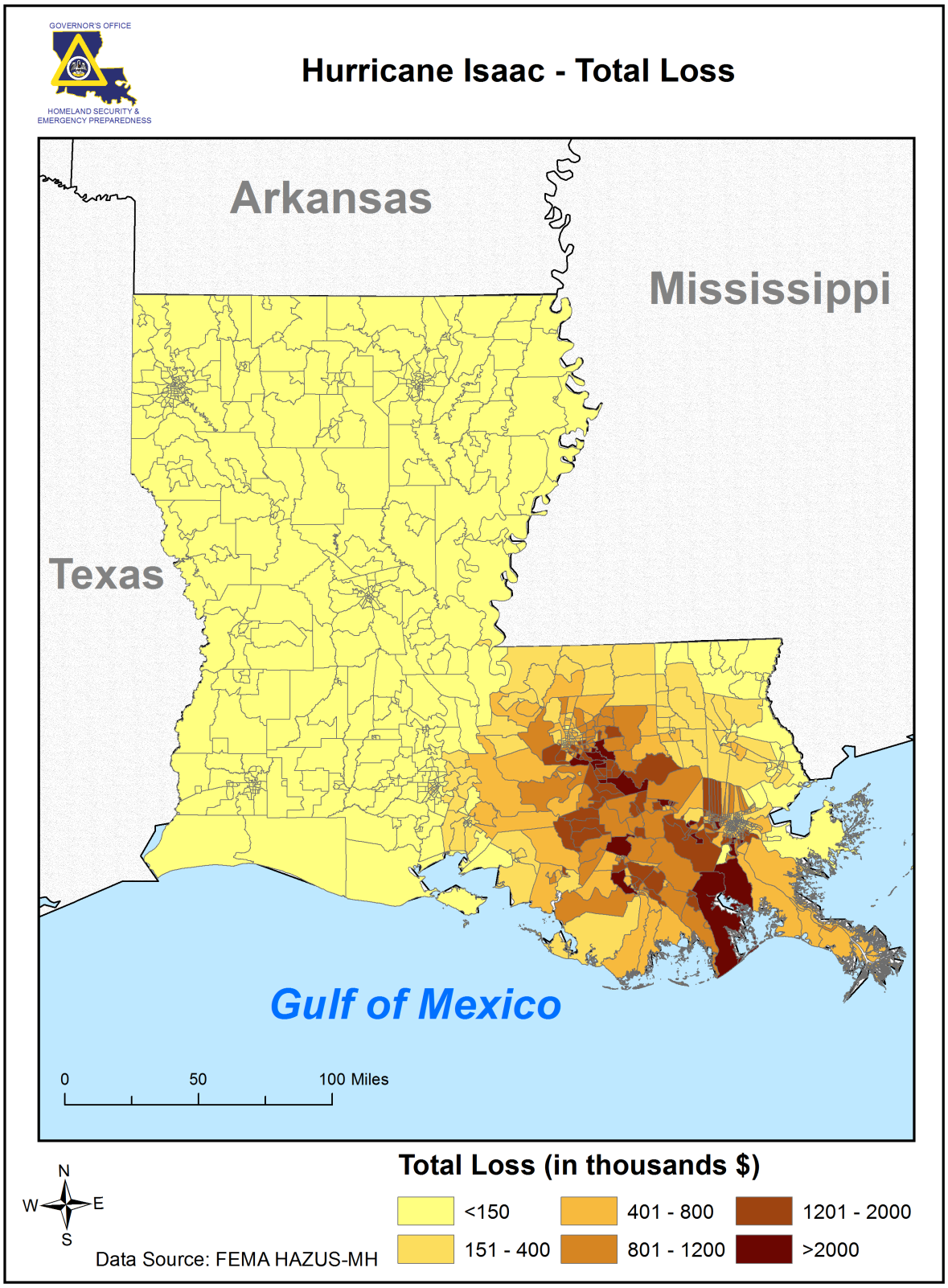
Map 2.78. Peak wind gusts during Hurricane Katrina based on Hazus modeling.



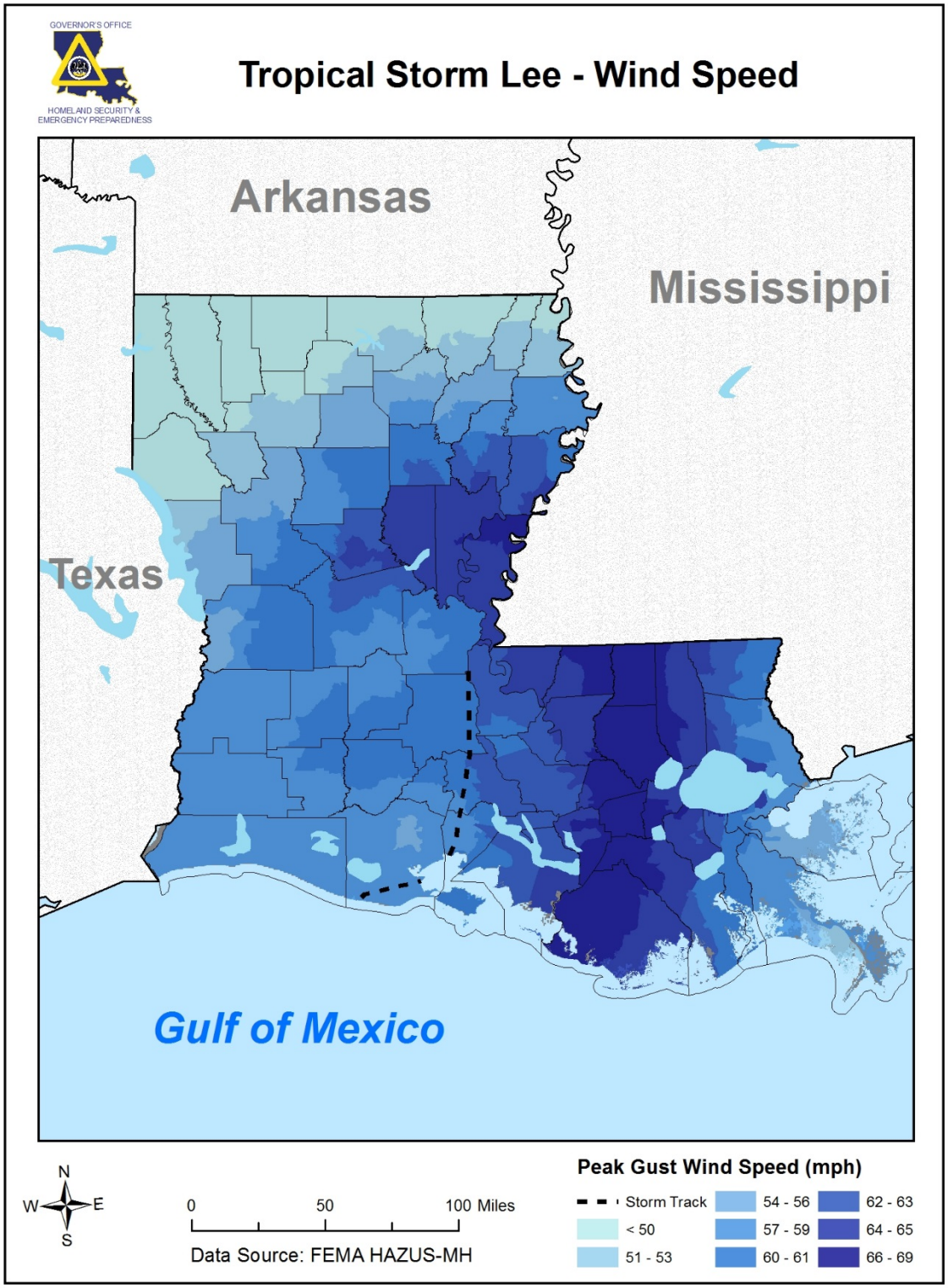
Map 2.79. Total residential building losses after Hurricane Katrina based on Hazus modeling.



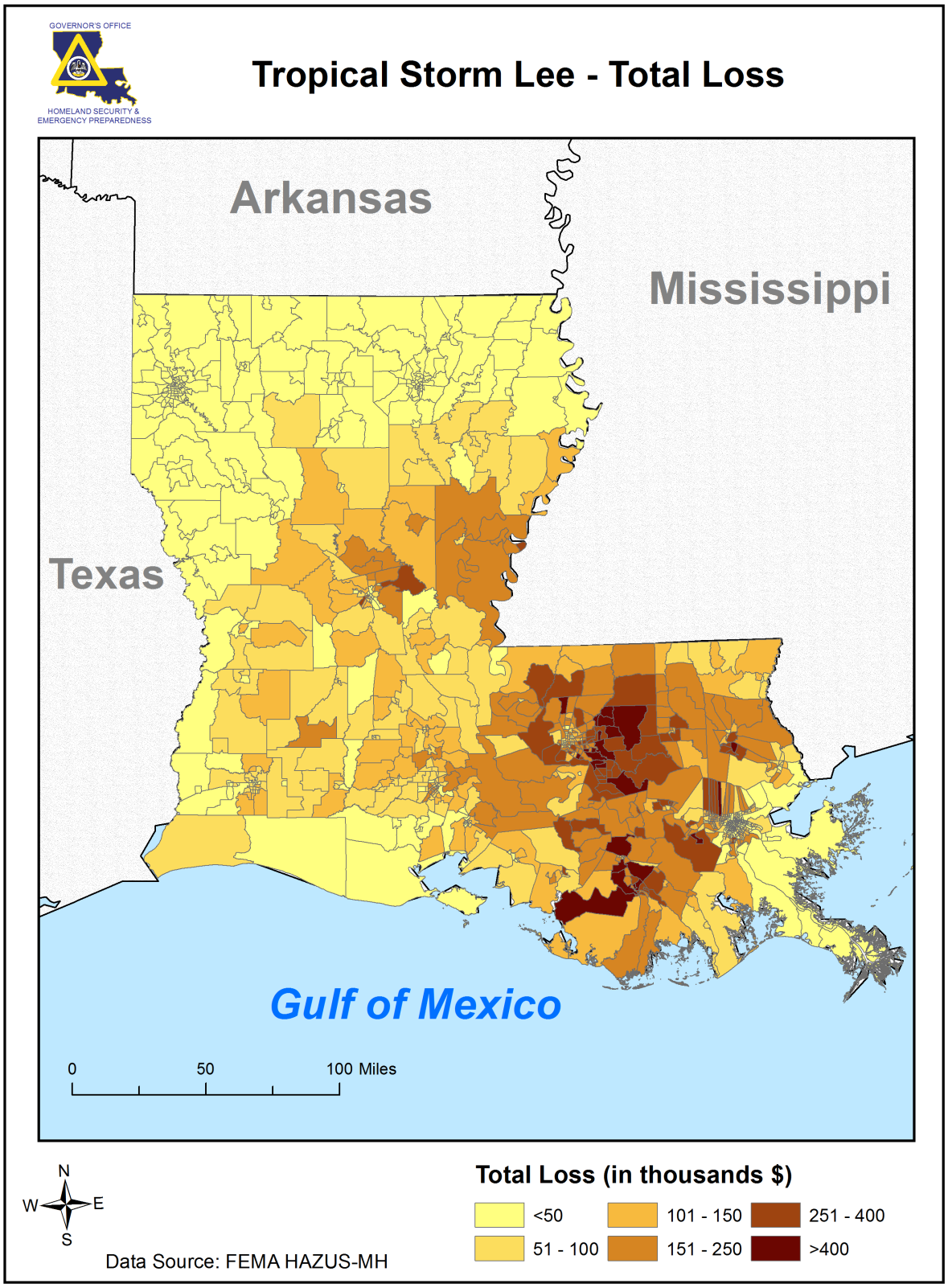
Map 2.80. Peak wind gusts during Hurricane Isaac based on Hazus modeling.



Map 2.81. Total residential building losses after Hurricane Isaac based on Hazus modeling.



Map 2.82. Peak wind gusts during Tropical Storm Lee based on Hazus modeling.



Map 2.83. Total residential building losses after Tropical Storm Lee based on Hazus modeling.

Possible future damage and economic loss are modeled by building type and occupancy for 10-, 50-, 100-, and 500-yr return period storms. Hazus-MH estimates losses of approximately $751.5 million for a 10-yr return period storm, $9.6 billion for a 50-yr, $19.1 billion for a 100-yr and $53.1 billion for a 500-yr hurricane event for the entire state. Table 2.33 details these estimations.

Table 2.33. Projected direct economic loss ($1,000) for residential buildings for 10-, 50-, 100-, 500-yr hurricane events.

Projected Economic Loss ($1,000) for Residential Buildings in Various Tropical Cyclone Events								
Event	Total Loss	Building Damage Loss	Content Damage Loss	Inventory Loss	Relocation Loss	Capital Related Loss	Wages Loss	Rental Income Loss
10-yr	$751,506	$533,421	$138,028	$2,000	$45,990	$5,092	$7,943	$19,032
50-yr	$9,643,209	$5,791,507	$2,337,131	$32,678	$895,703	$108,815	$137,915	$339,461
100-yr	$19,096,732	$11,264,910	$4,857,973	$82,156	$1,703,026	$248,625	$304,191	$635,851
500-yr	$53,132,249	$30,792,164	$14,231,400	$150,744	$4,219,211	$872,389	$1,043,856	$1,853,570

Wind speed, extent of damage, impacted critical facilities, and total building losses can be generated using the analysis results for 10-, 50-, 100- and 500-yr hurricane events. The following maps show the projected (1) peak wind gusts, (2) moderate damage and impacted critical facilities, and (3) residential building losses. In Hazus, police stations, medical offices, and fire stations are presumed to be able to continue operating with some temporary rearrangement and departmental relocation after sustaining moderate damage. The location of police stations, medical offices, and fire stations in damaged areas during the storm are shown on the maps. Maps 2.84, 2.85, 2.86 show the projected peak wind gusts, moderate damage and impacted critical facilities, and residential building losses for a 10-yr hurricane event. State-owned critical facilities located in areas affected by tropical cyclones are of the following types: hospitals, shelters, Emergency Operation Centers, data processing centers, and state police troop offices.

Maps 2.87, 2.88, 2.89 show the projected peak wind gusts, moderate damage and impacted critical facilities, and residential building losses for a 50-yr hurricane event.

Maps 2.90, 2.91, 2.92 show the projected peak wind gusts, moderate damage and impacted critical facilities, and residential building losses for a 100-yr hurricane event.

Maps 2.93, 2.94, 2.95 show the projected peak wind gusts, moderate damage and impacted critical facilities, and residential building losses for a 500-yr hurricane event.

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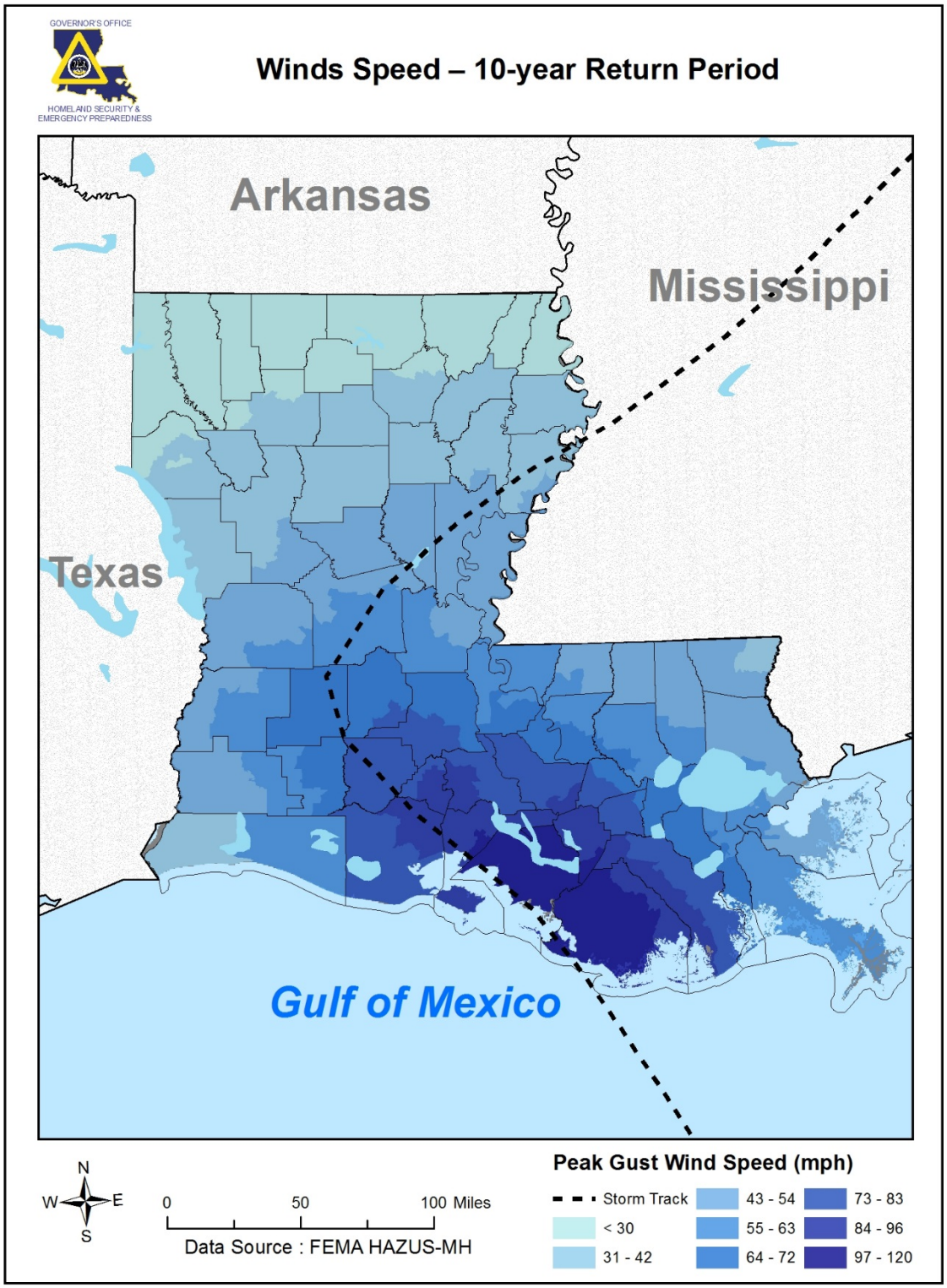
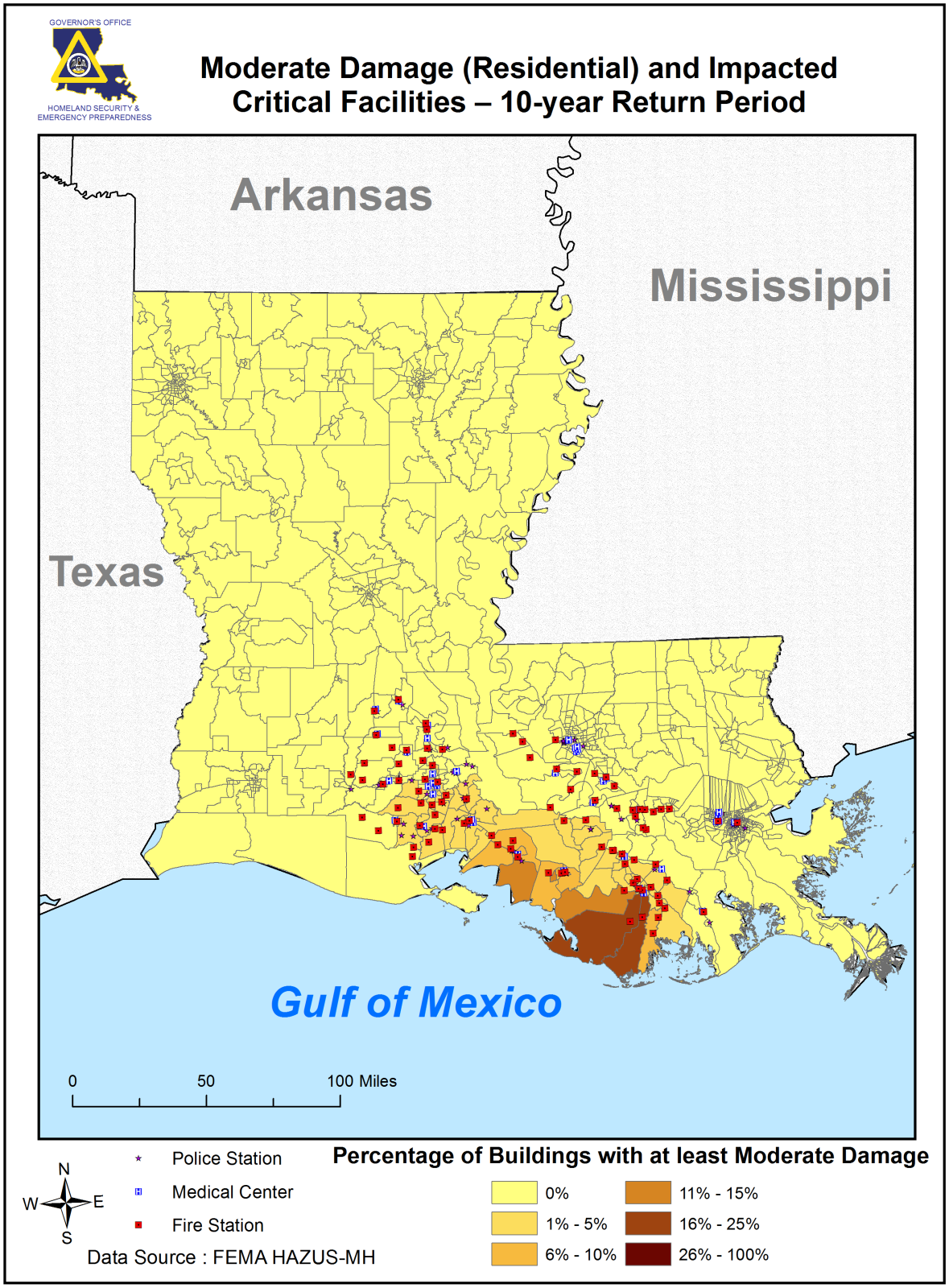
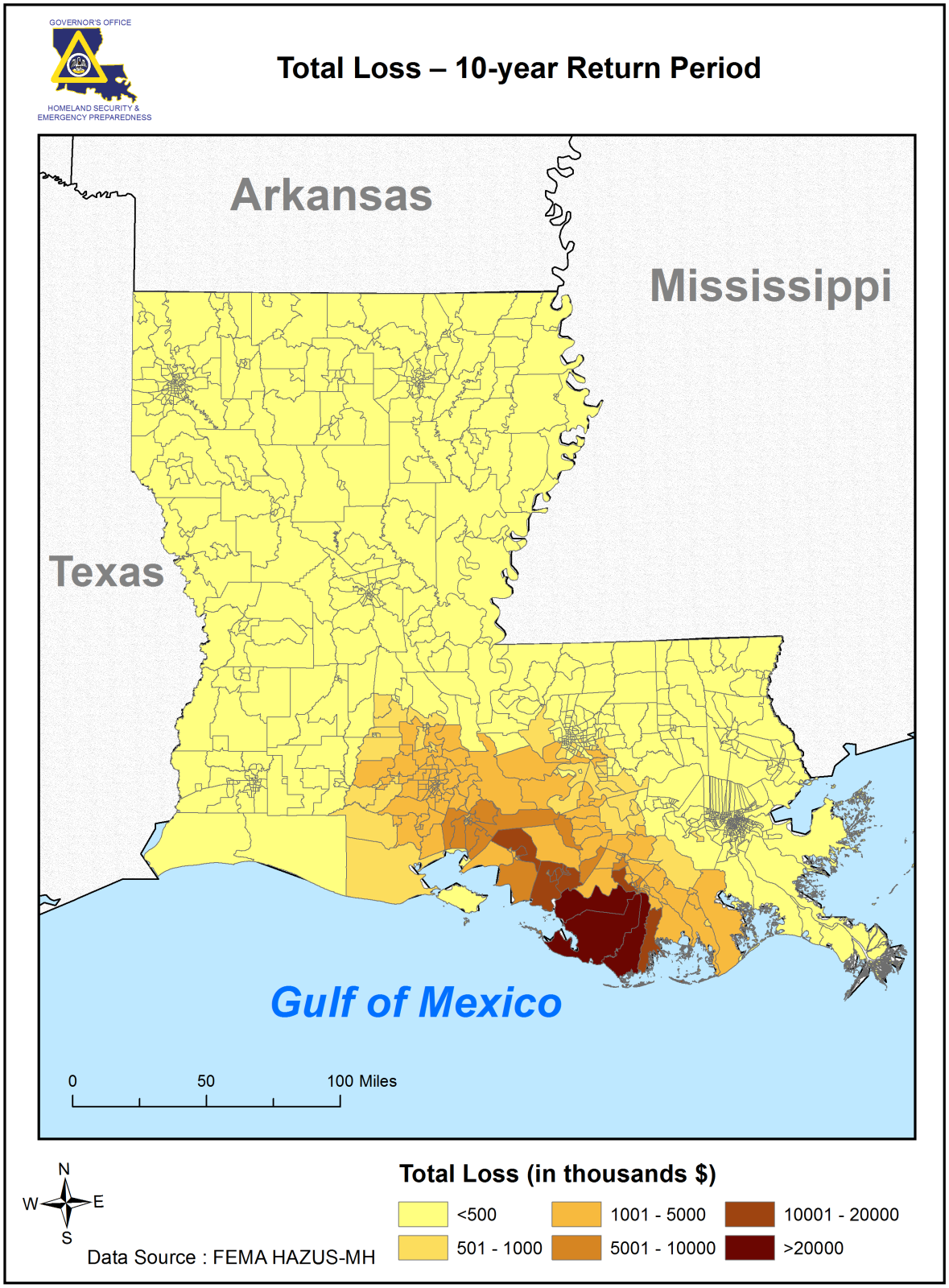


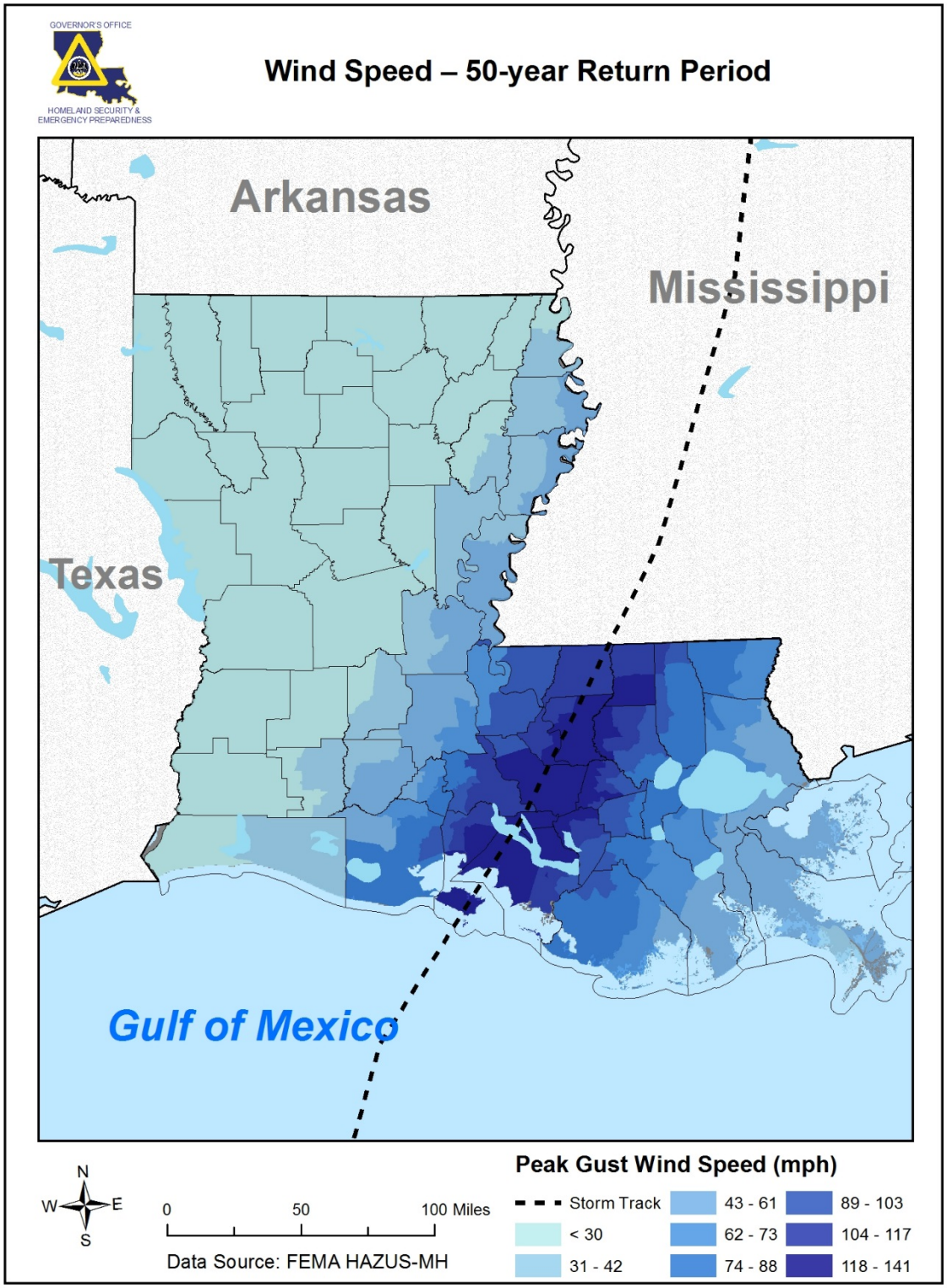
Map 2.84. Projected peak wind gusts during a 10-yr hurricane event, based on Hazus modeling.



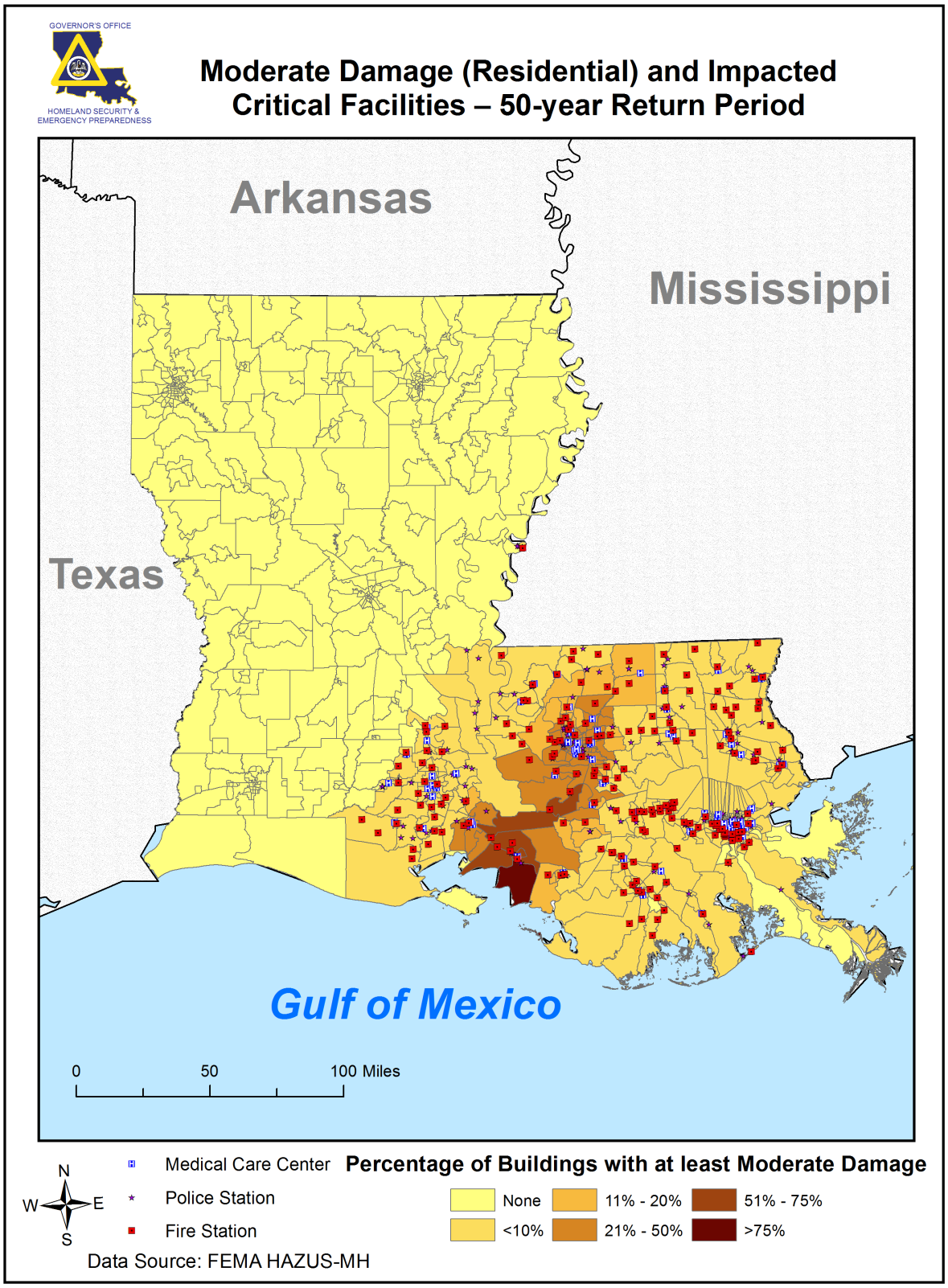
Map 2.85. Projected percentage of moderately damaged residential buildings and critical facilities (medical care center, police station, and fire station) after a 10-yr hurricane event.



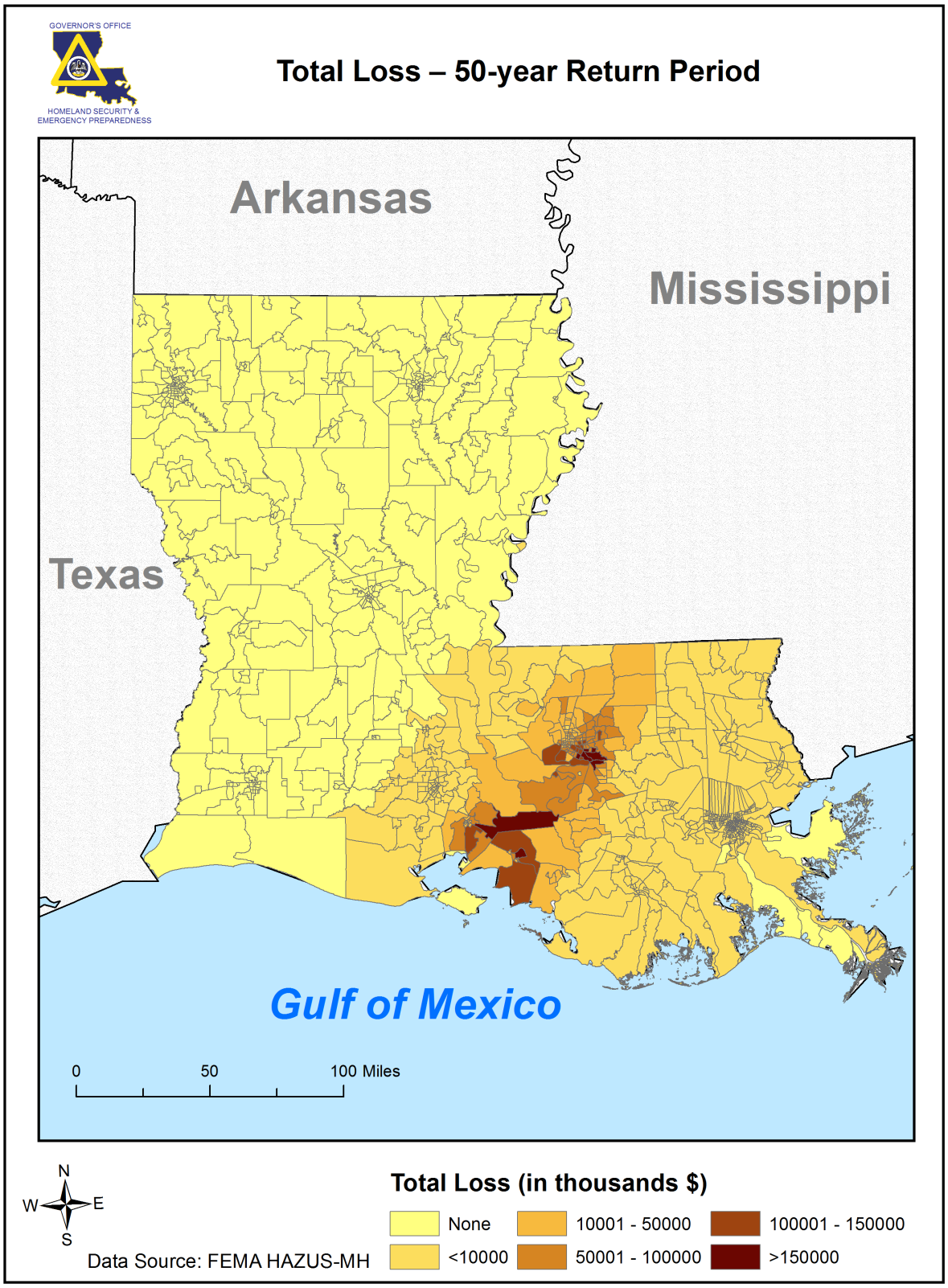
Map 2.86. Projected total economic losses (in thousands of dollars) to residential buildings after a 10-yr hurricane event.



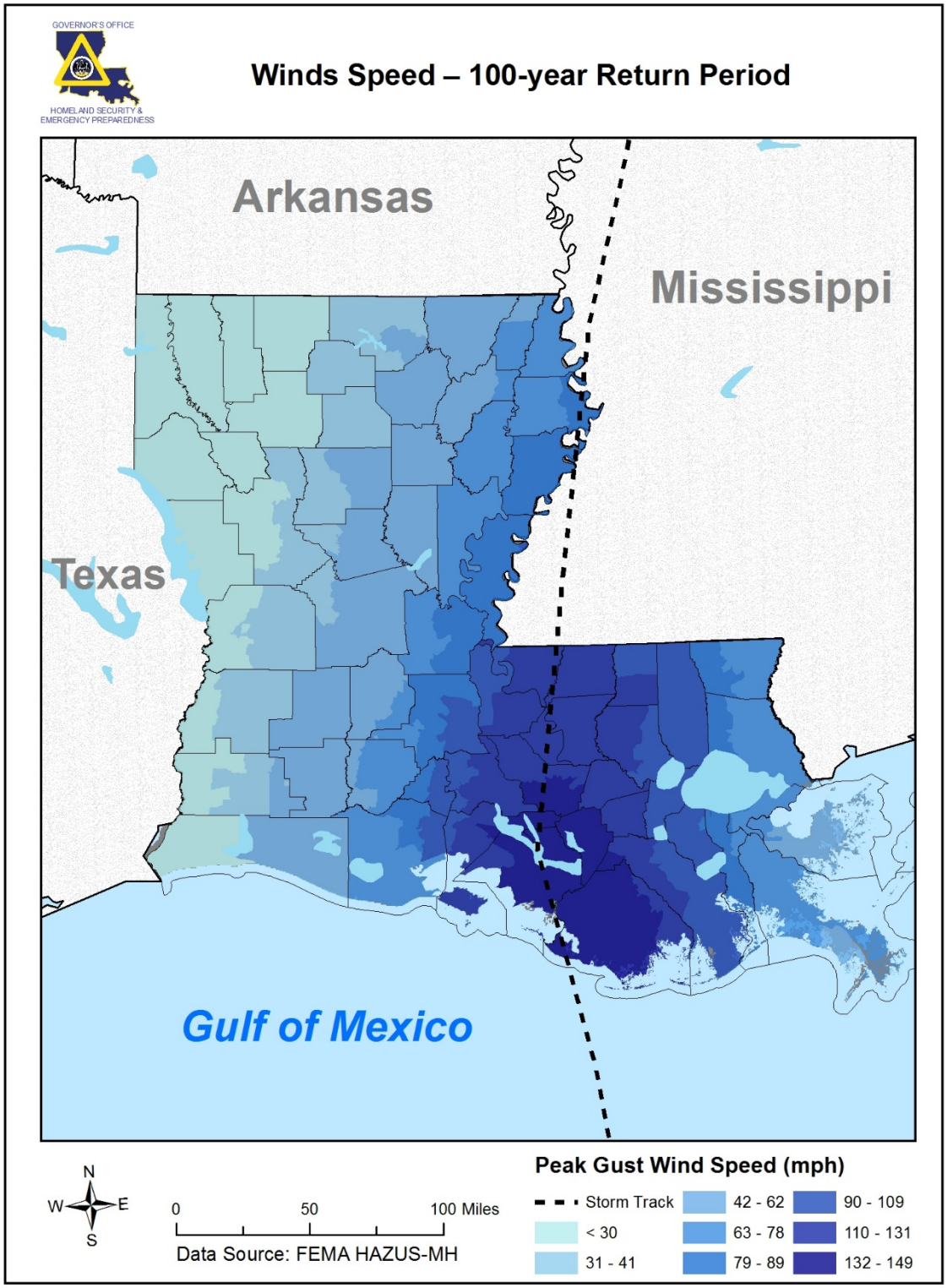
Map 2.87. Projected peak wind gusts during a 50-yr hurricane event, based on Hazus modeling.



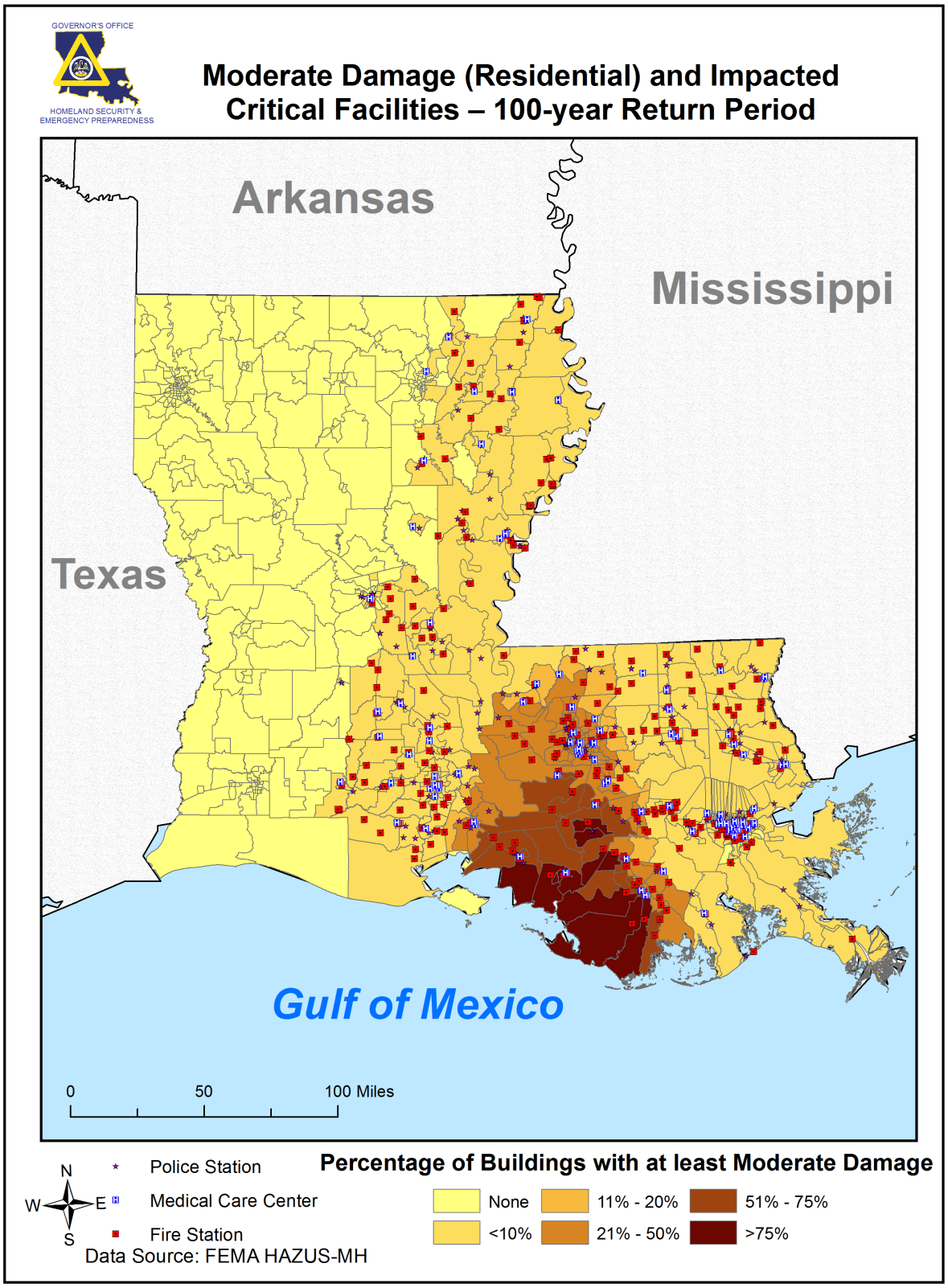
Map 2.88. Projected percentage of moderately damaged residential buildings and critical facilities (medical care center, police station, and fire station) after a 50-yr hurricane event.



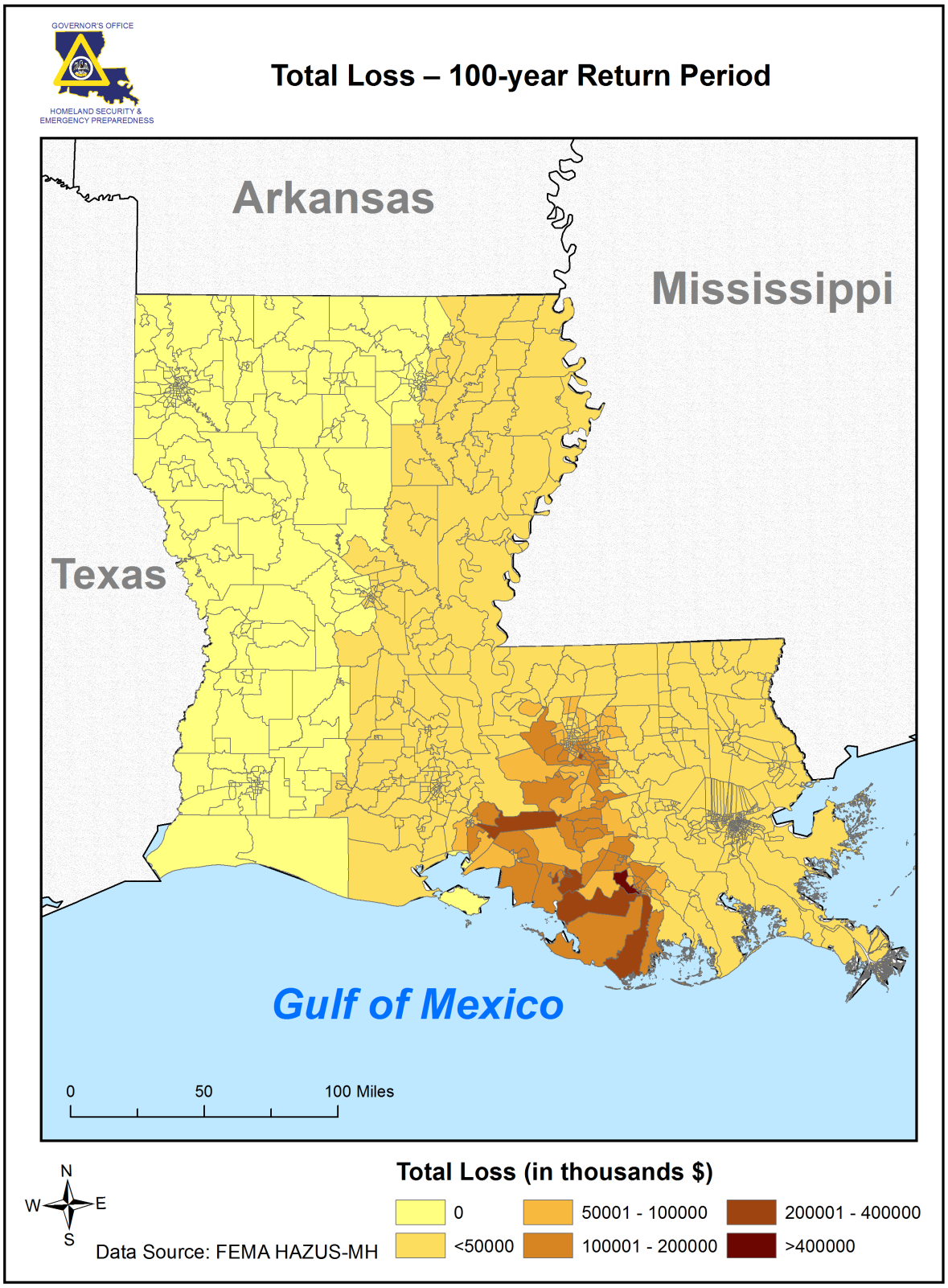
Map 2.89. Projected total economic losses (in thousands of dollars) to residential buildings after a 50-yr hurricane event.



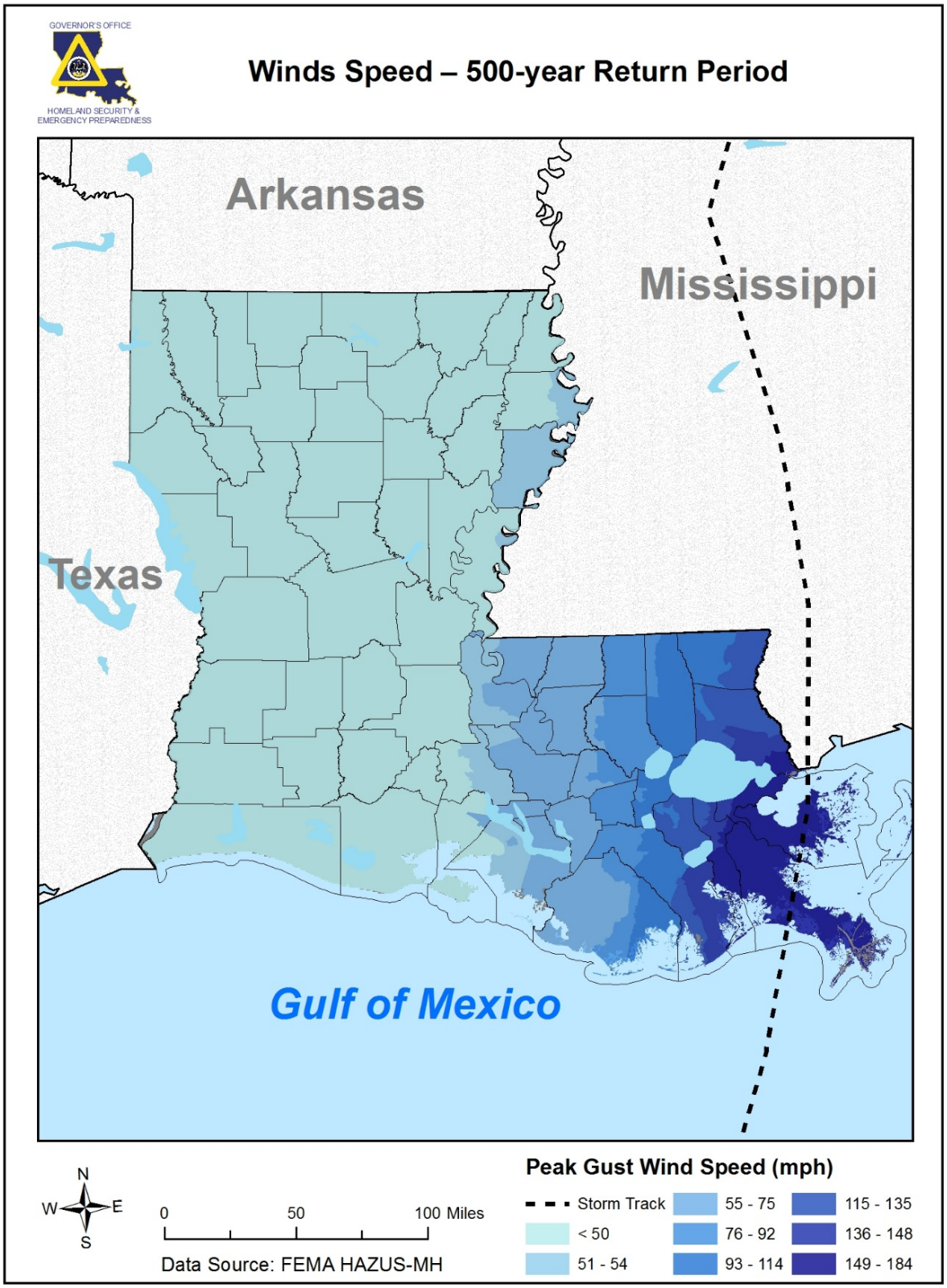
Map 2.90. Projected peak wind gusts during a 100-yr hurricane event, based on Hazus modeling.



