

## Impact 2011: Examining a Year of Catastrophes through the Lens of Resiliency

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The story of 2011 is one of natural disasters challenging our complex and vulnerable urban environments. As it's often said, natural disasters are man-made – our fragilities are directly related to how well or how poorly our built environment performs in critical times. So 2011, as it continues to unfold, is really a story of caution, where important examples of our sensitivities to natural disasters have continuously populated the headlines. The National Research Council (2011) defines national resilience as follows: “A disaster-resilient nation is one in which its communities, through mitigation and pre-disaster preparation, develop the adaptive capacity to maintain important community functions and recover quickly when major disasters occur.”

This “Impact 2011” report was prepared for the occasion of the 2011 Federal Alliance for Safe Homes (FLASH) Annual Meeting. WeatherPredict Consulting (WPC) is a FLASH legacy partner, monitoring catastrophic events on worldwide basis with an interest in helping the FLASH organization gather knowledge on resilience from natural disasters. This report is in part a catalog of how different natural catastrophes have affected our world, but more importantly, it's a

platform for recognizing common themes and ultimately, a framework to understand how resilience can be improved in our communities: building codes aimed at performance in addition to life-safety, preparedness that addresses the range of entities at risk, and flexible and adaptable recovery capabilities responsive to the unique conditions that natural catastrophes present.

In the context of historical natural catastrophes, 2011 continues to be a particularly infamous year, with significantly high human loss and property destruction; major events discussed in the paper are summarized in Table 1. The most devastating of these catastrophes include the earthquakes that struck Japan and New Zealand, causing a tragic number of deaths and outsized financial losses. The world has also seen typhoons, flooding, tornadoes, and hurricanes impacting our cities. The year began with floods and cyclones in Australia, devastating earthquakes in New Zealand, earthquakes and a tsunami in Japan, and in the US, spring flooding and severe tornado activity, wildfires, a widely felt eastern United States earthquake, and finally, Hurricane Irene. Of course, we have two months yet to go to finish the year.

### Summary of the 2011 Catastrophe Year

Beginning before the start of the year and continuing into January, eastern Australia experienced record floods, with total direct losses of over \$5 billion (Hurst, 2011) and insured losses of approximately \$3 billion (Guy Carpenter, 2011). Torrential rains that persisted for months combined with Tropical Storm Tasha to overwhelm flood defenses along several rivers in the Brisbane area, with some rivers cresting at nine meters above

flood stage. Thirty-five people were confirmed dead, with many fatalities occurring during a flash flood near Toowoomba. An estimated 28,000 homes were completely destroyed, with many thousands more requiring extensive repair. Commercial structures were also severely impacted, with 3,600 businesses inundated and severe damage to the agriculture, transportation and mining sectors (Australian Attorney-General's Department, 2011).

The woes of Australia were further exacerbated with the landfall of Severe Tropical Cyclone Yasi in early February. While that cyclone's worst effects bypassed Cairns, it still caused severe damage in the vicinity of Tully, Innisfail and Ingham. Yasi made landfall on February 3, 2011 (see Figure 1) as a Category 4 tropical cyclone on the Saffir-Simpson scale (Category 5 on the Australian scale) with maximum sustained winds of 140 mph. A 5 meter storm surge was observed near Cardwell. Yasi is one of the most severe tropical cyclones to strike Queensland in recorded history. Fortunately, major population centers were spared, which limited the total economic impact as well as insured losses, which were approximately \$1.2 billion (Guy Carpenter, 2011; Hurst, 2011). The combined economic loss of the Queensland Floods and Tropical Cyclone Yasi is expected to be in the range of \$15 to \$16 billion (PWC, 2011; World Bank, 2011a).

At the same time, the United States was experiencing the Groundhog Day Blizzard. This storm was tied to 36 deaths, and losses approaching \$2 billion (NOAA/NCDC, 2011a). The storm affected a large swath of North America, extending from New Mexico and Texas, through Chicago and New England, and into the greater Toronto area. Snow accumulations between one

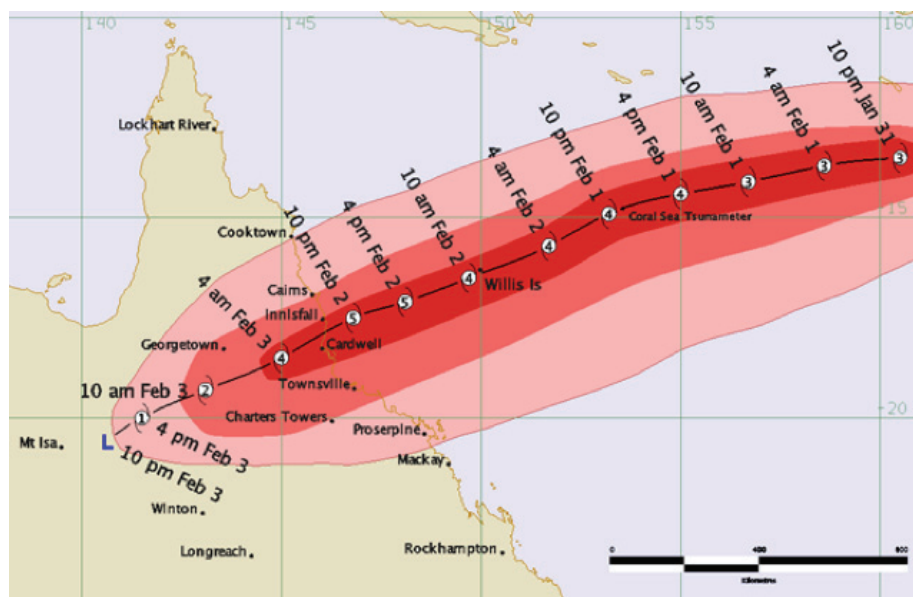


Figure 1: Track and Intensity Information for Severe Tropical Cyclone Yasi (Australian Bureau of Meteorology, <http://www.bom.gov.au/cyclone/history/yasi.shtml>)

<sup>1</sup> The first edition of the Impact 2011 paper was completed in mid-October 2011. Future editions will be revised to account for new information and events for the balance of 2011.

