Technical Appendix A

Local Risk Assessments

As part of the hazard identification and risk assessment process, the planning team reviewed parish plans in order to identify profiled hazards that were consistent with the State Hazard Mitigation Plan Committee's (SHMPC's) evaluation of the most serious natural hazard threats to the state. Some hazards identified in parish and municipal plans are not addressed directly in this 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 current parish plans in the state to identify the hazards profiled in each plan in order to determine (1) the frequency with which each was addressed, and (2) whether sufficient consistency between the local plans exists to integrate the data, methods, and results systematically into the plan update.

The following table lists the hazards profiled in the existing 64 parish plans for each of the hazards (or sub-hazards) included in this plan update. The hazard most often addressed by parish plans was tropical cyclones, with 62 of the 64 parishes including cyclones 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. Parish plans included an average of 11 of the 20 hazards (or sub-hazards) included in this plan update. The Iberville Parish plan considers the fewest 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 update.

Overall, the parish plans and the plan update were found to be consistent in identifying natural hazards that impact areas of the state. Although the identified hazards are 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 prevalent hazards are consistent among the parish and state plans.

X - Hazard Profiled

*** - Hazard Profiled but Discounted**

+ - Hazard Profiled but Plan Cited a Data Deficiency

	Subsidence	Land Loss	Coastal Erosion	Saltwater Intrusion	Sea Level Rise	Drought	Earthquake	Flooding	Extreme Heat	Thunderstorms	Tornadoes	Tropical Cyclones	Wildfires	Winter Storms	Dam Failure	Levee Failure	Sinkholes	Storm Surge	Fog	Expansive Soil	Hail Storms	Hazardous Materials
Acadia						X		X		X	X	X		X								
Ascension	X							X		X	X	X		X		X						
Assumption								X		X	X	X		X			X					
Beauregard						X		X	X	X	X	X	X				X					
Bossier						X	*	X		X	X	X		X	+	+						
Caddo						X	*	X	X	X	X	X	X	X	+	+						
Caldwell						X	*	X		X	X	X	X	X	+	+						
Cameron		X				X		X	X	X	X	X	X				X					
Catahoula						X		X		X	X	X		X								
Claiborne						X	*	X	X	X	X	X	X	X	+	+						
Concordia						X	*	X	X	X	X	X	X	X	+	+						
DeSoto						X	*	X	X	X	X	X	X	X	*	*						
East Baton Rouge	*	*				X	*	X		X	X	X	X	X	+	+						
East Carroll						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					
Grant						X		X		X	X	X	X	X		X						
Iberia		X				X		X		X	X	X			X		X					
Iberville	*	*						X		X	X	X				+	X					
Jefferson	X		X			X	X	X			X	X	X	X				X			X	
Jefferson Davis						X		X		X	X	X	X	X		X						
La Salle						X		X		X	X	X	X	X								
Lincoln						X	*	X	X	X	X	X	X	X	+							
Livingston	X	X				X		X		X	X	X									X	
Madison								X		X	X	X		X		+	X					
Morehouse						X		X	X	X	X	X	X	X	+	+						
Natchitoches						X		X		X	X	X	X	X								
Orleans	X		X			X		X	X		X	X		X	X	X		X				
Plaquemines	X			X	X			X			X	X				X	X					
Point Coupee						X		X		X	X	X		X	+	+						
Rapides	*	*				X		X		X	X	X	X	X								
Red River						X	*	X	X	X	X	X	X	X	+	+				*		
Richland						X		X		X	X	X		X	+	+						
Sabine						X		X		X	X	X	X	X	+							
St. Bernard	X			X				X		X	X	X					X					
St. Charles		X	X	X								X		X		X						X
St. Helena								X		X	X	X										
St. James	X					X		X		X	X	X	X	X			X			X		
St. John the Baptist						X		X	*	X	X	X		X						X		
St. Landry	*	*				X		X		X	X	X	X	X								
St. Martin	X					X		X			X	X				X				X	X	
St. Mary			X					X			X	X				X						
St. Tammany		X				X	X	X		X	X	X	X		X	X			X			
Tangipahoa	X	X				X		X		X	X	X	X	X						X		
Tensas						X	*	X	X	X	X	X	X	X		X	X					
Terrebone	X		X	X		X		X		X	X	X			X	X						
Vermilion		X						X			X	X					X					
Vernon						X	*	X	X	X	X	X	X	X	+	+						
Washington								X			X	X	X									
Webster						X	*	X	X	X	X	X	X	X	+	*	X					
West Baton Rouge	*	*				X	*	X	*	X	X	X	X	X			X					
West Carroll						X		X		X	X	X		X								
Winn						X		X		X	X	X	X				X					

The majority of the recent updates to jurisdictional plans follow the general methodology of the 2014 State Hazard Mitigation Plan. This current update enhanced these methodologies significantly. This plan update utilizes data from the Spatial Hazard Events and Losses Database for the United States (SHELDUS). This is considered an improvement over parish plan data, as SHELDUS integrates data from National Centers for Environmental Information with additional data from the NOAA Storm Prediction Center, National Hurricane Center, and U.S. Fire Administration. Additionally, data from multiple state agencies have been integrated into the current plan.

Changes in Development

PARISH-LEVEL POPULATION

Future population estimations were calculated at the block level of each Louisiana parish for 2043. "Annual Estimates of the Resident Population: April 1, 2010 to July 1, 2016" data were obtained from United States Census Bureau American Fact Finder for each parish. The file consists of yearly population estimates (Pyear) for each parish from 2010 to 2016. These population estimates are used to calculate how the population changed from the previous year up until 2016 for each parish. The overall average rate (r) of population change was calculated based of the six annual population changes determined for each parish (Equation 1).

Average population change from 2010 to 2016

$$r = \left(\frac{(P_{11} - P_{10})}{P_{10}} + \frac{(P_{12} - P_{11})}{P_{11}} + \frac{(P_{13} - P_{12})}{P_{12}} + \frac{(P_{14} - P_{13})}{P_{13}} + \frac{(P_{15} - P_{14})}{P_{14}} + \frac{(P_{16} - P_{15})}{P_{15}} \right) / 6 \quad \text{(Equation 1)}$$

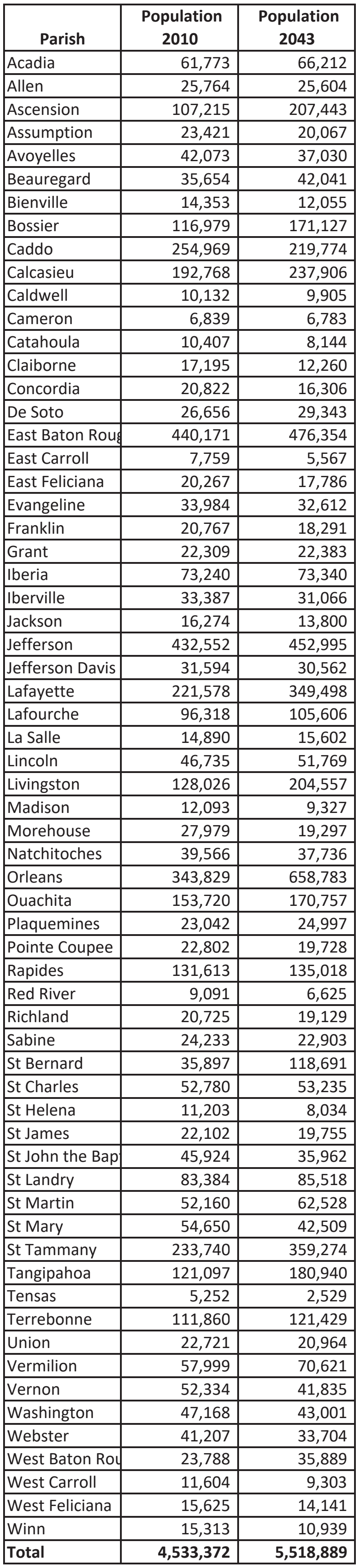
After the average annual population rate (r) was determined, future population estimates (Pf) for each Louisiana parish at the census block level were calculated for 2043 (Equation 2). The 2010 block level U.S. Census population data (P0) was used as the initial base to estimate how the future population Louisiana changed during the 33-year period (t).

$$P_f = P_0 e^{rt} \quad \text{(Equation 2)}$$

The latest three National Land Cover Databases (NLCD) are used to describe how the urban land cover across Louisiana has changed between 2001 and 2011. A description of the datasets used in the analysis is readily available and stated below from NLCD (https://www.mrlc.gov/finddata.php).

National Land Cover Database 2011 (NLCD 2011) is the most recent national land cover product created by the Multi-Resolution Land Characteristics (MRLC) Consortium. NLCD 2011 provides – for the first time – the capability to assess wall-to-wall, spatially explicit, national land cover changes and trends across the United States from 2001 to 2011. As with two previous NLCD land cover products, NLCD 2011 keeps the same 16-class land cover classification scheme that has been applied consistently across the United States at a spatial resolution of 30 meters. NLCD 2011 is based primarily on a decision-tree classification of circa 2011 Landsat satellite data.

The following table presents the parish-level population results.

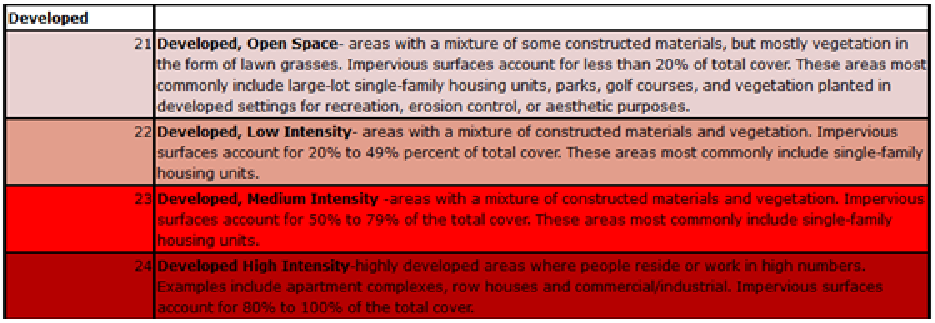


Parish	Population 2010	Population 2043
Acadia	61,773	66,212
Allen	25,764	25,604
Ascension	107,215	207,443
Assumption	23,421	20,067
Avoyelles	42,073	37,030
Beauregard	35,654	42,041
Bienville	14,353	12,055
Bossier	116,979	171,127
Caddo	254,969	219,774
Calcasieu	192,768	237,906
Caldwell	10,132	9,905
Cameron	6,839	6,783
Catahoula	10,407	8,144
Claiborne	17,195	12,260
Concordia	20,822	16,306
De Soto	26,656	29,343
East Baton Roug	440,171	476,354
East Carroll	7,759	5,567
East Feliciana	20,267	17,786
Evangeline	33,984	32,612
Franklin	20,767	18,291
Grant	22,309	22,383
Iberia	73,240	73,340
Iberville	33,387	31,066
Jackson	16,274	13,800
Jefferson	432,552	452,995
Jefferson Davis	31,594	30,562
Lafayette	221,578	349,498
Lafourche	96,318	105,606
La Salle	14,890	15,602
Lincoln	46,735	51,769
Livingston	128,026	204,557
Madison	12,093	9,327
Morehouse	27,979	19,297
Natchitoches	39,566	37,736
Orleans	343,829	658,783
Ouachita	153,720	170,757
Plaquemines	23,042	24,997
Pointe Coupee	22,802	19,728
Rapides	131,613	135,018
Red River	9,091	6,625
Richland	20,725	19,129
Sabine	24,233	22,903
St Bernard	35,897	118,691
St Charles	52,780	53,235
St Helena	11,203	8,034
St James	22,102	19,755
St John the Bap	45,924	35,962
St Landry	83,384	85,518
St Martin	52,160	62,528
St Mary	54,650	42,509
St Tammany	233,740	359,274
Tangipahoa	121,097	180,940
Tensas	5,252	2,529
Terrebonne	111,860	121,429
Union	22,721	20,964
Vermilion	57,999	70,621
Vernon	52,334	41,835
Washington	47,168	43,001
Webster	41,207	33,704
West Baton Rou	23,788	35,889
West Carroll	11,604	9,303
West Feliciana	15,625	14,141
Winn	15,313	10,939
Total	**4,533,372**	**5,518,889**

National Land Cover Database 2006 (NLCD 2006) is a 16-class land cover classification scheme that has been applied consistently across the conterminous United States at a spatial resolution of 30 meters. NLCD 2006 is based primarily on a decision-tree classification of circa 2006 Landsat satellite data. NLCD 2006 also quantifies land cover change between the years 2001 to 2006. The NLCD2006 land cover change product was generated by comparing spectral characteristics of Landsat imagery between 2001 and 2006, on an individual path/row basis, using protocols to identify and label change based on the trajectory from NLCD 2001 products.

National Land Cover Database 2001 (NLCD 2001) is a 16-class (additional four classes in Alaska only) land cover classification scheme that has been applied consistently across all 50 states of the United States and Puerto Rico at a spatial resolution of 30 meters. NLCD 2001 is based primarily on a decision-tree classification of circa 2001 Landsat satellite data. NLCD 2001 improves on NLCD92 in that it is comprised of three different elements: land cover, percent developed impervious surface, and percent tree canopy density.

To understand how the urban landscape has changed across Louisiana, NLCDs from 2001, 2006, and 2011 were obtained. Pixel values that are classified as "Developed" (21, 22, 23, and 24) are used to define an urban location in Louisiana for each NLCD. Once the urban pixels were selected for each database, a cross-comparison was conducted using the raster calculator made available in ArcGIS. This method determines how the urban landscape has changed between the two periods of 2001 to 2006 and 2006 to 2011 for the state of Louisiana and its major cities (Shreveport, Monroe, Alexandria, Lake Charles, Lafayette, Houma, Baton Rouge, and New Orleans).



Developed	
21	**Developed, Open Space**- areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	**Developed, Low Intensity**- areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	**Developed, Medium Intensity** -areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	**Developed High Intensity**-highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.

VULNERABLE POPULATIONS

Age demographics

Age demographic population estimations for young (<20 years old) and aging (>64 years old) populations were calculated at the parish level of each Louisiana parish for the year of 2043. Annual American Community Survey (ACS) 5-year estimates of the Age and Sex File (S0101) from 2010 to 2016 were obtained from United States Census Bureau American Fact Finder for each parish. The file consists of yearly population estimates (Pyear) for each parish from 2010 to 2016. These population estimates were used to calculate how the population changed in recent history until 2016 for each parish.

The overall average rate (r) of vulnerable population change was calculated based of the six annual population changes determined for each parish (Equation 1).

Average population vulnerable population change from 2010 to 2016:

$$r = \left(\frac{(P_{11} - P_{10})}{P_{10}} + \frac{(P_{12} - P_{11})}{P_{11}} + \frac{(P_{13} - P_{12})}{P_{12}} + \frac{(P_{14} - P_{13})}{P_{13}} + \frac{(P_{15} - P_{14})}{P_{14}} + \frac{(P_{16} - P_{15})}{P_{15}} \right) / 6 \quad \text{(Equation 1)}$$

Positive rates of change indicate parishes that have experienced increases in vulnerable populations over the past six years. Negative rates of change indicate parishes that have experienced overall average decreases in vulnerable populations over the past six years.

Using the same growth rate model, the following rates of change of vulnerable populations were evaluated.

Disability demographics

Annual ACS 5-year estimates of Disability Characteristics (S1810) data were obtained from United States Census Bureau American Fact Finder for each parish from 2012 to 2016.

Poverty demographics

Annual ACS 5-year estimates of Poverty Status in the Past 12 Months (B17001) data were obtained from United States Census Bureau American Fact Finder for each parish from 2012 to 2016.

Manufactured home estimates

Annual ACS 5-year estimates of Units in Structure (B25024) data were obtained from United States Census Bureau American Fact Finder for each parish from 2010 to 2016.

The table below provides the parish level average annual growth rates for each of the identified vulnerable populations. These values are summed by parish to provide an overarching indication of the direction of change for each parish across populations, where higher positive numbers indicate increased vulnerability, and higher negative numbers indicate decreased vulnerability. Rates closer to zero indicate less change from the current populations. The change rates are also averaged for the parishes, showing that on average, across the state, change in demographic vulnerability is modest in a positive or negative direction. By contrast, many parishes show more exaggerated increases in vulnerable populations. The parishes with the highest sum of vulnerable population growth rates, indicating a greater likelihood of future increase in demographic vulnerability, are Beauregard, Vernon, Tangipahoa, Ascension, Plaquemines, and Terrebonne Parishes. It is noted that no parishes have a negative growth rate for aging populations, defined as older than 64 years old.