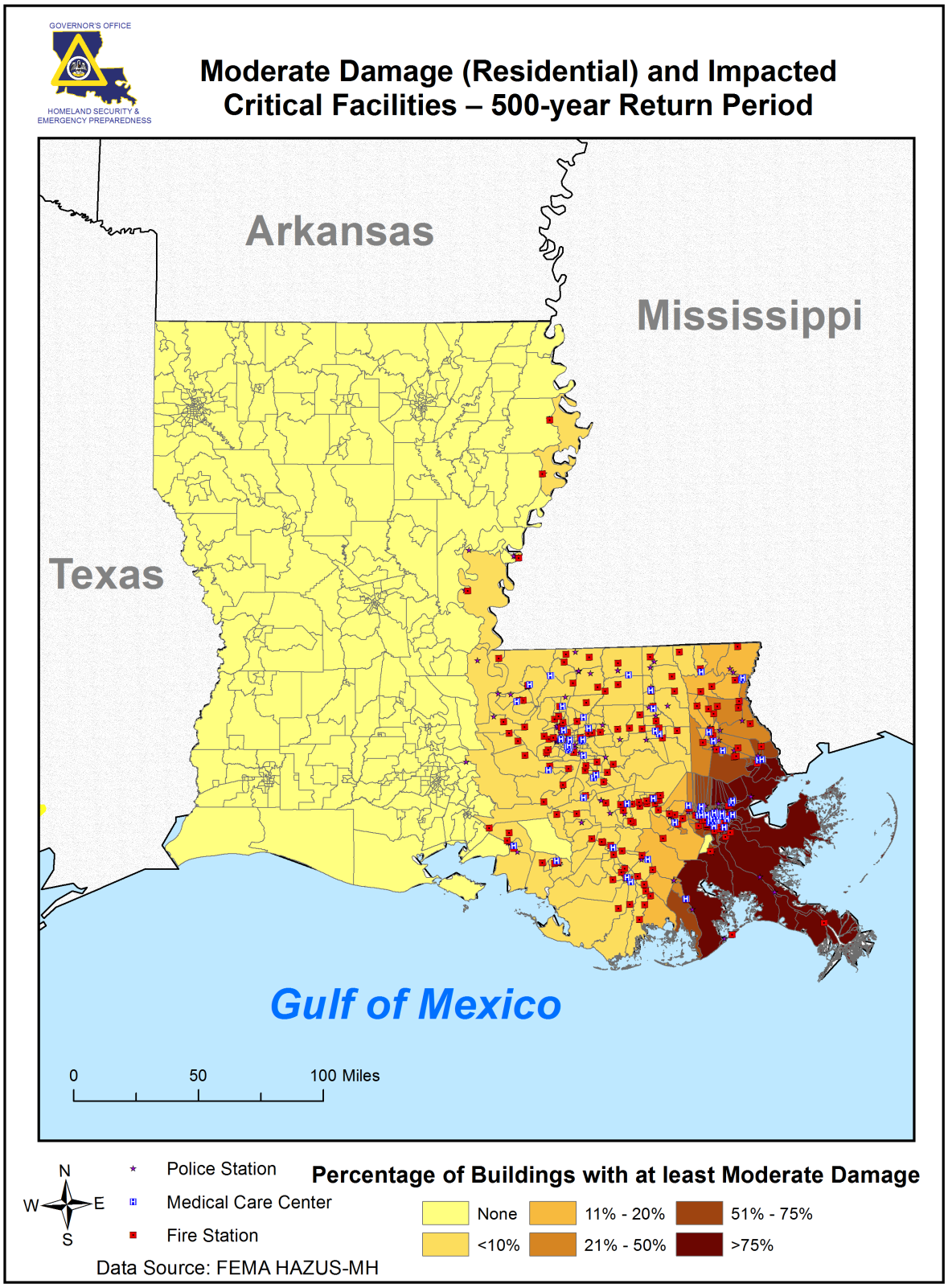
Map 2.91. Projected percentage of moderately damaged residential buildings and critical facilities (medical care center, police station, and fire station) after a 100-yr hurricane event.



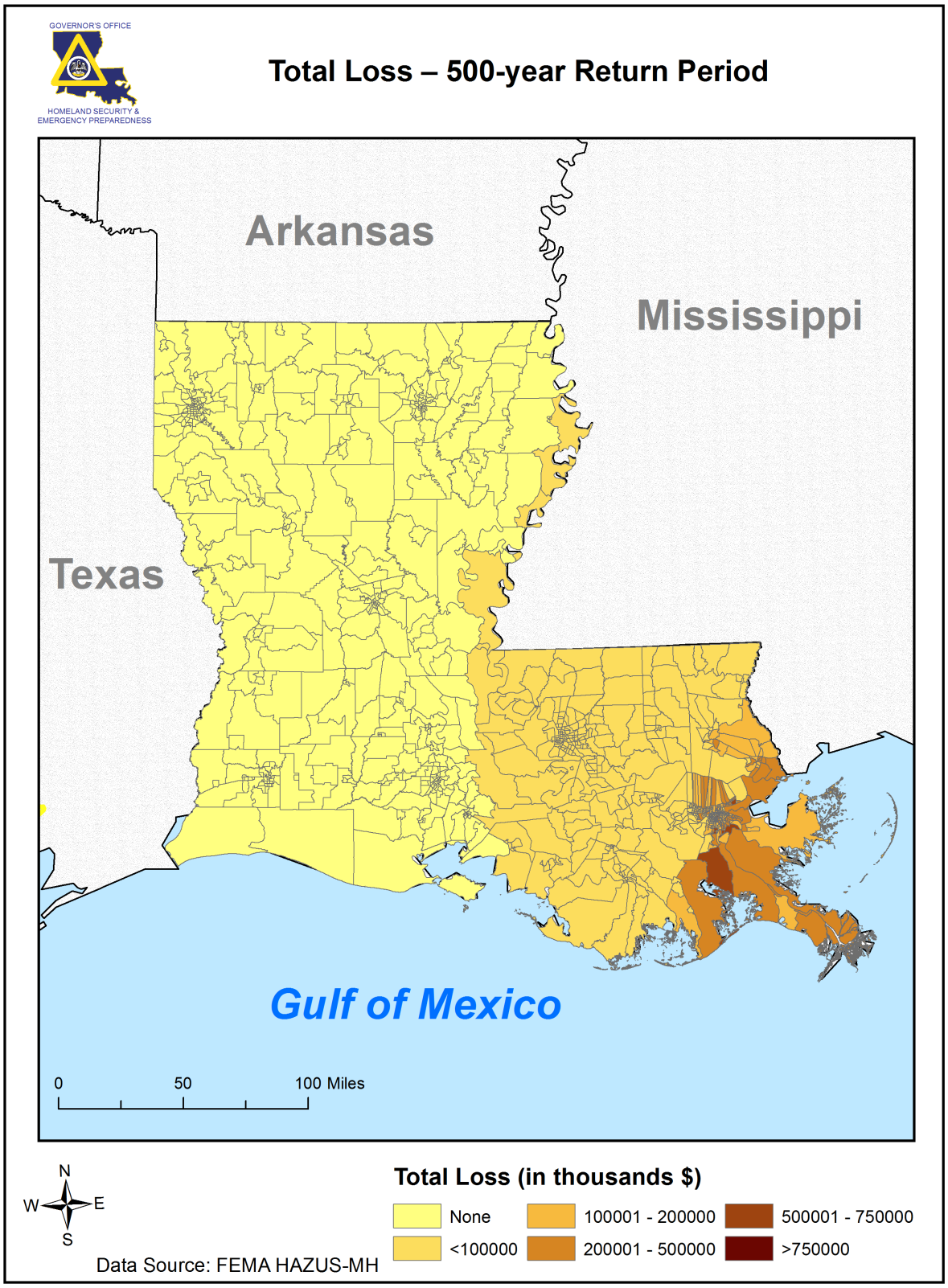
Map 2.92. Projected total economic losses (in thousands of dollars) to residential buildings after a 100-yr hurricane event.



Map 2.93. Projected peak wind gusts during a 500-yr hurricane event, based on Hazus modeling.



Map 2.94. Projected percentage of moderately damaged residential buildings and critical facilities (medical care center, police station, and fire station) after a 500-yr hurricane event.



Map 2.95. Projected total economic losses (in thousands of dollars) to residential buildings after a 500-yr hurricane event.

In terms of climate change, the impacts from tropical cyclones could increase in severity. Since the 1980s, the number of Category 4 and 5 hurricane events have increased considerably due to both natural variability and a changing climate. Studies suggest that in the future warming will cause fewer but *stronger* tropical storms, which will also carry more rainfall as the climate warms.[lxiii] Storm surges will likely be far worse given sea level rise, subsidence, the destruction of wetlands protection, and the greater precipitation totals during cyclone events. Maps 2.96, 2.97, 2.98, and 2.99 identify how tropical cyclones have affected the parishes of Louisiana between 1987 and 2012 in terms of total events, economic damage, injuries, and fatalities, respectively. As expected, the southeastern corner of the state is most directly affected by tropical cyclones, but every portion of Louisiana has been affected in the past. The entire coast is clearly always quite vulnerable to hurricane landfall. Lafayette, West Baton Rouge, Ascension, Livingston, Tangipahoa, and St. Tammany Parishes are at high risk (greater than 2.0 composite risk score) to tropical cyclones and have experienced significant population increases of more than 10% since 2000 with Ascension and Livingston Parishes experiencing greater than 20% increases in population (see Map 2.3). As a result, the vulnerability of these parishes to tropical cyclones has increased. Orleans, St. Bernard, and Plaquemines Parishes are at high risk to tropical cyclones, but have experienced significant population decreases of more than 10% since 2000 with Orleans and St. Bernard Parishes experiencing greater than 20% decreases in population (see Map 2.3). As a result, the vulnerability of these parishes to tropical cyclone has decreased.

Map 2.100 locates Louisiana's state assets previously damaged by tropical cyclones.

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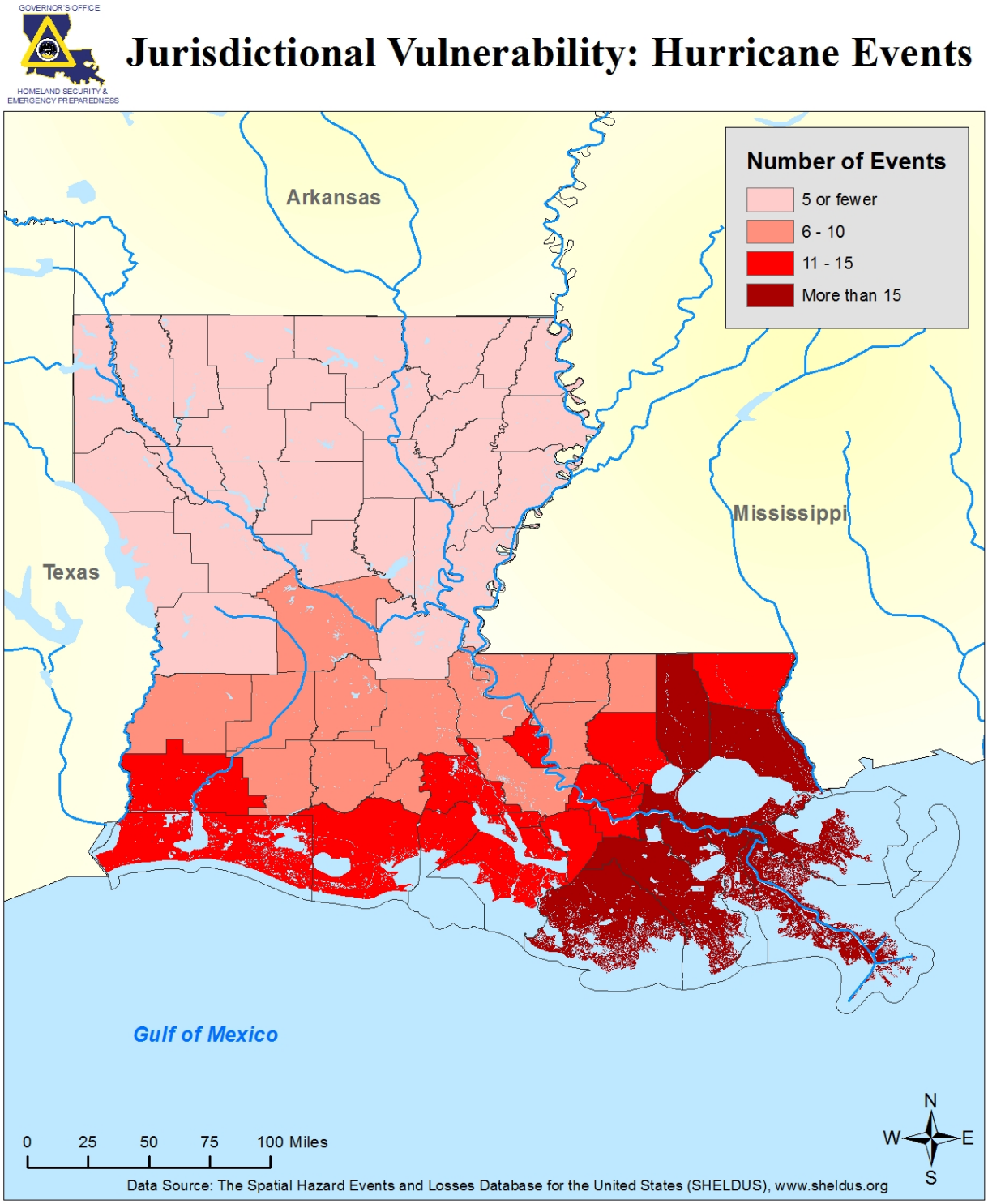
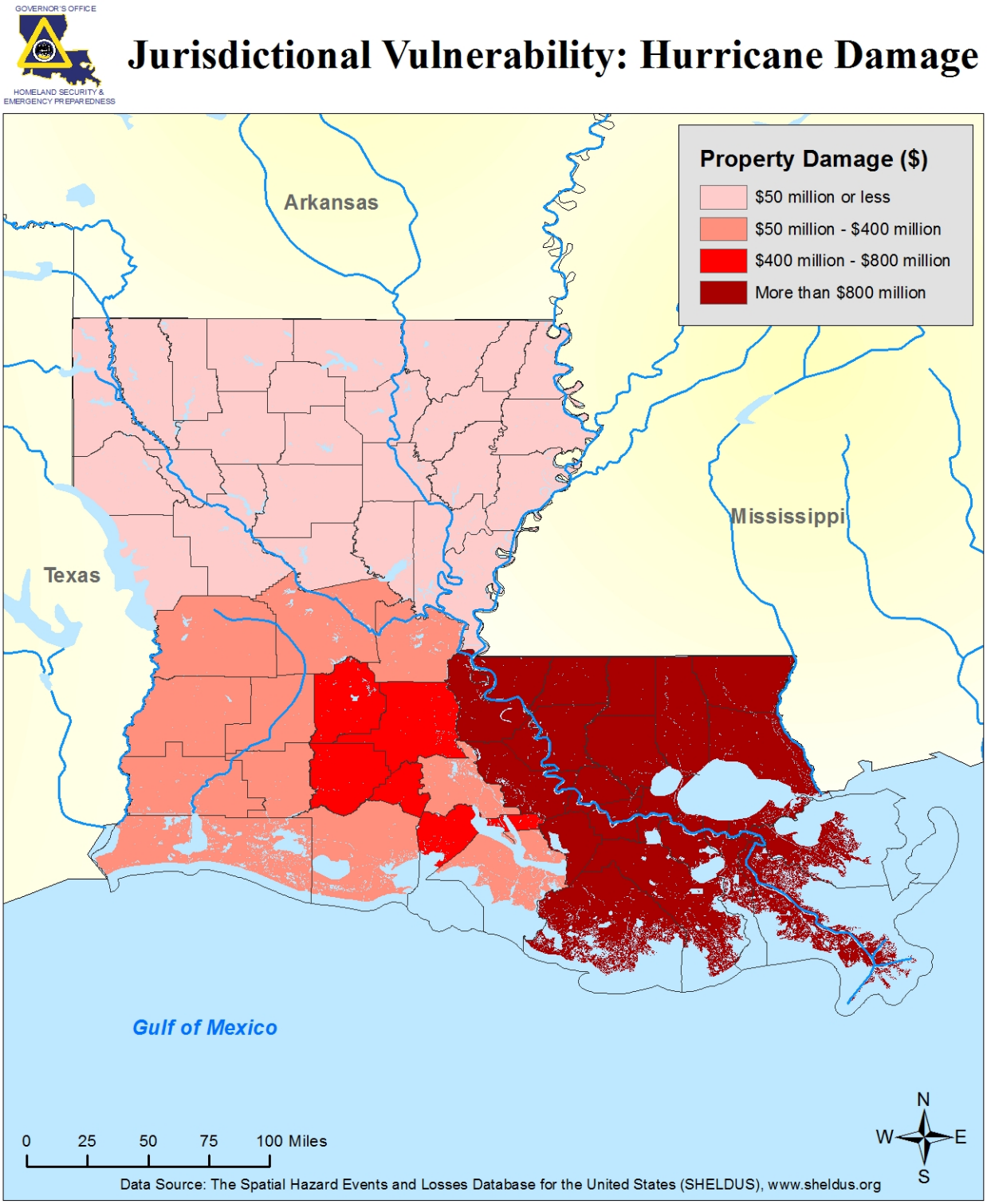
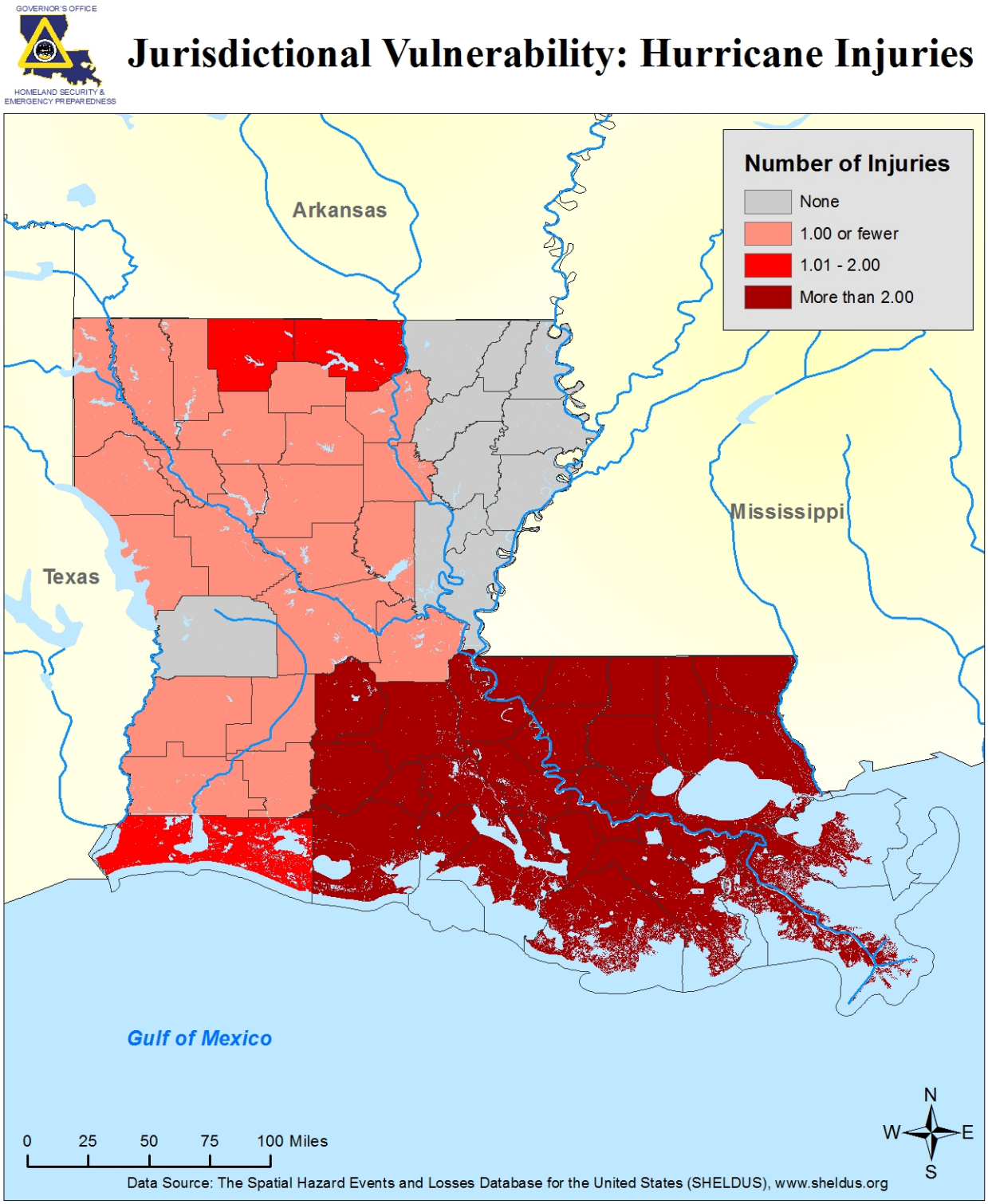


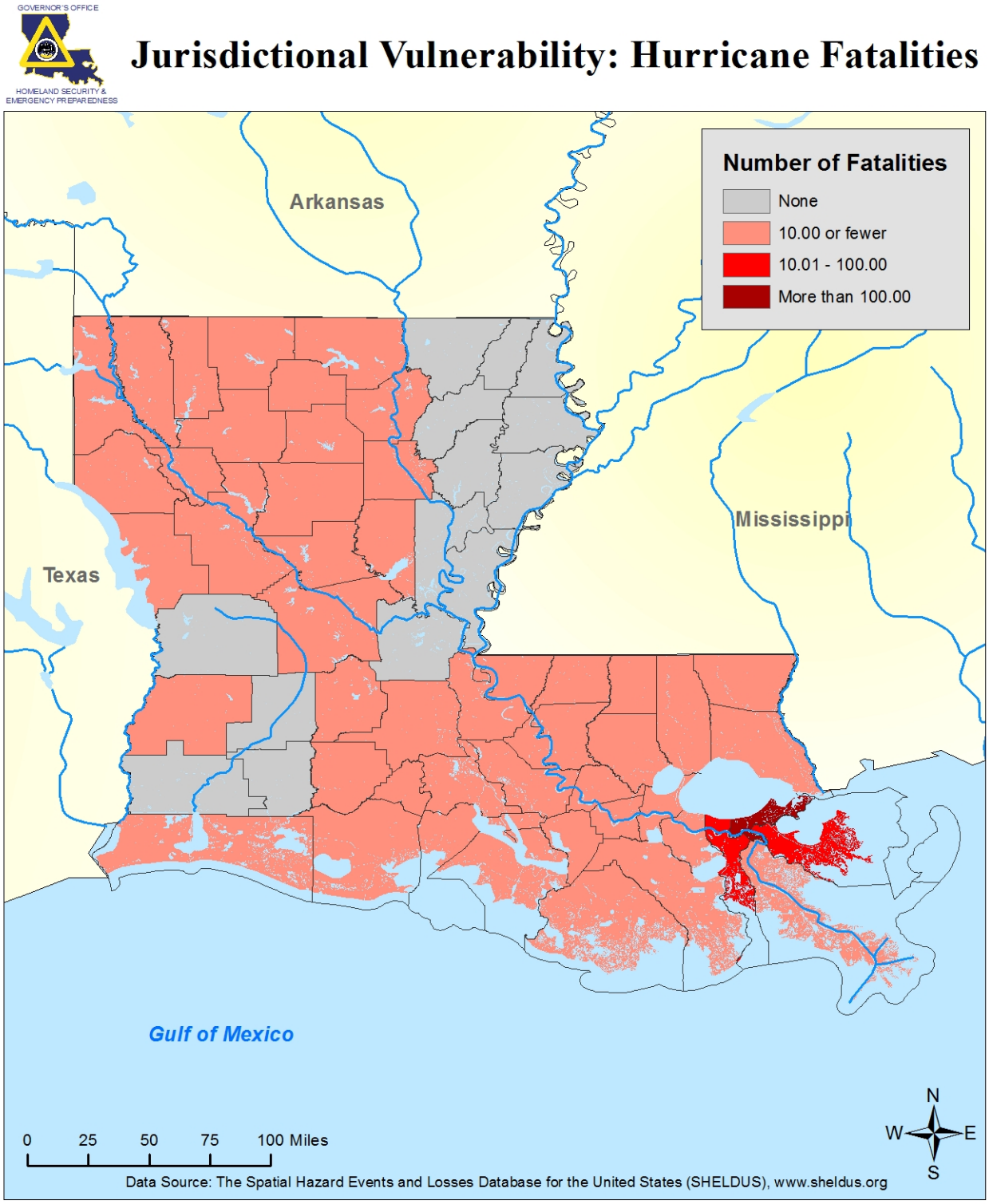
Map 2.96. Louisiana jurisdictional vulnerability for hurricane events based on data from 1987–2012.



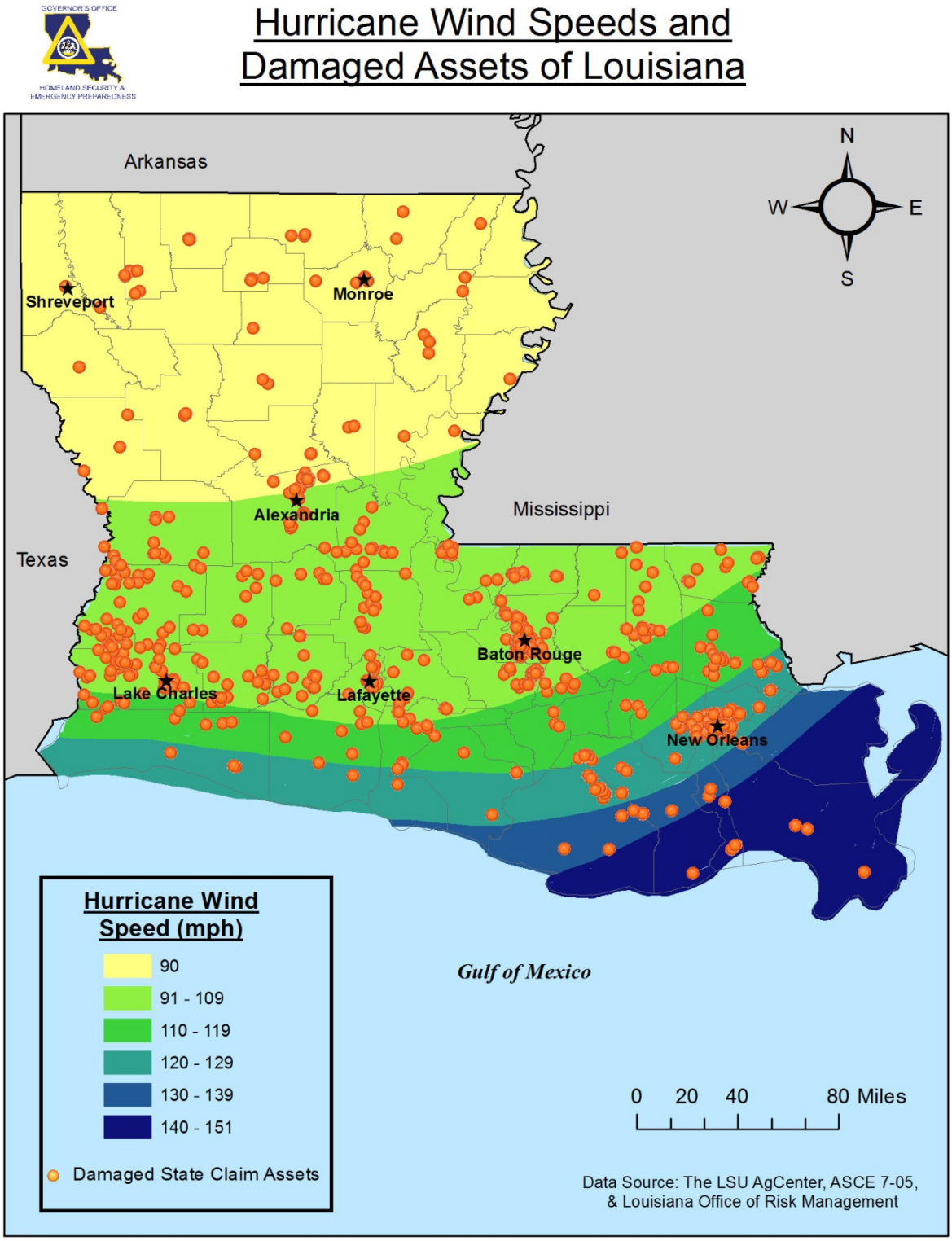
Map 2.97. Louisiana jurisdictional vulnerability for damage from hurricanes based on data from 1987–2012.



Map 2.98. Louisiana jurisdictional vulnerability for injuries from hurricanes based on data from 1987–2012.



Map 2.99. Louisiana jurisdictional vulnerability for fatalities from hurricanes based on data from 1987–2012.



Map 2.100. Louisiana state assets with paid repetitive claims for hurricane damage located within wind zones (map by ETSU student Hannah Miltier).

Table 2.34 lists the top 10 paid claims for hurricane-damaged state assets.

Table 2.34. Top 10 paid claims for hurricane-damaged state assets.

Top 10 Paid Claims for Hurricane-Damaged State Assets				
Building ID	Building Name	Location	Net Paid	Total Number of Claims (Hurricane)
S04024	Archives - LA State Penitentiary	Angola	$14,013,954	2
S11609	University Center - University of New Orleans	New Orleans	$10,675,735	2
S11557	Kiefer Lakefront Arena - University of New Orleans	New Orleans	$7,854,885	2
S13367	Credit Union - McNeese State University	Lake Charles	$4,540,204	1
S12847	New Orleans Sports Arena	New Orleans	$3,883,214	2
S03743	Administration and Reception Center - LA State Penitentiary	Angola	$3,669,256	1
S03722	Administration Building - LA State Penitentiary	Angola	$2,913,006	1
S08891	School of Nursing Building - University of Louisiana-Monroe	Monroe	$2,786,856	1
S04074	TU/CCR Cellblock - LA State Penitentiary	Angola	$2,325,721	2
S02834	Main Building - Capital Area Tech College (Westside)	Plaquemine	$2,303,923	1

Map 2.101 shows the composite jurisdictional risk for hurricanes in Louisiana based on the preceding data. The southeastern parishes have the highest comparative risk for damage from hurricane events.

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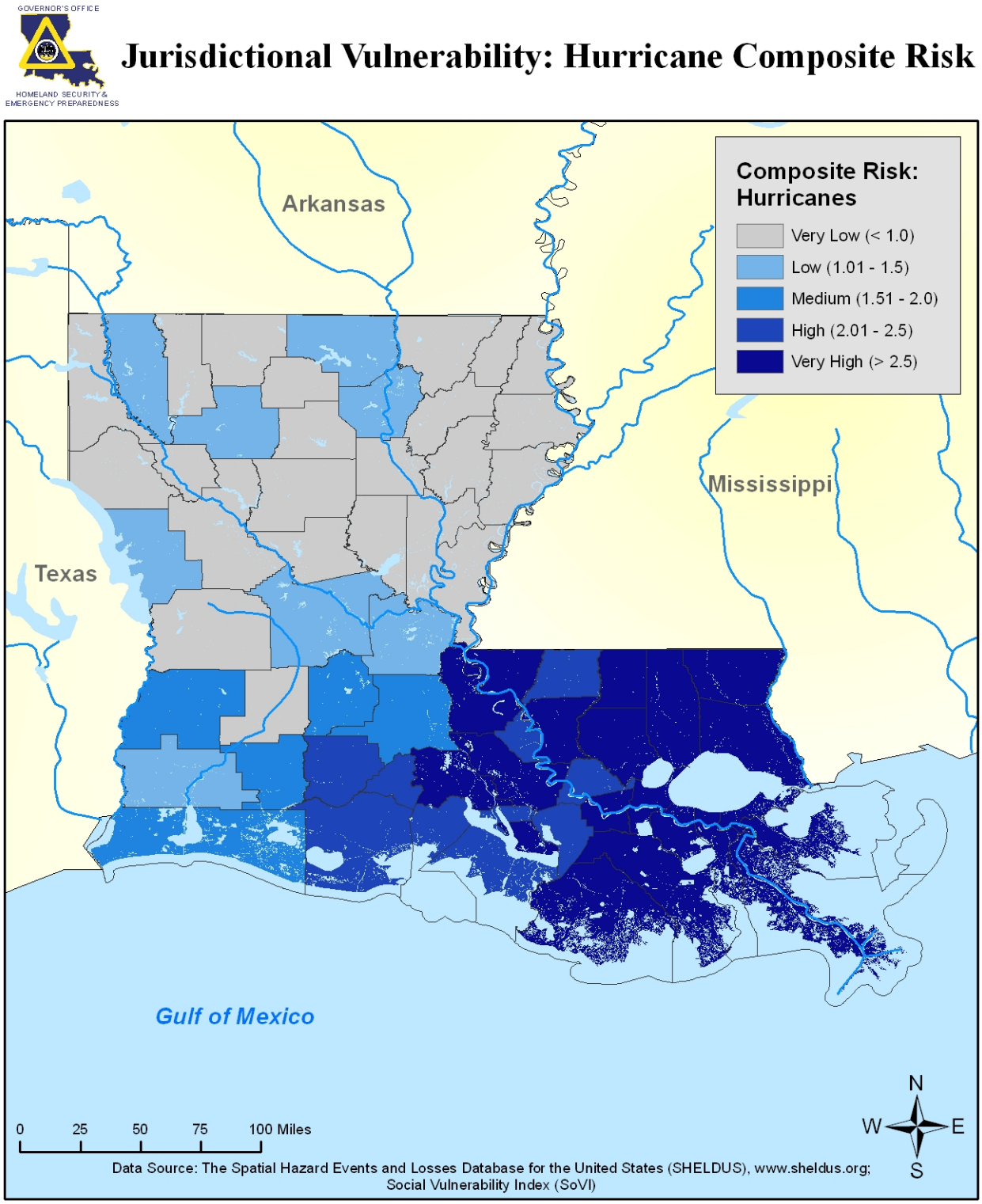
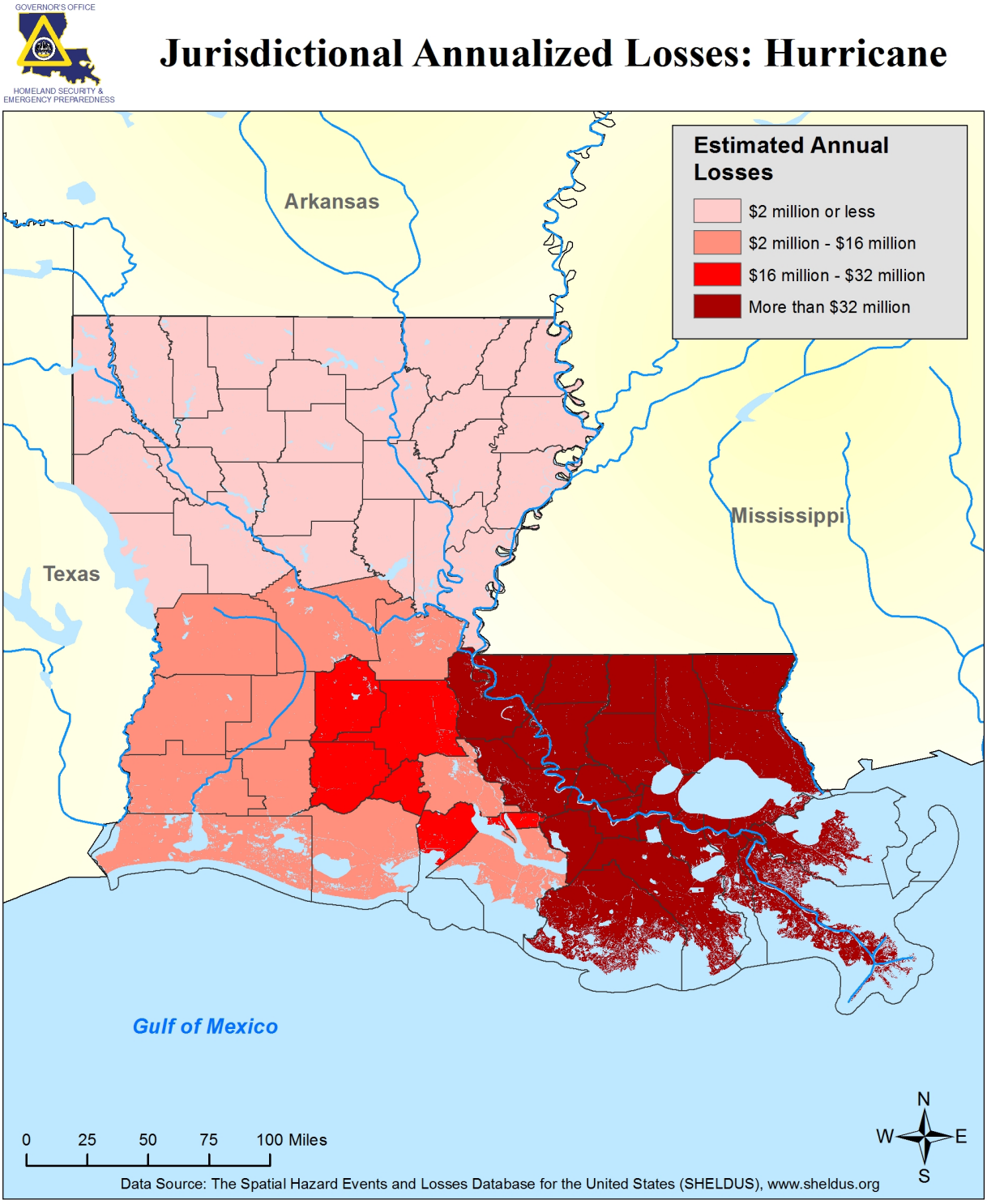


Map 2.101. Composite risk map for hurricanes, showing coastal parishes with the highest historical and highest potential risks (medium or greater). The southeastern parishes have the greatest risk (very high).

To determine potential loss estimates from hurricanes, the available historical loss data was annualized to determine future loss potential (see Map 2.102). As shown, parishes with the largest populations are predicted to have the highest potential annualized losses.



Map 2.102. Jurisdictional annualized loss due to hurricanes.

Potential Losses by Jurisdiction

Overview & Analysis of Potential Losses: Overall, most of Louisiana is vulnerable to tropical cyclones, but there are certain parishes that are more vulnerable than others. High wind and storm surge are major concerns in south Louisiana, while hurricane-induced flooding and the sheltering of evacuees appears to be a bigger issue in northern parishes. Similarly with tornadoes, poorly constructed or older homes and mobile home parks are at highest risk of sustaining the greatest damage during tropical cyclones.

Changes in jurisdictional population levels impact each parish across the state disparately. Changes in development are expected to impact loss estimates for tornadoes since most population growth and development is occurring in parishes within southern Louisiana that are impacted by both high wind and storm surge. In the parishes where tropical cyclone vulnerability has increased because of increases in population (Lafayette, West Baton Rouge, Ascension, Livingston, Tangipahoa, and St. Tammany), concomitant changes in development have impacted loss estimates and will cause an increase in future losses due to increased levels of exposure. In the parishes where tropical cyclone vulnerability has decreased because of decreases in population (Orleans, St. Bernard, and Plaquemines), concomitant changes in development have impacted loss estimates and will cause a decrease in future losses due to decreased levels of exposure. Any new development represents an increase in the number of structures that are vulnerable to the effects of tropical cyclones.

Potential Losses of State Facilities

The tropical cyclone hazard vulnerability assessment of state-owned buildings was based on the parish-level composite risk score, which incorporates the total number of tropical cyclone events, injuries, fatalities, and property damages as well as the social vulnerability of impacted parishes. The criteria used to determine specific vulnerability rankings for each building and the results of applying this ranking to the state-owned buildings are shown in Table 2.35.

Table 2.35. Tropical Cyclone Vulnerability Criteria and Ranking Results.

Tropical Cyclone Vulnerability Criteria and Ranking	
Ranking	Criteria
High	Composite risk score greater than 2.0
Medium	Composite risk score between 1.5 and 2.0
Low	Composite risk score less than 1.5

The tropical cyclone loss-estimate ranges are derived from the 2011 state hazard mitigation plan and inflation-adjusted to 2013 dollars. The January 2014 state facilities database was used to obtain accurate building numbers for each loss estimate range. Loss estimates of state-owned buildings in Louisiana involved an analysis of the following parameters:

- Hurricane Wind/Surge Hazard Vulnerability
- Average Building Type
- Hurricane Wind/Surge Damage Functions

Table 2.36. Tropical Cyclone Loss Estimate Ranges and Ranking Results.

TROPICAL CYCLONE LOSS ESTIMATE RANGES AND RANKING		
Ranking	Total Loss Estimate Ranges	Number of Buildings
High	$534,400 to $160,320,000	4669
Medium	$10,689 to $534,400	260
Low	$0 to $10,688	3756

WILDFIRES

A wildfire is combustion in a natural setting, marked by flames or intense heat. Most frequently, wildfires are ignited by lightning or unintentionally by humans. Fires set purposefully (but lawfully) are referred to as controlled fires or burns.

There are three different types of wildfires. (1) **Ground fires** burn primarily in the thick layers of organic matter directly on the forest floor and even within the soil. Ground fires destroy root networks, peat, and compact litter. These fires spread extremely slowly and can smolder for months. (2) **Surface fires** burn litter and vegetative matter in the underbrush of a forest. (3) **Crown fires** spread rapidly by wind and move quickly by jumping along the tops of trees. There are two types of crown fires—(a) *passive (or dependent)* crown fires rely on heat transfer from surface fire, whereas (b) *active (or independent)* crown fires do not require any heat transfer from below. Active crown fires tend to occur with greater tree density and drier conditions. A firestorm is a mass, crown fire (also called a running crown fire, area fire, or conflagration). They are large, continuous, intense fires that lead to violent convection. They are characterized by destructively violent surface in-drafts near and beyond their perimeter.

Crown fires are the most damaging and most difficult to contain. The intensity of crown fires enables the fire to produce its own wind gusts. These so-called *fire whirls* can move embers ahead of the fire front and ignite new fires. Fire whirls are spinning vortex columns of ascending hot air and gases rising from the fire. Large fire whirls have the intensity of a small tornado.

WILDFIRE PROFILE

The conditions conducive to the occurrence of wildfires are not distributed equally across the United States. Wildfires have a much greater likelihood of occurring in the western part of the country. Although less frequent than in other areas, wildfires do occur in Louisiana. Wildfire danger can vary greatly from season to season; it is exacerbated by dry weather conditions. Factors that increase susceptibility to wildfires are the availability of fuel (e.g., litter and debris), topography (i.e., slope and elevation affect various factors like precipitation, fuel amount, and wind exposure), and specific meteorological conditions (e.g., low rainfall, high temperatures, low relative humidity, and winds). The potential for wildfire is often measured by the Keetch–Byram Drought Index (KBDI), which represents the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in the soil. The KBDI tries to measure the amount of precipitation needed to return soil to its full field capacity, with KBDI values ranging from 0 (moist soil) to 800 (severe drought).

According to the State of Louisiana Forestry Division, most forest fires in Louisiana are caused by intentional acts (arson) or carelessness and negligence committed by people, exacerbated by human confrontation with nature. The wildland–urban interface (WUI) is the area in which development meets wildland vegetation, where both vegetation and the built environment

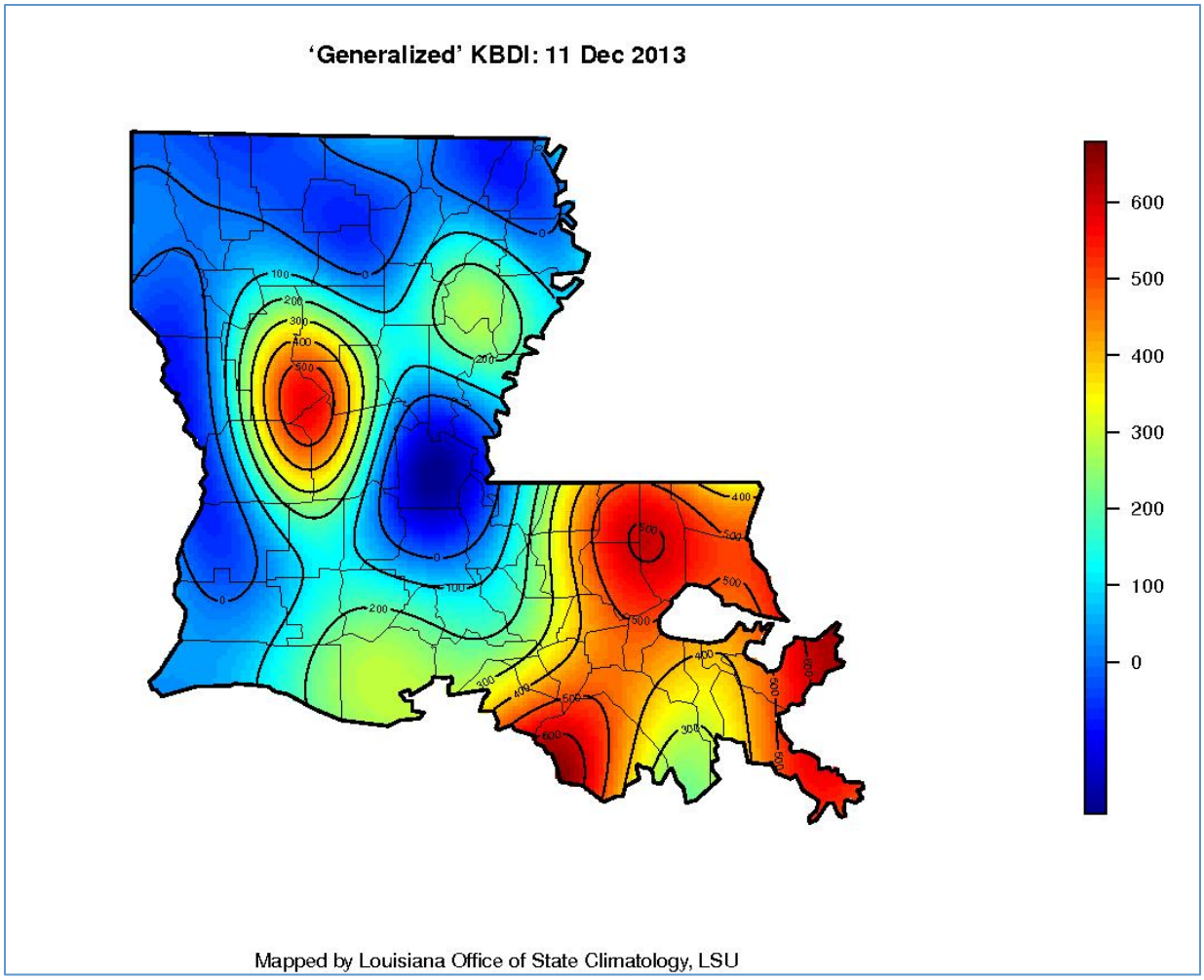
provide fuel for fires. As development near wildland settings continues, more people and property are exposed to wildfire danger.

According to the State Forestry Division, Louisiana's forestlands cover 13.8 million acres, about 48% of the state's area. Private, non-industrial landowners own 62% of the state's forestland, forest products industries own 29%, and public entities own 9%. Forests provide the raw material for Louisiana's second largest manufacturing employer, the forest products industry, with over 900 firms in 45 parishes employing more than 25,000 people. An additional 8,000 people work in harvesting and transportation of these resources. Louisiana's forests provide many other benefits, including clean air and water, wildlife habitat, recreational opportunities, and scenic beauty.

There have been few wildfires in Louisiana. On 19 August 2003, lightning sparked five wildfires in Cameron Parish in the Sabine National Wildlife Refuge, burning 12,000 acres. No injuries or damages to structures, property, or crops were reported. In September 2010, a wildfire burned 258 acres of ten-year-old pine forest in Webster Parish, but no homes or structures were damaged. During the last half of October 2010, drought conditions led to the burning of 4,363 acres of timberland in Kisatchie National Forest, but once again, no structures were damaged or destroyed. In the same month, 250 acres burned in Winn Parish, destroying some outbuildings, resulting in $107,000 (2013 USD) in damage. Finally, in September 2011, high temperatures, low humidity, and extreme drought conditions in northern Louisiana led to a few wildfires. In Natchitoches (Natchitoches Parish), strong winds from Tropical Storm Lee in conjunction with the heat and drought conditions led to the burning of 5000 acres and 10 structures, which resulted in $519,000 (2013 USD) in damages. In Caddo Parish, 3300 acres of timberland and grassland, in addition to 2 homes, 3 mobile homes, 3 outbuildings, and several fishing camps along Caddo Lake burned, leaving $415,000 in damage.

The damage and damage possibilities in these occurrences vary according to specific conditions. For instance, grass fires do not have a direct damage figure associated with them, unless the fields were used as fodder, in which case the burning would have an indirect cost to the owner. With regard to forest fires, damage can vary from forest litter (like leaves) being consumed to "stand replacement" fires where an entire area is destroyed. A mature stand of southern yellow pine can be worth, on average, $2500 per acre. A "young" stand, for example a 13-year-old stand of pine, can be worth approximately $1000 per acre. These are direct costs. They do not include the costs of clearing and replanting an area, as well as waiting a decade for maturity to harvest potential.