**Table 1: Summary of Major 2011 Events**

Date	Peril	Location	Economic Loss	Insured Loss	Deaths	Injuries	Homes Affected	Data Source
Jan 5, 2011	Flood	Australia	\$15-16B	\$3B	35		28,000 destroyed	Hurst, 2011; AAGD 2011; Guy Carpenter, 2011
Feb 1, 2011	Tropical Cyclone Yasi	Australia		\$1.2B	1 (indirect)			PWC 2011; World Bank, 2011a
Jan 29-Feb 3, 2011	Severe Weather - Groundhog Day Blizzard	Central and Eastern US	>\$1.8B	>\$1.0B	36			NOAA/NCDC 2011a
Feb 22, 2011	Earthquake	Christchurch, New Zealand	\$25B	\$10-11B	181	1,500	100,000 buildings damaged or destroyed	AonBenfield 2011; USGS 2011a
Mar 11, 2011	Earthquake	Japan	\$300B	\$30-40B	15,703 (+4,647 missing)	5,314	332,395 buildings damaged or destroyed	World Bank, 2011b; AonBenfield 2011; USGS 2011b
April 4-5, 2011	Tornado	Southeast/Midwest US	>\$2.8B	>\$2.0B	7	31		NOAA/NCDC 2011a, 2011b
Apr 8-11, 2011	Tornado	Southeast/Midwest US	>\$2.2B	>\$1.5B	0	36		NOAA/NCDC 2011a, 2011b
Apr 14-16, 2011	Tornado	Southeast/Midwest US	>\$2B	>\$1.4B	48	595		NOAA/NCDC 2011a, 2011b
Apr 25-30, 2011	Tornado	Southeast/Ohio Valley/ Midwest US	>\$9B	>\$6.6B	339	2,871		NOAA/NCDC 2011a, 2011b
May 22-27, 2011	Tornado	Southeast/Midwest US	>\$8B	>\$5.9B (Joplin \$1.5-2B)	177+		Joplin tornado destroyed 8,000 homes	NOAA/NCDC 2011a; Columbia Daily Tribune 2011
Spring-Summer 2011	Heat Wave/ Drought/ Wildfires	Southern Plains/ Southwest US	>\$9B	TBD			2,000 homes + 4,000 other structures lost	NOAA/NCDC 2011a
Spring-Summer 2011	Flood	Mississippi River, US	\$2-4B		2+			NOAA/NCDC 2011a
Summer 2011	Flood	Upper Midwest US/ Canada Prairies	>\$3B		5+		4,000	NOAA/NCDC 2011a
Aug 23, 2011	Earthquake	Virginia	\$91M		0			EERI 2011
Aug 20-29, 2011	Hurricane Irene	Mid-Atlantic/ Northeast US	\$7-10B	\$3.5B-5.0B	45+			NOAA/NCDC 2011a, Business Insurance 2011; Insurance Insider, 2011.

and two feet and winds in excess of 60 mph were recorded in the Chicago area. Road and air travel was severely disrupted with over 13,000 flights canceled in North America. Several states, including Illinois, Oklahoma and Missouri, declared a state of emergency, and widespread power outages were reported in New Mexico, Ohio, Illinois, Oklahoma, Indiana, Texas, Colorado and Kentucky.

In February, Christchurch New Zealand was pounded by a M6.3 earthquake, an aftershock of an earthquake sequence that began in the previous year. This near-field earthquake collapsed high-rise buildings and rendered much of that city uninhabitable – a city that was in the midst of recovering from the devastating M7.1 earthquake in September of 2010. The February earthquake struck during mid-day hours, killing 181 people and injuring as many as 1,500. The economic loss for this event is approximately \$25B, with an associated insured loss of \$10 to 11 billion (AonBenfield, 2011).

The world simply was not ready for the seminal earthquake that struck Japan in March of this year. The Tohoku earthquake, a Magnitude 9.0, was the 4th largest recorded since 1900. This earthquake simultaneously unleashed strong ground motions and an extraordinary tsunami, both of which produced severe effects along the northeastern part of Honshu. The tsunami also had wide-ranging impacts to coastlines across the Pacific Basin.

This massive earthquake underlines the challenges urban areas face from extreme events – the impacts are magnified where urban inter-dependencies become very complex, and at the same time, especially vulnerable to earthquake hazards. While it is widely recognized that Japan's political, social and built environment are among the best prepared for natural disasters, especially earthquake, many critical systems were compromised from the effects of this earthquake and tsunami. Classified as a megathrust earthquake, this event emanated from the Japan Trench subduction zone. Its significance in terms of the human disaster and destruction is unprecedented in many ways, including the technological disaster in nuclear power generation that continues to have worldwide ramifications. Recovery from

the radiological disaster will take decades.

The death toll of the Japan disaster is approximately 16,000, with 5,000 more still missing. There were more than 5,000 reported injuries and more than 130,000 persons displaced from their homes (USGS, 2011b). The economic losses from this earthquake and tsunami are enormous and yet, large urban centers, like Tokyo and Yokohama were not affected by the strongest ground motions and experienced relatively minor effects from this earthquake. Estimates for economic losses range upwards of \$300 billion (USGS, 2011b), with approximately \$25 to \$35 billion of that as losses to the insurance industry (The World Bank, 2011b; AonBenfield, 2011). Economic losses from this event range up to 5.7% of Japan's 2010 GDP (The World Bank, 2011b). While the press has moved on from their coverage of the earthquake and tsunami damage and nuclear release at Fukushima, the government and citizens of Japan still struggle in their recovery, with concerns ranging in scale from the future of nuclear power in Japan, to the safety of consuming produce grown on Japan's east coast.

While the world reeled from the devastating earthquakes in Japan and New Zealand, unfavorable climate conditions in the United States began to unfold, delivering multiple weather catastrophes throughout much of the spring.

Beginning in early April (April 4 – 5), the first of several major events took place in the Southeast and Midwest. There were over 1,000 reports of wind damage, including 46 tornadoes that touched down in nine states, causing close to \$3 billion in damage and seven deaths (NOAA/NCDC, 2011a, 2011b). A few days later (from April 8th through the 11th), the next severe weather outbreak spawned an estimated 38 tornadoes, primarily in Iowa and Wisconsin, although portions of the South, including Texas and Alabama, saw high winds as well.

In mid-April, a major tornado outbreak followed in the southern U.S. The hardest-hit states were Oklahoma and Arkansas on April 14th, Mississippi and Alabama on the 15th and North Carolina on the 16th. An estimated 177 tornadoes were observed in 15 states, and 48 people were killed (NOAA/NCDC, 2011a, 2011b). This event, one of

the worst in recent years, was then dwarfed by the 2011 Super Outbreak in late April, which by some measures was the most severe in U.S. history and comparable to the April 1974 Super Outbreak. Both the tornado and fatality count exceeded 300 in the 2011 outbreak, and about 92 of the tornadoes were rated as strong or violent (EF2+ on the Enhanced Fujita Scale). Alabama, Mississippi, Tennessee, and Georgia were hit hard. Total losses are estimated to exceed \$9 billion, with more than \$6.6 billion in insured loss (NOAA/NCDC, 2011a).