Table X: Average annual vulnerable population growth rates; positive values indicate increases in vulnerability while negative values indicate decreases in vulnerability

Parish	Younger than 20	Older than 64	Population with disabilities	Population living in poverty	Population living in manufactured housing	Sum of vulnerable population growth rates
Calcasieu	0%	2%	1%	1%	0%	5%
Union	-1%	2%	-3%	-2%	4%	0%
Tangipahoa	0%	4%	5%	2%	2%	14%
Caldwell	-2%	2%	-5%	0%	1%	-3%
Tensas	-2%	2%	-3%	-1%	11%	8%
Jackson	-1%	2%	0%	8%	-2%	6%
Grant	-2%	3%	-3%	-2%	5%	2%
Lincoln	-1%	2%	0%	4%	2%	8%
Jefferson Davis	-1%	1%	-2%	2%	1%	1%
Lafayette	0%	3%	1%	2%	1%	7%
Vermilion	0%	1%	3%	2%	1%	8%
East Carroll	-3%	0%	-3%	-5%	4%	-6%
East Feliciana	-2%	4%	-5%	-4%	0%	-7%
St. Bernard	9%	7%	2%	1%	-11%	8%
Iberville	-2%	3%	4%	-1%	2%	6%
Richland	0%	1%	1%	5%	3%	11%
St. Martin	-1%	3%	2%	2%	2%	8%
Claiborne	-1%	1%	1%	0%	1%	3%
Evangeline	-1%	1%	5%	-5%	1%	2%
St. Landry	-1%	1%	-2%	4%	1%	3%
Pointe Coupee	-1%	3%	2%	1%	1%	5%
LaSalle	-1%	2%	0%	2%	5%	9%
Webster	-1%	1%	-1%	-1%	1%	-1%
St. James	-2%	3%	2%	1%	0%	4%
Plaquemines	0%	2%	-5%	9%	6%	13%
Morehouse	-2%	1%	-3%	2%	0%	-2%
Rapides	0%	2%	-2%	3%	2%	5%
Avoyelles	-1%	1%	-6%	2%	1%	-3%
Winn	-2%	1%	-5%	0%	0%	-5%
Vernon	0%	2%	1%	11%	1%	15%
Catahoula	-1%	2%	-10%	4%	4%	-2%
Assumption	-2%	3%	0%	6%	0%	7%
DeSoto	-1%	3%	0%	2%	1%	6%
Caddo	-1%	2%	1%	0%	-1%	1%
Red River	-2%	1%	-3%	1%	7%	4%
Washington	-1%	2%	0%	6%	3%	10%
Sabine	-1%	2%	-6%	2%	1%	-2%
Jefferson	-1%	2%	0%	8%	-3%	7%
St. Tammany	0%	5%	3%	-1%	-1%	7%
Cameron	-2%	2%	-1%	2%	0%	1%
East Baton Rouge	-1%	3%	3%	1%	0%	6%
Iberia	-1%	2%	2%	3%	2%	8%
Natchitoches	-1%	3%	0%	-1%	1%	1%
Terrebonne	0%	3%	-3%	14%	-1%	12%
Bienville	-2%	0%	-4%	0%	4%	-2%
Bossier	1%	3%	2%	2%	2%	10%
Allen	-2%	1%	6%	3%	2%	10%
Ouachita	0%	2%	1%	2%	-1%	4%
St. John the Baptist	-3%	3%	-1%	0%	1%	0%
St. Helena	-3%	3%	1%	1%	1%	2%
West Feliciana	3%	6%	-5%	0%	2%	5%
St. Mary	-2%	2%	-4%	4%	0%	0%
Lafourche	-1%	2%	2%	1%	1%	6%
West Carroll	-1%	1%	-5%	0%	1%	-4%
Concordia	-2%	1%	-14%	3%	1%	-10%
Livingston	1%	5%	3%	2%	0%	11%
West Baton Rouge	1%	3%	3%	1%	0%	8%
Madison	-2%	1%	-6%	0%	-1%	-8%
Orleans	3%	6%	3%	0%	-17%	-5%
Ascension	2%	6%	2%	2%	2%	13%
Acadia	-1%	2%	0%	6%	1%	8%
St. Charles	-1%	2%	-5%	2%	0%	-2%
Beauregard	0%	3%	6%	7%	0%	15%
Franklin	-1%	1%	-3%	0%	4%	1%
Parish Average	-1%	2%	-1%	2%	1%	4%

Risk Assessment Approaches

The risk assessment calculates average annual losses in 2043 using an approach that considers the annual probability of occurrence and loss given that occurrence.

SHELDUS LOSS APPROACH

For extreme heat, drought, extreme cold, hail, lightning, and tornado hazards, the planning team used the SHELDUS per capita property loss data to calculate losses at the census block level. This value is adjusted to 2016 dollars, but it is not population-adjusted. The team then normalized the SHELDUS average per capita property loss by the hazard intensity and population, to represent hazard loss properly as a function of hazard and population.

$$L_{2043,i} = \frac{C_{2016} \sum_{i=1}^{N} P_{2010,i}}{\sum_{i=1}^{N} (H_i \times P_{2010,i})} \times H_i \times F_i \times P_{2043,i}$$

where,

$L_{2043,i}$ =projected annual property loss of census block i in 2043
C_{2016} =total SHELDUS average per capita property loss (2016 dollars)
$P_{2010,i}$ = population of census block i in 2010
H_i =average hazard intensity of census block i
F_i =future hazard multification factor for census block i in 2043
$P_{2043,i}$ =projected population in census block i in 2043

Crop Loss

The planning team used the SHELDUS average annual crop loss data, which is already adjusted to 2016 dollars, to calculate the losses by census block. The team did not consider population growth in the annual crop loss of each census block.

$$CL_{2043,i} = \frac{A_{2016}}{\sum_{i=1}^{N} Hi} \times H_i \times F_i$$

where,

$CL_{2043,i}$ = projected annual crop loss of census block i in 2043
A_{2016} = total SHELDUS average annual crop loss (2016 dollars)
H_i = average hazard intensity of census block i
F_i = future hazard multification factor for census block i in 2043

Ten critical facilities were identified within the high vulnerability classification (total average annual probability of damage >1.0%) are listed below.

Name	Address	City
Bossier City Fire Department	620 Benton Rd.	Bossier City
Mermentau Police Department	104 7th St.	Mermentau
Cameron Volunteer Fire Department	449 Marshall St.	Cameron
Grand Isle Police Department	170 Ludwig Ln.	Grand Isle
Grand Caillou Fire Department	6129 Grand Caillou Rd.	Dulac
Veterans Affairs Medical Center	1601 Perdido St.	New Orleans
District 13 Volunteer Fire Department	18838 W Hwy 82	Abbeville
Branch Volunteer Fire Department	173 Dr. Parrot Ave.	Branch
Plaquemines Parish Sheriff's	**123 Civic Dr.**	**Port Sulphur**
Slidell City Marshall	**501 Bouscaren St.**	**Slidell**

Parish	State Bulding Count	State Property Value	Total Building Value
Acadia	105	$93,539,938	$5,261,039,000
Allen	77	$49,922,070	$2,024,039,000
Ascension	23	$30,576,826	$10,207,618,000
Assumption	13	$19,953,012	$2,015,149,000
Avoyelles	140	$65,730,542	$3,372,286,000
Beauregard	123	$48,331,176	$2,901,477,000
Bienville	13	$1,331,134	$1,346,140,000
Bossier	186	$142,311,319	$11,612,653,000
Caddo	153	$382,440,080	$26,657,728,000
Calcasieu	207	$334,881,436	$18,611,725,000
Caldwell	43	$9,703,200	$929,825,000
Cameron	31	$10,539,160	$895,188,000
Catahoula	13	$1,581,482	$977,958,000
Claiborne	166	$54,445,393	$1,440,129,000
Concordia	31	$12,877,838	$1,783,169,000
De Soto	22	$6,846,428	$2,141,629,000
East Baton Rouge	713	$2,057,111,716	$49,284,426,000
East Carroll	26	$5,920,179	$579,023,000
East Feliciana	272	$209,468,911	$1,619,061,000
Evangeline	77	$17,374,408	$2,964,639,000
Franklin	61	$19,183,809	$1,793,669,000
Grant	59	$11,895,802	$1,693,683,000
Iberia	127	$68,471,341	$6,785,524,000
Iberville	305	$286,971,615	$2,967,884,000
Jackson	61	$13,529,932	$1,510,301,000
Jefferson	163	$244,190,198	$50,605,370,000
Jefferson Davis	33	$39,903,073	$2,938,401,000
Lafayette	252	$831,889,008	$23,926,875,000
Lafourche	149	$279,206,366	$8,747,345,000
LaSalle	34	$7,625,887	$1,320,148,000
Lincoln	357	$862,718,123	$3,982,863,000
Livingston	69	$22,448,862	$10,662,695,000
Madison	63	$25,903,321	$970,404,000
Morehouse	50	$12,106,524	$2,365,339,000
Natchitoches	136	$271,931,250	$3,467,710,000
Orleans	650	$3,981,504,056	$45,552,878,000
Ouachita	249	$554,634,691	$15,086,274,000
Plaquemines	26	$14,049,541	$2,370,738,000
Pointe Coupee	22	$5,528,886	$2,223,805,000
Rapides	822	$481,115,026	$13,188,443,000
Red River	9	$1,997,569	$777,721,000
Richland	66	$13,966,780	$1,757,520,000
Sabine	244	$45,155,183	$2,268,227,000
St. Bernard	44	$46,143,606	$3,740,400,000
St. Charles	16	$5,476,224	$5,579,051,000
St. Helena	13	$10,722,040	$833,445,000
St. James	3	$383,691	$2,072,726,000
St. John the Baptist	31	$56,522,577	$4,280,777,000
St. Landry	45	$38,264,319	$6,730,749,000
St. Martin	74	$23,992,392	$4,340,891,000
St. Mary	35	$21,184,799	$5,159,935,000
St. Tammany	134	$65,397,293	$25,683,122,000
Tangipahoa	279	$521,892,351	$9,555,337,000
Tensas	50	$6,497,772	$620,904,000
Terrebonne	40	$80,582,574	$11,560,024,000
Union	50	$8,632,322	$2,038,897,000
Vermilion	74	$20,589,386	$5,226,262,000
Vernon	69	$20,801,496	$4,111,654,000
Washington	182	$80,834,855	$3,581,078,000
Webster	333	$138,916,940	$3,887,221,000
West Baton Rouge	20	$5,833,301	$2,174,975,000
West Carroll	23	$4,981,614	$966,669,000
West Feliciana	559	$226,529,275	$1,171,689,000
Winn	78	$61,977,614	$1,311,667,000
Total	**8593**	**$13,096,969,532**	**$458,216,191,000**

ALTERNATIVE LOSS APPROACHES

For wildfire, sinkholes, and expansive soil, we developed customized loss estimation approaches based on consultation with state agencies and members of the SHMPC. For wind, flood, and dam failure, loss estimation used the data from FEMA's Hazus model. The methods for alternative loss approaches are described in the following sections.

CRITICAL FACILITY AND STATE ASSET LOSS APPROACH

All critical facilities and state buildings are vulnerable to hazards. At the state level, historic hazard losses for state buildings and detailed building stock information are lacking. These data limitations preclude utilization of either of the previously defined loss approaches. Therefore, because of this data deficiency and in consultation with the Louisiana Department of Insurance, the planning team derived a methodology to estimate average annual state asset losses. The methodology assumes that average annual losses for state buildings would echo historic/modeled losses for other occupancies, considering that the state building inventory is representative of the total building inventory in Louisiana.

Utilizing building-level data from the Louisiana Office of Risk Management, 8,593 state buildings were included in the loss assessment, considering a total building and contents replacement value of approximately $13 billion. The following table details the buildings considered in each parish, along with the replacement value of state buildings and the total building value within each parish. State asset losses were calculated using the ratio of state property value to total building value, and multiplied by the loss assessment results for each individual hazard. State asset losses are included in the total loss results and also reported separately.

PROPERTY LOSS RESULTS

The following parish-level property losses were determined for each hazard. All losses represent average annual losses, with the exception of flood hazards, which are reported for the 1% annual probability event. Although the annual losses are not truly additive with the 1% annual flood losses, the parish total reflects the summation of these values in an attempt to portray the relative risk for Louisiana parishes.

Parish	Wildfire Property Loss	Extreme Cold Property Loss	Wind Property Loss	Hail Property Loss	Lightning Property Loss	Tornado Property Loss	Flood Property Loss (1% annual chance event)	Dam Failure Property Loss	Sinkhole Property Loss	Expansive Soil Property Loss	Parish Average Annual Loss + 1% Annual Chance Flood Loss
Acadia	$4,657	$334,576	$6,960,833	$20,578	$26,912	$646,905	$3,974,012	$0	$48,849	$480,233	**$12,497,555**
Allen	$53,354	$201,258	$1,008,504	$9,841	$10,866	$71,725	$805,454	$194	$0	$95,869	**$2,257,065**
Ascension	$113,843	$1,233,057	$16,007,213	$60,235	$126,122	$938,322	$15,696,666	$0	$3,094	$3,688,243	**$37,866,794**
Assumption	$106	$80,929	$3,491,462	$4,634	$10,915	$78,166	$1,353,836	$0	$674	$495,381	**$5,516,104**
Avoyelles	$9,425	$255,341	$1,914,376	$16,015	$14,661	$140,980	$2,555,262	$6	$0	$85,400	**$4,991,465**
Beauregard	$119,904	$448,784	$1,507,995	$17,206	$18,184	$165,707	$594,851	$233	$241	$98,103	**$2,971,209**
Bienville	$9,083	$205,894	$249,843	$7,935	$4,339	$49,134	$106,379	$272	$2,607	$31,552	**$667,037**
Bossier	$175,905	$2,338,331	$4,788,258	$120,653	$56,470	$1,089,388	$11,311,567	$987,684	$0	$452,910	**$21,321,166**
Caddo	$259,465	$2,804,165	$5,744,359	$153,657	$74,166	$1,611,784	$7,341,406	$5,840	$0	$564,134	**$18,558,975**
Calcasieu	$253,951	$1,311,489	$23,665,716	$76,615	$126,633	$1,463,527	$13,049,845	$0	$81,201	$2,854,138	**$42,883,114**
Caldwell	$6,597	$141,820	$217,155	$5,772	$3,576	$23,521	$646,973	$1	$24	$118,280	**$1,163,718**
Cameron	$7,523	$22,497	$3,674,504	$1,841	$2,703	$33,190	$5,583,446	$0	$9,878	$196,269	**$9,531,850**
Catahoula	$2,511	$95,963	$265,060	$4,279	$3,211	$28,116	$1,099,314	$0	$200	$77,906	**$1,576,560**
Claiborne	$9,752	$243,447	$184,770	$8,661	$4,174	$41,658	$108,970	$40	$50	$26,228	**$627,749**
Concordia	$2,383	$191,049	$559,783	$8,288	$6,625	$67,374	$461,558	$0	$0	$123,529	**$1,420,589**
De Soto	$18,502	$427,465	$652,733	$18,987	$10,282	$145,053	$433,113	$280	$0	$61,999	**$1,768,413**
East Baton Roug	$302,810	$2,763,938	$24,483,495	$156,232	$316,994	$2,651,974	$27,491,184	$718	$0	$5,535,043	**$63,702,387**
East Carroll	$419	$66,679	$210,837	$3,507	$1,785	$24,750	$10,953	$0	$0	$32,736	**$351,667**
East Feliciana	$21,167	$166,644	$827,313	$6,985	$9,926	$55,578	$253,881	$0	$0	$36,105	**$1,377,599**
Evangeline	$25,901	$234,191	$2,035,458	$12,307	$12,865	$176,177	$1,457,856	$72	$2,439	$89,110	**$4,046,376**
Franklin	$2,323	$220,012	$788,450	$10,519	$6,532	$54,765	$552,308	$3	$1,586	$119,644	**$1,756,141**
Grant	$24,214	$228,603	$334,778	$11,622	$8,879	$64,061	$624,236	$1,587	$0	$161,658	**$1,459,638**
Iberia	$205	$291,830	$15,199,157	$18,371	$36,832	$425,347	$6,601,218	$0	$4,414	$924,033	**$23,501,406**
Iberville	$979	$180,850	$2,175,828	$9,062	$16,238	$126,713	$1,272,617	$0	$3,857	$513,408	**$4,299,552**
Jackson	$11,749	$228,845	$232,447	$8,681	$5,219	$59,282	$131,409	$294	$124	$119,560	**$797,610**
Jefferson	$101,698	$777,224	$93,277,706	$109,013	$282,945	$3,231,699	$43,788,687	$0	$8,778	$15,426,414	**$157,004,164**
Jefferson Davis	$8,805	$150,053	$4,118,518	$9,627	$12,371	$210,456	$1,464,005	$0	$5,036	$406,659	**$6,385,529**
Lafayette	$10,166	$1,774,949	$41,758,869	$101,558	$151,130	$3,303,632	$8,325,476	$0	$31	$4,432,987	**$59,858,797**
Lafourche	$467	$339,638	$32,330,442	$20,631	$54,645	$401,711	$17,528,704	$0	$3,129	$2,888,633	**$53,568,000**
La Salle	$14,943	$230,935	$268,505	$8,463	$6,143	$36,870	$278,653	$0	$6,139	$116,807	**$967,458**
Lincoln	$52,472	$803,113	$850,601	$34,136	$19,620	$242,644	$495,265	$781	$180	$290,524	**$2,789,337**
Livingston	$385,807	$1,689,598	$9,876,048	$68,344	$125,112	$1,087,519	$23,789,561	$0	$0	$1,561,912	**$38,583,900**
Madison	$494	$110,838	$228,753	$5,550	$3,204	$51,375	$337,035	$48	$1,963	$44,621	**$783,882**
Morehouse	$8,422	$347,278	$518,268	$12,268	$5,852	$78,175	$235,775	$0	$0	$48,461	**$1,254,500**
Natchitoches	$37,391	$396,163	$969,937	$21,592	$13,812	$119,187	$1,351,070	$2,851	$358	$309,612	**$3,221,973**
Orleans	$418,055	$815,479	$148,495,772	$160,785	$428,651	$4,427,779	$37,799,756	$0	$0	$24,020,446	**$216,566,722**
Ouachita	$105,478	$2,878,933	$4,212,412	$107,032	$59,856	$714,023	$5,144,834	$1,292	$0	$1,434,469	**$14,658,330**
Plaquemines	$3,023	$46,793	$9,661,428	$4,914	$15,098	$110,127	$11,254,362	$0	$16,504	$655,054	**$21,767,304**
Pointe Coupee	$1,630	$134,695	$1,215,358	$7,184	$9,228	$56,934	$1,306,603	$0	$0	$124,166	**$2,855,799**
Rapides	$223,272	$1,319,827	$3,879,291	$64,380	$55,193	$529,017	$18,044,297	$6,883	$84	$609,947	**$24,732,190**
Red River	$3,603	$105,244	$156,833	$4,134	$2,375	$21,075	$158,870	$200	$0	$28,847	**$481,181**
Richland	$3,419	$230,010	$716,029	$11,598	$6,430	$73,495	$632,580	$30	$0	$109,337	**$1,782,928**
Sabine	$29,018	$277,184	$621,912	$12,850	$8,130	$58,018	$1,679,245	$0	$0	$52,950	**$2,739,306**
St Bernard	$33,990	$237,692	$24,945,961	$27,792	$81,091	$645,944	$7,419,962	$0	$319	$3,886,376	**$37,279,127**
St Charles	$1,523	$161,913	$7,995,395	$12,857	$29,443	$360,073	$15,908,384	$0	$10,402	$2,124,986	**$26,604,976**
St Helena	$25,867	$90,922	$279,899	$3,140	$4,289	$35,391	$237,647	$0	$0	$24,926	**$702,082**
St James	$1,483	$92,867	$3,587,603	$4,971	$11,207	$83,253	$445,118	$0	$14,270	$484,857	**$4,725,630**
St John the Bapt	$5,623	$176,463	$4,322,322	$9,482	$20,392	$176,103	$5,552,716	$0	$0	$1,063,372	**$11,326,472**
St Landry	$10,470	$544,661	$4,672,238	$29,394	$33,395	$590,424	$5,113,660	$0	$2,185	$424,371	**$11,420,797**
St Martin	$929	$426,893	$5,854,555	$18,091	$29,387	$388,273	$4,299,088	$0	$59,763	$746,659	**$11,823,637**
St Mary	$26	$109,140	$9,753,500	$8,567	$22,101	$101,175	$10,843,573	$0	$41,298	$890,621	**$21,770,001**
St Tammany	$1,908,055	$2,778,390	$47,004,794	$115,238	$218,916	$1,465,355	$56,705,395	$0	$0	$7,160,021	**$117,356,164**
Tangipahoa	$762,680	$1,999,557	$7,148,748	$63,977	$107,985	$998,165	$8,902,431	$0	$0	$1,441,653	**$21,425,195**
Tensas	$630	$28,969	$152,302	$1,385	$941	$10,189	$136,185	$0	$758	$8,111	**$339,469**
Terrebonne	$172	$357,147	$33,650,164	$22,020	$62,402	$501,191	$41,496,891	$0	$2,829	$3,295,111	**$79,387,928**
Union	$14,625	$346,275	$347,125	$13,890	$7,176	$74,902	$622,413	$1,313	$0	$72,058	**$1,499,777**
Vermilion	$553	$265,618	$15,995,851	$18,378	$30,169	$548,048	$13,501,325	$0	$1,051	$770,805	**$31,131,798**
Vernon	$77,657	$496,403	$1,069,147	$19,540	$16,458	$147,324	$462,284	$430	$0	$177,584	**$2,466,827**
Washington	$135,834	$442,844	$2,346,171	$17,465	$19,521	$203,367	$1,326,370	$243	$0	$95,339	**$4,587,155**
Webster	$32,421	$655,529	$737,886	$23,887	$12,088	$144,249	$355,690	$39	$2,616	$85,777	**$2,050,179**
West Baton Rou	$2,894	$215,595	$1,718,713	$11,617	$21,482	$170,239	$275,318	$0	$287	$396,101	**$2,812,247**
West Carroll	$2,330	$127,366	$418,139	$5,899	$2,953	$34,903	$210,089	$0	$0	$36,035	**$837,713**
West Feliciana	$5,125	$108,101	$431,262	$5,685	$6,788	$33,754	$235,681	$3	$0	$27,445	**$853,843**
Winn	$8,436	$170,874	$158,567	$6,399	$4,320	$26,408	$206,444	$75	$4,855	$114,152	**$700,530**
Total Loss	**$5,876,211**	**$36,978,826**	**$642,927,351**	**$1,976,212**	**$2,917,407**	**$31,725,662**	**$451,389,758**	**$1,011,414**	**$342,071**	**$92,869,675**	**$1,268,014,588**

CROP LOSS RESULTS

The following parish-level crop losses were determined for each hazard. All losses represent average annual losses, with the exception of flood hazards.

