Hazus®

Estimated Annualized Earthquake Losses for the United States

FEMA P-366 / April 2017

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This work was conducted as a collaborative effort between the Federal Emergency Management Agency (FEMA), United States Geologic Survey (USGS), and the Pacific Disaster Center (PDC).

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To access the data from this study in an interactive GIS viewer please go to: https://arcg.is/0a09DK

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Executive Summary

Large earthquakes can cause social and economic disruption that can be unprecedented to any given community, and the full recovery from these impacts may or may not always be achievable. In the United States (U.S.), the 1994 M6.7 Northridge earthquake in California remains the third costliest disaster in U.S. history; and it was one of the most expensive disasters for the federal government. Internationally, earthquakes in the last decade alone have claimed tens of thousands of lives and caused hundreds of billions of dollars of economic impact throughout the globe (~90 billion U.S. dollars (USD) from 2008 M7.9 Wenchuan China, ~20 billion USD from 2010 M8.8 Maule earthquake in Chile, ~220 billion USD from 2011 M9.0 Tohoku Japan earthquake, ~25 billion USD from 2011 M6.3 Christchurch New Zealand, and ~22 billion USD from 2016 M7.0 Kumamoto Japan).

Recent earthquakes show a pattern of steadily increasing damages and losses that are primarily due to three key factors: (1) significant growth in earthquake-prone urban areas, (2) vulnerability of the older building stock, including poorly engineered non-ductile concrete buildings, and (3) an increased interdependency in terms of supply and demand for the businesses that operate among different parts of the world. In the United States, earthquake risk continues to grow with increased exposure of population and development even though the earthquake hazard has remained relatively stable except for the regions of induced seismic activity. Understanding the seismic hazard requires studying earthquake characteristics and locales in which they occur, while understanding the risk requires an assessment of the potential damage from earthquake shaking to the built environment and to the welfare of people—especially in high-risk areas.

Estimating the varying degree of earthquake risk throughout the United States is critical for informed decision-making on mitigation policies, priorities, strategies, and funding levels in the public and private sectors. For example, potential losses to new buildings may be reduced by proper land-use planning, applying most current seismic design codes and using new technologies and specialized construction techniques. However, decisions to spend money on any of those solutions require benefit and cost comparison against the perceived risk. Previous versions of the FEMA 366 studies are the only nationally accepted criteria and methodology for comparing seismic risk across regions.

Our understanding of seismic risk in active tectonic areas in the western U.S. such as Los Angeles, San Francisco and Seattle is constantly improving; there is also general recognition that other lower hazard regions such as New York City and Boston are still at high risk of significant damage and loss. This higher level of risk reflects the dense concentrations of buildings and infrastructure in these areas constructed prior to modern seismic design provisions. Despite previous nationwide FEMA 366 studies, earthquake risk quantification and its communication continue to pose challenges that have inhibited local governments from widespread adoption of state-of-the-art mitigation policies and practices at the local or regional level. An improved risk quantification requires rigorous local or regional level inventory compilation with detailed building-specific structural and nonstructural attributes. Similarly, communicating earthquake risk in areas of low earthquake hazards needs newer strategies that could lead to effective engagement of the local community and establishing newer benchmarks and standards for resilience-informed planning.

This study highlights the impacts of both high hazard and high exposure on losses caused by earthquakes. The study is based on loss estimates generated by Hazus, a geographic information system (GIS)-based earthquake loss estimation tool developed by the Federal Emergency Management Agency (FEMA). The Hazus 3.0 tool provides a method for quantifying future earthquake losses. It is national in scope, uniform in application, and comprehensive in its coverage of the built environment.

This study estimates seismic risk in select regions of the United States by using two interrelated risk indicators:

- The annualized earthquake loss (AEL), which is the estimated long-term value of earthquake losses to the general building stock in any single year in a specified geographic area (e.g., state, county, metropolitan area); and
- The annualized earthquake loss ratio (AELR), which expresses estimated annualized loss as a fraction of the building inventory replacement value.

While building-related losses are a reasonable indicator of relative regional earthquake risk, it is important to recognize that these estimates are not absolute determinants of the total risk from earthquakes. This is because factors such as amount of debris generated and social losses including casualty estimates, displaced households, and shelter requirements need to be considered; we address these in this investigation. Seismic risk also depends on other parameters not included herein such as damages to lifelines and other critical facilities and indirect economic loss.

In Hazus 3.0, the total estimated economic exposure (building stock as well as content) for the nation is approximately 59 trillion USD, of which over 30% comes from California, Texas, New York, and Florida. According to the U.S. Geological Survey, the 10 states with highest populations exposed to very strong ground shaking levels are California, Washington, Utah, Tennessee, Oregon, South Carolina, Nevada, Arkansas, Missouri, and Illinois. Together, these states account for over 26% of the nation's total economic exposure. Although such a level of shaking is estimated to occur relatively infrequently, it could cause significant damage and causalities. Within the central and eastern United States, the New Madrid seismic zone (NMSZ) and the Charleston South Carolina earthquake zone poses significant earthquake threat. The NMSZ covers parts of eight states: Illinois, Indiana, Missouri, Arkansas, Kentucky, Tennessee, Oklahoma, and Mississippi, and together they amount to approximately 15% of the total national exposure.

The Hazus analysis indicates that the AEL to the national building stock is $6.1 billion per year. The majority of average annual loss 61% ($3.7 billion per year) is concentrated in the state of California and overall, the West Coast (California, Oregon, and Washington) accounts for 73% of the total average annual loss in the U.S. The high concentration of loss in California is consistent with the state's high seismic hazard and large structural exposure. The remaining 27% ($1.7 billion per year) of annual loss is distributed throughout the rest of the United States (including Alaska, Hawaii and Puerto Rico) as reflected in Figure E-1.

When casualties, debris, and shelter data are aggregated by state, California accounts for over 60% of estimated debris generated, 64% of displaced households, and 63% of short-term shelter needs for the earthquake hazard with a 250-year return period.

While the majority of economic loss is concentrated along the West Coast, the distribution of relative earthquake risk, as measured by the AELR, is much broader and reinforces the fact that earthquakes are a national problem. There are relatively high earthquake loss ratios throughout the western and central United States (states within the NMSZ) and in the Charleston, South Carolina area.

Fifty-five metropolitan areas, led by the Los Angeles and San Francisco Bay areas, account for 80% of the total AEL. Los Angeles County alone has about 22% of the total AEL, and the Los Angeles and San Francisco Bay area's together account for nearly 35% of the total AEL. As measured by AELR, the metropolitan areas of Anchorage, San Germán, Puerto Rico (PR), and Charleston are within the top 20, along with many California communities. In California, El Centro is the metropolitan region with the highest AELR, followed closely by the San Jose and San Francisco metropolitan areas. This observation supports the need for strategies to reduce the current seismic risk. Strategies to reduce future losses throughout the nation need to be closely integrated with policies and programs that guide urban planning and development.

Loss estimates are based on the best science and engineering that was available when the study was conducted (during 2016-2017); thus, future estimates based on new technology will be different from those presented herein. To demonstrate how risk has changed with time, comparisons are drawn with FEMA 366, Hazus®99 *Estimated Annualized Earthquake Loss for the United States*, prepared in 2001, as well as the most recent version of the study performed as a part of FEMA 366 in 2008.

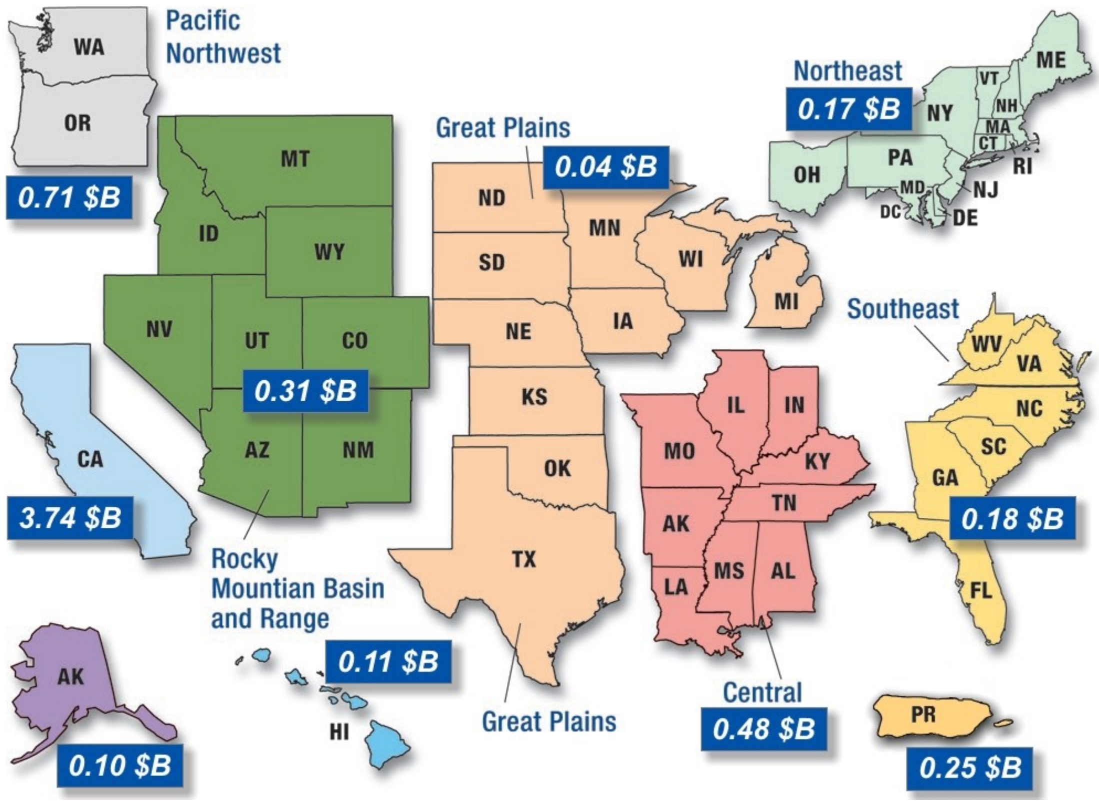


Figure E-1. Comparison of U.S. Regional Seismic Risk by Annualized Earthquake Losses (AEL).

This loss study is an important milestone in a long-term, FEMA-led effort to analyze and compare the seismic risk across regions in the United States and Puerto Rico. The study also contributes to the mission of the National Earthquake Hazards Reduction Program (NEHRP)—to develop and promote knowledge and mitigation practices and policies that reduce fatalities, injuries, and economic and other expected losses from earthquakes. The results of this study are useful in at least five ways:

1. Improving our understanding of the seismic risk in the nation;
2. Providing a baseline loss estimate for earthquake policy development, the promotion of state and local risk awareness, and comparison of mitigation action in states and high-risk local communities;
3. Supporting the adoption and enforcement of seismic provisions of building codes;
4. Comparing the seismic risk with that of other natural hazards; and
5. Supporting pre-disaster planning for earthquake response and recovery.

1 Introduction

Background

Policies and practices associated with minimization of earthquake impacts in the United States have been shaped by knowledge of the earthquake hazard, which focuses on the location and type of faulting and ground failure, and the distribution of strong ground motion or shaking. Earthquake hazard databases and maps—produced by the U.S. Geological Survey (USGS), state geological surveys and other research institutions—provide consistent and useful data. While hazard maps contribute to understanding earthquakes, there is increasing recognition among policy makers, researchers and practitioners of the need to analyze and map the earthquake risk in the United States. As urban development continues in earthquake-prone regions there is growing concern about the exposure of buildings, lifelines (e.g., utilities and transportation systems), and people to the potential effects of destructive earthquakes. Earthquake risk analysis begins with hazard identification, but goes beyond that to investigate the potential consequences to people and property, including buildings, lifelines, and the environment (see Appendix A). Risk analysis is useful for communities, regions, and the nation in making better decisions about how to best allocate resources and set priorities. At a national level, the ability to compare risk across states and regions is critical to formulation of effective earthquake-risk mitigation measures. At the state and community level, an understanding of seismic risk is important for planning, evaluating costs and benefits associated with building codes, and other prevention measures. Additionally, an understanding of earthquake risk is important to risk management for businesses and industries. In addition, understanding the consequences of earthquakes is critical to developing emergency operations plans for catastrophes.

This study uses Hazards U.S. (Hazus) Version 3.0, a PC-based standardized tool that uses a uniform engineering-based approach to measure damages, casualties and economic losses from earthquakes nationwide. Hazus 3.0 was released by FEMA in 2015 and incorporates updates to the building valuation data using 2014 U.S. dollar values and the 2010 census, as well as enhanced geotechnical data. Appendix B contains a detailed discussion of Hazus 3.0.

Study Objectives and Scope

The objective of this study is to assess levels of seismic risk in the United States and Puerto Rico using Hazus 3.0 and nationwide data. The study updates *Hazus-MH MR2 Estimated Annualized Earthquake Losses for the United States* (FEMA 366, 2008) and incorporates the 2014 updates to the USGS national seismic hazard map (Petersen et al. 2014) and 2010 census data to estimate annualized economic losses, and debris, shelter and casualty estimates for all 50 states and Puerto Rico.

The analysis computes two interrelated metrics to characterize earthquake risk: Annualized Earthquake Loss (AEL) and the Annualized Earthquake Loss Ratio (AELR).

The AEL addresses two key components of seismic risk: the probability of ground motion occurring in a given study area and the consequences of the ground motion in terms of physical damage and economic loss. It takes into account the regional variations in risk. For example, the level of earthquake risk in the New Madrid seismic zone is measurably different from the risk in the Los Angeles Basin with respect to (a) the probability of damaging ground motions, and (b) the consequences of the ground motions, which are largely a function of building construction type and quality, as well as ground shaking and failure during earthquakes. The level of seismic hazard and its impact do vary regionally; for example, the earthquake hazard is higher in Los Angeles than in Memphis, but the general building stock in Los Angeles is more resistant to the effects of earthquakes.

The AEL annualizes expected losses by averaging them per year, which factors in historical patterns of frequent smaller earthquakes with infrequent but larger events to provide a balanced presentation of earthquake risk. This enables the comparison of risk between two geographic areas, such as Los Angeles and Memphis, or California and South Carolina. The AEL values are also presented on a per capita basis, to allow comparison of relative risk across regions based on population.

The AELR is the AEL as a fraction of the replacement value of the building inventory and is useful for comparing the relative risk of different regions or events. For example, $10 million in earthquake damages in Evansville, Indiana, represents a greater loss than a comparable dollar loss in San Francisco, a much larger city. The annualized loss ratio allows gauging the relationship between AEL and building replacement value. Similarly, this ratio can be used as a measure of relative risk between regions and, since it is normalized by replacement value, it can be directly compared across metropolitan areas, counties, or states.

Casualties, Debris and Shelter Requirements

This study addresses three additional dimensions of earthquake risk: casualties, debris and shelter. With FEMA's emphasis on planning for catastrophic earthquakes, estimates of casualties, debris and shelter are useful metrics.

Casualty estimates are central to medical response planning and identification of potential lifesaving measures. For example, Hazus 3.0 can measure reduced casualties that would result from various combinations of retrofit schemes for the general building stock.

Estimates of debris are useful for preparing removal and disposal plans, particularly in urban areas, and for scaling mission requirements for urban search and rescue operations. The ability to compare debris estimates on a regional, state and local scale—including estimates by category such as brick, wood, reinforced concrete, and steel—is valuable for planning and preparing risk-reduction strategies.

Estimating shelter requirements for households and individuals is useful for measuring the effects of building codes and other mitigation measures designed to strengthen structures to reduce damage to buildings and lessen the need for post-disaster shelter. Recent disasters continue to reinforce the critical nature of shelter planning. The ability to compare shelter needs for 250-year and 1,000-year return periods help in estimating shelter capacity and in decision-making for investment in shelter retrofits.

This report is organized into five chapters. Chapter 1 is an introduction that lays out the study objectives and scope. Chapter 2 summarizes the identification of risk parameters and describes the procedures used to develop the economic loss estimates. The actual loss estimates are presented at the state, regional, county, and metropolitan level in Chapter 3 in a series of maps and tables. Chapter 4 discusses how changes in the 2008 and 2014 versions of the USGS seismic hazard maps, census data and building inventory affect loss estimates. The report concludes with Chapter 5, which is a summary of the major findings and recommendations for using results of this work. The Appendices contain a glossary of terms as well as more detailed technical information on the methodology and data.

2 Analyzing Earthquake Risk

Introduction

Earthquake risk analysis requires measuring the likely damage, casualties, and costs of earthquakes within a specified geographic area over defined periods of time. A comprehensive risk analysis assesses various levels of the hazard, as well as the consequences to structures and populations, should an event occur. Appendix A defines terminology related to risk analysis.

There are two types of risk analyses—probabilistic and scenario. This study uses a probabilistic, or statistical, hazard analysis to measure the potential effects of earthquakes of various locations, magnitudes, and frequencies. The probabilistic analyses allow for uncertainties and randomness in the occurrences of earthquakes.

To estimate average annualized loss, a number of hazard and building structural characteristics were input into the Hazus 3.0 earthquake model, as described in Table 2-1.

Computing annualized earthquake loss (AEL), annualized earthquake loss ratios (AELRs), and casualty, debris and shelter needs was a five-step process. In the first step, the USGS earthquake hazard data were processed into a format compatible with Hazus 3.0. In the second step, the building inventory in Hazus 3.0 was used to estimate losses at the census tract level for specific return periods. Third, Hazus was used to compute the AEL. Fourth, the annualized loss values were divided by building replacement values to determine the AELRs, and in the final step, casualty, debris and shelter estimates were computed. Each of the five steps is described in this section, with greater detail supplied in Appendix C.