Also in April, unusual amounts of snow melt along the northern tributaries of the Mississippi River combined with rainfall from several major storm systems, creating historical flooding that propagated along the Mississippi River watershed all the way from Illinois to Louisiana. In Arkansas, flash flooding created by local rainfall combined with upstream flood waters, causing numerous levee breaches and a rapid rise of flood waters. Of the many local residents caught off guard, at least two deaths were attributed to the flooding. The magnitude of the flooding event was comparable to the flood of 1927 – the worst Mississippi River flood of the 20th century that left at least 246 dead and over \$4 billion (in 2011 dollars) in damages. The financial damage from the 2011 flooding event is estimated between \$2 and \$4 billion (NOAA/NCDC, 2011a), far less than initially feared. The relatively low damage and human losses are largely credited to quick response by the U.S. Army Corps of Engineers and to the Morganza Spillway that was built after the 1927 event.

In May, a significant severe weather outbreak took place from the 22nd to the 27th, during which 180 tornadoes were recorded in 19 states. Total losses have been estimated to exceed \$8 billion, with more than \$5.9 billion in insured losses (NOAA/NCDC, 2011a). The most active corridor spanned from Texas and Oklahoma, northeastward into the Mississippi and Ohio valleys. Within this outbreak sequence, on May 22nd, a devastating EF5 tornado with wind gusts over 200 mph tore across the south side of Joplin, Missouri, causing 159 fatalities and billions of dollars in damage (NOAA/NCDC, 2011b). Produced by a super cell thunderstorm which crossed into southwest Missouri from Kansas, it was the first ever tornado in southwest Missouri to be

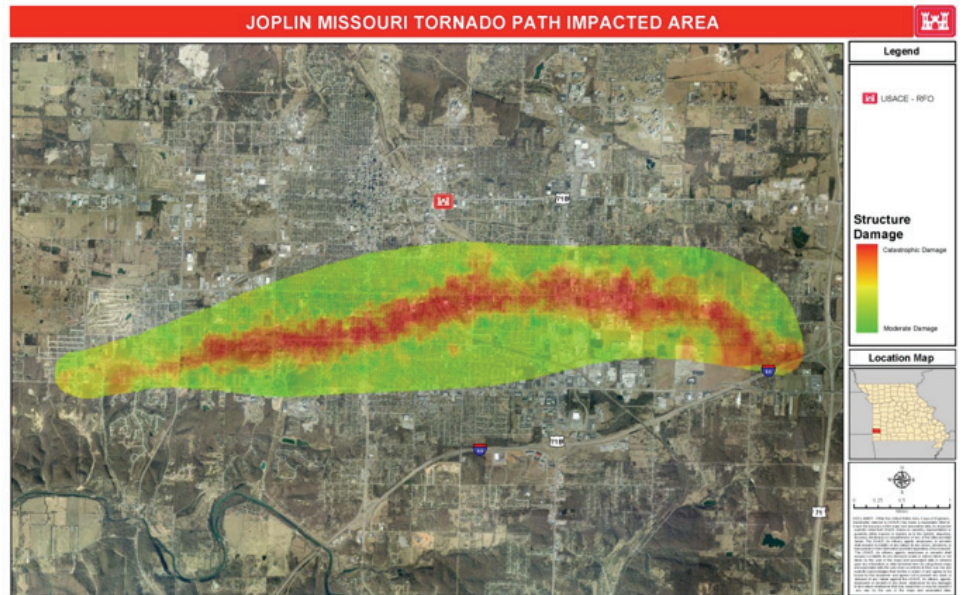


Figure 2: US Army Corps of Engineers Damage Estimates for the Joplin Tornado (USACE Kansas District)

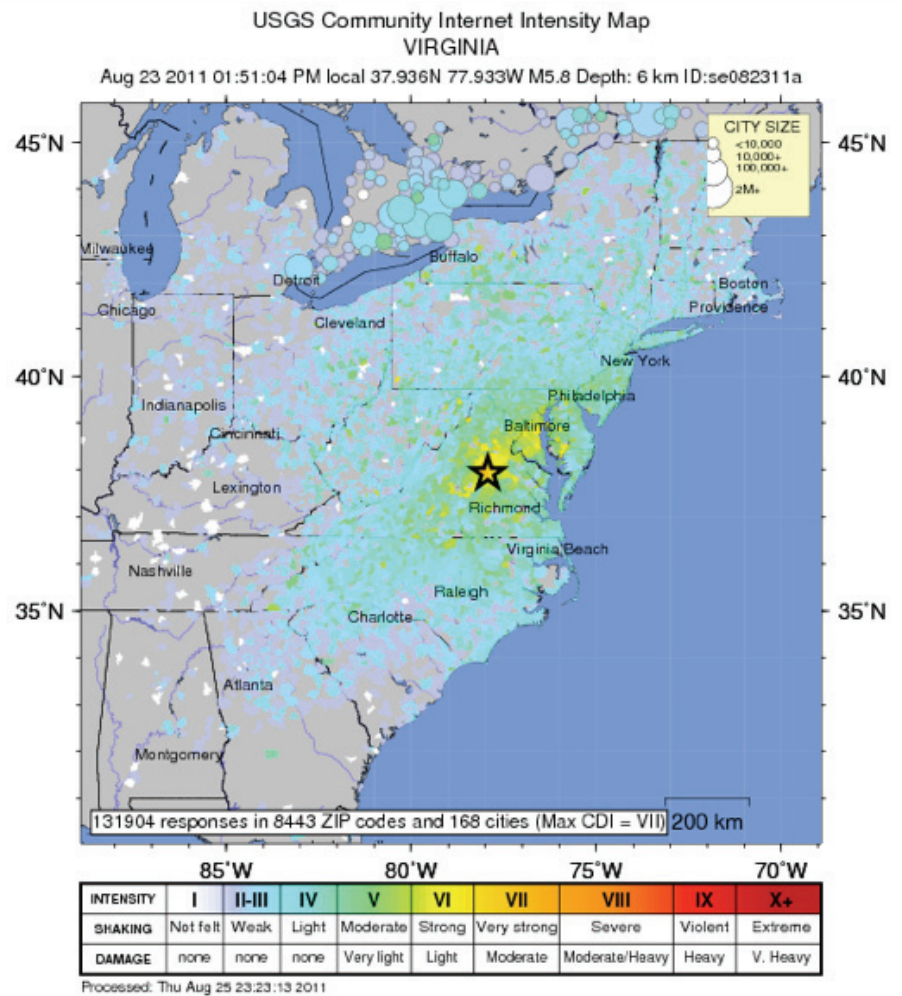


Figure 3: USGS Community Internet Intensity (“Did You Feel It”) Map for the M5.8 Virginia Earthquake of August 23, 2011

rated an EF5. Interestingly, on that day, there were no other violent (EF4 or EF5) tornadoes reported in the U.S., although there were about three dozen tornadoes rated EF0 to EF3 from Oklahoma to Wisconsin. The lack of other violent tornadoes in southwest Missouri underscores the extraordinary and random nature of the Joplin event.

