Hurricane

A tropical storm or hurricane impacts the U.S. resulting in direct economic losses of greater than $100 Million.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high impacts. In addition, low and high impacts are not necessarily correlated with each other between different impact categories.

Category	Description	Metric	Low	Best	High
Health and Safety	Fatalities	Number of Fatalities[1]	0	26	1,200
	Injuries and Illnesses	Number of Injuries or Illnesses[1]	0	650	30,000
Economic	Direct Economic Loss	U.S. Dollars (2011)[1]	$100 Million	$5.7 Billion	$92 Billion
Social	Social Displacement	People Displaced from Home ≥ 2 Days[2]	140	520,000	5 Million
Psychological	Psychological Distress	Qualitative Bins	See text		
Environmental	Environmental Impact	Qualitative Bins[3]	High[4]		
LIKELIHOOD	Frequency of Events	Number of Events per Year[5]	0.33	1.9	7

Event Background

For the purpose of the SNRA, a national-level hurricane is defined as a hurricane producing direct economic loss in excess of $100 million dollars. Economic damages reported here are a combination of coastal flooding and wind damage generated by hurricanes and tropical storms. A 40 year time period, from 1970 to 2010, was used to estimate the interarrival rates/frequencies and impacts for hurricanes exceeding the $100 million threshold. While accurate hurricane damages have been recorded since before 1900, mitigation and evacuation strategies have significantly changed since the turn of the 20th century, substantially lowering hurricane impacts. To capture a representative subset for current hurricane impacts, only storms recorded after 1970 were used for this report. Table 1 reports the maximum, average, and minimum frequency with which such hurricanes occurred in the United States, and the maximum, average and minimum

[1] Low, best, and high estimates for fatalities, injuries and illnesses, and direct economic loss are the historical minimum, average, and maximum for each impact type in the event set. Extremal events for one impact type may but generally do not correspond to those for other impact types.
[2] Low, average, and high reported "total affected" for hurricanes causing greater than $100M in economic damage as recorded in the EM-DAT database during the time period 1970-2011. See Social Displacement section in this summary sheet for details.
[3] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental impacts for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories. Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[4] Hurricanes were given a best estimate of 'High', with a second best estimate of 'Moderate'. The experts assessed that hurricanes can cause ecological impacts, beach erosion, nutrient loading, chemical contamination, salt water intrusion into fresh water bodies, and removal of plants leading to erosion. Large areas can experience impacts.
[5] Historical low, average, and maximum number of events per year (calculated from interarrival times).

impacts for fatalities, injuries, and direct economic losses associated with hurricanes in the set. A list of all hurricanes with accompanying economic impacts and fatalities is shown in Table 2.

Low, average and high estimates were developed in the following manner from the normalized impact estimates and historic record. For fatalities, injuries and direct economic loss, the low estimate is the smallest impact for events that exceed $100 million. For event frequency, the low estimate is derived from the greatest time gap, t_{max}, between years with national level events. The average frequency is the expected number of events in a given year. Similarly, the average for fatalities, injuries/illness, and direct economic loss are the expected value for each measure given the occurrence of a national level hurricane. The maximum frequency is the maximum number of national level hurricanes recorded in a single year. The maximum for fatalities, injuries/illness, and direct economic loss is the greatest value produced by a single storm in each impact category.

It is important to note that the frequency estimates reported here differ from probabilities. The frequency of a national-level hurricane can be greater than one, while a probability cannot. Additionally, while the average estimates for impacts and frequency are correlated and approximate the average annual loss when multiplied together, the maximum and minimum historical values for impact and frequency are uncorrelated and do not have meaning when multiplied together.

Fatalities

Fatality estimates are based directly on the historic record (Blake, Landsea, & Gibney, August 2011). The historical maximum for fatalities was Katrina in 2005 with an estimated 1,200 deaths.[6] Several storms within the 40 year time period exceeded $100 million in economic damages without causing any loss of life. While several storms have zero recorded fatalities, fatality estimates were not always available for events with less than 25 fatalities. In the case where records were not available, fatality estimates were apportioned as percentages of yearly hurricane fatalities based on economic damages. The average of all national level hurricanes was then used to produce the historical average of 26 fatalities per storm. The table of national level hurricanes, Table 2, contains a total of 2016 fatalities from 78 distinct events.