Map 2.103 indicates the KBDI at the time this report went to publication. As Map 2.104 suggests, four areas are prevalent for fires in Louisiana. The highest densities are found where forestry and agriculture are present, along with national parks.



Map 2.103. KBDI at time of publication, indicating drought conditions that could precipitate wildfire.

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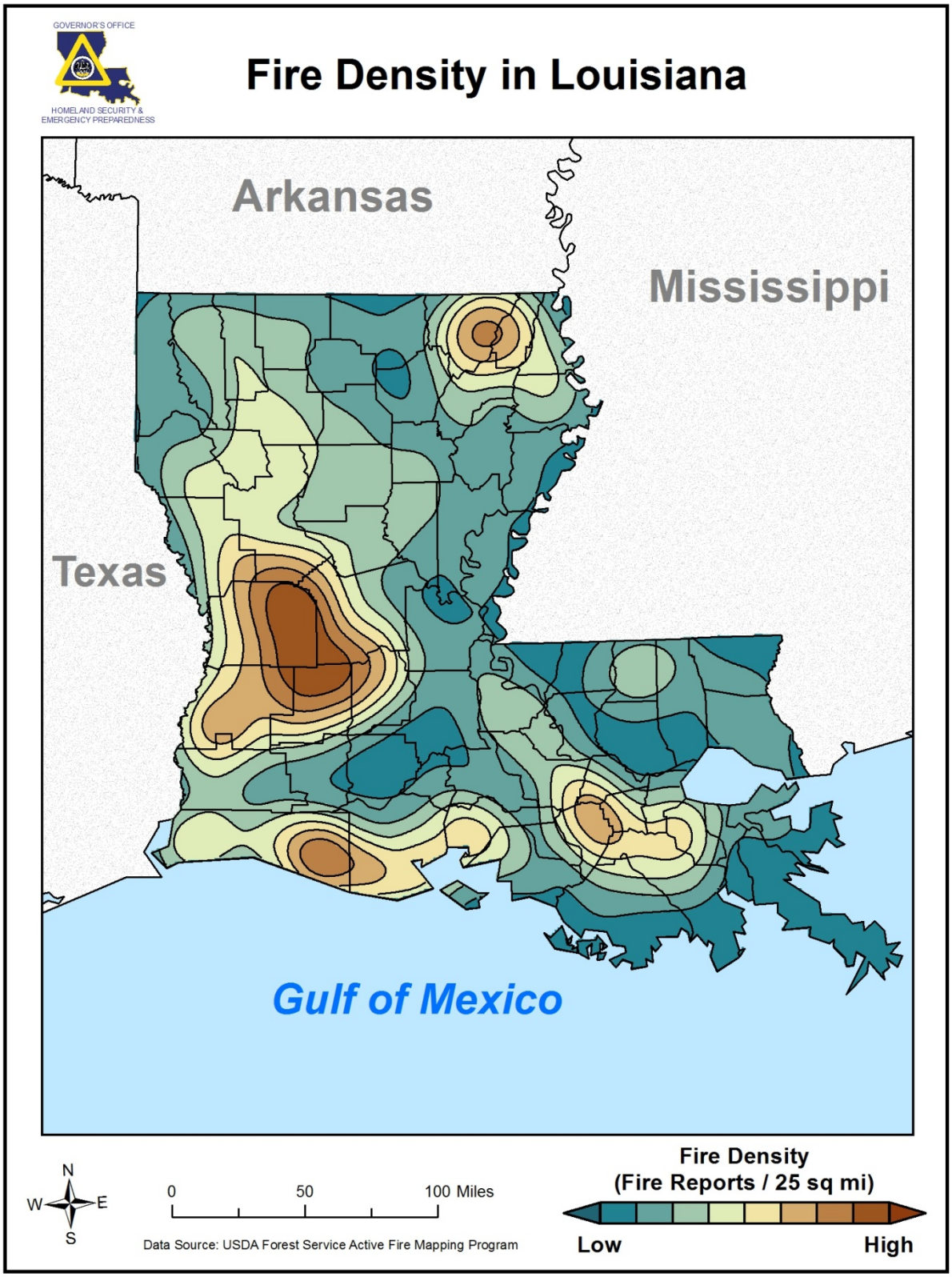

Map 2.104. Density of wildfires in Louisiana (source: USDA Forest Service Active Fire Mapping Program, 2001-2012).

Wildfire Risk Assessment

Based on historical records, and as indicated in Map 2.105, the probability of future occurrences of wildfire in Louisiana is **High**. However, impact on the built environment due to wildfire is minimal: there are few reports of actual monetary damage, and even fewer reports of human injuries. Still, wildfires can be an occasional hazard in Louisiana and will be included for Risk Assessment. Maps 2.106, 2.107, 2.108, and 2.109 represent historical data from the past 25 years and indicate the total wildfire events, as well as the damages, injuries, and fatalities attributed to wildfire. Since wildfire impacts are minimal, historical records are best at showing historical risk but limited in conveying vulnerability.

Areas of WUI signify locations where the built environment and a forested (or "wild") environment border each other. Importantly, the WUI identifies the locations of urban and suburban periphery areas, as well as migration trends. As the historical maps, WUI map, and wildfire density map suggest, Lincoln, Ascension, Livingston, Tangipahoa, and St. Tammany parishes are at high risk to wildfire and have also experienced significant population increases of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability of these parishes to wildfire has increased. Cameron Parish is at high risk to wildfire based on its population density, but it has experienced a significant population decrease of more than 10% since 2000 (see Map 2.3). As a result, Cameron Parish's vulnerability to wildfire has decreased.

Map 2.110 shows classification change of WUI areas between 1990 and 2010, while Map 2.111 reveals the specific locations within each parish where the WUI has changed or remained the same since 1990. An additional map (Map 2.112) quantifies changes in the total area of WUI for each parish over a 20-year period (1990-2010). Parishes tended to increase in population when areas classified as interface increased, and vice versa. One parish, Ascension, experienced the opposite effect, however: a large population increase with a measurable decrease in interface areas. This could be the result of other development and land use changes. Ascension Parish contains some areas of prairieland (as opposed to forest), and it is possible that developers cleared large areas and unintentionally created a buffer between the interface areas and new developments. Regardless, over 25% of Ascension Parish is still classified as an interface area.

Map 2.113 locates state facilities and state parks within WUI areas—a much more specific criteria than simply examining their locations within a parish. There are 7 state parks (of 19 in the state) and 1,871 state facilities (of 8,685 in the state) within these areas. State-owned critical facilities located in these areas are of the following types: hospitals, shelters, and state police troop offices.

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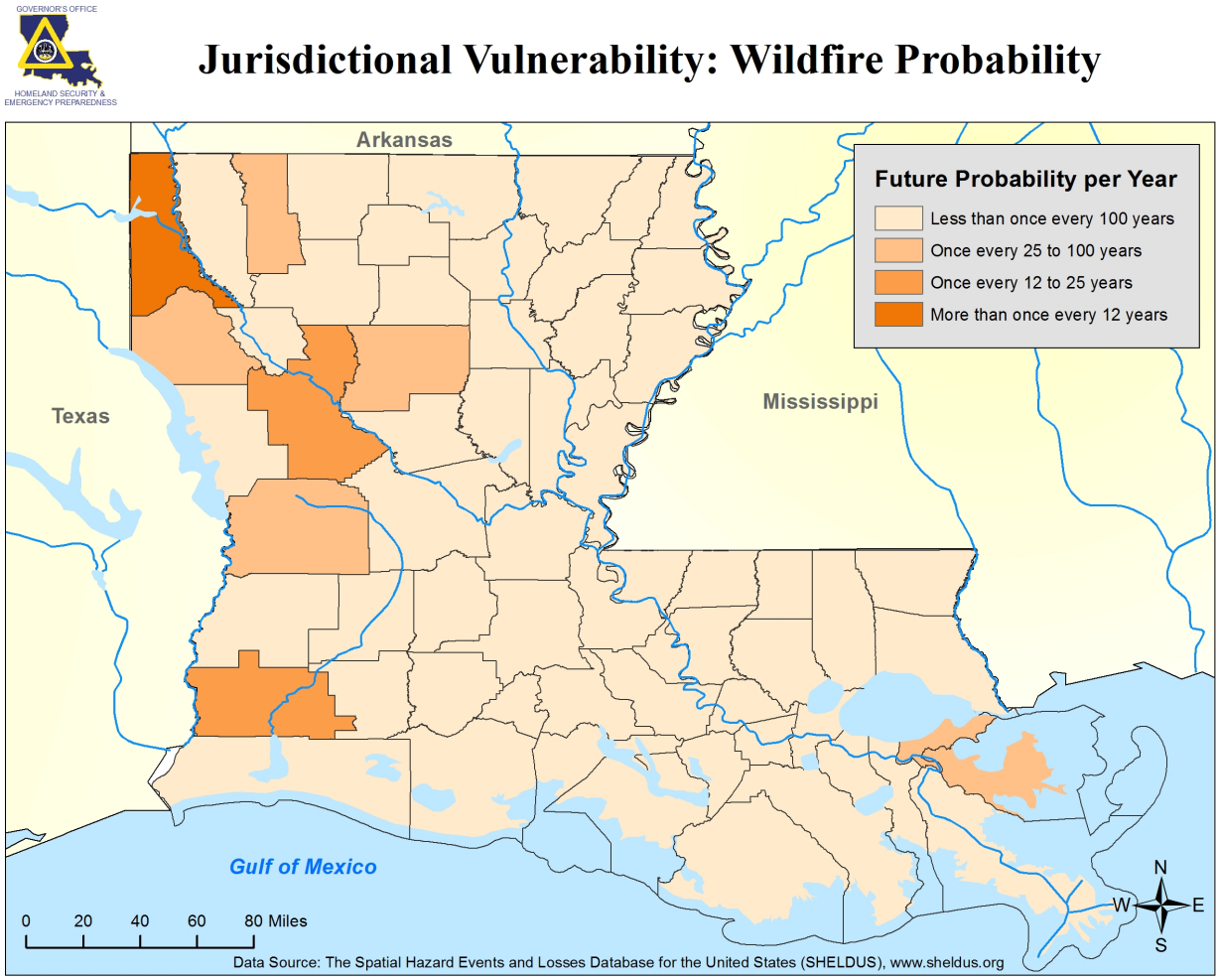

Map 2.105. Probability of wildfire events in Louisiana by parish based on data from 1987–2012.

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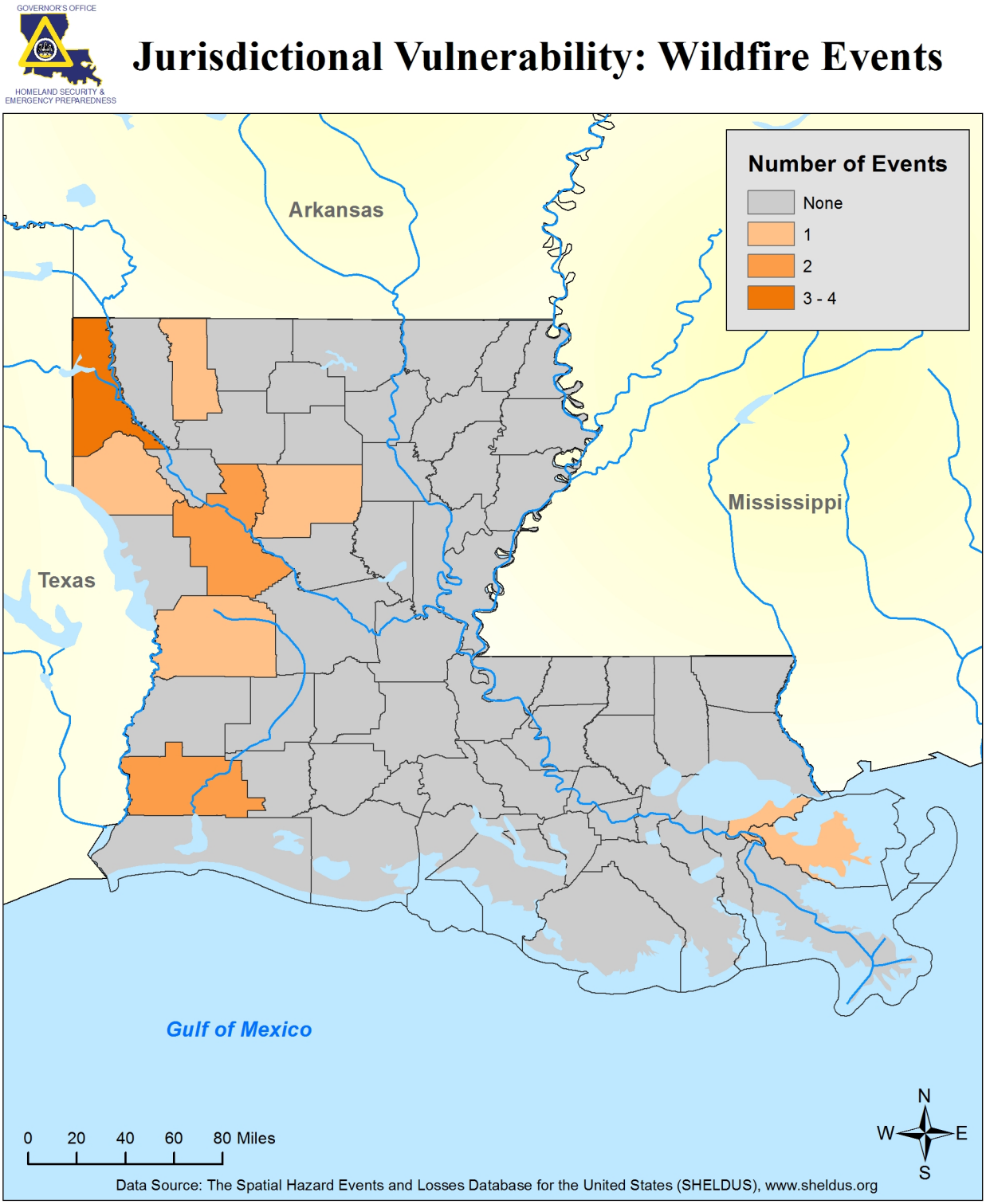
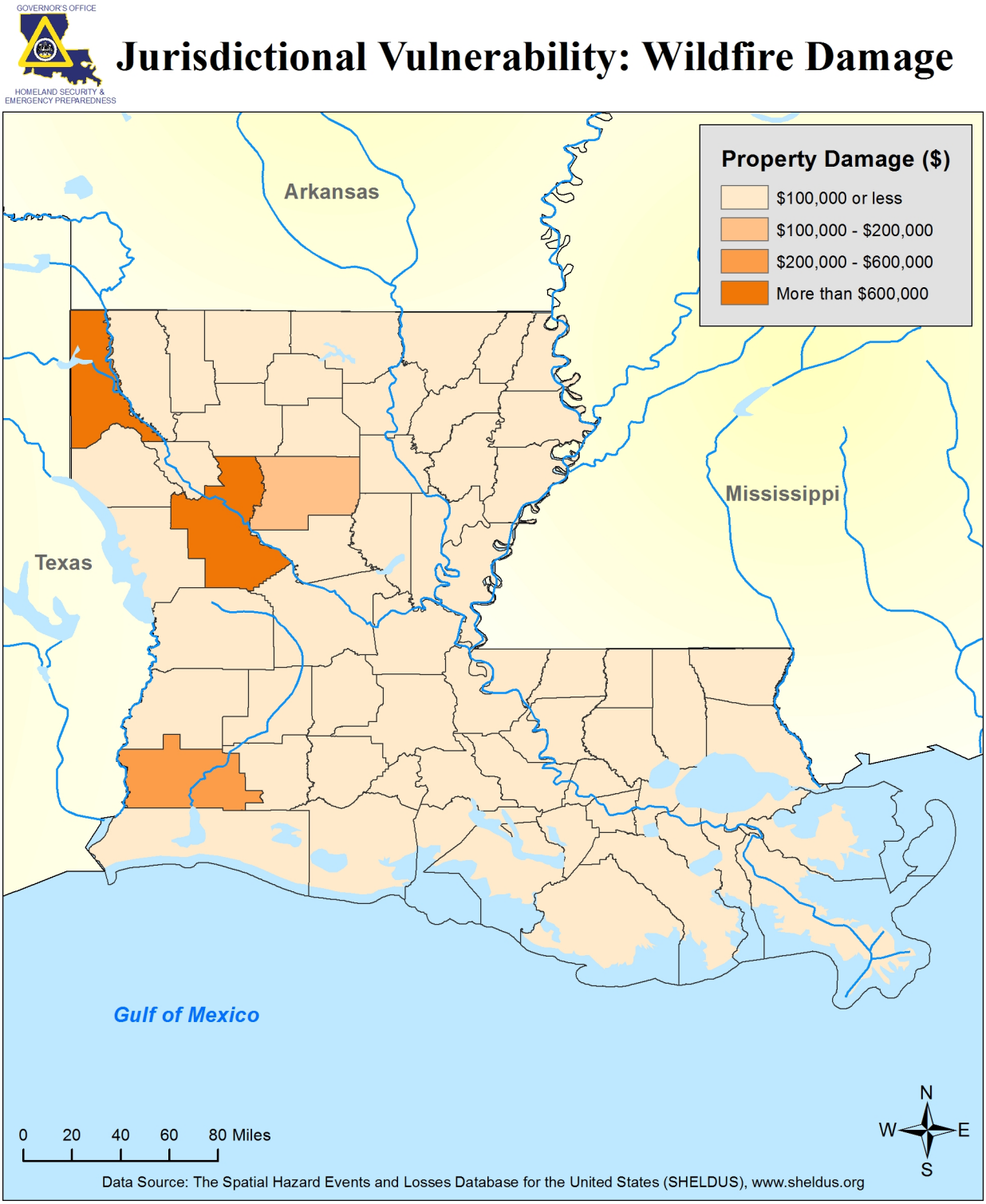


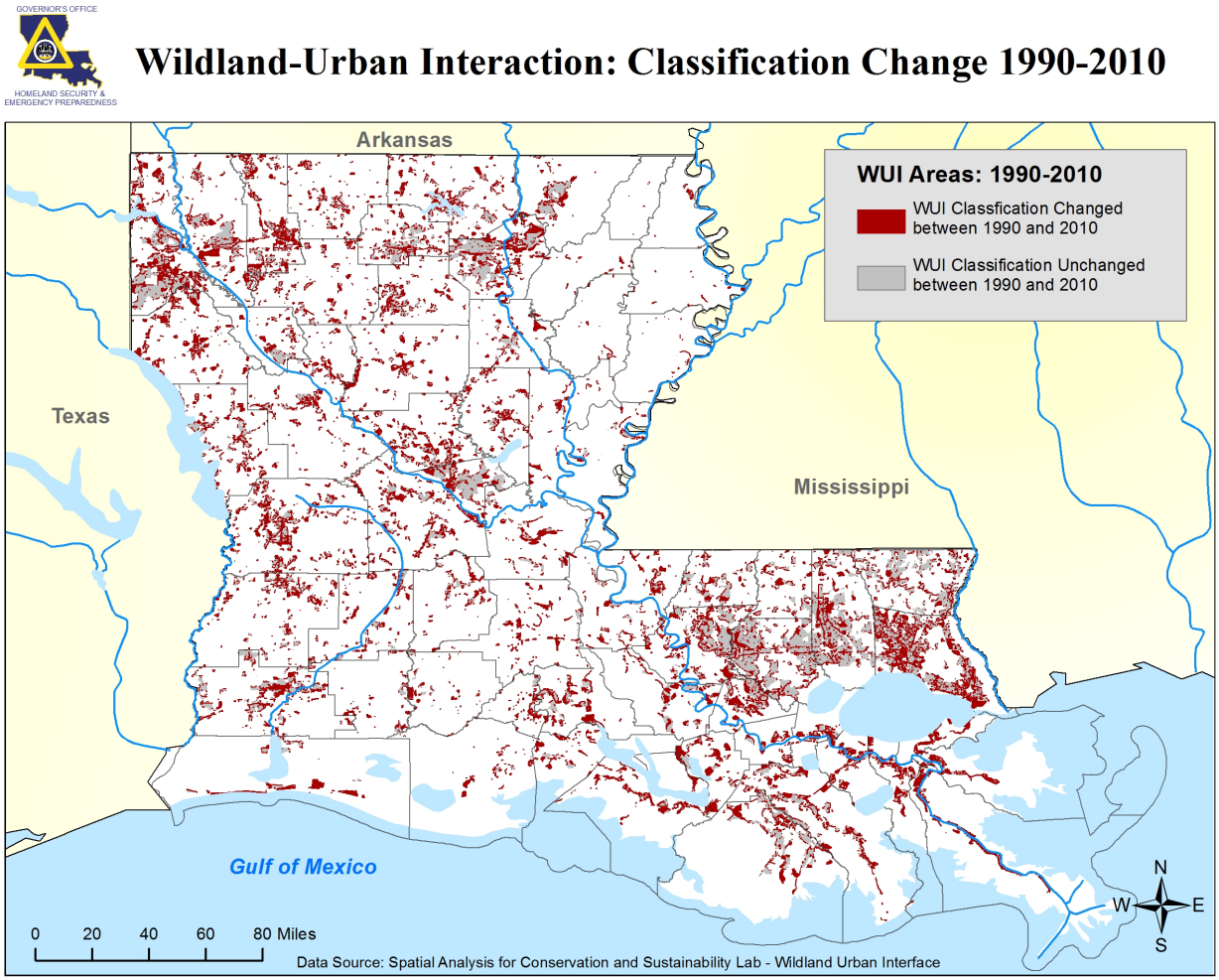
Map 2.106. Louisiana jurisdictional vulnerability for wildfire events based on data from 1987–2012.



Map 2.107. Louisiana jurisdictional vulnerability for damage from wildfire based on data from 1987–2012.

Map 2.108. Louisiana jurisdictional vulnerability for injuries from wildfire based on data from 1987–2012.

Map 2.109. Louisiana jurisdictional vulnerability for fatalities from wildfire based on data from 1987–2012.



Map 2.110. WUI areas are grouped by areas (1) that were classified as interface in 1990 and remained the same through 2010 and (2) whose interface classification has changed. The first areas are in gray, the second in red. The Florida parishes, as well as several northern parishes, show large areas of classification change.

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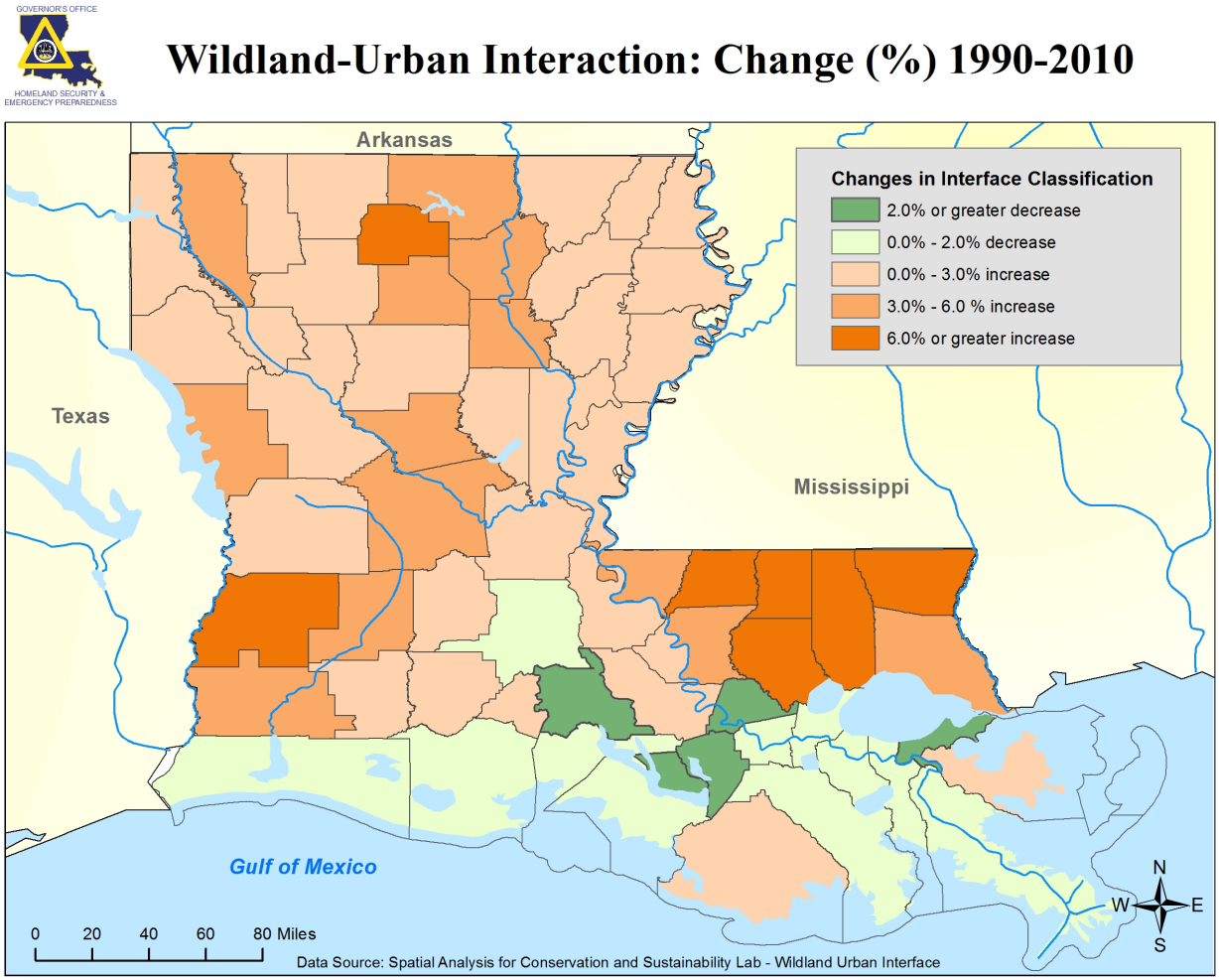

Map 2.111. Louisiana changes in jurisdictional vulnerability based on increases/decreases in WUI areas.

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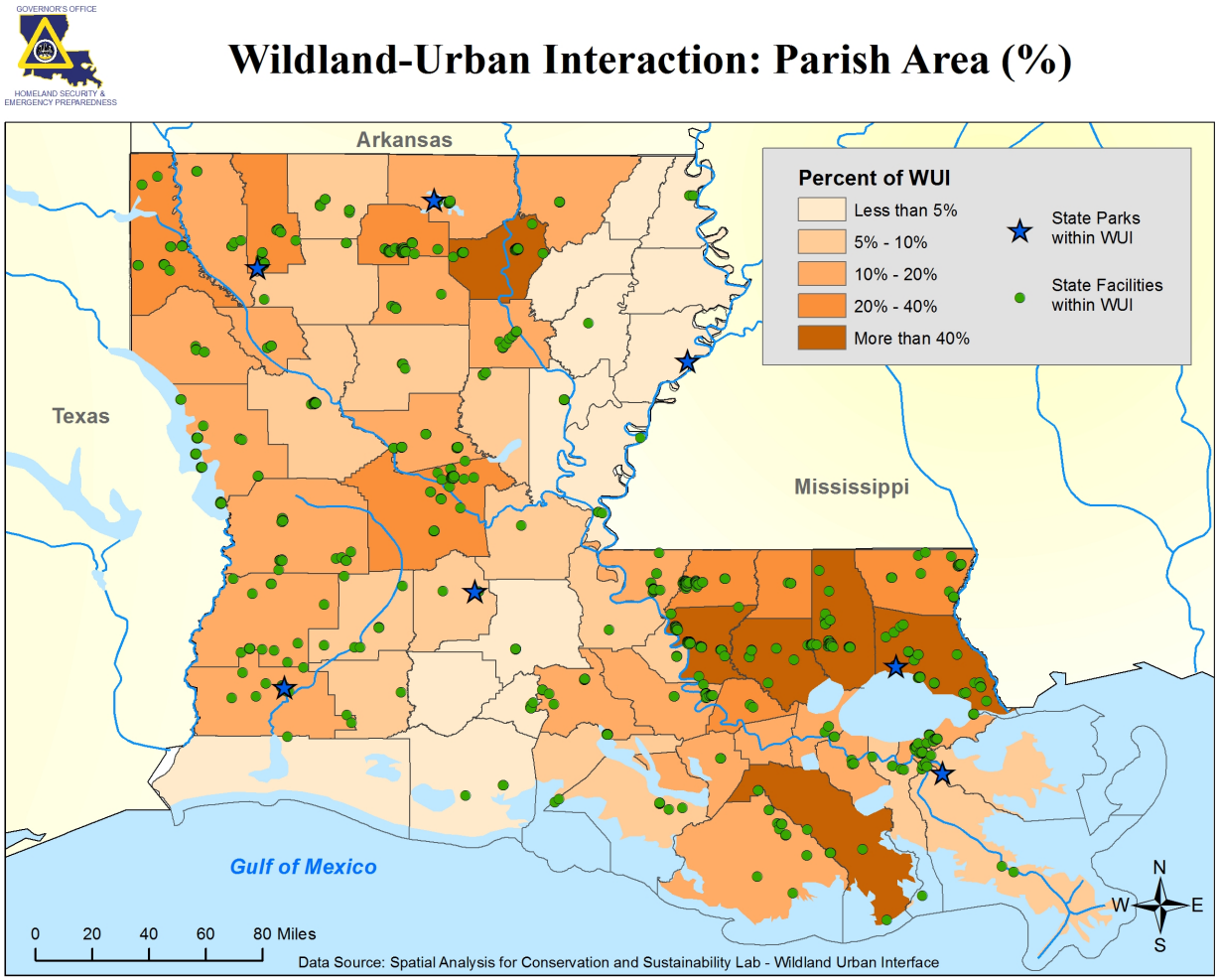

Map 2.112. Louisiana jurisdictional vulnerability based on the percentage of area in each parish that is considered to be a WUI area.

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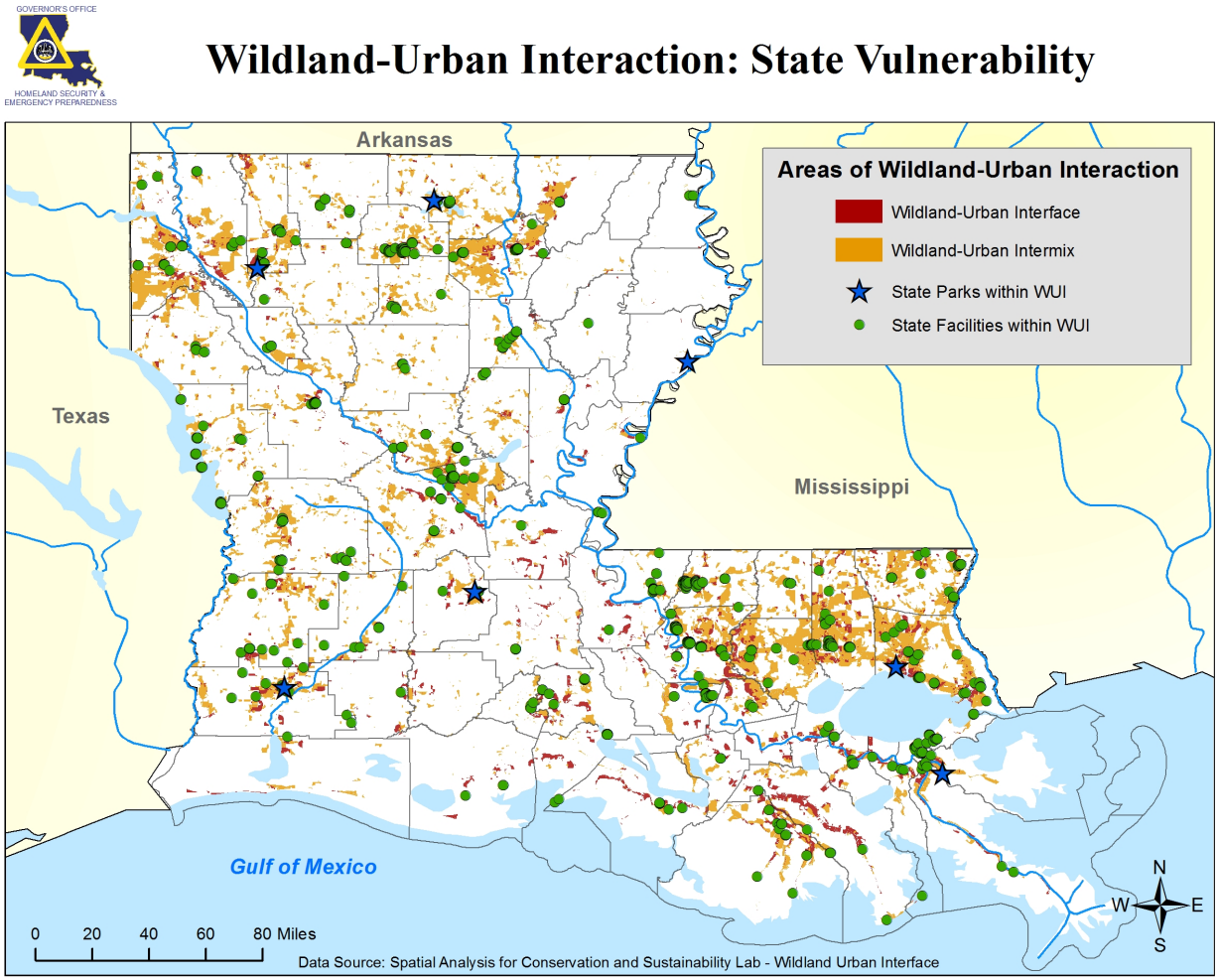

Map 2.113. Louisiana state-owned property located within a WUI area.

Map 2.114 shows the composite jurisdictional risk for wildfire in Louisiana based on the historical data. Several northwestern Louisiana parishes have the greatest risk of wildfire hazards (medium to very high).

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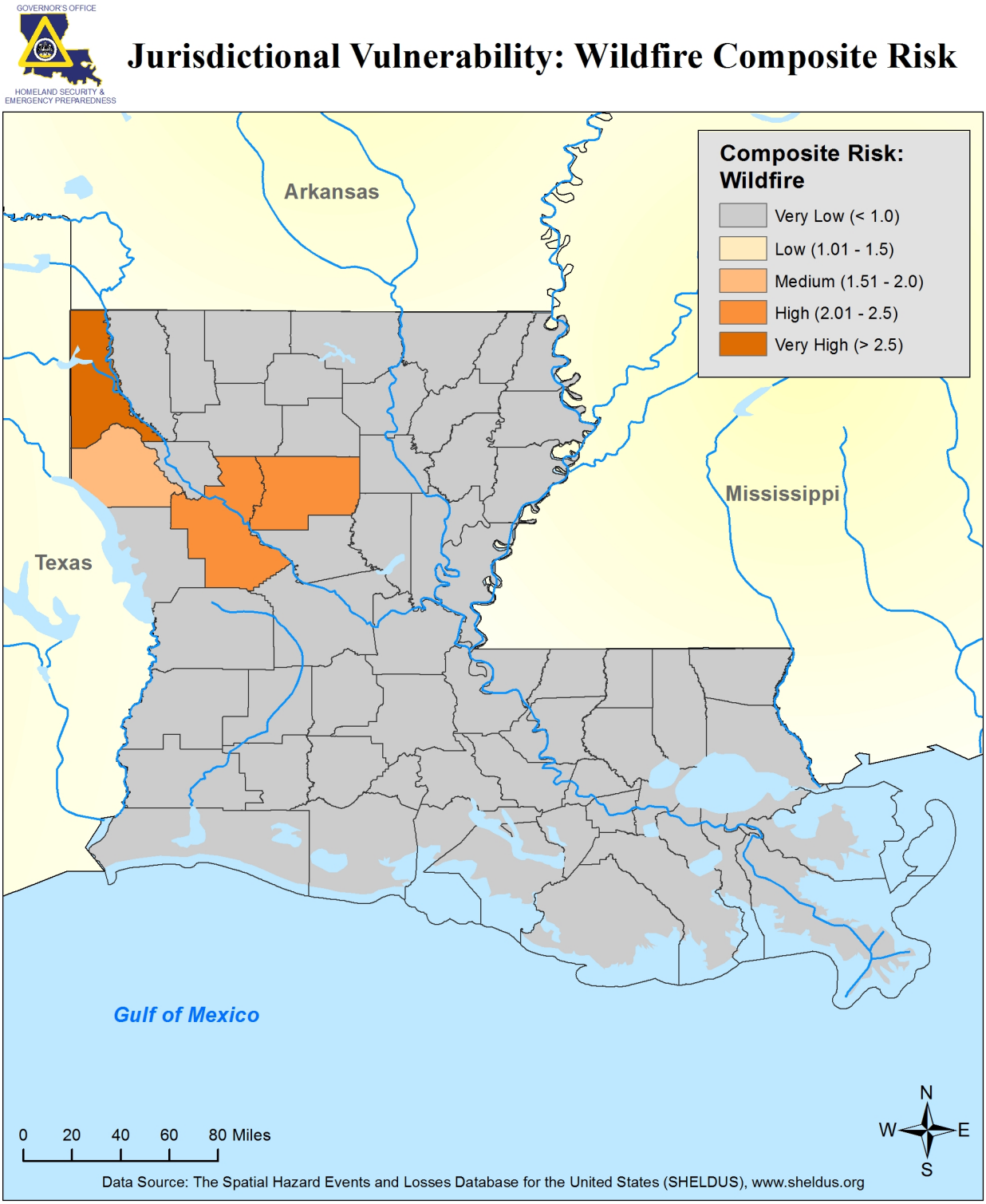

Map 2.114. Composite risk map for wildfire events showing parishes with the highest historical and highest potential risks, mostly in northwest Louisiana.

Potential Economic Loss

Based on multiple sources (e.g., SHELDUS, NOAA, NCDC, USDA, Silvis), the following parishes are most likely to be affected by wildfires: Ascension, Assumption, Allen, Caddo, Cameron, De Soto, EBR, E. Feliciana, Lafourche, Lincoln, Livingston, Morehouse, Natchitoches, Ouachita, Rapides, St. Helena, St. Tammany, Tangipahoa, Vernon, Washington, Webster, W. Carroll, and Winn. Caddo, East Baton Rouge, and St. Tammany parishes are the three most populated parishes and have the highest infrastructure dollar exposures within Louisiana. These three parishes are considered to have the highest vulnerability to wildfires within the state.

Table 2.37 shows the overall exposure for high-risk parishes based on the Hazus-MH 2.1 inventory database and the 2010 population for each parish.

Table 2.37. Exposure data for the 18 highest wildfire risk parishes in Louisiana.

Exposure Data for Parishes with Highest Wildfire Risk		
Parish	Population (2010)	Total Exposure ($1,000)
Allen	25,764	$5,363,704
Ascension	107,215	$15,289,421
Assumption	23,421	$6,251,796
Caddo	254,969	$34,345,146
Cameron	6,839	$5,497,935
De Soto	26,656	$5,177,055
East Baton Rouge	440,171	$62,537,076
East Feliciana	20,267	$6,572,795
Lafourche	96,318	$14,695,652
Lincoln	46,735	$7,424,222
Livingston	128,026	$19,554,361
Morehouse	27,979	$6,391,012
Natchitoches	39,566	$8,404,586
Ouachita	153,720	$19,349,689
Rapides	131,613	$18,821,281
St. Helena	11,203	$5,465,428
St. Tammany	233,740	$31,411,675
Tangipahoa	121,097	$13,106,990
Vernon	52,334	$8,476,619
Washington	47,168	$6,658,683
Webster	41,207	$7,109,218
West Carroll	11,604	$2,412,695
Winn	15,313	$4,087,182
TOTALS	**2,062,925**	**$314,404,221**

This Plan Update also utilizes Hazus-MH 2.1 for the analysis of building exposure in each of the most vulnerable parishes by general occupancy type, which is detailed in Table 2.38.

Table 2.38. Building exposure for wildfire by general occupancy type.

Building Exposure of Most Vulnerable Parishes							
Exposure Type ($1,000)							
Parish	Residential	Commercial	Industrial	Agricultural	Religion	Government	Education
Allen	4,206,938	636,086	145,594	69,414	190,696	55,518	59,458
Ascension	11,107,747	2,419,973	1,186,650	51,686	309,422	111,001	102,942
Assumption	4,325,874	844,545	762,247	31,480	154,616	46,439	86,595
Caddo	24,028,899	6,808,440	1,781,362	103,056	1,140,772	226,850	255,767
Cameron	4,209,736	691,929	393,622	37,564	90,194	38,602	36,288
De Soto	4,099,351	547,708	210,562	28,702	199,404	45,114	46,214
East Baton Rouge	44,435,690	12,153,263	2,615,210	137,030	1,511,136	960,722	724,025
East Feliciana	4,986,588	868,098	308,317	34,200	201,656	116,666	57,270
Lafourche	11,267,397	2,122,336	708,103	55,486	245,694	98,260	198,376
Lincoln	5,441,177	1,083,517	388,514	45,284	275,472	45,226	145,032
Livingston	15,814,237	2,391,656	645,224	48,770	419,458	88,160	146,856
Morehouse	4,880,603	788,741	239,143	83,610	272,078	61,893	64,944
Natchitoches	6,407,131	1,087,075	253,406	48,482	392,736	80,155	135,601
Ouachita	12,968,015	4,382,733	938,805	80,576	616,220	181,698	181,642
Rapides	13,024,701	3,854,973	754,563	110,124	687,004	204,171	185,745
St. Helena	3,837,930	997,830	253,788	16,936	227,926	73,970	57,048
St. Tammany	23,583,443	5,750,413	927,918	111,050	565,620	246,405	226,826
Tangipahoa	9,581,467	2,226,918	520,534	67,496	435,132	101,324	174,119
Vernon	6,834,217	994,277	177,845	34,900	273,636	85,019	76,725
Washington	5,129,019	819,489	254,003	64,838	266,440	55,916	68,978
Webster	5,530,603	790,119	376,432	29,676	271,698	41,297	69,393
West Carroll	1,722,320	287,341	107,687	76,142	144,518	41,231	33,456
Winn	3,236,881	429,077	141,778	17,204	180,002	44,561	37,679
TOTALS	**230,659,964**	**52,976,537**	**14,091,307**	**1,383,706**	**9,071,530**	**3,050,198**	**3,170,979**

Based on the baseline Hazus-MH 2.1 inventory database, the Louisiana Digital Map GIS database (via LOSCO), and the U.S. Census Bureau, regional vulnerability to wildfire is listed in Table 2.39.

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Table 2.39. Regional vulnerability to wildfire.

REGIONAL VULNERABILITY TO SEVERE WILDFIRE	
Vulnerable Locations	Number of Records
Louisiana Parishes	23
Dams	524
Airports	54
Communication Towers/Facilities	254
Electricity Providers/Facilities	51
Emergency Response Centers	11
Fire Stations	417
Hospitals	104
Nuclear Plants	1
Police Stations	441
Elementary/Secondary Schools	1,317
Universities/Colleges	12

Wildfires prompt multiple hazards. The most damaging of these is the burning of property. Wildfires can spread quickly under ideal weather scenarios for combustion, including dry conditions combined with a strong wind. In strong winds, wildfires can spread rapidly from fields and forested areas into adjacent interface zones. In addition to the obvious danger from open flames, smoke from wildfires is a major health concern, particularly if few weather systems move through the area. Frontal boundaries can bring rain and winds to help push smoke out of an area and minimize smoke inhalation and the spread of wildfire, but a long period of time can pass between frontal boundaries.

To determine potential loss estimates from wildfire, the available historical loss data were annualized to determine future loss potential, as illustrated in Map 2.115. As the map demonstrates, Caddo, Natchitoches, Winn, and Calcasieu parishes are predicted to have the highest potential annualized losses.

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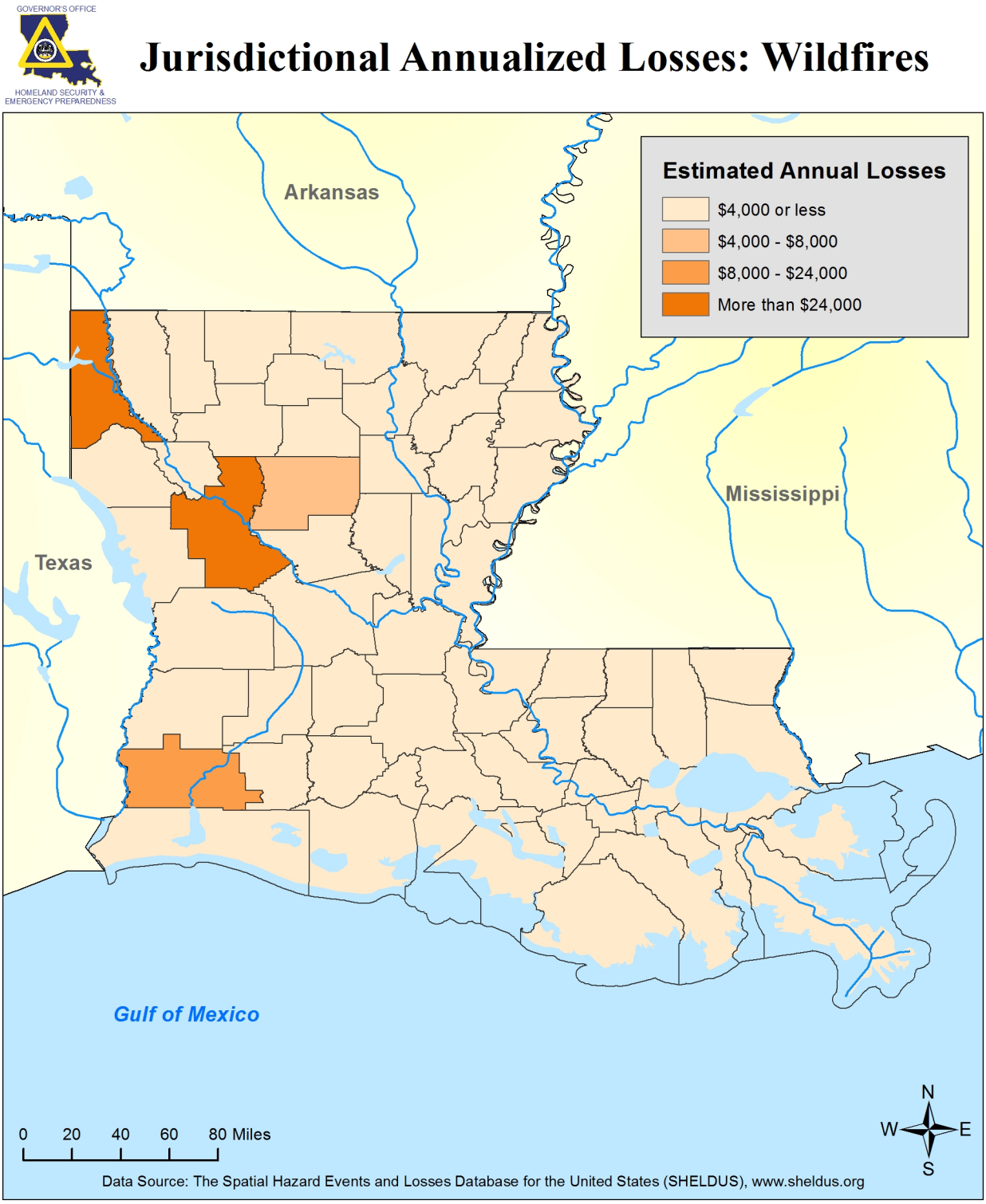

Map 2.115. Jurisdictional annualized loss due to wildfire.

All of Louisiana is potentially vulnerable to wildfire, but areas of rapid development in interface zones are especially so. Roads, bridges, utilities, and communications systems could be greatly impeded or even destroyed, resulting in high-level vulnerability for each impacted community. Transportation and emergency response could be inhibited, and utilities such as electricity, water, gas, sewer, and communications could be completely shut down. The elderly and young children are most vulnerable to smoke inhalation. State, local, and federal facilities located in the wildfire area would also be shut down and operations greatly hindered. State and local governments, churches, charities, and other support organizations could be stretched beyond their limits to furnish shelter and food to their citizens if an evacuation is required, although this has never happened in Louisiana. Other critical facilities, such as police, fire, and medical facilities, would be strained with an excess of calls and medical emergencies in the case of a very large wildfire. Without backup power, these institutions would be inoperable due to lost communication and mobility.

Potential Losses by Jurisdiction

Overview & Analysis of Potential Losses: All jurisdictions in Louisiana can suffer losses due to wildfires. Crop damage is the most common loss, but the built environment and human populations can experience loss as well.

Changes in jurisdictional population levels impact each parish across the state disparately. In the parishes where wildfire vulnerability has increased because of increases in population (Ascension, Livingston, Tangipahoa, and St. Tammany), concomitant changes in development have impacted loss estimates and will cause an increase in future losses due to increased levels of exposure. In Cameron Parish, where wildfire vulnerability has decreased because of decreases in population, concomitant changes in development have impacted loss estimates and will cause a decrease in future losses due to decreased levels of exposure.

Potential Losses of State Facilities

The wildfire hazard vulnerability assessment of state-owned buildings was based on their location relative to the WUI, the percent of each parish covered by WUI zones, and the parish-level composite risk score, which incorporates the total number of wildfire events, injuries, fatalities, and property damages as well as the social vulnerability of impacted parishes. The criteria used to determine specific vulnerability rankings for each building and the results of applying this ranking to the state-owned buildings are shown in Table 2.40.

Table 2.40. Wildfire Vulnerability Criteria and Ranking Results.

Wildfire Vulnerability Criteria and Ranking	
Ranking	Criteria
High	Located within the Wildland Urban Interface
Medium	Composite risk score between 1.5 and 2.0 & more than 10% WUI
Low	Composite risk score less than 1.5 and less than 10% WUI

The wildfire loss estimate ranges are derived from a ratio based on the expected annual losses in parishes with high, medium, and low vulnerability rankings. The January 2014 state facilities database was used to obtain accurate building numbers for each loss estimate range. Loss estimates of state-owned buildings in Louisiana involved an analysis of the following parameters:

- Wildfire Hazard Vulnerability
- Previous Losses and Annual Loss Estimations
- Percentage of Parish Defined as Interface
- Location of Interface Zones

Table 2.41. Wildfire Loss Estimate Ranges and Ranking Results.

Wildfire Loss Estimate Ranges and Ranking		
Ranking	Total Loss Estimate Ranges	Number of Buildings
High	$22,500 - $67,500	1871
Medium	$7,500 - $22,500	675
Low	$0 - $7,500	6139

Winter Weather

For Louisiana and other parts of the southeastern U.S., a severe winter storm occurs when humid air from the Gulf of Mexico meets a cold air mass from the north. As the temperature falls once the cold air mass crosses Louisiana, precipitation may fall in the form of snow or sleet. If the ground temperature is cold enough but air temperature is above freezing, rain can freeze instantly on contact with the surface, causing massive ice storms.

Winter storms are not only a direct threat to human health through conditions like frostbite and hypothermia, but they are also an indirect threat to human health due to vehicle accidents, loss of power and heat, and freezing of vital parts of the state's infrastructure. For instance, telecommunications and power can be disrupted for days. Moreover, unprotected pipes are especially vulnerable, causing disruption in water service and decreases in water pressure, which cause a cascading problem for emergency responders. Freezing rain can also cover roadways and electric utility poles, affecting travel and electric service. Depending on ice thickness, the size of the area covered, and the duration of the ice storm, the impact can be crippling: roadways become impassible, power is disrupted, communication is severed, and travel by vehicle or by foot becomes treacherous, causing injuries and fatalities. Homes and buildings are damaged by ice accumulation, either directly by the weight of the ice on the roofs or by trees and/or limbs falling on buildings.