Table 2-1. Hazard and Building Parameters Used in the Study

Parameters Used in the Study	
Geotechnical Parameters	Basis for ground motion parameters: The 2014 USGS national seismic hazard map site-corrected ground motion parameters for eight return periods between 100 and 2,500 years (100, 250, 500, 750, 1,000, 1,500, 2,000, and 2,500 years) for the lower 48 States. The USGS 2007, 1998 and 2003 site-corrected ground motion maps were used for Alaska, Hawaii and Puerto Rico, respectively. Ground motion parameters located at the census tract centroid. Ground-failure effects (liquefaction, landslide) were not included in the analyses due to the lack of a nationally applicable database.
Building Inventory Parameters	Basis for general building inventory exposure*: The 2010 U.S. Census for residential buildings (U.S. Bureau of the Census, 2010), 2006 Dun & Bradstreet (2006) for nonresidential buildings, and 2014 R.S. Means (2014) for all building replacement costs. Building-related direct economic losses (structural and nonstructural replacement costs, contents damage, business inventory losses, business interruption, and rental income losses), debris, shelter and casualties due to ground shaking were computed. All other economic losses were ignored due to the lack of a nationally applicable database.

* https://www.fema.gov/summary-databases-hazus-multi-hazard

Step One: Prepare Probabilistic Hazard Data

The primary sources of earthquake hazard data used in this study are probabilistic hazard curves developed by the USGS (https://earthquake.usgs.gov/hazards/hazmaps/). These were processed for compatibility with Hazus. The curves specify ground motion, such as peak ground acceleration (PGA) and spectral acceleration (SA), as a function of the average annual frequency that a level of motion will be exceeded in an earthquake. Examples of the USGS probabilistic hazard curves are illustrated in Figure 2-1 that show average annual frequency of exceedance as a function of PGA for single points in seven major U.S. cities.

The USGS has developed these data for most regions of the U.S. (see Petersen et al. 2014, http://earthquake.usgs.gov) as part of the National Earthquake Hazards Reduction Program (NEHRP). The curves were developed for individual points in a uniform grid that covers all 50 states, Washington, D.C., and Puerto Rico.

A 2014 USGS map illustrating site-corrected PGA for an average return period of 250 years and 1,000 years is shown in Figure 2-2a and 2-2b, respectively.

The 2014 USGS hazard curves were converted to a Hazus-compatible database of probabilistic ground shaking values. Note that the recent increase in U.S. seismic hazards due to induced seismicity represented in the USGS 2017 one-year model (Petersen et al. 2017) is not included in this study. Probabilistic hazard data for the PGA, spectral acceleration at 0.3 seconds (SA@0.3), and spectral acceleration at 1.0 second (SA@1.0) were processed for each census tract for each of the eight different return periods. Figure 2-3 compares a Hazus 3.0 seismic hazard (PGA) map for the 1,000-year return period for California to the USGS map for the same return period to illustrate that the re-mapping process does not significantly affect the estimated losses. The default USGS-computed ground motions apply to rock (site class B/C boundary soil), and these estimates are corrected to local site soil conditions based on topography-based Vs30 estimates from USGS Global Vs30 Model (https://earthquake.usgs.gov/data/vs30/) and the NEHRP 2015 site soil correction factors (NEHRP 2015).

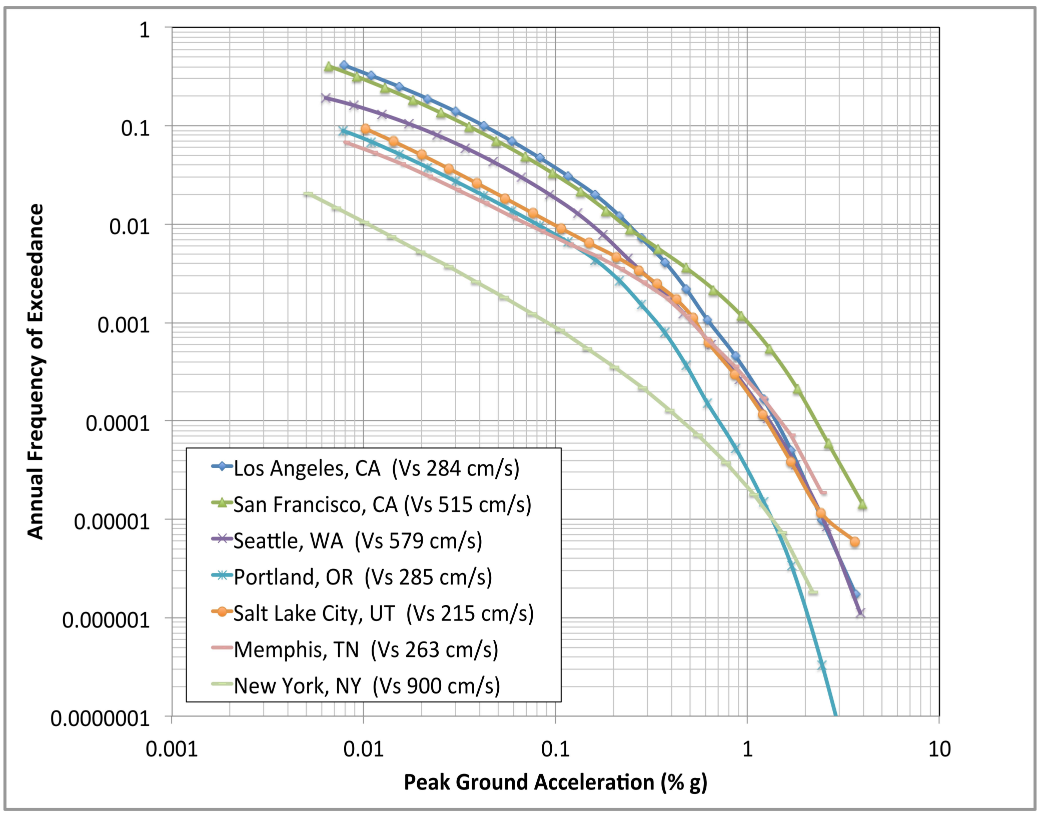


Figure 2-1. Average Annual Frequency of Site-Corrected Peak Ground Acceleration for Seven Major Cities

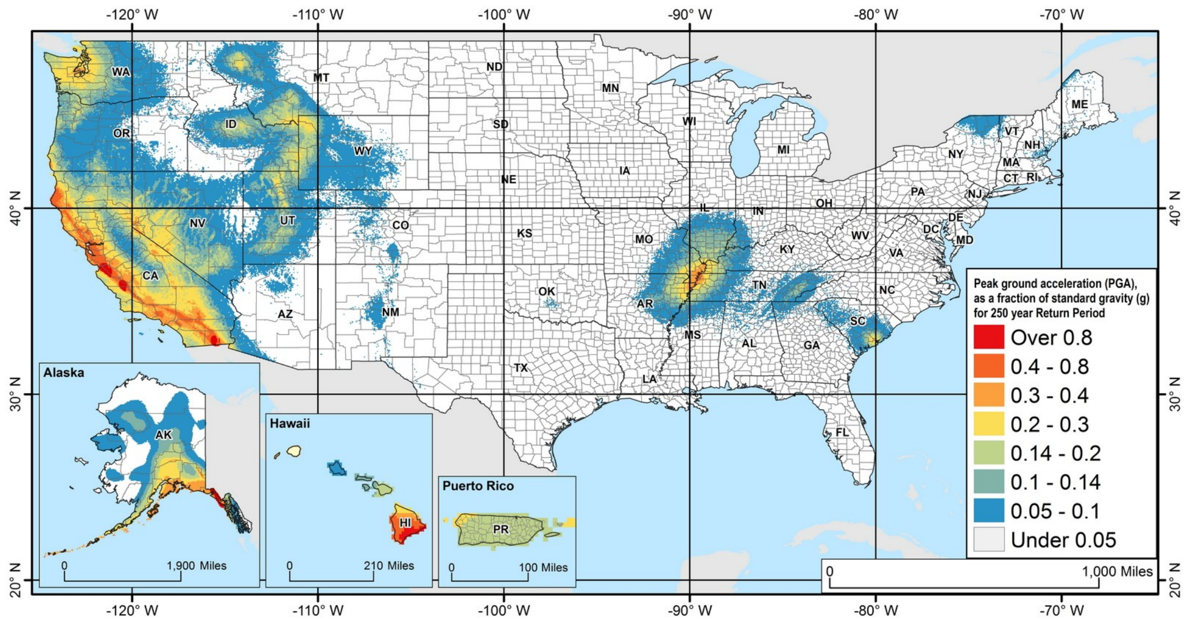


Figure 2-2A. USGS 2014 Site-Corrected and Geo-referenced Seismic Hazard Map in terms of Peak Ground Acceleration for the 250-year Return Period

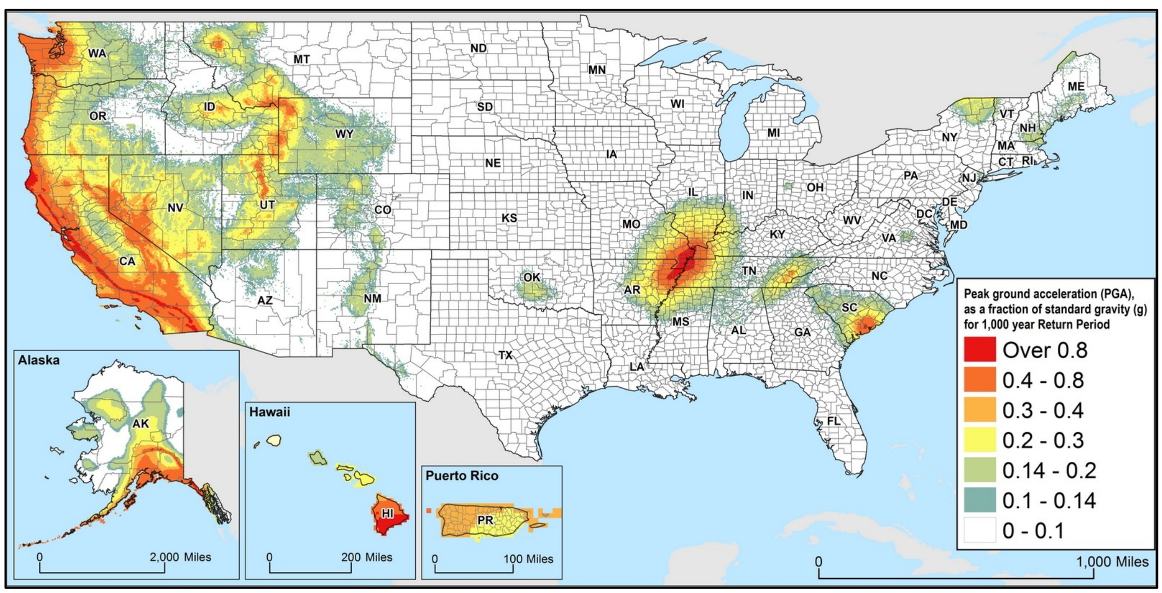
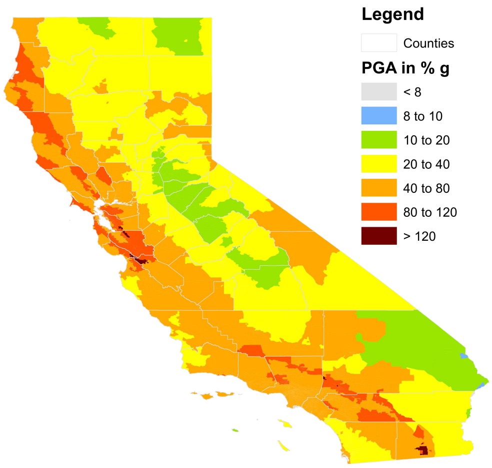


Figure 2-2B. USGS 2014 Site-Corrected Seismic Hazard Map in terms of Peak Ground Acceleration for the 1000-year Return Period



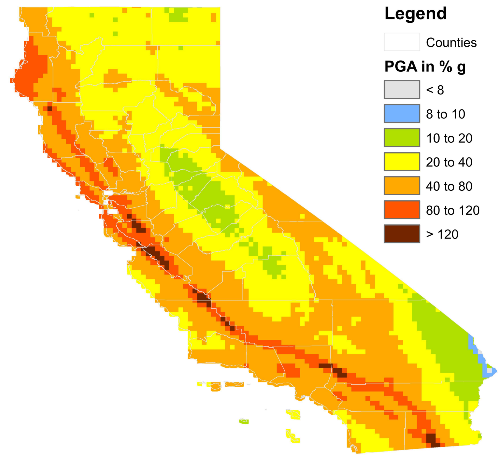


Figure 2-3. Comparison of Site-Corrected Hazus 3.0 Seismic Hazard Map for PGA in % g (left) and a USGS Site-Corrected 2014 Hazard Map (right) for 1,000-year Return Period Ground Motion

Step Two: Compute Building Damage and Loss

In the second step, Hazus was used to generate damage estimates for the probabilistic ground motions associated with each of the eight return periods. The building damage estimates were then used as the basis for computing direct economic losses. These include building repair costs, contents and business inventory losses, costs of relocation, capital-related, wage and rental losses. The analyses were completed for the entire Hazus building inventory for each of the approximately 74,000 census tracts in the U.S. These building-related losses serve as a reasonable indicator of relative regional risk, as described in greater detail in Appendix B.

Damage and economic losses to critical facilities, transportation and utility lifelines were not considered in this study. While it is understood that these losses are a component of risk, the AEL computation in Hazus did not account for these types of losses.

For loss estimation, the replacement value of the building inventory is first estimated. Modification factors representing the relative differences in the cost of rebuilding is included for each county. A map illustrating replacement value of buildings (by county) is shown in Figure 2-4 which is based only on the value of the building components and omits the land value and building contents. Building components include structural and nonstructural systems (interior and exterior cladding, piping, fixtures, and mechanical and electrical systems).

The building data were combined at various levels to compare replacement value between different regions. For example, Figure 2-5 compares the replacement value by state as a percentage of total replacement value for the United States. The building exposure data help to identify concentrations of replacement value and potential areas of increased risk.

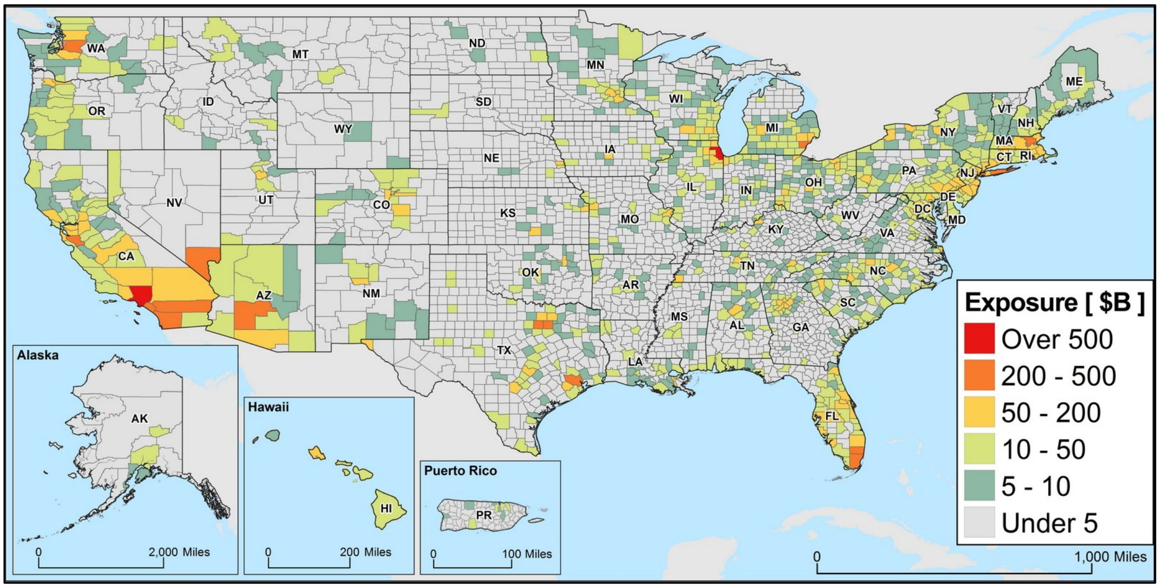


Figure 2-4. Replacement Value of Hazus 3.0 Building Inventory by County

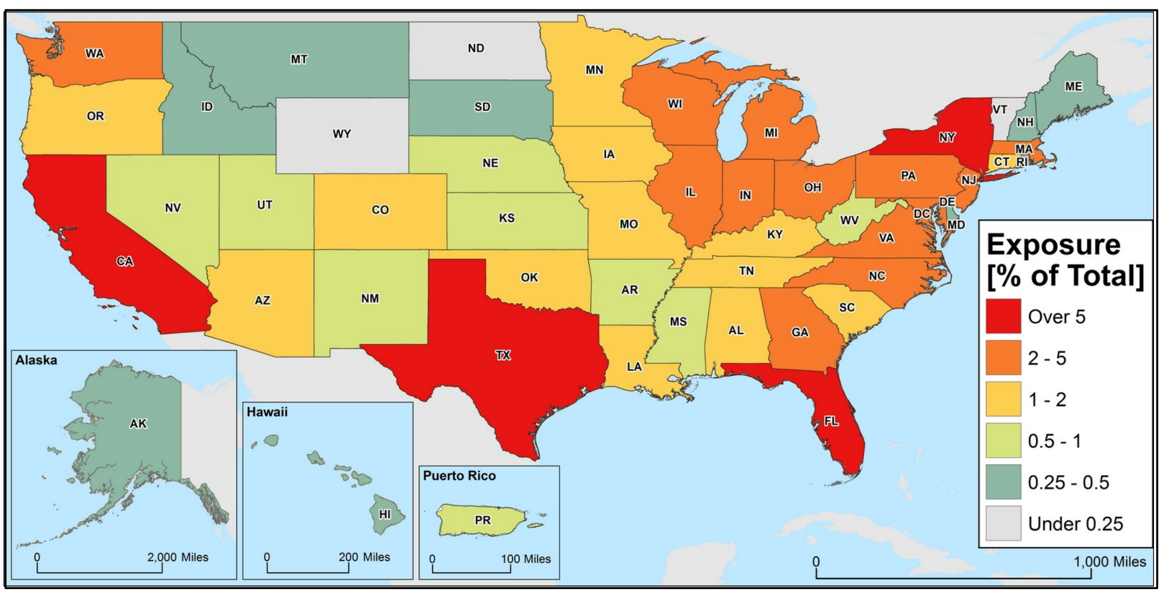


Figure 2-5. Distribution of Building Replacement Value by State

Step Three: Compute the Average Annualized Earthquake Losses (AEL)

In this step, the AEL was computed by multiplying losses from eight potential ground motions by their respective annual frequencies of occurrence, and then summing the values. Several assumptions were made for this computation. First, the losses associated with ground motion with return periods greater than 2,500 years were assumed to be no worse than the losses for a 2,500-year event as per the AEL computation engine implemented within Hazus. Second, the losses for ground motion with less than a 100-year return period were assumed to be generally small enough to be negligible, except in California, where losses from ground motion with less than a 100-year return period can account for up to an additional 15% of the overall statewide AEL estimate (FEMA 366, 2008).