Injuries and Illnesses

Injury/illness estimates were produced for each hurricane based on a linear model relating fatalities to injuries and illness. The model is derived from Hurricane Andrew in 1992 (CDC, 1993). A model was needed because accurate injury and illness estimates were not readily available for most hurricanes. Fatality, injury and illness statistics are available for regional hospitals and mobile clinics, but these reports do not provide comprehensive estimates for hurricane related injuries. Evacuees can travel hundreds of miles (Faul, Weller, & Jones, September 2011) before receiving medical attention creating a difficult task when accounting for the number of storm related injuries. The CDC, however, has published injury/illness and fatality estimates for 19 parishes during Hurricane Andrew (CDC, 1993) that the SNRA project team used to model a multiplier for estimating total injuries. There were approximately 25 injuries to

[6] Note that fatality and economic damage estimates can differ across sources, including official U.S. Government sources, depending upon different definitions of what is counted. The fatality estimate of 1,200 for Hurricane Katrina was the latest official estimate of the National Hurricane Service for fatalities directly caused by the hurricane as of August 2011, as reported in the primary source used for fatality data by the SNRA (Blake and Landsea, p. 5). Counts of all fatalities including indirect fatalities can total 1,833, the current official estimate for all fatalities, or higher.

every fatality within the study group. The multiplier was applied to the fatality estimates to obtain injury/illness estimates for hurricane impacts.

Economic Loss

To provide an accurate assessment for current year planning, historic economic damage estimates have been updated to a 2011 base year. Economic and health & safety impacts, derived directly from historic record, are updated based on changes in populations, building structures, and infrastructure. These damage estimates are published by ICAT and available via the internet.[7] A full description of methods used in economic loss normalization is documented by Pielke (Pielke Jr., Gratz, Landsea, Collins, Saunders, & Musulin, 2008). In total, 78 hurricanes exceeding the $100 million threshold are aggregated in the findings of this report. These estimates potentially contain indirect economic losses. There is not a clear disambiguation for economic loss estimates as there is no readily available record for each loss estimate. Due to this ambiguity, economic loss estimates have the potential to be biased high by as much as 20 percent.

For economic loss, $100 million (1993 Hurricane Emily) is the smallest normalized historic loss that meets the $100 million threshold. Twelve historic events exceeding the economic threshold did not result in any fatalities and, consequently, were not estimated to cause any injuries/illness resulting in a minimum for both fatalities and injuries/illness of zero. The greatest gap occurs between 1985 and 1988. This three year time lapse between national level events results in an interarrival frequency of 0.33, or $1/t_{max}$.

The average economic impact is $5.7 billion per event. On average, 26 fatalities occur per event with an average of 650 injuries per event. The average time between national level events is approximately six months, resulting in 1.9 events expected per year. An estimate of the average annual loss for each impact type (e.g., fatalities per year or economic loss per year) can be obtained by multiplying the average frequency by the average impact in a category. The average annual fatality and economic losses for the set of 78 historic events analyzed are approximately 26 fatalities per year and approximately $5.7 billion per year.

[7] ICAT damage estimates are available at http://www.icatdamageestimator.com. Accessed September 16, 2011.