Winter weather can also have a devastating effect on agriculture, particularly on crops (like citrus) that are dependent on warm weather. Long exposures to low temperatures can kill many kinds of crops, and ice storms can weight down branches and fruit. A number of techniques exist to temper the effects of cold weather on crops, such as covering crops with blankets or even a thin layer of water so a thin layer of ice protects the crop from even colder air. Farmers have long encountered cold weather events and have developed a number of successful mitigation strategies that they should continue putting into action.

While Louisiana is far less likely to have heavy snow and ice accumulation than most other states, winter weather is expected to occur at least once each winter. According to data from the National Climatic Data Center, Louisiana is in the lowest category of probable snow depth, with a 5% chance of <25 cm snow depth being equaled or exceeded in any given year. In Louisiana, damaging winter storms are generally associated with ice accumulations between 1 and 3 in.

Winter Weather Profile

An account of some of the major winter weather events in Louisiana can also indicate the surprising severity of these events in the state, as well as the geographic extent of the worst hazards. The winter weather events that affect the state are categorized as ice storms, freezes, and snow events. Each event can affect any part of the state.

Of the winter weather types listed above, ice storms are the most dangerous. In the past 20 years, Louisiana has suffered a few major ice storms. As might be expected, these ice storms have tended to affect the northern part of the state, in such parishes as Caddo, De Soto, Bossier, Red River, Webster, Claiborne, Bienville, Lincoln, Union, Ouachita, Morehouse, Richland, West Carroll, East Carroll, and Madison. But they can affect the whole state (see Map 2.116 for average maximum daily January temperatures in the state). In February 1989, an ice storm affected northwestern Louisiana, producing over 2 in. of ice and causing major power outages, in addition to the expected agricultural and forest damage.[lxiv] In February 1994, another ice storm affected northern Louisiana, which also turned out to be one of the worst disasters to affect the state. It began on February 9, appearing to be a normal cold air event, but an influx of humid Gulf air that confronted an Arctic anticyclone resulted in major ice accumulation across the southeastern United States. In Louisiana, more than 100,000 homes and businesses went without power for the duration of the four-day storm. Damage was estimated conservatively at $13.5 million in the state.[lxv] But the southern part of the state is not invulnerable to ice events. In January 1997, a storm caused extensive icing throughout southwestern Louisiana, in addition to southeastern Texas, resulting in a loss of power for several days in the area west of Lake Charles. Other areas of the state reached record ice accumulation, as well.[lxvi]

As ice storms can affect any part of the state, so can freezing temperatures. A freeze that affected Louisiana just before Christmas in 1989 demonstrates the widespread, severe, and often indirect effects of winter weather hazards, even in states bordering the Gulf. New Orleans observed freezing and below freezing temperatures for nearly three consecutive days, with 81 hours total below freezing. Temperatures in Baton Rouge plummeted to as low as 8°F. One of the worst aspects of the freeze were the breakage of water pipes, as illustrated by the 100+ fires recorded in New Orleans due to a loss of water pressure and improperly utilized heating sources. At least five deaths were attributed to the event in southern Louisiana.[lxvii] Crops in the area also suffered greatly.

Of all winter weather events to affect the whole state, snow events are the least common. Nevertheless, small snow events (called flurries and “dustings”) occur almost every year in the northern part of the state. And in recent years, even the southern part of the state has experienced a surprising frequency of larger snow events. In early December 2008, the southern part of the state experienced one of the earliest recorded snow accumulations, exceeding 5 in. in some places. The winter season of 2009–2010 caused two major snowfalls in the southern parishes, in December and then in February. The latter event seems to be the first acknowledged occurrence of snow in all 48 of the continental United States.[lxviii]

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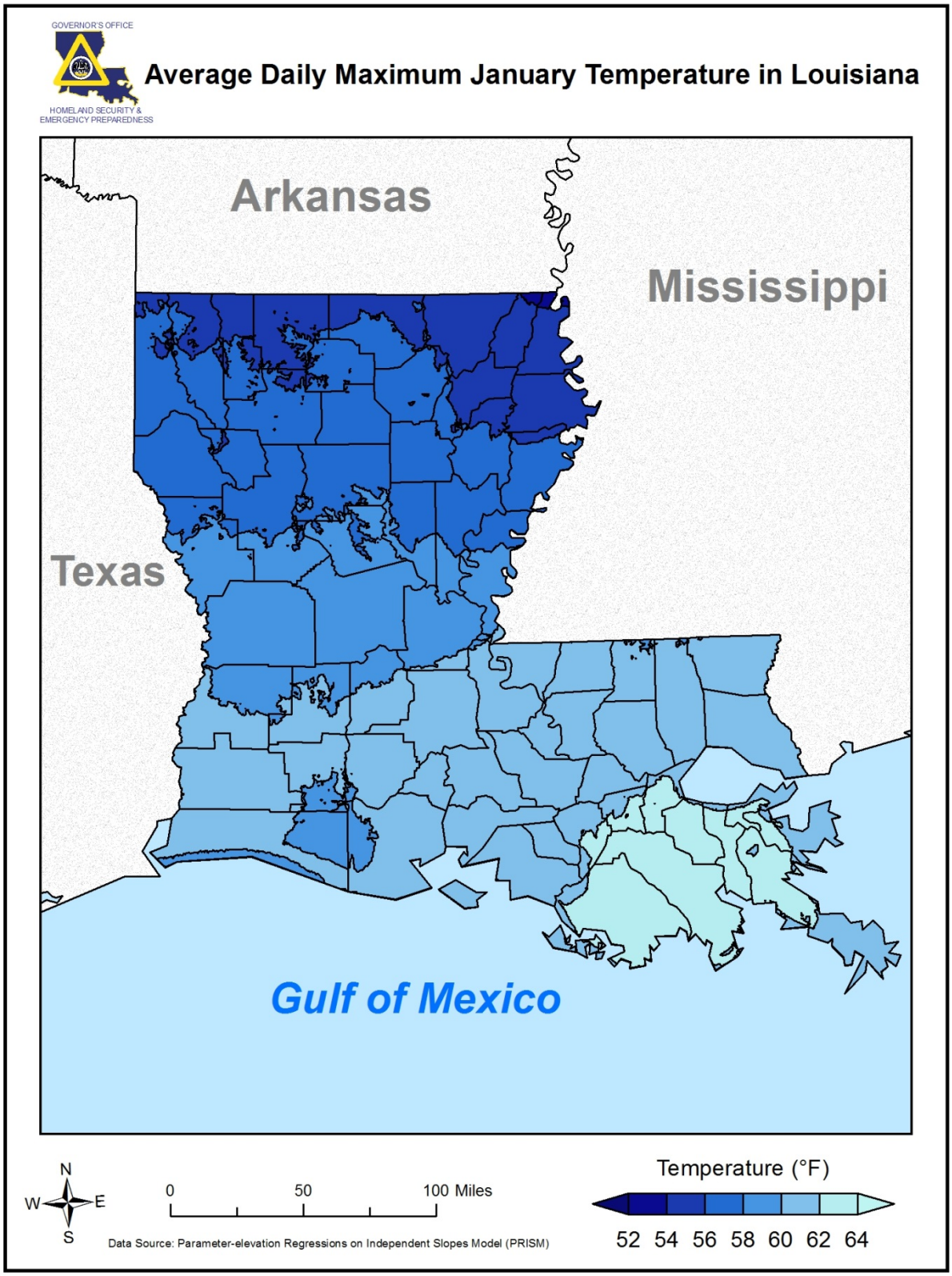

Map 2.116. Average maximum daily January temperatures by parish.

It may be tempting to dismiss the severity of winter events in Louisiana, but particularly for the most vulnerable citizens of the state—such as the elderly, poor, and homeless—these events can be deadly. Nevertheless, they can be mitigated effectively, given proper attention.

Winter Weather Risk Assessment

Based on historical records, and as indicated in Map 2.117, the probability of future occurrences of winter weather in Louisiana is **High**. Because extreme winter weather occurrences tend to be very disruptive to transportation and commerce, and due to a continued history of damaging ice storms in the state, ice storms are one of the hazards included for Risk Assessment. Maps 2.118, 2.119, 2.120, and 2.121 indicate the total winter weather events, as well as the damages, injuries, and fatalities attributed to winter weather. Bossier, Grant, and Lincoln Parishes are at high risk (greater than 2.0 composite risk score) to winter weather and have experienced significant population increases of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability of these parishes to winter weather has increased. East Carroll, Madison, and Tensas Parishes are at high risk to winter weather, but have experienced significant population decreases of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability of these parishes to winter weather has decreased.

Map 2.122 locates previously damaged state asset properties in relation to the density of winter weather events over the past 25 years. State-owned critical facilities located in areas affected by winter weather are of the following types: hospitals, shelters, Emergency Operation Centers, data processing centers, and state police troop offices.

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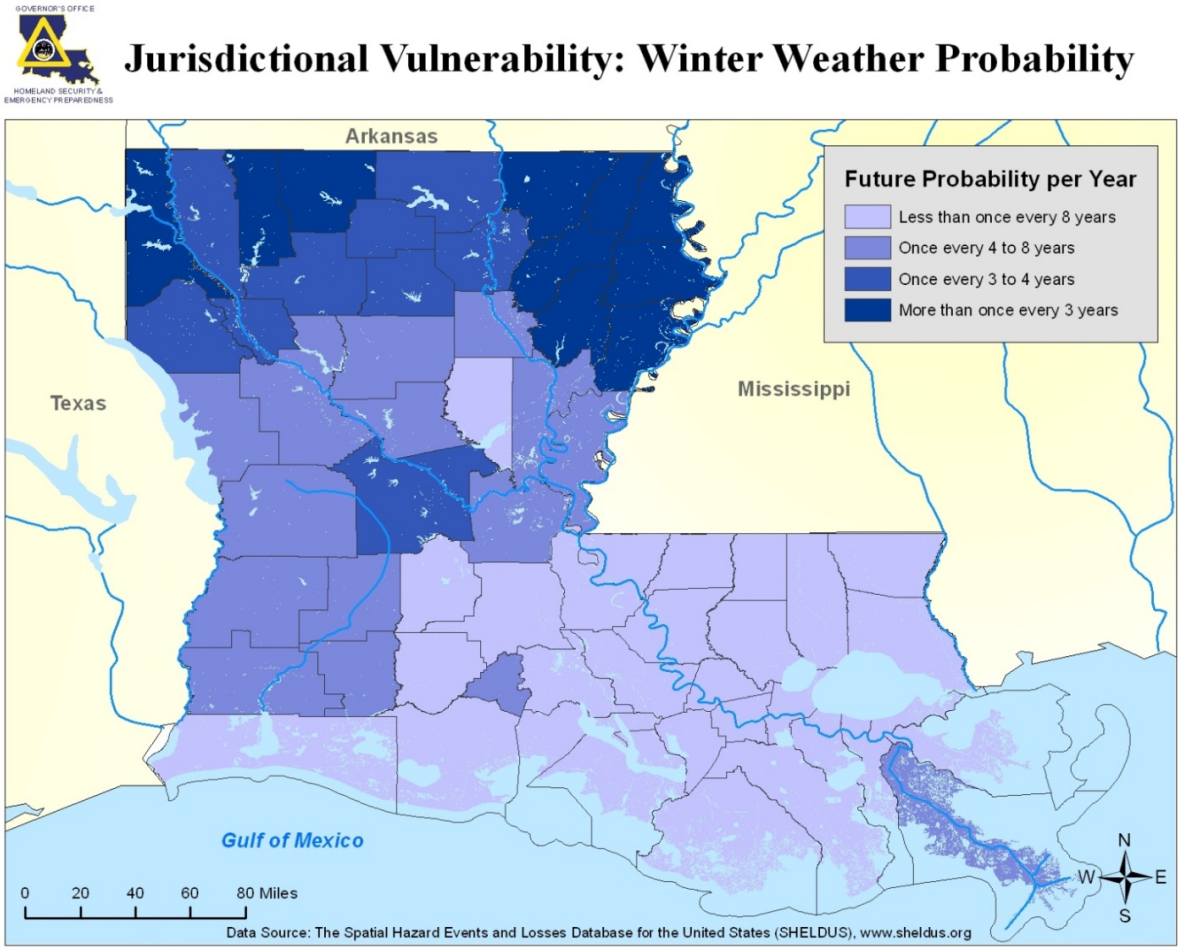

Map 2.117. Probability of future winter weather events in Louisiana by parish based on data from 1987–2012.

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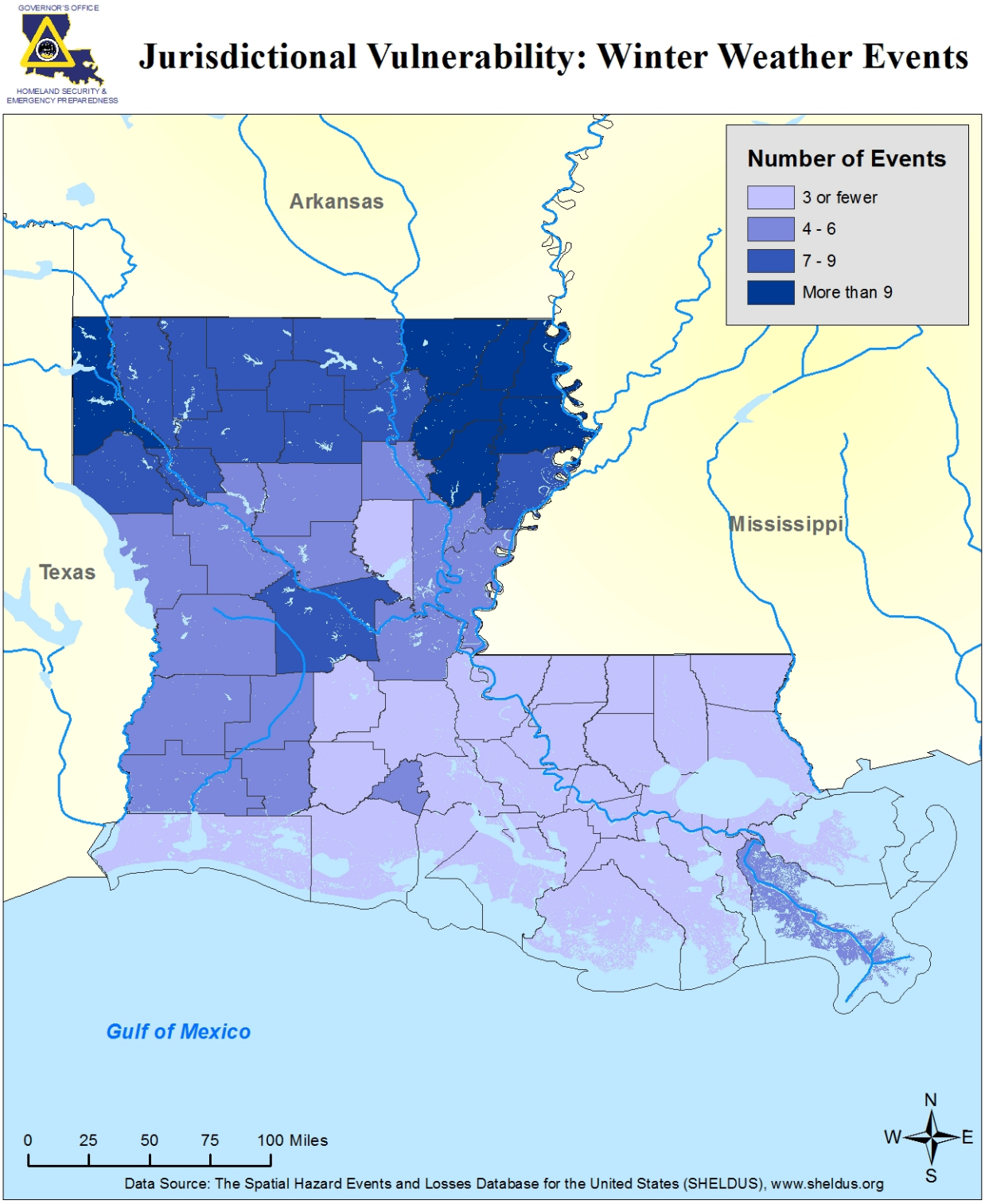
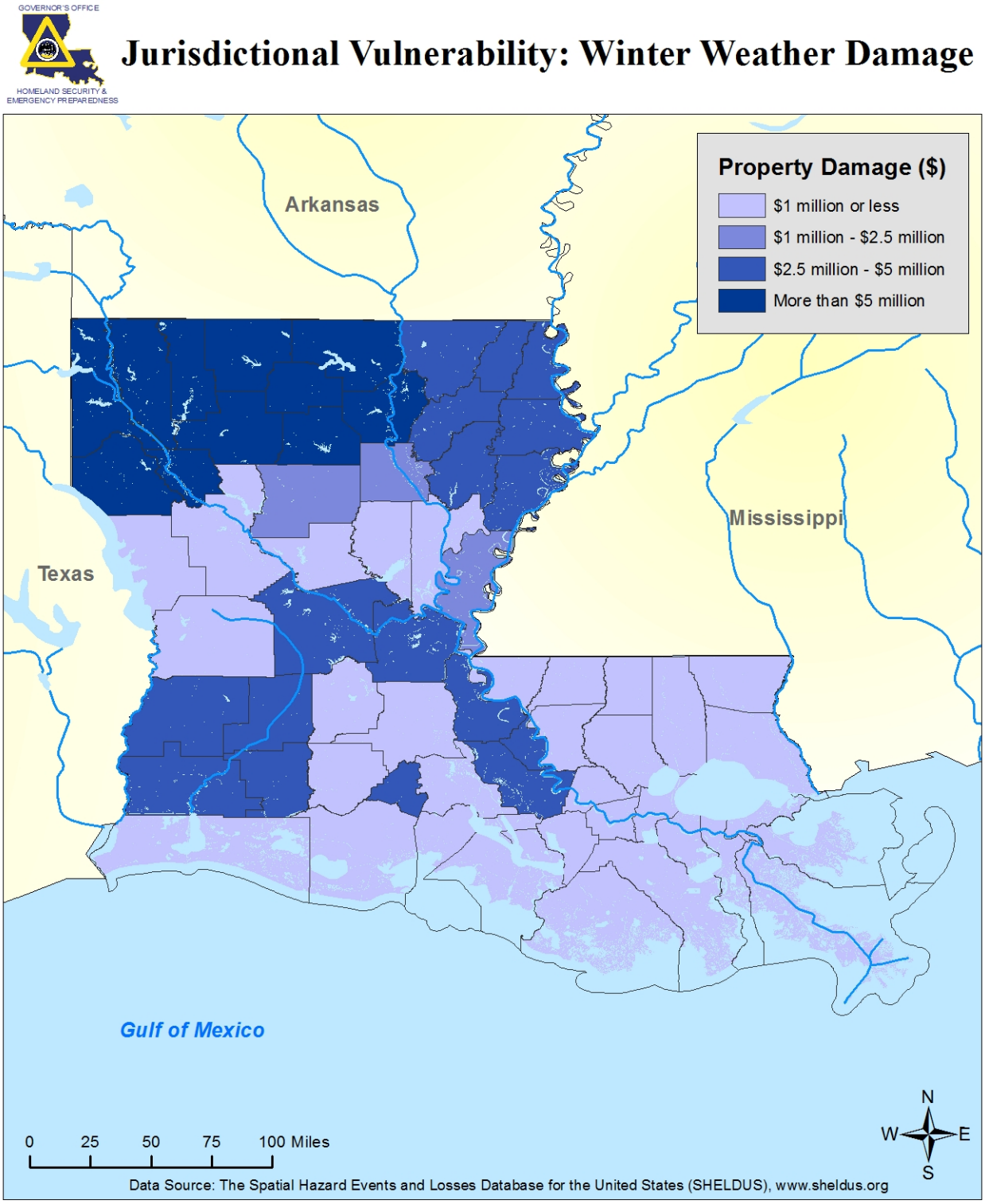
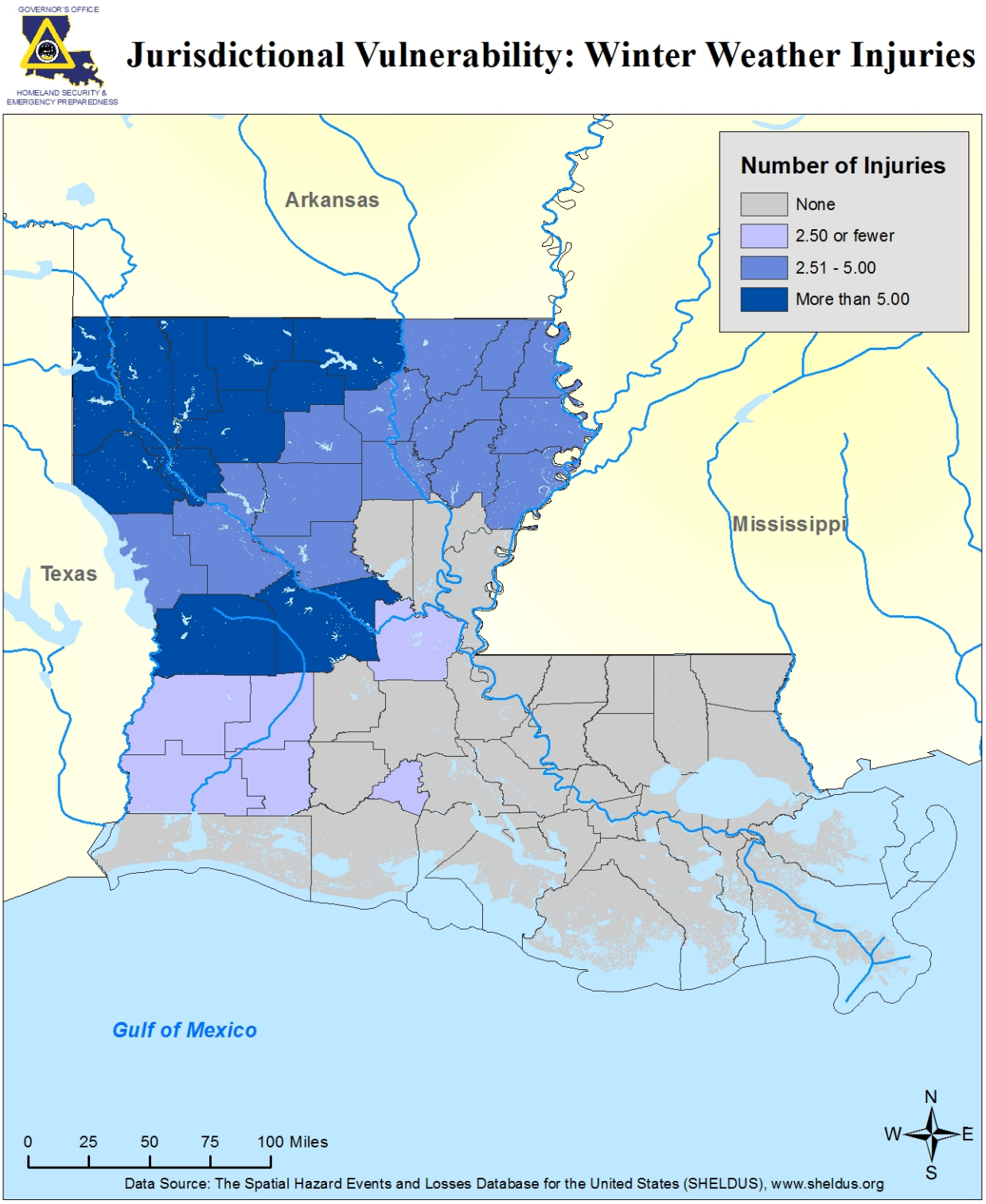


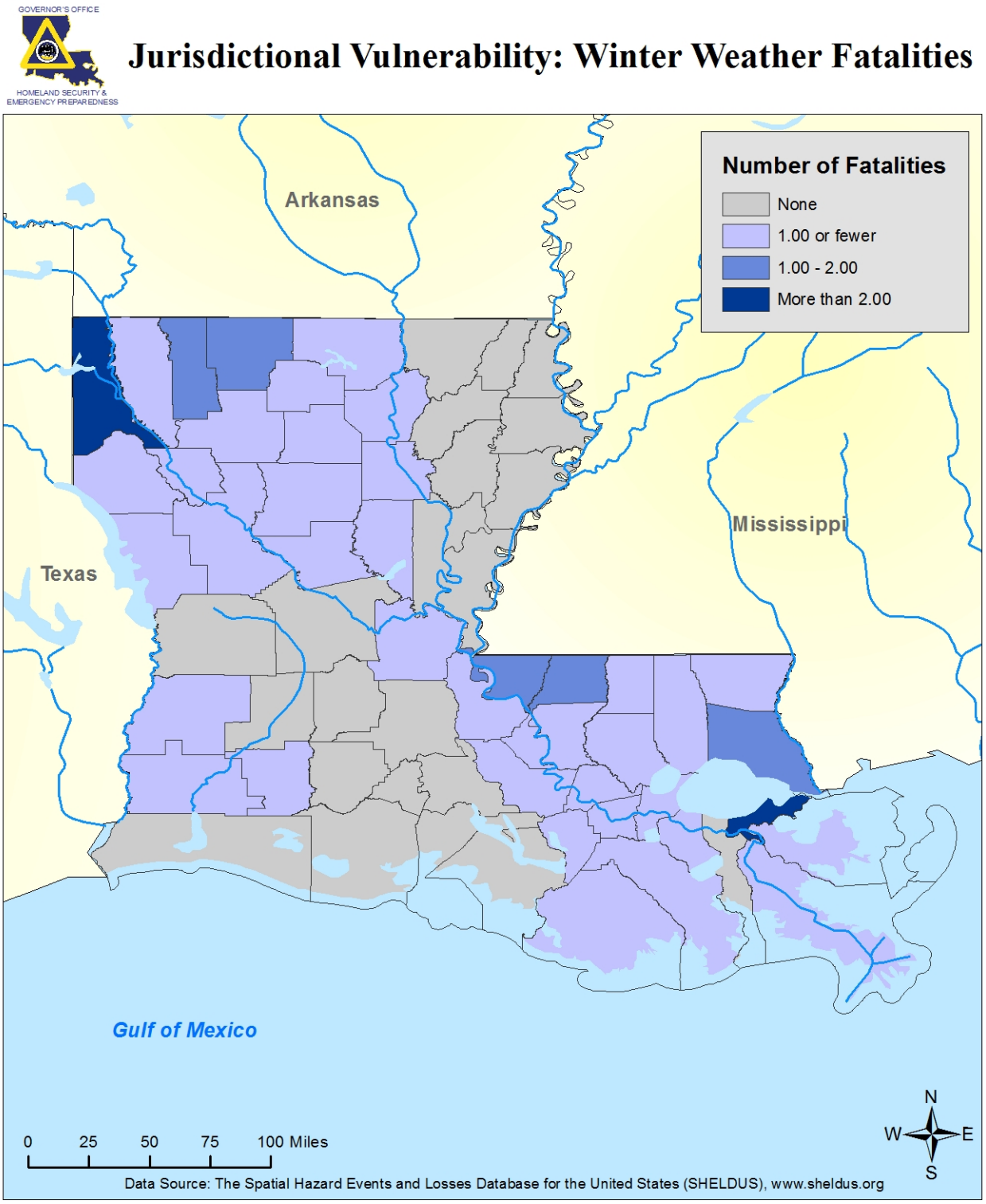
Map 2.118. Louisiana jurisdictional vulnerability for winter weather events based on data from 1987–2012.



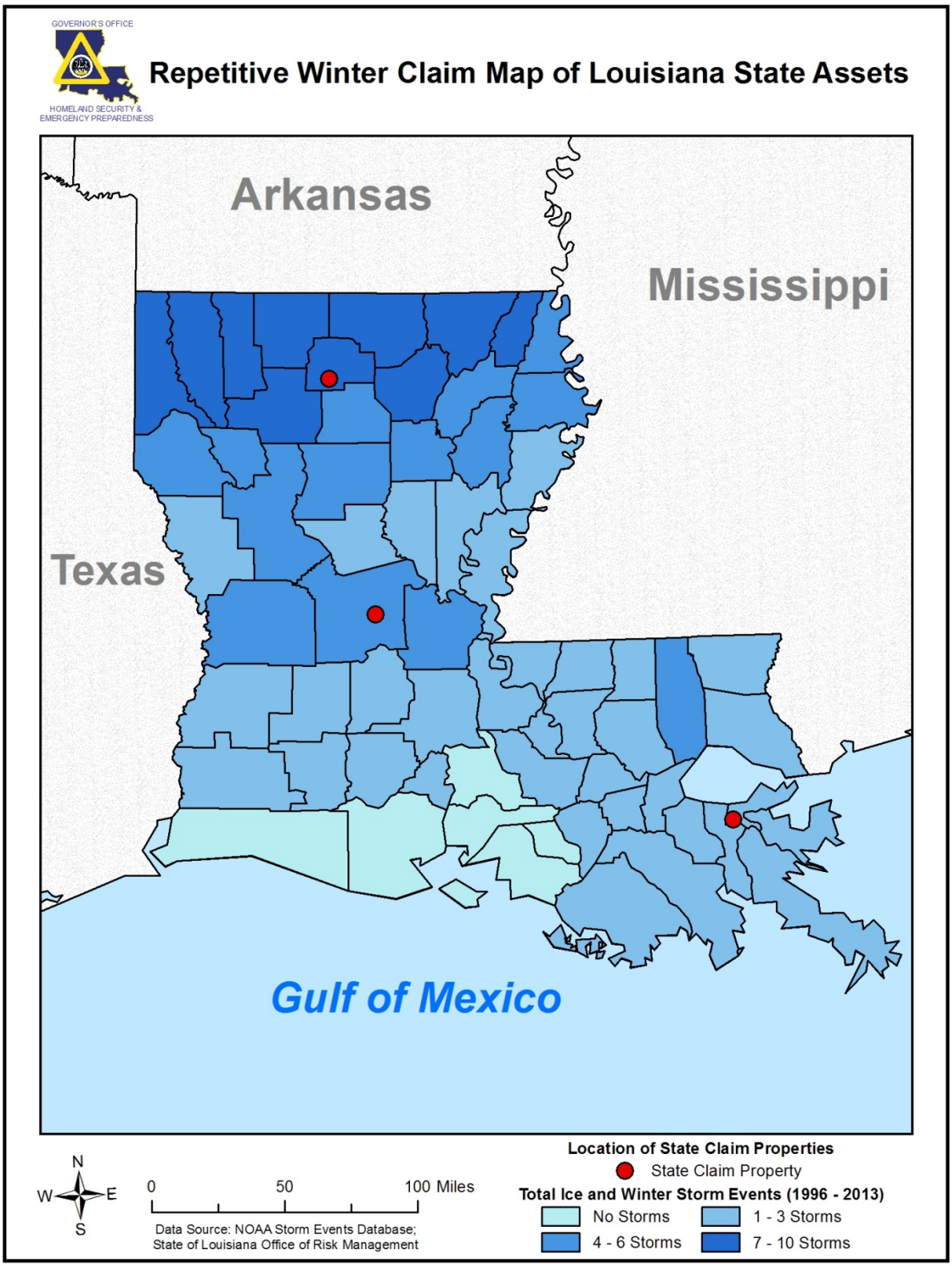
Map 2.119. Louisiana jurisdictional vulnerability for damage from winter weather based on data from 1987–2012.



Map 2.120. Louisiana jurisdictional vulnerability for injuries from winter weather based on data from 1987–2012.



Map 2.121. Louisiana jurisdictional vulnerability for fatalities from winter weather based on data from 1987–2012.



Map 2.122. Louisiana state assets with paid repetitive claims for winter weather damage.

Table 2.42 lists the top 10 winter-weather-damaged paid losses repetitive claims properties (source: Louisiana Office of Risk Management).

Table 2.42. Top paid claims for winter-weather-damaged state assets.

Top Paid Claims for Winter-Weather-Damaged State Assets				
Building ID	Building Name	Location	Net Paid	Total Number of Claims (All Hazards)
S00533	School of Nurses Building - Delgado Community College	New Orleans	$0	1
S10958	Medical Education Building - LSU Health Science Center	New Orleans	$1,860	1
S15630	State Evacuation Shelter	Alexandria	$5,750	1
S16064	Performing Arts Center - Grambling University	Dubach	$0	1

Map 2.123 shows the composite jurisdictional risk for winter weather in Louisiana based on the preceding data. The northern Louisiana parishes have the greatest risk of winter weather hazards (very high).

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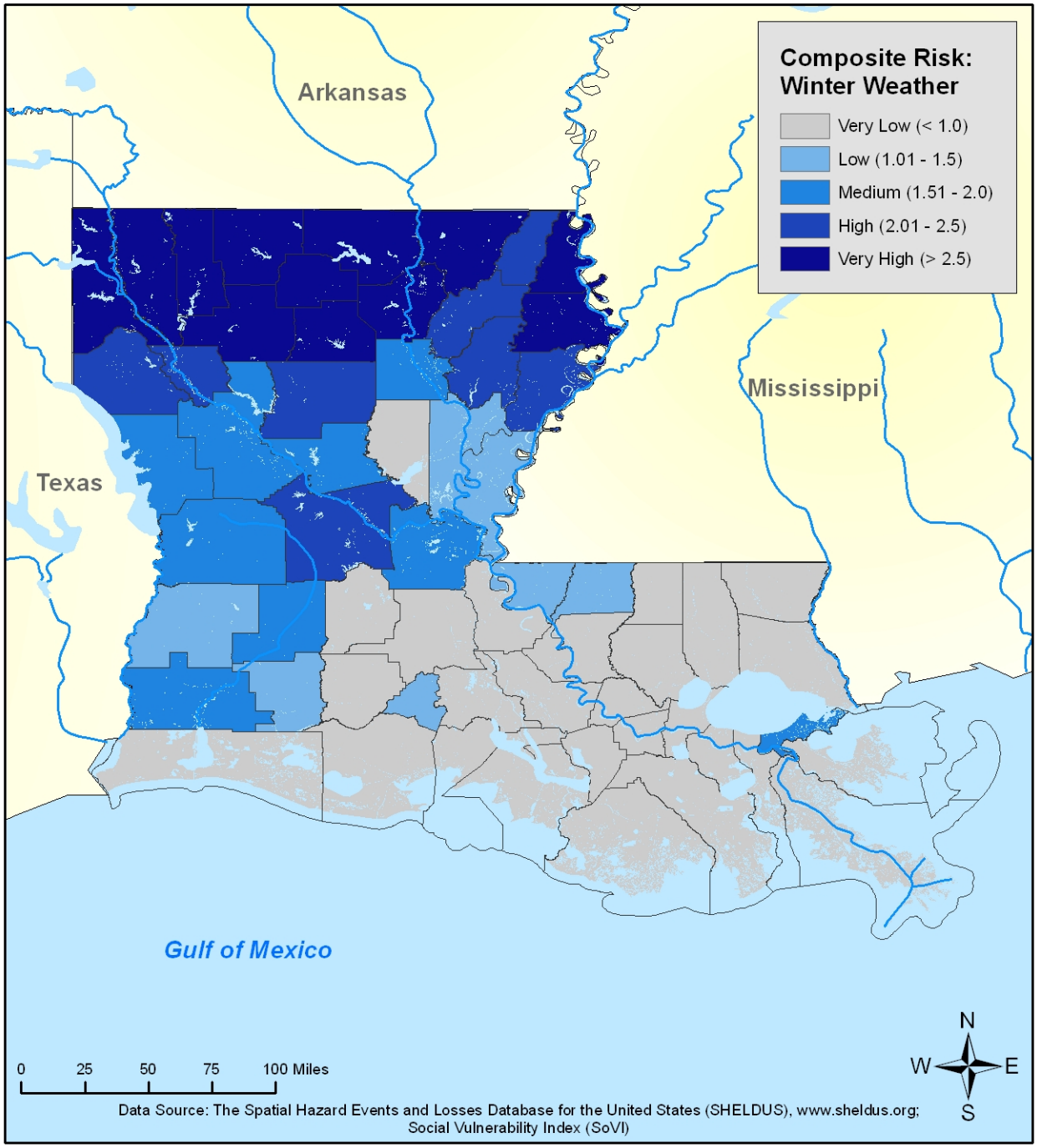

Map 2.123. Composite risk map for winter weather events showing parishes with the highest historical and highest potential risks scattered across Louisiana.

Severe winter weather events do not occur with the same frequency within all parts of Louisiana. The northern quarter of Louisiana has historically experienced the most severe winter events between 1987 and 2012. The central and, to an even greater extent, the southern parts of the state experienced the fewest severe winter events.

While snow has historically impacted Louisiana to varying degrees, the impacts resulting from ice storm events are often more severe in regards to human and economic losses.

- Deaths and injuries have occurred in the past from winter storm events. Deaths and injuries have resulted from various accidents including automobile collisions due to poor driving conditions or hypothermia resulting from insufficient heat.

- Emergency medical response can be severely hindered from the effects of a winter storm event. Roads and highways are most vulnerable to the effects of winter storms. Roads and, most often, bridges frequently become iced over resulting in accidents, injuries, deaths, and traffic congestion.

- Roads can be heavily damaged due to winter weather events. Potholes and cracks can be found on roadways after a winter weather event resulting in the need for repairs causing further economic losses to the local area.

- Electrical transmission lines are highly vulnerable to severe winter weather. Trees frequently are felled by heavy amounts of ice accumulating on branches. Trees falling on nearby power lines result in disruption of power service, resulting in additional costs for repairs and maintenance.

- Other impacts resulting from winter storms include damage to plumbing, sewers and waterlines, as well as minor roof damage and house fires caused by portable heaters.

- First responders are increasingly at risk as they respond to traffic incidents and calls for medical attention. They are vulnerable to the same transportation dangers as other citizens, but often have to proceed into the elements when ordinary citizens would not.

- During a winter storm and the days that follow, many people do not travel due to the road conditions. The absenteeism of workers impacts the overall continuity of the state government.

- Severe winter storms can result in localized environmental changes such as downed trees and flash flooding due to large amounts of ice and melting snow. Snow melt from upstream (US Midwest and Plains) could also be considered a winter storm event, but is accounted for in the flooding section of the hazard mitigation plan.

- Northern Louisiana contains large, rural farming communities and any winter weather events can have an adverse effect on crops ranging from a late winter/early spring storm that decimates crops as they are beginning to grow to heavy ice events that damage standing crops or impact animals.

Potential Economic Loss

Based on multiple sources (e.g., SHELDUS, NOAA, NCDC), the following parishes are most likely to be affected by severe winter weather: Bienville, Bossier, Caddo, Claiborne, De Soto, East Carroll, Franklin, Jackson, Lincoln, Madison, Morehouse, Ouachita, Red River, Richland, Tensas, Union, Webster, and West Carroll. Bossier, Caddo, and Ouachita Parishes are the three most populated parishes and have the highest infrastructure dollar exposures within Louisiana. These three parishes are considered to have the highest vulnerability to severe winter weather within the state.

Table 2.43 shows the overall exposure for high-risk parishes based on the Hazus-MH 2.1 inventory database, and the percentage of residences composed of mobile home structures in each parish.

Table 2.43. Exposure data for the 18 highest winter storm risk parishes in Louisiana.

Exposure Data for Parishes with Highest Winter Weather Risk			
Parish	Population (2010)	Total Exposure ($1,000)	Mobile Homes (%)
Bienville	14,353	$5,752,097	25.6
Bossier	116,979	$16,148,468	15.5
Caddo	254,969	$34,345,146	9.3
Claiborne	17,195	$4,272,885	24.3
De Soto	26,656	$5,177,055	30.0
East Carroll	7,759	$2,430,145	18.3
Franklin	20,767	$3,818,331	18.7
Jackson	16,274	$6,573,859	22.5
Lincoln	46,735	$7,424,222	17.6
Madison	12,093	$2,712,688	14.4
Morehouse	27,979	$6,391,012	16.9
Ouachita	153,720	$19,349,689	13.7
Red River	9,091	$4,618,478	19.9
Richland	20,725	$4,905,466	17.7
Tensas	5,252	$2,158,271	10.0
Union	22,721	$5,591,013	27.1
Webster	41,207	$7,109,218	20.5
West Carroll	11,604	$2,412,695	24.0
TOTALS	**826,079**	**$141,190,738**	**19.2 (Average)**

Based on the geographic extents determined in the hazard profile and the jurisdictional vulnerability assessments, the parishes in blue in Map 2.124 have the highest risk factor with respect to winter weather. The corridor outlined in red marks the extent of this high-risk area.

Map 2.124. High risk areas for severe winter weather in Louisiana.

This Plan Update also utilizes Hazus-MH 2.1 for the analysis of building exposure in each of the most vulnerable parishes by general occupancy type, which is detailed in Table 2.44.

Table 2.44. Building exposure for winter weather by general occupancy type.

BUILDING EXPOSURE OF MOST VULNERABLE PARISHES							
	Exposure Type ($1,000)						
Parish	Residential	Commercial	Industrial	Agricultural	Religion	Government	Education
Bienville	4,510,931	570,939	282,913	36,384	264,558	37,245	49,127
Bossier	11,891,551	2,709,321	761,501	59,494	432,384	192,803	101,414
Caddo	24,028,899	6,808,440	1,781,362	103,056	1,140,772	226,850	255,767
Claiborne	3,222,505	469,511	284,397	28,354	170,516	43,930	53,672
De Soto	4,099,351	547,708	210,562	28,702	199,404	45,114	46,214
East Carroll	1,686,708	359,608	121,147	56,672	127,054	39,850	39,106
Franklin	2,797,175	530,282	139,622	72,966	183,488	48,884	45,914
Jackson	5,186,884	670,191	304,068	29,986	256,162	37,219	89,349
Lincoln	5,441,177	1,083,517	388,514	45,284	275,472	45,226	145,032
Madison	1,993,179	379,309	109,226	59,224	118,460	25,696	27,594
Morehouse	4,880,603	788,741	239,143	83,610	272,078	61,893	64,944
Ouachita	12,968,015	4,382,733	938,805	80,576	616,220	181,698	181,642
Red River	3,754,707	430,231	176,860	29,058	161,502	31,370	34,750
Richland	3,420,917	774,645	265,348	90,184	234,316	67,130	52,926
Tensas	1,490,623	421,817	63,506	52,738	70,438	30,406	28,743
Union	4,533,455	594,390	197,758	32,350	166,228	26,885	39,947
Webster	5,530,603	790,119	376,432	29,676	271,698	41,297	69,393
West Carroll	1,722,320	287,341	107,687	76,142	144,518	41,231	33,456
TOTALS	**103,159,603**	**22,598,843**	**6,748,851**	**994,456**	**5,105,268**	**1,224,727**	**1,358,990**

Based on the baseline Hazus-MH 2.1 inventory database, the Louisiana Digital Map GIS database (via LOSCO), and the U.S. Census Bureau, regional vulnerability to severe winter weather is listed in Table 2.45.

Winter storms can be accompanied by strong winds creating blizzard conditions with blinding wind-driven snow, severe drifting, and dangerous wind chill. These types of conditions are very rare in Louisiana – even north Louisiana – but ice storms are more common. The climatic line between snow and rain often stalls over north Louisiana creating ideal conditions for ice accumulation. Strong winds with these intense storms and cold fronts can knock down trees, utility poles, and power lines. Extreme cold often accompanies a winter storm or is left in its wake. Prolonged exposure to the cold can cause frostbite or hypothermia and become life-threatening. Infants and elderly people are most susceptible. Freezing temperatures can cause severe damage to crops and other critical vegetation. Pipes may freeze and burst in homes or businesses that are poorly insulated or without heat. Mobile homes are often most vulnerable because most pipes are left exposed in the crawlspace. Structure fires occur more frequently in the winter due to lack of proper safety precautions and present a greater danger because water supplies may freeze, and impede firefighting efforts. People die of hypothermia from prolonged exposure to the cold. Indigent and elderly people are most vulnerable to winter storms and

account for the largest percentage of hypothermia victims largely due to improperly or unheated homes, but the leading cause of death during winter storms is from automobile or other transportation accidents.

Table 2.45. Regional vulnerability to severe winter weather.

Regional Vulnerability to Severe Winter Weather	
Vulnerable Locations	Number of Records
Louisiana Parishes	18
Dams	334
Airports	40
Communication Towers/Facilities	171
Electricity Providers/Facilities	35
Emergency Response Centers	5
Fire Stations	247
Hospitals	54
Nuclear Plants	0
Police Stations	237
Elementary/Secondary Schools	636
Universities/Colleges	8

Heavy accumulations of ice can bring down trees, electrical wires, telephone poles and lines, and communication towers. These are the most common consequences of severe winter weather in Louisiana. Communications and power can be disrupted for days while utility companies work to repair the extensive damage. Even small accumulations of ice may cause extreme hazards to motorists and pedestrians.

Heavy snow can immobilize an area and paralyze a city, stranding commuters, stopping the flow of supplies, and disrupting emergency services. Accumulations of snow can collapse buildings and knock down trees and power lines. In rural areas, homes and farms may be isolated for days, and unprotected livestock may be lost. The cost of snow/ice removal, repairing damages, and loss of business can have large economic impacts on cities and towns.

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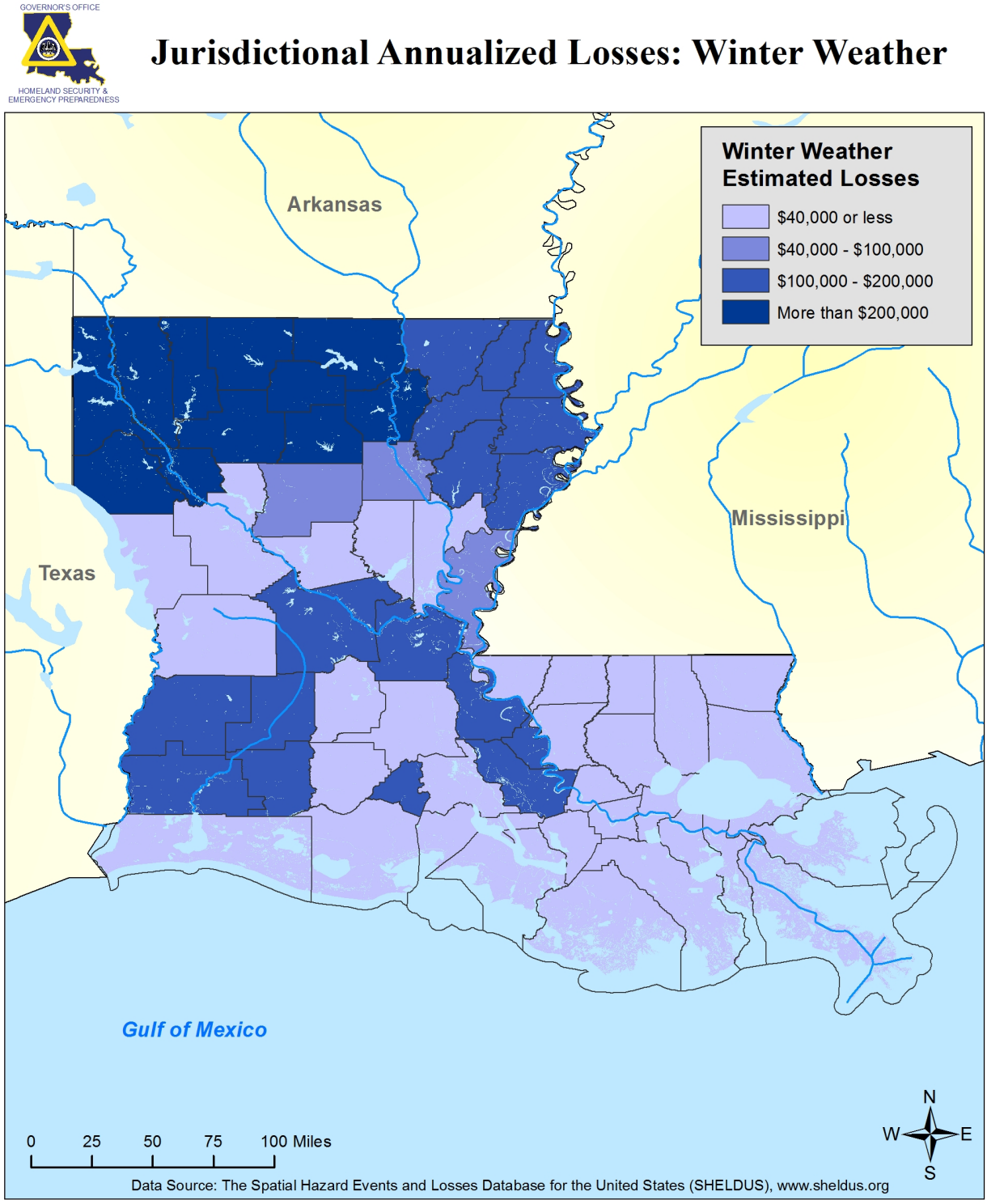
To determine potential loss estimates from winter weather, the available historical loss data was annualized to determine future loss potential (see Map 2.125). As shown, parishes with the largest populations are predicted to have the highest potential annualized losses.



Map 2.125. Jurisdictional annualized loss due to winter weather.

All of Louisiana can experience the impacts of winter storms, but north Louisiana is especially vulnerable. Winter storms are considered deceptive killers as they indirectly cause transportation accidents, and injury and death resulting from exhaustion/overexertion, hypothermia and frostbite from wind chill, and asphyxiation. Roads, bridges, utilities, and communications systems could be greatly impeded or completely brought to a total stop resulting in a high level vulnerability in Shreveport, Monroe, and other north Louisiana communities. Transportation and emergency response could be inhibited and utilities such as electricity, water, gas, sewer, and communications could be completely shut down. Buildings could collapse from ice and/or snow accumulation. The elderly and young children are vulnerable to the cold temperatures and without power or other forms of heat could become sick or fall victim to the cold temperatures. State, local, and federal facilities located in the winter storm area would also be shut down and operations greatly hindered. Broken and falling tree limbs would endanger people, power lines, vehicles, and buildings they happen to fall on or strike. Severe winter storms often paralyze entire communities. State and local governments, churches, charities, and others can be stretched beyond their limits to furnish shelter, food and warmth to the citizens of the jurisdiction. Other critical facilities such as police, fire, and medical facilities are strained with an excess of calls and medical emergencies. Without backup power these institutions often become unable to operate due to lost communication and mobility.

POTENTIAL LOSSES BY JURISDICTION

Overview & Analysis of Potential Losses: All jurisdictions in Louisiana can suffer losses due to winter weather. Nevertheless, the northern parishes of Louisiana are most vulnerable to the broadest spectrum of impacts from winter weather including heavy snowfall, damage to utilities from ice accumulation, damage to utilities from freezing weather, traffic accidents from ice/snow accumulation, crop damage from freezing temperatures and ice, and slippery sidewalks caused by ice accumulation. The central parishes of Louisiana are most vulnerable to ice-related impacts, while they are less vulnerable to snowfall accumulation. The southern parishes rarely experience winter weather, but they can still suffer losses due to it. Most impacts can be attributed to ice accumulation that could cause traffic accidents, slippery sidewalks, and minor damage to utilities.