Parish	Extreme Heat Crop Loss	Drought Crop Loss	Extreme Cold Crop Loss	Hail Crop Loss	Lightning Crop Loss	Tornado Crop Loss	Parish Average Annual Crop Loss
Acadia	$25,181	$1,968,721	$24,276	$3,405	$146	$19,324	**$2,041,052**
Allen	$5,301	$430,953	$7,246	$770	$19	$1,400	**$445,689**
Ascension	$5,161	$759,174	$11,915	$1,206	$75	$3,840	**$781,371**
Assumption	$3,564	$942,335	$10,782	$1,021	$43	$4,276	**$962,020**
Avoyelles	$25,004	$1,711,877	$28,698	$3,691	$85	$6,670	**$1,776,026**
Beauregard	$14,694	$867,575	$23,205	$1,052	$34	$3,634	**$910,193**
Bienville	$4,395	$194,459	$7,934	$417	$6	$795	**$208,006**
Bossier	$19,457	$897,249	$27,477	$2,338	$35	$4,398	**$950,954**
Caddo	$28,829	$1,357,751	$38,649	$3,261	$66	$6,108	**$1,434,663**
Calcasieu	$7,250	$1,118,983	$15,724	$1,684	$80	$7,091	**$1,150,810**
Caldwell	$5,009	$218,361	$7,353	$506	$9	$594	**$231,832**
Cameron	$1,510	$358,893	$3,213	$372	$15	$1,893	**$365,896**
Catahoula	$18,055	$1,048,388	$27,910	$2,695	$60	$3,992	**$1,101,101**
Claiborne	$5,395	$293,152	$13,223	$603	$1	$1,045	**$313,418**
Concordia	$18,644	$1,230,091	$37,899	$3,845	$86	$5,718	**$1,296,283**
De Soto	$16,004	$804,616	$25,746	$1,736	$13	$3,544	**$851,660**
East Baton Rouge	$4,760	$451,966	$9,677	$1,093	$272	$2,845	**$470,613**
East Carroll	$10,595	$615,742	$20,438	$2,333	$34	$3,464	**$652,606**
East Feliciana	$2,880	$280,408	$7,839	$455	$6	$1,102	**$292,690**
Evangeline	$28,821	$1,301,506	$21,689	$2,823	$71	$7,387	**$1,362,297**
Franklin	$45,457	$1,987,494	$62,264	$5,824	$96	$6,730	**$2,107,866**
Grant	$4,368	$267,787	$5,125	$642	$6	$734	**$278,662**
Iberia	$8,511	$1,085,056	$12,090	$1,977	$119	$7,561	**$1,115,314**
Iberville	$3,752	$567,412	$9,003	$1,091	$70	$2,611	**$583,939**
Jackson	$2,066	$85,863	$3,801	$164	$0	$422	**$92,316**
Jefferson	$614	$59,112	$286	$99	$0	$473	**$60,584**
Jefferson Davis	$12,135	$1,672,634	$20,251	$2,611	$102	$10,669	**$1,718,401**
Lafayette	$14,226	$1,730,778	$22,630	$3,198	$149	$18,646	**$1,789,627**
Lafourche	$7,007	$1,796,948	$15,661	$1,897	$138	$8,273	**$1,829,924**
La Salle	$2,649	$160,429	$4,993	$275	$0	$364	**$168,710**
Lincoln	$4,444	$192,651	$7,816	$364	$3	$895	**$206,172**
Livingston	$5,547	$541,051	$12,959	$741	$52	$3,088	**$563,438**
Madison	$23,620	$1,338,454	$46,928	$5,305	$88	$9,426	**$1,423,822**
Morehouse	$17,036	$891,638	$36,574	$2,512	$47	$3,596	**$951,404**
Natchitoches	$27,086	$1,073,202	$27,667	$2,640	$34	$3,480	**$1,134,108**
Orleans	$273	$36,934	$176	$2	$0	$158	**$37,543**
Ouachita	$19,677	$769,596	$30,701	$2,265	$37	$3,495	**$825,770**
Plaquemines	$2,118	$318,929	$1,619	$237	$3	$994	**$323,900**
Pointe Coupee	$14,227	$1,045,998	$19,952	$2,060	$55	$3,544	**$1,085,836**
Rapides	$19,069	$1,045,358	$22,623	$2,457	$99	$3,925	**$1,093,530**
Red River	$9,136	$400,325	$14,597	$990	$13	$1,397	**$426,458**
Richland	$38,633	$1,870,910	$57,616	$5,376	$87	$7,300	**$1,979,923**
Sabine	$8,697	$371,114	$11,540	$654	$5	$1,056	**$393,065**
St Bernard	$194	$25,408	$138	$160	$0	$227	**$26,127**
St Charles	$4,037	$512,644	$4,774	$671	$59	$3,641	**$525,826**
St Helena	$2,155	$155,536	$5,125	$192	$1	$831	**$163,840**
St James	$4,799	$776,109	$10,334	$1,061	$35	$3,770	**$796,109**
St John the Baptist	$2,473	$361,785	$4,797	$822	$20	$1,812	**$371,709**
St Landry	$36,645	$2,255,969	$36,026	$5,363	$184	$16,587	**$2,350,776**
St Martin	$15,234	$1,378,884	$25,162	$2,251	$77	$9,797	**$1,431,404**
St Mary	$1,868	$1,285,577	$9,814	$1,617	$113	$3,355	**$1,302,345**
St Tammany	$8,868	$888,174	$22,149	$1,131	$42	$3,857	**$924,220**
Tangipahoa	$11,562	$835,298	$25,518	$1,239	$55	$5,087	**$878,759**
Tensas	$31,042	$1,221,734	$43,658	$3,894	$70	$6,518	**$1,306,916**
Terrebonne	$1,390	$510,730	$4,035	$693	$41	$2,465	**$519,353**
Union	$6,178	$290,962	$12,176	$694	$7	$1,095	**$311,113**
Vermilion	$15,992	$2,332,045	$22,154	$3,245	$193	$18,179	**$2,391,808**
Vernon	$11,397	$457,902	$12,263	$646	$2	$1,605	**$483,816**
Washington	$7,039	$601,427	$16,162	$816	$40	$3,127	**$628,611**
Webster	$11,427	$567,002	$23,655	$1,327	$52	$1,937	**$605,400**
West Baton Rouge	$6,638	$717,844	$13,389	$1,875	$84	$4,433	**$744,262**
West Carroll	$20,011	$1,151,958	$39,555	$3,156	$43	$4,711	**$1,219,434**
West Feliciana	$3,303	$242,758	$4,940	$377	$5	$627	**$252,011**
Winn	$1,241	$63,512	$2,297	$144	$0	$187	**$67,381**
Total Loss	**$744,345**	**$52,795,132**	**$1,155,889**	**$110,057**	**$3,483**	**$281,804**	**$55,090,711**

TOTAL LOSS RESULTS

The following parish level total (property and crop) losses were determined for each hazard.
All losses represent average annual losses, with the exception of flood hazards, which are reported for the 1% annual probability event. Although the annual losses are not truly additive with the 1% annual flood losses, the parish total reflects the summation of these values, in an attempt to portray the relative risk for Louisiana parishes.

Parish	Extreme Heat Loss	Drought Loss	Wildfire Loss	Extreme Cold Loss	Wind Loss	Hail Loss	Lightning Loss	Tornado Loss	Flood Loss	Dam Failure Loss	Sinkhole Loss	Expansive Soil Loss	Parish Average Annual Loss + 1% Annual Chance Flood Loss
Acadia	$25,181	$1,968,721	$4,657	$358,852	$6,960,833	$23,982	$27,059	$666,229	$3,974,012	$0	$48,849	$480,233	**$14,538,607**
Allen	$5,301	$430,953	$53,354	$208,504	$1,008,504	$10,611	$10,884	$73,125	$805,454	$194	$0	$95,869	**$2,702,754**
Ascension	$5,161	$759,174	$113,843	$1,244,971	$16,007,213	$61,441	$126,198	$942,162	$15,696,666	$0	$3,094	$3,688,243	**$38,648,165**
Assumption	$3,564	$942,335	$106	$91,711	$3,491,462	$5,655	$10,958	$82,442	$1,353,836	$0	$674	$495,381	**$6,478,124**
Avoyelles	$25,004	$1,711,877	$9,425	$284,039	$1,914,376	$19,706	$14,746	$147,650	$2,555,262	$6	$0	$85,400	**$6,767,491**
Beauregard	$14,694	$867,575	$119,904	$471,989	$1,507,995	$18,258	$18,218	$169,341	$594,851	$233	$241	$98,103	**$3,881,403**
Bienville	$4,395	$194,459	$9,083	$213,828	$249,843	$8,352	$4,344	$49,930	$106,379	$272	$2,607	$31,552	**$875,043**
Bossier	$19,457	$897,249	$175,905	$2,365,808	$4,788,258	$122,991	$56,506	$1,093,786	$11,311,567	$987,684	$0	$452,910	**$22,272,120**
Caddo	$28,829	$1,357,751	$259,465	$2,842,814	$5,744,359	$156,918	$74,231	$1,617,892	$7,341,406	$5,840	$0	$564,134	**$19,993,639**
Calcasieu	$7,250	$1,118,983	$253,951	$1,327,213	$23,665,716	$78,299	$126,712	$1,470,618	$13,049,845	$0	$81,201	$2,854,138	**$44,033,924**
Caldwell	$5,009	$218,361	$6,597	$149,173	$217,155	$6,278	$3,585	$24,114	$646,973	$1	$24	$118,280	**$1,395,549**
Cameron	$1,510	$358,893	$7,523	$25,710	$3,674,504	$2,213	$2,718	$35,083	$5,583,446	$0	$9,878	$196,269	**$9,897,746**
Catahoula	$18,055	$1,048,388	$2,511	$123,873	$265,060	$6,975	$3,271	$32,108	$1,099,314	$0	$200	$77,906	**$2,677,660**
Claiborne	$5,395	$293,152	$9,752	$256,670	$184,770	$9,263	$4,175	$42,702	$108,970	$40	$50	$26,228	**$941,167**
Concordia	$18,644	$1,230,091	$2,383	$228,948	$559,783	$12,132	$6,711	$73,092	$461,558	$0	$0	$123,529	**$2,716,872**
De Soto	$16,004	$804,616	$18,502	$453,211	$652,733	$20,723	$10,295	$148,597	$433,113	$280	$0	$61,999	**$2,620,073**
East Baton Roug	$4,760	$451,966	$302,810	$2,773,615	$24,483,495	$157,325	$317,266	$2,654,819	$27,491,184	$718	$0	$5,535,043	**$64,173,000**
East Carroll	$10,595	$615,742	$419	$87,117	$210,837	$5,840	$1,819	$28,214	$10,953	$0	$0	$32,736	**$1,004,273**
East Feliciana	$2,880	$280,408	$21,167	$174,483	$827,313	$7,440	$9,932	$56,681	$253,881	$0	$0	$36,105	**$1,670,289**
Evangeline	$28,821	$1,301,506	$25,901	$255,881	$2,035,458	$15,130	$12,936	$183,564	$1,457,856	$72	$2,439	$89,110	**$5,408,673**
Franklin	$45,457	$1,987,494	$2,323	$282,276	$788,450	$16,343	$6,628	$61,495	$552,308	$3	$1,586	$119,644	**$3,864,007**
Grant	$4,368	$267,787	$24,214	$233,728	$334,778	$12,264	$8,885	$64,795	$624,236	$1,587	$0	$161,658	**$1,738,300**
Iberia	$8,511	$1,085,056	$205	$303,919	$15,199,157	$20,348	$36,951	$432,908	$6,601,218	$0	$4,414	$924,033	**$24,616,721**
Iberville	$3,752	$567,412	$979	$189,853	$2,175,828	$10,153	$16,308	$129,324	$1,272,617	$0	$3,857	$513,408	**$4,883,491**
Jackson	$2,066	$85,863	$11,749	$232,646	$232,447	$8,845	$5,220	$59,704	$131,409	$294	$124	$119,560	**$889,926**
Jefferson	$614	$59,112	$101,698	$777,510	$93,277,706	$109,112	$282,946	$3,232,172	$43,788,687	$0	$8,778	$15,426,414	**$157,064,748**
Jefferson Davis	$12,135	$1,672,634	$8,805	$170,303	$4,118,518	$12,238	$12,473	$221,125	$1,464,005	$0	$5,036	$406,659	**$8,103,931**
Lafayette	$14,226	$1,730,778	$10,166	$1,797,580	$41,758,869	$104,756	$151,279	$3,322,278	$8,325,476	$0	$31	$4,432,987	**$61,648,425**
Lafourche	$7,007	$1,796,948	$467	$355,299	$32,330,442	$22,528	$54,782	$409,983	$17,528,704	$0	$3,129	$2,888,633	**$55,397,924**
La Salle	$2,649	$160,429	$14,943	$235,928	$268,505	$8,738	$6,143	$37,234	$278,653	$0	$6,139	$116,807	**$1,136,168**
Lincoln	$4,444	$192,651	$52,472	$810,929	$850,601	$34,500	$19,623	$243,539	$495,265	$781	$180	$290,524	**$2,995,508**
Livingston	$5,547	$541,051	$385,807	$1,702,557	$9,876,048	$69,085	$125,164	$1,090,607	$23,789,561	$0	$0	$1,561,912	**$39,147,338**
Madison	$23,620	$1,338,454	$494	$157,766	$228,753	$10,855	$3,292	$60,801	$337,035	$48	$1,963	$44,621	**$2,207,704**
Morehouse	$17,036	$891,638	$8,422	$383,852	$518,268	$14,780	$5,898	$81,771	$235,775	$0	$0	$48,461	**$2,205,903**
Natchitoches	$27,086	$1,073,202	$37,391	$423,830	$969,937	$24,232	$13,846	$122,666	$1,351,070	$2,851	$358	$309,612	**$4,356,081**
Orleans	$273	$36,934	$418,055	$815,655	$148,495,772	$160,787	$428,651	$4,427,938	$37,799,756	$0	$0	$24,020,446	**$216,604,265**
Ouachita	$19,677	$769,596	$105,478	$2,909,633	$4,212,412	$109,297	$59,893	$717,519	$5,144,834	$1,292	$0	$1,434,469	**$15,484,100**
Plaquemines	$2,118	$318,929	$3,023	$48,412	$9,661,428	$5,150	$15,101	$111,121	$11,254,362	$0	$16,504	$655,054	**$22,091,204**
Pointe Coupee	$14,227	$1,045,998	$1,630	$154,648	$1,215,358	$9,244	$9,284	$60,478	$1,306,603	$0	$0	$124,166	**$3,941,634**
Rapides	$19,069	$1,045,358	$223,272	$1,342,450	$3,879,291	$66,837	$55,291	$532,942	$18,044,297	$6,883	$84	$609,947	**$25,825,720**
Red River	$9,136	$400,325	$3,603	$119,841	$156,833	$5,124	$2,388	$22,472	$158,870	$200	$0	$28,847	**$907,639**
Richland	$38,633	$1,870,910	$3,419	$287,626	$716,029	$16,974	$6,516	$80,795	$632,580	$30	$0	$109,337	**$3,762,851**
Sabine	$8,697	$371,114	$29,018	$288,724	$621,912	$13,503	$8,134	$59,074	$1,679,245	$0	$0	$52,950	**$3,132,371**
St Bernard	$194	$25,408	$33,990	$237,830	$24,945,961	$27,952	$81,091	$646,171	$7,419,962	$0	$319	$3,886,376	**$37,305,254**
St Charles	$4,037	$512,644	$1,523	$166,687	$7,995,395	$13,528	$29,502	$363,714	$15,908,384	$0	$10,402	$2,124,986	**$27,130,802**
St Helena	$2,155	$155,536	$25,867	$96,047	$279,899	$3,332	$4,290	$36,223	$237,647	$0	$0	$24,926	**$865,922**
St James	$4,799	$776,109	$1,483	$103,201	$3,587,603	$6,033	$11,243	$87,023	$445,118	$0	$14,270	$484,857	**$5,521,739**
St John the Bapt	$2,473	$361,785	$5,623	$181,259	$4,322,322	$10,304	$20,412	$177,915	$5,552,716	$0	$0	$1,063,372	**$11,698,181**
St Landry	$36,645	$2,255,969	$10,470	$580,687	$4,672,238	$34,757	$33,579	$607,011	$5,113,660	$0	$2,185	$424,371	**$13,771,572**
St Martin	$15,234	$1,378,884	$929	$452,055	$5,854,555	$20,342	$29,464	$398,070	$4,299,088	$0	$59,763	$746,659	**$13,255,042**
St Mary	$1,868	$1,285,577	$26	$118,955	$9,753,500	$10,184	$22,215	$104,530	$10,843,573	$0	$41,298	$890,621	**$23,072,346**
St Tammany	$8,868	$888,174	$1,908,055	$2,800,539	$47,004,794	$116,369	$218,958	$1,469,212	$56,705,395	$0	$0	$7,160,021	**$118,280,384**
Tangipahoa	$11,562	$835,298	$762,680	$2,025,075	$7,148,748	$65,216	$108,040	$1,003,252	$8,902,431	$0	$0	$1,441,653	**$22,303,955**
Tensas	$31,042	$1,221,734	$630	$72,628	$152,302	$5,279	$1,011	$16,707	$136,185	$0	$758	$8,111	**$1,646,386**
Terrebonne	$1,390	$510,730	$172	$361,181	$33,650,164	$22,713	$62,443	$503,656	$41,496,891	$0	$2,829	$3,295,111	**$79,907,281**
Union	$6,178	$290,962	$14,625	$358,451	$347,125	$14,584	$7,184	$75,997	$622,413	$1,313	$0	$72,058	**$1,810,890**
Vermilion	$15,992	$2,332,045	$553	$287,772	$15,995,851	$21,622	$30,362	$566,227	$13,501,325	$0	$1,051	$770,805	**$33,523,605**
Vernon	$11,397	$457,902	$77,657	$508,667	$1,069,147	$20,186	$16,460	$148,929	$462,284	$430	$0	$177,584	**$2,950,643**
Washington	$7,039	$601,427	$135,834	$459,006	$2,346,171	$18,282	$19,561	$206,494	$1,326,370	$243	$0	$95,339	**$5,215,766**
Webster	$11,427	$567,002	$32,421	$679,183	$737,886	$25,214	$12,139	$146,186	$355,690	$39	$2,616	$85,777	**$2,655,579**
West Baton Rou	$6,638	$717,844	$2,894	$228,984	$1,718,713	$13,492	$21,566	$174,671	$275,318	$0	$287	$396,101	**$3,556,509**
West Carroll	$20,011	$1,151,958	$2,330	$166,921	$418,139	$9,055	$2,996	$39,613	$210,089	$0	$0	$36,035	**$2,057,147**
West Feliciana	$3,303	$242,758	$5,125	$113,041	$431,262	$6,062	$6,793	$34,380	$235,681	$3	$0	$27,445	**$1,105,854**
Winn	$1,241	$63,512	$8,436	$173,171	$158,567	$6,543	$4,320	$26,594	$206,444	$75	$4,855	$114,152	**$767,911**
Total Loss	**$744,345**	**$52,795,132**	**$5,876,211**	**$38,134,715**	**$642,927,351**	**$2,086,269**	**$2,920,890**	**$32,007,466**	**$451,389,758**	**$1,011,414**	**$342,071**	**$92,869,675**	**$1,323,105,298**