Step Four: Compute the Average Annualized Earthquake Loss Ratios (AELR)

The AEL is an objective measure of risk; however, since risk is a function of the hazard, building stock, and vulnerability, variation in any of these three parameters affects the overall risk at any one site. Understanding how the parameters such as exposure influences the risk is key to developing effective risk management strategies. To facilitate that understanding for regional comparisons, the AEL was normalized by the building inventory exposure to create a loss-to-value ratio, termed the AELR, and expressed in terms of dollars per million dollars of building inventory exposure.

Between two regions with similar AEL, the region with the smaller building inventory typically has a higher relative risk, or AELR, than the region with a larger inventory, since annualized loss is expressed as a fraction of the building replacement value. For example, while Charleston, South Carolina, and Memphis, Tennessee, have similar AELs (see Table 3.2), the former has a higher earthquake loss ratio, since Charleston has less building inventory and building replacement value.

Step Five: Compute the Annualized Casualty, Debris, and Shelter Requirements

The Hazus 3.0 software provides the capability to directly compute annualized casualty estimates. However, this automated capability does not exist for annualized debris and shelter estimates. In the present investigation, Hazus 3.0 was run to produce debris and shelter estimates for 250- and 1,000-year return periods.

Casualties are estimated as a function of direct structural or nonstructural building damage with the nonstructural-related casualties derived from structural damage output. The Hazus methodology is based on the correlation between building damage (both structural and nonstructural) and the number and severity of casualties. This method does not include casualties that might occur during or after earthquakes that are not directly related to damaged buildings such as heart attacks, car accidents, mechanical failure from power outages, incidents during post-earthquake search and rescue, post-earthquake clean-up and construction, electrocution, tsunami, landslides, liquefaction, fault rupture, dam failures, fires, or hazardous materials releases. Psychological effects of earthquakes are also not modeled.

Debris is estimated using an empirical approach for two types of debris. The first is large debris, such as steel members or reinforced concrete elements of buildings that require special handling to break them into smaller pieces before removal. The second type of debris is smaller and more easily moved directly with bulldozers and other machinery and tools, and includes bricks, wood, glass, building contents, and other materials.

Two types of shelter needs are estimated: the number of displaced households and the number of individuals requiring short-term shelter. Both are a function of the loss of habitability of residential structures directly from damage or from a loss of water and power. The methodology for calculating short-term shelter requirements recognizes that only a portion of displaced people will seek public shelter while others will seek shelter even though their residence may have no damage or insignificant damage because of reluctance to remain in a stricken area.

Study Limitations

The estimates provided by this study are not determinations of total risk since not all aspects of earthquake impacts are addressed. For example, the study only addresses direct economic losses to buildings. A comprehensive risk study would include the potential damage to lifelines and other critical facilities, as well as indirect economic losses sustained by communities and regions.

There are also inherent uncertainties in computing losses using estimated building values, averaged building characteristics, spatial averaging of ground conditions, soil response and ground motion that are located at the centroids of census tracts, variables such as the maximum magnitude of future events, and significant variations in the attenuation of strong ground motion due to basin effects. These variables must be considered when comparing the results of other loss studies based on Hazus or other methodologies.

3 Results of the Study

In this chapter, the annualized earthquake loss (AEL) and the annualized earthquake loss ratios (AELRs) are presented at five levels of geographic resolution: nation, state, county, region, and metropolitan area.

Nation

The analysis yielded an estimate of the national AEL of $6.1 billion per year. As previously stated, this does not include losses to lifeline infrastructure or indirect (long-term) economic losses, nor does it consider the risk/loss associated with induced seismicity; it 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.

States and Counties

While the AEL measures the annualized earthquake losses in any single year, the AELR addresses seismic risk in relation to the value of the buildings in the study area. By relating annualized loss to the replacement value in a given study area, the AELR provides a comparison of seismic risk between regions.

Figures 3-1 and 3-2 show the AEL and the AELR at the state level, and Figures 3-3 and 3-4 show the results at the county level. Relatively high earthquake-loss ratios exist throughout the western U.S. (including Alaska and Hawaii), the central U.S. states within the New Madrid seismic zone, the Charleston, South Carolina area, and parts of New England, as reflected in Figures 3-2 and 3-4.

Seventy-three percent ($4.45 billion) of the annualized losses occur in California, Oregon and Washington, and about 61% ($3.7 billion) are concentrated in the State of California alone, which is consistent with the State's population and building inventory exposed to significant earthquake hazard (see Figures 2-2 and 2-4).

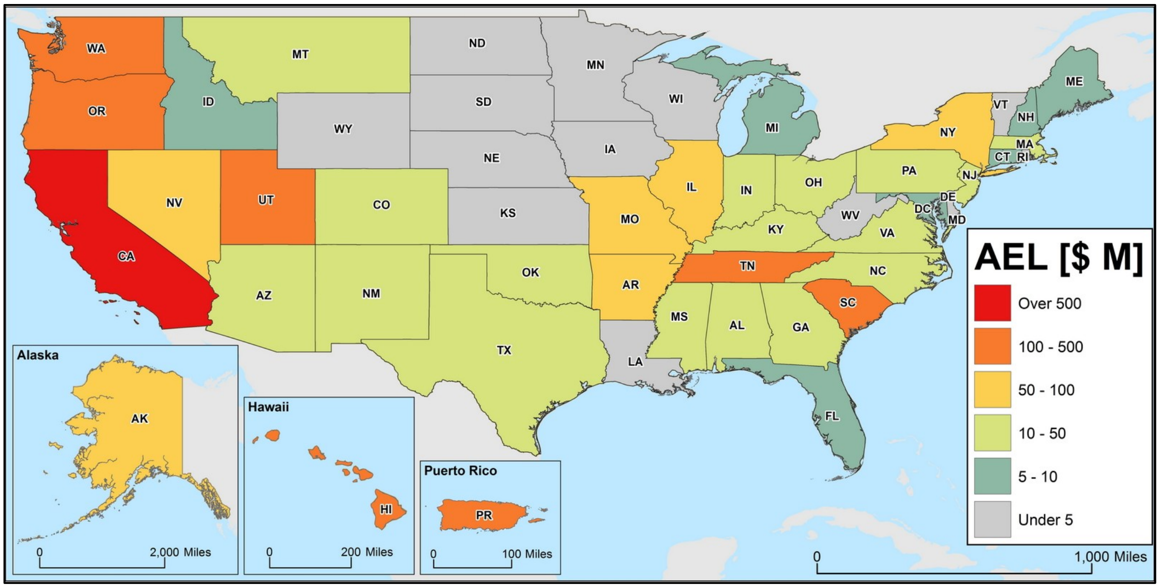


Figure 3-1. Annualized Earthquake Losses by State

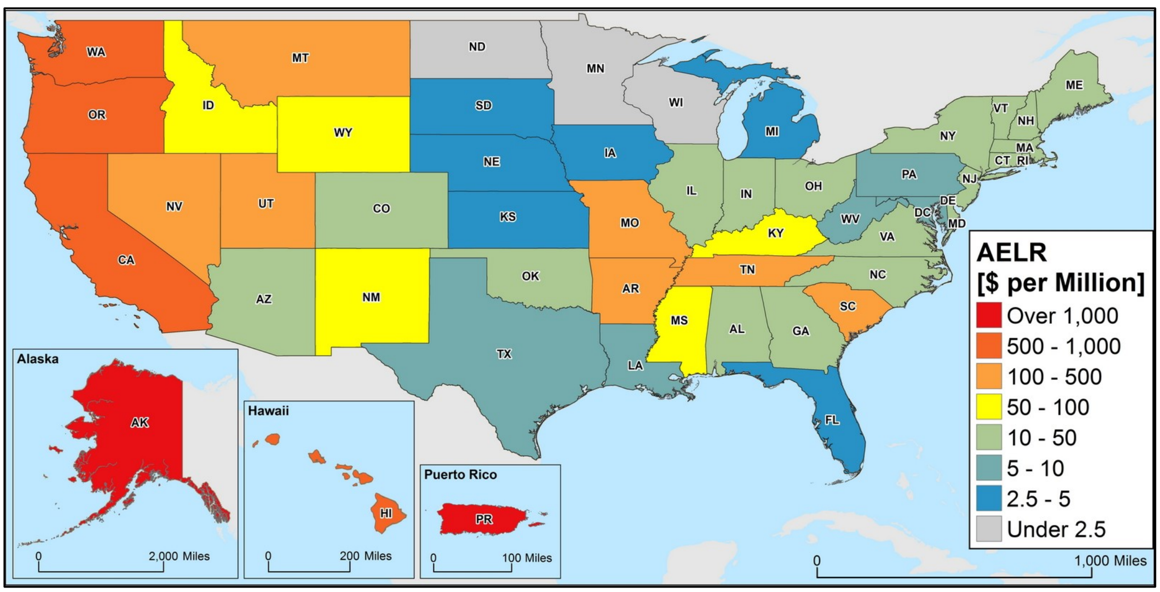


Figure 3-2. Annualized Earthquake Loss Ratios by State

AEL and AELR values for the 50 states, Washington, D.C., and Puerto Rico are shown in Table 3-1. While California accounts for the majority of losses, the regional distribution of annualized loss and loss ratios demonstrates that seismic risk is a national concern. The juxtaposition of New York and Arkansas in the AEL column of Table 3-1 illustrates the trade-offs between the value of the building inventory and the level of seismic hazard when estimating seismic risk. States with low hazard and high value building inventories (e.g., New York) can have annualized losses comparable to states with greater hazards but smaller building inventories (e.g., Arkansas).

Comparing the rankings of individual states in the AEL and AELR columns of Table 3-1 shows that California and the Pacific Northwest region retain a high relative standing. A majority of the states with the highest AELRs are located in the western United States, while other significant concentrations occur in the Southeast (South Carolina), Northeast (New Hampshire), and the Central United States (Tennessee, Arkansas, Missouri).

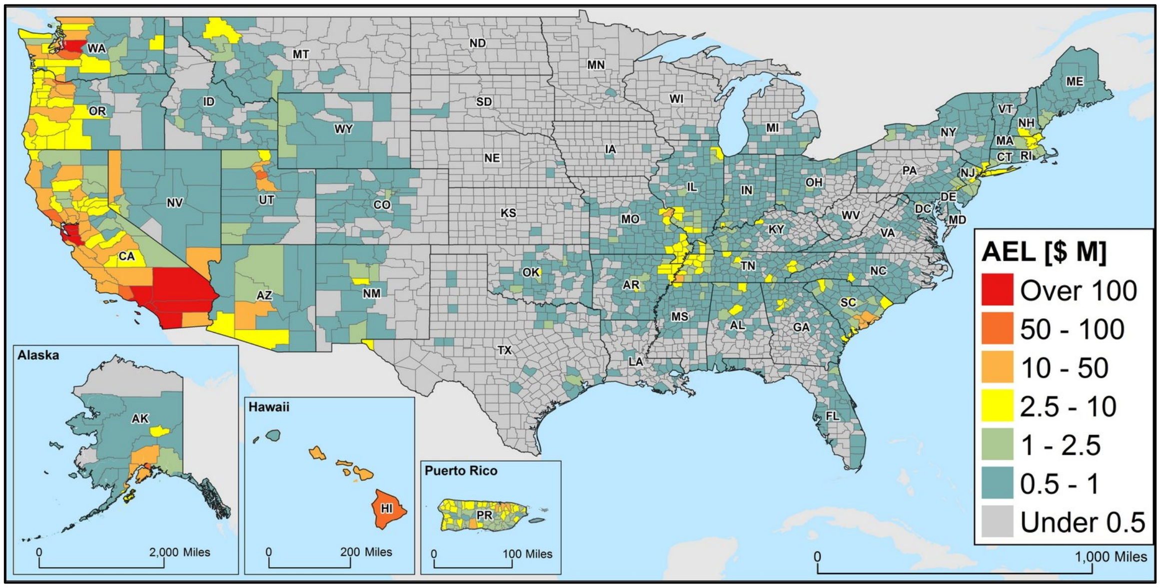


Figure 3-3. Annualized Earthquake Losses by County

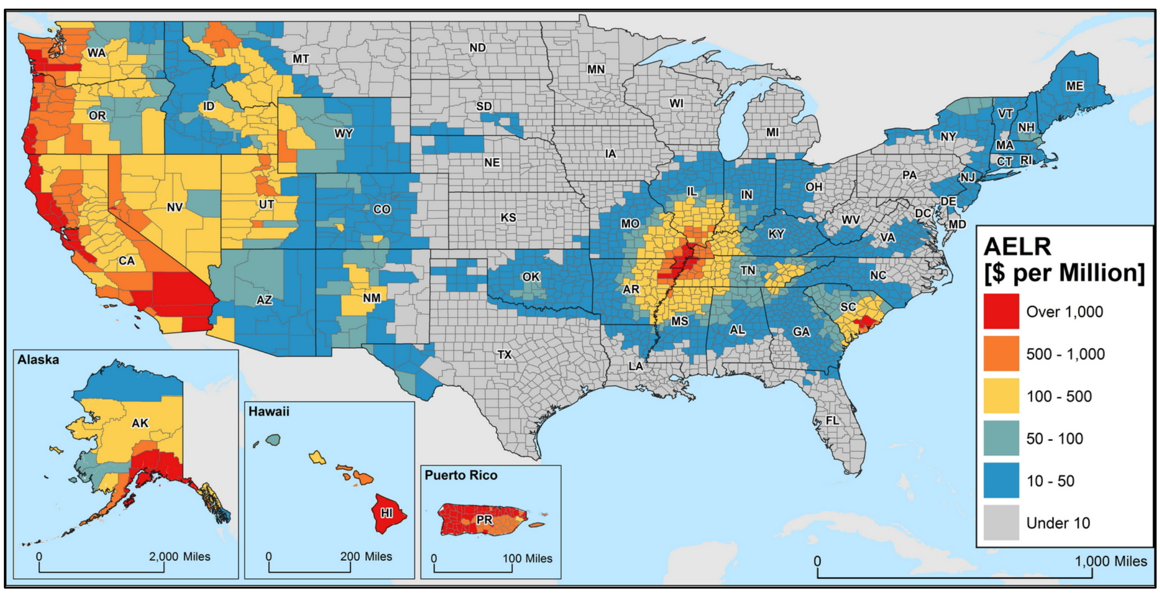


Figure 3-4. Annualized Earthquake Loss Ratios (AELR) by County

Table 3-1. Ranking of States by Annualized Earthquake Loss (AEL) and Annualized Earthquake Loss Ratios (AELR)

Rank	State	AEL ($x1,000)
1	California	3,739,125
2	Washington	438,524
3	Oregon	271,113
4	Puerto Rico	252,911
5	Tennessee	142,221
6	Utah	124,637
7	South Carolina	112,989
8	Hawaii	106,825
9	Nevada	99,364
10	Alaska	95,901
11	Missouri	83,762
12	Illinois	73,430
13	New York	59,352
14	Arkansas	51,079
15	Kentucky	43,846
16	Georgia	35,637
17	Indiana	34,888
18	New Jersey	27,434
19	Arizona	26,751
20	Massachusetts	26,264
21	Mississippi	23,299
22	Alabama	19,956
23	Montana	15,947
24	Ohio	15,721
25	North Carolina	15,380
26	New Mexico	15,205
27	Oklahoma	14,653
28	Texas	13,334
29	Pennsylvania	12,929
30	Virginia	11,740
31	Colorado	10,978
32	Idaho	8,231
33	New Hampshire	7,301
34	Connecticut	6,755
35	Florida	6,335
36	Michigan	5,808
37	Maryland	5,767
38	Maine	5,689
39	Wyoming	4,837
40	Louisiana	3,671