Table 2: National Level Hurricane Events from 1970 to 2010

STORM NAME	CURRENT DAMAGE ($ 2011)	Year	Yearly Fatalities[8]	Event Fatalities (Estimated if < 25)
Hermine	$250,000,000	2010	13	12
Hanna	$170,000,000	2008	41	0
Fay	$590,000,000	2008	41	1
Dolly	$1,080,000,000	2008	41	2
Gustav	$4,220,000,000	2008	41	7
Ike	$19,600,000,000	2008	41	31
Ernesto	$550,000,000	2006	0	0
Cindy	$360,000,000	2005	1225	0
Dennis	$2,670,000,000	2005	1225	2
Rita	$11,330,000,000	2005	1225	8
Wilma	$26,210,000,000	2005	1225	16
Katrina	$92,050,000,000	2005	1225	1200
Charley	$120,000,000	2004	60	0
Gaston	$160,000,000	2004	60	0
Jeanne	$9,350,000,000	2004	60	8
Frances	$12,310,000,000	2004	60	11
Charley	$18,520,000,000	2004	60	16
Ivan	$18,480,000,000	2004	60	25
Claudette	$250,000,000	2003	24	1
Isabel	$4,820,000,000	2003	24	22
Isidore	$480,000,000	2002	9	2
Lili	$1,210,000,000	2002	9	6
Gabrielle	$390,000,000	2001	45	2
Allison	$8,330,000,000	2001	45	43
Dennis	$270,000,000	1999	62	2
Irene	$1,430,000,000	1999	62	9
Floyd	$7,700,000,000	1999	62	50
Earl	$150,000,000	1998	23	0
Frances	$970,000,000	1998	23	3
Bonnie	$1,440,000,000	1998	23	4
Georges	$4,100,000,000	1998	23	14
Danny	$200,000,000	1997	4	4
Josephine	$310,000,000	1996	36	1
Bertha	$610,000,000	1996	36	3
Fran	$7,260,000,000	1996	36	32
Jerry	$110,000,000	1995	29	0
Erin	$820,000,000	1995	29	3
Erin	$830,000,000	1995	29	3
Opal	$7,490,000,000	1995	29	23

STORM NAME	CURRENT DAMAGE ($ 2011)	Year	Yearly Fatalities[9]	Event Fatalities (Estimated if < 25)
Beryl	$180,000,000	1994	38	3
Gordon	$1,230,000,000	1994	38	16
Alberto	$1,290,000,000	1994	38	20
Emily	$100,000,000	1993	4	2
Andrew	$66,770,000,000	1992	26	26
Bob	$3,620,000,000	1991	16	16
Marco	$210,000,000	1990	13	13
Jerry	$210,000,000	1989	56	1
Chantal	$280,000,000	1989	56	1
Allison	$1,680,000,000	1989	56	4
Hugo	$18,320,000,000	1989	56	51
Gilbert	$200,000,000	1988	6	5
Bob	$120,000,000	1985	30	0
Danny	$160,000,000	1985	30	0
Gloria	$520,000,000	1985	30	1
Kate	$1,270,000,000	1985	30	2
Gloria	$2,490,000,000	1985	30	6
Elena	$4,340,000,000	1985	30	9
Juan	$4,560,000,000	1985	30	11
Diana	$370,000,000	1984	4	4
Alicia	$9,670,000,000	1983	22	22
Dennis	$140,000,000	1981	0	0
Allen	$2,060,000,000	1980	2	2
David	$980,000,000	1979	22	1
David	$1,570,000,000	1979	22	1
Claudette	$1,710,000,000	1979	22	3
Frederic	$12,640,000,000	1979	22	17
Amelia	$190,000,000	1978	36	36
Belle	$570,000,000	1976	9	9
Eloise	$6,230,000,000	1975	21	21
Subtrop 1 1974	$130,000,000	1974	1	0
Carmen	$1,140,000,000	1974	1	1
Delia	$300,000,000	1973	5	5
Agnes	$20,300,000,000	1972	122	122
Ginger	$190,000,000	1971	8	0
Edith	$310,000,000	1971	8	1
Fern	$480,000,000	1971	8	1
Doria	$2,400,000,000	1971	8	6
Celia	$6,850,000,000	1970	11	11

Social Displacement

To estimate social displacement for the SNRA, U.S. hurricane event data from the international disaster database EM-DAT[10] was used to approximate the number of people forced to leave home for two days or greater. EM-DAT provides estimates of the "total number affected" by