Changes in jurisdictional population levels impact each parish across the state disparately. In the parishes where winter weather vulnerability has increased because of increases in population (Bossier, Grant, and Lincoln), concomitant changes in development have impacted loss estimates and will cause an increase in future losses due to increased levels of exposure. In the parishes where winter weather vulnerability has decreased because of decreases in population (East Carroll, Madison, and Tensas), concomitant changes in development have impacted loss estimates and will cause a decrease in future losses due to decreased levels of exposure.

Potential Losses of State Facilities

The winter weather hazard vulnerability assessment of state-owned buildings was based on the parish-level composite risk score, which incorporates the total number of winter weather events, injuries, fatalities, and property damages as well as the social vulnerability of impacted parishes. The criteria used to determine specific vulnerability rankings for each building and the results of applying this ranking to the state-owned buildings are shown in Table 2.46.

Table 2.46. Winter Weather Vulnerability Criteria and Ranking Results.

Winter Weather Vulnerability Criteria and Ranking	
Ranking	Criteria
High	Composite risk score greater than 2.0
Medium	Composite risk score between 1.5 and 2.0
Low	Composite risk score less than 1.5

The winter weather loss estimate ranges are derived from the 2011 state hazard mitigation plan and inflation-adjusted to 2013 dollars. The January 2014 state facilities database was used to obtain accurate building numbers for each loss estimate range. Loss estimates of state-owned buildings in Louisiana involved an analysis of the following parameters:

- Winter Weather Hazard Vulnerability
- Average Building Type
- Winter Weather Damage Functions

Table 2.47. Winter Weather Loss Estimate Ranges and Ranking Results.

Winter Weather Loss Estimate Ranges and Ranking		
Ranking	Total Loss Estimate Ranges	Number of Buildings
High	$1,604 to $10,153,600	2740
Medium	< $1,603	1690
Low	$0	4255

GEOLOGICAL/HUMAN-INFLUENCED HAZARDS

The geological/human-influenced hazards profiled in this section (coastal erosion, dam failure, earthquakes, levee failure, saltwater intrusion, sea level rise, sinkholes, and subsidence) are difficult to categorize because they tend to influence and be influenced by each other, and some can be related to the climatological hazards profiled above, to some degree. For instance, sea level rise contributes to saltwater intrusion, which contributes to the formation of salt domes, which—when mined extensively—can form sinkholes. Additionally, dam and levee failure, which might be prompted by earthquakes, can exacerbate or even cause flooding. Obviously, all of these are impacted by the effects of hazards like coastal storms. Nevertheless, a certain subset of these hazards can be considered in the framework of one major danger to the state of Louisiana: coastal hazards. Most especially, these coastal hazards contribute to a major ongoing problem for Louisiana: land loss. Land loss is the process by which coastal lands, particularly wetlands, erode or sink into open water as a result of violent storms, coastal erosion, sediment deprivation, saltwater intrusion, and rising sea levels. Thus, in this plan, coastal hazards are those hazards which directly influence the delicate ecosystem of Louisiana's Gulf coastline, here comprising coastal erosion, saltwater intrusion, sea level rise, and subsidence. Land loss can be mitigated through major coastal restoration and protection measures that are beyond the scope of most funding programs associated with DMA 2000 hazard mitigation planning, but which are being planned and implemented by other entities within the state and federal governments.

It should still be remembered, though, that these hazards are not isolated from the other geological/human-influenced hazards, as indicated above. Dam and levee failure, earthquakes, and sinkholes can all contribute to coastal hazards, but they are not constrained in threat to the coast like coastal erosion, saltwater intrusion, sea level rise, and subsidence.[lxix] First, this plan profiles the coastal hazards before moving on to dam failure, earthquakes, levee failure, and sinkholes. Since coastal erosion, saltwater intrusion, sea level rise, and subsidence are not addressed as stand-alone hazards, all of these hazards are subsumed under existing, expert plans for coastal protection and restoration—including the actions of Louisiana's Department of Natural Resources (DNR) Office of Coastal Management, NOAA's National Coastal Zone Management (CZM) Program, and the state's Coastal Protection and Restoration Authority (CPRA) Master Plan.

Coastal Land Loss

Coastal land loss is the loss of land (especially through beach, shoreline, or dune material) by natural and/or human influences. Coastal land loss occurs through various means, including coastal erosion, subsidence (the sinking of land over time as a result of natural and/or human-caused actions), saltwater intrusion, coastal storms, littoral drift, changing currents, manmade canals, rates of accretion, and sea level rise. The effects of these processes are difficult to differentiate because of their complexity and because they often occur simultaneously, with one influencing each of the others, as Figure 2.3 illustrates.

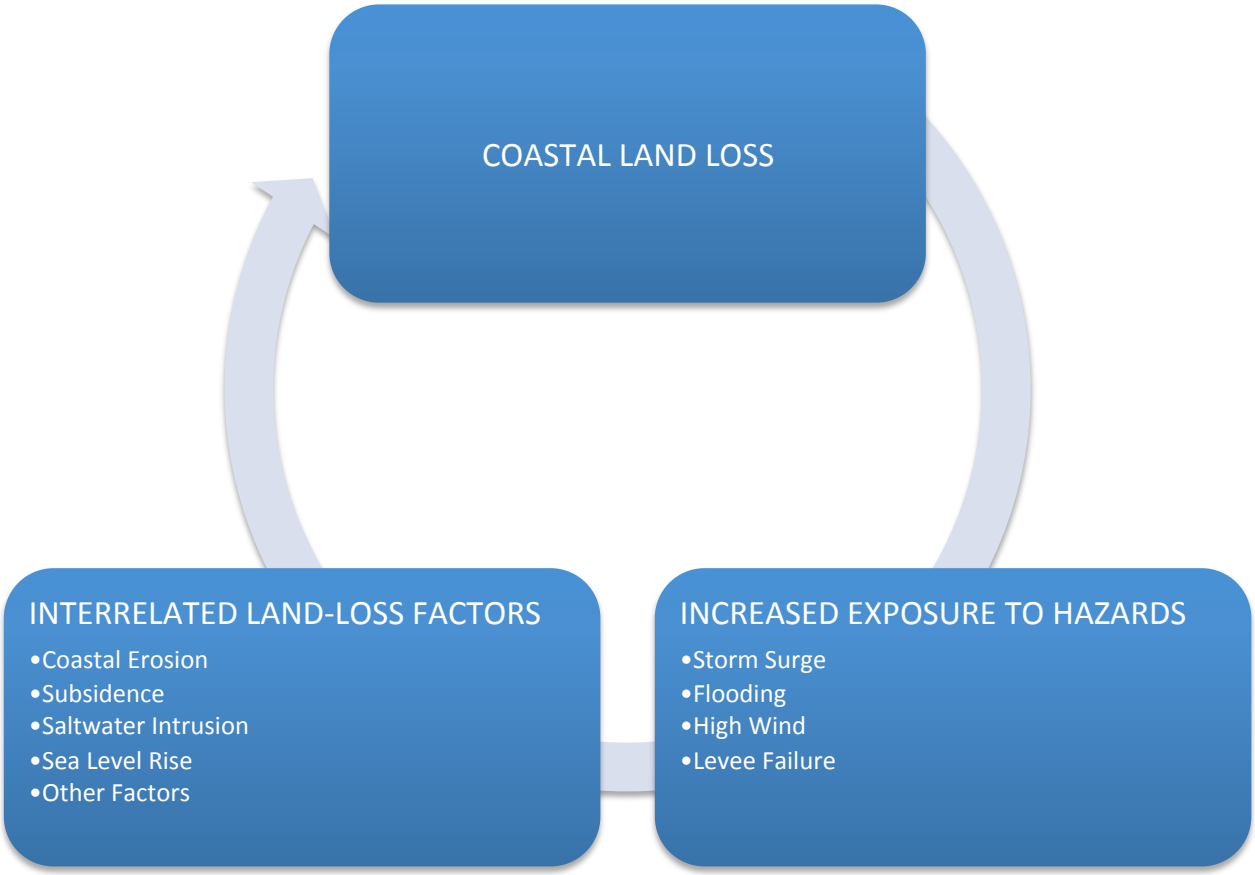
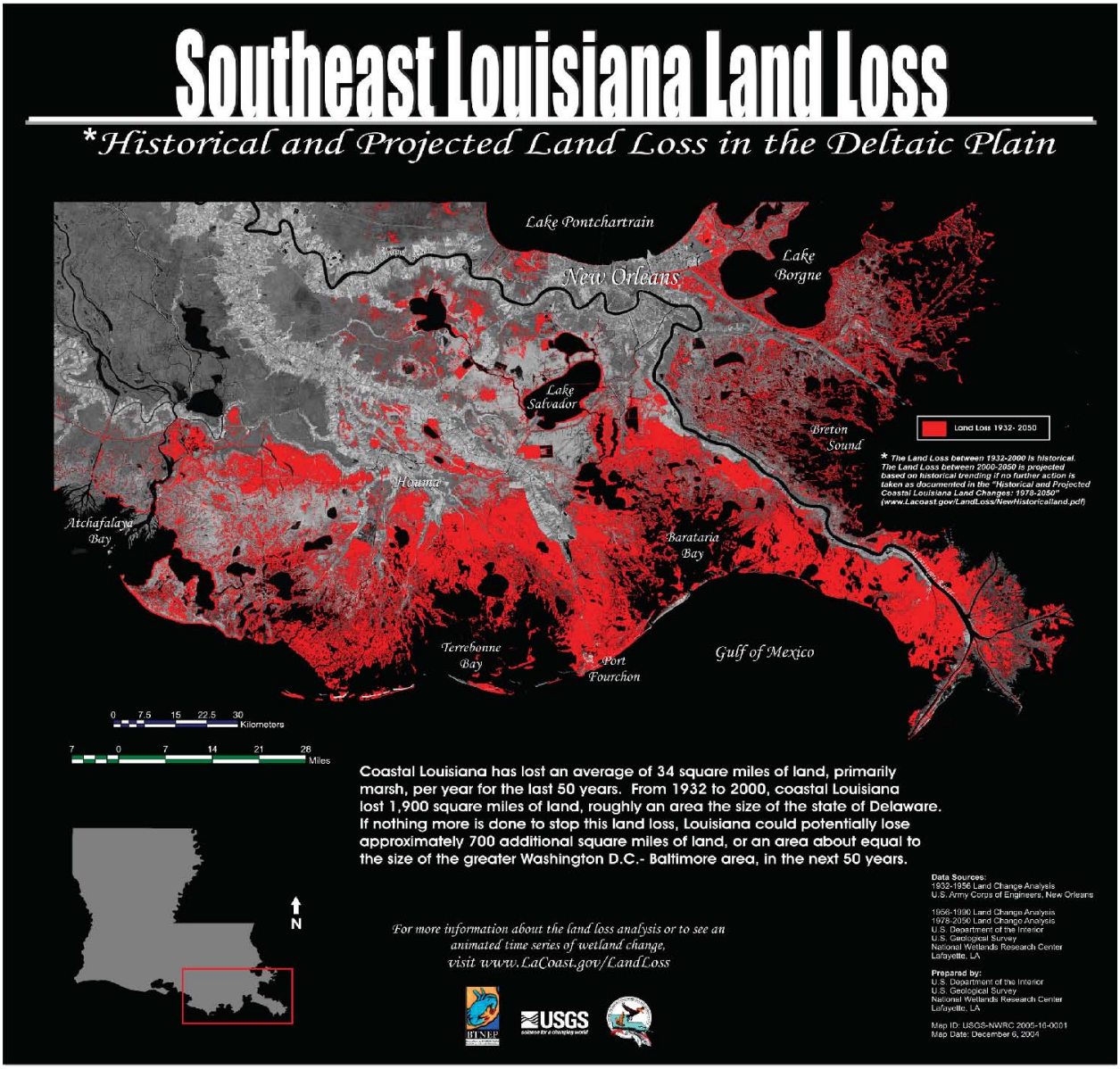


Figure 2.3. Interrelated factors contributing to coastal land loss, and their subsequent and cyclic effect on hazard vulnerability.

Regardless, most of southern Louisiana is vulnerable to coastal land loss because most of it is at—or only a few feet above—sea level. Map 2.126 illustrates historical coastal land loss since 1932 projected through 2050 for southeast Louisiana.



Map 2.126. Historical and projected land loss (map portions in red) along the southeastern Louisiana coast between 1932 and 2050 (source: USGS).

This loss and its causes are an environmental and economic concern not only for Louisiana, but also for the entire United States. Louisiana supplies an essential and unique natural waterway and wetland for fishery, shipping, water supply, seafood nursery, migratory waterfowl flyway, and recreational purposes, and therefore coastal erosion threatens the state's very livelihood.

Ironically, a delicate system of wetlands is all that protects these waterways from destruction inundation, even as those very waterways threaten the wetlands themselves. These wetlands are crucial to the mitigation of a variety of hazards that threaten Louisiana. As Figure 2.4

implies, artificial channels created for navigation purposes endanger the adjacent wetlands. Yet the wetlands surrounding them also help immensely to protect them, along with pipelines, ports, and property at the coast and farther inland. And again, ironically, many of the industries these wetlands protect also contribute to their destruction. Construction of dams and levees, the dredging of canals, and draining and filling in support of various coastal industries have altered the coastline by contributing to saltwater intrusion and the destruction of wetlands, which intensify Louisiana's coastal land loss.[lxx] Saltwater intrusion is the inland encroachment of saltwater into areas that previously contained freshwater, either above or below the land surface, and it is thus a very common problem in coastal areas. Despite the simplicity of the hazard, saltwater intrusion has numerous causes and consequences. In Louisiana specifically, it comes from coastal storms, wetland loss, canal construction, sea level rise, coastal erosion, and subsidence. As with all coastal hazards, most of these processes are interrelated. In canal construction, for instance, saltwater finds a straight and deep channel to freshwater areas (because it is more dense than freshwater), killing off freshwater plants and thus reducing wetlands. In terms of our nation's environment, the loss of wetlands to coastal land loss is catastrophic. The state contains about 40% of the nation's wetlands and accounts for 90% of coastal wetland loss in the continental United States.[lxxi]

Figure 2.4. "Navigation channel dissecting eroding marsh in coastal Louisiana" (source: Tim Carruthers, University of Maryland Center for Environmental Science).

Some of the worst recent contributors to coastal land loss in the state are the tropical cyclones of the past decade. Two storms that stand out in this regard are Hurricanes Katrina and Rita. These powerful cyclones completely covered large tracts of land in a very brief period, permanently altering the landscape.

As Map 2.127 reveals, Hurricane Rita effectively pushed the coastline back a few mi. temporarily. Much of that land and other areas along the coast—217 mi^2 in total—were inundated permanently.[lxxii] Most noticeably, Katrina and Rita wiped out 85% of the above-surface land of the Chandeleur Islands. As Figure 2.5 shows, this major shield that protected Louisiana's coast just east of New Orleans was almost obliterated, leaving the city dangerously exposed. Figure 2.6 provides a microcosmic view of the storms' impact on the islands.

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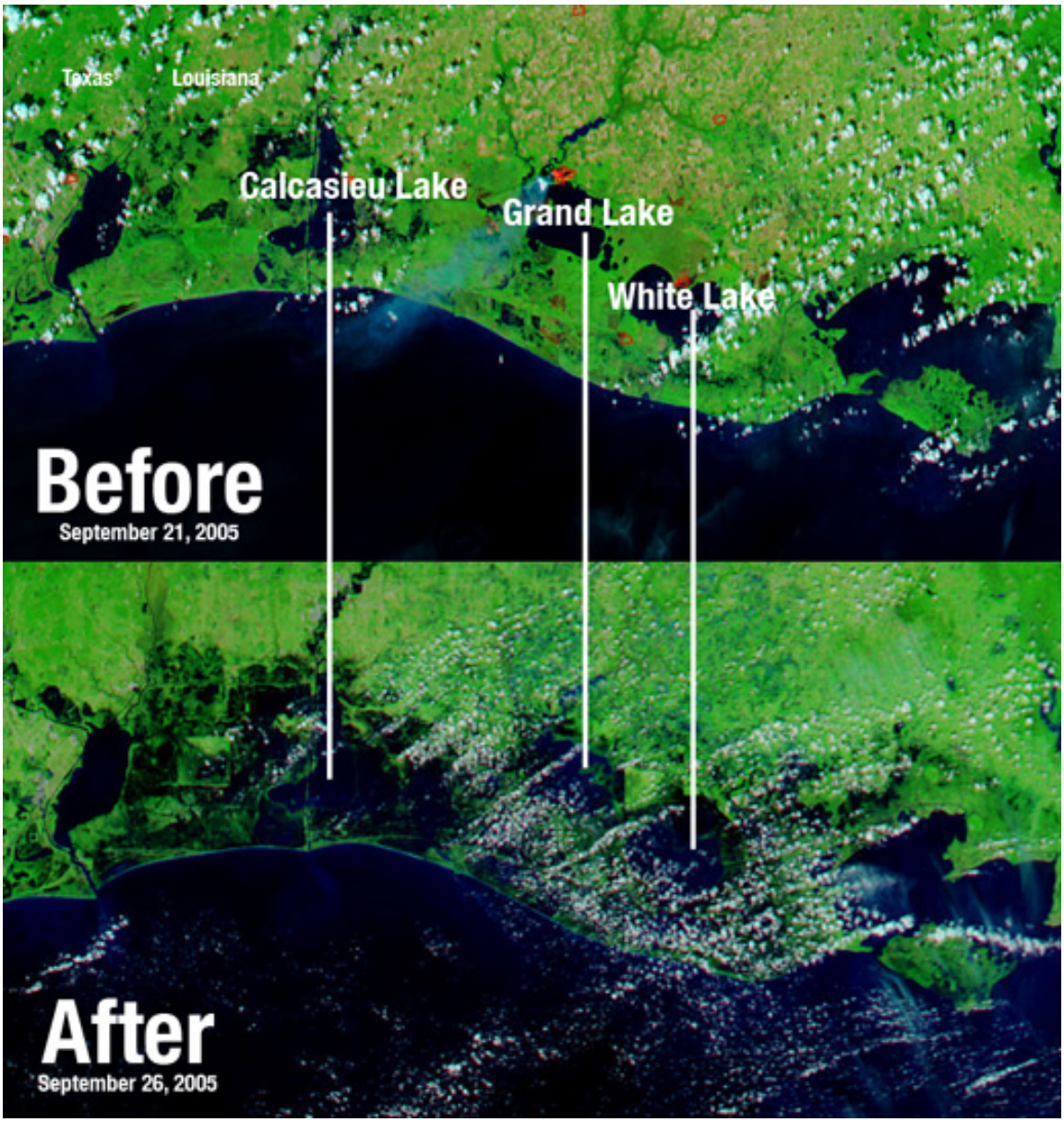

Map 2.127. Coastal land loss due to Hurricane Rita. Source: http://www.nasa.gov/vision/earth/lookingatearth/h2005_rita.html.

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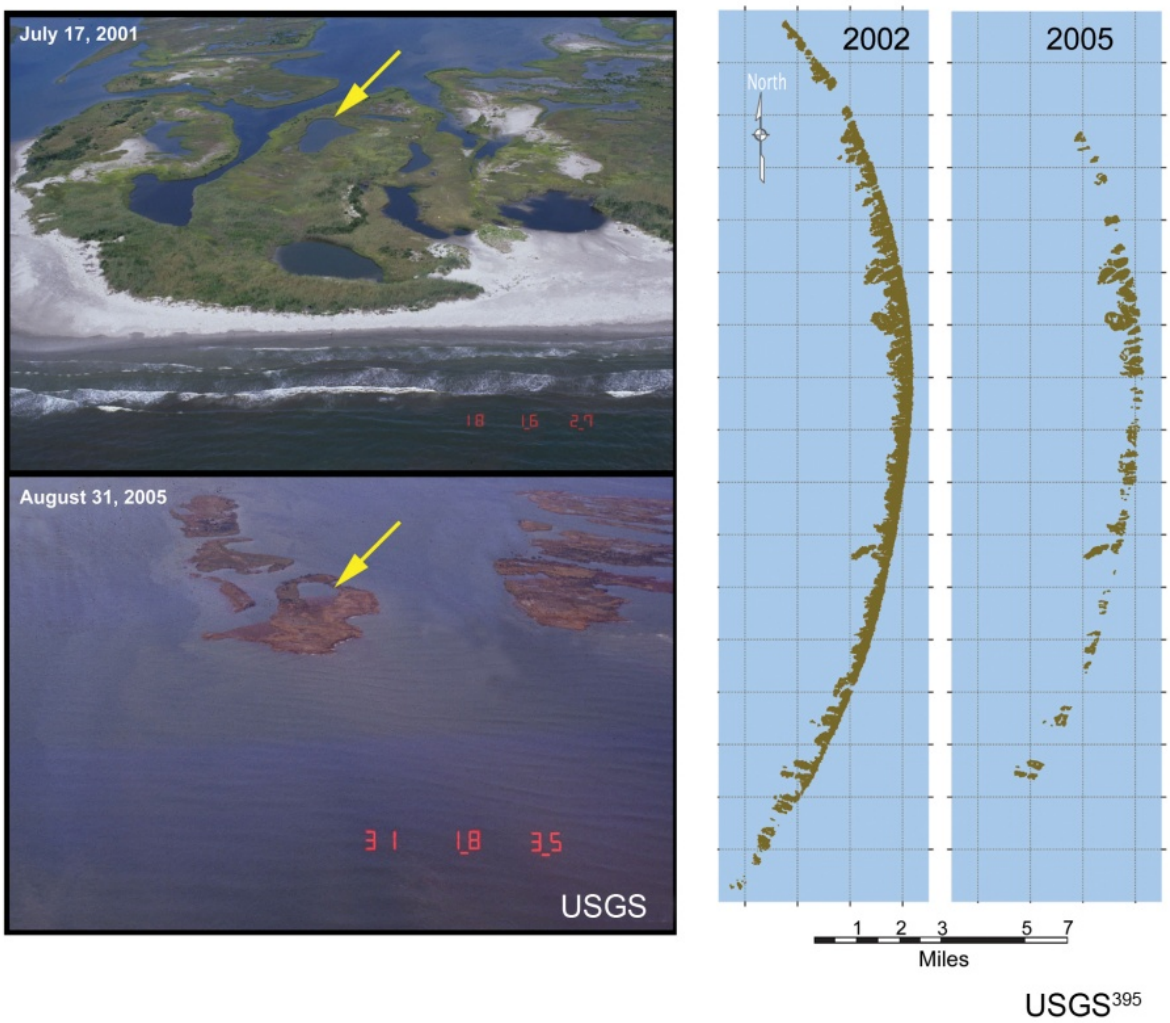

In 2005, 217 square miles of land and wetlands were lost to open water during hurricanes Rita and Katrina. The photos and maps show the Chandeleur Islands, east of New Orleans, before and after the 2005 hurricanes; 85 percent of the islands' above-water land mass was eliminated.

Figure 2.5. Loss to Chandeleur Islands after Hurricanes Rita and Katrina. Source: USGCRP (2009).

Figure 2.6. Pre- and post-Katrina photographs of part of the Chandeleur Islands. Source: USGS.

The disastrous legacy of these storms concentrated already ongoing efforts to combat coastal land loss and wetland loss. Nevertheless, consistent with the 2008 and 2011 updates to the State Hazard Mitigation Plan (and as indicated earlier), this 2014 Plan Update does not address coastal land loss as a stand-alone hazard, but rather considers it in terms of two of the most dominant factors: sea level rise and subsidence.

Sea level rise and subsidence impact Louisiana in a similar manner—again making it difficult to separate impacts. Together, rising sea level and subsidence—known together as **relative sea level rise**—can accelerate coastal erosion and wetland loss, exacerbate flooding, and increase the extent and frequency of storm impacts. According to NOAA, *global* sea level rise refers to the upward trend currently observed in the average global sea level. *Local* sea level rise is the level that the sea is rising relative to a specific location (or, benchmark) at the coastline. The most prominent causes of sea level rise are thermal expansion, tectonic actions (such as sea floor spreading), and the melting of the Earth's glacial ice caps. Observed local sea levels may vary widely from the average rate of global sea level rise, depending on local conditions such as subsidence or isostatic rebound; the latter does not affect Louisiana directly, as it refers to local rising motion in response to the release of compressive forces from the weight of glacial ice. Map 2.128 illustrates predictions of sea level rise in southern Louisiana by 2100.

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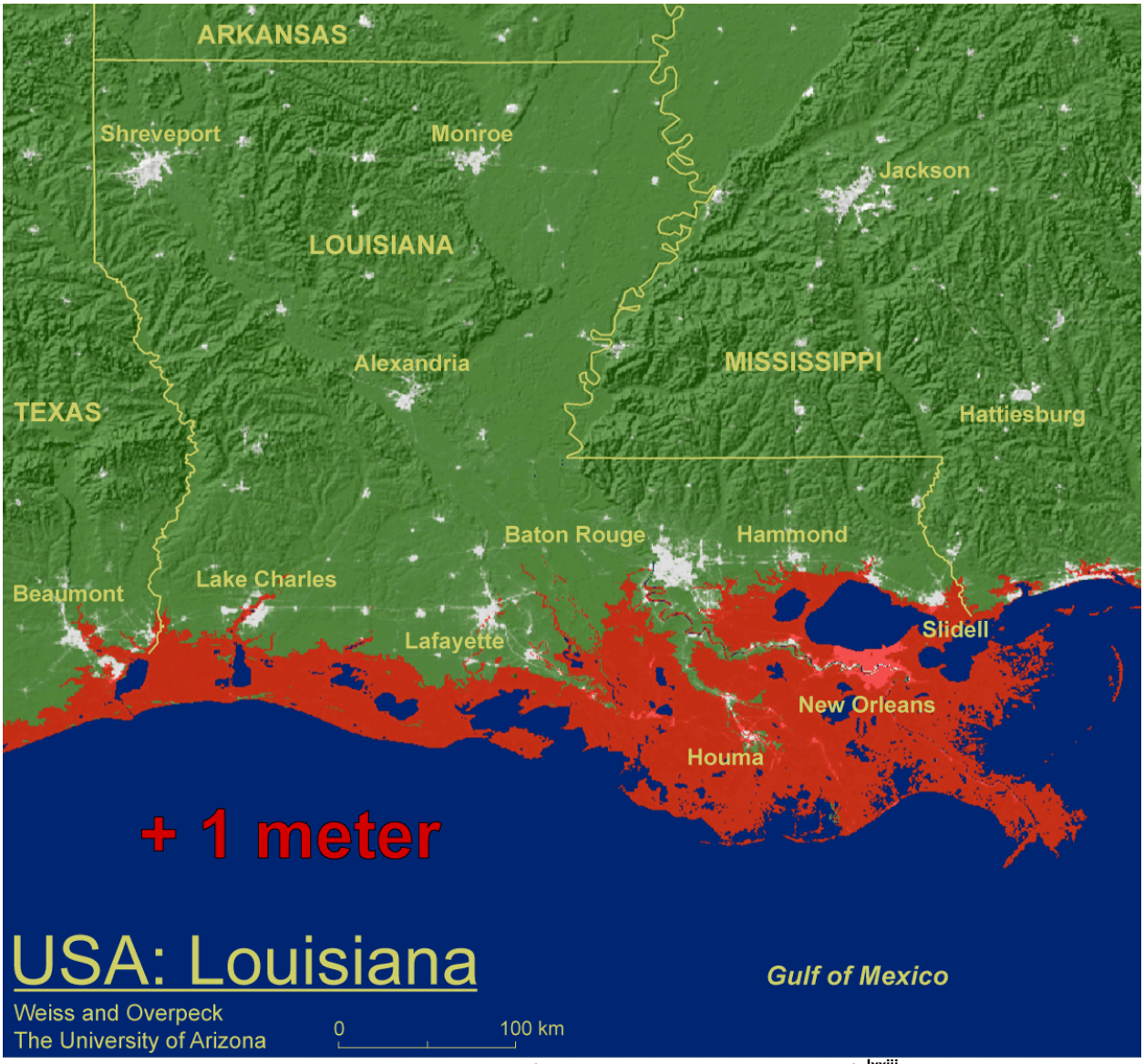

Map 2.128. Predictions of sea level rise by 2100 (source: Weiss and Overpeck).[lxxiii]

The current U.S. Environmental Protection Agency (EPA) estimate of global sea level rise is 10–12 in. per century, while future sea level rise could be within the range of 1–4 ft. by 2100.[lxxiv] According to the U.S. Geological Survey (USGS), the Mississippi Delta plain is subject to the highest rate of relative sea level rise of any region in the nation largely due to rapid geologic subsidence. This hazard has been identified as one that is of such a scale and extent that it is addressed through the actions of multiple state agencies such as the Department of Transportation and Development, Department of Natural Resources, and CPRA, in addition to being addressed in this Plan Update.

Subsidence results from a number of factors including:

- Compaction/consolidation of shallow strata caused by the weight of delta deposits from the Mississippi River, soil oxidation, and aquifer draw-down (shallow component)
- Gas/oil/resource extraction (shallow & intermediate component)
- Consolidation of deeper strata (intermediate components)
- Tectonic effects (deep component)

This last element was only recently quantified, and research indicates that it may account for 50% or more of subsidence.[lxxv]

As a stand-alone hazard, subsidence has not been identified as a significant *acute* contributor to direct disaster damages in Louisiana. However, it is certainly one of the main drivers of land loss in Louisiana, and thus it dramatically increases flood risk—which is one of the most dangerous hazards the state faces.

For the most part, subsidence is a slow-acting process with effects that are not as evident as hazards associated with a discrete "event." Although subsidence effects in the New Orleans metropolitan area and in the coastal zone can be readily seen over the course of decades or even years, subsidence is a "creeping" hazard event with chronic impacts. The highest rate of subsidence is occurring at the Mississippi River Delta (estimated at greater than 3.5 ft./century). Subsidence rates tend to decrease inland, and they also vary across the coast. Overall, subsidence creates three distinct problems in Louisiana:

- By lowering elevations in coastal Louisiana, subsidence accelerates the effects of saltwater intrusion and other factors that contribute to land loss
- By lowering elevations elsewhere in Louisiana, subsidence may make structures more vulnerable to flooding
- By destabilizing elevations in general, subsidence undermines the accuracy of surveying benchmarks (including those affecting levee heights, coastal restoration programs, surge modeling, BFEs, and other engineering inputs), which can contribute to additional flooding problems if construction occurs at lower elevations than anticipated or planned

Coastal Land Loss Risk Assessment

Based on historical subsidence rates and land loss/gain trends, the probability of future land loss in Louisiana is **100% certain**, but actual rates of subsidence and land loss/gain vary greatly along the coast based on various meteorological, geological, and human-influenced dynamics (e.g., water/resource extraction, canal dredging, saltwater intrusion, marsh restoration projects, etc.). Because coastal land loss is, and will continue to be, a major issue in Louisiana and has become very disruptive to transportation, commerce, and general livelihood over the past half century, coastal land loss is one of the hazards included for Risk Assessment. Coastal land loss is an ongoing process and data used for the risk assessment represent the aggregation of all previous occurrences, including discrete (hurricanes) and continuous (subsidence)

processes. 2012 Hurricane Isaac is a recent example of a discrete event that caused some level of land loss in southeast Louisiana.

Areas of land loss and land gain between 1932 and 2010 are shown in Map 2.129, and rates of subsidence are shown in Map 2.130. Map 2.131 indicates the specific areas and associated parishes of coastal Louisiana where subsidence (and consequently land loss) is quantifiable and a major concern. Parishes at risk include Ascension, Assumption, Calcasieu, Cameron, Iberia, Jefferson, Lafourche, Livingston, Orleans, Plaquemines, St. Bernard, St. Charles, St. James, St. John the Baptist, St. Martin, St. Mary, St. Tammany, Tangipahoa, Terrebonne, and Vermilion. Ascension, Livingston, St. Tammany, and Tangipahoa Parishes are at risk (within subsidence zone) to coastal land loss and have experienced significant population increases of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability of these parishes to coastal land loss has increased. Cameron, Orleans, Plaquemines, and St. Bernard Parishes are at high risk to coastal land loss, but have experienced significant population decreases of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability of these parishes to coastal land loss has decreased.

Assessing the state's vulnerability to coastal land loss is complicated and varies across space. Parishes that contain areas of subsidence are vulnerable to coastal land loss, but in some cases areas of subsidence do not cover an entire parish. Additionally, subsidence rates change across space. Coastal land loss vulnerability is directly related to the location of state facilities within subsidence zones, which are located in Map 2.131. Map 2.132 locates state facilities within these zones. Four state parks are located within subsidence zones out of a total of 19 and there are 1,425 state facilities within subsidence zones out of a total of 8,685. State-owned critical facilities located in areas affected by coastal land loss are of the following types: hospitals, shelters, Emergency Operation Centers, data processing centers, and state police troop offices.

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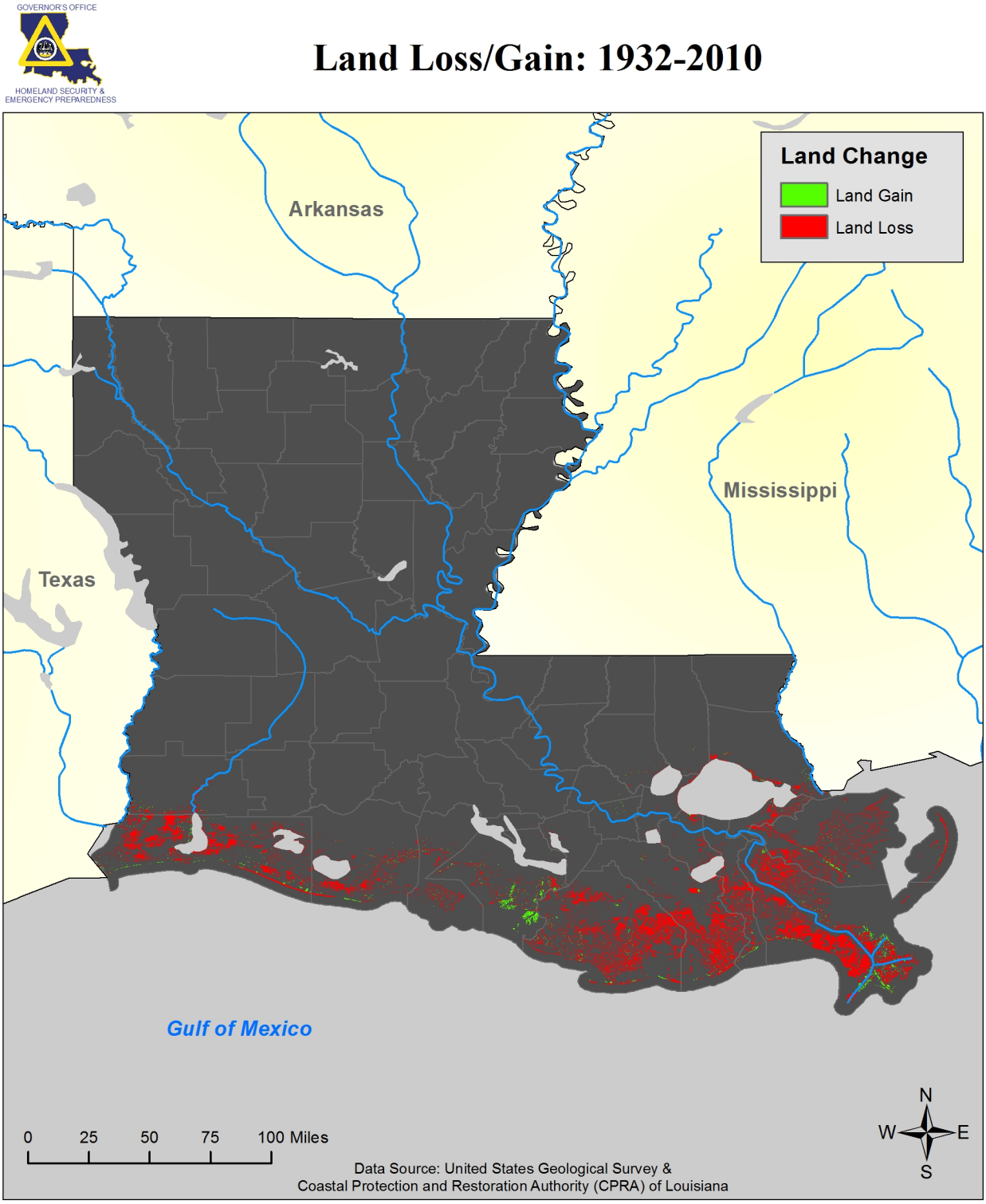
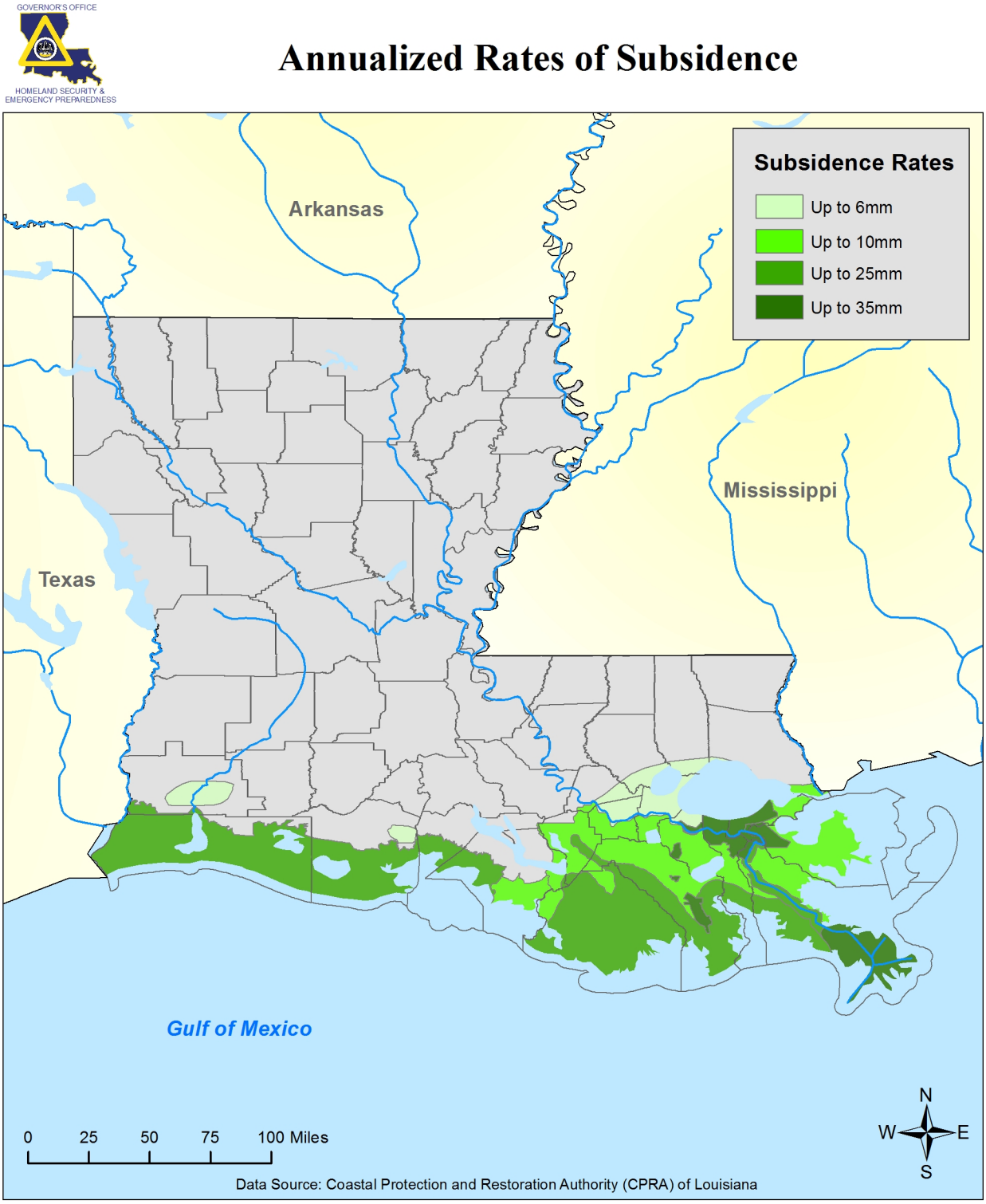
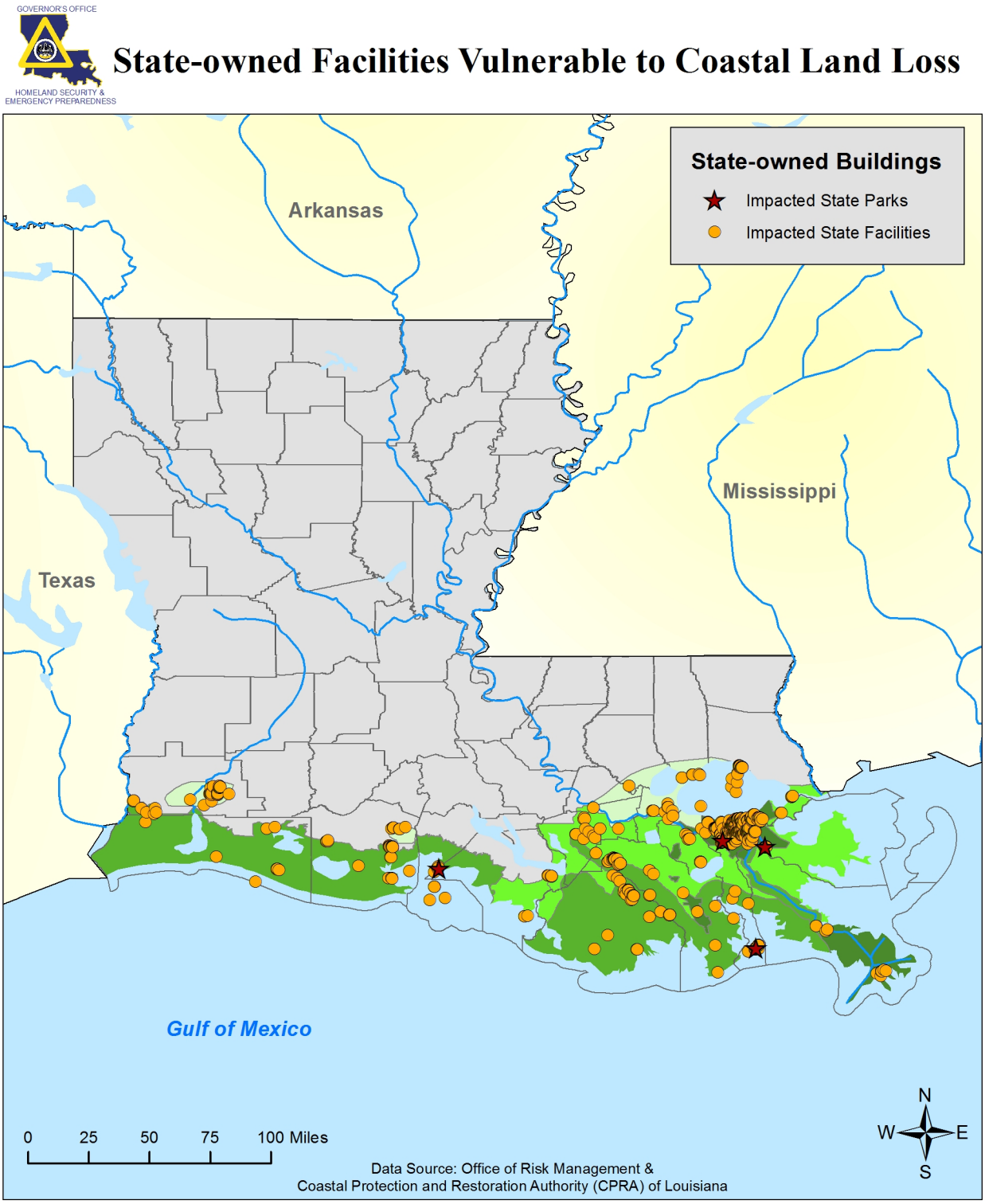


Map 2.129. Historical areas of land loss and gain in coastal Louisiana between 1932 and 2010.



Map 2.130. Maximum annual subsidence rates based on subsidence zones in coastal Louisiana.

Map 2.131. Louisiana jurisdictional vulnerability for coastal land loss based on long-term subsidence rates.



Map 2.132. Louisiana state-owned property located within the major subsidence zones.

Map 2.133 shows the parishes within each vulnerability level based on the extent and rate of subsidence zones. The southern-most coastal Louisiana parishes have the greatest risk of ongoing coastal land loss (**High**) across most of each parish, while smaller spatial extents of Calcasieu, Ascension, Livingston, Tangipahoa, and St. Tammany Parishes are at risk of ongoing coastal land loss.

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Map 2.133. Vulnerability rating map for coastal land loss showing parishes with the highest risk in Louisiana.

POTENTIAL ECONOMIC LOSS

Since 1932, the average annual land loss in Louisiana is 35 mi^2, while the average annual land gain has been 3 mi^2 for a net change of -32 mi^2 per year. It is noted that erosion and land loss caused by hurricane storm surge account for a large percentage of total land loss and are the cause of many land loss peaks seen in Figure 2.7 below. The majority of land loss is currently occurring outside of populated areas in coastal marshes. While these marshes are extremely important, their loss does not directly affect the results of loss estimates to buildings using tools such as Hazus-MH, as building inventory is not located in these areas.

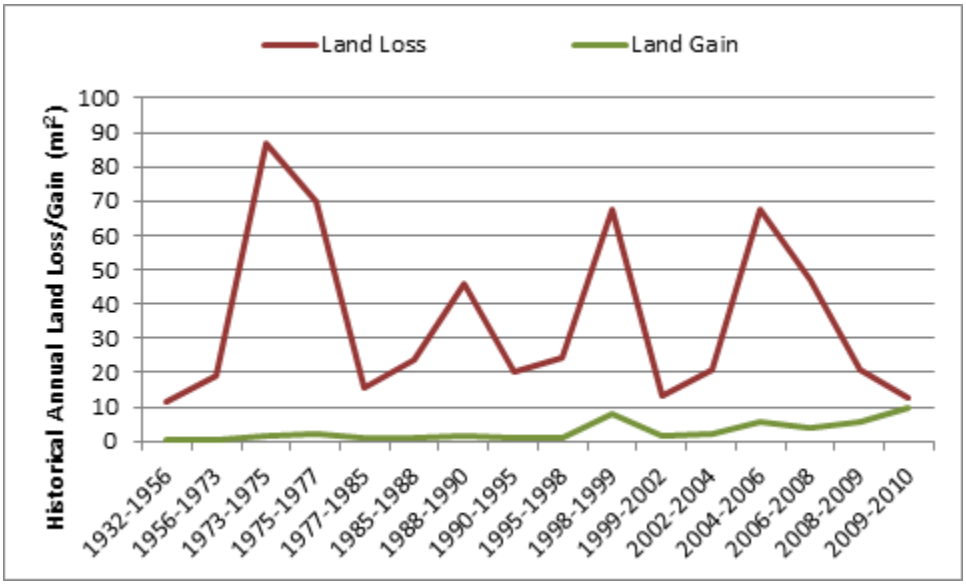

Figure 2.7. USGS historic land loss/land gain rates (annualized), 1932-2010.

Therefore, to conduct the economic loss assessment, two parameters were considered to estimate the projected increases in coastal flood losses from storm surge scenarios – global sea level rise and subsidence. A timeframe of 10 years was selected for evaluation of future effects of sea level rise and subsidence for comparison with current conditions. The NOAA Sea, Lake and Overland Surges from Hurricanes (SLOSH) model was used to estimate the maximum of maximum (MOM) storm surge elevations for a Category 1 hurricane at mean tide along the entire coast of Louisiana. It should be noted that the MOM scenario is not designed to describe the storm surge that result from a particular event, but rather evaluates the impacts of multiple hurricane scenarios with varying forward speeds and storm track trajectories to truly create storm surge elevation surface that would occur given the simultaneous occurrence of all hurricane events for a given category. The economic loss assessment, therefore, is best used to describe the increase in expected coastal flood losses resulting from sea level rise and subsidence over 10 years, rather than to describe the estimated actual losses.

There are many global sea level rise scenarios from which to select; however, within a 10-year timeframe, methods that predict accelerating sea level rise rates do not deviate significantly

from straight line methods. Therefore, a linear sea level rise projection for the sea level rise occurring in 10 years (SLR_{2024}) using a linear global sea level rise rate of 3.1 mm/year was selected (IPCC, 2007), which is also in accordance with the CPRA Coastal Master Plan. This resulted in an increase of 0.01 feet, which was applied to the NOAA MOM storm surge elevation results over the model output domain.

$$SLR_{2024} = 0.0031 \frac{mm}{year} x\ 10\ years$$
$$SLR_{2024} = 0.031\ meters = 0.10\ ft\ in\ 2024$$

To estimate the effects of subsidence, the elevation profile for southern Louisiana was separated into sections based on subsidence zones (see Map 2.131). The 20th percentile values for subsidence were used, in accordance with the CPRA Master Plan. The 20th percentile values for subsidence were then subtracted from the digital elevation model (DEM) for each zone and re-joined to create a final subsided ground elevation layer. To perform the economic loss assessment, depth grids were created for current conditions (SLOSH MOM Results—Current Land Elevation) and for projected 2024 conditions ([SLOSH MOM Results + 0.1 ft sea level rise]–[Current Land Elevation—Subsidence]). Hazus-MH was used to calculated economic loss for the current and future depth grids.

Table 2.48 shows the current and future exposure potential for high-risk parishes based on the Hazus-MH 2.1 inventory database. The entire parish was not considered as a whole, but rather each census block group was analyzed within the model. While parish-level estimates vary widely based on a number of factors, the overall projected increase in coastal flood losses from sea level rise and subsidence for a Saffir-Simpson Category 1 hurricane is 12%.

Table 2.48. Exposure data for the 20 at risk parishes for coastal land loss in Louisiana.

Exposure Data for Parishes with Highest Coastal Land Loss Risk				
Parish	Population (2010)	Current Conditions ($1,000)	Future (2024) ($1,000)	% Change (2024 vs. 2014)
Ascension	107,215	$147	$264	80%
Assumption	23,421	$36,483	$41,354	13%
Calcasieu	192,768	$21,241	$24,114	14%
Cameron	6,839	$150,211	$163,646	9%
Iberia	73,240	$94,780	$100,613	6%
Jefferson	432,552	$9,590,934	$10,599,915	11%
Lafourche	96,318	$301,398	$364,605	21%
Livingston	128,026	$1,907	$1,934	1%
Orleans	343,829	$7,489,485	$8,523,617	14%
Plaquemines	23,042	$469,040	$545,913	16%
St. Bernard	35,897	$98,224	$136,734	39%

Exposure Data for Parishes with Highest Coastal Land Loss Risk				
Parish	Population (2010)	Current Conditions ($1,000)	Future (2024) ($1,000)	% Change (2024 vs. 2014)
St. Charles	52,780	$183,449	$214,750	17%
St. James	22,102	$13	$110	746%
St. John the Baptist	45,924	$1,014	$1,446	43%
St. Martin	52,160	$25,843	$28,416	10%
St. Mary	54,650	$229,620	$252,844	10%
St. Tammany	233,740	$50,279	$51,185	2%
Tangipahoa	121,097	$0	$0	0%
Terrebonne	111,860	$583,804	$666,616	14%
Vermilion	57,999	$77,339	$84,512	9%
TOTALS	**2,215,459**	**$19,405,211**	**$21,802,588**	**12%**

Map 2.134 shows the projected changes over the next 10 years for each census block group with many areas expecting an increase in losses. It is also possible to see that some census block groups that are currently unaffected by a Category 1 hurricane will be impacted in 2024 based on subsidence and sea level rise projections (Map 2.135).