Rank	State	AELR ($/million $)
1	Puerto Rico	1,080.5
2	Alaska	1,057.7
3	California	971.5
4	Hawaii	708.4
5	Oregon	661.9
6	Washington	591.5
7	Utah	498.6
8	Nevada	345.9
9	South Carolina	231.1
10	Tennessee	207.5
11	Arkansas	175.5
12	Montana	147.6
13	Missouri	118.0
14	Kentucky	94.0
15	Mississippi	83.1
16	New Mexico	82.7
17	Wyoming	78.4
18	Idaho	54.3
19	Indiana	45.8
20	Illinois	45.2
21	New Hampshire	43.3
22	Arizona	42.4
23	Alabama	39.7
24	Oklahoma	36.3
25	Maine	35.0
26	Georgia	33.2
27	Massachusetts	29.6
28	New York	25.4
29	New Jersey	24.1
30	Vermont	23.3
31	Colorado	19.0
32	North Carolina	14.7
33	Rhode Island	14.5
34	Connecticut	13.8
35	Virginia	11.6
36	Ohio	11.0
37	Delaware	10.6
38	District of Columbia	9.6
39	Pennsylvania	8.8
40	Louisiana	8.0

41	Rhode Island	1,944
42	Vermont	1,894
43	Kansas	1,648
44	West Virginia	1,456
45	Wisconsin	1,295
46	Delaware	1,286
47	Iowa	972
48	District of Columbia	906
49	Nebraska	584
50	Minnesota	383
51	South Dakota	374
52	North Dakota	58

41	West Virginia	7.4
42	Maryland	7.4
43	Texas	5.1
44	Kansas	4.9
45	Michigan	4.6
46	South Dakota	4.2
47	Florida	2.9
48	Nebraska	2.7
49	Iowa	2.5
50	Wisconsin	1.7
51	North Dakota	0.7
52	Minnesota	0.5

Region

Figure 3-5 shows the distribution of AEL by region. Oregon, Washington, and California account for $4.45 billion in estimated annualized earthquake losses, or 73% of the United States total. The remaining 27% of estimated annualized losses are distributed across the central United States ($0.48 billion), the northeastern states ($0.17 billion), the Rocky Mountain/Great Basin region ($0.31 billion), the Great Plains ($0.04 billion per year), and the Southeast ($0.18 billion per year). The state of Hawaii and Alaska have a combined AEL of $0.21 billion, and Puerto Rico has $0.25 billion AEL as shown in Table 3-1.

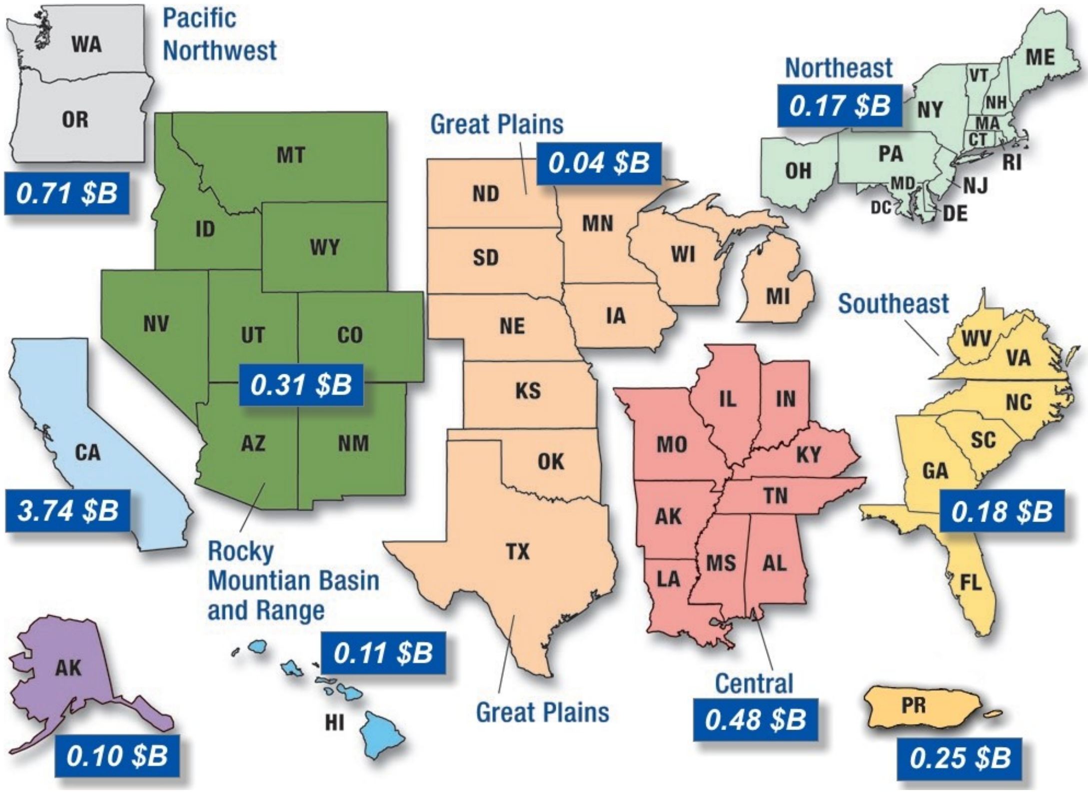


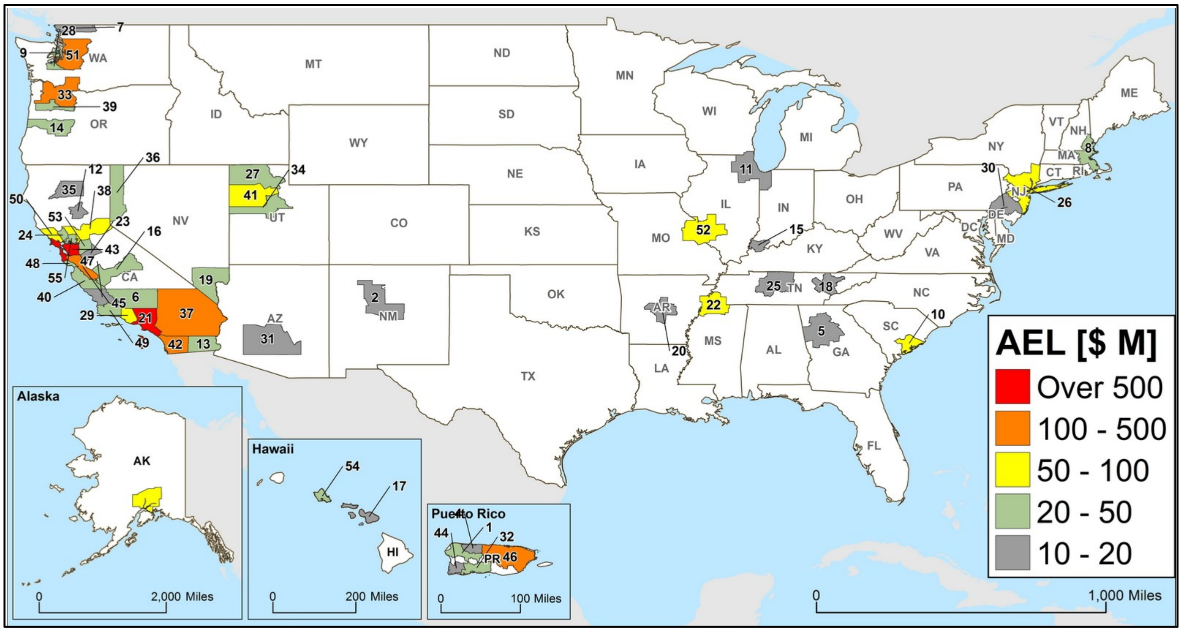
Figure 3.5 Distribution of Average Annualized Earthquake Loss by Seismic Region

Metropolitan Areas

Census tract level data can be combined to create loss estimates for metropolitan areas, defined by the census as the primary Metropolitan Statistical Areas (U.S. Census, 2010). Metropolitan areas with annualized losses greater than $10 million are listed in Table 3-2.

These 55 metropolitan areas, led by the Los Angeles and San Francisco Bay areas, account for 85% of the total annualized losses in the United States. Los Angeles alone accounts for 22% of the national figure. Annualized earthquake loss values for selected metropolitan areas are shown in Figures 3-6 and 3-7.

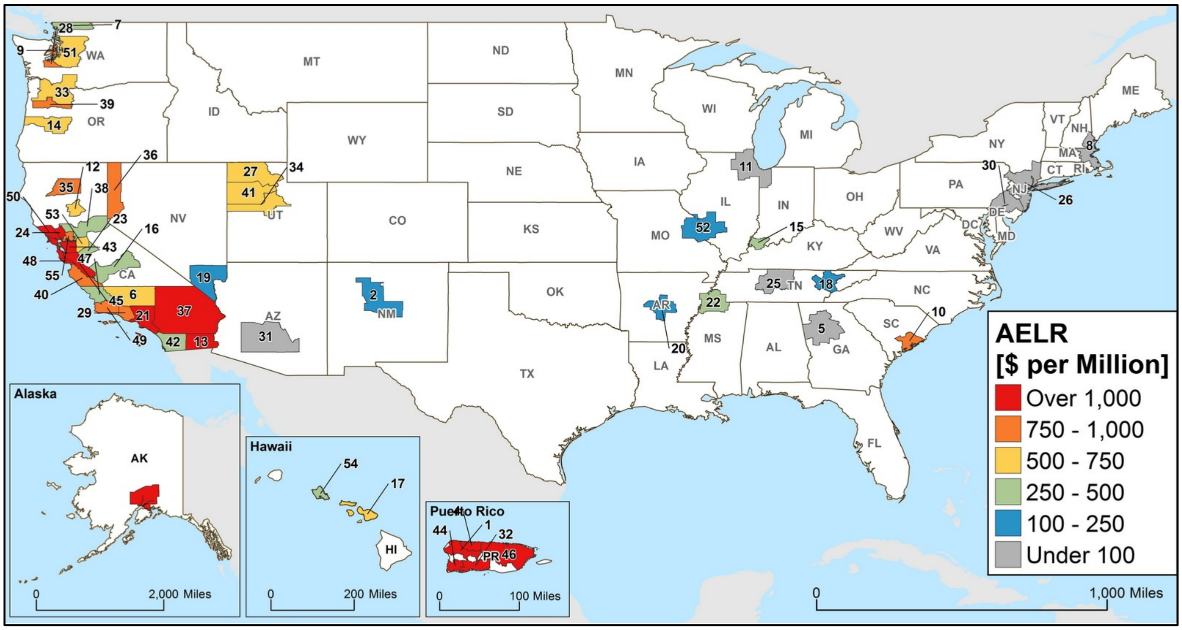
When losses for the 55 metropolitan areas are expressed as a fraction of total building value in the AELR column of Table 3-2, several cities rise in the rankings, notably El Centro, CA, Anchorage, AK, and San Germán, PR. Again, this is a reflection of high seismic hazard and lower relative value of building inventory.



Metropolitan Areas with AEL Over 10 Million

#	City	#	City	#	City	#	City
1	Aguadilla-Isabella, PR	15	Evansville, IN-KY	29	Oxnard-Thousand Oaks-Ventura, CA	43	San Francisco-Oakland-Hayward, CA
2	Albuquerque, NM	16	Fresno, CA	30	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	44	San Germain, PR
3	Anchorage, AK	17	Kahului-Wailuku-Lahaina, HI	31	Phoenix-Mesa-Scottsdale, AZ	45	San Jose-Sunnyvale-Santa Clara, CA
4	Arecibo, PR	18	Knoxville, TN	32	Ponce, PR	46	San Juan-Carolina-Caguas, PR
5	Atlanta-Sandy Springs-Roswell, GA	19	Las Vegas-Henderson-Paradise, NV	33	Portland-Vancouver-Hillsboro, OR-WA	47	San Luis Obispo-Paso Robles-Arroyo Grande, CA
6	Bakersfield, CA	20	Little Rock-North Little Rock-Conway, AR	34	Provo-Orem, UT	48	Santa Cruz-Watsonville, CA
7	Bellingham, WA	21	Los Angeles-Long Beach-Anaheim, CA	35	Redding, CA	49	Santa Maria-Santa Barbra, CA
8	Boston-Cambridge-Newton, MA-NH	22	Memphis, TN-MS-AR	36	Reno, NV	50	Santa Rosa, CA
9	Bremerton-Silverdale, WA	23	Modesto, CA	37	Riverside-San Bernardino-Ontario, CA	51	Seattle-Tacoma-Bellevue, WA
10	Charleston-Naperville-Elgin, IL-IN-WI	24	Napa, CA	38	Sacramento-Roseville-Arden-Arcade, CA	52	St. Louis, MO-IL
11	Chicago-Naperville-Elgin, IL-IN-WI	25	Nashville-Davidson-Murfreesboro-Franklin, TN	39	Salem, OR	53	Stockton-Lodi, CA
12	Chico, CA	26	New York-Newark-Jersey City, NY-NJ-PA	40	Salinas, CA	54	Urban Honolulu, HI
13	El Centro, CA	27	Ogden-Clearfield, UT	41	Salt Lake City, UT	55	Vallejo-Fairfield, CA
14	Eugene, OR	28	Olympia-Tumwater, WA	42	San Diego-Carlsbad, CA	//	//

Figure 3-6. Metropolitan Areas (listed alphabetically) with Annualized Earthquake Losses Greater than $10 Million



Metropolitan Areas with AELR Over 10 Million

#	City	#	City	#	City	#	City
1	Aguadilla-Isabella, PR	15	Evansville, IN-KY	29	Oxnard-Thousand Oaks-Ventura, CA	43	San Francisco-Oakland-Hayward, CA
2	Albuquerque, NM	16	Fresno, CA	30	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	44	San Germain, PR
3	Anchorage, AK	17	Kahului-Wailuku-Lahaina, HI	31	Phoenix-Mesa-Scottsdale, AZ	45	San Jose-Sunnyvale-Santa Clara, CA
4	Arecibo, PR	18	Knoxville, TN	32	Ponce, PR	46	San Juan-Carolina-Caguas, PR
5	Atlanta-Sandy Springs-Roswell, GA	19	Las Vegas-Henderson-Paradise, NV	33	Portland-Vancouver-Hillsboro, OR-WA	47	San Luis Obispo-Paso Robles-Arroyo Grande, CA
6	Bakersfield, CA	20	Little Rock-North Little Rock-Conway, AR	34	Provo-Orem, UT	48	Santa Cruz-Watsonville, CA
7	Bellingham, WA	21	Los Angeles-Long Beach-Anaheim, CA	35	Redding, CA	49	Santa Maria-Santa Barbra, CA
8	Boston-Cambridge-Newton, MA-NH	22	Memphis, TN-MS-AR	36	Reno, NV	50	Santa Rosa, CA
9	Bremerton-Silverdale, WA	23	Modesto, CA	37	Riverside-San Bernardino-Ontario, CA	51	Seattle-Tacoma-Bellevue, WA
10	Charleston-Naperville-Elgin, IL-IN-WI	24	Napa, CA	38	Sacramento-Roseville-Arden-Arcade, CA	52	St. Louis, MO-IL
11	Chicago-Naperville-Elgin, IL-IN-WI	25	Nashville-Davidson-Murfreesboro-Franklin, TN	39	Salem, OR	53	Stockton-Lodi, CA
12	Chico, CA	26	New York-Newark-Jersey City, NY-NJ-PA	40	Salinas, CA	54	Urban Honolulu, HI
13	El Centro, CA	27	Ogden-Clearfield, UT	41	Salt Lake City, UT	55	Vallejo-Fairfield, CA
14	Eugene, OR	28	Olympia-Tumwater, WA	42	San Diego-Carlsbad, CA	//	//

Figure 3-7. Annualized Earthquake Loss Ratios for Metropolitan Areas (listed alphabetically).