STATE ASSET LOSS RESULTS

The following parish-level state asset losses were determined for each hazard. All losses represent average annual losses, with the exception of flood hazards, which are reported for the 1% annual probability event. Although the annual losses are not truly additive with the 1% annual flood losses, the parish total reflects the summation of these values, in an attempt to portray the relative risk for Louisiana parishes.

Parish	Wildfire Property Loss	Extreme Cold Property Loss	Wind Property Loss	Hail Property Loss	Lightning Property Loss	Tornado Property Loss	Flood Property Loss	Dam Failure Property Loss	Sinkhole Property Loss	Expansive Soil Property Loss	State Property Average Annual Loss + 1% Annual Chance Flood Loss
Acadia	$83	$5,949	$123,762	$366	$478	$11,502	$70,657	$0	$533	$8,538	**$221,868**
Allen	$1,316	$4,964	$24,874	$243	$268	$1,769	$19,866	$5	$0	$2,365	**$55,670**
Ascension	$341	$3,694	$47,949	$180	$378	$2,811	$47,019	$0	$6	$11,048	**$113,426**
Assumption	$1	$801	$34,571	$46	$108	$774	$13,405	$0	$4	$4,905	**$54,615**
Avoyelles	$184	$4,977	$37,314	$312	$286	$2,748	$49,806	$0	$0	$1,665	**$97,291**
Beauregard	$1,997	$7,476	$25,119	$287	$303	$2,760	$9,909	$4	$3	$1,634	**$49,491**
Bienville	$9	$204	$247	$8	$4	$49	$105	$0	$2	$31	**$659**
Bossier	$2,156	$28,656	$58,679	$1,479	$692	$13,350	$138,622	$12,104	$0	$5,550	**$261,288**
Caddo	$3,722	$40,229	$82,410	$2,204	$1,064	$23,123	$105,322	$84	$0	$8,093	**$266,253**
Calcasieu	$4,569	$23,598	$425,818	$1,379	$2,279	$26,333	$234,806	$0	$897	$51,355	**$771,034**
Caldwell	$69	$1,480	$2,266	$60	$37	$245	$6,751	$0	$0	$1,234	**$12,144**
Cameron	$89	$265	$43,260	$22	$32	$391	$65,735	$0	$70	$2,311	**$112,174**
Catahoula	$4	$155	$429	$7	$5	$45	$1,778	$0	$0	$126	**$2,549**
Claiborne	$369	$9,204	$6,985	$327	$158	$1,575	$4,120	$2	$1	$992	**$23,732**
Concordia	$17	$1,380	$4,043	$60	$48	$487	$3,333	$0	$0	$892	**$10,259**
De Soto	$59	$1,367	$2,087	$61	$33	$464	$1,385	$1	$0	$198	**$5,653**
East Baton Rouge	$12,639	$115,366	$1,021,931	$6,521	$13,231	$110,692	$1,147,471	$30	$0	$231,030	**$2,658,911**
East Carroll	$4	$682	$2,156	$36	$18	$253	$112	$0	$0	$335	**$3,596**
East Feliciana	$2,739	$21,560	$107,035	$904	$1,284	$7,191	$32,846	$0	$0	$4,671	**$178,229**
Evangeline	$152	$1,372	$11,929	$72	$75	$1,032	$8,544	$0	$9	$522	**$23,709**
Franklin	$25	$2,353	$8,433	$113	$70	$586	$5,907	$0	$11	$1,280	**$18,776**
Grant	$170	$1,606	$2,351	$82	$62	$450	$4,384	$11	$0	$1,135	**$10,252**
Iberia	$2	$2,945	$153,372	$185	$372	$4,292	$66,612	$0	$27	$9,324	**$237,130**
Iberville	$95	$17,487	$210,386	$876	$1,570	$12,252	$123,052	$0	$228	$49,643	**$415,588**
Jackson	$105	$2,050	$2,082	$78	$47	$531	$1,177	$3	$1	$1,071	**$7,145**
Jefferson	$491	$3,750	$450,100	$526	$1,365	$15,594	$211,297	$0	$26	$74,438	**$757,589**
Jefferson Davis	$120	$2,038	$55,929	$131	$168	$2,858	$19,881	$0	$43	$5,522	**$86,689**
Lafayette	$353	$61,711	$1,451,871	$3,531	$5,254	$114,861	$289,460	$0	$1	$154,126	**$2,081,169**
Lafourche	$15	$10,841	$1,031,955	$659	$1,744	$12,822	$559,498	$0	$62	$92,202	**$1,709,798**
LaSalle	$86	$1,334	$1,551	$49	$35	$213	$1,610	$0	$22	$675	**$5,575**
Lincoln	$11,366	$173,960	$184,247	$7,394	$4,250	$52,559	$107,278	$169	$24	$62,930	**$604,176**
Livingston	$812	$3,557	$20,793	$144	$263	$2,290	$50,086	$0	$0	$3,288	**$81,233**
Madison	$13	$2,959	$6,106	$148	$86	$1,371	$8,997	$1	$32	$1,191	**$20,904**
Morehouse	$43	$1,777	$2,653	$63	$30	$400	$1,207	$0	$0	$248	**$6,421**
Natchitoches	$2,932	$31,066	$76,061	$1,693	$1,083	$9,346	$105,948	$224	$17	$24,279	**$252,650**
Orleans	$36,540	$71,276	$12,979,125	$14,053	$37,466	$387,006	$3,303,850	$0	$0	$2,099,483	**$18,928,799**
Ouachita	$3,878	$105,842	$154,866	$3,935	$2,201	$26,250	$189,146	$48	$0	$52,737	**$538,902**
Plaquemines	$18	$277	$57,256	$29	$89	$653	$66,696	$0	$59	$3,882	**$128,959**
Pointe Coupee	$4	$335	$3,022	$18	$23	$142	$3,249	$0	$0	$309	**$7,100**
Rapides	$8,145	$48,147	$141,517	$2,349	$2,013	$19,299	$658,257	$251	$2	$22,251	**$902,230**
Red River	$9	$270	$403	$11	$6	$54	$408	$1	$0	$74	**$1,236**
Richland	$27	$1,828	$5,690	$92	$51	$584	$5,027	$0	$0	$869	**$14,169**
Sabine	$578	$5,518	$12,381	$256	$162	$1,155	$33,430	$0	$0	$1,054	**$54,533**
St. Bernard	$419	$2,932	$307,747	$343	$1,000	$7,969	$91,537	$0	$2	$47,944	**$459,894**
St. Charles	$1	$159	$7,848	$13	$29	$353	$15,615	$0	$6	$2,086	**$26,111**
St. Helena	$333	$1,170	$3,601	$40	$55	$455	$3,057	$0	$0	$321	**$9,032**
St. James	$0	$17	$664	$1	$2	$15	$82	$0	$2	$90	**$874**
St. John the Baptist	$74	$2,330	$57,071	$125	$269	$2,325	$73,317	$0	$0	$14,041	**$149,553**
St. Landry	$60	$3,096	$26,562	$167	$190	$3,357	$29,071	$0	$8	$2,413	**$64,923**
St. Martin	$5	$2,359	$32,359	$100	$162	$2,146	$23,761	$0	$207	$4,127	**$65,227**
St. Mary	$0	$448	$40,044	$35	$91	$415	$44,520	$0	$101	$3,657	**$89,311**
St. Tammany	$4,859	$7,075	$119,689	$293	$557	$3,731	$144,390	$0	$0	$18,232	**$298,826**
Tangipahoa	$41,656	$109,212	$390,450	$3,494	$5,898	$54,518	$486,232	$0	$0	$78,740	**$1,170,199**
Tensas	$7	$303	$1,594	$14	$10	$107	$1,425	$0	$5	$85	**$3,550**
Terrebonne	$1	$2,490	$234,568	$153	$435	$3,494	$289,266	$0	$12	$22,970	**$553,389**
Union	$62	$1,466	$1,470	$59	$30	$317	$2,635	$6	$0	$305	**$6,350**
Vermilion	$2	$1,046	$63,017	$72	$119	$2,159	$53,190	$0	$3	$3,037	**$122,645**
Vernon	$393	$2,511	$5,409	$99	$83	$745	$2,339	$2	$0	$898	**$12,480**
Washington	$3,066	$9,996	$52,960	$394	$441	$4,591	$29,940	$5	$0	$2,152	**$103,545**
Webster	$1,159	$23,427	$26,370	$854	$432	$5,155	$12,711	$1	$58	$3,065	**$73,231**
West Baton Rouge	$8	$578	$4,610	$31	$58	$457	$738	$0	$0	$1,062	**$7,542**
West Carroll	$12	$656	$2,155	$30	$15	$180	$1,083	$0	$0	$186	**$4,317**
West Feliciana	$991	$20,900	$83,378	$1,099	$1,312	$6,526	$45,566	$1	$0	$5,306	**$165,078**
Winn	$8,436	$170,874	$7,492	$6,399	$4,320	$1,248	$9,755	$4	$142	$991	**$209,662**
Total	**$157,889**	**$1,189,351**	**$20,544,070**	**$64,803**	**$94,702**	**$973,424**	**$9,138,278**	**$12,955**	**$2,624**	**$3,211,214**	**$35,389,312**

HISTORIC PROPERTIES HAZARD EXPOSURE

Because building and contents values are not available for many historic sites, hazard parameters were extracted for each of the evaluated historic properties, which can help inform risk for these properties.

Name	Parish	Days over 95°F (Yearly)	Weekly Drought Probability (%)	Annual Wildfire Burn Probability (%)	Days under 32°F (Yearly)	700 Year Peak Gust Wind Speed (mph)	Hail Days per Year	Flashes/sq. mile/year	Tornado Days per Year	Diatance to Nearest High Hazard Potential Dam (miles)	Flood Zone	Distance to Nearest Sinkhole (miles)	Soil Clay Content of High Swelling Potentiality (%)
Blanchard Bldg.	Natchitoches	42	26.2	1.31	19	107	4	13	1	1.7	X	11.4	< 50
Cabildo	Orleans	13	25.4	0.25	2	144	2	28	1	70.5	X	10.7	> 50
Congo Square	Orleans	12	25.4	0.25	2	144	2	28	1	70.1	X	11.0	> 50
Destrehan Platation	St. Charles	11	24.3	0.02	6	141	2	21	1	55.2	A	3.9	> 50
Ducournau Square	Natchitoches	42	26.2	1.31	19	107	4	14	1	1.6	X	11.4	< 50
Evergreen Plantation	St. John the Baptist	8	23.5	0.12	10	141	2	23	1	38.7	X	6.0	> 50
Fort Jackson	Plaquemines	0	23.2	0.00	2	165	1	14	0	113.5	A	5.1	> 50
Fort Pike	Orleans	4	24.7	2.46	9	144	2	20	1	55.7	VE	19.3	< 50
Fort Proctor	St. Bernard	3	24.6	0.29	5	150	2	23	0	76.6	VE	6.9	> 50
Gallier Hall	Orleans	14	25.4	0.21	2	144	2	28	1	70.3	X	10.2	> 50
GB Cooley House	Ouachita	38	25.4	0.70	32	106	5	14	1	20.1	X	26.2	< 50
Jackson Barracks	Orleans	12	25.0	0.31	3	145	2	28	1	70.8	X	10.0	> 50
Jackson Square	Orleans	13	25.4	0.25	2	144	2	28	1	70.5	X	10.6	> 50
Kaffie-Frederick Hardware Store	Natchitoches	42	26.2	1.31	19	107	4	13	1	1.7	X	11.3	< 50
Los Adaes State Historic Site	Natchitoches	36	25.5	1.33	22	108	4	15	1	11.1	X	22.7	< 50
Louisiana State Capital	East Baton Rouge	10	23.1	0.21	7	124	2	26	1	5.4	X	7.9	> 50
Lower Pontalba Building	Orleans	13	25.4	0.25	2	144	2	28	1	70.5	X	10.7	> 50
LSU Indian Mounds	East Baton Rouge	10	23.2	0.17	7	125	2	25	1	3.6	X	8.6	> 50
Madame Johns Legacy	Orleans	13	25.4	0.25	2	144	2	28	1	70.5	X	10.8	> 50
Marksville State Historic Site	Avoyelles	20	26.9	0.27	13	112	3	15	1	21.5	X	16.0	< 50
Melrose Plantation	Natchitoches	34	25.9	1.39	17	109	4	16	1	13.5	X	16.4	< 50
NatchitochesOld Courthouse Museum	Natchitoches	42	26.2	1.31	19	107	4	14	1	1.5	X	11.5	< 50
Oak Alley Plantation	St. James	7	23.2	0.07	9	139	2	21	1	34.4	X	2.8	> 50
Oakley Plantation	West Feliciana	18	21.9	0.28	13	119	3	20	1	7.1	X	22.7	< 50
Old Courthouse Natchitoches	Natchitoches	42	26.2	1.31	19	107	4	14	1	1.5	X	11.5	< 50
Old Governor's Mansion	East Baton Rouge	10	23.1	0.20	7	124	2	27	1	4.8	X	8.1	> 50
Old State Capital	East Baton Rouge	10	23.1	0.19	6	124	2	27	1	5.0	X	7.8	> 50
Old U.S. Mint	Orleans	12	25.4	0.26	2	144	2	28	1	70.7	X	10.8	> 50
Old Urseline Convent	Orleans	13	25.4	0.26	2	144	2	28	1	70.5	X	10.8	> 50
Ormond Planation	St. Charles	10	23.4	0.02	6	141	2	21	1	53.8	A	3.2	> 50
Poche Plantation	St. James	7	23.1	0.06	9	137	2	20	1	32.2	X	5.4	> 50
Port Hudson State Historic Site	East Feliciana	16	21.6	0.27	13	119	3	21	1	14.1	X	16.2	< 50
Poverty Point National Monument	West Carroll	22	25.4	0.44	24	106	5	13	1	11.2	X	19.1	< 50
Presbytere-LA state museum	Orleans	13	25.4	0.25	2	144	2	28	1	70.5	X	10.7	> 50
Prudhomme Bldg.	Natchitoches	42	26.2	1.31	19	107	4	14	1	1.7	X	11.4	< 50
Ruston POW Camp Bldgs.	Lincoln	31	26.2	1.29	30	105	5	14	1	20.8	X	14.7	< 50
Sabine Pass Lighthouse	Cameron	7	23.9	2.65	8	145	2	14	1	71.2	AE	14.9	< 50
San Fransico Plantation	St. John the Baptist	9	24.0	0.16	10	136	2	23	1	39.5	X	8.4	> 50
Southern Forest Heritage Museum and Research Center	Rapides	29	28.9	5.18	20	114	3	16	1	10.3	X	17.9	< 50
St. Louis Cathedral	Orleans	13	25.4	0.25	2	144	2	28	1	70.5	X	10.7	> 50
Upper Pontalba Building	Orleans	13	25.4	0.24	2	144	2	28	1	70.5	X	10.6	> 50
US Bureau of Immigration & Customs Enforcement	Orleans	14	25.4	0.21	2	144	2	28	1	70.0	X	10.5	> 50
USS Kidd	East Baton Rouge	10	23.1	0.19	6	124	2	27	1	5.0	AE	7.7	> 50

Changes in Future Hazard Conditions

The following sections describe the rationale behind the selection of changes in future hazard conditions projections, and also describe specialized risk assessment approaches for hazards that did not use the SHELDUS loss approach.