[8] Fatalities due to all hurricanes in same year.
[9] Fatalities due to all hurricanes in same year.
[10] EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be, Université Catholique de Louvain, Brussels (Belgium) [official citation]. EM-DAT is maintained by the World Health Organization Collaborating Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Université Catholique de Louvain, Brussels, Belgium (http://www.emdat.be/frequently-asked-questions), and is supported by the Office of U.S. Foreign Disaster Assistance (OFDA) of USAID (http://transition.usaid.gov/our_work/humanitarian_assistance/disaster_assistance/). See Criteria and Definition, http://www.emdat.be/criteria-and-definition, EMDAT Data Entry Procedures, at http://www.emdat.be/source-entry , and EMDAT Glossary, at http://www.emdat.be/glossary/ for details of criteria, thresholds, and methodology for the EM-DAT database.

disaster events. The national-level hurricane events for which EM-DAT data on "total number affected" was available are listed in Table 3 below. (EM-DAT data was available for approximately one-third of the national-level hurricane events identified from the historic record.) The low, high, and average of the "total affected" data in Table 3 are used as the social displacement estimates for hurricanes in the SNRA.

The "total affected" measure includes the number of people needing immediate assistance, which can include displacements and evacuations; the number of people needing immediate assistance for shelter; and the number of people injured. Because EM-DAT includes injuries in the "total affected" measure, there is potential for double-counting between the SNRA injury and displacement estimates for this event. However, displacement due to hurricanes is typically significantly greater than the number of injuries, so using EM-DAT's "total affected" measure was judged to provide an estimate of social displacement of sufficient precision for the SNRA. Note that the low estimate may be biased low due to incomplete reporting of displacement and evacuations in EM-DAT.

Table 3: Social Displacement

Storm Name	Current Damage ($2011)	Category	Year	EMDAT Total Affected
Alberto	$1,290,000,000	TS	1994	20,022
Allison	$8,330,000,000	TS	2001	172,000
Andrew	$66,770,000,000	5	1992	250,055
Bob	$3,620,000,000	2	1991	1,200
Bonnie	$1,440,000,000	2	1998	17,000
Charley	$18,520,000,000	4	2004	30,000
Charley	$120,000,000	1	2004	545
Elena	$4,340,000,000	3	1985	1,000,000
Erin	$830,000,000	1	1995	6,000
Ernesto	$550,000,000	TS	2006	140
Fay	$590,000,000	TS	2008	400
Floyd	$7,700,000,000	2	1999	3,000,010
Fran	$7,260,000,000	3	1996	4,000
Frances	$12,310,000,000	2	2004	5,000,000
Georges	$4,100,000,000	2	1998	5,127
Gustav	$4,220,000,000	2	2008	2,100,000
Hugo	$18,320,000,000	4	1989	25,000
Ike	$19,600,000,000	2	2008	200,000
Isabel	$4,820,000,000	2	2003	225,000
Isidore	$480,000,000	TS	2002	13,200
Jeanne	$9,350,000,000	3	2004	40,000
Katrina	$92,050,000,000	3	2005	500,000
Opal	$7,490,000,000	3	1995	78,000
Rita	$11,330,000,000	3	2005	300,000
Wilma	$26,210,000,000	3	2005	30,000

*Note: EM-DAT estimate for TS Frances (1998) was not included because it only includes injuries, not displacement.

Psychological Distress

Psychological impacts for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[11] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental impacts for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental impact category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence (impact)[12] as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental impacts as "moderate." Hurricanes can cause ecological impacts, beach erosion, nutrient loading, chemical contamination, salt water intrusion into fresh water bodies, and removal of plants leading to erosion. Large areas can experience impacts.

Expected Wind Damage Versus Return Period

The results reported in Tables 1 and 2 capture both wind and coastal flooding. An additional perspective into hurricane damage is the effect of wind damage alone. Figure 1 provides a loss exceedance probability for wind related hurricane damages in addition to damages from the top 11 hurricane wind events.