Table 3-2. Annualized Earthquake Loss (AEL) and Annualized Earthquake Loss Ratios (AELR) for 55 Metropolitan Areas with AEL Greater Than $10 Million

Rank	State	AEL ($Million)
1	Los Angeles-Long Beach-Anaheim, CA	1,352.9
2	San Francisco-Oakland-Hayward, CA	794.2
3	Riverside-San Bernardino-Ontario, CA	414.9
4	San Jose-Sunnyvale-Santa Clara, CA	342.8
5	Seattle-Tacoma-Bellevue, WA	284.2
6	Portland-Vancouver-Hillsboro, OR-WA	168.5
7	San Juan-Carolina-Caguas, PR	157.8
8	San Diego-Carlsbad, CA	132.4
9	Oxnard-Thousand Oaks-Ventura, CA	84.4
10	Santa Rosa, CA	75.9
11	Charleston-North Charleston, SC	74.7
12	Sacramento--Roseville--Arden-Arcade, CA	71.2
13	New York-Newark-Jersey City, NY-NJ-PA	70.1
14	Anchorage, AK	69.2
15	Salt Lake City, UT	65.5
16	Memphis, TN-MS-AR	64.4
17	St. Louis, MO-IL	60.7
18	Vallejo-Fairfield, CA	43.6
19	Reno, NV	41.8
20	Santa Cruz-Watsonville, CA	40.7
21	Urban Honolulu, HI	39.8
22	Salinas, CA	39.5
23	Las Vegas-Henderson-Paradise, NV	37.3
24	Santa Maria-Santa Barbara, CA	36.1
25	Bakersfield, CA	35.3
26	Stockton-Lodi, CA	34.6
27	Salem, OR	27.6
28	Aguadilla-Isabela, PR	26.8
29	Ogden-Clearfield, UT	26.8
30	Boston-Cambridge-Newton, MA-NH	24.1
31	Fresno, CA	23.9
32	Eugene, OR	23.9
33	El Centro, CA	23.9
34	Napa, CA	22.9
35	Olympia-Tumwater, WA	21.6
36	Ponce, PR	21.2
37	Bremerton-Silverdale, WA	21.1

Rank	State	AELR ($/Million $)
1	El Centro, CA	2,043.8
2	San Jose-Sunnyvale-Santa Clara, CA	1,594.5
3	Anchorage, AK	1,477.5
4	San Francisco-Oakland-Hayward, CA	1,437.3
5	San Germán, PR	1,328.8
6	Aguadilla-Isabela, PR	1,316.6
7	Santa Cruz-Watsonville, CA	1,284.0
8	Napa, CA	1,273.6
9	Santa Rosa, CA	1,258.3
10	Arecibo, PR	1,142.0
11	Riverside-San Bernardino-Ontario, CA	1,090.0
12	Los Angeles-Long Beach-Anaheim, CA	1,054.2
13	San Juan-Carolina-Caguas, PR	1,050.2
14	Ponce, PR	1,033.6
15	Vallejo-Fairfield, CA	982.5
16	Charleston-North Charleston, SC	977.1
17	Salinas, CA	960.5
18	Oxnard-Thousand Oaks-Ventura, CA	943.6
19	Redding, CA	868.9
20	Reno, NV	838.1
21	Santa Maria-Santa Barbara, CA	817.1
22	Olympia-Tumwater, WA	787.4
23	Bremerton-Silverdale, WA	759.5
24	Salem, OR	755.0
25	Seattle-Tacoma-Bellevue, WA	703.7
26	Portland-Vancouver-Hillsboro, OR-WA	687.5
27	Eugene, OR	665.0
28	Kahului-Wailuku-Lahaina, HI	637.3
29	Salt Lake City, UT	633.2
30	Chico, CA	594.8
31	Stockton-Lodi, CA	545.9
32	Bakersfield, CA	529.1
33	Provo-Orem, UT	524.4
34	Ogden-Clearfield, UT	503.4
35	Bellingham, WA	455.9
36	San Luis Obispo-Paso Robles-Arroyo Grande, CA	440.6
37	Memphis, TN-MS-AR	434.3

38	Provo-Orem, UT	20.8
39	Modesto, CA	18.7
40	Atlanta-Sandy Springs-Roswell, GA	17.6
41	Nashville-Davidson--Murfreesboro--Franklin, TN	15.8
42	Knoxville, TN	15.5
43	Redding, CA	15.3
44	Chicago-Naperville-Elgin, IL-IN-WI	14.9
45	San Luis Obispo-Paso Robles-Arroyo Grande, CA	14.1
46	Evansville, IN-KY	13.7
47	Arecibo, PR	13.5
48	Chico, CA	12.5
49	Kahului-Wailuku-Lahaina, HI	12.5
50	Little Rock-North Little Rock-Conway, AR	12.4
51	San Germán, PR	12.3
52	Phoenix-Mesa-Scottsdale, AZ	12.2
53	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	11.1
54	Albuquerque, NM	10.7
55	Bellingham, WA	10.2

38	Modesto, CA	408.5
39	San Diego-Carlsbad, CA	403.6
40	Urban Honolulu, HI	389.8
41	Evansville, IN-KY	358.3
42	Fresno, CA	304.9
43	Sacramento--Roseville--Arden-Arcade, CA	300.6
44	Las Vegas-Henderson-Paradise, NV	181.7
45	St. Louis, MO-IL	173.7
46	Knoxville, TN	167.8
47	Little Rock-North Little Rock-Conway, AR	158.7
48	Albuquerque, NM	127.5
49	Nashville-Davidson--Murfreesboro--Franklin, TN	80.4
50	Boston-Cambridge-Newton, MA-NH	39.3
51	New York-Newark-Jersey City, NY-NJ-PA	28.7
52	Phoenix-Mesa-Scottsdale, AZ	28.3
53	Atlanta-Sandy Springs-Roswell, GA	27.3
54	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	14.9
55	Chicago-Naperville-Elgin, IL-IN-WI	12.2

Socio-Economics

The ability to correlate population density and annualized loss is useful for developing policies, programs and strategies to minimize socio-economic impact from earthquakes. The ability to examine earthquake impact in terms of other demographic parameters such as ethnicity, age, and income could also be important. Figures 3-8 and 3-9 present the AEL values on a per capita basis by county and state to show where effects on people are most pronounced. These figures also show annualized loss in relation to 2010 population distribution and reveal two important facts:

1. The high rankings include areas with high seismic hazard and high building exposure (e.g., Los Angeles and San Francisco Bay areas), but also areas with high seismic hazard and low building exposure (e.g., Hawaii and Alaska); and
2. California, Oregon, Washington, Tennessee, Hawaii, and Puerto Rico have the highest seismic risk when measured on a per capita basis at the state level.

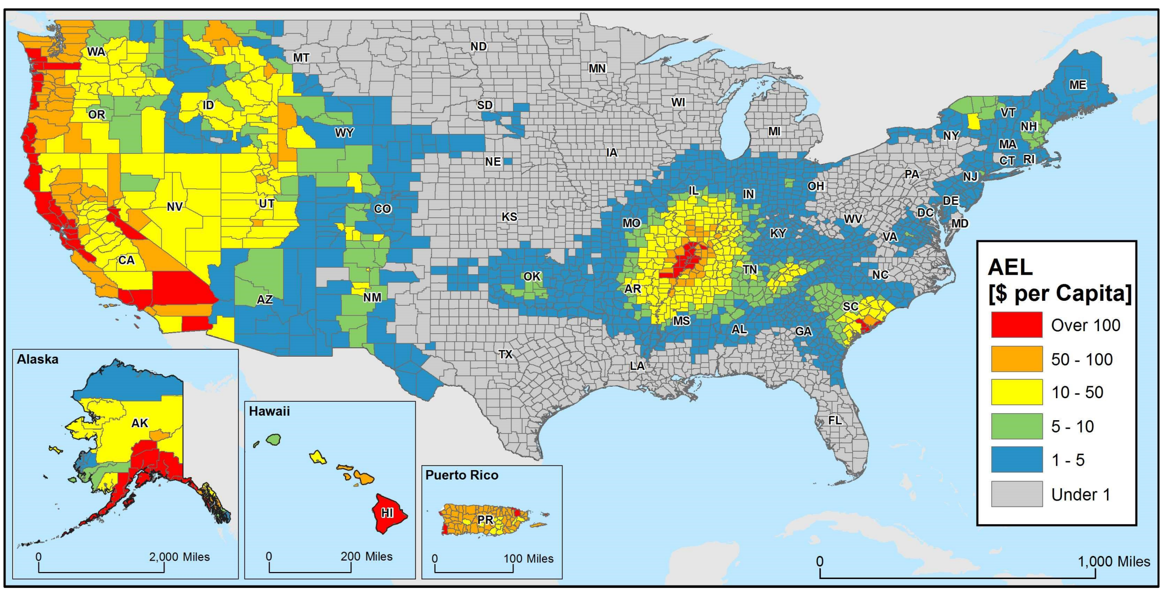


Figure 3-8. AEL Per Capita at the County Level

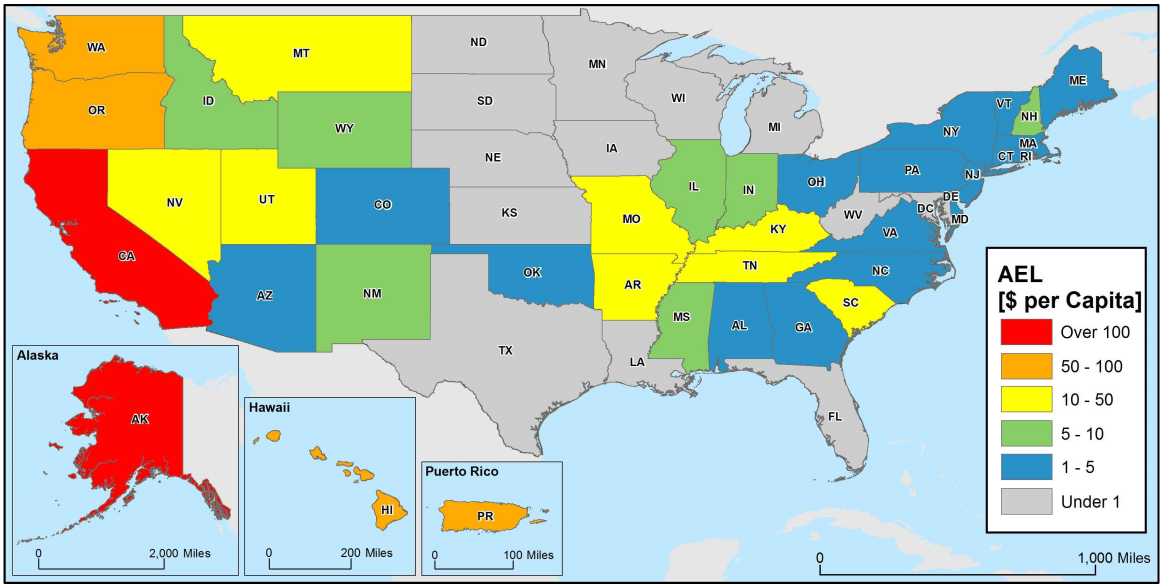
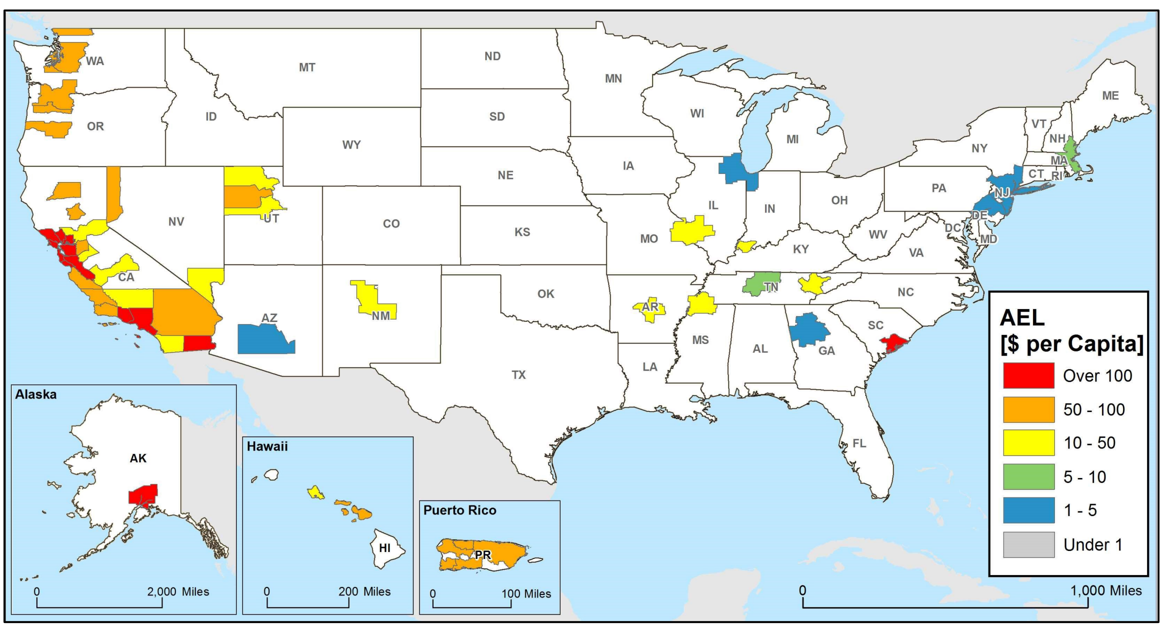


Figure 3-9. AEL Per Capita at the State Level



Metropolitan Areas with AEL Over 10 Million

#	City	#	City	#	City	#	City
1	Aguadilla-Isabella, PR	15	Evansville, IN-KY	29	Oxnard-Thousand Oaks-Ventura, CA	43	San Francisco-Oakland-Hayward, CA
2	Albuquerque, NM	16	Fresno, CA	30	Philadelphia-Camden-Wilmington, PA-NJ-MD-DE	44	San Germain, PR
3	Anchorage, AK	17	Kahului-Wailuku-Lahaina, HI	31	Phoenix-Mesa-Scottsdale, AZ	45	San Jose-Sunnyvale-Santa Clara, CA
4	Arecibo, PR	18	Knoxville, TN	32	Ponce, PR	46	San Juan-Carolina-Caguas, PR
5	Atlanta-Sandy Springs-Roswell, GA	19	Las Vegas-Henderson-Paradise, NV	33	Portland-Vancouver-Hillsboro, OR-WA	47	San Luis Obispo-Paso Robles-Arroyo Grande, CA
6	Bakersfield, CA	20	Little Rock-North Little Rock-Conway, AR	34	Provo-Orem, UT	48	Santa Cruz-Watsonville, CA
7	Bellingham, WA	21	Los Angeles-Long Beach-Anaheim, CA	35	Redding, CA	49	Santa Maria-Santa Barbra, CA
8	Boston-Cambridge-Newton, MA-NH	22	Memphis, TN-MS-AR	36	Reno, NV	50	Santa Rosa, CA
9	Bremerton-Silverdale, WA	23	Modesto, CA	37	Riverside-San Bernardino-Ontario, CA	51	Seattle-Tacoma-Bellevue, WA
10	Charleston-Naperville-Elgin, WI-IL-IN	24	Napa, CA	38	Sacramento-Roseville-Arden-Arcade, CA	52	St. Louis, MO-IL
11	Chicago-Naperville-Elgin, IL-IN-WI	25	Nashville-Davidson-Murfreesboro-Franklin, TN	39	Salem, OR	53	Stockton-Lodi, CA
12	Chico, CA	26	New York-Newark-Jersey City, NY-NJ-PA	40	Salinas, CA	54	Urban Honolulu, HI
13	El Centro, CA	27	Ogden-Clearfield, UT	41	Salt Lake City, UT	55	Vallejo-Fairfield, CA
14	Eugene, OR	28	Olympia-Tumwater, WA	42	San Diego-Carlsbad, CA	//	//

Figure 3-10. AEL Per Capita for Selected Metropolitan Areas (listed alphabetically)

Estimates of Causalities, Debris, and Shelter Requirements

Annualized casualty estimates and debris and shelter requirement estimates for 250- and 1,000-year return periods were derived using Hazus 3.0. Table 3-3 and Figures 3-11 and 3-12 depict the estimates of debris for 250-year and 1,000-year return periods, respectively. Estimating annualized estimates for debris and shelter requirements required significant post-Hazus analyses of data obtained from individual runs and it was beyond the scope of present investigation.

A cursory examination of the 250- and 1,000-year return period maps shows larger increases in debris estimates for the 1,000-year return period event, notably the states in the New Madrid seismic zone (Tennessee, Arkansas, Missouri, Illinois, Alabama, and Ohio), as well as New York, South Carolina, North Carolina, and Oregon.