Post-storm surveys showed that the Joplin tornado had a maximum width of almost one mile, with a damage length of 22.1 miles (see Figure 2). It destroyed about 8,000 homes, along with hundreds of small to large businesses and public buildings. Over 18,000 vehicles sustained damage. Among the commercial structures destroyed were a bank, a sports academy, a Wal-Mart, a Home Depot, a Pepsi distribution center, and a large construction firm. The St. John's Regional Medical Center also sustained a high level of damage. Total insured losses are estimated to be between \$1.5 and \$2 billion, according to a report from the Missouri Department of Insurance (Columbia Daily Tribune, 2011).

Two days later, another EF5 touched down in central Oklahoma, while significant hail fell across Dallas/Fort Worth. Finally, about a week following this, a rare strong tornado moved across the Springfield Massachusetts Metropolitan area.

In parallel to the severe tornado activity in the Midwest, a long period of excessively dry conditions, stretching from Arizona eastward through the Gulf Coast states and into the Carolinas, brought severe impacts to agriculture as well as to communities on the urban-wildland interface. Windy dry conditions impacted many areas, but the vast majority of wildfire events were distributed across the southwest (Arizona, New Mexico, and Texas) and the southeast (North Carolina, Florida, and Georgia) United States. Especially hard hit were Texas, New Mexico and Arizona, where wildfires burned for weeks. In New Mexico the Los Alamos National Laboratory had to be closed when one wildfire threatened that facility. Approximately 2,000 homes were lost and along with impacts to agriculture, losses already exceed \$9 billion (NOAA/NCDC, 2011a). However, this number continues to rise: the Labor Day weekend saw the loss of several lives and at least 500 homes in

east and central Texas (Insurance Council of Texas, 2011).

The early part of the summer in the United States saw some of the worst flooding experienced in the upper-Midwest. Due to several antecedent conditions, including large snow packs, high spring precipitation levels and already saturated ground conditions, large segments of the Missouri river and the Souris rivers were above flood stage for many weeks. Especially hard hit were agricultural interests in the US Corn Belt with millions of acres flooded. In the town of Minot, North Dakota, some 11,000 people were evacuated and 4,000 homes were flooded. Estimated economic losses were at least \$2 billion in the United States, with an additional \$1 billion in Canada (NOAA/NCDC, 2011a).

In August, a M5.8 earthquake struck Virginia. This was one of the largest ever recorded earthquakes in the region. As scientists described, this earthquake "rang the bell", as the earthquake's energy was transmitted far and wide (see Figure 3) – an important characteristic of Central and Eastern United States earthquakes. Also, for the insurance industry the bell was rung, alerting millions of their customers to the very real threat that

earthquakes pose to lives and property. While no one was killed and damage was limited, this event bears mention here in that it points to the challenges of high consequence, low frequency catastrophe events and the positive role government and industry can play in encouraging preparation and resilience for the inevitable.

Hurricane Irene, the ninth named storm, first hurricane and first major hurricane of the 2011 Atlantic hurricane season, made landfall over eastern North Carolina's Outer Banks on August 27th as a Category 1 hurricane. After briefly re-emerging over water, Irene made a second hurricane landfall near Little Egg Inlet in New Jersey, and continued tracking northward over Brooklyn, New York and further into New England. Estimates for total economic losses from Irene in the US range from \$7 to \$10 billion (NOAA/NCDC, 2011a; Business Insurance, 2011), with current estimates of insured losses ranging between \$1.5 and \$6 billion, as reported by three major catastrophe modeling firms (National Underwriter, 2011).

Irene caused hurricane and gale force winds that uprooted trees, downed power lines, and damaged structures over a broad swath of

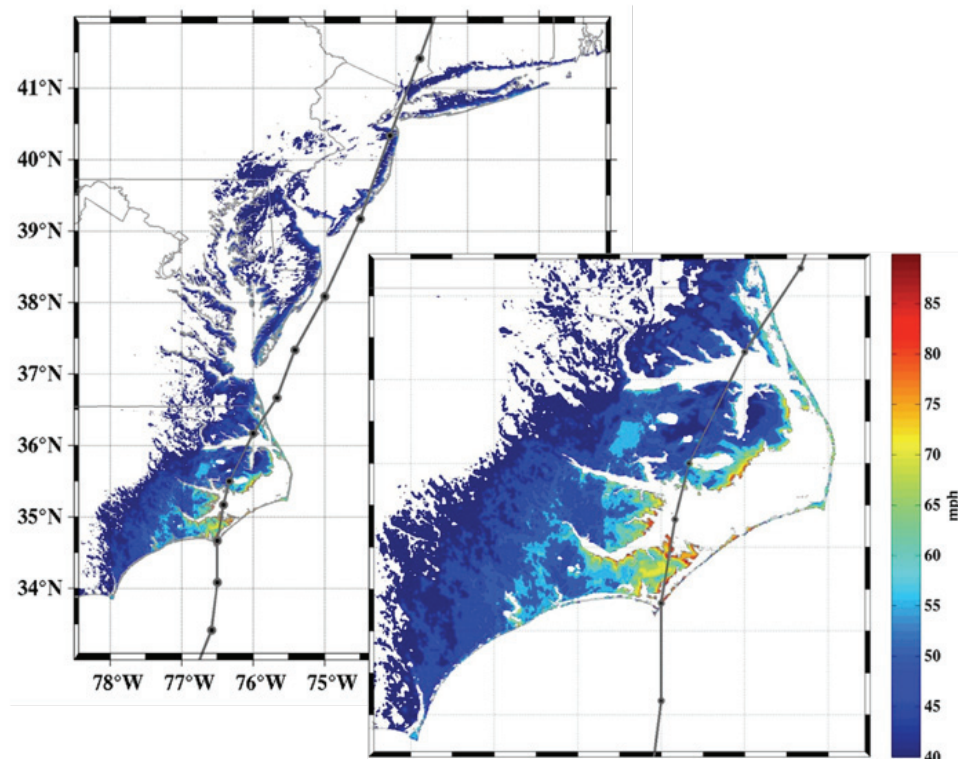


Figure 4: Windspeed footprint for Hurricane Irene, as calculated by WeatherPredict Consulting