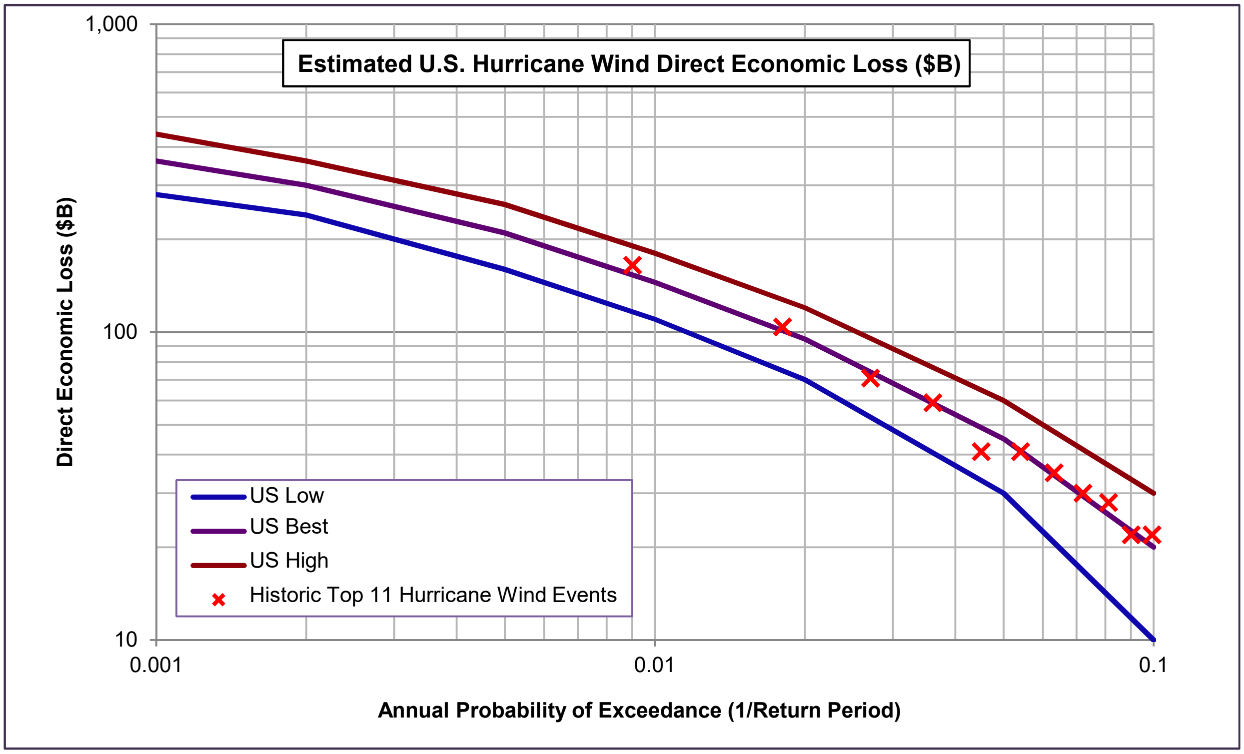
[11] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human impact metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological impacts. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: hurricanes were given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

[12] The 2011 SNRA referred to impacts as 'consequences' because of prior usage in quantitative risk assessment (Kaplan and Garrick [1981, March], On the quantitative definition of risk: *Risk Analysis* 1(1) 11-32). Except where it will cause confusion, 'impact' is used synonymously in this document because of pre-existing connotations of the word 'consequence' within FEMA.

Figure 1: Probability of Exceeding Direct Economic Losses[13]



Additional Relevant Information

Figure 2 depicts the likelihood that a tropical storm or hurricane would affect the area sometime during the Atlantic hurricane season. This figure was created by the National Oceanic and Atmospheric Administration's Hurricane Research Division using data from 1944 to 1999 and counting hits when a storm or hurricane was within approximately 100 miles (165 kilometers) of each location.

As shown in Figure 2, the probability of potential impact varies across the U.S. coastline. Portions of the North Carolina Outer Banks have the same probability of occurrence (42 to 48 percent) as South Florida and southern Louisiana. Parts of the southeastern U.S. coastline as well as the Florida panhandle and portions of the Texas coastline have a lower probability of occurrence, in the 24 to 36 percent range. The northeastern U.S. coastline has the lowest probability, in the 12 to 24 percent range. The ranges provided in the "Data Summary" on Page 1 reflect the range of probability from a national perspective.