Of the parishes that have been and will continue to be impacted by coastal land loss, Jefferson and Orleans Parishes are the two most populated parishes and have the highest infrastructure dollar exposures within Louisiana. These parishes are considered to have the highest vulnerability to coastal land loss within the state.

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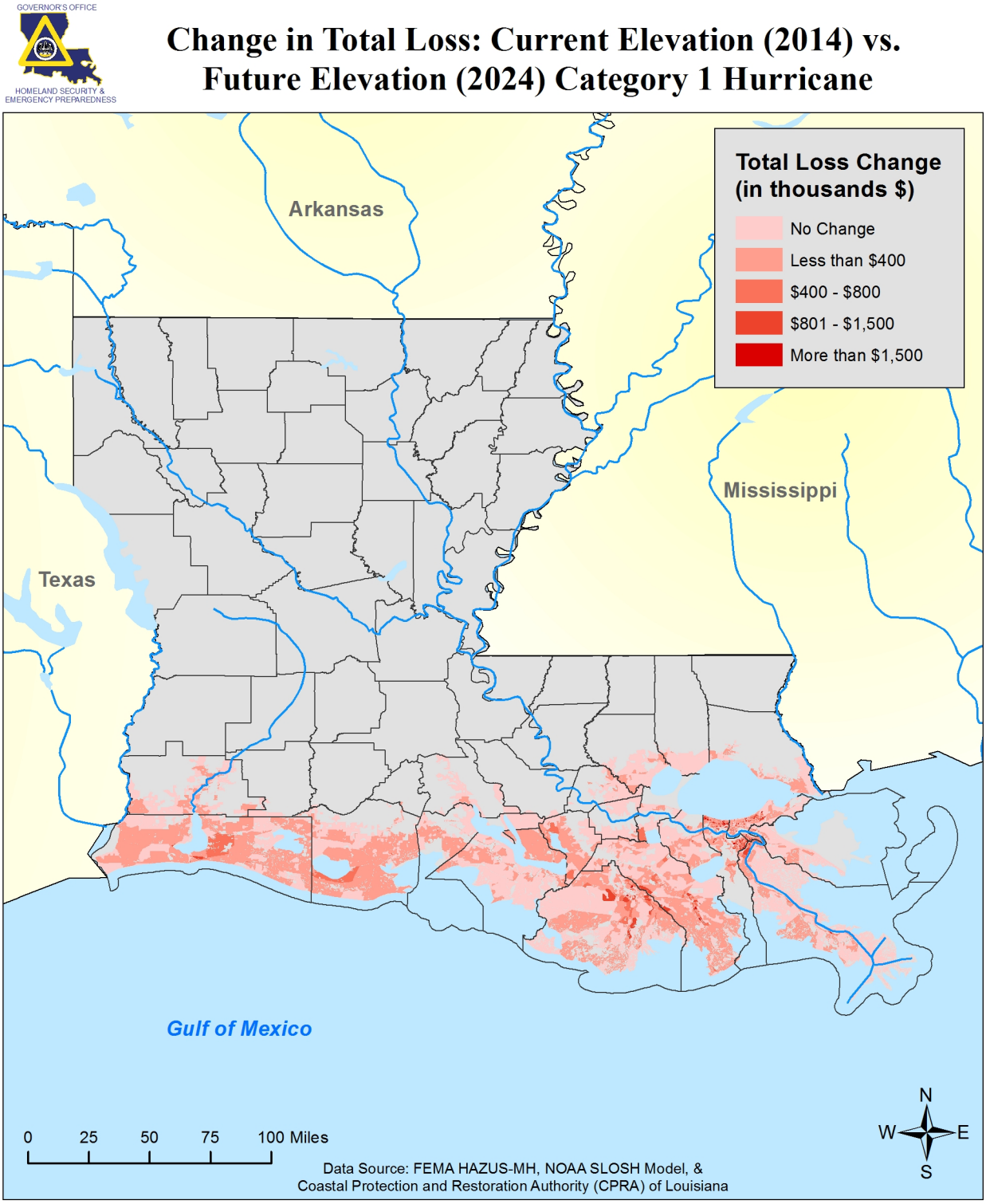

Map 2.134. Expected changes in loss estimates by census block group in 2024 based on the Hazus-MH flood model and NOAA SLOSH model.

Map 2.135. Census block groups that are currently not impacted by Category 1 hurricanes but expected to be impacted by the same category of hurricane in 2024 can be seen in red.

Based on the baseline Hazus-MH 2.1 inventory database, the Louisiana Digital Map GIS database (via LOSCO), and the U.S. Census Bureau, regional vulnerability to coastal land loss is listed in Table 2.49.

Table 2.49. Regional vulnerability to coastal land loss.

Regional Vulnerability to Coastal Land Loss	
Vulnerable Locations	Number of Records
Louisiana Parishes	20
Dams	119
Airports	47
Communication Towers/Facilities	208
Electricity Providers/Facilities	45
Emergency Response Centers	7
Fire Stations	308
Hospitals	96
Nuclear Plants	2
Police Stations	378
Elementary/Secondary Schools	1250
Universities/Colleges	7

To determine potential loss estimates for coastal land loss, increased exposure estimates over the next 10 years calculated using Hazus-MH were annualized (Map 2.136). As shown, parishes in southeast Louisiana and specifically the two parishes with the largest populations (Orleans and Jefferson) are predicted to have the highest potential annualized losses.

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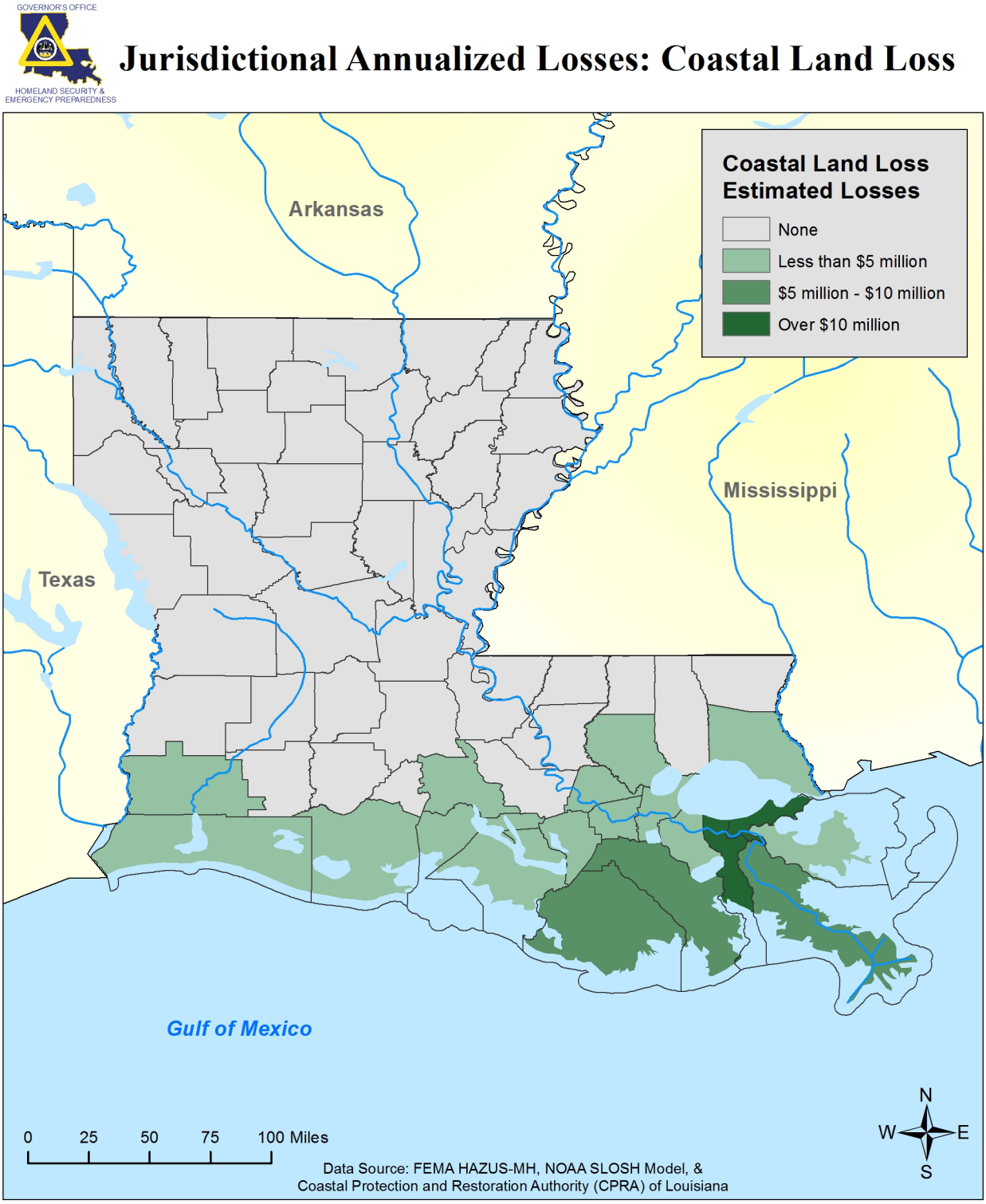

Map 2.136. Jurisdictional annualized loss due to coastal land loss.

All of coastal Louisiana can experience the impacts of coastal land loss, but certain areas are more vulnerable than others. Coastal land loss is relatively unpredictable, but subsidence rates have been quantified in specific areas (Map 2.131). Roads, bridges, utilities, and communications systems could be greatly impeded or become completely unusable, resulting in a high level of vulnerability in all High vulnerability parishes. Transportation and emergency response could be inhibited and utilities such as electricity, water, gas, sewer, and communications could be compromised over a long period of time. Buildings could collapse and, at a minimum, lose their structural integrity if they are within zones that have high rates of subsidence. Coastal land loss can impact all demographics and age groups. State, local, and federal facilities located within highly vulnerable coastal land loss areas could be eventually permanently shut down and forced to re-locate. Long-term sheltering and permanent relocation could be a concern and is already being discussed by communities that are at the highest risk for future coastal land loss. Some communities have lost most of their residents as their once dry land transitions to marsh and open water. Other critical facilities such as police, fire, and medical facilities could become unusable within a community impacted by coastal land loss.

Potential Losses by Jurisdiction

Overview & Analysis of Potential Losses: All jurisdictions in coastal Louisiana can suffer losses due to coastal land loss. Nevertheless, the southern-most and southeastern parishes of Louisiana are most vulnerable to the broadest spectrum of impacts from coastal land loss.

Changes in jurisdictional population levels impact each parish across the state disparately. In the parishes where coastal land loss vulnerability has increased because of increases in population (Ascension, Livingston, Tangipahoa, St. Tammany), concomitant changes in development have impacted loss estimates and will cause an increase in future losses (relative to what potential losses could be) due to increased levels of exposure. In the parishes where coastal land loss vulnerability has decreased because of decreases in population (Cameron, Orleans, Plaquemines, and St. Bernard), concomitant changes in development have impacted loss estimates and will cause a decrease in future losses (relative to what potential losses could be) due to decreased levels of exposure.

Potential Losses of State Facilities

The coastal land loss hazard vulnerability assessment of state-owned buildings was based on sea level rise, the occurrence and location of subsidence, the rate of subsidence in each zone, the extent of subsidence, and the annualized loss estimates. The criteria used to determine specific vulnerability rankings for each building and the results of applying this ranking to the state-owned buildings are shown in Table 2.50.

Table 2.50. Coastal Land Loss Vulnerability Criteria and Ranking Results.

COASTAL LAND LOSS VULNERABILITY CRITERIA AND RANKING	
Ranking	Criteria
High	Subsidence: high rate, extent, & annualized loss
Medium	Subsidence: medium rate, extent, & annualized loss
Low	Subsidence: low rate, extent, & annualized loss

The coastal land loss economic loss estimate ranges are based on the expected future flooding losses in each parish resulting from a combination of subsidence and global sea level rise. The January 2014 state facilities database was used to obtain accurate building numbers for each loss estimate range. Loss estimates of state-owned buildings in Louisiana involved an analysis of the following parameters:

- Subsidence Zones and Associated Rates
- Extent of Subsidence Relative to Parish Infrastructure

Table 2.51. Coastal Land Loss Economic Loss Estimate Ranges and Ranking Results.

COASTAL LAND LOSS ECONOMIC LOSS ESTIMATE RANGES AND RANKING		
Ranking	Total Loss Estimate Ranges	Number of Buildings
High	$375,000 - $2 million	886
Medium	$187,500 - $375,000	203
Low	< $187,500	336
Very Low	$0	7,260

DAM FAILURE

Dams are water storage, control, or diversion barriers that impound water upstream in reservoirs. Dams are a vital part of our nation's infrastructure, providing drinking water, flood protection, renewable hydroelectric power, navigation, irrigation, and recreation. These critical daily benefits are also inextricably linked to the potential harmful consequences of a dam failure.

Dam failure is a collapse or breach in the structure. A dam failure can result in severe loss of life, economic disaster, and extensive environmental damage. While most dams have storage volumes small enough that failures have few repercussions, dams with large storage volumes can cause significant flooding downstream. Dam failures often have a rapid rate of onset, leaving little time for evacuation. The first signs of the failure may go unnoticed upon visual inspection of the dam structure. However, continual maintenance and inspection of dams often provide the opportunity to identify possible deficiencies in their early stages and can prevent a possible catastrophic failure event.[lxxvi]

The duration of the flooding event caused by the failure depends largely on the amount of water and downstream topography. Given smaller volumes of water and a topography suited for transporting the water rapidly downstream, the event may only last hours. Because of the lack of seasonality and other predictive factors, a predictive frequency or likelihood of dam failures cannot be determined. However, the National Dam Safety Program (NDSP) produces hazard rankings (high, significant, and low) and definitions of dam structures, based on potential impact.

Dam/reservoir failures can result from any one of or a combination of the following causes:

- Prolonged periods of rainfall and flooding, which cause most failures;
- Inadequate spillway capacity, resulting in excess overtopping flows;
- Internal erosion caused by embankment or foundation leakage or piping;
- Improper maintenance, including failure to remove trees, repair internal seepage problems, replace lost material from the cross-section of the dam and abutments, or maintain gates, valves, and other operational components;
- Improper design, including the use of improper construction materials and construction practices;
- Negligent operation, including the failure to remove or open gates or valves during high flow periods;
- Failure of upstream dams on the same waterway;
- Landslides into reservoirs, which cause surges that result in overtopping;
- High winds, which can cause significant wave action and result in substantial erosion; and
- Earthquakes, which typically cause longitudinal cracks at the tops of the embankments that can weaken entire structures.

Louisiana has 147 USDA Natural Resources Conservation Service (NRCS)-assisted project dams built under the Small Watershed Protection Program and Flood Prevention Act authority. In Louisiana there are 548 dams managed by the Department of Transportation, Public Works & Water Resources Section as of March 2013. Map 2.137 shows dam locations per the Louisiana Department of Transportation and Development (LDOTD) inventory. The USACE National Inventory of Dams classifies dams as a "high hazard potential," "significant hazard potential," and "low hazard potential." These categories are defined below.

- *High hazard potential* dams are dams where failure or improper operation will probably cause loss of human life.
- *Significant hazard potential* dams are those where failure or improper operation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or other impacts. Dams classified as having "significant hazard potential" are often located in predominantly rural or agricultural areas but could be located in areas with population and significant infrastructure.
- *Low hazard potential* dams are those where failure or improper operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the owner's property.

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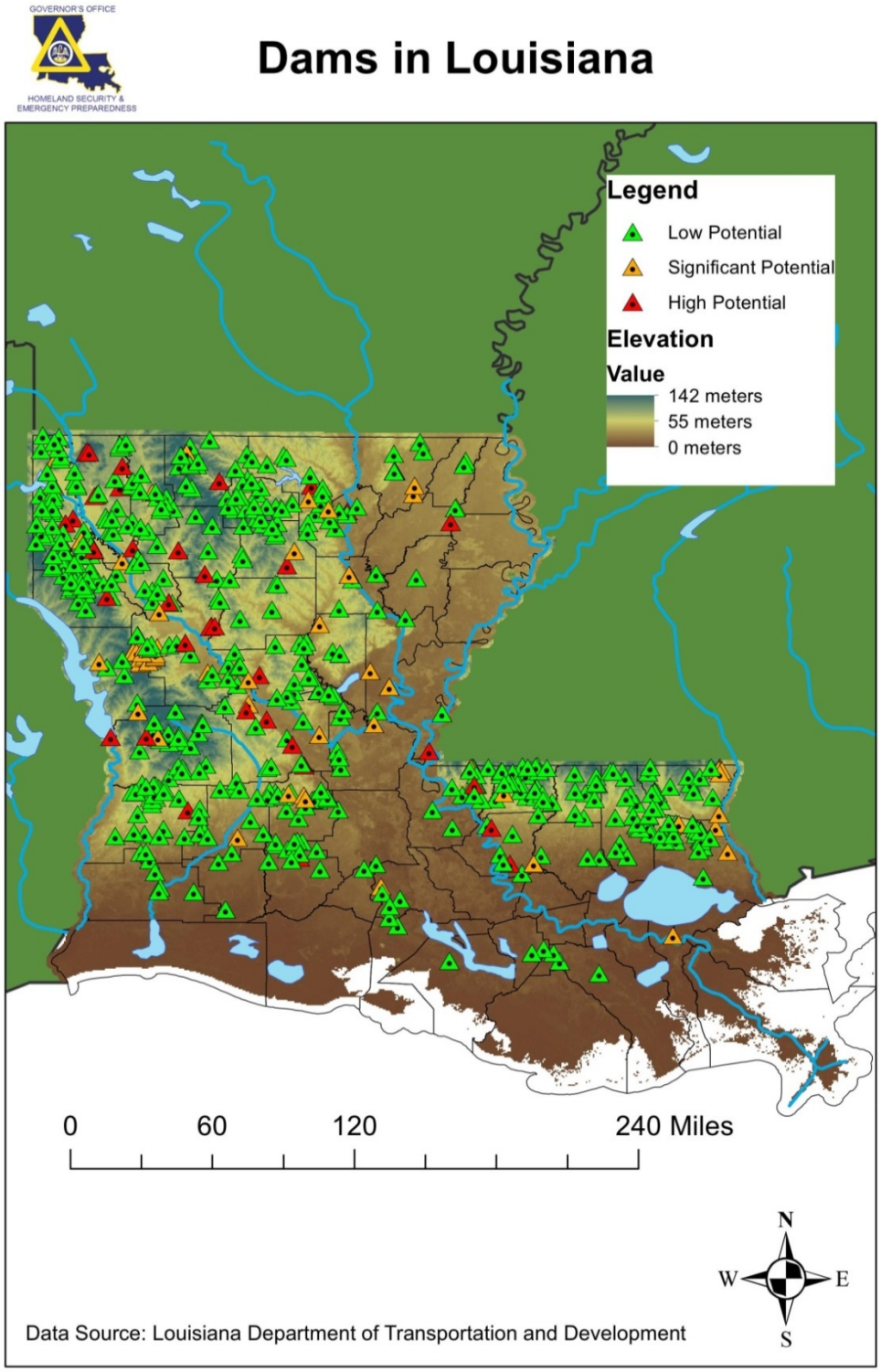

Map 2.137. Dam locations in Louisiana with respect to hazard potential (map by ETSU student Douglas Vance).

Most dams were built with a 50-yr life span. Louisiana has a number of dams that have reached their designed life span in the past few years, and more will reach their life span in the near future: 2013 (three dams), 2014 (two dams), and 2015 (one dam). Of the NRCS-assisted project dams in Louisiana, 7 dams are classified as having a high hazard potential, 26 as having a significant hazard potential, and 114 as having a low hazard potential. Twenty-eight of these dams will reach the end of their lifespan by 2017.[lxxvii] High-hazard potential dams are inspected by DOTD annually, and low-hazard potential dams are inspected every five years.

Dam Failure Profile

While there are no reports of significant dam failures in Louisiana, the National Performance of Dams Program, a database of dam incidents (events that affect the structural and functional integrity of dams, though not necessarily causing failure and not including ordinary maintenance and repair, vandalism, acts of war, recreational accidents, and sabotage) maintained by Stanford University, lists one incident from the autumn of 1985. Park managers at the Cotile Lake Dam/Reservoir in Rapides Parish reported seepage due to sand and gravel deposits that displaced concrete slabs. There was no dam failure or controlled breach reported in this incident.

In general, dam inspection by the LDOTD has very successfully mitigated against dam failure. For instance, upon inspection of their low hazard-potential earthen dams, owners have allowed controlled dewatering of their natural or manual impoundments in lieu of fixing the deficiencies noted during the periodic inspection. In the case of high water levels after Hurricane Isaac, high-water stress from the storm threatened the Percy Quin Dam (otherwise known as the Lake Tangipahoa Dam) near McComb, Mississippi, which led Tangipahoa Parish officials to order a mandatory evacuation of 60,000 people along the Tangipahoa River from Kentwood to Robert, Louisiana in case a dam failure caused flooding from the already swollen river.[lxxviii] Emergency crews were able to stabilize the dam, and evacuations ensured that had the dam failed, Tangipahoa residents would have been safe.[lxxix]

Dam Failure Risk Assessment

The future likelihood of dam failure is **Low**, but its impacts are devastating. Due to the high potential for significant personal injury and property damage for the state, this hazard will be carried forward for technical risk assessment. Map 2.138 shows the location density of dams by parish, while Map 2.139 provides an estimation of building loss due to dam failure. Map 2.140 indicates which populations are located near dams posing high or significant danger. Bossier, Grant, and St. Tammany Parishes contain multiple significant and/or high hazard dams and are at high risk to dam failure. These parishes have also experienced significant population increases of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability of these parishes to dam failure has increased. Orleans Parish contains a significant hazard dam and is at

high risk to dam failure, but it has experienced a significant population decrease of more than 20% since 2000 (see Map 2.3). As a result, the vulnerability of Orleans Parish to dam failure has decreased.

Map 2.141 reveals the top 10 repetitive paid claims (for any hazard) located near potentially dangerous dams. State-owned critical facilities located in areas affected by dam failure are of the following types: hospitals, shelters, Emergency Operation Centers, data processing centers, and state police troop offices.

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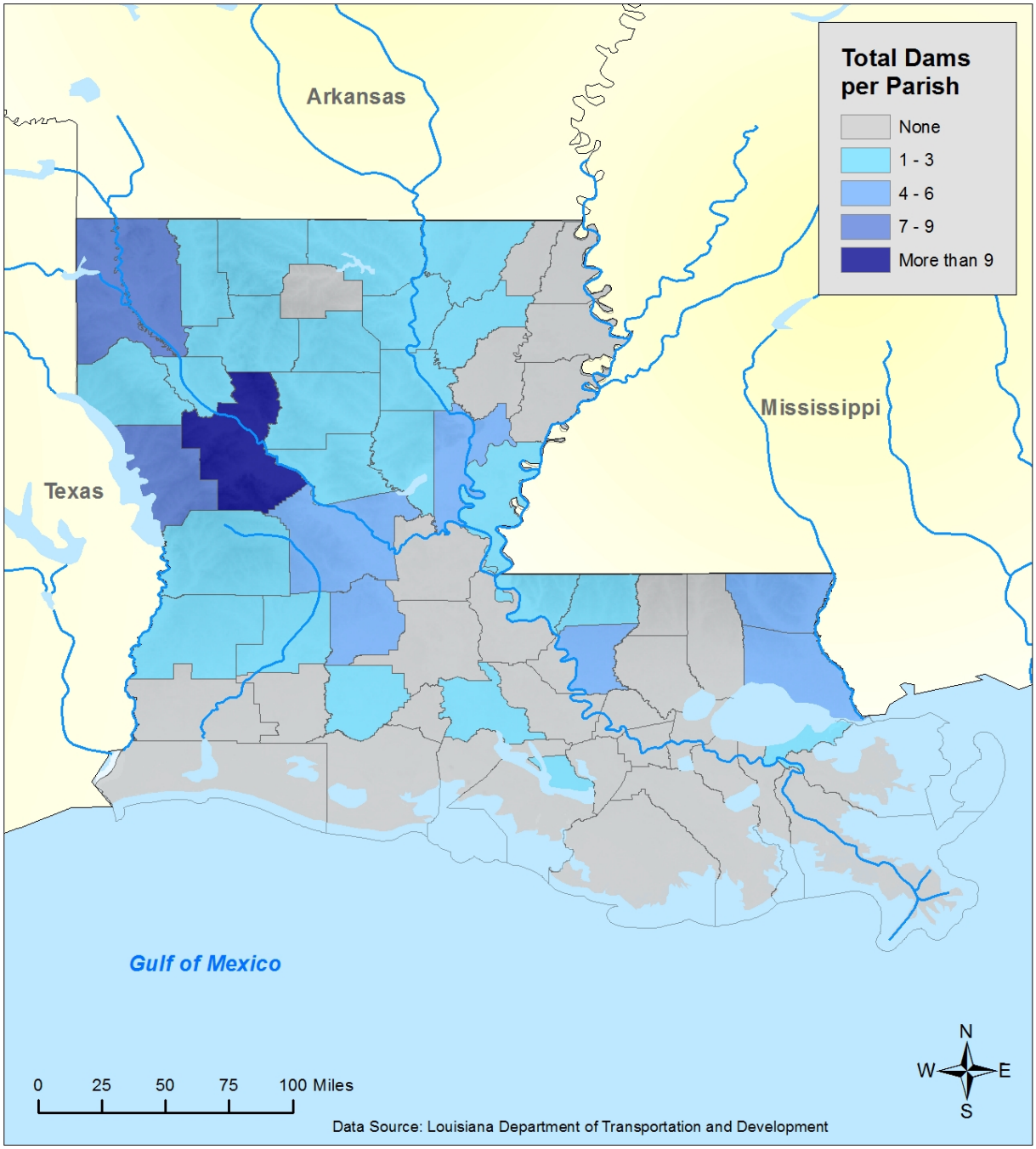
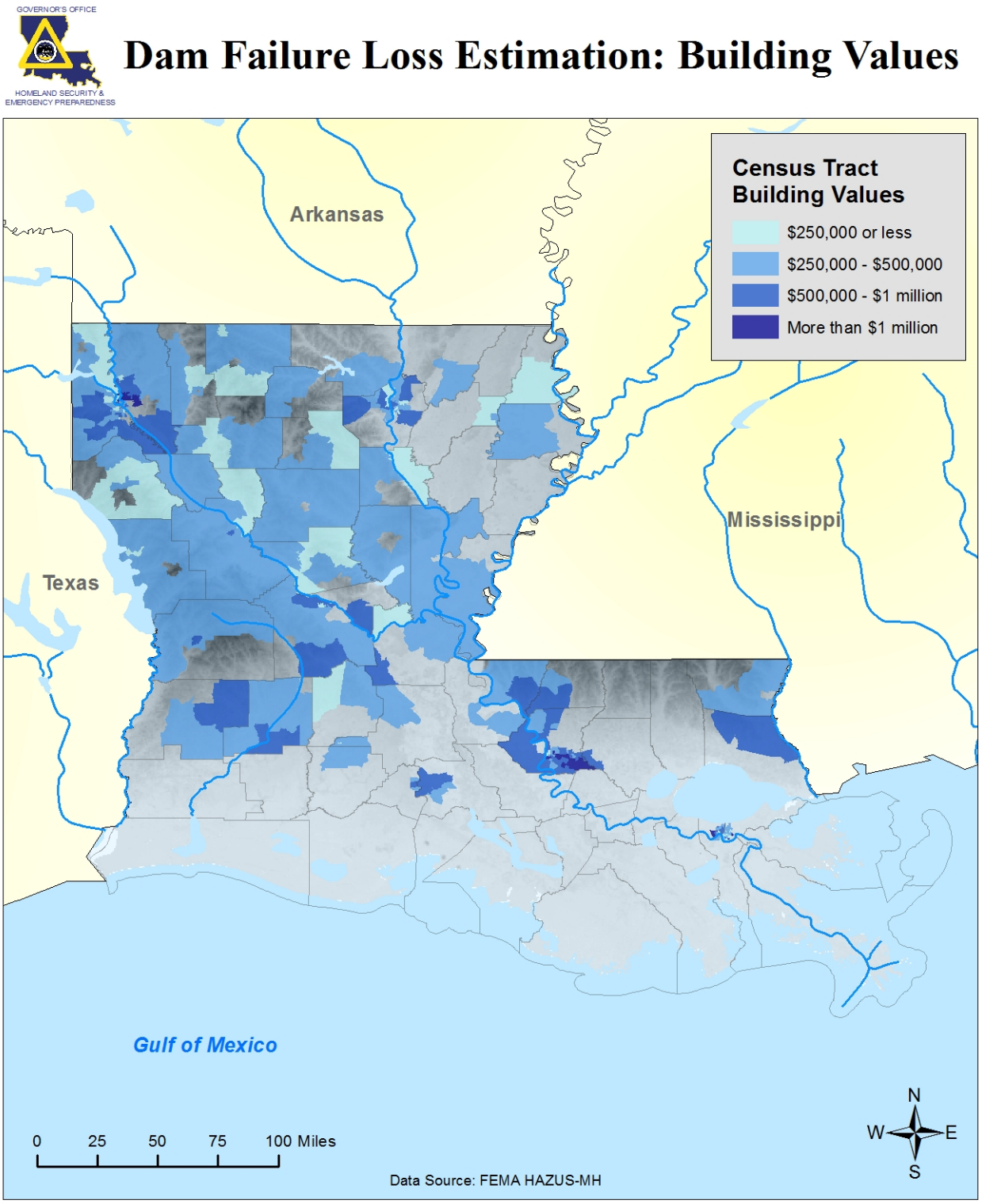
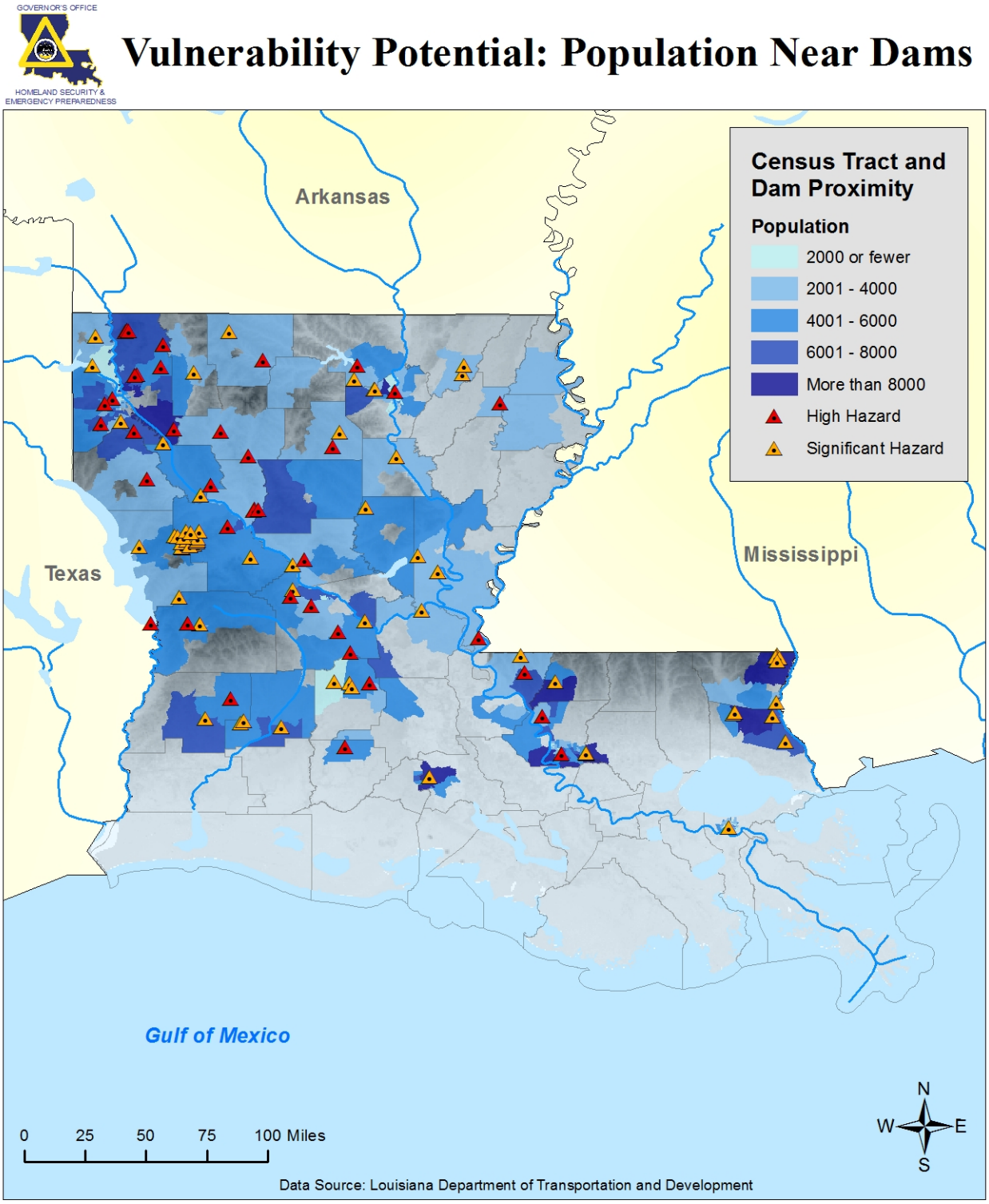


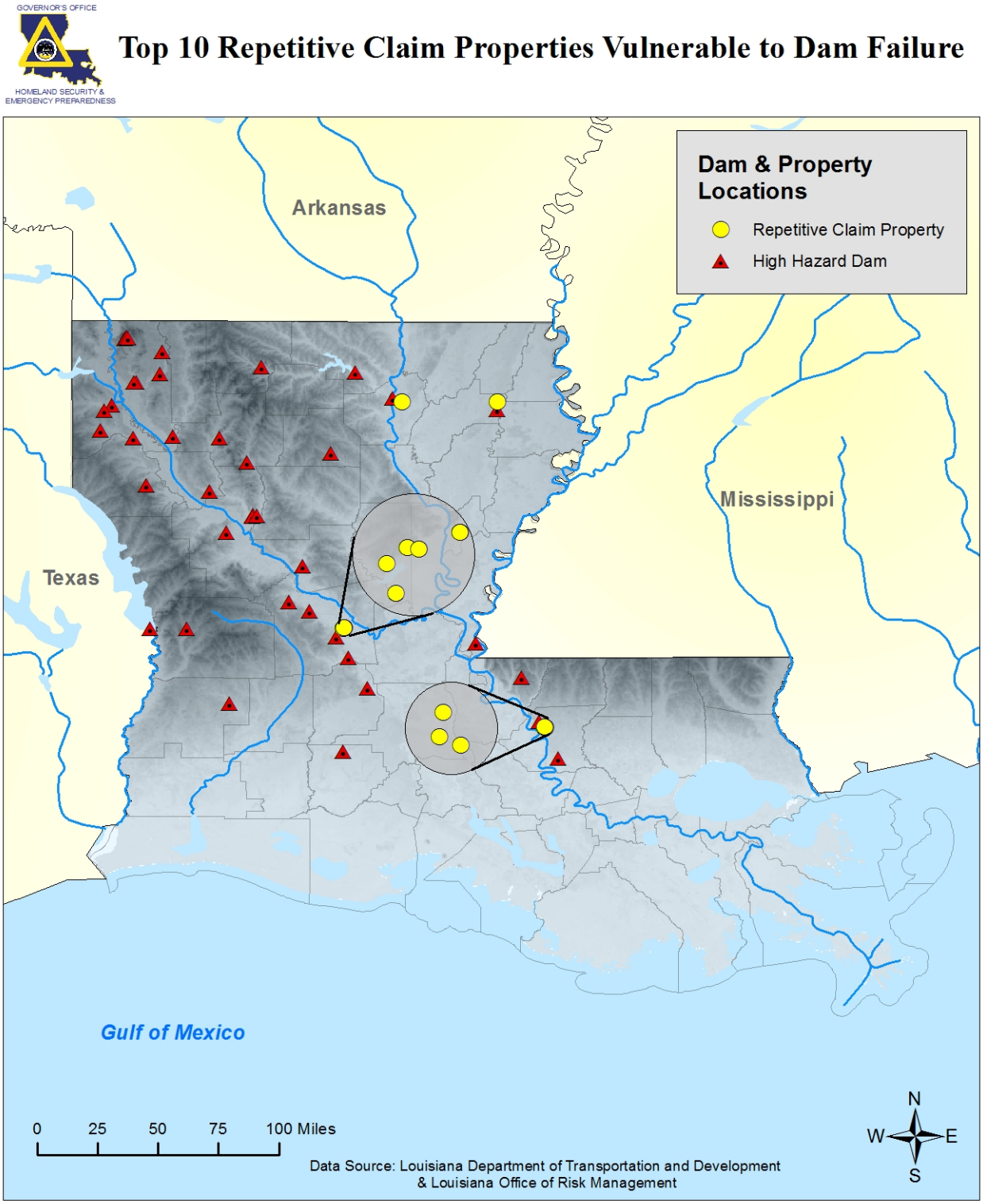
Map 2.138. Total number of dams in Louisiana by parish.



Map 2.139. Estimation of building damage in Louisiana by dam failure.



Map 2.140. Dam locations posing high or significant hazard to jurisdictional populations in Louisiana.



Map 2.141. Top 10 repetitive claim properties in relation to high hazard dams.

Based on the data presented in the preceding maps, Map 2.142 clarifies the jurisdictions most vulnerable to dam failure

Due to insufficient data, annualized losses for parishes are not available, but Map 2.139 illustrates the potential loss to specific census tracts that contain dams.

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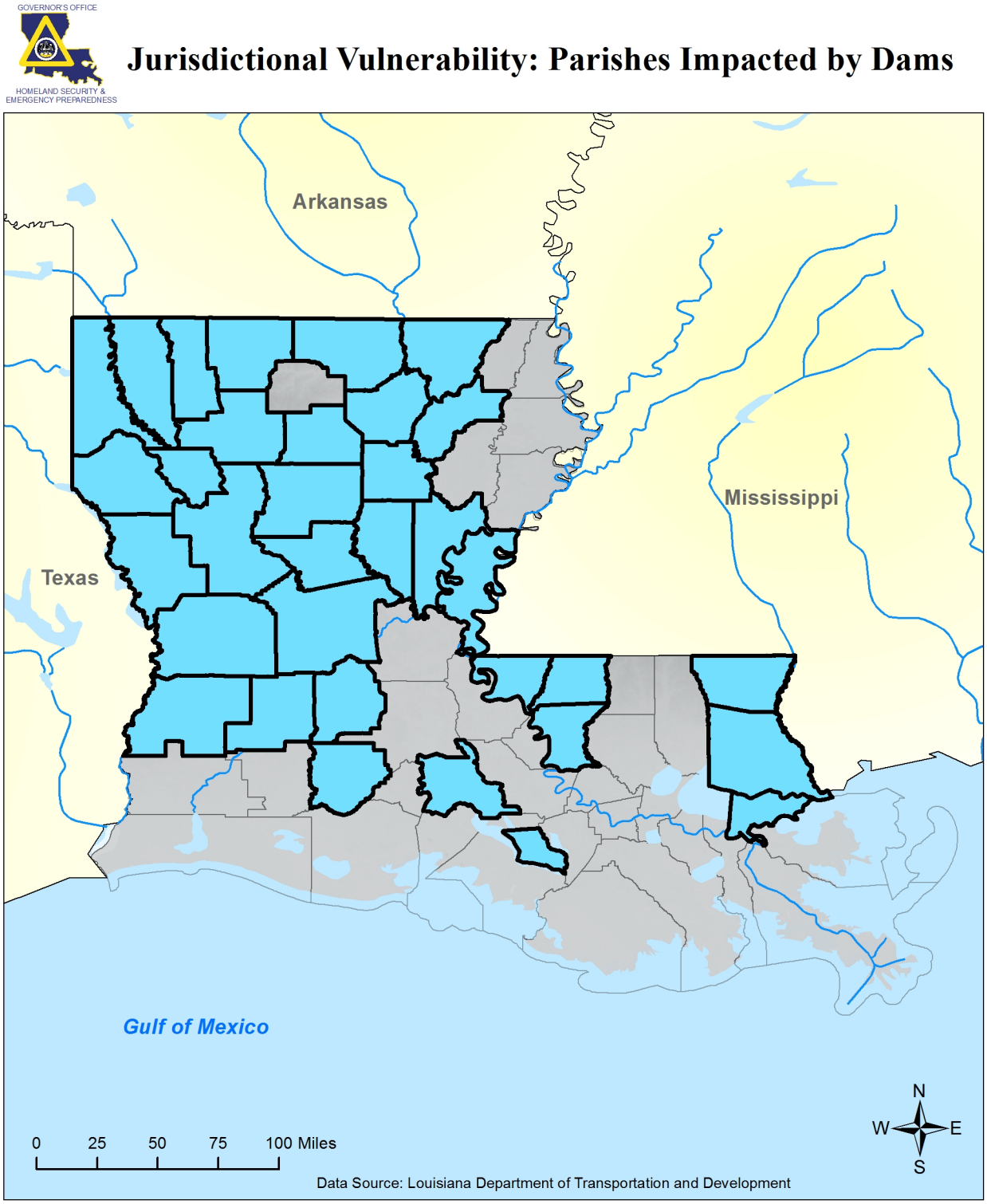

Map 2.142. Parishes impacted by dams.

Table 2.52 provides data on the risk posed to buildings and populations based on location to significant or high hazard dams, and Table 2.53 lists the top 10 paid claims (for any hazard) of state assets near high hazard dams.

Table 2.52. Statewide dam vulnerability based on proximity to dams of significant or high hazard (source: Hazus-MH).

LOUISIANA DAM VULNERABILITY			
Total Population	Population at Risk	Number of Buildings at Risk	Value of Buildings at Risk
4,533,372	1,413,219	602,083	$164,482,658

Table 2.53. Top 10 paid claims (of any hazard type) located within 5 miles of a high hazard dam (source: Louisiana Office of Risk Management).

TOP 10 PAID CLAIMS FOR STATE ASSETS NEAR HIGH-HAZARD DAMS				
Building ID	Building Name	Location	Net Paid	Total Number of Claims (All Hazards)
S02340	L. Jetson Correctional Center A	Baton Rouge	$789,817	2
S10461	LSU-Alexandria – General Operations A	Alexandria	$12,812	4
S12811	LSU-Alexandria – General Operations B	Alexandria	$3,600	2
L15257	LSU-Alexandria – The Oaks Apartments	Alexandria	$2,480	2
S10476	LSU-Dean Lee Agriculture Center Farm Supervisor Residence	Alexandria	$2,392	2
S08893	University of Louisiana-Monroe Baseball Field	Monroe	$2,021	2
S13309	L. Jetson Correctional Center B	Baton Rouge	$1,556	2
S10478	LSU-Dean Lee Agriculture Center Animal Science Residence	Alexandria	$1,322	2
S02337	L. Jetson Correctional Center C	Baton Rouge	$1,315	2
S13637	Poverty Point Reservoir	Delhi	$1,255	1

POTENTIAL LOSSES BY JURISDICTION

Overview & Analysis of Potential Losses: Areas at risk for dam failure are very specific in nature and are generally located within 3-5 miles downstream. Dams are located in many parts of the state, but parishes of central and northern Louisiana are most vulnerable. Two parishes (St. Tammany and Washington) in southeast Louisiana are also vulnerable to dam failure.

Changes in jurisdictional population levels impact each parish across the state disparately. Changes in development may greatly impact loss estimation associated with dam failure. Downstream building regulations do not need to be compliant with the NFIP as long as development is not below the BFE. This allows for development that could be in harm's way during a dam failure. In the parishes where dam failure vulnerability has increased because of increases in population (Bossier, Grant, and St. Tammany), concomitant changes in development have impacted loss estimates and will cause an increase in future losses due to increased levels of exposure. In Orleans Parish, where dam failure vulnerability has decreased because of a decrease in population, concomitant changes in development have impacted loss estimates and will cause a decrease in future losses due to decreased levels of exposure.

Potential Losses of State Facilities

The dam failure hazard vulnerability assessment of state-owned facilities was based on the potential inundation from dam failure. The criteria used to determine specific vulnerability rankings for each building and the results of applying this ranking to the state-owned critical facilities are shown in Table 2.54.

Table 2.54. Dam Failure Vulnerability Criteria and Ranking Results.

Dam Failure Vulnerability Criteria and Ranking	
Ranking	Criteria
High	Structures within dam failure areas
Medium	Structures outside dam failure hazard radius, but within same census tract
Low	Not within radius/census tract or insufficient data available

The dam failure loss estimate of state-owned buildings in Louisiana involved an analysis of the following parameters.

- Dam Failure Hazard Vulnerability
- Average Inundation Depth
- Average Building Type
- Inundation Depth-Damage Functions

Table 2.55. Dam Failure Loss Estimate Ranges and Ranking Results.

Dam Failure Loss Estimate Ranges and Ranking		
Ranking	Total Loss Estimate Ranges	Number of Buildings
High	$1,000,001 to $70,000,000	153
Medium	< $1,000,000	6526
Low	$0	2006

EARTHQUAKE

An earthquake is a sudden motion or trembling of the Earth caused by an abrupt release of stored energy in the rocks beneath the Earth's surface. The energy released results in vibrations which are known as seismic waves. Ground motion from seismic waves is expressed as peak ground acceleration (PGA), the fastest measured change in speed for a particle at ground level that is moving because of an earthquake. PGA is commonly measured as a percentage of acceleration due to Earth's gravity (%g). This measurement is relied on to determine seismic load engineering design and construction requirements.

Earthquakes are typically described in terms of magnitude and intensity. Magnitude is the measure of the amplitude of the seismic wave and is often expressed by the Richter scale, and intensity is a measure of how strong the shock was felt at a particular location, indexed by the Modified Mercalli Intensity (MMI) scale. The Richter scale is a logarithmic measurement whereby an increase in the scale by one whole number represents a tenfold increase in measured ground motion of the earthquake (and an increase in energy released of more than 30 times). An increase by two whole numbers represents a 10^2 (or 100-fold) increase in ground motion, and thus more than 30^2 (or 900) times the energy released. Table 2.56 shows the rough correlation between the Richter scale, PGA, and the MMI. The relationship between these is approximate and depends upon such specifics as the depth of the focus (the location of the actual rock movement) and distance from the epicenter (the location on the Earth's surface above the earthquake focus) of the earthquake.

The system of subsidence faults in southern Louisiana developed due to accelerated land subsidence and rapid sediment deposition from the Mississippi River. The system stretches across the southern portion of the state from Beauregard Parish in the west to St. Tammany Parish in the east and it includes every parish south of this line. This system is thought to be responsible for many of the recorded earthquakes from 1843 to the present. All of the earthquakes that occurred over this period of time were of low magnitude, resulting mostly in limited property damage (such as broken windows, damaged chimneys, and cracked plaster). While faults throughout the northwestern parishes are thought to be inactive, the New Madrid seismic zone lies just to the north of Louisiana and originates in the region of New Madrid, Missouri. The magnitude of historic earthquakes originating in the New Madrid seismic zone is far greater than that generated by the subsidence fault system in coastal Louisiana. A significant seismic event from the New Madrid seismic zone is more likely to have a greater impact on Louisiana than a seismic event from the subsidence fault system.

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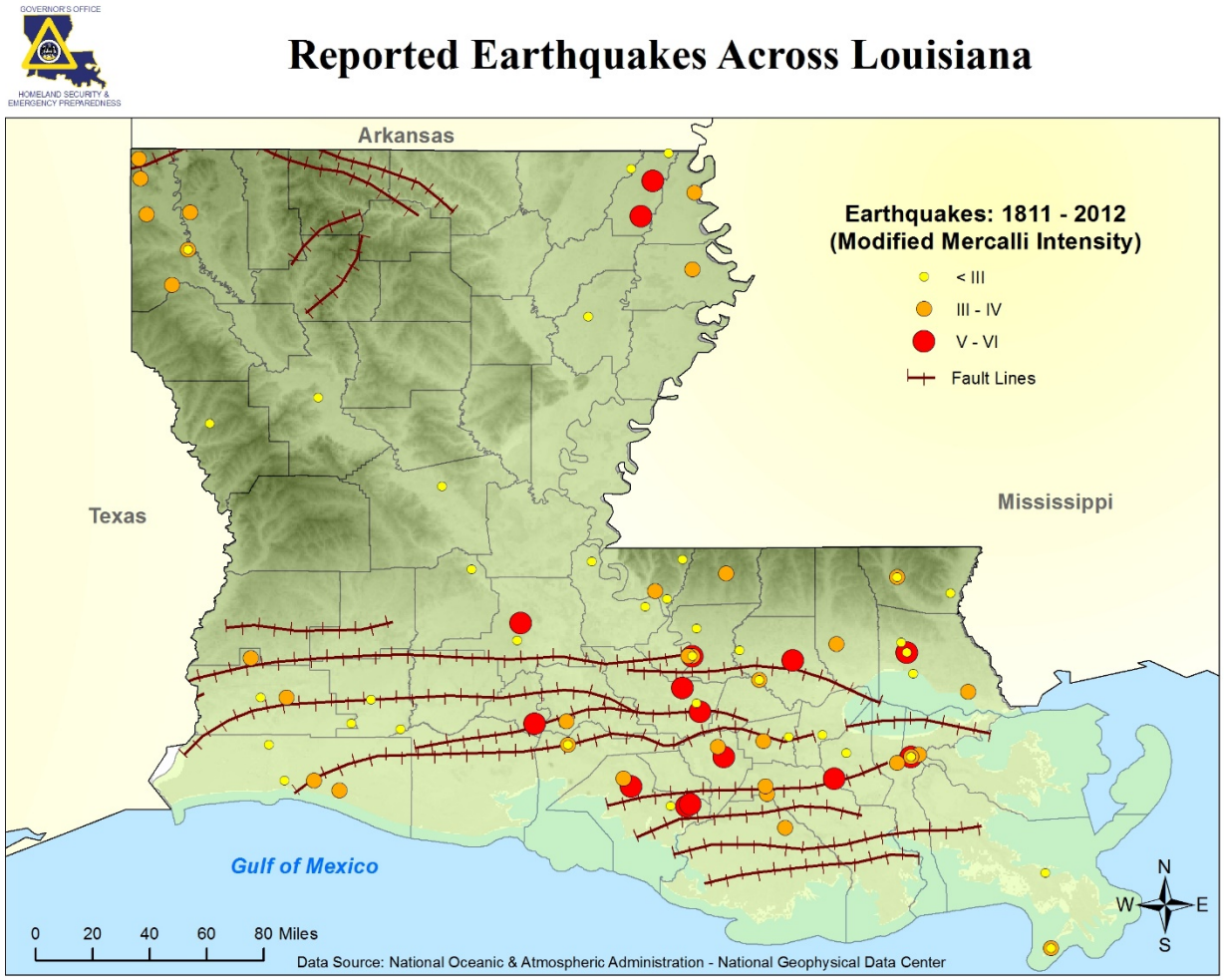
Table 2.56. Comparison of earthquake magnitudes for PGA, Richter, and MMI (source: USGS Earthquake Hazards Program).