Temperature Hazards

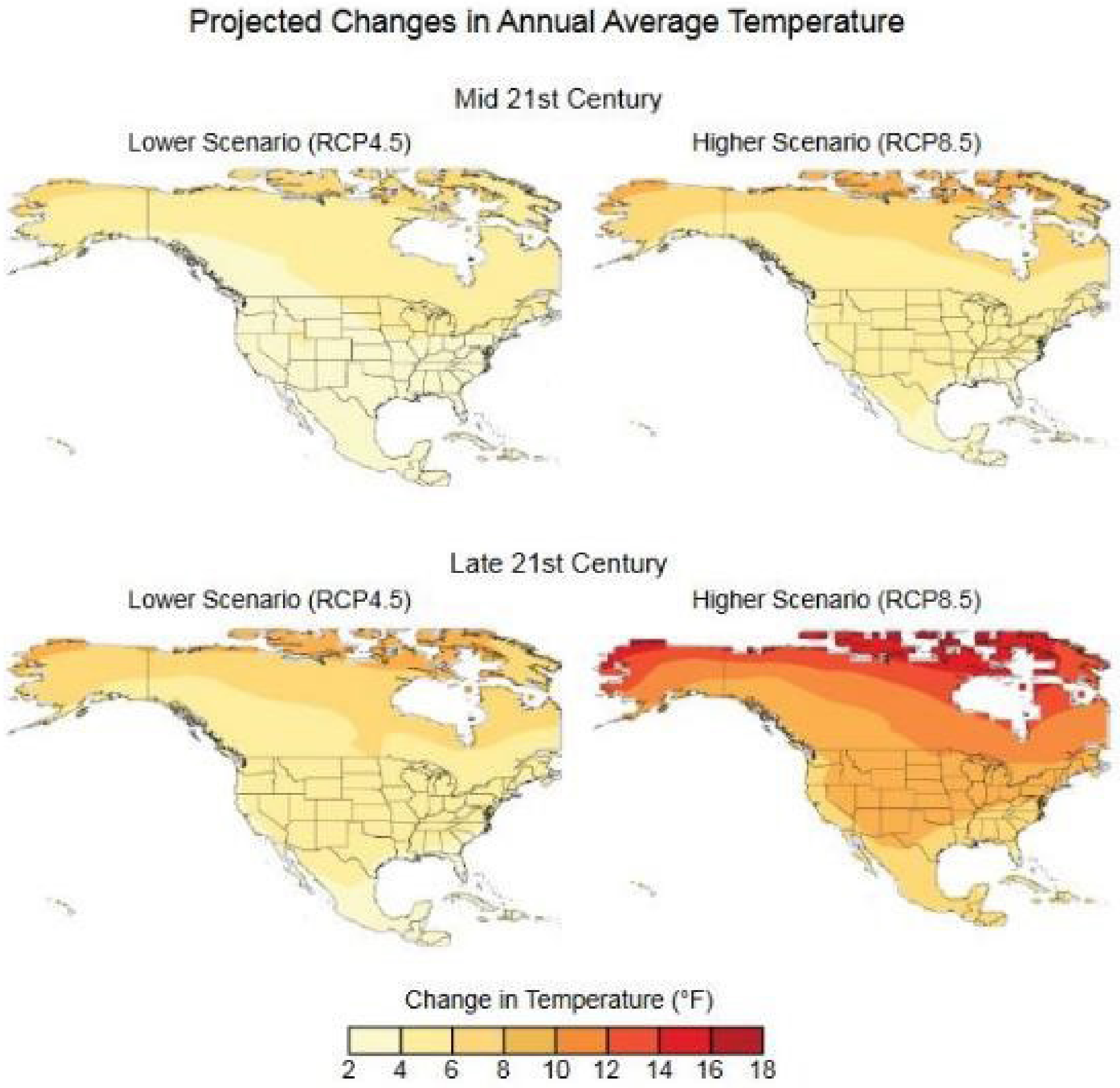
Future Conditions: Extreme Heat and Cold

Any reasonable assessment of future vulnerability to extreme temperatures must begin with a review of the consensus of the major general circulation model (GCM) output for mean temperature. From that point, more specific estimates of extreme temperatures might be possible. The Fourth National Climate Assessment (NCA4; 2017; https://science2017.globalchange.gov) utilizes output from the Intergovernmental Panel for Climate Change (IPCC) reports, with specialized focus on each world region.

The southeastern U.S., including Louisiana, exhibited little or no change in temperature from 1986 to 2015 relative to 1901 to 1960 (Wuebbles et al., 2017; their Figure 1.3). The observed temperature record of the southeastern is characterized by a warm peak during the 1930s and 1940s, followed by a cool period in the 1960s and 1970s, with temperatures increasing again since 1970 (NCA, 2017). Louisiana has exhibited little overall warming in surface temperatures over the 20th century (Frankson et al., 2017). Vose et al. (2017) suggest that the 1986 to 2016 period was up to 1°F warmer than the 1901 to 1960 period in Louisiana, with the most Louisiana warming in the northeastern and coastal southeastern parts of the state. This warming is much less than that reported in most of the northern and western United States. The confidence in these conclusions by NCA4 (2017) is reported as "very high."

By 2050, warming is expected to intensify for the southeastern United States, including Louisiana. More specifically, NCA4 (2017) says that, "statistically significant warming is projected for all parts of the United States throughout the [21st] century…warming rates (and spatial gradients) are greater at higher latitudes." The confidence in these conclusions by NCA4 (2017) is reported as "high." The additional evapotranspiration in the Southeast, due to warming, will allow additional condensation and cloud cover, which will in turn suppress further warming. This contrasts with other regions in which moisture is not as abundant. In those regions, the extra energy input will result in higher increases in temperature.

NCA4 (2017) analyzed modeled changes in mean temperature by 2036-2065, as compared to 1976-2005. Two scenarios were chosen, to conform to those used by the Intergovernmental Panel on Climate Change. The higher radiative forcing scenario (Representative Concentration Pathway (RCP) 8.5 (suggesting an increase of 8.5 Watts per square meter of energy loading)) would result in a mean temperature increase of 2-6 °F in Louisiana across the two thirty-year periods (Figure X; same as Figure 6.7 in NCA4 (2017)), with a mean increase across the U.S. Southeast of 4.30 °F. The lower forcing scenario (RCP4.5) would result in 2-4 °F increases in mean temperature across Louisiana, with a mean increase by mid-century of 3.40 °F for the U.S. Southeast region. Under a higher emissions pathway, historically unprecedented warming is projected for Louisiana by the end of the 21st century (Frankson et al., 2017; https://statesummaries.ncics.org/la).



Projected Changes in Annual Average Temperature

NCA4 (2017) also projected changes to temperature extremes. RCP8.5 would increase the temperature of the coldest day of the year by 2-4 °F and the warmest day of the year by 2-4 °F in Louisiana, except for the extreme coastal southeast, where increases of 0-2 °F are projected (Figure Y – Same as Figure 6.8 in Vose et al., 2017). Mean increases for the U.S. Southeast region are 4.97 °F and 5.79 °F, respectively (Vose et al., 2017). Louisiana might expect 20 to 30 more days annually with temperatures above 90 °F and 1 to 20 fewer days per year with freezing temperatures by the 2036-2065 period (Figure Z – same as Figure 6.9 in Vose et al., 2017). Larger increases in extreme high temperature frequency are expected in inland regions, including northern Louisiana. Much smaller increases in the mean number of days per year exceeding 95 °F are expected in coastal Louisiana, but on a percentage basis, these increases are also substantial. The confidence in these conclusions by NCA4 (2017) about changes to U.S. extreme temperature days is reported as "very high." NCA4 (2017) does not examine the changes to extremes that would occur in an RCP4.5 scenario.

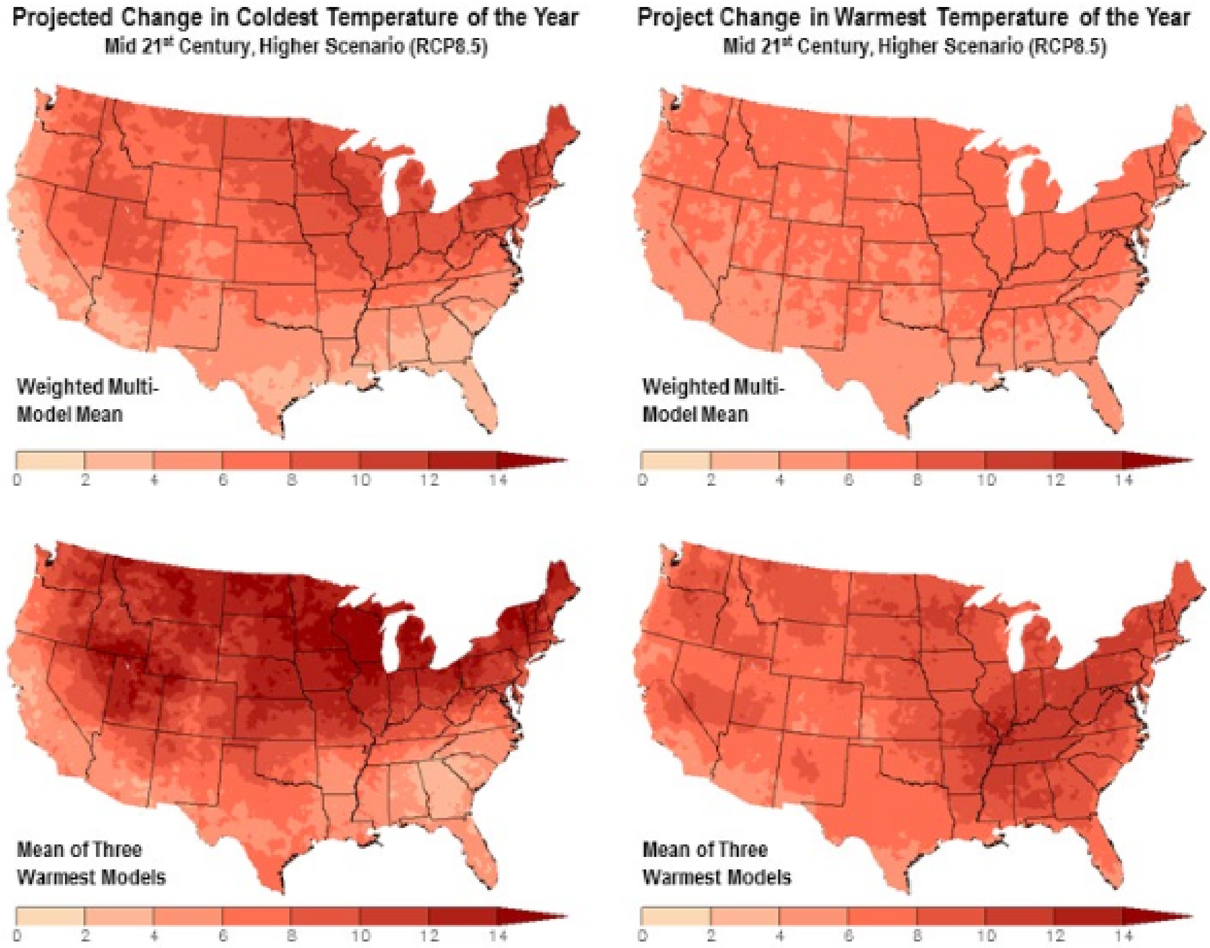


Figure 6.8. Projected changes in the coldest and warmest daily temperatures (°F) of the year in the contiguous United States. Changes are the difference between the average for mid-century (2036–2065) and the average for near-present (1976–2005) under the higher scenario (RCP8.5). Maps in the top row depict the weighted multimodel mean whereas maps on the bottom row depict the mean of the three warmest models (that is, the models with the largest temperature increase). Maps are derived from 32 climate model projections that were statistically downscaled using the Localized Constructed Analogs technique.[51] Increases are statistically significant in all areas (that is, more than 50% of the models show a statistically significant change, and more than 67% agree on the sign of the change[45]). (Figure source: CICS-NC and NOAA NCEI).

References:

Frankson, R., K. Kunkel, and S. Champion, 2017: Louisiana State Summary. NOAA Technical Report NESDIS 149-LA, 4 pp.

Vose, R.S., D.R. Easterling, K.E. Kunkel, A.N. LeGrande, and M.F. Wehner, 2017: Temperature changes in the United States. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 185-206, doi: 10.7930/J0N29V45.

Wuebbles, D.J., D.R. Easterling, K. Hayhoe, T. Knutson, R.E. Kopp, J.P. Kossin, K.E. Kunkel, A.N. LeGrande, C. Mears, W.V. Sweet, P.C. Taylor, R.S. Vose, and M.F. Wehner, 2017: Our globally changing climate. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 35-72, doi: 10.7930/J08S4N35.

Future Conditions: Drought and Wildfire

The definitive study on future conditions of drought and wildfire in the U.S. is the Fourth National Climate Assessment (NCA4, 2017; https://science2017.globalchange.gov). The Drought, Floods, and Wildfire section of that report (Wehner et al., 2017) concludes that:

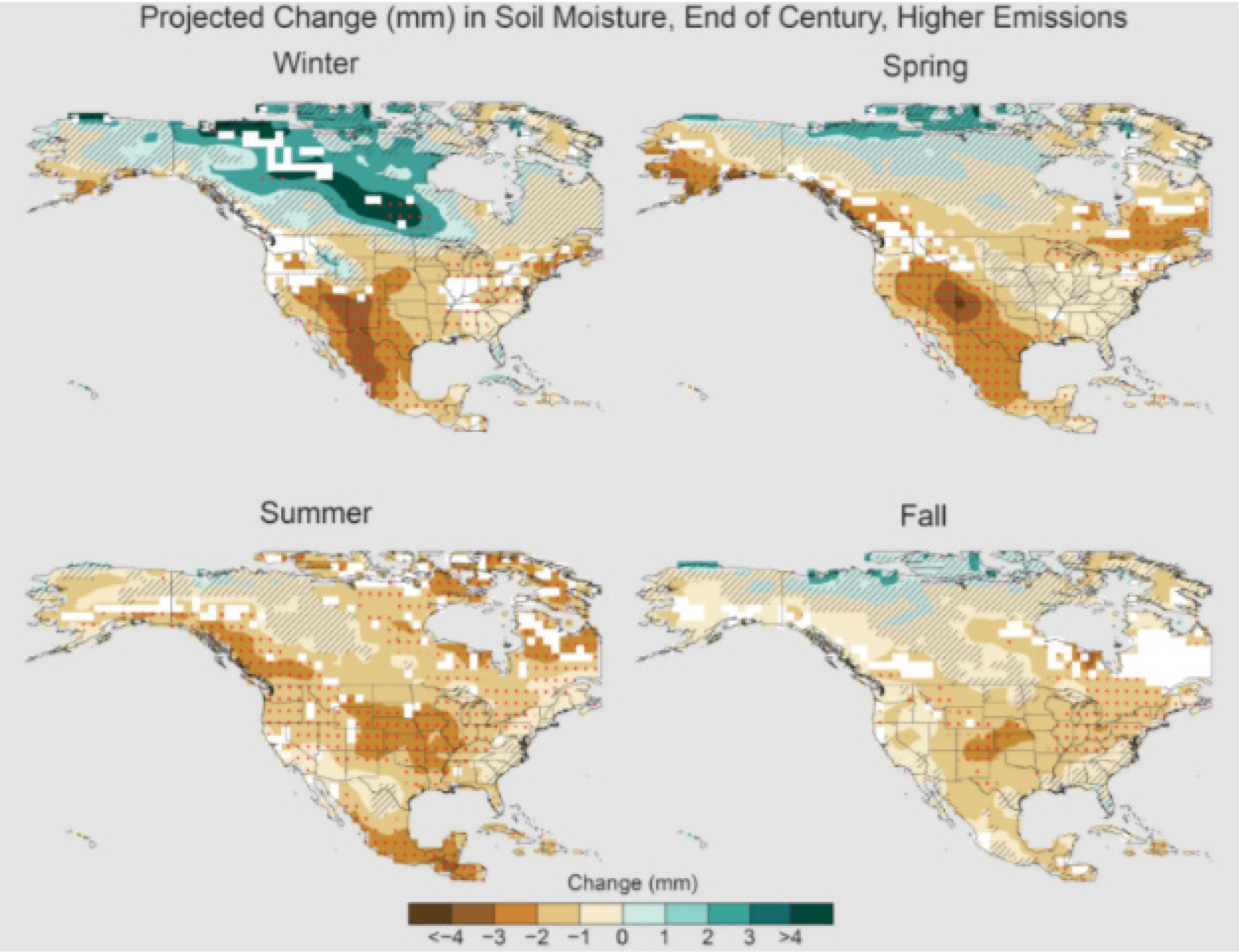
"The human effect on recent major U.S. droughts is complicated. Little evidence is found for a human influence on observed precipitation deficits, but much evidence is found for a human influence on surface soil moisture deficits due to increased evapotranspiration caused by higher temperatures."

Wehner et al. (2017) suggest that by 2050, daily precipitation will increase by 9–13 percent in Louisiana, with higher increases corresponding to the higher radiative forcing scenario. The report also uses dynamically downscaled model output to find that, for the U.S. as a whole in the higher forcing scenario, a more extreme precipitation climate is to be expected by 2100. This includes substantial increases in the frequency of "no precipitation" and the (present) zero-to-tenth-percentile precipitation daily totals, sharp increases in the frequency of days having a greater than 90th percentile of precipitation, and decreases in every other decile of precipitation totals.

The projected increases in temperature and precipitation, and the seasonality of each, would induce changes in soil moisture, which in turn would cause changes in drought and wildfire. Therefore, it is appropriate to search the literature for projected changes in soil moisture by mid-century. Wehner et al. (2017) acknowledge that projections of seasonal precipitation deficits lack confidence, but they recognize that the preponderance of evidence suggests that evapotranspiration caused by increased temperatures will outpace the projected increasing precipitation totals, resulting in drying soils by 2100 over much of the continental United States, including Louisiana, at least under higher radiative forcing and emissions scenario (Figure X). These changes will impact soil moisture availability in Louisiana. Specifically, in Louisiana, soil moisture decreases in autumn are expected to be small relative to natural variability, but in the other three seasons the soil moisture decreases are projected to be large relative to natural variability. These soil moisture forecasts are made with a "medium" degree of confidence.

Soil moisture changes could be expected to produce changes in wildfire vulnerability. However, because the Fourth NCA focuses on the western U.S. in its discussion of wildfire, other sources must be used to assess the threat to Louisiana by 2050. Prestemon et al. (2016) used three general circulation models and three IPCC-based emission scenarios to assess future conditions of wildfire in the U.S. Southeast; the study concluded that median annual area affected by lightning-ignited wildfire will increase by 34 percent, and that total wildfire will increase by 4 percent by 2056–60 compared with the years 2016–2020.

A few other studies have been conducted in the last ten years to make projections to changes in wildfire vulnerability. For such purposes, the Keetch-Byram Drought Index (KBDI), which is calculated based on observed or simulated changes in maximum temperature and precipitation, is most useful. The KBDI was developed by the U.S. Forest Service using a water balance approach. Specifically, it examines the relationship of modeled evapotranspiration (driven largely by temperature and latitude, the latter of which controls sun angle and number of hours of daylight) to precipitation in the organic matter on a forest floor and in the highest soil layers. The KBDI actually represents the number of millimeters of precipitation that would be required to saturate the soil (i.e., reduce the KBDI to zero). Values from 0 to 200 indicate minimal wildfire threat, with values of 200 to400 suggesting that the lower litter layer is drying and beginning to be susceptible to drought. Values from 400 to 600, which are more typical of late summer and early autumn, indicate that there is a moderate burn potential. Values of 600 to 800 are associated with more severe drought and active potential for burning.