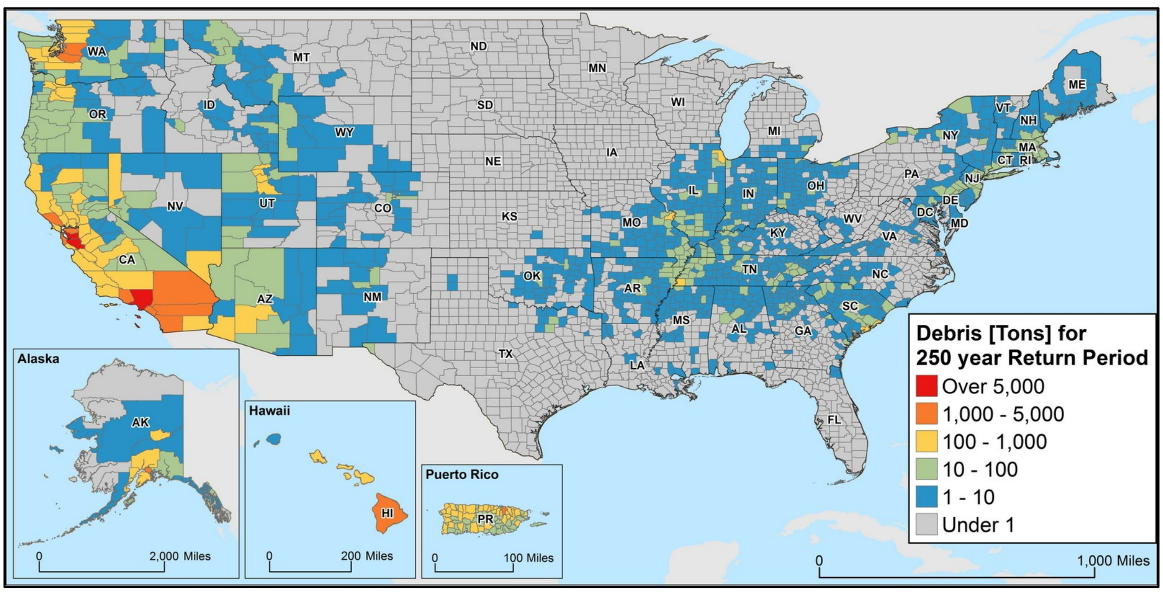


Figure 3-11 Estimates of Debris Generated for 250-Year Return Period

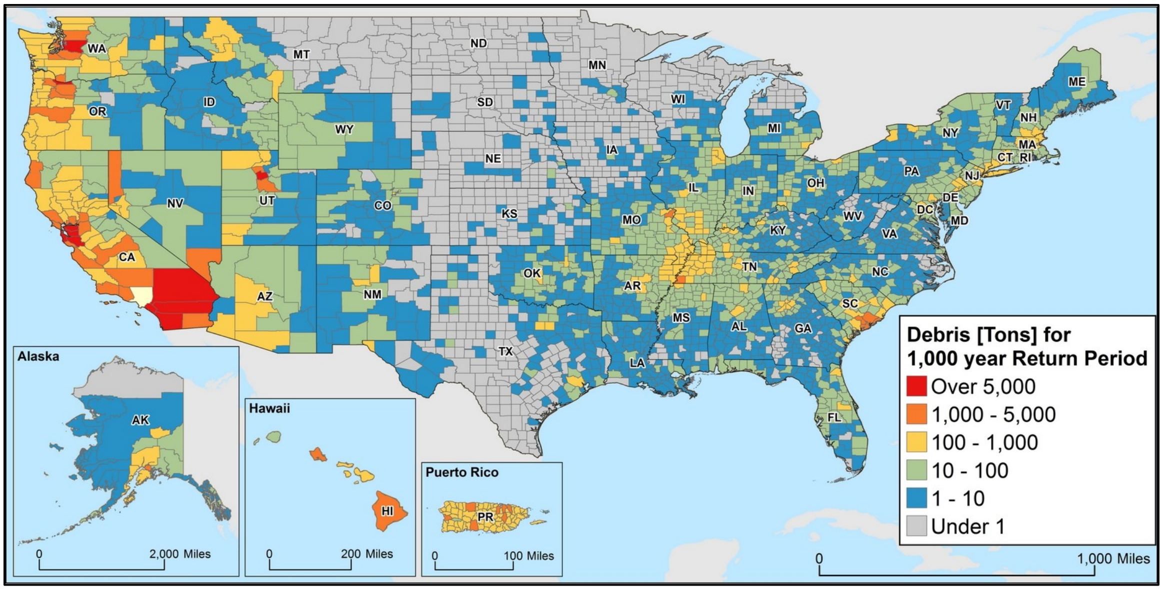


Figure 3-12 Estimates of Debris Generated for 1,000-Year Return Period

Table 3-3. Estimates of Debris (x 1000 tons)

Rank	State	250-Year Event	1,000-Year Event
1	California	57,621	157,069
2	Puerto Rico	12,033	38,474
3	Washington	6,231	23,470
4	Oregon	2,197	21,680
5	Hawaii	2,160	4,898
6	Alaska	1,897	4,071
7	Utah	1,337	10,594
8	Nevada	1,236	5,374
9	Tennessee	1,229	11,220
10	Missouri	878	7,404
11	Illinois	870	6,224
12	South Carolina	633	8,877
13	New York	539	3,838
14	Indiana	492	2,805
15	Arkansas	484	5,090
16	Kentucky	483	3,692
17	Georgia	456	2,206
18	Arizona	391	2,286
19	Ohio	303	1,773
20	Massachusetts	239	1,444
21	Oklahoma	229	1,459
22	New Jersey	220	1,693
23	Alabama	202	1,221
24	Montana	199	1,030
25	Mississippi	175	1,873
26	Virginia	159	1,195
27	Pennsylvania	158	1,551
28	Texas	127	1,534
29	Colorado	126	788
30	North Carolina	123	940
31	New Mexico	114	1,211
32	Maryland	73	704
33	Idaho	73	447
34	Connecticut	70	436
35	Michigan	65	723
36	Wyoming	58	294
37	New Hampshire	56	361
38	Maine	52	306
39	Louisiana	48	466
40	West Virginia	30	200
41	Vermont	24	120
42	Rhode Island	23	134
43	Delaware	17	136
44	Florida	17	1,465
45	Kansas	14	217
46	District of Columbia	10	130
47	Iowa	3	165
48	Nebraska	2	85
49	Wisconsin	2	207
50	South Dakota	2	46
51	Minnesota	0	58
52	North Dakota	0	9

Table 3-4. Estimates of Displaced Households

Rank	State	250-Year Event	1,000-Year Event
1	California	188,146	620,114
2	Puerto Rico	36,065	165,707
3	Washington	24,038	98,805
4	Alaska	7,935	16,662
5	Oregon	7,822	79,901
6	Hawaii	7,678	22,579
7	Nevada	3,658	20,310
8	Utah	2,429	31,828
9	Tennessee	1,646	23,079
10	South Carolina	1,353	28,715
11	Missouri	1,249	18,327
12	New York	1,235	14,349
13	Illinois	1,120	11,921
14	Arkansas	640	10,560
15	Georgia	624	4,039
16	Kentucky	592	6,439
17	Massachusetts	567	4,929
18	Indiana	487	3,856
19	Arizona	379	3,011
20	New Jersey	354	4,353
21	Montana	328	2,353
22	Alabama	264	2,056
23	Ohio	255	2,065
24	Mississippi	188	2,536
25	Oklahoma	154	1,644
26	Texas	137	2,131
27	Pennsylvania	135	1,915
28	Connecticut	128	1,148
29	Virginia	125	1,475
30	New Hampshire	120	1,104
31	Maine	103	818
32	North Carolina	97	1,138
33	Colorado	93	927
34	New Mexico	81	1,693
35	Wyoming	67	516
36	Idaho	56	590
37	Michigan	53	772
38	Maryland	52	774
39	Rhode Island	52	432
40	Louisiana	44	581
41	Vermont	42	282
42	West Virginia	20	182
43	Kansas	12	256
44	Delaware	11	138
45	District of Columbia	9	183
46	Florida	9	991
47	Wisconsin	3	294
48	Iowa	2	172
49	Nebraska	2	87
50	South Dakota	1	62
51	Minnesota	0	65
52	North Dakota	0	13

Table 3-5 and Figures 3-13 and 3-14 show the estimate of the number of people looking for shelter (shelter requirements) based on ground shaking estimates corresponding to 250-year and 1,000-year return period, respectively, aggregated at county level.

The estimates of shelter requirements follow the trend of displaced households with California, Puerto Rico, Washington, Hawaii, and Oregon together accounting for over 90%, and California accounting for nearly 65% of the total. A comparison of the standings of individual states in the Shelter and Shelter Ratio (# of people per million) columns of Tables 3-5 and 3-6 show that while California, Washington and Oregon rank in the top tier, New York and New Jersey—states with relatively low hazard and high population—drop from 11th to 23rd and 20th to 29th place, respectively. Table 3.7 divides annualized casualty estimates into three categories of injury: (1) minor (non life-threatening); (2) major (defined as injuries that pose an immediate life-threatening condition if not treated adequately; and (3) fatal. Casualty rates are a direct function of the time of day or night that an earthquake occurs, as reflected in Table 3.7. A majority of injuries are in the non-life-threatening category. An earthquake in the daytime is more lethal than a similar-sized earthquake occurring in the nighttime, since severe damage and casualty rates are generally lowest in nighttime residential (primarily wood frames) occupancies for the majority of the U.S.

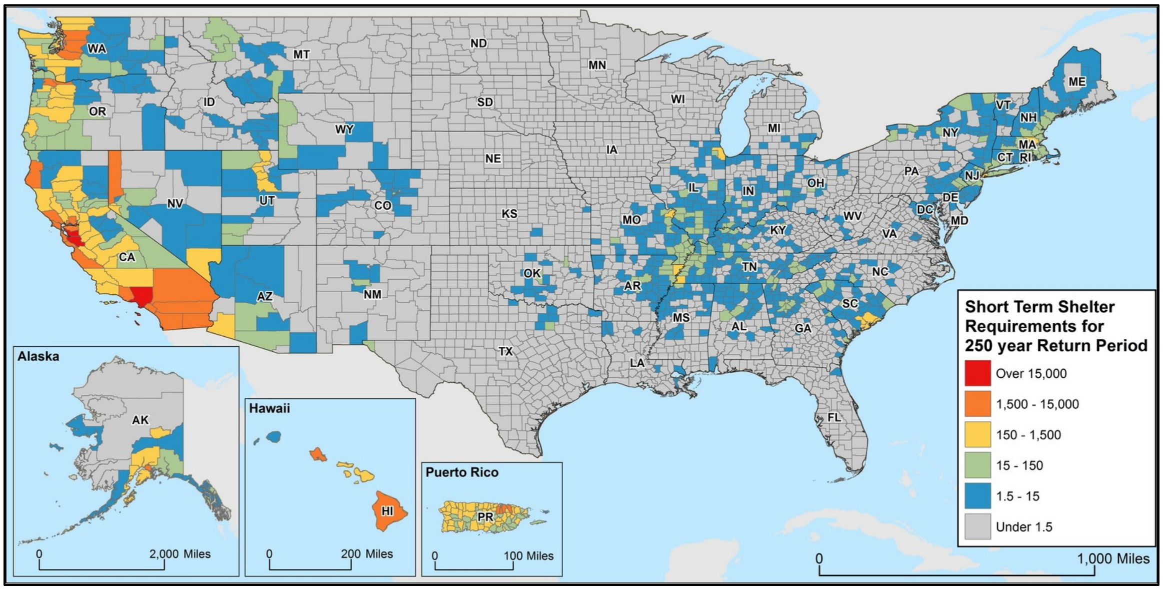


Figure 3-13 Estimates of Shelter Requirements for 250-year Return Period

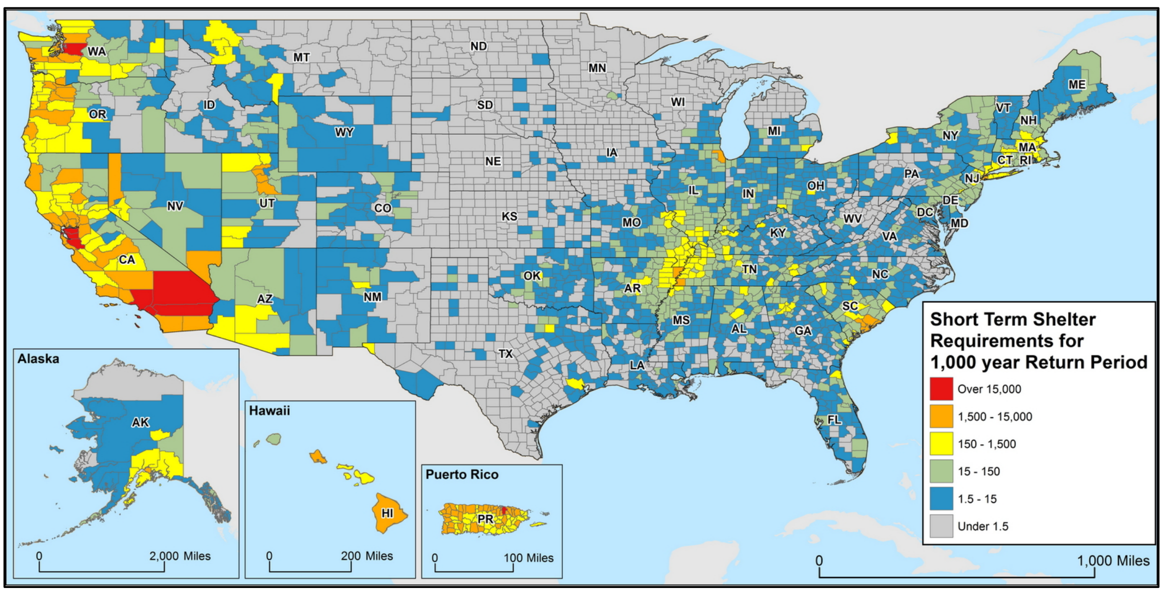


Figure 3-14 Estimates of Shelter Requirements for 1000-year Return Period

Table 3-5. Estimates of Short-Term Shelter Requirements (# of People)

Rank	State	250-Year Event	1,000-Year Event
1	California	137,972	446,260
2	Puerto Rico	37,513	175,625
3	Washington	13,692	56,668
4	Hawaii	5,020	14,594
5	Oregon	4,775	48,933
6	Alaska	4,631	9,655
7	Nevada	2,376	13,555
8	Utah	1,717	22,169
9	Tennessee	1,168	16,695
10	South Carolina	907	19,010
11	New York	864	10,134
12	Missouri	832	12,442
13	Illinois	756	7,965
14	Arkansas	468	7,755
15	Georgia	444	2,910
16	Kentucky	391	4,203
17	Massachusetts	352	3,055
18	Arizona	351	2,419
19	Indiana	309	2,440
20	New Jersey	241	2,963
21	Montana	191	1,378
22	Alabama	184	1,425
23	Ohio	159	1,288
24	Mississippi	149	1,985
25	Texas	114	1,701
26	Oklahoma	102	1,089
27	Pennsylvania	87	1,214
28	Connecticut	85	759
29	Virginia	79	910
30	New Hampshire	64	591
31	North Carolina	64	753
32	Maine	58	466
33	Colorado	56	561
34	New Mexico	54	1,137
35	Idaho	38	387
36	Wyoming	37	283
37	Rhode Island	34	284
38	Michigan	34	501
39	Louisiana	33	421
40	Maryland	33	479
41	Vermont	23	159
42	West Virginia	13	115
43	Kansas	8	159
44	Delaware	7	87
45	Florida	7	633
46	District of Columbia	5	106
47	Wisconsin	3	186
48	Iowa	1	104
49	Nebraska	1	53
50	South Dakota	1	38
51	Minnesota	0	37
52	North Dakota	0	7

Table 3-6. Estimates of Short-Term Shelter Ratio for 250-year event (# of People/Million)

Rank	State	250-Year Event
1	Alaska	11,173
2	Puerto Rico	9,680
3	Hawaii	5,644
4	California	5,050
5	Washington	3,575
6	Oregon	2,042
7	Nevada	1,355
8	Utah	879
9	Montana	331
10	South Carolina	292
11	Tennessee	259
12	Arkansas	220
13	Missouri	208
14	Kentucky	136
15	Wyoming	119
16	New Hampshire	91
17	Illinois	87
18	Massachusetts	87
19	Maine	77
20	Indiana	75
21	Vermont	66
22	Georgia	64
23	New York	64
24	Mississippi	63
25	Arizona	59
26	Alabama	55
27	Rhode Island	49
28	Oklahoma	41
29	New Jersey	40
30	New Mexico	39
31	Idaho	36
32	Connecticut	36
33	Ohio	22
34	Colorado	19
35	Virginia	16
36	District of Columbia	15
37	Delaware	13
38	West Virginia	11
39	Pennsylvania	11
40	North Carolina	10
41	Louisiana	10
42	Maryland	9
43	Texas	5
44	Michigan	5
45	Kansas	4
46	South Dakota	2
47	Nebraska	1
48	Iowa	1
49	Wisconsin	1
50	Florida	0
51	Minnesota	0
52	North Dakota	0

Table 3-7. Annualized Estimates of Injury (Day/Night)

Rank	State	Day			Night		
		Minor	Life Threatening	Fatal	Minor	Life Threatening	Fatal
1	California	1,302	56	109	596	12	22
2	Puerto Rico	108	5	9	236	10	19
3	Washington	182	8	16	69	1	3
4	Oregon	166	8	16	51	1	3
5	Utah	62	3	6	33	1	2
6	Tennessee	64	2	5	32	1	2
7	Missouri	37	1	3	26	1	2
8	South Carolina	51	2	4	30	1	2
9	Hawaii	45	2	4	21	1	1
10	Illinois	34	1	2	21	1	1
11	Arkansas	27	1	2	16	0	1
12	Alaska	35	2	3	15	0	1
13	Nevada	40	2	3	16	0	1
14	Kentucky	23	1	2	10	0	0
15	New York	19	0	1	15	0	0
16	Indiana	13	0	1	8	0	0
17	Mississippi	14	1	1	6	0	0
18	Arizona	9	0	0	8	0	0
19	New Mexico	6	0	0	4	0	0
20	Georgia	12	0	0	6	0	0
21	Oklahoma	5	0	0	4	0	0
22	New Jersey	6	0	0	4	0	0
23	Texas	7	0	0	4	0	0
24	Pennsylvania	3	0	0	4	0	0
25	Massachusetts	6	0	0	3	0	0
26	Ohio	5	0	0	4	0	0
27	Alabama	7	0	0	3	0	0
28	Montana	6	0	0	2	0	0
29	Virginia	3	0	0	3	0	0
30	Florida	2	0	0	3	0	0
31	Maryland	1	0	0	1	0	0
32	Idaho	2	0	0	1	0	0
33	Colorado	2	0	0	2	0	0
34	Michigan	2	0	0	1	0	0
35	North Carolina	3	0	0	2	0	0
36	Wyoming	1	0	0	1	0	0
37	New Hampshire	2	0	0	1	0	0
38	Connecticut	1	0	0	1	0	0
39	Louisiana	2	0	0	1	0	0

40	Maine	1	0	0	1	0	0
41	West Virginia	0	0	0	0	0	0
42	Delaware	0	0	0	0	0	0
43	Rhode Island	0	0	0	0	0	0
44	Kansas	1	0	0	0	0	0
45	District of Columbia	0	0	0	0	0	0
46	Wisconsin	0	0	0	0	0	0
47	Vermont	0	0	0	0	0	0
48	Iowa	0	0	0	0	0	0
49	Nebraska	0	0	0	0	0	0
50	South Dakota	0	0	0	0	0	0
51	Minnesota	0	0	0	0	0	0
52	North Dakota	0	0	0	0	0	0

4 Comparison to Previous Studies

In this chapter, we compare the results of this study with the original earthquake loss studies (FEMA 366, 2001 & 2008) and examine how changes in the earthquake hazard and building inventory have affected potential earthquake losses. In the present study, two different analyses were performed, as described below.