Comparison of Earthquake Metrics			
PGA (%g)	Magnitude (Richter)	Intensity (MMI)	Description (MMI)
<0.17	1.0 - 3.0	I	**I**. Not felt except by a very few under especially favorable conditions.
0.17 - 1.4	3.0 - 3.9	II - III	**II**. Felt only by a few persons at rest, especially on upper floors of buildings. **III**. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
1.4 - 9.2	4.0 - 4.9	IV - V	**IV**. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motorcars rock noticeably. **V**. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
9.2 - 34	5.0 - 5.9	VI - VII	**VI**. Felt by all. Some heavy furniture moved; a few instances of fallen plaster. Damage slight. **VII**. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
34 - 124	6.0 - 6.9	VII - IX	**VIII**. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. **IX**. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
>124	7.0 and higher	**VIII** or higher	**X**. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent. **XI**. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly. **XII**. Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Earthquake Profile

A number of earthquakes have occurred over the past two hundred years in the state, 47 of which were recorded by USGS (see Map 2.143 for geographic location of reported earthquakes in Louisiana). However, most were very minor. The two most significant historic earthquakes

were the New Madrid earthquakes (1811–1812) and the 1930 earthquake in Donaldsonville in southern Louisiana, the latter of which measured 4.2 on the Richter scale.



Map 2.143. Reported earthquakes in Louisiana 1811 to 2012.

The New Madrid earthquakes were among the largest earthquake events ever to occur in the United States. Occurring near New Madrid, Missouri, from December 16, 1811 to February 7, 1812, a number of earthquakes originated in this region, with the three strongest earthquakes thought to have magnitudes between 8.4 and 8.7 on the Richter scale. The strongest tremors were felt from New Orleans to Quebec, and the course of the Mississippi River was permanently changed. Aftershocks were felt for more than five years after the initial series of earthquakes.

The largest recorded earthquake event originating in Louisiana occurred in Donaldsonville on October 19, 1930. The earthquake was felt over a 1,500-mi^2 area of southeastern Louisiana. The towns that suffered the most damage were Donaldsonville, Gonzales, Napoleonville, and White

Castle. There were reports of damaged brick chimneys, broken windows and overturned small objects. Other towns affected were Morgan City, Franklin, Elemans, Berwick, and Plaquemine, each reporting doors and windows rattling, houses creaking, and hanging objects swinging.

Based on historic events, the most severe earthquakes in the state are likely to occur to the very north (near the Arkansas–Mississippi border), originating from the New Madrid seismic zone, and to the south (near the coast) from the subsidence fault system. Nevertheless, the USGS has recorded only five minor earthquakes in Louisiana in the past 25 years (see Table 2.57 for information on those earthquakes). Historically, earthquakes have caused minimal damage.

Table 2.57. Information on five most recent earthquake events (source: USGS Earthquake Hazards Program).

Recent Recorded Earthquakes in Louisiana						
Event # (since 1843)	Date	Latitude	Longitude	Depth (miles) to Focus	Richter Magnitude	Nearest Parish
43	6/10/1994	33.01°	-92.67°	3.1	3.2	Union
44	3/3/2001	33.19°	-92.66°	3.1	3.0	Union
45	12/17/2001	33.2°	-92.7°	6.2	2.8	Union
46	12/20/2005	30.26°	-90.71°	3.1	3.0	Livingston
47	5/16/2007	33.3°	-92.59°	3.1	3.0	Union

Based on previous occurrences, the probability of future likelihood of earthquakes is **Low**. Based on the results of the hazard profiling for this plan update, earthquakes are not considered significant by the SHMPC in comparison to the other profiled hazards. Therefore, a technical risk assessment is not included.

LEVEE FAILURE

Levees and floodwalls are flood control barriers constructed of earth, concrete, or other materials. For the purposes of this plan, levees are distinguished from smaller flood barriers (such as berms) by their size and extent. Berms are barriers that only protect a small number of structures, or at times only a single structure. Levees and floodwalls are barriers that protect significant areas of residential, commercial, or industrial development; at a minimum, they protect a neighborhood or small community.

Levee failure involves the overtopping, breach, or collapse of the levee. Levee failure is especially destructive to nearby development during flood and hurricane events. The northern half of Louisiana is protected by levees on the Ouachita River, under the authority of the Vicksburg District of the United States Army Corp of Engineers (USACE). The Vicksburg District encompasses 68,000 mi^2 in the States of Arkansas, Mississippi and Louisiana. They manage seven drainage basins, including the Yazoo, Pearl, Big Black, Red, Ouachita, and Mississippi Rivers; 12 locks and dams on the Pearl, Red, and Ouachita rivers; 1,808 mi. of levees, including 468 along the Mississippi River; and multiple lakes with 1,709 mi. of shoreline. Map 2.144 illustrates the leveed areas in the Vicksburg and New Orleans Districts.

Coastal and southern Louisiana is protected by an extensive levee system under the authority of the New Orleans District of the USACE. This system includes 30,000 mi^2 of Louisiana south of Alexandria, including 961 mi. of river levees in the Mississippi River and Tributaries Project, 449 mi. of river levees in the Atchafalaya Basin, and 340 mi. of hurricane-protection levees. Other levees have been built along stretches of rivers throughout Louisiana by local levee districts and private citizens. The data regarding these non-federal levees are managed by the individual entity responsible for construction and subsequent maintenance and are not kept in consistent format for a comprehensive hazard analysis.

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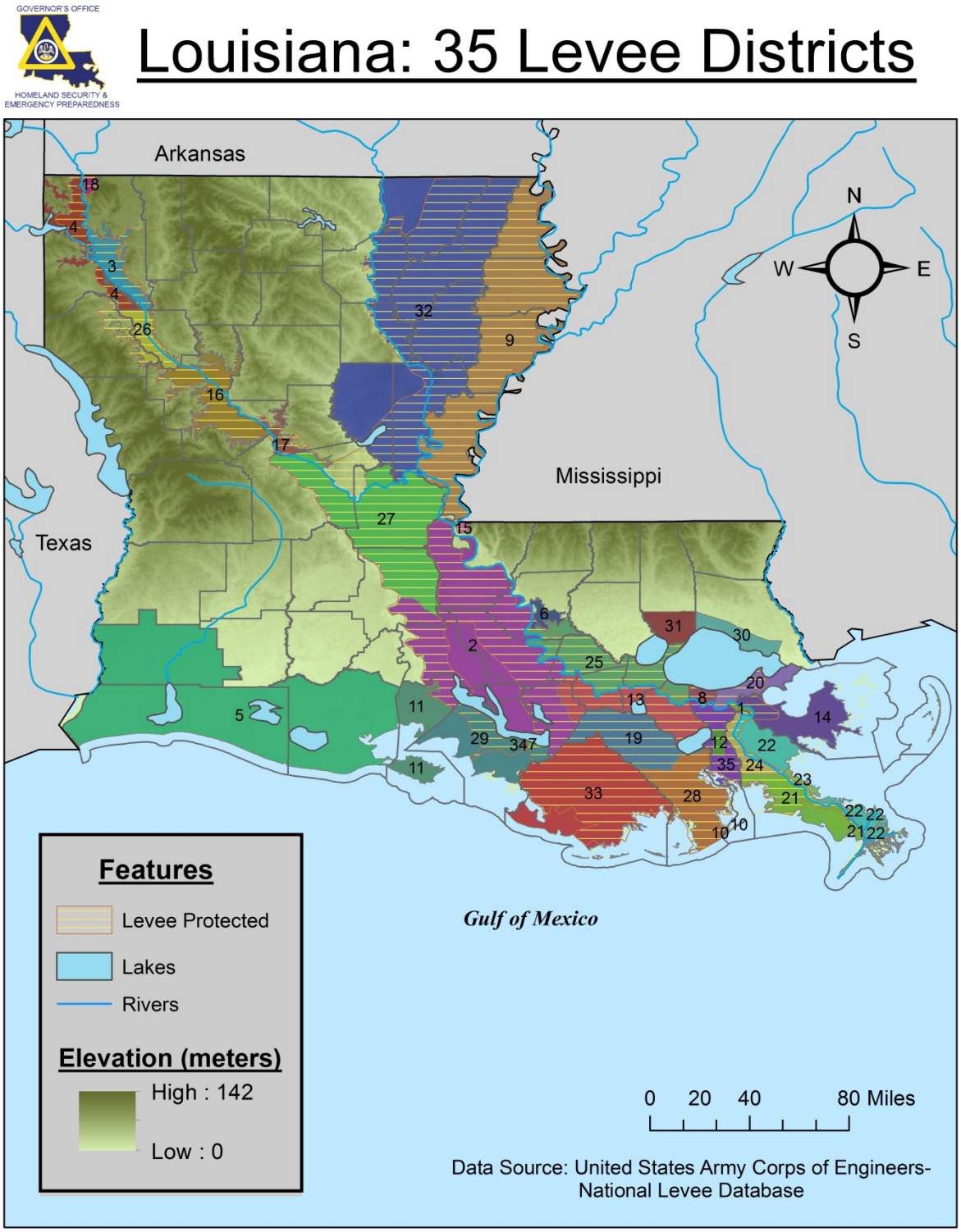
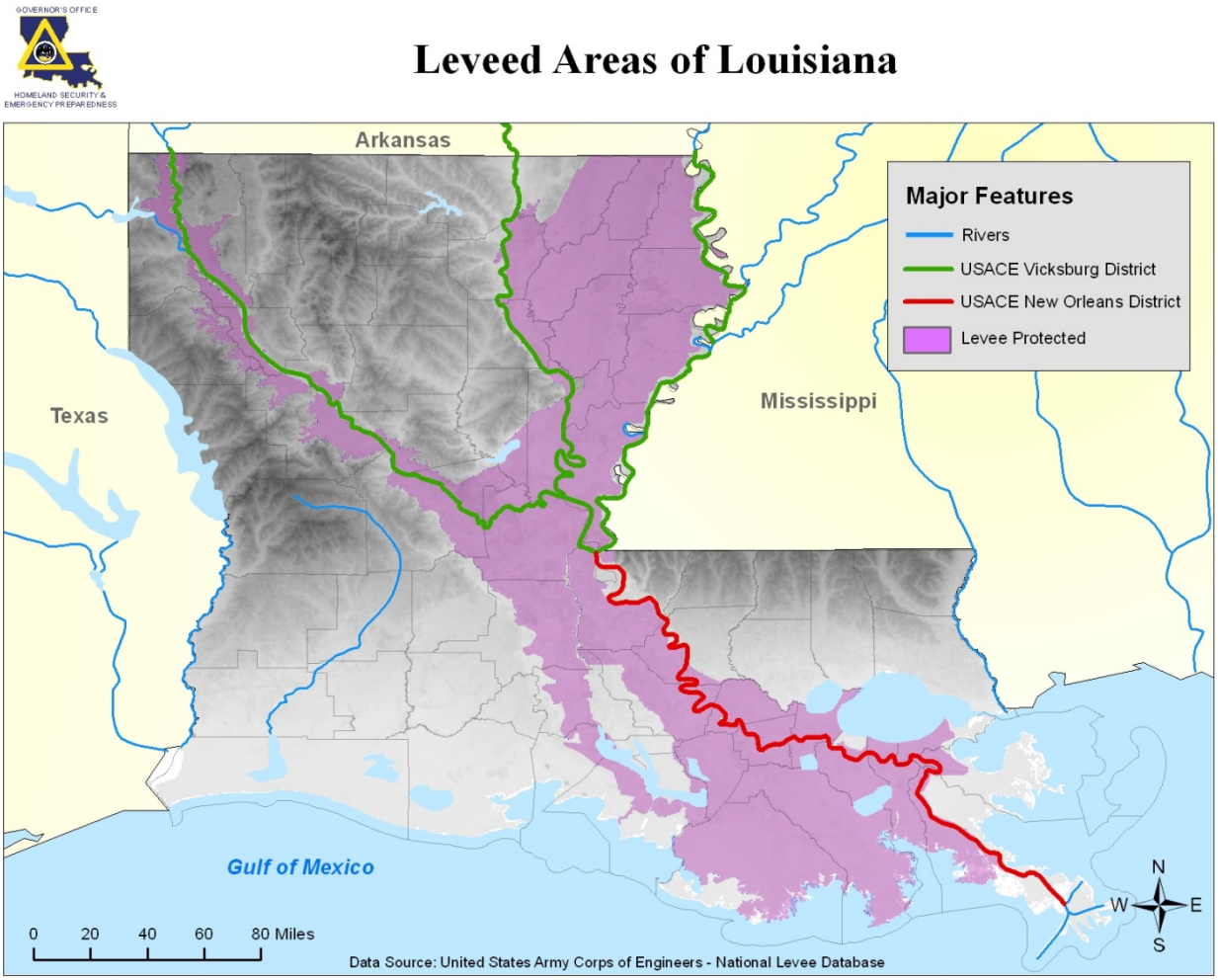


Map 2.144. Location of USACE levee districts of Louisiana (map by ETSU student Hannah Miltier).

Table 2.58 indexes the names of the numbered levee districts shown in Map 2.144, while Map 2.145 shows the levee-protected areas under the jurisdiction of the USACE Vicksburg and New Orleans Districts.

Table 2.58. Levee-protected areas under jurisdiction of USACE Vicksburg and New Orleans Districts.

LEVEE DISTRICTS IN LOUISIANA	
1	Algiers Levee District
2	Atchafalaya Basin Levee District
3	Bossier Levee District
4	Caddo Levee District
5	Chenier Plain Coastal Restoration and Protection Authority
6	City of Baton Rouge
7	City of Morgan City
8	East Jefferson Levee District
9	Fifth Louisiana Levee District
10	Grand Isle Independent Levee District
11	Iberia Parish Levee, Hurricane Protection, and Conservation District
12	Lafitte Area Independent Levee District
13	Lafourche Basin Levee District
14	Lake Borgne Basin Levee District
15	Louisiana State Penitentiary
16	Natchitoches Levee and Drainage District
17	Nineteenth Louisiana Levee District
18	North Bossier Levee and Drainage District
19	North Lafourche Conservation, Levee, and Drainage District
20	Orleans Levee District
21	Plaquemines Parish (Buras Levee District)
22	Plaquemines Parish (Grand Prairie Levee District)
23	Plaquemines Parish (Orleans Levee District)
24	Plaquemines Parish (West Plaquemines Levee District)
25	Pontchartrain Levee District
26	Red River Levee and Drainage District
27	Red River, Atchafalaya, and Bayou Boeuf Levee District
28	South Lafourche Levee District
29	St. Mary Levee District
30	St. Tammany Levee District
31	Tangipahoa Levee District
32	Tensas Basin Levee District
33	Terrebonne Levee and Conservation District
34	Town of Berwick
35	West Jefferson Levee District



Map 2.145. Levee-protected areas under the jurisdiction of the USACE Vicksburg and New Orleans Districts.

Levee Failure Profile and Risk Assessment

Levees have been overtopped or breached during flood events and non-flood events. In 1985, a section of levee along the Mississippi River near Marrero failed due to scour in a non-flood-related event. The causes of this failure included scouring and erosion of sand from the toe of the river bank, which created an over-steepened slope and resultant instability of the upper bank. Severe scour at the toe resulted as the channel bottom deepened through the sandy substratum. Flow failure in the sands then led to loss of the upper bank. Thus, the location of the failure was controlled by the nature of the geologic deposits beneath the levee combined with progressive deepening of the river channel at that location.

Several sections along Lake Pontchartrain and along both navigation and drainage canals failed in New Orleans during Hurricane Katrina. The extent and depth of these levee failures resulting from Hurricane Katrina caused extreme flooding in New Orleans.

As storm surges breached the low-lying levees along navigation canals, including the Mississippi River Gulf Outlet (which connects the city directly to the Gulf), the first levee failures occurred in St. Bernard Parish. Another breach occurred along the 17th Street Canal, separating Orleans and Jefferson Parishes, while more failures occurred at the London Avenue Canal and the Internal Canal. Ultimately, these failures left 80% of the city under water.

In the end, though, it was simply pressure failures within the bodies of the levees that led to failure. The piling reinforcements that extended into the subsurface to provide more support often did not extend in deep enough. Indeed, the effects of subsidence will continue to contribute to that reinforcement vulnerability.

Besides the failure of the levee system in design and maintenance, likely the biggest contributor to the flooding of the city was the construction of the Mississippi River Gulf Outlet (MRGO). The 600-ft-wide canal channeled surge waters directly into the city from the Gulf, leading to about 20 percent higher-than-normal water levels. The MRGO also directed waters to populated regions 100–200% faster than the natural landscape would have allowed.

Areas of Bossier, Grant, West Baton Rouge, Ascension, Livingston, and Tangipahoa Parishes are protected by levees and are consequently at high risk (greater than 2.0 composite risk score) to levee failure. These parishes have also experienced significant population increases of more than 10% since 2000 with Ascension and Livingston Parishes experiencing greater than 20% increases in population (see Map 2.3). As a result, the vulnerability of these parishes to levee failure has increased. Areas of East Carroll, Madison, Tensas, Orleans, St. Bernard, and Plaquemines Parishes are protected by levees and are consequently at a high risk to levee failure. These parishes, however, have experienced significant population decreases of more than 10% since 2000 with Orleans and St. Bernard Parishes experiencing greater than 20% decreases in population (see Map 2.3). As a result, the vulnerability of these parishes to levee failure has decreased.

In any case, there have been no levee failures since Katrina. Although the likelihood of future occurrence for this hazard is **Low**, due to the high potential for significant personal injury and property damage for the state due to its occurrence, this hazard will be included in the Risk Assessments. Based on the data presented in Map 2.145, Map 2.146 clarifies the jurisdictions most vulnerable to levee failure.

Due to insufficient data, annualized losses for parishes are not available, but Map 2.147 (further below) illustrates the potential loss to specific census tracts that contain levees.

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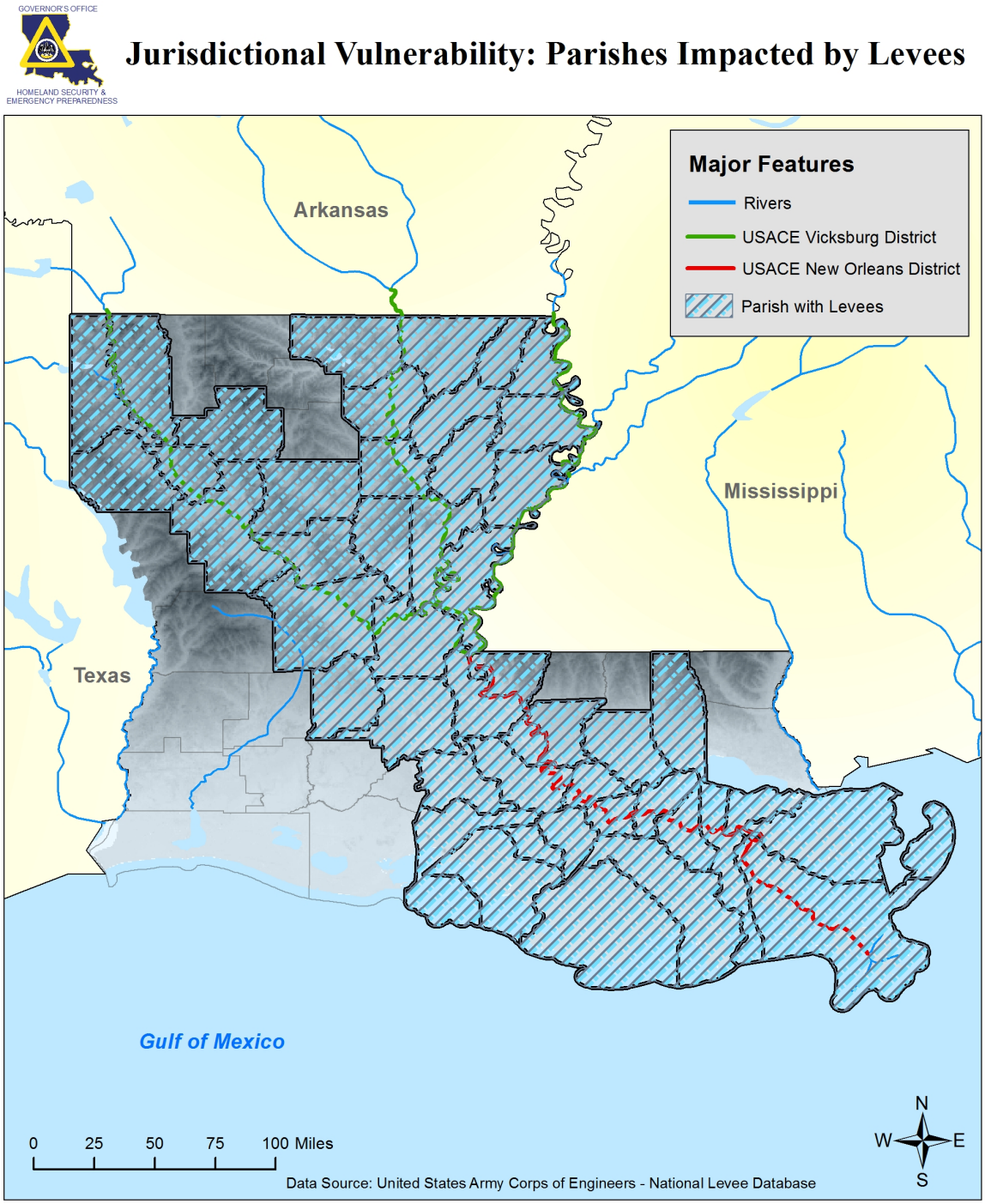

Map 2.146. Parishes impacted by levees, divided by levee-district lines.

POTENTIAL ECONOMIC LOSS

Table 2.59 provides data based on the recent census to indicate population and building vulnerability in leveed areas of Louisiana, while Maps 2.147 and 2.148 provide these data at the

census tract levels. State-owned critical facilities located in areas affected by levee failure are of the following types: hospitals, shelters, Emergency Operation Centers, data processing centers, and state police troop offices.

Table 2.59. Population and building vulnerability in leveed areas based on census data.

Population and Building Vulnerability in Leveed Areas			
Total Population	Population at Risk	Number of Buildings at Risk	Value of Buildings at Risk
4,533,372	2,596,766	1,044,883	$289,419,758

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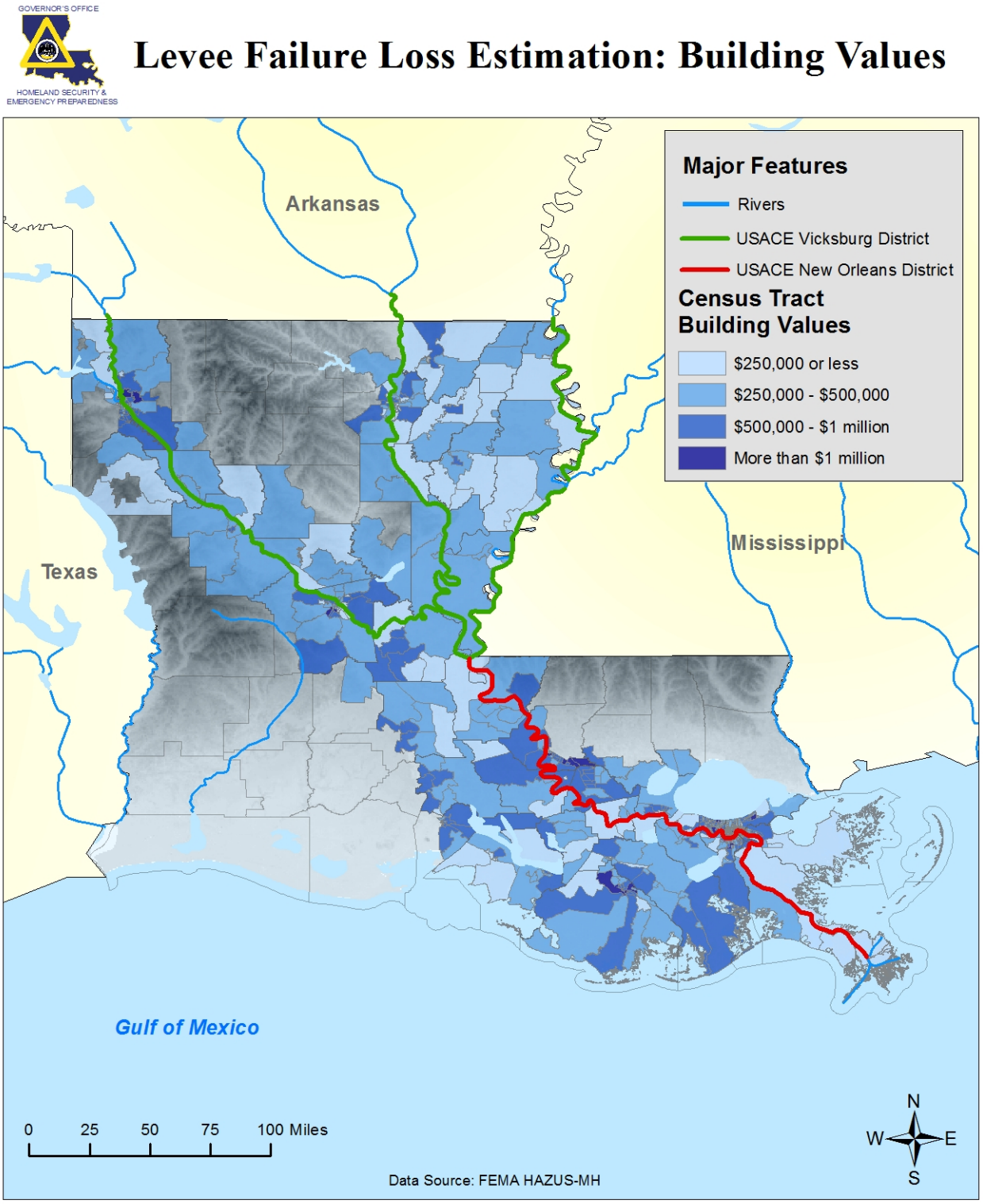
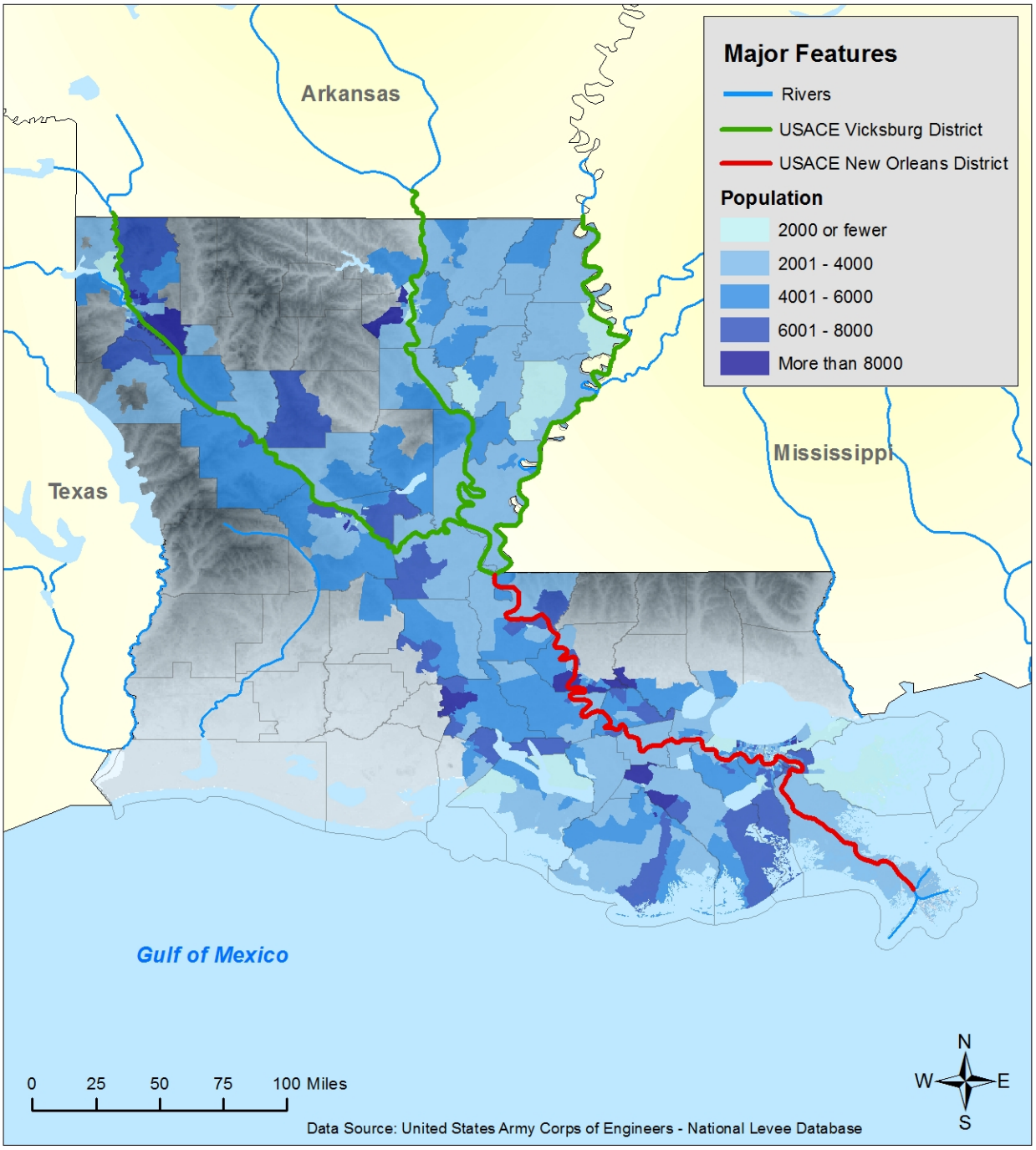


Map 2.147. Estimation of building losses due to levee failure.



Map 2.148. Vulnerable populations located within leveed areas.

Potential Losses by Jurisdiction

Overview & Analysis of Potential Losses: Half of the state's population is vulnerable to levee failure. Entire cities are either partially or fully-protected by a levee system – most notably the major cities along the Red River, Ouachita River, and Mississippi River including Shreveport, Bossier City, Alexandria, Pineville, Baton Rouge, Monroe, and New Orleans. Levee failure represents a potentially catastrophic loss for many parts of Louisiana and vast quantities of infrastructure are vulnerable.

Changes in jurisdictional population levels impact each parish across the state disparately. Changes in development may greatly impact loss estimation associated with levee failure. In the parishes where levee failure vulnerability has increased because of increases in population (Bossier, Grant, West Baton Rouge, Ascension, Livingston, and Tangipahoa), concomitant changes in development have impacted loss estimates and will cause an increase in future losses due to increased levels of exposure. When a large amount of development occurs within a leveed area (as in Baton Rouge and New Orleans), these new developments are highly vulnerable to levee failure. Lack of regulations within leveed areas allows for development that could be in harm's way during a levee failure and is representative of the false sense of security that levees provide. In the parishes where levee failure vulnerability has decreased because of decreases in population (East Carroll, Madison, Tensas, Orleans, St. Bernard, and Plaquemines), concomitant changes in development have impacted loss estimates and will cause a decrease in future losses due to decreased levels of exposure.

Potential Losses of State Facilities

The levee failure hazard vulnerability assessment of state-owned facilities was based on the potential inundation from levee failure. The criteria used to determine specific vulnerability rankings for each building and the results of applying this ranking to the state-owned critical facilities are shown in Table 2.60.

Table 2.60. Levee Failure Vulnerability Criteria and Ranking Results.

Levee Failure Vulnerability Criteria and Ranking	
Ranking	Criteria
High	Structures within levee protection zones
Medium	Structures outside of the levee protection zones, but within same census tract
Low	Not within zone/census tract or insufficient data available

The levee failure loss estimate of state-owned buildings in Louisiana involved an analysis of the following parameters:

- Levee Failure Hazard Vulnerability
- Average Inundation Depth
- Average Building Type
- Inundation Depth-Damage Functions

Table 2.61. Levee Failure Loss Estimate Ranges and Ranking Results.

LEVEE FAILURE LOSS ESTIMATE RANGES AND RANKING		
Ranking	Total Loss Estimate Ranges	Number of Buildings
High	$100,001 to $215,000,000	2903
Medium	<$100,000	3626
Low	$0	2156

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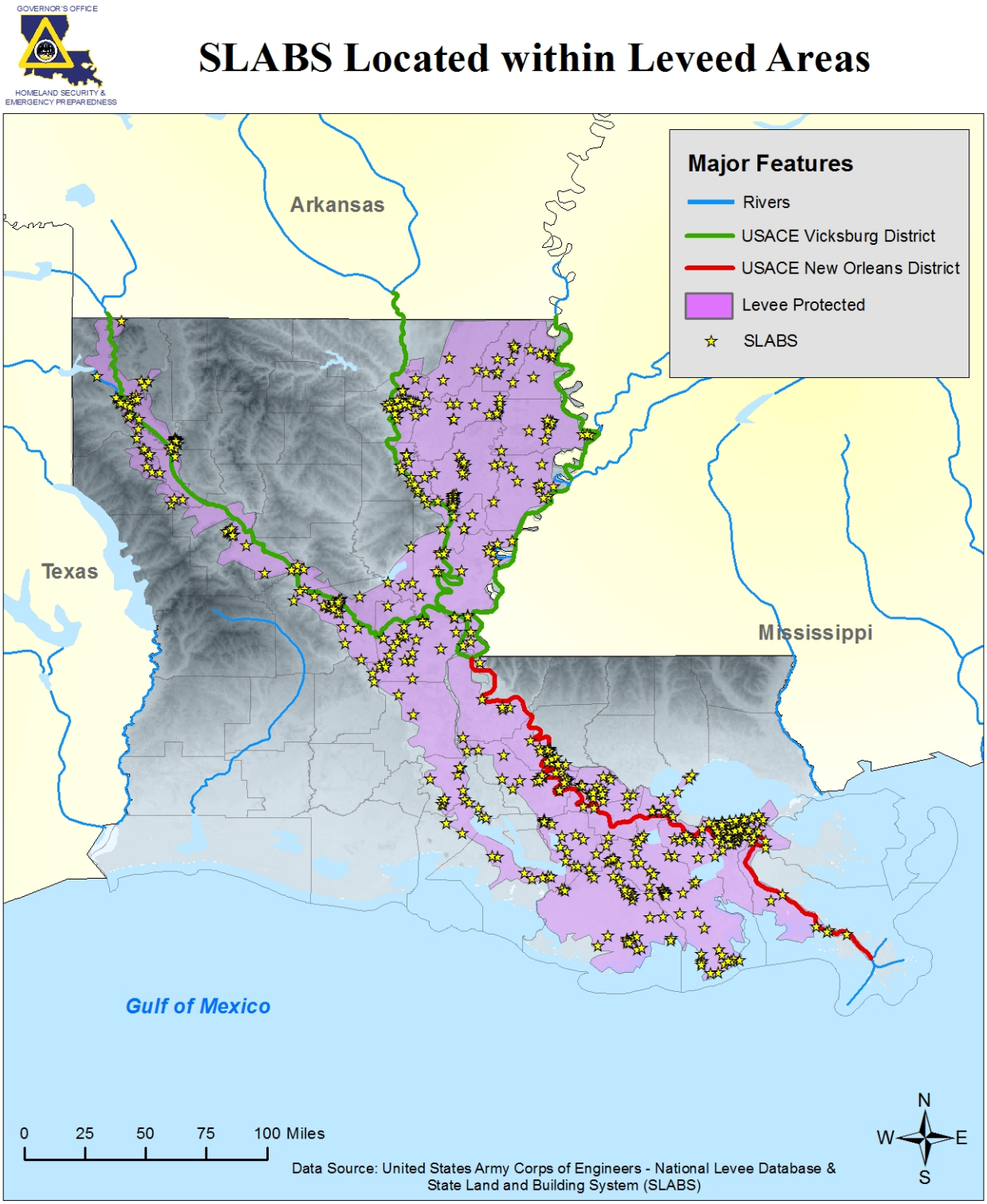

Map 2.149. State Land and Building Systems (SLABS) located within leveed areas.

SINKHOLES

Sinkholes are areas of ground—varying in size from a few square feet to hundreds of acres, and reaching in depth from 1 to more than 100 ft.—with no natural external surface drainage. Sinkholes are usually found in *karst terrain*—that is, areas where limestone, carbonate rock, salt beds, and other water-soluble rocks lie below the Earth's surface. Karst terrain is marked by the presence of other uncommon geologic features such as springs, caves, and dry streambeds that lose water into the ground. Nevertheless, sinkholes are defined by any collapse of the earth's surface. In general, sinkholes form gradually (in the case of cover-subsidence sinkholes), but they can also occur suddenly (in the case of cover-collapse sinkholes).

General sinkhole formation is a very simple process. Whenever water is absorbed through soil and encounters water-soluble bedrock, and then begins to dissolve it, sinkholes start to form. The karst rock dissolves along cracks; as the fissures grow, soil and other particles fill the gaps, loosening the soil above the bedrock. Figure 2.8 illustrates the development of a cover-subsidence sinkhole. As the soil sinks from the surface, a depression forms, which draws in more water, funneling it down to the water-soluble rock. The increase of water and soil in the rock pushes open the cracks, again drawing more soil and water into it. This positive feedback loop continues, unless clay plugs into the cracks in the bedrock, at which time a pond may form. A sudden cover-collapse sinkhole occurs when the topsoil above dissolving bedrock does not sink, but forms a bridge over the soil that is sinking beneath it. As Figure 2.9 demonstrates, underground soil continues to fill the bedrock fissures, until finally the soil bridge collapses and fills the void beneath it.

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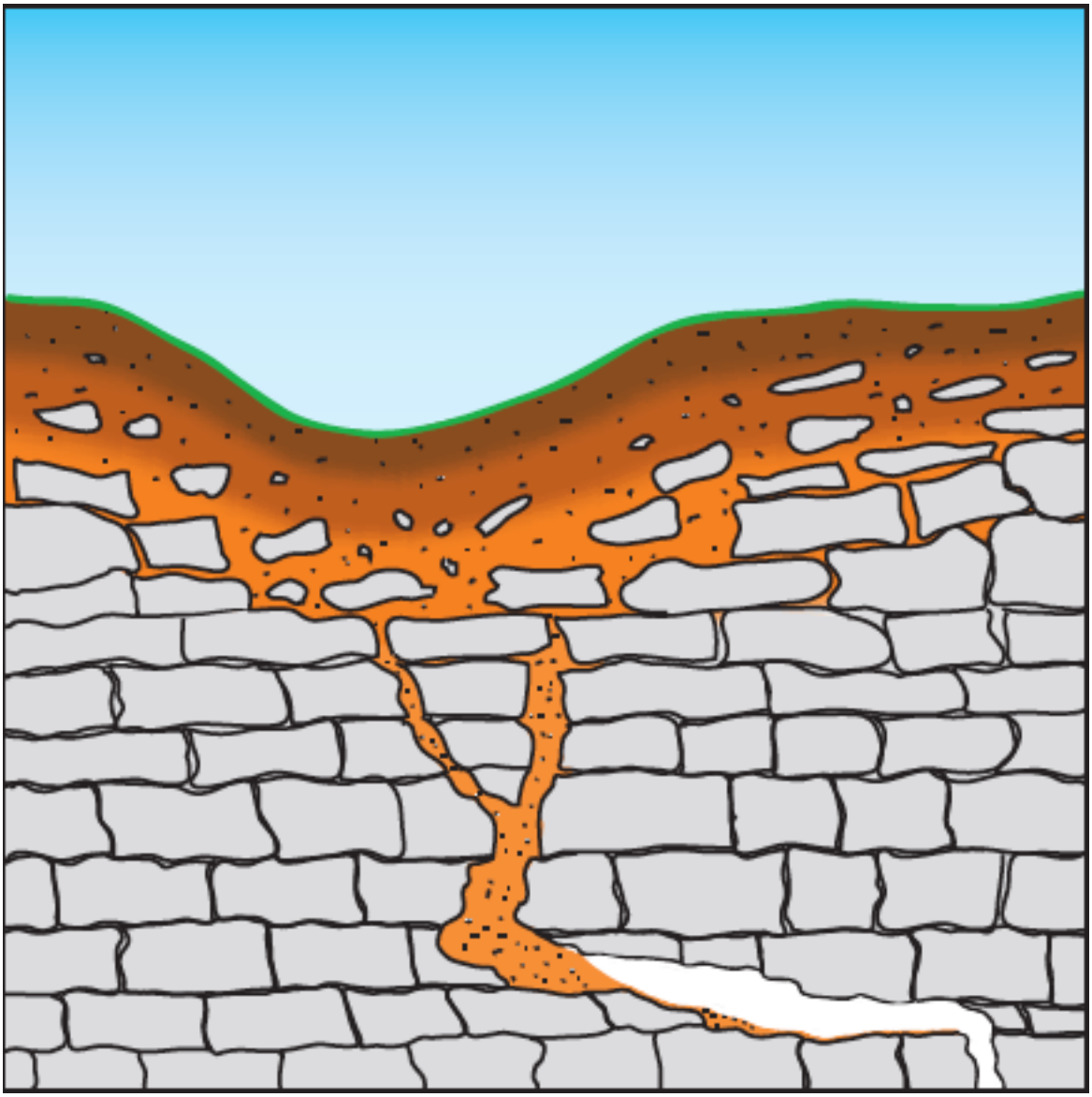

Figure 2.8. Cover-subsidence sinkhole formation from the breaking apart of karst bedrock by soil deposit (courtesy USGS Sinkholes Fact Sheet).

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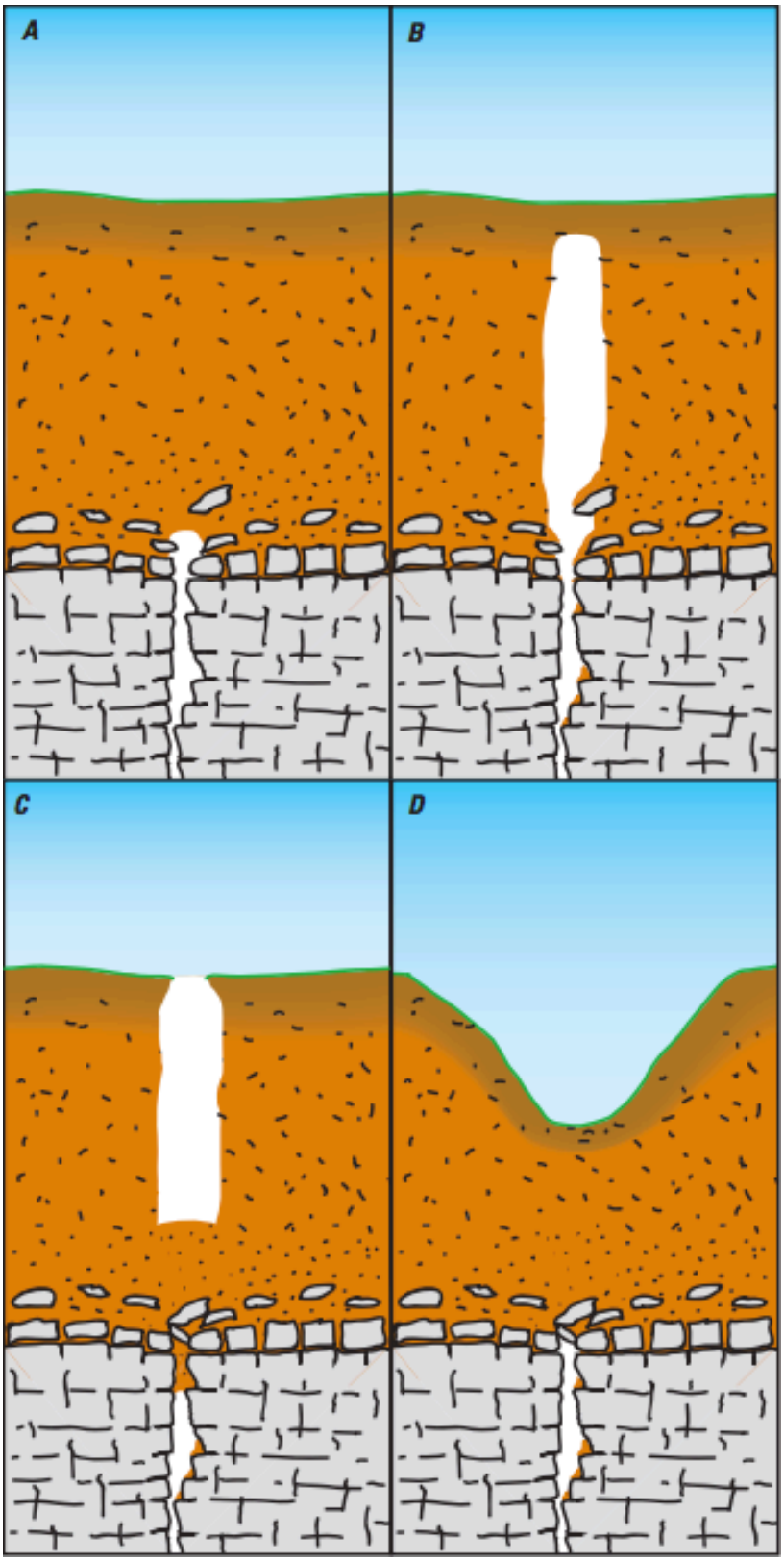

Figure 2.9. Formation of cover-collapse sinkhole after a soil bridge forms above dissolving bedrock (courtesy of USGS Sinkhole Fact Sheet).

Both kinds of sinkholes can occur naturally or through human influence. While sinkholes tend to form naturally in karst areas, sinkholes can form in other geological areas that have been altered by humans such as mining, sewers, hydraulic fracture drilling, groundwater pumping, irrigation, or storage ponds. In all of these cases, and others, the cause for the sinkhole is that support for surface soil has been weakened or substantially removed. In fact, Louisiana is not especially susceptible to karst-induced sinkholes since very little of Louisiana is located on either exposed or even buried karst terrain. Only a relatively small portion of Louisiana, cutting across some of its northern and central parishes (Madison, Franklin, Tensas, Caldwell, La Salle, and Grant Parishes) lie on buried karst ground.[lxxx] Sinkholes from such terrain have been negligible.

Sinkhole Profile

In the United States, 20% of land is susceptible to sinkholes, although their types vary. Most of this area lies in Florida, Texas, Alabama, Missouri, Kentucky, Tennessee, and Pennsylvania. However, two of the most well-known sinkholes in North America are actually located in Louisiana, both of which were precipitated by the human-influenced collapse of salt dome caverns (Map 2.150).

The Lake Peigneur sinkhole (in Iberia Parish—Map 2.124) began to form on November 20, 1980 when an oil rig accidentally drilled into an underlying salt mine, leading to a rush of water from the lake into the mine. The 10-ft. lake quickly emptied through the drilled hole and into the salt mine. Due to a quick response, all of the miners evacuated the mine before it filled. The rush of water drained the lake and pulled water from the adjoining Delcambre Canal, reversing the natural flow of the water to Vermilion Bay and causing (temporarily) the largest waterfall in Louisiana. The whirlpool caused by the mine penetration swallowed eleven barges, several boats, a number of trees, an oil rig, and other debris. Several days later, nine of the barges resurfaced, after pressure equalized.[lxxxi] Luckily, no humans were injured, although many people were in serious danger of perishing. The landscape was permanently altered, changing the previously freshwater lake into a saltwater lake and increasing its depth.

At the time of publication, the Bayou Corne sinkhole is an ongoing disaster in Assumption Parish, about 40 mi. south of Baton Rouge (Map 2.124). Since the sinkhole event continues, certain details of the disaster are relatively few. Texas Brine, a salt-mining company, reported problems with its Oxy Geismar 3 cavern and well in early 2011, and closed it in June of that year. About a year later, on 30 May 2012, bubbles in Bayou Corne were reported, and throughout June and July residents and Texas Brine employees reported tremors. The continuing bubbling eruptions come from escaping methane and oil as the caverns and fissures fill. On August 3, Texas Brine employees reported a sighting of the sinkhole. By late September, drillers determined that the Oxy 3 cavern had collapsed. The sinkhole began as a 200 ft.-by-200 ft. hole, but has grown to include at least 24 acres.[lxxxii]

Some argue that the number of sinkholes reported has increased in recent years, although there is not enough data to know for certain since sinkholes are not systematically tracked. More information is needed to track trends in Louisiana. Florida's Office of Insurance Regulation has reported a dramatic increase in claims due to sinkholes in recent years, and Louisiana should attempt a similar tracking system for sinkhole claims. With increases in hydraulic fracture drilling—particularly near the Haynesville Shale in northwestern Louisiana—sinkhole incidents will almost certainly occur more often, although their location should be easily determined by such drilling.