Projected end of the 21st century weighted CMIP5 multimodel average percent changes in near surface seasonal soil moisture (mrsos) under the higher scenario (RCP8.5). Stippling indicates that changes are assessed to be large compared to natural variations. Hashing indicates that changes are assessed to be small compared to natural variations. Blank regions (if any) are where projections are assessed to be inconclusive (Appendix B). (Figure source: NOAA NCEI and CICS-NC).

Liu et al. (2009) modeled seasonal changes to the KBDI using the A2a scenario – the "non-fossil-intensive" variety of the "A2" scenario that had been used by NCA before its fourth assessment report. The A2a scenario assumed that global population surpasses 10 billion by 2050, with relatively slow economic and technological development, creating global CO2 mixing ratios of 575 parts per million (ppm) by 2050 and 870 ppm by 2100 (compared to the current 407 ppm). Validation of output from four general circulation models for global climate for the 1961-1990 period led Liu et al. (2009) to conclude that the Hadley Centre climate model version 3 (Pope et al. 2000) is most effective for simulating global KBDI for the 2070-2100 period. Figure Y shows those projected changes to the KBDI (2070-2100 minus 1961-1990) for the United States. In autumn and winter (September through February), decreases of 50–150 mm per three-month period were forecasted in Louisiana, while in March through May and June through August decreases of 200-250 mm per three-month period were projected in Louisiana.

The midpoint of the time series of the projection by Liu et al. (2009) is 2085, so we assumed that half of the projected changes in KBDI will occur by 2050. Thus, decreases of 25-75 mm per three-month period (or 8-25 mm per month, with 17 mm per month as the midpoint) are projected for each month from September through February in Louisiana by 2050. Decreases of 100-125 mm per three-month period (or 33-42 mm per month, with 38 mm per month as the midpoint) are projected for each month from March through August in Louisiana by 2050 (Table 1).

To provide more detail for Louisiana based on Liu et al.'s (2009) results, we collected average monthly precipitation data for 31°N, 91.5°W from the Web-based, Water-Budget, Interactive, Modeling Program (WebWIMP, http://climate.geog.udel.edu/~wimp/wimp_map_input.php). Results suggest that decreases in soil moisture in the upper-layers of 12.2 percent (February) to 46.1 percent (August) are projected.

Based on these model results, we project a 25 percent decrease in available moisture in the organic matter and uppermost soil layers, and a 25 percent increase in wildfire susceptibility across Louisiana by 2050.

Our projections are not without their caveats. For example, these changes do not take into account projected changes in global air temperature. According to NCICS (https://statesummaries.ncics.org/la), Louisiana's mean air temperature trends have not mimicked global temperature trends, as:

> "Louisiana has exhibited little overall warming in surface temperatures over the 20th century. However, under a higher emissions pathway, historically unprecedented warming is projected by the end of the 21st century."
>
> The changes described here assume no change in temperature by 2050 from current values. Nor do they take into account the precipitation changes that are expected to replenish the soil layers during wet times, but also desiccate the soil more rapidly during the lengthening dry periods. Thus, caution should be exercised in our interpretation of the results.

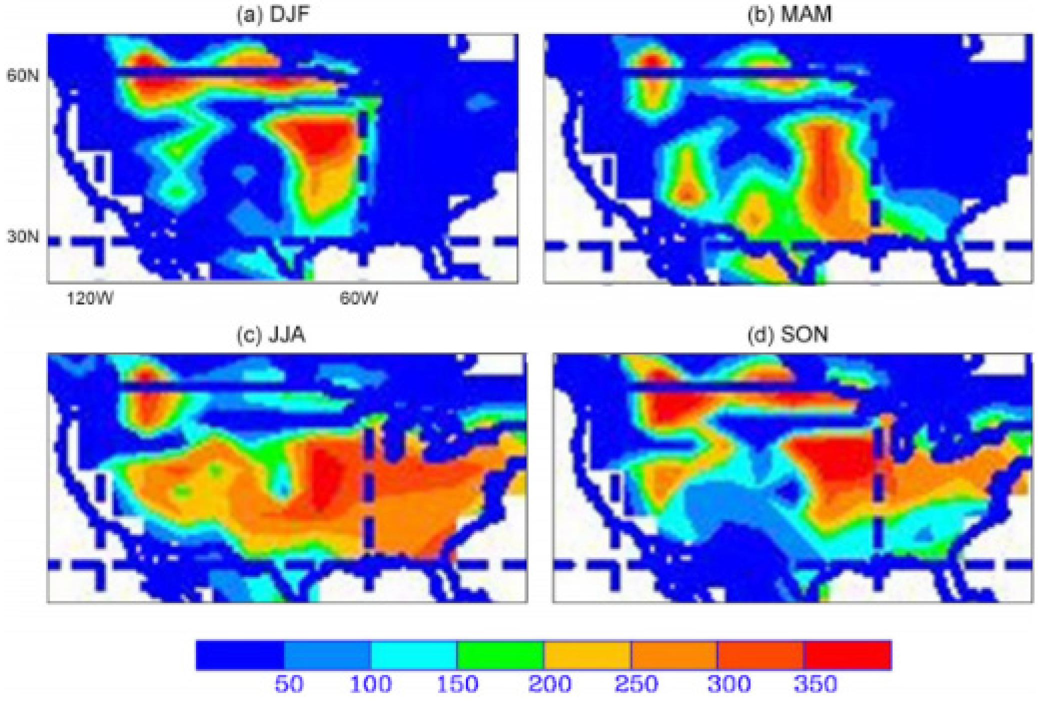


Figure Y – Projected changes to KBDI (mm) by annual quarter (Liu et al., 2009)

Table 1: Current monthly precipitation and projected decrease in KBDI and available water for precipitation by 2050, for 31ºN, 91.5ºW.

	Mean current precipitation (mm)	Projected decrease (mm) in available moisture in upper litter layers (KBDI)	Projected decrease in available water as a percentage of current precipitation (%)
January	133.8	17	12.7
February	139.5	17	12.2
March	159.7	38	23.8
April	130	38	29.2
May	132.6	38	28.7
June	95.6	38	39.7
July	94	38	40.4
August	82.4	38	46.1
September	80.1	17	21.2
October	74.1	17	22.9
November	113	17	15
December	128.6	17	13.2

Recent research (Krueger et al., 2017) suggests that the fraction of available water (FAW) is a better predictor of large growing-season wildfires than the KBDI. FAW is calculated as the ratio of plant available water to soil water capacity. But FAW has not yet been projected as confidently to 2050 as precipitation.

Wildfire Risk Assessment:

Property loss due to wildfire is calculated as

$$L_{2043,i} = I_{2043,i} \times p(f)_i \times p(d|f)_i \times F_i$$

where,

$L_{2043,i}$=projected annual preperty loss of census block i in 2043
$I_{2043,i}$=estimated total building inventory value of census block i in 2043
$p(d|f)_i$ = conditional probability of damage of census block i when a fire occurs
$p(f)_i$ = probability of fire occurrence of census block i
F_i= future hazard multiplication factor for census block i in 2043

We summed the probability of large fires from FSim and calculated the annual probability of small fires using FPA data. Based on LDAF records 2007–2017, 12,979 Louisiana residences have been threatened by fire. Of these, 389 were damaged and 12,590 were protected, a relative damage frequency of 0.03. Therefore, $p(d|f) = 0.03$. The losses were calculated, assuming that 3% of buildings exposed to fire were damaged, with a relative loss of 5% of the value of each building.

References:

Krueger, E.S., T.E. Ochsner, S.M.Quiring, D.M. Engle, J.D. Carlson, D. Twidwell, and S.D. Fuhlendorf, 2017: Measured soil moisture is a better predictor of large growing-season wildfires than the Keetch-Byram Drought Index. Soil Science Society of America Journal 81:490–502. doi: 10.2136/sssaj2017.01.0003.

Liu, Y.; Stanturf, J.A.; Goodrick, S.L. 2009. Trends in global wildfire potential in a changing climate. Forest Ecology and Management 259:685–697. doi: 10.1016/j.foreco.2009.09.002.

Pope, V., Gallani, M.L., Rowntree, P.R., Stratton, R.A., 2000. The impact of new physical parameterizations in the Hadley Centre climate model: HadAM3. Climate Dynamics 16:123–146.

Prestemon, J.P., U. Shankar, A. Xiu, K. Talgo, D. Yang, E. Dixon, D. McKenzie, and K.L. Abt, 2016: Projecting wildfire area burned in the south-eastern United States, 2011–60. International Journal of Wildland Fire, 25:715–729. doi: 10.1071/WF15124.

Wehner, M.F., J.R. Arnold, T. Knutson, K.E. Kunkel, and A.N. LeGrande, 2017: Droughts, floods, and wildfires. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 231-256. doi: 10.7930/J0CJ8BNN.

Future Conditions: Tropical Cyclones

Future vulnerability to tropical cyclones has been a topic of intense scrutiny in the scholarly literature of the last decade. On the one hand, several natural processes linked to enhancement of tropical cyclones might seem to become more favored in a warming world. For example, warming would increase the geographic extent at which water temperatures are high enough to provide the energy required to support or enhance a tropical cyclone and/or lead to a longer period in the year in which tropical cyclones may occur. Also, because the Earth's surface is anticipated to warm at a greater rate than the upper-level atmosphere, thermal turbulence and atmospheric instability would be enhanced, possibly leading to more evaporation from the surface. Atmospheric water vapor capacity would also increase under warmer conditions. Furthermore, a warming world could also be likely to cause a poleward retreat in the west-to-east-moving subtropical and polar front jet stream, both of which separate tropical air from much colder air. Because the jet streams shear the tops off of developing tropical cyclones, their migration poleward would provide a more favorable environment for growth of tropical systems, unimpeded by the shear that might weaken them or carry them eastward across the Atlantic Ocean, away from Louisiana. These concerns are exacerbated by research that suggests a tight linkage between global temperature and tropical cyclone activity via feedbacks related to ocean mixing and transport (Sriver, 2010).

On the other hand, simulation models do not necessarily agree that the frequency of tropical cyclones will increase in a warming world. Bengtsson et al. (2007) projected a 20 percent decrease in frequency by the end of the 21st Century, including a 5-10 percent decrease in the Gulf of Mexico from the 20th to the 21st Century. Ensemble modeling by Colbert et al. (2013) suggested that the weakening easterly trade winds under double CO2 conditions (i.e., 720 ppm) by 2100 would decrease the frequency of tropical cyclones in the Gulf of Mexico by one to 1.5 per decade. Wang and Wu (2013) isolated the impacts of global warming from that attributable to the Atlantic Multidecadal Oscillation (AMO) a naturally-occurring warm-cold oscillation of Atlantic Ocean temperatures that began its most recent warm phase in 1995 with the conclusion that global warming causes an eastward shift in the Atlantic tropical cyclone genesis zone, while the warm-phase AMO is responsible for basinwide enhancement. The implication is that frequency may decrease when the AMO flips back to the cold phase in the coming decades. More recent work, summarized in the Fourth National Climate Program Assessment (Kossin et al., 2017) suggests that, with low confidence, the frequency of the most intense Atlantic tropical cyclones is projected to increase.

The impact of global warming on the intensity of tropical cyclones, however, is a different matter. Bengtsson et al. (2007) projected no decreases, and perhaps a substantial increase, in the frequency of the most intense tropical cyclones. Tory et al. (2013) confirmed such projections with a new generation of models.

The most recent research on the topic generally seems to confirm the "increased intensity" conclusions of previous studies, with warning of additional dangers associated with the increased intensity of tropical cyclones under a warming global climate. For example, Moore et al. (2015) concurred with the previous conclusions, while also anticipating a decrease in the periodicity of the El Niño/Southern Oscillation, which is known to suppress Gulf-Caribbean-Atlantic tropical cyclone activity. The resulting increased interannual variability could leave people uncertain of the trend of the hazard. Walsh et al. (2016) projected increases in tropical cyclone precipitation intensities in addition to the changes previously discussed. Such precipitation could increase even farther inland than today. Sun et al. (2017) noted that the area of the tropical cyclone-induced high winds will increase under global warming scenarios. And Appendini et al. (2017) warned that the wave activity associated with tropical cyclones will likely increase in the northern Gulf of Mexico under global warming scenarios. The Fourth National Climate Assessment (Kossin et al., 2017) provides an ominous reminder that atmospheric scientists tend to be converging toward a conclusion on the matter:

"Both theory and numerical modeling simulations generally indicate an increase in tropical cyclone (TC) intensity in a warmer world, and the models generally show an increase in the number of very intense TCs. For Atlantic and eastern North Pacific hurricanes and western North Pacific typhoons, increases are projected in precipitation rates (high confidence) and intensity (medium confidence)."

In general, however, more work is needed, particularly under assumptions of less drastic increases in CO2 emissions, with a focus on the middle of the 21st century rather than the end, and at the regional rather than the basinwide scale.

Scholars have also estimated the future impacts resulting from such a consensus of increases in intensity and/or frequency of the most intense tropical cyclones. While emphasizing the inherent uncertainty and difficulty with projecting the future tropical cyclone hazard, Knutson et al. (2010) cautiously projected no major macro-scale changes in tropical cyclone genesis location, tracks, duration, or areas of impact, but cautioned that the future vulnerability to tropical-cyclone-induced storm surge-related flooding will increase due to sea level rise and coastal development. Ranson et al. (2014) used ensemble models to project a 63 percent increase in tropical cyclone damage in the North Atlantic basin, the highest increase of any basin in the world.

Regardless of projections of the impact of global warming on regional tropical cyclone activity, Louisiana will always be in a geographic position in which tropical cyclones may track. Any increased intensities in the future, even with decreased frequencies, are likely to enhance Louisiana's future vulnerability, given that the intense storms have enormous potential to devastate the physical, urban, agricultural, economic, and sociocultural infrastructure of our state. We project a 25 percent increase in the future vulnerability to tropical cyclones, with a near-certain expectation that Louisiana will experience another major tropical cyclone before mid-century.

References:

Appendini, C.M. A. Pedrozo-Acuña, R. Meza-Padilla, A. Torres-Freyermuth, R. Cerezo-Mota, J. López-González, and P. Ruiz-Salcines, 2017: On the role of climate change on wind waves generated by tropical cyclones in the Gulf of Mexico. Coastal Engineering Journal 59(2), Art No. 1740001.

Bengtsson, L., K.I. Hodges, M. Esch, N. Keenlyside, L. Kornblueh, J.J. Luo, and T. Yamagata, 2007: How may tropical cyclones change in a warmer climate? Tellus Series A – Dynamic Meteorology and Oceanography 59:539-561.

Colbert, A.J., B.J. Soden, G.A. Vecchi, and B.P. Kirtman, 2013: The impact of anthropogenic climate change on North Atlantic Tropical Cyclone Tracks. Journal of Climate 26:4088-4095.

Knutson, T.R., J.L. McBride, J. Chan, K. Emanuel, G. Holland, C. Landsea, I. Held, J.P. Kossin, A.K. Srivastava, and M. Sugi, 2010: Tropical cyclones and climate change. Nature Geoscience 3:157-163.

Kossin, J.P., T. Hall, T. Knutson, K.E. Kunkel, R.J. Trapp, D.E. Waliser, and M.F. Wehner, 2017: Extreme storms. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 257-276, doi: 10.7930/J07S7KXX.

Moore, T.R., H.D. Matthews, C. Simmons, and M. Leduc, 2015: Quantifying changes in extreme weather events in response to warmer global temperatures. Atmosphere-Ocean 53, 412-425.

Ranson, M., C. Kousky, M. Ruth, L. Jantarasami, A. Crimmins, and L. Tarquinio, 2014: Tropical and extratropical cyclone damages under climate change. Climatic Change 127, 227-241.

Sriver, R.L., 2010: Climate change: tropical cyclones in the mix. Nature 463(7284), 1032-1033.

Sun, Y., Z. Zhong, T. Li, L. Yi, Y.J. Hu, H.C. Wan, H.S. Chen, Q.F. Liao, C. Ma, and Q.H. Li, 2017: Impact of ocean warming on tropical cyclone size and its destructiveness. Scientific Reports 7, Art. No. 8154.

Tory, K.J., S.S. Chand, J.L. McBride, H. Ye, and R.A. Dare, 2013: Projected changes in late-twenty-first-century tropical cyclone frequency in 13 coupled climate models from Phase 5 of the Coupled Model Intercomparison Project. Journal of Climate 26, 9946-9959.

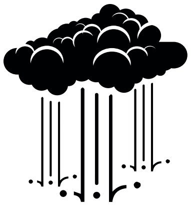
Walsh, K.J.E., J.L. McBride, P.J. Klotzbach, S. Balachandran, S.J. Camargo, G. Holland, T.R. Knutson, J.P. Kossin, T.-c. Lee, A. Sobel, and M. Sugi, 2016: Tropical cyclones and climate change. Wiley Interdisciplinary Reviews-Climate Change 7, 65–89.
Wang, R.F. and L.G. Wu, 2013: Climate changes of Atlantic tropical cyclone formation derived from twentieth-century reanalysis. Journal of Climate 26, 8995-9005.

Future Conditions: High Wind

Future frequency of high wind events is particularly difficult to predict, because high wind may accompany many different types of storms, each with their own distinct patterns of projected changes. NCA4 (2017; https://science2017.globalchange.gov) is again the most comprehensive source that synthesizes recent research on the topic. That document reports:

"Climate models consistently project environmental changes that would putatively support an increase in the frequency and intensity of severe thunderstorms (a category that combines tornadoes, hail, and winds), especially over regions that are currently prone to these hazards, but confidence in the details of this projected increase is low."

Even though the frequency of the most intense tropical cyclones and tornadoes is expected to increase, such events are rare. High wind events are much more commonly linked to thunderstorms, for which there is presently little evidence of a change in frequency by mid-century. Therefore, we estimate no change to future conditions.



Future Conditions: Hail

Unlike most other forms of severe weather, hail has been studied fairly comprehensively for temporal trends and relationship to global climate change. As was described in the severe thunderstorm future vulnerability section, intuitively, several counteracting potential forces seem to be at work. Increases in surface temperatures, at a rate exceeding the increase in upper-atmospheric temperatures, would destabilize the atmosphere further. In other words, the warmed air at the surface would acquire increased buoyancy, allowing for enhancement in vertical cloud growth, assuming that adequate moisture is present, which would in turn support stronger and perhaps more frequent hail events. The energized atmosphere under global warming situations would also presumably provide more evaporation over the oceans, which would indeed contribute the moisture needed to produce the enhanced cumulonimbus clouds that would support hail-bearing thunderstorms. However, an atmosphere in which the poles warm more strongly than the tropical parts of the Earth might be expected to weaken the tropical-to-pole gradient of energy, and therefore weaken frontal boundaries separating the two, making hail-bearing thunderstorms less frequent and intense. Likewise, any increases in atmospheric temperature might be more likely to allow hail that forms to melt partially or completely when precipitating.