For the contiguous United States (48 States and Washington D.C.):

Hazus 3.0 methods and data/2014 site-corrected USGS national seismic maps. This analysis provides a snapshot of the current earthquake risk using the most up-to-date version of Hazus and recent building, population, and hazard maps.

For Alaska, Hawaii and Puerto Rico:

Hazus 3.0 methods and data/older (AK, 2007; HI, 1998; and PR, 2003) site-corrected USGS national seismic maps. This analysis provided a snapshot of the current earthquake risk using the most up-to-date version of Hazus and recent building, population, and hazard maps.

Study Parameters

Table 4.1 highlights the key changes in datasets and parameters between the Hazus 99, Hazus-MH MR2 and Hazus 3.0. The original earthquake loss study (FEMA 366, 2001) used the Hazus 99 methodology, the 1994 building data, and population data from the 1990 census. With the release of Hazus-MH MR2, several parameters changed as shown in Table 4.1. Hazus MR2 relied upon 2002 USGS seismic hazard maps. The present study Hazus 3.0 makes use of 2014 seismic hazard models as the basis for the annualized loss analyses; these changes are reflected in the results.

Table 4-1. Summary of Key Changes Incorporated into Hazus 3.0

Hazus 99 (FEMA 366, 2001)	**Hazus-MH MR2** (FEMA 366, 2008)	**Hazus 3.0** (this study)
1996 National Seismic Hazard Maps	2002 USGS National Seismic Hazard Maps	2014 USGS National Seismic Hazard Maps
Loss estimates based on 1990 Census Data	Loss estimates based on 2000 Census Data	Loss estimates based on 2010 Census Data
1994 Building Inventory and Occupancy to Building Type Distributions	2002 Building Inventory (Dun & Bradstreet, 2002), RS Means (2005), and updated Occupancy to Building Type Distributions	2006 Building Inventory (Dun & Bradstreet, 2006)
Building and Content Exposure based on square footage from pre-defined regions	Building and Content Exposure based on General Building Stock datasets in the study region.	Building and Content Exposure based on General Building Stock datasets in the study region.
Losses reported in 1994 values of dollars	Losses reported in 2005 values of dollars	Losses reported in 2014 values of dollars

Comparison of AEL and AELR

In this study, we estimate a national AEL of $6.1 billion (2014 dollars), which also includes the losses estimated for Puerto Rico. There is a 10% increase over the 2008 FEMA 366 estimate of $5.3 billion (2005 dollars). However, if we adjust the 2008 FEMA 366 study results to reflect the current version values (2002 to 2014 dollars adjustment using Consumer Price Index, Inflation Calculator: www.bls.gov/cpi), the FEMA 366 (2008) loss estimate would increase to $6.4 billion, which indicates that this update represents a net small decrease in the overall earthquake loss potential. This difference is mainly due to changes in the estimate of long-term earthquake hazard and an improved site characterization model adopted in the present study. Since Hazus-MH MR2, which relied on year 2002 building inventory, the national building inventory increased by almost 50%, and the inflation-adjusted estimated earthquake loss decreased by 5%. In the following sections, the reasons why the loss decreased, especially in relation to the increased inventory, will be discussed.

Effect of a Change in Hazard

Figure 4-1 depicts the differences in hazard, where the negative values represent a decrease since 2002 and the positive values represent an increase since 2002. The following patterns are noted:

- Significant change in the hazard in the western United States, except for some parts of Washington and Oregon where the changes are small.
- A slight change in the hazard in the Great Plains.
- A slight change in hazard in the Southeast, except for modest changes in some areas of Virginia, North Carolina, and a significant decrease in the Charleston, South Carolina area.
- Significant decrease in hazard in the central region, which includes the New Madrid seismic zone (shown in blue), with a small increase in parts of Tennessee.
- A slight change in hazard in the Northeast, except for some areas of New York and New Jersey, where the hazard has gone down.

The significance in the changes in probabilistic hazard estimates from the 2008 USGS model to the 2014 USGS model (while keeping the other analysis parameters constant) on annualized earthquake loss estimates is discussed in Jaiswal et al. (2015). In general, the authors found that there is 10% to 20% reduction in AELs for the highly seismic states of the western United States, whereas the reduction is even more significant for the central and eastern United States.

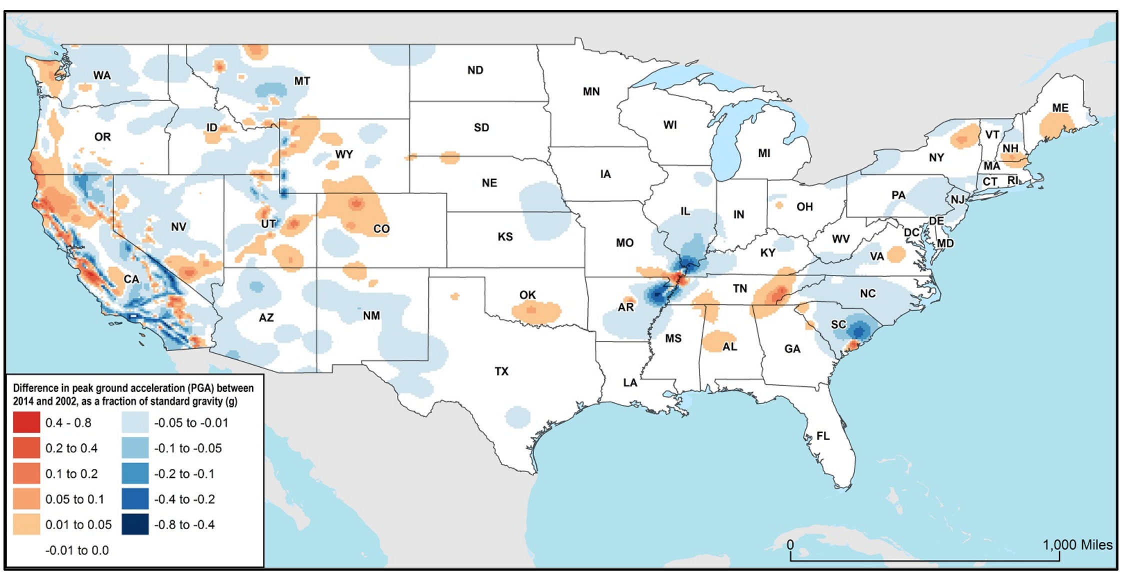


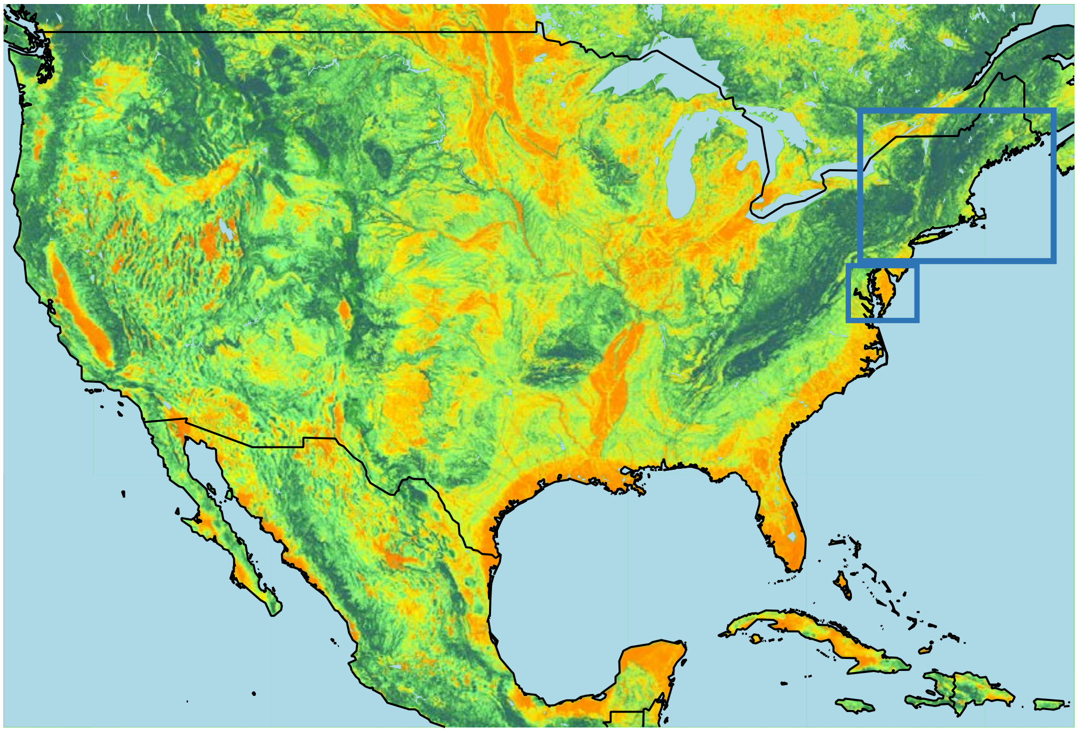
Figure 4-1 Difference in the 1,000-year Return Period USGS Seismic Hazard Map 2014 and USGS Seismic Hazard Map 2002

Hazard Changes, Site Effects and Site Soil Categorization

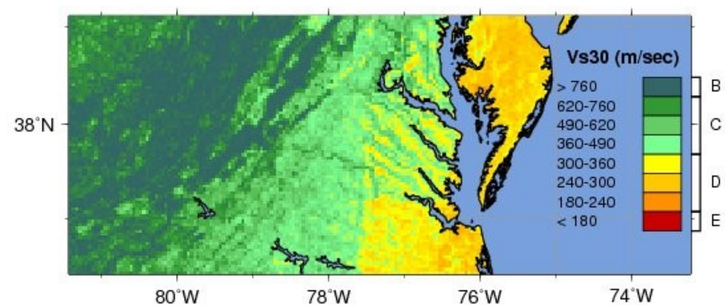
An important factor that influences the hazard and ultimately led to changes in loss estimates is the effect of local site soil condition. Previous AEL studies in the United States including the most recent FEMA 366 2008 study were based on assumption of uniform site D (stiff soil) condition. The USGS B/C site category hazard curves were amplified to uniform site class D assumption when performing AEL computation, even though the site conditions are known to vary significantly throughout the nation as shown in Figure 4.2a.

In this investigation, the 2015 NEHRP site soil amplification factors were used (Table 4.2). Note that we applied these site factors outside of Hazus directly to the 2014 USGS B/C boundary category hazard curves. We used straight-line interpolation to obtain intermediate values of coefficients based on topo-based Vs30 values (Figure 4.2a, see https://earthquake.usgs.gov/data/vs30/) and to derive the amplitude of ground motions.

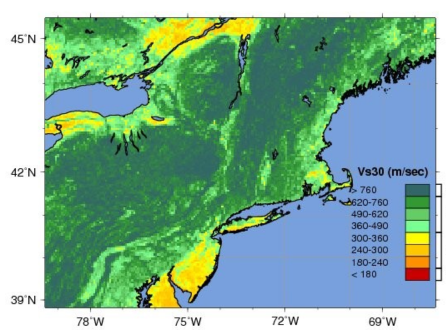
For example, in Virginia (Figure 4.2b), much of the western portion of the State can be categorized into site classes B and C. The east coast of Virginia, for example, Richmond can be associated with site classes C and D and Virginia Beach with site class D. Similarly, the State of New York (Figure 4.2c) is mostly site class B or B/C whereas portions of the State along the east coast can be categorized into site class C or D. However, in the FEMA 2008 study, the AEL calculations for the entire region were performed using uniform site class D assumption (Figure 4.3a & 4.3b). Thus, in the 2008 study, the hazard for most of the state was increased by a factor ranging from 1.1 to 1.6 for short-period spectral acceleration and by a factor of 1.5 to 2.4 for long-period spectral acceleration. In contrast, the new NEHRP site factors for site class B led to a reduction in site class B/C boundary hazard values from the 2014 USGS model by approximately 10-20%. Although the population and building stock exposure have increased in these states according to the census 2010 and commercial inventory, the site-corrected hazard characterization in this study led to 50% reduction in the AEL values compared to the previous study.



(a) Contiguous United States



(b) Virginia



(c) New York and other northeast regions

Figure 4-2 Site Categorization Using Global Topo-based Vs30 Approximation Obtained Using the USGS Global Vs30 Model (https://earthquake.usgs.gov/data/vs30/).

Table 4-2. Short-Period (SS) and Long-Period (S1) NEHRP Site Coefficient (NEHRP 2015). The SS factors were applied for SA@0.3 and the S1 factors were applied for SA@1.0 ground motions.

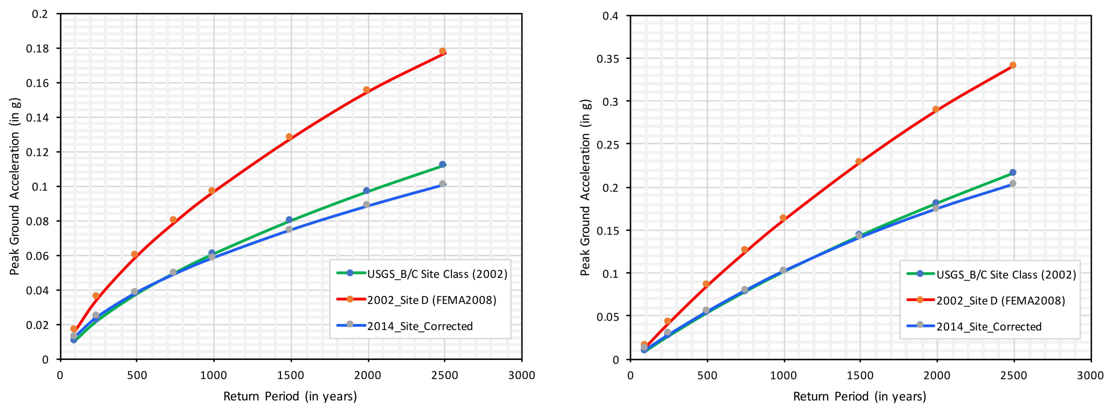
Short-Period Site Coefficient, F_a

Site Class	$S_S \leq 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S = 1.25$	$S_S \geq 1.5$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.3	1.2	1.2	1.2	1.2
D	1.6	1.4	1.2	1.1	1.0	1.0
E	2.4	1.7	1.3	1.1[1]	0.9[1]	0.8[1]

Long-Period Site Coefficient, F_v

Site Class	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 = 0.5$	$S_1 \geq 0.6$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.8	0.8	0.8	0.8	0.8	0.8
C	1.5	1.5	1.5	1.5	1.5	1.4
D	2.4	2.2	2.0	1.9	1.8	1.7
E	4.2	3.3	2.8	2.4	2.2	2.0

[1] *coefficients referenced from Seyhan and Stewart (2014)*



(a) 42.00° N, 72.00° W; Vs30 ~ 770 m/s; Site Class B-C ***(b) 40.70° N, 74.00° W; Vs30 ~ 600 m/s; Site Class B-C***

Figure 4-3 Comparison of the Hazard Curves for Locations in (a) Virginia and (b) New York Using 2002 and 2014 USGS national seismic hazard model (NSHM).

Table 4-3 shows the annualized loss obtained from Hazus 3.0 using the 2014 hazard maps and the Hazus-MH MR2 analysis based on the 2002 USGS national seismic hazard maps for all the states, including the percentage change. The negative values represent a decrease in losses. Analysis of the results reveals a general decrease in AEL, with some exceptions. Utah, Mississippi, Tennessee, South Carolina, and Oregon show increases in losses, based primarily on changes in hazard and site characterization. The Alaska and Hawaii increases are primarily related to the increased exposure as the hazard model has not been updated. As discussed above, the large decreases for states like West Virginia, Vermont, Pennsylvania, and New York are largely a result of using site-corrected ground motions rather than the NEHRP Type D (soft soils) default used in the previous study. Table 4-4 lists the annualized loss ratio from 1996, 2002 and 2014 hazard models for all the states. The reductions in loss ratios are quite high for total losses. This reduction is based on the combined influence of a reduced hazard and due to addition of substantial newer construction (new exposure) which is built to newer code standard and of a reduced vulnerability.