The probability of storm occurrences will vary significantly based on the return interval for different categories of magnitude. The probability of less intense storms (lower return periods) is higher than more intense storms (higher return periods).

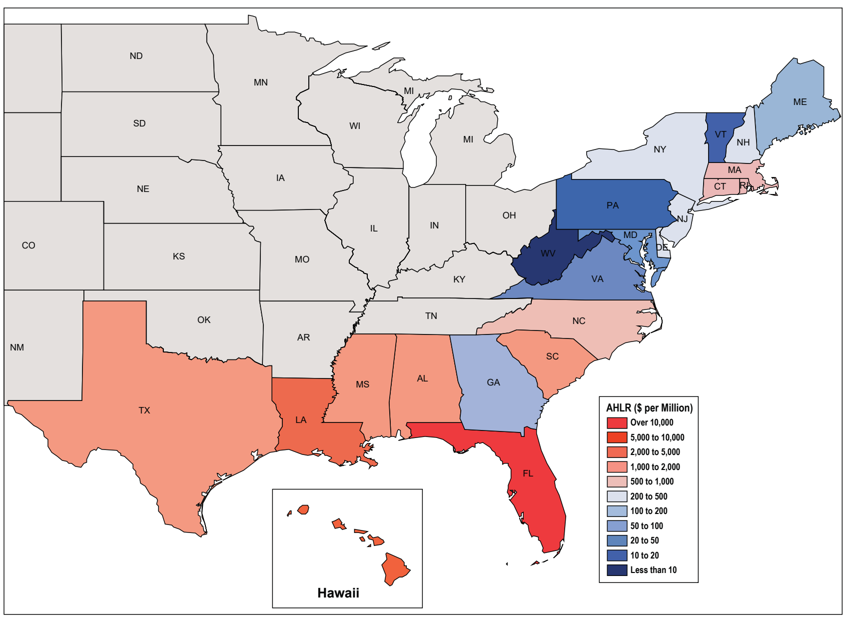
In 2007, FEMA estimated average annualized losses for hurricane wind for the nation by state. The estimated average annualized loss (AAL) addresses the key idea of risk: the probability of the loss occurring in the study area (largely a function of building construction type and quality). By annualizing estimated losses, the AAL factors in historic patterns of frequent, smaller events

[13] Graphical output of modeling done by HAZUS-MH contract support and provided to the SNRA project team.

with infrequent but larger events to provide a balanced presentation of the event risk. The AAL analysis, which only considered those 22 states and the District of Columbia that are susceptible to the hurricane wind hazard, yielded an estimate of the national AAL of $11.1 billion per year. This estimate does not include storm surge, lifeline infrastructure losses or indirect (long-term) economic losses, and is therefore a minimum estimate of the potential losses. Moreover, the estimate represents a long-term average and actual losses in any single year may be much larger or smaller. It is important to recognize that the nationwide losses are the result of averaging losses caused by hurricanes occurring in different parts of the nation in different years.

The annualized loss ratio (ALR) represents the AAL as a fraction of the replacement value of the local inventory. The ALR gauges the relationship between average AAL and replacement value. This ratio can be used as a measure of vulnerability in the areas and, because it is normalized by replacement value, it can be directly compared across different geographic units such as metropolitan areas or counties.