In China, observational reports of a decrease in both the number of hail days (Xie et al., 2008) and the size of hail (Ni et al. 2017) have been identified. In a follow up study, Xie et al. (2010) found no significant trends in hail size across five provinces analyzed, as increases in convective available potential energy (CAPE) – a thermodynamic indicator of severe thunderstorms that often produce hail – tended to be offset by an increase in the height of the freezing level, which would tend to oppose hail generation. These results generally support the notion that opposing meteorological factors are at work.

Recent studies in a given part of the world often have conflicting results regarding future hail occurrence. For example, modeling work suggests future decreases in CAPE in southeastern Australia under enhanced greenhouse concentrations (Niall and Walsh, 2005). However, Leslie et al. (2008) disagree, reporting model simulations of a gradual increase in frequency and intensity of hailstorms in the Sydney Basin out to 2050. In Europe, Sanderson et al. (2015) projected a decrease in damaging hailstorms in the United Kingdom throughout the 21st century. Dessens et al. (2015) generally concur for the southern Atlantic French coast, forecasting a slight decrease in the number of hailstorms, but with no significant change in hail frequency by 2040. On the other hand, observational studies suggest that synoptic environments that favor hail precipitation have increased in the Mediterranean region (Sanchez et al., 2017) and much of central Europe (Mohr and Kunz, 2013). Bayesian modeling suggests a modest increase in the number of hail days by 2031-2045 in Germany (Kapsch et al., 2015). In the United States, Mahoney et al. (2012) used high-resolution modeling to predict substantial decreases in hail frequency in the Colorado mountains by mid-century (2041-2070). But Allen (2017) disagreed, suggesting a potential increase in both the mean hail size and the frequency of major hailstorms in North America. Brooks (2013) summarized previous work by suggesting that CAPE can be expected to increase in the future, while wind shear will decrease, leaving the net effect on tornado and hail occurrence in the future open to question. Again, this conclusion supports the notion that theoretical factors important to generating hail under a warming climate are in opposition.

In perhaps the most comprehensive recent study of future hail events in North America, Brimelow et al. (2017) used sophisticated modeling techniques to conclude that fewer days of small, medium, and large hail are expected over much of North America over the 2041-2070 period, including the U.S. Southeast and Louisiana, in spring and summer (Figure X). Figure X does suggest some possible increase in the frequency of large hail for southeastern Louisiana.

The Fourth National Climate Assessment (2017) cites Allen and Tippett (2015) in reaching the conclusion that although evidence exists for an increasing hail frequency in the U.S., the uncertainty in reported hailstone size reduces the confidence in projections (Kossin et al. 2017). Given the conflicting theoretical impacts of hail above, the comprehensiveness of the Brimelow et al. (2017) work, and the near-certainty of an increased population to be impacted, we project no net change in the future vulnerability to hail in Louisiana by mid-century.

References:

Allen, J.T., 2017: Atmospheric hazards hail potential heating up. Nature Climate Change 7:474–475.

Allen, J.T. and M.K. Tippett, 2015: The characteristics of United States hail reports: 1955–2014. E-journal of Severe Storms Meteorology 10.

Brimelow, J.C., W.R. Burrows, and J.M. Hanesiak, 2017: The changing hail threat over North America in response to anthropogenic climate change. Nature Climate Change 7:516–523.

Brooks, H.E., 2013: Severe thunderstorms and climate change. Atmospheric Research 123:129–138.

Dessens, J., C. Berthet, and J.L. Sanchez, 2015: Change in hailstone size distributions with an increase in the melting level height. Atmospheric Research 158:245–253.

Kapsch, M. L., Kunz, M., Vitolo, R. & Economou, T. Long-term variability of hail-related weather types in an ensemble of regional climate models. J. Geophys. Res. 117, D15 107 (2012).

Kossin, J.P., T. Hall, T. Knutson, K.E. Kunkel, R.J. Trapp, D.E. Waliser, and M.F. Wehner, 2017: Extreme storms. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 257–276.

Leslie, L. M., M. Leplastrier, & B.W. Buckley, 2008: Estimating future trends in severe hailstorms over the Sydney Basin: A climate modelling study. Atmospheric Research 87:37–51.

Mahoney, K., M.A. Alexander, G. Thompson, J.J. Barsugli, and J.D. Scott, 2012: Changes in hail and flood risk in high-resolution simulations over Colorado's mountains. Nature Climate Change 2:125–131.

Mohr, S. & M. Kunz, 2013: Recent trends and variabilities of convective parameters relevant for hail events in Germany and Europe. Atmospheric Research 123:211–228.

Ni, X., Q.H. Zhange, C.T. Liu, X.F. Li, T. Zou, J.P. Lin, H.I. Kong, and Z.H. Ren, 2017: Decreased hail size in China since 1980. Scientific Reports 7, Art. No. 10913.

Niall, S. & K. Walsh, 2005: The impact of climate change on hailstorms in Southeastern Australia. International Journal of Climatology 25:1933–1952.

Sanchez, J.L., A. Merino, P. Melcon, E. Carcia-Ortega, S. Fernandez-Gonzalez, C. Berthet, and J. Dessens, 2017: Are meteorological conditions favoring hail precipitation change in southern Europe? Analysis of the period 1948-2015. Atmospheric Research 198:1–10.

Sanderson, M.G., W.H. Hand, P. Groenejeijer, P.M. Boorman, J.D.C. Webb, and L.J. McColl, 2015: Projected changes in hailstorms during the 21st century over the UK. International Journal of Climatology 35:15–24.

Xie, B., Q. Zhang, and Y. Wang, 2008: Trends in hail in China during 1960–2005. Geophysical Research Letters 35 (2008), p. LI 3801.

Xie, B., Q. Zhang, Y. Wang, 2010: Observed characteristics of hail size in four regions in China during 1980–2005. Journal of Climate 23:4973–4982.

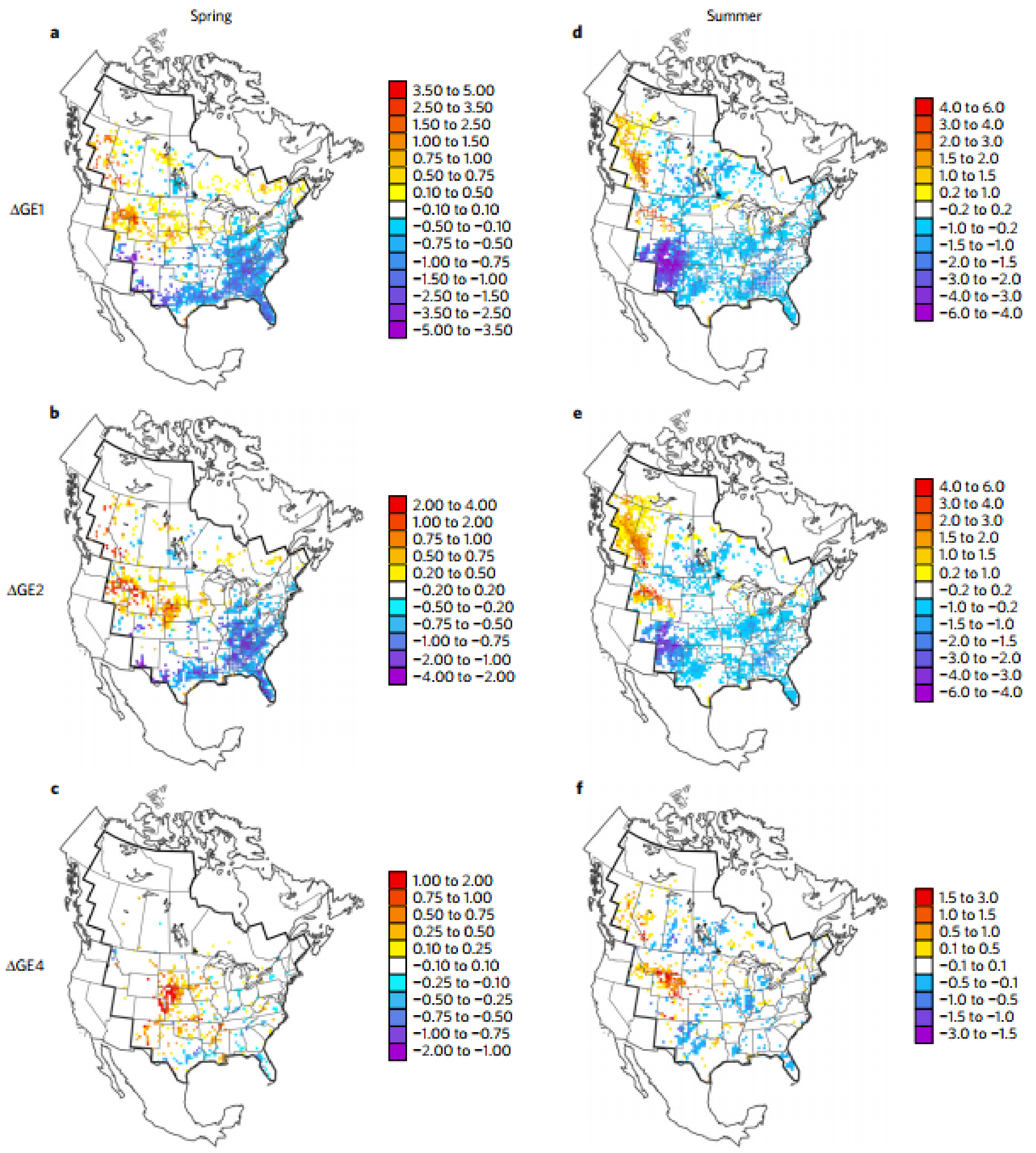
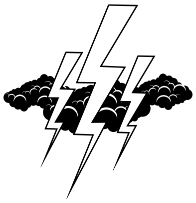


Figure 1 | Spatial changes in hail diameter classes for spring and summer. a–c, Mean multi-model changes in future (2041–2070) minus present (1971–2000) for spring hail days (GE1; $D_s \geq 1.0$ cm) per season (**a**), severe hail days (GE2; $D_s \geq 2$ cm) per season (**b**), and very large-hail days (GE4; $D_s \geq 4$ cm) per season (**c**). **d–f**, The same variables as for **a–c**, except for summer. Coloured cells indicate mean changes for all model pairings that agree on the direction of change; cells with coloured circles indicate mean changes for at least two model pairings that are statistically significant (90% significance).

Source: Verbatim from Brimelow et al. (2017)



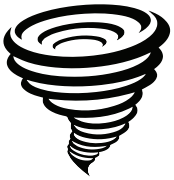
Future Conditions: Lightning

Future changes to lightning frequency in the southern U.S. are not discussed directly in NCA4 (2017), nor is the topic covered extensively in the refereed literature. As was described in the assessment of future conditions for high winds, there is currently low confidence in projection of severe thunderstorms. Furthermore, there is even less evidence for changes in weak to moderate thunderstorms. Because weak to moderate thunderstorms are much more frequent than severe thunderstorms, collectively they produce most of the lightning strokes. Therefore, there is very little certainty in any changes in lightning by mid-century. Recent research from China (Yang et al. 2018) suggests that future increases can be expected. For the U.S. as a whole, a suite of 11 general circulation models predicted mean increases in lightning strikes for the 2079-2088 period of between 3.4% and 17.6% per °C of temperature increase (Romps et al. 2014). Based on this seminal paper, a 10 percent increase in the lightning hazard is assumed by 2050 for Louisiana.

References:

Romps, D.M., J.T. Seeley, D. Vollaro, J. Molinari, 2014: Projected increase in lightning strikes in the United States due to global warming. Science 346(6211): 851–854

Yang, Y.R., D. Song, S.Y. Wang, P. Li, and Y. Xu, 2018: Characteristics of cloud-to-ground lightning and its relationship with climate change in Muli, Sichuan province, China. Natural Hazards 91: 1097–1112.



Future Conditions: Tornadoes

The updraft of air in tornadoes always rotates because of wind shear (differing horizontal speed height), 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.

The Enhanced Fujita (EF) Scale is used to classify 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.

Enhanced Fujita (EF) Scale.

Enhanced Fujita Scale						
	EF0	EF1	EF2	EF3	EF4	EF5
Wind Speed	65-85 mph	86-110 mph	111-135 mph	136-165 mph	166-200 mph	>200 mph

Any estimates on changing tornado frequencies or intensities should begin with an assessment of the likelihood of changing precursor conditions for tornadoes. Increases in the frequency of convergence of very warm, humid air masses with very cold air masses and/or increases in the intensity of the temperature gradient across air masses would be likely to increase the tornado frequency and/or intensity, and therefore presumably increase vulnerability to tornadoes. Likewise, increasing vertical temperature gradients between the surface and aloft (i.e. more rapid decreases in temperature with increasing height) would also make tornadoes stronger and/or more likely, and therefore exacerbate tornado vulnerability. A related ingredient is vertical wind shear (i.e., sharp increases in wind speed with increasing height), with increasing vertical wind shear over time promoting increasing situations of the horizontal rotation that could then be raised to a vertically oriented rotating mass if warming air near the surface increases the tendency for it to rise. Increases in tropical cyclone frequency would also be likely to increase the number of tropical cyclone-induced tornadoes, and presumably tornado vulnerability. And finally, enhancements in detection capabilities and increasing population generally would increase the number of reported tornadoes, particularly weaker ones.

There remains a general lack of consensus regarding the impact of global climatic change on tornado frequency and/or intensity (Long and Stoy, 2014). Part of the difficulty in making such projections is the large difference in scale between global climate change projections and the local nature of the weather conditions that create tornadoes (Mika, 2013), along with an incomplete understanding of the physics involved (Moore et al., 2015). Nevertheless, the existing scientific literature can give at least some basis for assessing tornado vulnerability regarding the scenarios described in the previous paragraph. Atmospheric scientists overwhelmingly agree that global temperatures will continue increasing, though the magnitude and rate of increase will vary spatially, seasonally, and within the diurnal cycle (National Climate Assessment, 2017; https://science2017.globalchange.gov).

As was discussed, temperature is expected to increase in Louisiana at least through mid-century. Increasing temperatures would logically move the boundary between the cold and warm air masses poleward, leaving Louisiana farther from the most dangerous zone for tornadic development a larger percentage of the time, and therefore reduce tornado frequency and/or intensity. Because tornado frequency in Louisiana is less seasonal than in most other places, the nuances of changing tornado vulnerability may be slightly less dependent on the uncertainties of the seasonal temperature changes than in most other places.

However, the other factors that also impact tornado frequencies must also be considered. As suggested above, tornadic activity is also favored when very warm, humid air near the surface underlies air that is much colder aloft. Thus, amplification of the temperature difference between the surface and the upper atmosphere (i.e., destabilizing the atmosphere) might be considered to enhance the probability of tornadic development. Brooks (2013) used climate model simulations to conclude that indeed, that vertical gradient, as represented by convective available potential energy (CAPE), is projected to increase into the future. However, Brooks (2013) also noted that the vertical wind shear needed for tornadic development is generally weakening under global change climate simulations. Gensini et al. (2014) noted through the use of a regional model simulation that extreme destabilization of the atmosphere (in the form of the number of days having an extremely high CAPE) is likely to increase over a large section of the northeastern U.S.A., which would make tornadoes more likely. However, the same study showed that CAPE is likely to decrease over nearly all of Louisiana, at least when the 2041-2065 period is compared to the 1981-1995 interval, which would create a less favorable environment for tornadoes.

On the other hand, Diffenbaugh et al. (2013) disagreed, noting that the days with weakening vertical wind shear tend to be concentrated on days when CAPE is low; with high-CAPE days showing less evidence of weakening shear. Seeley and Romps (2015) generally concurred with Diffenbaugh et al. (2013), excepting that their analysis was for severe thunderstorms rather than tornadoes per se. Through ensemble modeling, Seeley and Romps (2015) found consistent spring and summer increases in the frequency of severe-thunderstorm environments over the U.S., including Louisiana, from 2079-2088, as represented by high CAPE days and vertical wind shear, under medium and high scenarios of greenhouse forcing.

Furthermore, tornadic development also occurs in association with tropical cyclones, so any changes in tropical cyclone frequency and/or intensity might be coincident with a change in tropical-cyclone-induced tornadic development. As previously discussed, tropical cyclones are expected to become more problematic in the future, even if only because of increased coastal population. Therefore, in the absence of prevailing scientific consensus on the topic in the refereed literature, it seems reasonable to suggest that the tropical-cyclone-induced tornado hazard will follow a proportionate increase to that of tropical cyclones for Louisiana.

And finally, as tornado detection capabilities continue to improve due to larger populations and improved equipment to observe their occurrence, tornado frequencies are expected to increase.

When comparing the 1954–1983 period to the 1984–2013 period, Agee et al. (2016) found that, not surprisingly, winter was the season in which the most prominent tornado frequency increases occurred. For Louisiana, that study showed an increase in the latter period in (E)F1–(E)F5 tornadoes, but decreases in the (E)F2–(E)F5 and in the (E)F3–(E)F5 tornadoes. However, Louisiana experienced a simultaneous decrease in the number of days on which a tornado occurred (Agee et al, 2016), which suggests that tornado outbreaks may be becoming more frequent, even while tornado frequencies are not. Tippett et al. (2016) concurred, suggesting that increases in larger outbreaks will be more pronounced than increases in smaller outbreaks. And importantly, NCA4 (2017) agrees that the frequency of tornado days in the U.S. as a whole has decreased since 1970, but that the number of tornadoes touching down on those days has increased over the same time period (Kossin et al., 2017). The latter study also reports an earlier onset of tornado season in the United States.

Modeling studies of future tornadic activity reveal a mixed bag. Trapp and Hoogewind (2016) found that updrafts, while intense under projected increases in CAPE by the latter 21st century, do not increase proportionately to the projected CAPE. Kossin et al. (2017) agree in NCA4, as historical tornado outbreaks such as the Joplin, Missouri, tornadoes of 2011 do not become even more severe when placed in an environment of CAPE by the late 21st century, but nor do such outbreaks break apart either.

As coastal population increases and temperature rises, the destabilization in the atmosphere could result in more frequent tornado outbreaks, which would occur when abundant vertical wind shear is present over Louisiana and/or in the presence of a tropical cyclone. However, the literature is uncertain on whether the windows of time in which these conditions are met may change.