the eastern US ranging from North Carolina into Maine (see Figure 4). Electrical service was interrupted for some 5.8 million people (New York Times, 2011). The most notable destruction was caused by sound-side flooding as Irene passed to the north of the Outer Banks of North Carolina and rain-induced flooding in New Jersey, New York and Vermont. More than ten rivers recorded record flood levels in the mid-Atlantic and New England, and six states reported floods in excess of one hundred-year and/or five hundred-year levels. Flooding destroyed bridges and damaged roads and railways, making some communities – particularly in Vermont – inaccessible by land, and impeding travel over broad areas of the Northeast. Flooding conditions created by Irene throughout the Northeast were compounded by heavy rains brought in by remnants of Tropical Storm Lee a few days later. Several communities around Pennsylvania and New York were flooded, forcing nearly 100,000 people to seek higher ground. At least 12 deaths have been blamed on Lee and its remnants, with damage concentrated along the Susquehanna River in Wilkes-Barre, and dozens of miles up the river in Binghamton, N.Y., as well as other communities along the river. It was the worst flooding in almost 40 years, since Hurricane Agnes in 1972.

### The Themes

Creating a resilient society starts with knowledge and insight into how natural disasters affect our communities. “Impact 2011” reports on worldwide natural catastrophes to heighten the discussion around risk management and our resiliency to natural perils, especially as it applies to those in the United States that are most at risk. The Federal Alliance for Safe Homes as well as several other non-profit organizations support “Impact 2011” as part of their work in guiding us towards smarter and safer communities.

How can we use this intelligence to better protect ourselves? Natural catastrophes dominated headlines in 2011 as the world experienced one disaster after another. While the statistics of lives lost, injuries sustained and economic destruction provide evidence that this has been a particularly challenging year worldwide, we should also recognize



*Figure 5. Typical liquefaction damage to modern single-family home in Christchurch, New Zealand. Note that this home will likely need to be completely rebuilt due to extensive foundation damage.*

that 2011 provides a cautionary tale for those at risk in the United States. This tale is certainly one of how large urban societies can be challenged when critical elements of their infrastructure are impaired, but it is also a tale of success in the face of adversity, where robust preparation saved lives and avoided the unnecessary loss of critical infrastructure, homes and businesses.

### Earthquake

Global earthquake disasters captured the world’s attention for much of this year, and for many, there was a new found realization that this peril impacts regions not commonly understood to have significant seismic risk. With the very severe events in New Zealand and Japan, we see ample evidence of how important resiliency is in the face of the effects of strong ground shaking. It’s also important to note that both earthquakes underscored the fact that strong ground shaking is not the only hazard; local soil effects like liquefaction (see Figure 5) and global effects like the massive tsunami can leave many lives and communities in shambles.

In 2010, the stark contrast between the earthquakes in Haiti and Chile illustrated why resiliency matters so much for life-safety. The developed world benefits from investments in building codes and engineering that create minimum standards for life-safety. In 2011, the earthquakes in New Zealand and Japan showed us the nuances of differing building codes, where even the developed world has different levels of resiliency. This is largely driven by how much the political, social and built environment is prepared for earthquake effects, and importantly, how these elements respond and adapt to the aftermath of the earthquake.

This paper specifically explores how resiliency for earthquake varies in different areas of the United States. As shown in Box 1, extreme earthquake events have the potential to cause significant damage and disruption in many areas of the US, including the Midwest and in the Southeast. A M7.7 earthquake in the New Madrid Seismic Zone would cause damaging shaking in more than 83 counties across eight states, with building damage averaging 8% of building value. A M7.3 repeat of the 1886 earthquake



in Charleston would result in even greater average building damage than the New Madrid scenario, reaching almost 10% of building value. In contrast, a M9.0 Cascadia subduction zone event would result in building damage of just 4% of building value within impacted counties in the states of Washington, Oregon and California. Similar to the March 11 Tohoku Earthquake offshore of Honshu, Japan, this type of subduction zone event could spawn a tsunami, which would increase damage significantly. In contrast, a large earthquake on the San Andreas in Southern California (the subject of significant previous study as part of the “ShakeOut” Scenario<sup>2</sup>) would result in an average building damage of just over 1% of building value, further demonstrating the positive impacts of seismic building codes.

Certainly, with the recent Virginia earthquake, millions were given an important reminder that they too are exposed to earthquake risk. Because of the infrequency of earthquakes in the Midwest and eastern United States, much less investment has been focused on seismic safety. By looking at potential scenario earthquakes in these different areas, we can begin to see the potential for disproportionate effects on communities, from the standpoint of damageability of buildings, life safety, and economic consequences, and draw parallels between Charleston and Christchurch and the Pacific Northwest and Honshu, Japan. Events like these could just as easily have struck US cities with similar effects.

Even moderate-sized earthquakes can cause significant damage in the near-field. While many focus on the likelihood of large events on the San Andreas Fault, the Cascadia Subduction Zone or other well known faults, there is less recognition that smaller events that strike close to urban centers can also be destructive. In Christchurch, the more devastating earthquake was moderate in size (M6.3), but situated very close to the central business district. Lesser known but critically important faults can deliver outsized ground motions in the near-field, and this is exactly what happened in the Christchurch earthquake of February 2011. In Southern

California, sources like the Puente Hills thrust fault or the Newport-Inglewood fault could deliver higher losses to the urbanized areas of the Los Angeles metropolitan region than the better known, but more distant, San Andreas Fault. The recent M5.8 Virginia earthquake could have easily struck closer to the City of Richmond, with dire consequences for that community.

While the potential for both significant aftershocks and triggered events is known by the scientific and engineering communities, how major events might influence seismic risk when we include aftershock potential is still being studied. Significant triggered earthquakes have occurred in the United States and abroad, as in the 1992 Landers Earthquake in Southern California (M7.3) which triggered the Big Bear Earthquake (M6.4) on a different fault three hours later. The New Madrid sequence of earthquakes over three months in 1811-1812 is an example of how complex earthquake sequences need to be assessed relative to community response (e.g., to protect recovery workers and residents during aftershocks). The Sumatra megathrust earthquake (M9.2, 2004) was followed some 3 months later by a triggered event of M8.6 that was also devastating to the region. The possibility that the Tohoku event could trigger another large earthquake to its south is a serious concern. Such an event would impact the densely populated Tokyo metropolitan area and would be a very high consequence event.