Figure 3: Hazus-MH Hurricane Wind Annualized Loss Ratios by State

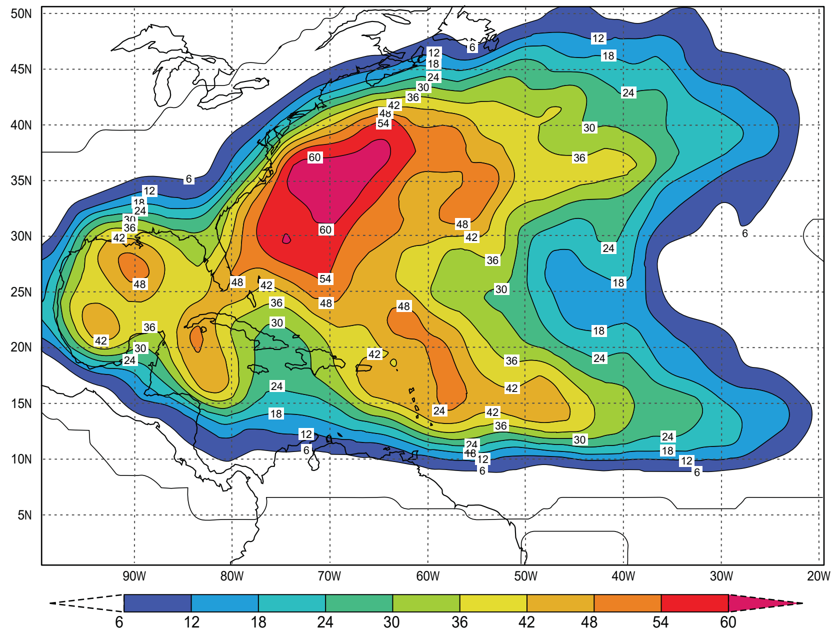


Source: FEMA, September 2007[14]

Figure 3 shows the resulting state ALRs from this study,[15] which helps to illustrate from a national perspective those areas that are more vulnerable to potential hurricane wind impacts. Based on this data, Florida has the highest expected ALR among all states exposed to hurricane winds and therefore has the highest likelihood of experiencing losses due to hurricane wind in any given year. Other high potential loss states include Louisiana, Texas, Mississippi, Alabama and South Carolina. Table 4 ranks states according to hurricane wind AAL and ALR.

[14] Estimated annualized hurricane wind losses for the United States calculated September 2007 using HAZUS-MH, and provided to the SNRA project team by FEMA.
[15] FEMA 610: HAZUS-MH Estimated Annualized Hurricane Wind Losses for the United States, draft September 2007 (pre-publication draft, no corresponding publication in FEMA Library).

Figure 2: Empirical Probability of a Named Hurricane or Tropical Storm



Source: National Oceanic and Atmospheric Administration[16]

[16] Available through NOAA, National Weather Service, Tropical Cyclone Climatology; at http://www.prh.noaa.gov/cphc/pages/FAQ/Climatology.php (accessed 3/16/2013).

Table 4: Hazus-MH Annualized Hurricane Loss (AHL) and Annualized Hurricane Loss Ratios (AHLR) Ranking

Order	State	AHL ($ K)	Order	State	AHLR ($ Million)
1	Florida	5,610,000	1	Florida	5,660
2	Texas	1,450,000	2	Louisiana	3,560
3	Louisiana	889,000	3	Hawaii	2,520
4	New York	505,000	4	Mississippi	1,600
5	Massachusetts	430,000	5	Rhode Island	1,510
6	Hawaii	335,000	6	Texas	1,170
7	Alabama	303,000	7	South Carolina	1,160
8	North Carolina	262,000	8	Alabama	1,120
9	South Carolina	247,000	9	Massachusetts	875
10	Mississippi	210,000	10	Connecticut	728
11	New Jersey	194,000	11	North Carolina	622
12	Connecticut	187,000	12	New York	357
13	Georgia	125,000	13	New Hampshire	320
14	Rhode Island	113,000	14	Delaware	310
15	Virginia	72,500	15	New Jersey	307
16	Pennsylvania	34,100	16	Georgia	262
17	Maryland	31,000	17	Maine	224
18	New Hampshire	25,000	18	Virginia	174
19	Maine	17,800	19	Maryland	91
20	Delaware	17,300	20	District of Columbia	45
21	District of Columbia	2,160	21	Vermont	43
22	Vermont	1,560	22	Pennsylvania	42
23	West Virginia	792	23	West Virginia	7

Source: FEMA, September 2007[17]

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[17] Estimated Annualized Hurricane Loss (AHL) and Annualized Hurricane Loss Ratios (AHLR) calculated September 2007 using HAZUS-MH, provided to the SNRA project team by FEMA and rounded to three significant figures.