All of these factors lead us to estimate an increase in future vulnerability to tornadoes by 10% by 2050.

References:

Agee, E., J. Larson, S. Childs, and A. Marmo, 2016: Spatial redistribution of U.S. tornado activity between 1954 and 2013. Journal of Applied Meteorology and Climatology 55(8), 1681–1697.

Brooks, H.E., 2013: Severe thunderstorms and climate change. Atmospheric Research 123, 129–138.

Diffenbaugh, N.S., M. Scherer, and R.J. Trapp, 2013: Robust increases in severe thunderstorm environments in response to greenhouse forcing. Proceedings of the National Academy of Sciences of the United States of America 110(41), 16361–16366.

Kossin, J.P., T. Hall, T. Knutson, K.E. Kunkel, R.J. Trapp, D.E. Walisre, and M.F. Wehner, 2017: Extreme storms. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 257–276. doi: 10.7930/J07S7KXX.

Long, J.A. and P.C. Stoy, 2014: Peak tornado activity is occurring earlier in the heart of "Tornado Alley." Geophysical Research Letters 41, 6259–6264.

Mika, J., 2013: Changes in weather and climate extremes: Phenomenology and empirical approaches. Climatic Change 121(1), 15–26.

Moore, T.R., H.D. Matthews, C. Simmons, and M. Leduc, 2015: Quantifying changes in extreme weather events in response to warmer global temperature. Atmosphere-Ocean 53(4), 412–425.

Seeley, J.T. and D. M. Romps, 2015: The effect of global warming on severe thunderstorms in the United States. Journal of Climate 28(6), 2443–2458.

Tippett, M.K., C. Lepore, and J.E. Cohen, 2016: More tornadoes in the most extreme U.S. tornado outbreaks. Science 354(6318), 1419–1423.

Trapp, R. J. and K.A. Hoogewind, 2016: The realization of extreme tornadic storm events under future anthropogenic climate change. Journal of Climate 29, 5251–5265.

Future Conditions: Floods

As noted in NCA4 (2017), projection of the flood hazard to 2050 is a complex multivariate problem, as human activities such as deforestation, urban development, construction of dams, flood mitigation measures, and changes in agricultural practices impact future flood statistics. In addition, Louisiana's geography superimposes such local-to-regional-scale changes on similar changes upstream over a significant portion of the nation, and these changes are superimposed on climatic changes and eustatic sea level rise.

Despite the fact that these complications invite caution in the interpretation of results, it is safe to conclude that flood is likely to remain Louisiana's costliest, most ubiquitous, and most life-threatening hazard. This is because floods are the by-product of several other hazards profiled earlier in this report, including thunderstorms, tropical cyclones, coastal hazards, dam failure, and levee failure. The "future conditions" sections of those hazards (presented earlier in this report) projected changes in vulnerability as summarized in Table X below.

Table X. Estimated change in future vulnerability in Louisiana by 2050, by hazard

Hazard	Estimated Change in Future Vulnerability by 2050 (%)
Severe thunderstorms	10
Tropical cyclones	25
Coastal hazards	"High"
Dam failure	0
Levee failure	0

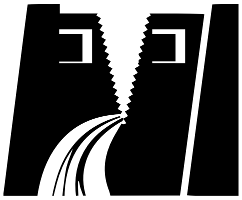
Based on the information summarized in Table X, there is no reason to expect that the flood hazard in Louisiana will abate, particularly as population increases. We fully support the use of Louisiana's Comprehensive Master Plan for a Sustainable Coast in planning for the future flood hazard.

However, the news is not all dire, nor is the situation hopeless. By some accounts, the rate of coastal land loss has shown some signs of slowing. Renewed commitment to smart-growth strategies, especially in floodplains, levee-protected areas, and in the area vulnerable to direct inundation from storm surge or meteotsunami, will mitigate the future flood disaster. These strategies include, but are not limited to, the "multiple lines of defense" approach (Lopez, 2009) and effective implementation of recommendations in Louisiana's Comprehensive Master Plan for a Sustainable Coast (Coastal Protection and Restoration Authority of Louisiana, 2017). And there are several effective examples of environmental challenges that have been mitigated through public awareness/education, and mutual resolve (e.g., ozone hole, oil spills, nuclear power plant meltdowns, etc.). While the flooding hazard in Louisiana will never be eliminated, it is possible that we can coexist sustainably alongside the hazard.

References:

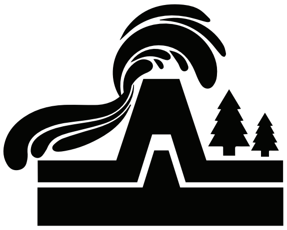
Ashley, S.T. and W.S. Ashley, 2008: Flood fatalities in the United States. Journal of Applied Meteorology and Climatology 47:805–818.

Coastal Protection and Restoration Authority of Louisiana. 2017. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Coastal Protection and Restoration Authority of Louisiana. Baton Rouge, LA.
Louisiana's Comprehensive Master Plan for a Sustainable Coast.
Lopez, J.A., 2009: The multiple lines of defense strategy to sustain coastal Louisiana. Journal of Coastal Research 54:186–197.



Future Conditions: Dam Failures

Even if extreme precipitation events would increase in frequency and/or magnitude in the future and earthquake probability increases, there is no evidence to suggest that future conditions would contribute to an enhanced likelihood of dam failures due to natural causes. As the dams are designed to standards, this should already be contemplated in the design guidance. The anthropogenic component of the dam failure hazard is beyond the scope of this analysis. Therefore, despite anticipated increases in other natural hazards, there is no indication that these increases will result in additional dam failures, at least from a natural hazard perspective.



Future Conditions: Levee Failures

Any assessment of the future conditions relating to levee failures in Louisiana must begin with an assessment of the future conditions relative to the natural hazards that would most likely cause the levees to fail. These hazards include tropical cyclones (including storm surge), flooding, and earthquakes. Earlier reports in this document have assessed each of these hazards as likely to increase in the future.

Possible opposing forces that might mitigate the levee hazard include smart growth, lessons learned from the Katrina levee failures, new science and technology, and improved engineering.

To calculate the current probability of failure, it is conservatively assumed that 2,000 distinct levee breaches have occurred nationally in the past 25 years. This figure includes The Great Flood of 1993, where Mississippi River levees were overtopped or breached in over 1,000 locations, and Hurricane Katrina in 2005, where 50 levee breaches were reported to have occurred. Assuming a distance of 1 mile between distinct breaches and the 29,828 miles of levees in the U.S. (https://levees.sec.usace.army.mil/#/), the probability of failure within one mile of levee is calculated as:

$$\left.\frac{2{,}000\text{ breaches}}{29{,}828\text{ miles of levees}}\right/ 25\text{ years} = 0.3\%\text{ annual probability}$$

But because the previous occurrences for this hazard are rare, the increased hazard in the future will be minimal.

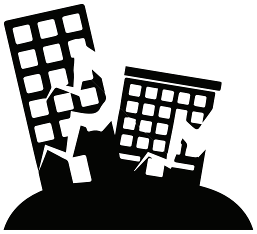
There are no future conditions related to the levees themselves that would enhance the probability of levee failures due to natural causes. Design guidance and oversight in the future should ensure that the levees are designed to appropriate engineering standards. Therefore, even though we anticipate increases in rainfall and earthquake hazards, there is no indication that these increases will result in additional levee failures.

Geologic Hazards

Earthquake

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. 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 a more than thirty-fold increase in energy released). An increase by two whole numbers represents a 102 (or 100-fold) increase in ground motion, and thus more than 302 (or 900) times the energy released. Intensity is a measure of how strongly the shock was felt at a particular location, indexed by the Modified Mercalli Intensity (MMI) scale.

A fault is a fracture in the Earth's crust where movement occurs on one side relative to the other. Known faults in Louisiana are often caused by subsidence. 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, including 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).



Future Conditions: Earthquakes

Earthquakes are considered by most to be among the least ominous hazards in Louisiana's future. However, there are several indications that the hazard in Louisiana is likely to increase in the future. First, wastewater injection into deep wells, oil and gas exploration, and hydraulic fracturing ("fracking") are believed to be contributing to a sudden increase in earthquake activity, especially in the oil and gas mining areas, with such activities showing no signs of decrease in the near future. In the most comprehensive recent research on the earthquake hazard for the central and eastern U.S., Petersen et al. (2016) found that seismicity has increased by up to one order of magnitude over the last decade in some oil and gas-producing areas. While Petersen et al. (2016) found no induced earthquakes reported in Louisiana over the 2014–2015 period, several earthquakes associated with wells were reported in nearby adjacent Arkansas and Texas (Figure X.Y). Walter et al. (2016) suggested that seismicity is indeed increasing in northwestern Louisiana in response to energy extraction activities. Second, Louisiana lies sufficiently near the New Madrid fault to be impacted by future movement, as it was during the series of quakes from 1811 to 1812. Page and Hough (2014) found no evidence to suggest that the seismicity associated with this fault is decaying with time. Increasing development over time would make any impacts to the Mississippi River, including but not limited to a catastrophic change of its course as happened in 1811-1812, catastrophic. These impacts could trigger a levee failure. And third, the continuing lax building codes for mitigating earthquake damage invites additional concern for an increased future vulnerability to this hazard. If anything, elevation of structures to mitigate the flood, storm surge, rising sea level, and tropical cyclone hazards might increase vulnerability to damage from non-Mississippi-River-impacted earthquakes.

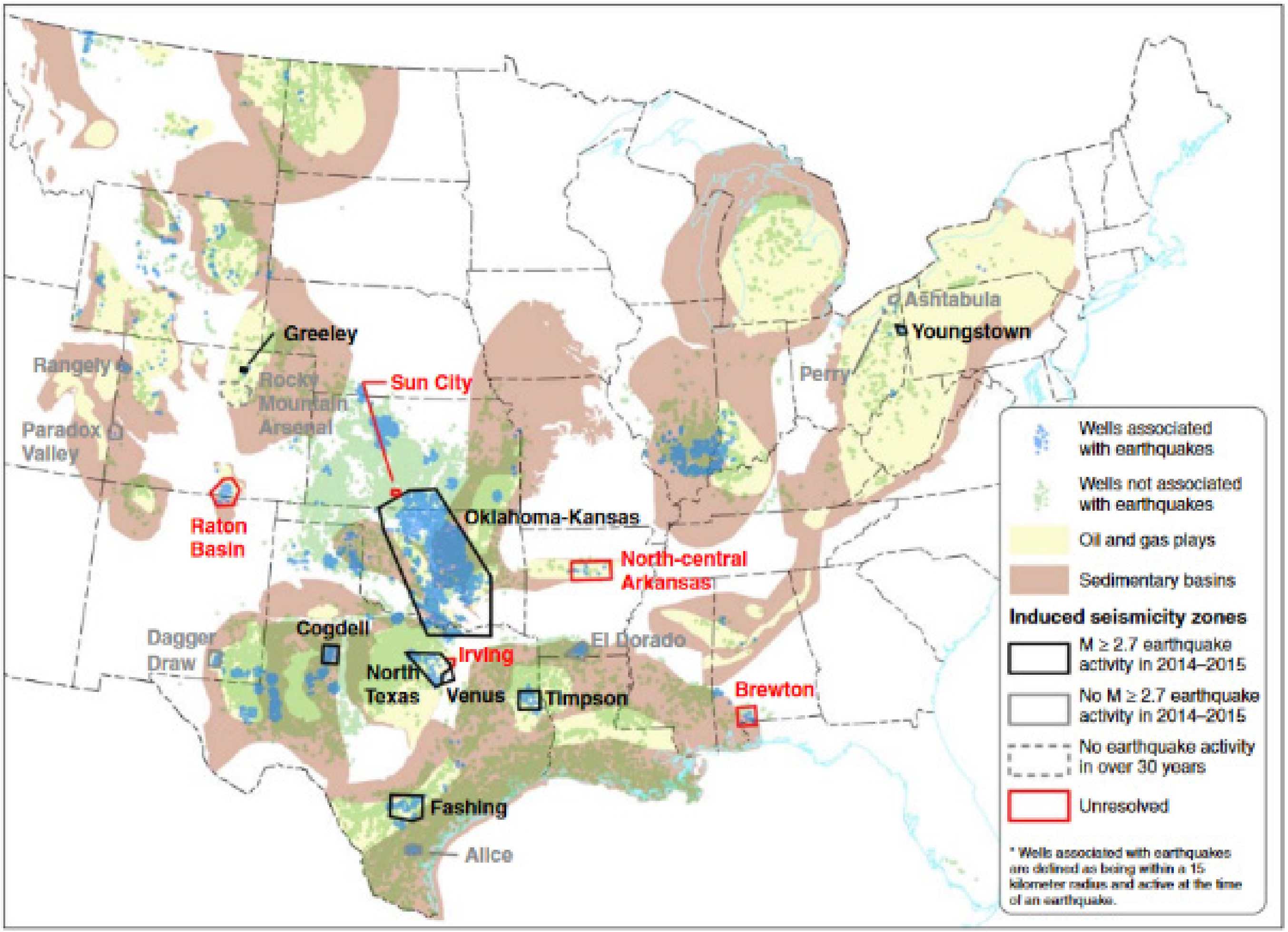
For these reasons, the team assessed the future conditions relative to the earthquake hazard over the next thirty years as increasing by 10 percent.

References:

Page, M.T. and S.E. Hough, 2014: The New Madrid seismic zone: Not dead yet. Science 343(6172):762–764.

Petersen, M.D., C.S. Mueller, M.P. Moschetti, S.M. Hoover, A.L. Llenos, W.L. Ellsworth, A.J. Michael, J.L. Rubinstein, A.F. McGarr, and K.S. Rukstales, 2016: Seismic-hazard forecast for 2016 including induced and natural earthquakes in the central and eastern United States. Seismological Research Letters 87:1327–1341.

Walter, J.I., P.J. Dotray, C. Frohlich, and J.F. W. Gale, 2016: Earthquakes in northwest Louisiana and the Texas-Louisiana border possibly induced by energy resource activities within the Haynesville shale play. Seismological Research Letters 87:285–294.



▲ **Figure 1.** Zones of induced seismicity defined in this report. Additional details about the zones are provided in Table 1. Information on oil and gas plays, sedimentary basins (U.S. Energy Information Administration, 2015), wells that are associated with earthquakes (Weingarten *et al.*, 2015), and the earthquake zones applied in this analysis. (Figure from Petersen *et al.*, 2016). The color version of this figure is available only in the electronic edition.

Future Conditions: Sinkholes

The geological bedrock and regolith underlying Louisiana will not change on human timescales, and the relatively small percentage of Louisiana's land area composed of carbonate bedrock points to a small hazard related to karst-induced sinkholes. Nevertheless, Autin (2002) emphasizes that uplift of the Five Islands of southwestern Louisiana is probably still active, leaving tectonic and geomorphic instability possible in the future. The hazard relative to sinkholes could change much more rapidly with land use change and the pressures of increased resource extraction and population growth. Vulnerability to sinkholes could also increase as a "side effect" to changes in the vulnerability to in other hazards. More specifically, sea level rise contributes to saltwater intrusion, which contributes to the formation of salt domes, which–when mined extensively–can form sinkholes.

Inasmuch as the increasing pressures of increased population (and therefore groundwater pumping) and resource extraction (including hydraulic fracture drilling), along with both global and regional sea level rise, appear to be inevitable, the sinkhole hazard appears to be increasing. We project a 10 percent increase in the state's sinkhole hazard by 2050.

Sinkhole Risk Assessment:

Property loss due to sinkhole is calculated as

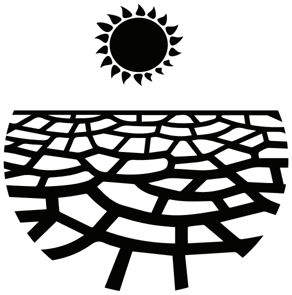
$$L_{2043,i} = I_i \times \frac{A_i}{100} \times R_{SS} \times F_i \times P_i$$

where

$L_{2043,i}$=projected annual preperty loss of census block *i* in 2043
I_i =total building inventory value of census block *i*
F_i =future hazard multification factor for census block *i* in 2043
A_i =percentage of area of census block *i* under saltdomes
P_i = probability of sinkhole incident in census block *i*
R_{SS} = ratio between sinkholes to salt domes

We consider the ratio of largest sinkhole incident area in Louisiana (although there were only two incidents) to the largest salt dome area to calculate the losses. Caution should be exercised in the interpretation of results because identification of which portion/part of salt domes will turn into sinkholes is highly uncertain.

Autin, W.J., 2002: Landscape evolution of the Five Islands of south Louisiana: Scientific policy and salt dome utilization and management. Geomorphology 47(2-4):227-244.



Future Conditions: Expansive Soil

The soil structure will remain largely unchanged on anthropogenic time scales. However, long-term changes in the freeze-thaw climatology and/or precipitation climatology could impact the stability of the soil structure for supporting construction. The anticipated decrease in number of freezing-temperature days would diminish the future expansive soil hazard due to freeze-thaw expansion/contraction. However, the likelihood of heavier precipitation interrupted by lengthening dry periods might be expected to offset this effect by increasing expansion/contraction due to more frequent and/or amplified water absorption/desiccation cycles. Therefore, we project no net change in the expansive soil hazard by 2050.

Expansive Soil Risk Assessment:

Property loss due to expansive soil is calculated as

$$L_{2043,i} = 0.075 \times I_i \times \frac{SP_i}{R} \times F_i$$

where

$L_{2043,i}$ =projected annual property loss of census block *i* in 2043
I_i =total building inventory value of census block *i*
F_i =future hazard multiplication factor for census block *i* in 2043
SP_i =average swelling potentiality of census block *i*
R =average life span of a residential building

The inventory value of one-story, single-family and multi-family residential properties were calculated. This assumes that the annual loss is 7.5% of the property value over the 70-year assumed building life, at the census block level, for census blocks having swelling potential (SP). The expansive soil risk assessment includes data derived from Wang (2016), who developed the function for SP – the percentage of soil swell from optimum to saturated moisture content:

$$SP = 0.00216 I_p^{2.44}$$

where
I_p = plasticity index

Wang's (2016) point-based SP was mapped based on data measured by Seed et al. (1962).

Seed HB, Woodward, Lundgren R. 1962. Prediction of Swelling Potential for Compacted Clays. Journal of the Soil Mechanics and Foundations Division 88(3), 53-88.
Wang, J.X., 2016. Expansive Soils and Practice in Foundation Engineering. A presentation delivered at the 2016 Louisiana Transportation Conference 03/07/2016. http://www.ltrc.lsu.edu/ltc_16/pdf/presentations/10-University%20Transportation%20Centers%20(Part%201)-Characterization%20of%20Expansive%20Soils%20in%20Northern%20Louisiana.pdf