Our understanding of the impact of aftershocks on overall depictions of risk needs to be improved. We also need to understand how the cumulative impact of ground motions might diminish the inherent resiliency of existing construction. An understanding of the incremental increase in damage and loss in subsequent events, and the increased risk of failure associated with shaking an already-damaged inventory, do not yet exist. More often than not, aftershocks are not consequential to the earthquake’s overall loss, but there remains some likelihood that an aftershock sequence will be devastating, as in the case

of the February Christchurch earthquake. Of course, the larger the main shock, the more likely it is that an aftershock will increase damage, or even widen the damage footprint. In Japan’s Tohoku event, many buildings saw two minutes or more of strong shaking. Could this have an impact on the resilience of “undamaged” buildings in future earthquakes? Within an hour of the main Tohoku earthquake, the country experienced M7.9 and M7.7 aftershocks. It’s important to note that aftershocks diminish in frequency over time, but not in size.

For residential construction, building codes focus on life-safety, not on the avoidance of damage. That being said, single family residential homes usually have little or no structural engineering as part of their design process. In both the New Zealand and Japan earthquakes, single-family residential construction experienced moderate losses due mainly to non-structural damage (e.g., damaged interior walls or chimneys), often without any accompanying structural damage. This year’s earthquakes delivered a familiar message for single-family residential construction: damage is accentuated in homes with unreinforced masonry chimneys, unreinforced brick veneer exterior walls, walls that lack shear capacity (e.g., no plywood shear walls), and heavy clay or masonry tile roofs.

When earthquakes, even moderate ones, strike close to urban centers, commercial structures can see ground motions that exceed their design levels. Even the most modern commercial construction remains vulnerable to high ground motions found in the near-field of an earthquake. This is especially the case for older, unreinforced masonry buildings (prevalent in the Midwest United States and older cities such as Wellington and Christchurch) and non-ductile concrete frame buildings. Both unreinforced masonry and non-ductile concrete buildings are major threats to life-safety when damaged, and tend to suffer damage at lower ground motion levels than their more modern counterparts. Urban centers all over the United States, including Los Angeles and San Francisco, have many buildings that

<sup>2</sup> For more information on the “ShakeOut” Scenario, see: <http://pubs.usgs.gov/of/2008/1150/>. It should be noted that the published ShakeOut scenario analysis, conducted with significantly more detailed data and analyses, produced larger loss estimates. For the current relative risk comparison, an “apples-to-apples” comparison of estimates produced with consistent data and methods was desired, so the published “ShakeOut” results have not been utilized.

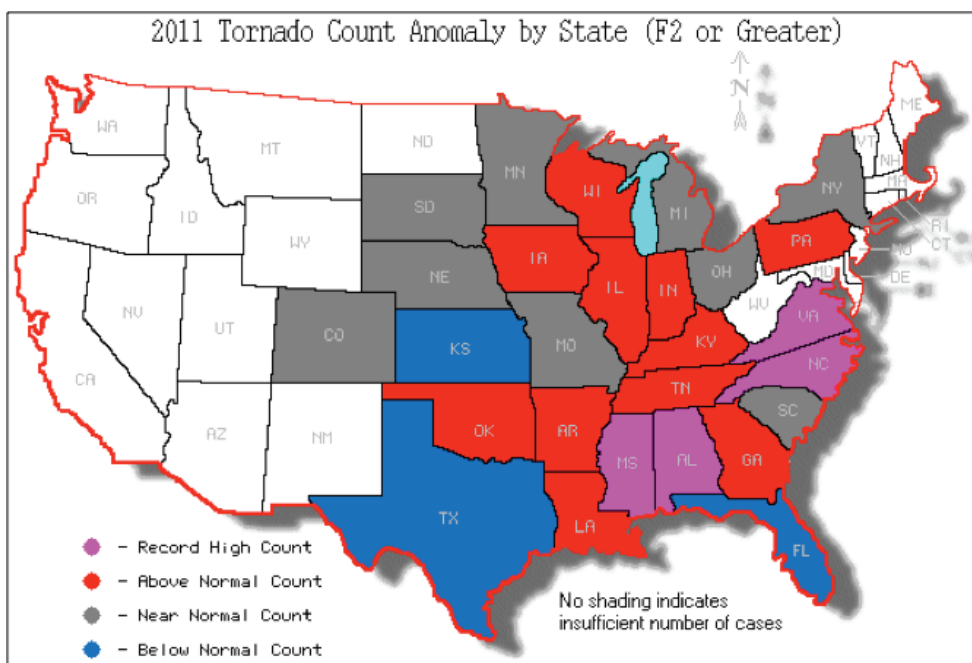


Figure 6: Tornado count anomaly (F2 or higher) in 2011 through the month of May. The base period is from 1970 to 2010. Data source: NOAA's Storm Prediction Center.

fall into these very dangerous categories. A recent study estimates that there are on the order of 17,000 non-ductile concrete frame buildings in just the 23 highest seismicity counties of California (Concrete Coalition, 2011). Notably, non-ductile concrete buildings are often mid-to-high rise towers, with risk of collapse in significant ground motions. Further, the design of many modern structures is focused on life-safety, and may not consider serviceability. In some cases, these structures may suffer significant levels of non-structural damage, increasing the owner's economic loss, as well as increasing the loss of occupancy times and lengthening overall recovery efforts.

In areas where soil is susceptible to liquefaction, losses will dramatically increase. Our ability to manage this type of hazard and to identify its overall risk in terms of land-use practices may need further refinement. In both New Zealand and Japan, very high losses were associated with soil liquefaction. For both residential and commercial construction, foundations are especially susceptible to damage when there is soil failure due to liquefaction (e.g., lateral spreading, differential settlement), because it is difficult or impossible to re-level

the building's foundation after the event. The presence of soils that are susceptible to liquefaction confound land-use decisions and change the economics of the recovery process – some regions in the aftermath of the New Zealand earthquake will not be available for rebuilding.