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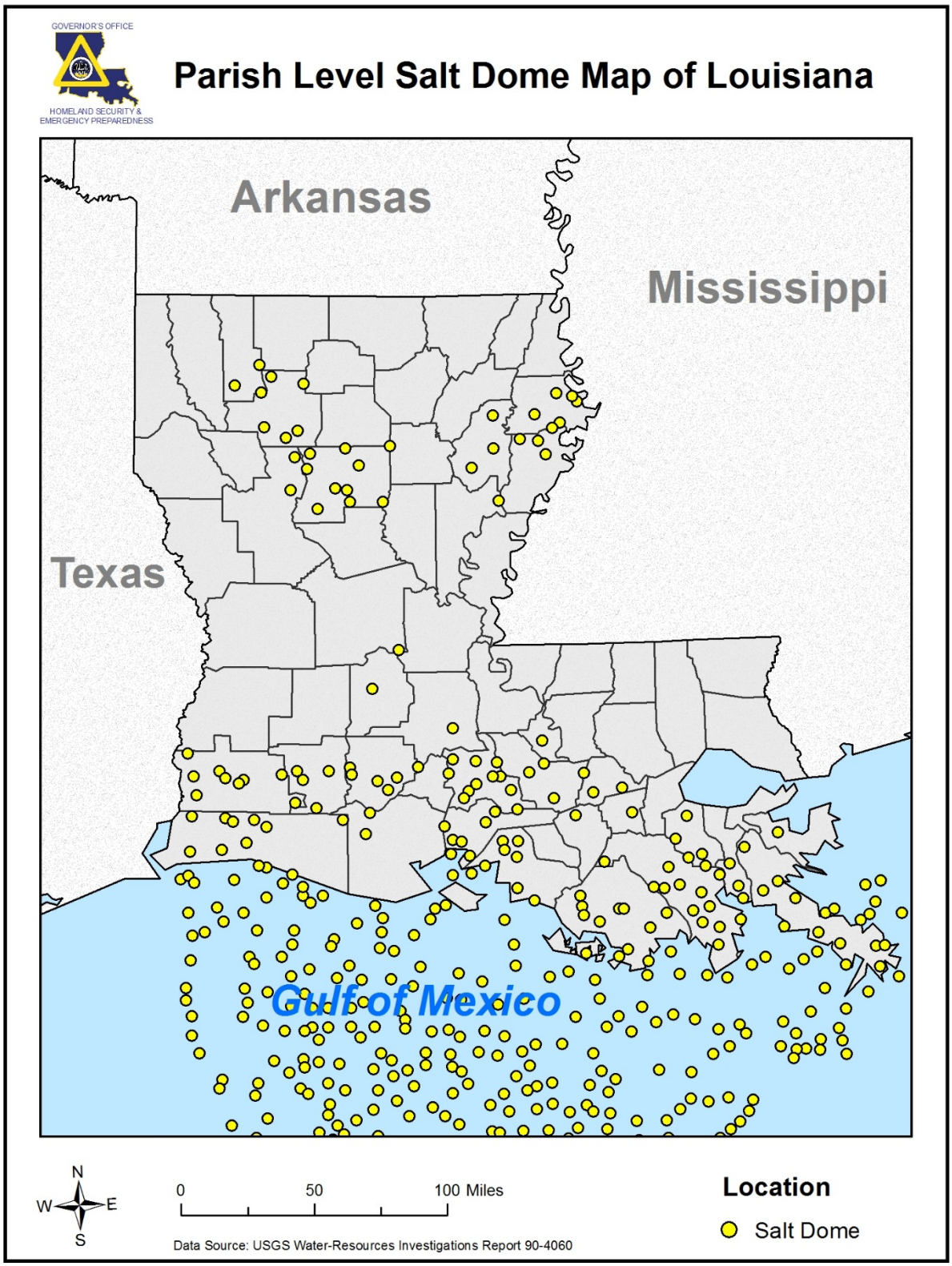
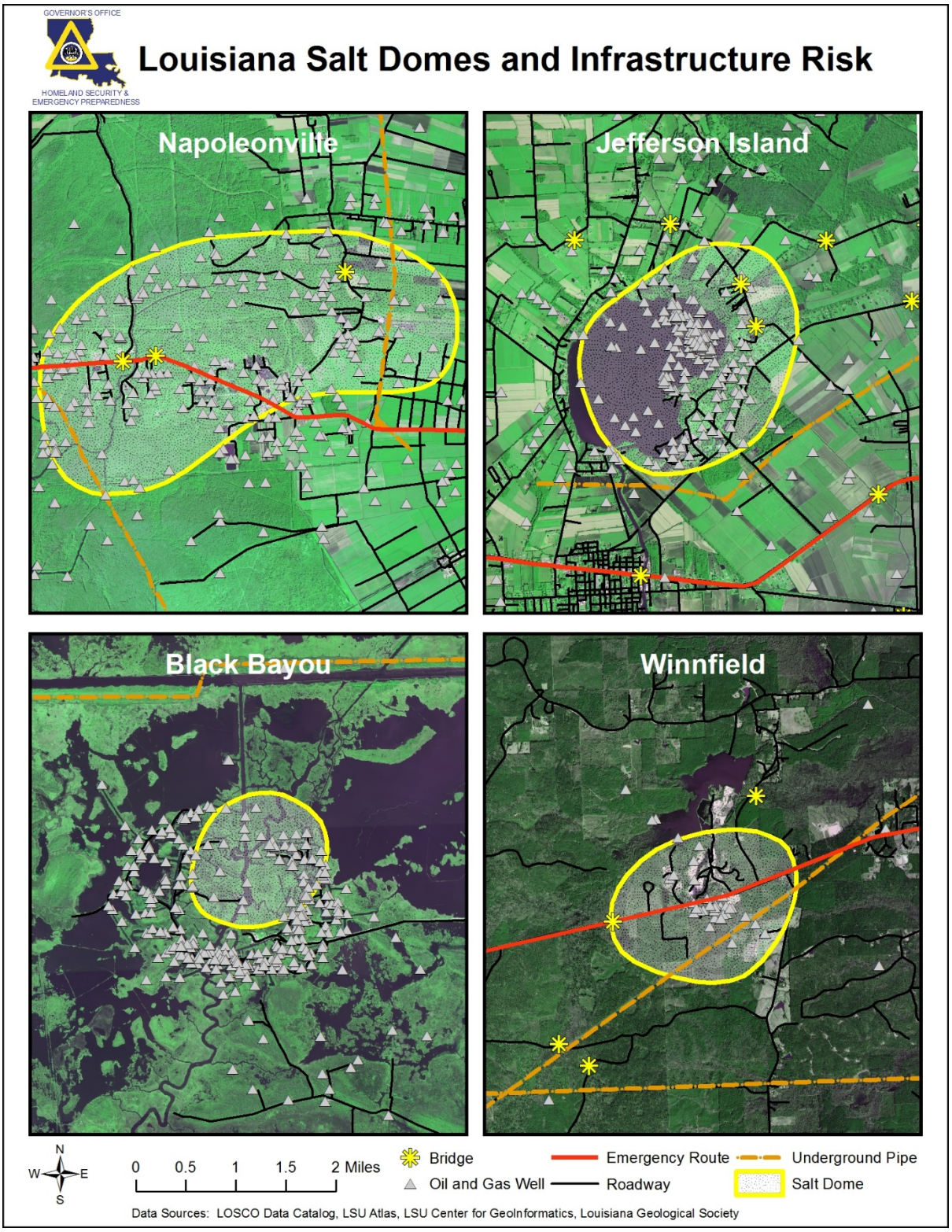


Map 2.150. Locations of salt domes across Louisiana.



Map 2.151. Notable salt domes in Louisiana with nearby infrastructure shown. The Bayou Corne sinkhole is located above a section of the Napoleonville salt dome and the Lake Peigneur sinkhole is located above a section of the Jefferson Island salt dome.

Sinkhole Risk Assessment

Based on historical records, the probability of future occurrences of sinkholes in Louisiana is **Medium**. Sinkholes of any kind, including those created by salt dome collapses, are usually infrequent in Louisiana, but their potential impact can be considerable. Sinkholes are disruptive to transportation and commerce, and can even force the indefinite evacuation of entire communities, as has been the case for Bayou Corne. For this reason, sinkholes are one of the hazards included for Risk Assessment. Since karst terrain is a very rare cause of sinkholes in Louisiana, Map 2.152 indicates the total number of salt domes in each parish. Ascension, Bossier, Lafayette, Lincoln, and West Baton Rouge parishes are at high risk (within 2 miles of a salt dome) to sinkholes, and have experienced significant population increases of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability of these parishes to sinkholes has increased. Cameron, Madison, Plaquemines, St. Bernard, and Tensas parishes are at high risk to sinkholes, but have experienced significant population decreases of more than 10% since 2000 (see Map 2.3). As a result, the vulnerability of these parishes to sinkholes has decreased.

Assessing the state's vulnerability to sinkholes is complicated and requires a tiered approach. Parishes that contain salt domes are obviously vulnerable to future sinkholes, but salt domes bordering parish boundaries can also increase the vulnerability of an adjacent parish. Sinkhole vulnerability is directly related to distance from a salt dome. For this reason, vulnerability can be classified into two categories: (1) High: complete infrastructure loss could occur within 2 miles of a sinkhole; and (2) Medium: possible infrastructure loss and evacuation orders can extend up to 25 miles beyond the sinkhole.[lxxxiii] Map 2.153 locates state facilities in relation to 2- and 25-mile distances away from salt domes. There were 14 state parks (out of 19) within the 25-mile "Medium Vulnerability" buffer, and there were 6,060 state facilities (out of 8,685) within the 25-mile "Medium Vulnerability" buffer. There were no state parks within the two-mile "High Vulnerability" buffer, while there were 147 state facilities within the two-mile "High Vulnerability" buffer. State-owned critical facilities located in High and Medium vulnerability areas are of the following types: hospitals, shelters, Emergency Operation Centers, data processing centers, and state police troop offices.

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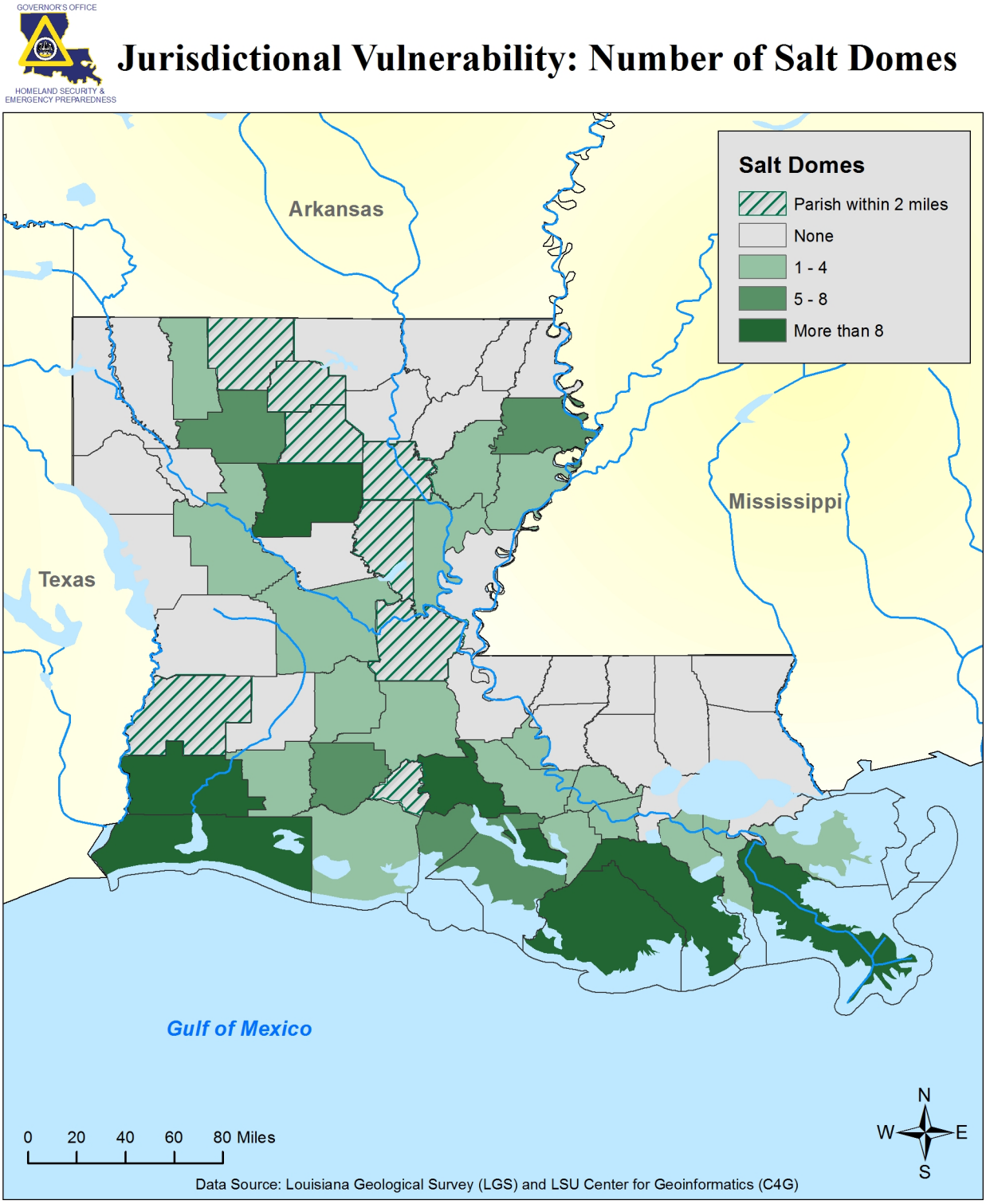
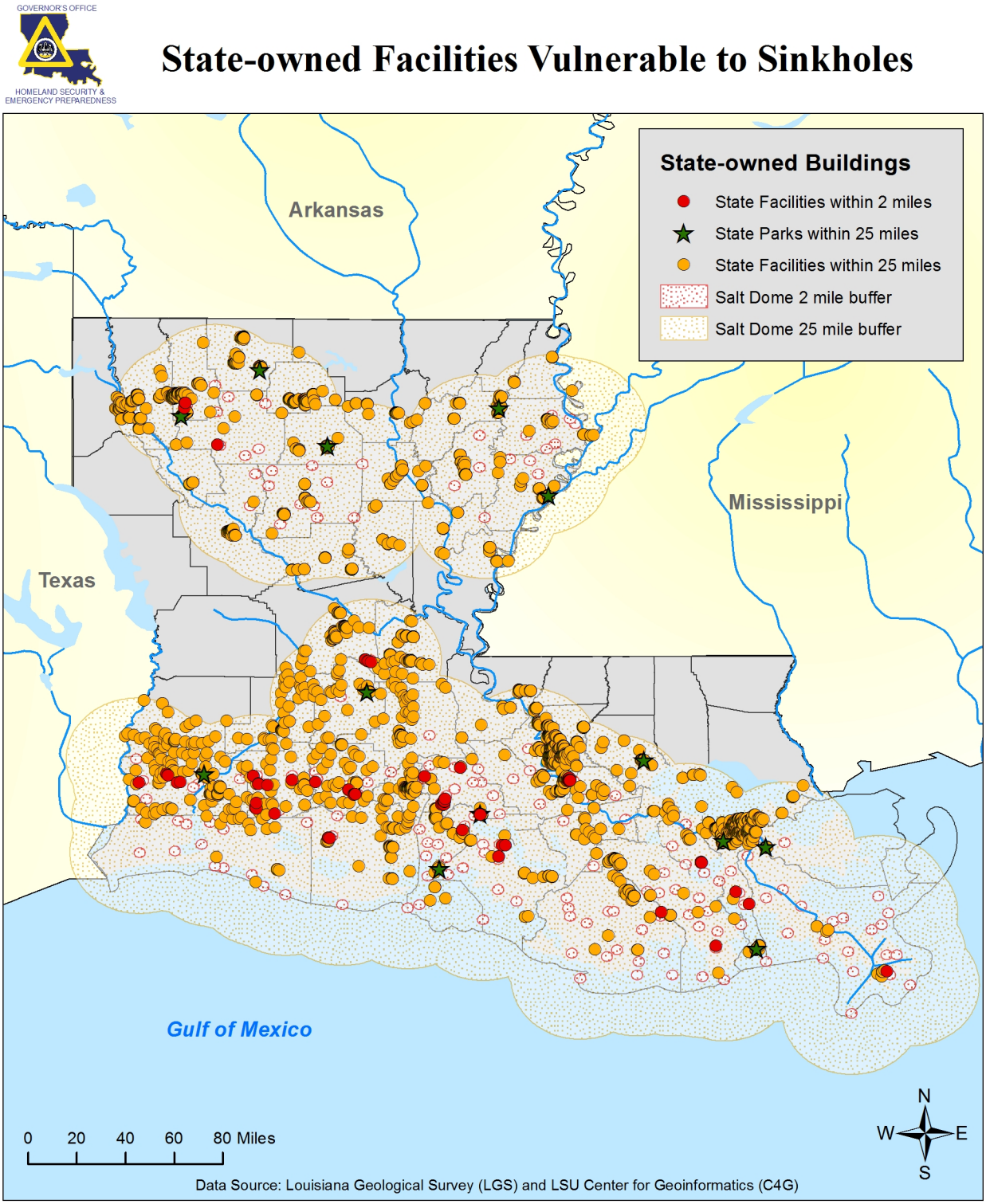


Map 2.152. Louisiana jurisdictional vulnerability for sinkholes based on the location of known salt domes.



Map 2.153. Louisiana state-owned property located within either the two-mile High Vulnerability zone or the twenty-five-mile Medium Vulnerability zone.

Map 2.154 shows which parishes fall within each vulnerability level based on proximity to the 2- and 25-mile buffer zones. The southern coastal Louisiana parishes and the parishes of northeast and north central Louisiana have the greatest risk of future sinkhole hazards (**High**).

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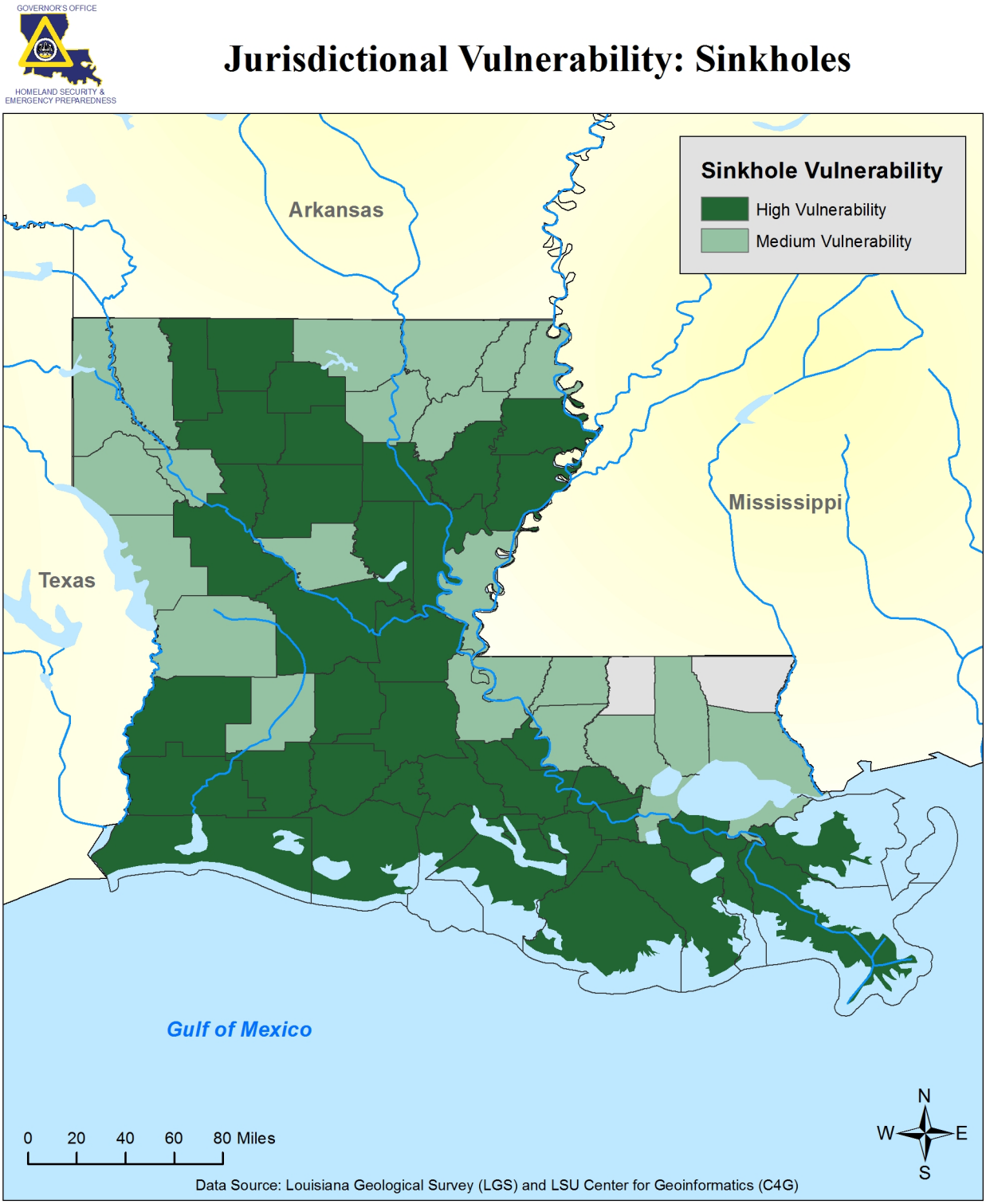

Map 2.154. Vulnerability rating map for sinkholes showing parishes with the highest risk in Louisiana.

POTENTIAL ECONOMIC LOSS

Based on their proximity to salt domes, the following parishes are most likely to be severely affected by sinkholes: Acadia, Ascension, Assumption, Bienville, Calcasieu, Cameron, Catahoula, Evangeline, Franklin, Iberia, Iberville, Jefferson, Jefferson Davis, Lafourche, Lincoln, Madison, Natchitoches, Plaquemines, Rapides, St. Bernard, St. Charles, St. James, St. Landry, St. Martin, St. Mary, Tensas, Terrebonne, Vermilion, Webster, West Baton Rouge, and Winn. While no salt domes exist within parish boundaries, salt domes within adjacent parishes are located within 2 miles of the border of the following parishes and could thus be severely affected by sinkholes: Claiborne, Lincoln, Jackson, Caldwell, La Salle, Avoyelles, Beauregard, and Lafayette. The following parishes are located more than 2 miles from a salt dome, but are within 25 miles and could be moderately affected by sinkholes: Allen, Bossier, Caddo, Concordia, De Soto, East Baton Rouge, East Carroll, East Feliciana, Grant, Livingston, Morehouse, Orleans, Ouachita, Pointe Coupee, Red River, Richland, Sabine, St. John the Baptist, St. Tammany, Tangipahoa, Union, Vernon, West Carroll, and West Feliciana. Of the high vulnerability parishes, Jefferson, Lafayette, and Calcasieu parishes are the three most populated parishes and have the highest infrastructure dollar exposures within Louisiana. These three parishes are considered to have the highest vulnerability to sinkholes within the state.

Table 2.62 shows the overall exposure for High-risk parishes based on the Hazus-MH 2.1 inventory database.

Table 2.62. Exposure data for the 38 highest sinkhole risk parishes in Louisiana.

EXPOSURE DATA FOR PARISHES WITH HIGHEST SINKHOLE RISK		
Parish	Population (2010)	Total Exposure ($1,000)
Acadia	61,773	$10,551,833
Ascension	107,215	$15,289,421
Assumption	23,421	$6,251,796
Avoyelles	42,073	$7,711,021
Beauregard	35,654	$6,495,682
Bienville	14,353	$5,752,097
Calcasieu	192,768	$21,704,525
Caldwell	10,132	$3,123,824
Cameron	6,839	$5,497,935
Catahoula	10,407	$4,153,475
Claiborne	17,195	$4,272,885
Evangeline	33,984	$7,912,259
Franklin	20,767	$3,818,331
Iberia	73,240	$13,706,899
Iberville	33,387	$8,154,084
Jackson	16,274	$6,573,859

Exposure Data for Parishes with Highest Sinkhole Risk		
Parish	Population (2010)	Total Exposure ($1,000)
Jefferson	432,552	$68,890,600
Jefferson Davis	31,594	$8,082,036
Lafayette	221,578	$30,145,227
Lafourche	96,318	$14,695,652
La Salle	14,890	$4,480,265
Lincoln	46,735	$7,424,222
Madison	12,093	$2,712,688
Natchitoches	39,566	$8,404,586
Plaquemines	23,042	$9,583,932
Rapides	131,613	$18,821,281
St. Bernard	35,897	$9,052,282
St. Charles	52,780	$11,391,140
St. James	22,102	$7,071,972
St. Landry	83,384	$14,242,451
St. Martin	52,160	$16,854,779
St. Mary	54,650	$8,329,232
Tensas	5,252	$2,158,271
Terrebonne	111,860	$17,127,125
Vermilion	57,999	$10,828,531
Webster	41,207	$7,109,218
West Baton Rouge	23,788	$10,683,120
Winn	15,313	$4,087,182
TOTALS	**2,305,855**	**$423,145,718**

This Plan Update also utilizes Hazus-MH 2.1 for the analysis of building exposure in each of the most vulnerable (High) parishes by general occupancy type, which is detailed in Table 2.63.

Table 2.63. Building exposure for sinkholes by general occupancy type.

Building Exposure of Most Vulnerable Parishes							
	Exposure Type ($1,000)						
Parish	Residential	Commercial	Industrial	Agricultural	Religion	Government	Education
Acadia	7,979,614	1,419,342	563,874	148,772	237,546	56,573	146,112
Ascension	11,107,747	2,419,973	1,186,650	51,686	309,422	111,001	102,942
Assumption	4,325,874	844,545	762,247	31,480	154,616	46,439	86,595
Avoyelles	6,100,503	818,924	338,086	68,440	219,704	88,786	76,578
Beauregard	5,160,055	734,709	222,434	35,364	212,554	68,910	61,656
Bienville	4,510,931	570,939	282,913	36,384	264,558	37,245	49,127
Calcasieu	15,879,101	3,805,841	1,011,908	58,492	576,612	150,541	222,030
Caldwell	2,453,379	349,881	110,233	27,778	121,548	28,696	32,309
Cameron	4,209,736	691,929	393,622	37,564	90,194	38,602	36,288
Catahoula	3,057,422	629,752	138,779	63,292	153,556	57,673	53,001

Claiborne	3,222,505	469,511	284,397	28,354	170,516	43,930	53,672
Evangeline	5,944,281	1,182,228	269,190	95,536	237,802	85,080	98,142
Franklin	2,797,175	530,282	139,622	72,966	183,488	48,884	45,914
Iberia	9,678,096	2,192,541	1,254,014	65,726	233,766	118,320	164,436
Iberville	5,919,008	1,099,213	718,947	39,230	234,530	75,678	67,478
Jackson	5,186,884	670,191	304,068	29,986	256,162	37,219	89,349
Jefferson	50,104,392	13,418,248	3,024,142	114,922	1,204,366	437,819	586,711
Jefferson Davis	6,364,838	911,215	320,585	64,622	239,620	75,342	105,814
Lafayette	20,352,559	6,720,522	2,019,583	101,370	430,730	219,274	301,189
Lafourche	11,267,397	2,122,336	708,103	55,486	245,694	98,260	198,376
La Salle	3,559,732	449,362	206,503	20,330	148,028	51,762	44,548
Lincoln	5,441,177	1,083,517	388,514	45,284	275,472	45,226	145,032
Madison	1,993,179	379,309	109,226	59,224	118,460	25,696	27,594
Natchitoches	6,407,131	1,087,075	253,406	48,482	392,736	80,155	135,601
Plaquemines	7,797,736	1,087,148	385,252	20,648	170,950	52,157	70,041
Rapides	13,024,701	3,854,973	754,563	110,124	687,004	204,171	185,745
St. Bernard	7,159,720	1,160,684	438,162	13,074	149,344	51,617	79,681
St. Charles	8,318,110	1,948,898	717,882	25,498	204,072	96,946	79,734
St. James	5,072,548	966,014	685,835	33,634	182,106	66,993	64,842
St. Landry	11,074,652	1,981,588	525,532	84,532	312,906	112,478	150,763
St. Martin	11,788,213	2,844,362	1,539,197	69,592	319,552	138,656	155,207
St. Mary	5,740,011	1,301,020	810,172	30,540	250,480	108,412	88,597
Tensas	1,490,623	421,817	63,506	52,738	70,438	30,406	28,743
Terrebonne	11,485,574	3,445,304	1,463,699	62,230	379,368	122,228	168,722
Vermilion	8,196,283	1,596,191	631,852	69,528	161,172	57,631	115,874
Webster	5,530,603	790,119	376,432	29,676	271,698	41,297	69,393
West Baton Rouge	7,025,303	1,813,154	691,744	35,842	270,942	456,833	389,302
Winn	3,236,881	429,077	141,778	17,204	180,002	44,561	37,679
Totals	**309,963,674**	**68,241,734**	**24,236,652**	**2,055,630**	**10,321,714**	**3,711,497**	**4,614,817**

Based on the baseline Hazus-MH 2.1 inventory database, the Louisiana Digital Map GIS database (via LOSCO), and the U.S. Census Bureau, regional vulnerability to sinkholes is listed in Table 2.64.

Table 2.64. Regional vulnerability to sinkholes.

Regional Vulnerability to Sinkholes	
Vulnerable Locations	Number of Records
Louisiana Parishes	38
Dams	483
Airports	96
Communication Towers/Facilities	397
Electricity Providers/Facilities	77
Emergency Response Centers	24
Fire Stations	621

Regional Vulnerability to Sinkholes	
Vulnerable Locations	Number of Records
Hospitals	113
Nuclear Plants	1
Police Stations	714
Elementary/Secondary Schools	1,785
Universities/Colleges	10

Very little information was available to determine potential loss estimates from sinkholes, but based on the current cost of the Bayou Corne sinkhole (~$10 million), and the expectation that this cost will double, we can assume that a major sinkhole disaster can result in $20 million of damage. The Bayou Corne and Lake Peigneur sinkholes are the only sinkholes on record in Louisiana and occurred 32 years apart. If a sinkhole can at least be expected to occur once every 32 years, then the annual cost per sinkhole would average to $625,000. Thus, each salt dome was assigned this annualized amount to determine future loss potential by parish (Map 2.155). As shown, parishes with the most salt domes are predicted to have the highest potential annualized losses.

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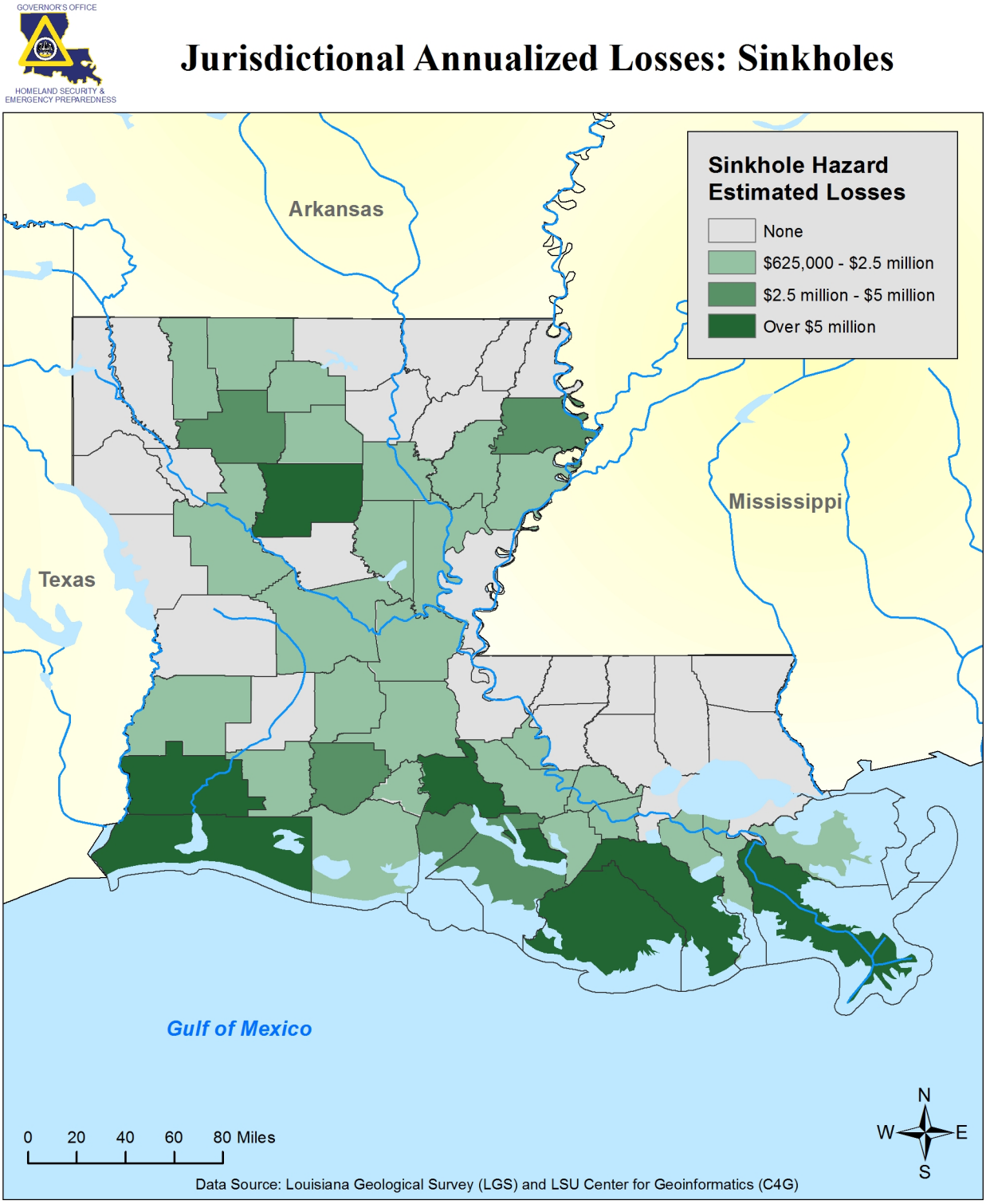

Map 2.155. Jurisdictional annualized loss due to sinkholes.

Almost every parish in Louisiana could be impacted in some way by a sinkhole, with the exception of the parishes of Washington and St. Helena. Sinkholes are extremely unpredictable

and have historically been caused by human error in Louisiana. Roads, bridges, utilities, and communications systems could be greatly impeded or completely brought to a total stop resulting in a high level vulnerability in all High vulnerability parishes. Transportation and emergency response could be inhibited and utilities such as electricity, water, gas, sewer, and communications could be completely shut down. Buildings could collapse and, at a minimum, lose their structural integrity if they are within 2 miles of a sinkhole. A sinkhole can impact all demographics and age groups, as the evacuation of the Bayou Corne community demonstrates. State, local, and federal facilities located near a sinkhole would also be shut down, their operations greatly hindered. Long-term sheltering could be a concern if a sinkhole impacts a high-population area. Other critical facilities, such as police, fire, and medical facilities, could become unusable within a community impacted by a sinkhole.

Potential Losses by Jurisdiction

Overview & Analysis of Potential Losses: Most jurisdictions in Louisiana can suffer direct and/or indirect losses due to sinkholes. The coastal, northeast, and north-central parishes are most vulnerable based on the locations of known salt domes and karst terrain.

Changes in jurisdictional population levels impact each parish across the state disparately. In the parishes where sinkhole vulnerability has increased because of increases in population (Ascension, Bossier, Lafayette, Lincoln, and West Baton Rouge), concomitant changes in development have impacted loss estimates and will cause an increase in future losses due to increased levels of exposure. In the parishes where sinkhole vulnerability has decreased because of decreases in population (Cameron, Madison, Plaquemines, St. Bernard, and Tensas), concomitant changes in development have impacted loss estimates and will cause a decrease in future losses due to decreased levels of exposure.

Potential Losses of State Facilities

The sinkhole hazard vulnerability assessment of state-owned buildings was based on the two-mile "High Vulnerability" zone and the twenty-five-mile "Medium Vulnerability" zone around each salt dome. The criteria used to determine specific vulnerability rankings for each building and the results of applying this ranking to the state-owned buildings are shown in Table 2.65.

Table 2.65. Sinkhole Vulnerability Criteria and Ranking Results.

Sinkhole Vulnerability Criteria and Ranking	
Ranking	Criteria
High	Facility located within 2 miles of salt dome
Medium	Facility located within 25 miles of salt dome
Low	Facility not located within 25 miles of salt dome

The sinkhole loss estimate ranges are based on actual values of state facilities. A 100% loss is assumed for buildings ranked as High Vulnerability and a 1–10% loss is assumed for buildings ranked as Medium Vulnerability. The January 2014 state facilities database was used to obtain accurate building numbers for each loss estimate range. Loss estimates of state-owned buildings in Louisiana involved an analysis of the following parameters:

- Proximity to Salt Domes
- Distance-based Damage and Loss Estimate Ratios

Table 2.66. Sinkhole Loss Estimate Ranges and Ranking Results.

Sinkhole Loss Estimate Ranges and Ranking		
Ranking	Total Loss Estimate Ranges	Number of Buildings
High	$104,703,200	147
Medium	$109,869,334 - $1,098,693,337	6060
Low	$0	2478

SUMMARY OF RISK ASSESSMENTS

On a statewide basis, per the results in this section, risk factors for some hazards are essentially equal throughout the State. For example, the risk due to lightning strikes or severe summer weather (i.e., high heat) is basically the same throughout the state. However, for the more significant hazards, potential effects tend to vary in different parts of the state. For instance, the coastal parishes have a higher percentage of weak tornadoes, while the northern parishes experience a higher percentage of stronger tornadoes (although weaker tornadoes are more prevalent throughout the state than stronger tornadoes).

The following discussion divides the State into four simplified regions for purposes of summarizing key sources of risk from natural hazards (see Map 2.156):

- Coastal parishes
- Inland southern parishes
- Central parishes
- Northwest parishes

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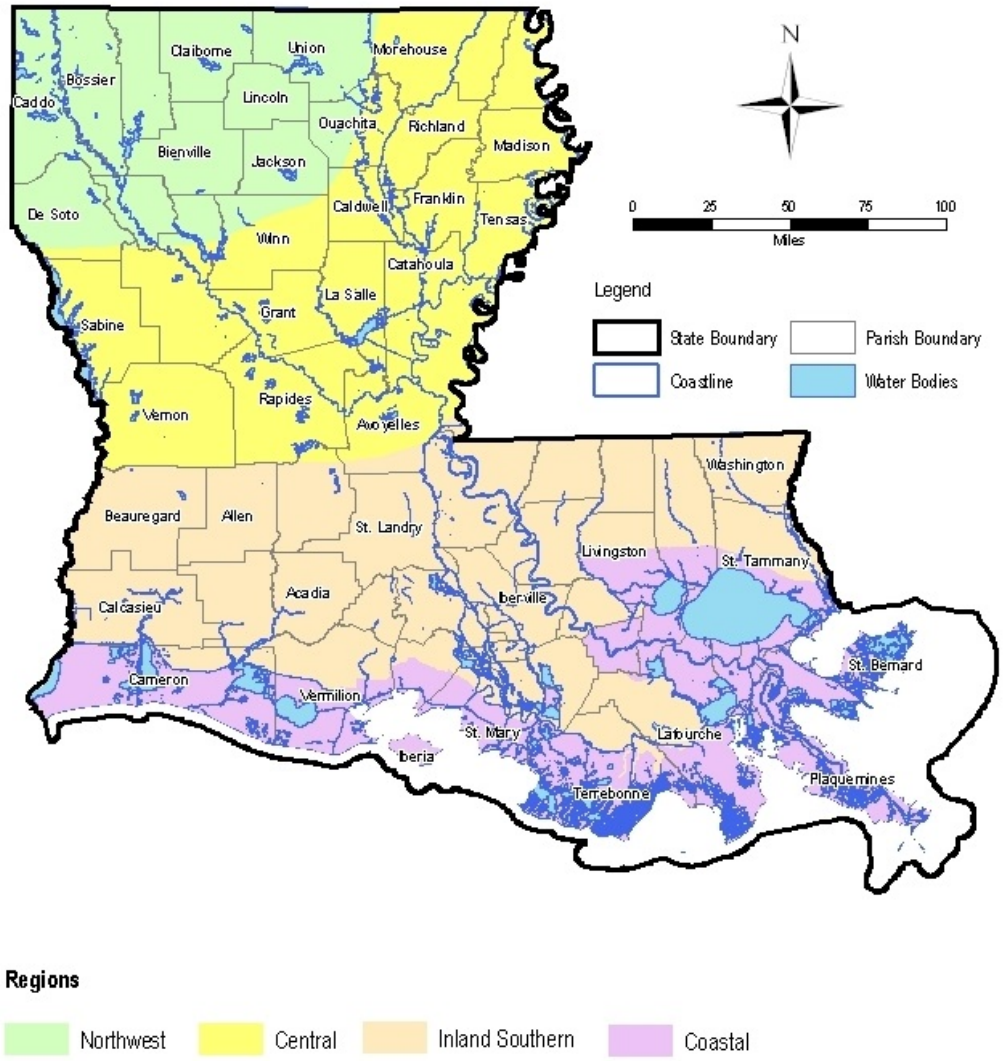

Map 2.156. General regions of Louisiana parishes.

COASTAL PARISHES

- High risk of loss of life, injury, and property damage due to inundation and wave action from storm surge caused by tropical storms and hurricanes. The largest concentrations of repetitive and severe repetitive loss properties in the State occur in the heavily populated areas in this region. Due to a variety of factors, including salt water intrusions, diversion of natural seasonal flooding, coastal erosion, subsidence and sea level rise, the extent and effectiveness of land and wetland buffers are decreasing. As a result, risk due to storm surge in existing urban areas is expected to increase.

- High risk of damage due to inundation directly from riverine and backwater flooding. The failure of levees, floodwalls, and forced drainage systems along the major rivers and

drainage systems all pose a high risk in the southeast coastal parishes. Subsidence in much of this area—again, particularly in the southeast—is a significant contributing factor to an anticipated increase in exposure and risk to existing and future structures.

- High risk of direct wind damage and damage from wind-borne debris in existing pre-Uniform Construction Code (UCC) structures caused by tropical storms, hurricanes and tornadoes spawned by these major storm events.

- Low risk of drought, hailstorms, ice storms, earthquakes, and wildfires.

Inland Southern Parishes

- High risk of damage due to inundation directly from riverine and backwater flooding and failure of levees, floodwalls, and forced drainage systems along the major rivers and drainage systems. Future development is likely to occur in this region associated with existing urban areas and corridors between existing urban centers.

- Moderate-to-high risk of direct wind damage and low-to-moderate risk of damage from wind-borne debris in existing pre-UCC structures caused by tropical storms, hurricanes, and tornadoes. Risk caused by hurricane wind exposure or storm surge increases in direct relation to proximity to the coast.

    - Notable convergence of tornado tracks near Crowley and Rayne.

- Low risk of hailstorms and ice storms.

Central Parishes

- Moderate risk of damage due to inundation directly from riverine and backwater flooding. The failure of levees, floodwalls and forced drainage systems along the major rivers and drainage systems poses a particularly severe risk in parishes that about one of the two major river systems in the state: the Mississippi and the Red Rivers. Urban centers have concentrations of repetitive and severe repetitive loss properties. Rural parishes in this area have relatively low concentrations of repetitive and severe repetitive loss properties.

- Low risk of direct wind damage from tropical storms or hurricanes and in existing pre-UCC structures. Risk of damage from wind borne debris due to tropical storms and hurricanes is not considered as significant in these areas, compared to coastal and inland southern parishes. Moderate risk of tornado damage, with the exception of the far northeastern parishes, where the risk is high.

- Moderate-to-high risk of hailstorms, particularly in the northeastern parishes.

- Low-to-moderate risk of ice storms.

NORTHWEST PARISHES

- Much higher risk of hailstorms and ice storms than the rest of the state; tornadoes tend to have longer tracks and higher EF-scale status. In fact, given the tendency for longer-track tornadoes and the higher likelihood for stronger tornadoes in the northern parishes, the state should consider the recent tornado disasters in Moore, Tuscaloosa, and Joplin as possibilities, albeit extreme ones.

- Low-to-moderate risk of damage due to direct inundation from riverine and backwater flooding and failure of levees; floodwalls and forced drainage systems along the major rivers; and drainage systems. Similar to the central parishes, urban centers have concentrations of repetitive and severe repetitive loss properties. However, rural parishes in this region have the lowest concentrations of repetitive and severe repetitive loss properties in the State. Based on 19 of the high-hazard dam inundation areas, the parishes at highest risk due to dam failure are in the far northwestern corner of the state.

- Low risk of storm surge and direct wind damage from tropical storms. Moderate risk of direct wind damage from tornadoes in existing pre-UCC structures.

Map 2.157 indicates the total economic damage by parish that Louisiana's state assets have claimed since 1987. Map 2.158 locates by parish those state assets that have claimed damage for a hazard, in order of total economic damage since 1987, ranging from under $1 million to over $100 million. As Maps 2.157 and 2.158 demonstrate, state assets suffering the greatest economic losses due to repetitive claims are concentrated in the parishes with the largest cities. Nevertheless, as Map 2.158 shows more clearly, state assets with repetitive claims under $10 million can be found evenly throughout the state, except in the least populated parishes.

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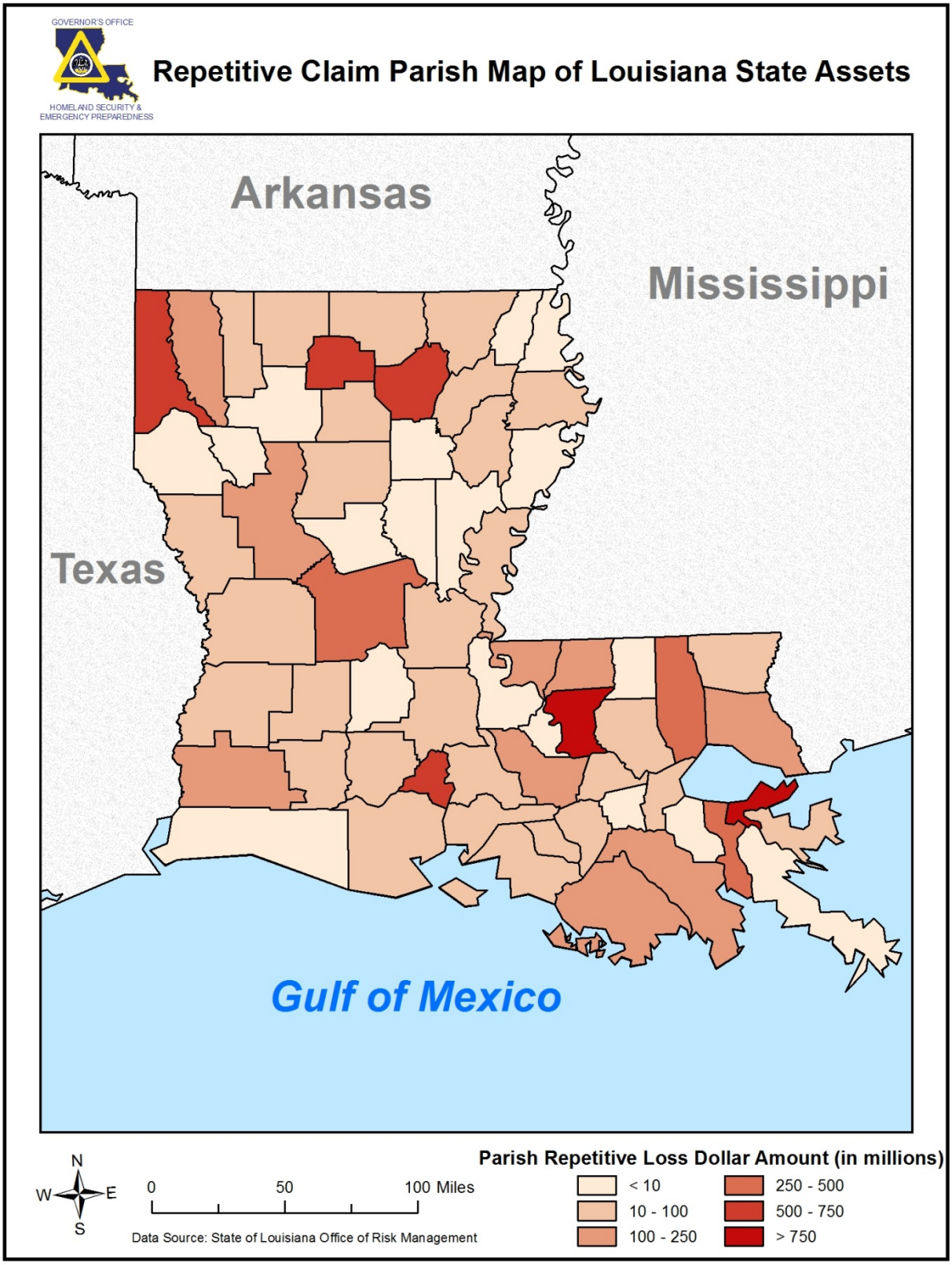
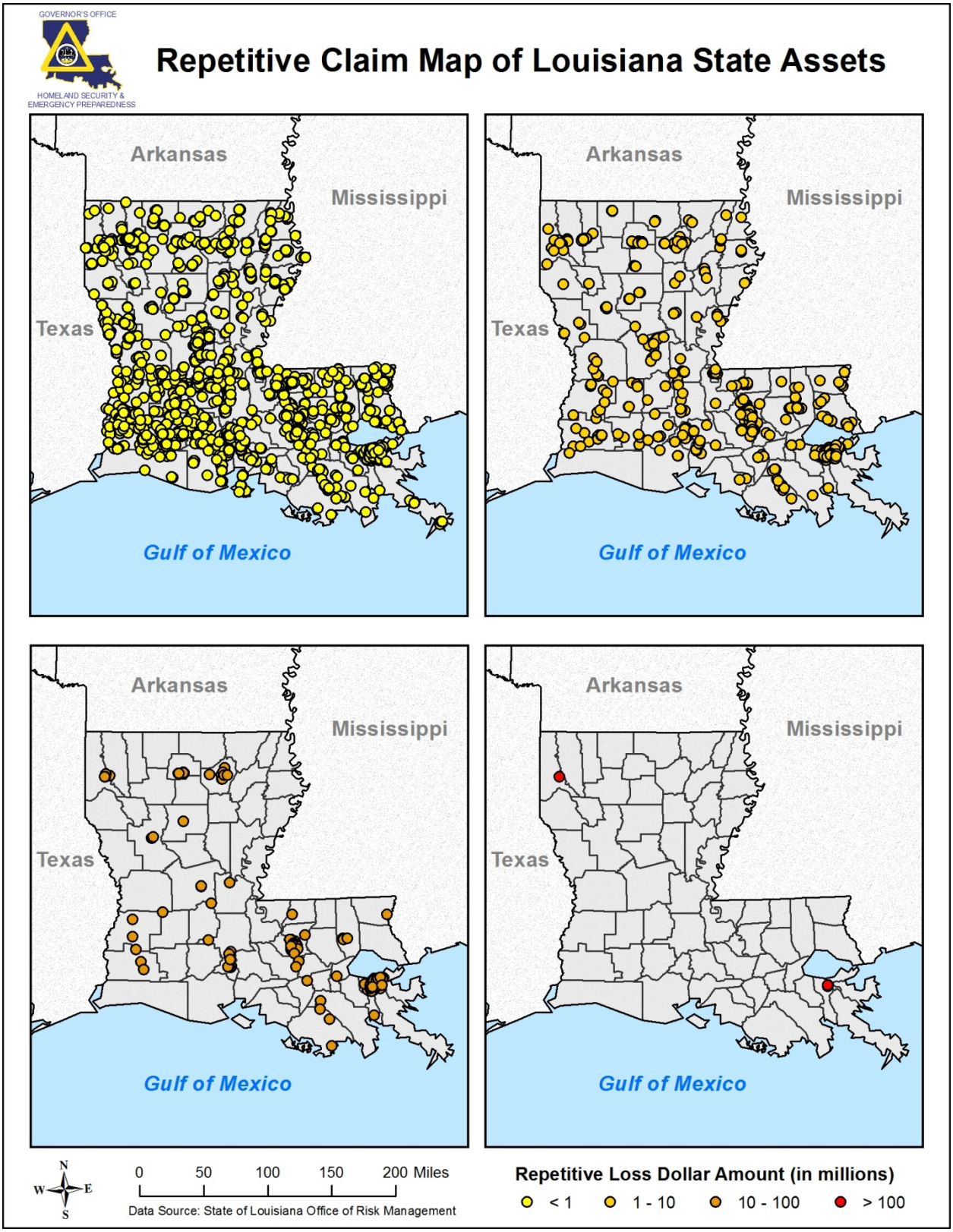


Map 2.157. Location of state assets with repetitive claims by parish.



Map 2.158. State assets with repetitive claims of less than $1 million, between $1 and $10 million, between $10 and $100 million, and over $100 million.