On a worldwide basis, we must continue to ask how well we understand the hazards posed by subduction zones. In the aftermath of the Tohoku earthquake, communities at risk should be very dubious of consensus earthquake fault models which don't adequately reflect potential uncertainties. We also need to continue to be cautious of the magnitude and frequency assignments of subduction zones models, and other source characterizations, throughout the world. As subduction zones are often associated with tsunami-genic sources, gaining a better understanding of the frequency and magnitude of earthquakes in subduction zones will directly translate into a better awareness of tsunami potential. As resilience is very dependent on defining hazards realistically, the uncertainty inherent in depicting hazards must also be an explicit element of any community's risk assessment and management plan.

**Certainly the takeaway from this year's devastating tornadoes is that more focus and investment needs to be put into building codes that save lives and reduce overall damage in those tornado winds that are sustainable, the level of an EF1 or EF2.**

## Severe Weather and Tornadoes

The horrendous impact of severe weather mainly associated with tornadoes left many wondering if weather risk patterns are changing in the United States. Although anomalous climate conditions were in place during the 2011 winter and spring, including an unusually strong temperature contrast from Texas to the Pacific Northwest, the general location of U.S. tornado outbreaks in April and May was not all that unusual. “Dixie Alley” in the Southeast is an area where tornadoes typically form in the early- to mid-spring. This includes much of Arkansas, Mississippi, northern Alabama, northern Louisiana, and parts of adjacent states. What was so unusual this spring was the extreme frequency of widespread severe weather outbreaks, with an unusually high number of significant tornadoes (EF2 or higher). Figure 6 illustrates this point; 15 states had an above average EF2+ tornado count through May of 2011, and four of those states reached a record-high count. Not only is this year on a near-record pace for tornado counts, but significant tornadoes have crossed into highly populated areas, such as Joplin, St. Louis, Tuscaloosa, the suburbs of Birmingham, Raleigh, Minneapolis, and even Springfield, Massachusetts. Having more tornadoes certainly increases the probability that a particular location will be affected; this year, both rural and urban areas experienced significant tornado damage.

Our collective resilience to severe weather outbreaks must be increased, especially in light of the high number of casualties experienced this year. There are numerous examples of how simple investments in life-safety can give families superior protection. The installation of tornado safe rooms is certainly one of the best defenses in single-family homes as well as other structures. They are also an efficient way to protect individuals from flying projectiles in a tornado; with an investment on the order of \$3,000 to \$6,000 (Federal Alliance for Safe Homes, 2011) an interior room of a newly constructed home can be designed to also serve as an easily accessible safe room. Fitting existing homes with safe rooms could be more expensive, depending on the type of home and options available, but certainly many understand that this is a worthwhile

investment in a family’s wellbeing during a tornado outbreak. Our first challenge is to protect lives. Survey teams looking at damage in Tuscaloosa and Joplin observed that engineered buildings, including schools, were designed without consideration for tornado safe rooms (Coulborne, 2011). Individuals need to be able to act on our improvements in warnings and have feasible alternatives for accessible and safe shelter. Good luck is not resilience.

Researchers point to wind damage from the less severe, but more frequent tornados (EF0, EF1 and EF2), which can be reduced in cost-effective ways (Prevatt, 2011). With respect to design, more focus on continuous load paths, including better connections between walls, roofs and foundations, will help reduce debris and reduce damage severity. And of course, improvements in construction also reduce the severity of losses for buildings that are on the periphery of the track for stronger tornadoes. Other investigators of the Joplin aftermath pointed out that commercial tilt-up buildings had critical vulnerabilities, due to their lightweight roofs and inadequate connections between precast panels (McGraw, 2011).

Certainly the takeaway from this year’s devastating tornadoes is that more focus and investment needs to be put into building codes that save lives and reduce overall damage in those tornado winds that are sustainable, the level of an EF1 or EF2. In too many areas, the building code for new construction does not adequately address basic, minimum standards for wind resistance. More evidence of this can be found in some of the first tests done in the Insurance Institute for Business and Home Safety’s Research Center. In that full-scale laboratory, two-story residential homes constructed to different standards were tested side-by-side in realistic winds that could be experienced in a severe thunderstorm. The paired tests were on identical homes that differed only by their construction standards: one was built to conventional standards that would be found in the Midwestern United States, and the other was built to the “FORTIFIED for Safer Living®” standard – essentially a verified code-plus regime for construction. Performance differences in 96-mph straight-

line winds tell a story of resilience achieved with a minimum of additional building costs, producing significantly lower repair costs (IBHS, 2010).

As we turn to tropical cyclones affecting both Australia and the United States, it is clear that there needs to be more recognition of the hazards faced by inland communities from severe rainfalls that are related to these tropical systems. Most individuals are aware of the hazards of severe wind and even storm surge as a result of tropical cyclones, but the experience of Irene shows our communities to be very vulnerable to inland flooding that is not storm-surge related. In the aftermath of Irene, many communities were completely isolated and had to survive for days without power, outside emergency services, and other necessities. While individual resilience is really focused first on risk awareness, many smaller communities found out how difficult it was to cope with extreme precipitation levels and should now review land-use planning decisions, critical facilities risks, and community shelter and evaluation plans.

For flood risk we are in a constant race, whereby the footprint of our built environment continues to expand, decreasing areas where beneficial flooding might be welcome and at the same time, increasing runoff volumes for those riverine systems downstream. The solutions for mitigating flood risk vary; existing development has fewer options, but new development has the ability to use strong land-use planning measures in conjunction with regional risk assessment to mitigate their flood risk. In existing communities, good risk management practices continue to mitigate flood losses, including such measures as raising foundations where possible, making basements waterproof, making sure electrical utilities and building mechanical equipment are protected from rising water, and designing first-floor structures that allow flood waters to pass through without damaging the structure. And when necessary, communities can invest in the construction of levees to protect low-lying developments that cannot be relocated.

This year we saw how the decisions of floodplain managers can often be very

difficult, as they balance the demands on flood control systems with the need to protect communities that are at risk when the system's capacity is overwhelmed. A major source of flood damages in Vermont in the Irene-related flood was fast moving waters in swollen streams. An important message for flood mitigation from this event was that it is not enough to get structures out of the flood plain; one needs also to watch out for erosion hazard as well. Eliminating natural stream meanders for development purposes leads to significantly higher hydraulic loads during flooding. These loads cause erosion of the stream banks and damage structures built alongside of the stream.

A thorough understanding of the flood hazard is necessary for proper mitigation and development planning. Communities that understand and educate their citizens on these risks of inundation will benefit greatly. Identifying areas in a community that can be expected to flood will enable individuals to make better decisions on where to locate, or at the very minimum, encourage them to maintain a flood insurance policy to cover future losses.

## Conclusion

In 2011, numerous natural catastrophes offered the world lessons in how to achieve greater disaster resilience in our cities. This report has focused on disasters in the developed world to underline the fact that even the most modern communities are often at a disproportionate risk from natural disasters, largely because buildings, infrastructure and other critical systems do not offer the resilience necessary for safety and security from extreme events. The criticality of resilience measures increases as the economic intensity of urban centers grows: our management of this urban risk has never been more important as the ramifications to worldwide economic systems continues to multiply. The most efficient way to finance the most concentrated elements of this risk is through mitigation efforts aimed at existing and new construction.

We know that the only way to make any community truly sustainable is to attain robust performance of buildings and infrastructure during extreme events. In 2011 we've witnessed how unsustainable some urban development can be, with large proportions of building inventory being destroyed or at least rendered unusable, whether from earthquakes overseas or tornadoes in the United States. This cycle of capital destruction coupled with the unnecessary impacts on the environment can be, in many cases, broken. Certainly, we find many clear cases where basic building codes reduce the human calamity of natural disasters, but we need to implement the newest technology available to achieve performance based design to allow consumers, which include home buyers as well as risk managers, much more certainty in the survivability of their properties in the face of natural disasters. If these consumers are armed with the information and incentive to demand resilient performance from their buildings, we can make great progress towards managing this risk for the benefit of our whole community.

WeatherPredict Consulting (WPC) continues to monitor the impacts of natural disasters on the developed world, recognizing that better quantification of the effects of natural disasters will support informed decisions in their management. Currently, WPC is involved in funding research on modeling of tropical cyclones in our collaboration with the University of Rhode Island (URI) and NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, New Jersey. In addition, WPC is committed to advancing research efforts into the costs and benefits of mitigating the effects of severe weather, as well as supporting organizations that seek engineering solutions for the mitigation of seismic risk. Finally, WPC is also working with the Federal Alliance for Safe Homes (FLASH) to educate and encourage consumers to adopt building practices with disaster safety in mind. Through the strengthening of homes, families can be better safeguarded from the impacts of natural catastrophes.

### Box 1: Potential Impacts of Extreme Earthquake Events in the US

Four extreme earthquake events have been modeled using the Federal Emergency Management Agency's HAZUS (HAZards US ) Software, with maps of estimated earthquake ground shaking developed by the United States Geological Survey. Extreme event scenarios include a M7.7 in the New Madrid Seismic Zone, a M7.3 earthquake in Charleston South Carolina, a M9.0 Cascadia Subduction Zone earthquake off the coast of Oregon and Washington, and a M7.8 earthquake on the San Andreas Fault in Southern California.

The Midwest's New Madrid Seismic Zone is the site of some of the largest historic earthquakes in the United States – four events of Magnitude 7-8 in 1811 and 1812. The modeled M7.7 scenario earthquake would cause damaging shaking in more than 83 counties across 6 states (AR, IL, KY, MO, MS & TN). Building damage is expected to average 8% of building value and the economic impact of this building damage could reach as high as 38% of the region's economic output (in terms of aggregate metropolitan area GDP). Population impacts would also be significant; approximately 2.6% of households would be displaced by building damage, and more than 700 people per 100,000 would be injured in a daytime event, with an additional 40 per 100,000 killed.

Another significant east coast event is a repeat of the 1886 Charleston South Carolina earthquake. This scenario earthquake would result in even greater average building damage than the New Madrid scenario, reaching almost 10% of building value. This represents 28% of Regional GDP, somewhat smaller than the New Madrid event, but still quite significant. More than 3% of households are expected to be displaced by building damage in this event, and casualties are expected to be of the same order of magnitude as the New Madrid event.

A large event in the Cascadia Subduction Zone would cause damaging shaking across coastal portions of Washington, Oregon and California. Similar to the March 11 Tohoku Earthquake offshore of Honshu Japan, such an event could potentially spawn a tsunami, which could increase damage estimates significantly. Western communities, with their increased earthquake experience, are expected to have more robust building codes, a fact reflected by the lower damage and loss levels in this scenario event. The shaking from this scenario earthquake would result in building damage totaling about 4% of building value, with associated economic loss representing just 10% of the region's

GDP. One percent of households are expected to be displaced, and about 300 people per 100,000 could be expected to be injured or killed.

Finally, a large earthquake on the San Andreas in Southern California (the subject of significant previous study as part of the "ShakeOut" Scenario ) would result in an average building damage of just over 1%, representing 3% of regional GDP. Less than 1% of the households in the 8 impacted counties would be displaced by building damage, and about 100 people per 100,000 could be injured or killed.

**Box 1: Potential Impacts of Extreme Earthquake Events in the US**

	Extreme Earthquake Scenario			
	New Madrid	Charleston	Cascadia Subduction	Southern San Andreas
<b>Earthquake Magnitude</b>	7.7	7.3	9.0	7.8
<b>States/Counties Impacted</b>	83 counties in AR, IL, KY, MO, MS & TN	28 counties in SC	36 counties in CA, OR & WA	8 counties in CA
<b>Major Cites Impacted</b>	Memphis, TN	Charleston, SC	Seattle, WA & Portland, OR	Los Angeles, CA
<b>Population Impacted (2000 Census)</b>	3,036,952	2,418,141	6,883,309	19,991,484
<b>Average Building Damage Ratio</b>	8%	10%	4%	1%
<b>Building Damage as a % of Regional GDP</b>	38%	28%	10%	3%
<b>Percent of Households Displaced</b>	2.6%	3.1%	1.2%	0.2%
<b>Daytime Non-Fatal Injuries per 100,000 population</b>	715	765	290	95
<b>Daytime Death per 100,000 population</b>	40	50	15	5
<b>Potential Additional Secondary Hazards</b>	Liquefaction, Landslide	Liquefaction, Landslide	Liquefaction, Landslide, Tsunami	Liquefaction, Landslide

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<sup>3</sup> For more information on HAZUS, see: [www.fema.gov/HAZUS](http://www.fema.gov/HAZUS)

<sup>4</sup> Information on the USGS’ ShakeMap Program may be found at: <http://earthquake.usgs.gov/earthquakes/shakemap/>

<sup>5</sup> For more information on the “ShakeOut” Scenario, see: <http://pubs.usgs.gov/of/2008/1150/>. It should be noted that the published “ShakeOut” Scenario analysis, conducted with significantly more detailed data and analyses, produced larger loss estimates. For the current relative risk comparison, an “apples-to-apples” comparison of estimates produced with consistent data and methods was desired, so the “ShakeOut” results have not been utilized.

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