Table 4-3. National Comparison of the AEL Values in $ by State for 2014 and 2002 USGS Hazard Maps

Rank	State	AEL 2014 Hazard (x $1,000)	AEL 2002 Hazard (x $1,000)	Percent Change
1	California	3,739,125	3,503,816	7%
2	Washington	438,524	366,431	20%
3	Oregon	271,113	207,686	31%
4	Puerto Rico	252,911	--	--
5	Tennessee	142,221	94,728	50%
6	Utah	124,637	89,554	39%
7	South Carolina	112,989	77,547	46%
8	Hawaii	106,825	64,961	64%
9	Nevada	99,364	77,841	28%
10	Alaska	95,901	52,628	82%
11	Missouri	83,762	73,082	15%
12	Illinois	73,430	59,146	24%
13	New York	59,352	95,185	-38%
14	Arkansas	51,079	42,957	19%
15	Kentucky	43,846	39,163	12%
16	Georgia	35,637	36,733	-3%
17	Indiana	34,888	27,999	25%
18	New Jersey	27,434	39,724	-31%
19	Arizona	26,751	23,354	15%
20	Massachusetts	26,264	25,294	4%
21	Mississippi	23,299	15,368	52%
22	Alabama	19,956	25,144	-21%
23	Montana	15,947	16,725	-5%
24	Ohio	15,721	19,932	-21%
25	North Carolina	15,380	26,027	-41%
26	New Mexico	15,205	20,621	-26%
27	Oklahoma	14,653	11,797	24%
28	Texas	13,334	14,355	-7%
29	Pennsylvania	12,929	29,585	-56%
30	Virginia	11,740	13,204	-11%
31	Colorado	10,978	11,234	-2%
32	Idaho	8,231	8,042	2%
33	New Hampshire	7,301	7,199	1%
34	Connecticut	6,755	11,622	-42%
35	Florida	6,335	5,460	16%
36	Michigan	5,808	4,214	38%
37	Maryland	5,767	7,218	-20%
38	Maine	5,689	5,917	-4%

39	Wyoming	4,837	4,993	-3%
40	Louisiana	3,671	3,069	20%
41	Rhode Island	1,944	2,720	-29%
42	Vermont	1,894	3,804	-50%
43	Kansas	1,648	2,107	-22%
44	West Virginia	1,456	4,122	-65%
45	Wisconsin	1,295	1,613	-20%
46	Delaware	1,286	1,995	-36%
47	Iowa	972	1,068	-9%
48	District of Columbia	906	1,313	-31%
49	Nebraska	584	1,021	-43%
50	Minnesota	383	473	-19%
51	South Dakota	374	436	-14%
52	North Dakota	58	69	-16%
	Total Excluding Puerto Rico	**$5,829,477**	**$5,280,296**	**10%**
	Total	**$6,082,805**		

Table 4-4. National Comparison of the AELR Values by State for 2014, 2002 and 1996 USGS Hazard Maps

Rank	State	AELR 2014 Hazard ($/million $)	AELR 2002 Hazard ($/million $)	AELR 1996 Hazard ($/million $)
1	Puerto Rico	1,080.5	--	--
2	Alaska	1,057.7	951	1,005
3	California	971.5	1,452	1,580
4	Hawaii	708.4	488	531
5	Oregon	661.9	850	935
6	Washington	591.5	884	811
7	Utah	498.6	817	802
8	Nevada	345.9	617	626
9	South Carolina	231.1	363	417
10	Tennessee	207.5	287	268
11	Arkansas	175.5	273	210
12	Montana	147.6	304	332
13	Missouri	118.0	218	190
14	Kentucky	94.0	151	140
15	Mississippi	83.1	117	98
16	New Mexico	82.7	205	245
17	Wyoming	78.4	187	214
18	Idaho	54.3	106	116
19	Indiana	45.8	73	70
20	Illinois	45.2	71	67
21	New Hampshire	43.3	92	128
22	Arizona	42.4	79	108
23	Alabama	39.7	93	102
24	Oklahoma	36.3	56	53
25	Maine	35.0	74	101
26	Georgia	33.2	77	102
27	Massachusetts	29.6	51	76
28	New York	25.4	67	104
29	New Jersey	24.1	63	97
30	Vermont	23.3	103	149
31	Colorado	19.0	40	40
32	North Carolina	14.7	62	80
33	Rhode Island	14.5	36	53
34	Connecticut	13.8	45	71
35	Virginia	11.6	32	47
36	Ohio	11.0	26	30
37	Delaware	10.6	36	56
38	District of Columbia	9.6	28	38

39	Pennsylvania	8.8	37	53
40	Louisiana	8.0	12	14
41	West Virginia	7.4	34	45
42	Maryland	7.4	21	30
43	Texas	5.1	12	12
44	Kansas	4.9	14	11
45	Michigan	4.6	6	6
46	South Dakota	4.2	12	10
47	Florida	2.9	6	6
48	Nebraska	2.7	11	9
49	Iowa	2.5	6	4
50	Wisconsin	1.7	4	4
51	North Dakota	0.7	2	2
52	Minnesota	0.5	1	1
	Totals Excluding Puerto Rico	**$6,697.00**	**$9,652.00**	**$10,299.00**
	Total	**$7,778.00**		

Effect of Change in Building Inventory

This significant reduction in projected annualized losses in certain regions (Table 4.3) is driven largely by changes to the building inventory (Figure 4.4), which illustrates the importance of incorporating updated building stock information into Hazus analyses when available. Building stock inventory efforts, particularly at the city or community level, can enhance the accuracy of Hazus analyses. This refinement in turn helps to increase awareness of the dangers posed by highly vulnerable structure types such as unreinforced masonry (URM) buildings.

Two recent examples highlight this potential. FEMA-funded Rapid Visual Screening efforts directed by the Utah Seismic Safety Commission have brought to light the large number of high-risk URM buildings, particularly schools, in the Salt Lake Valley and have prompted a Utah State legislation for statewide screening of school buildings at high seismic risk (FEMA P-774 2009, Siegel 2011). The Northeast States Emergency Consortium (NESEC) has piloted a cost-effective inventory methodology that used Hazus data, Google Earth satellite & StreetView imagery, and parcel data to improve URM inventory accuracy (NESEC 2013). Studies such as these can enhance the effectiveness of Hazus studies in accurately identifying high-risk areas of the country.

In Hazus 3.0, even though the default general building stock mapping schemes remained the same, the building distribution for the inventory of California was changed significantly, because the residential occupancy category like RES1 grew faster than others. The primary change in the building distribution (see Table 4-5) for California was a proportional increase in wood-frame buildings (+14%) and a reduction in the amount of masonry, steel, concrete buildings. This revision in the building distribution was less significant in other states. In Hazus 3.0 the default mapping scheme applied on 2010 census data led to a slight reduction in wood-frame dwellings and a proportionate increase in concrete buildings as shown in Table 4-5.

Table 4-5.* *Change in Building Distribution by General Structural Types in California

	Wood	Steel	Concrete	Masonry	Manufactured Homes
Hazus 99	63	10	11	13	3
Hazus-MH MR2	80	4.2	8	7	0.8
Hazus 3.0	77	5	9	7	2
Percent Change (Hazus 3.0 vs. Hazus 99)	**14.00**	**(5. 0)**	**(2.00)**	**(6.00)**	**(1.0)**

Table 4-6 illustrates the broad range and types of economic losses that are directly related to building damage. An important observation in both of these modeled losses and recent earthquakes in the U.S. is that the largest contribution to losses is damage to the nonstructural elements of buildings and contents. This observation should be considered when prioritizing mitigation strategies designed to reduce economic losses. In addition, mitigation strategies that address potential nonstructural and content losses are often relatively low cost and easier to implement such as bracing light and ceiling fixtures in offices, schools and hospitals. This type of mitigation will also contribute to reducing earthquake injuries.

Generally, wood frame construction is less vulnerable to earthquake damage than other building types, so this change in inventory composition was expected to cause a reduction in the AELR for California. Consequently, since California accounted for over two-thirds of the total AEL for the U.S., this change was expected to have a substantial impact on the overall study. This reduction in normalized loss was also driven by a reduction in the USGS probabilistic seismic hazard between the 2002, 2008 and 2014 hazard models. The FEMA 2008 study documented that 78% of the loss reduction between Hazus-MH MR2 versus Hazus 99 was attributed to the change in building distribution; while 22% was due to a reduction in the probabilistic seismic hazard for California.

In addition, changes in population across the country have influenced the change in the built environment in many high-risk areas.

Table 4-6. Economic Losses by Type of Impact (in thousands of dollars) for the State of California

Building Loss • Structural $443,563 • Nonstructural $2,033,791	$2,477,354
Content Loss	$787,674
Inventory Loss	$19,307
Relocation Costs	$188,309
Income Loss	$76,507
Rental Loss	$97,646
Wage Loss	$92,326
Total Loss	$3,739,123

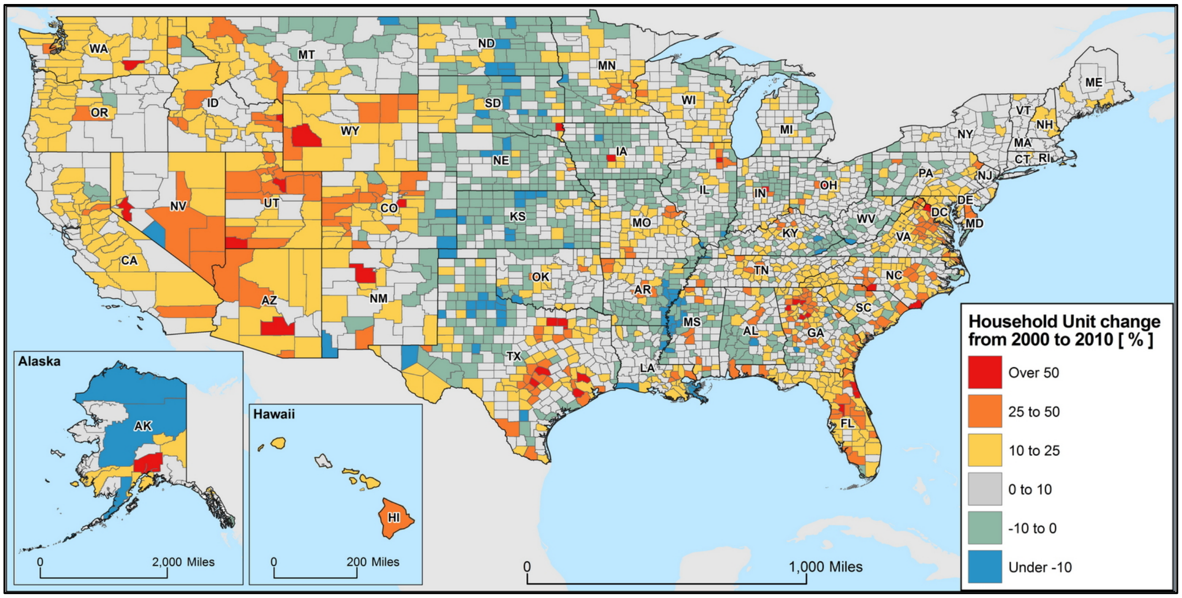


Figure 4-4 Comparison of Household Population Demographics between 2000 and 2010.

5 Interpretation and Applications

While there is a well-established body of information on how the earthquake hazard varies among regions, there is less understanding of how earthquake risk differs from one region to another, and how the risk may be affected by changes in the underlying hazard model and building inventory. From a public policy and emergency management standpoint, understanding and documenting how these changes affect regional, state and local earthquake exposure and risk are fundamental to garnering and sustaining support for risk reduction strategies, seismic policy and program development.

Study Findings

- Although greatest on the West Coast, seismic risk exists in other areas of the U.S.
  The annualized loss from earthquakes nationwide is estimated to be $6.1 billion per year, with California, Oregon and Washington accounting for $3.7 billion, or 72%. The remaining 28% of losses are distributed among the central states ($0.48 billion per year), the Northeast ($0.17 billion per year), and the Southeast ($0.18 billion per year). Hawaii and Alaska have a combined $0.203 billion, while Puerto Rico averages $0.253 billion in annualized losses.

- An increase in building inventory will not always translate to a proportional increase in seismic risk.
  In Hazus 3.0, the occupancy-to-building-type profile for California was modified to include a higher proportion of wood frame construction (see Table 4-6). Wood frame construction is less vulnerable to earthquake damage than other types of building construction types, such as masonry construction. This modification to the building type profile was the primary reason for the reduction in the AELR for California [972 (Hazus 3.0) and 1,452 (Hazus-MH MR2) versus 1,580 (Hazus 99)] and is a good example of the potential loss reduction that can occur by replacing aging construction with more earthquake resistant construction.

- Earthquake risk continues to be highest in urban areas, most notably California and on the West Coast.
  In a number of states—New York, South Carolina, Utah, Alaska, Hawaii, California, Oregon, and Washington—estimated losses in metropolitan areas account for up to 80% of total state losses, which has important implications for a national strategy to reduce seismic risk. More than 60% of the annualized losses in California are expected in the three metropolitan areas of San Francisco, Los Angeles and San Diego. These three metropolitan regions have a combined population of 21 million (2015) and account for over 37% of the total estimated annualized earthquake loss in the United States.

- Changes in the USGS probabilistic seismic maps will translate to changes in risk. In Hazus, the probabilistic seismic hazard decreased for many states in the central U.S. This decrease was due to changes in the USGS seismic hazard models (USGS, 2014) for the central U.S. and resulted in a decrease in the AELR for many states (see Table 4-3).

Applications

The findings in this study may be used to support analysis, decision making and risk reduction, including:

1. To improve understanding of the seismic risk in the U.S.

   This study builds on the knowledge gained from the original studies (FEMA 366, 2001 and FEMA 366, 2008) to incorporate new data that directly influences earthquake loss and mitigation. In particular, this study utilizes: (1) the seismic hazard (2014 hazard data); (2) inventory (2014 RS Means values); (3) population at risk (2010 census data); and (4) estimated social losses. By modifying these important parameters, the study provides a clearer picture of the role of each data type in shaping seismic risk in the U.S. In a broader sense, the information in this study is an integral component of a “national seismic risk baseline”—aggregated at the metropolitan, county, state and regional level. Key parameters that can be updated include: (1) seismic hazard; (2) inventory (general building stock, lifelines, and essential facilities); (3) demographic data; and (4) loss estimation and other analyses.

2. To promote risk awareness and mitigation of high-risk communities.

   AEL and AELR serve as an overall first-line earthquake risk measures for potential earthquake-related losses to local communities in the corresponding county and state. In high-risk regions, local communities work with their state earthquake program managers who can seek support from FEMA’s NEHRP, Earthquake Consortium and State Support Program to develop and implement earthquake risk awareness and reduction activities. This program provides funding for the following eligible activities:

- Develop seismic mitigation plans;
- Prepare inventories and conduct seismic safety inspections of critical structures and lifelines;
- Update building codes, zoning codes, and ordinances to enhance seismic safety;
- Increase earthquake awareness and education; and
- Encourage the development of multi-state groups for such purposes.

Many communities have successfully promoted earthquake awareness, preparedness and mitigation at schools, businesses, and community events for local residents. Some of the successes include training and education on various earthquake mitigation options, screening vulnerable buildings, ShakeOut exercise and QuakeSmart outreach activities (NEHRP Earthquake Consortium and State Support Program Fact Sheet, see NEHRP (2017) for details). In addition, FEMA NEHRP provides a broad range of earthquake risk-reduction guidelines and resource documents (see Catalog of FEMA Earthquake Resources, FEMA P-736B).

3. To support the adoption and enforcement of seismic building code provisions.

One of the objectives of the National Earthquake Hazards Reduction Program (NEHRP) is to promote the adoption and enforcement (Burby and May 1999) of seismic building codes in regions of the U.S. that experience infrequent but damaging earthquakes. The uneven distribution of seismic risk across the U.S. necessitates the need for uniform adoption and enforcement. Typically, localities with infrequent earthquakes place a low priority on seismic code enforcement. However, this study demonstrates the actual regional risk in terms of potential damage and economic loss. The Hazus 3.0 data may be applied to evaluate the effectiveness of different mitigation strategies by measuring risk and their uncertainties before and after they are implemented. For example, a FEMA study (FEMA 294, 1997) concludes that if the Los Angeles area had been built to high seismic design standards (UBC zone 4 or NEHRP zone 7) prior to the 1994 Northridge earthquake, the losses would have been reduced by $11.3 billion (including buildings, contents, and income). This is equivalent to avoiding about 40% of losses (when adjusting for additional costs to design and construct to higher seismic standards). This type of analysis is valuable when determining policy and program options for long-term risk management measures, including those that address building codes, land use planning, and resource allocation.

4. To support disaster response and recovery planning.

When planning for catastrophic earthquakes, the ability to compare 250- and 1,000-year estimates of debris, casualties and shelter requirements on a regional, state and municipal scale enables planners to anticipate potential resource requirements under the National Response Plan. Such estimates are useful as planning tools, as well as identifying and prioritizing mitigation measures that address life, safety, and functionality of essential facilities.

References

Brookshire, D.S., Chag, S.E., Cochrane, H., Olson, R.A., Rose, A., and Steenson J., 1997. Direct and indirect economic losses from earthquake damage, Earthquake Spectra, Vol. 13, No. 4, pp. 683-702.

Burby, Raymond and May, Peter, 1999. Making Building codes an effective tool for earthquake hazard mitigation, Environmental Hazards, 1, p. 27-37.

Federal Emergency Management Agency (FEMA), 2013. Catalog of FEMA Earthquake Resources, FEMA P-736B, 2013, https://www.fema.gov/media-library/assets/documents/15092.

Dun & Bradstreet, 2002. Market Analysis Profile aggregated by Standard Industrial Classification (SIC) Code Clusters.

Dun & Bradstreet, 2006. Market Analysis Profile aggregated by Standard Industrial Classification (SIC) Code Clusters, July 2006.

Federal Emergency Management Agency (FEMA), 1997. Federal Emergency Management Agency, Report on the Costs and Benefits of Natural Hazard Mitigation, FEMA 294, Washington, D.C., U.S. Government Printing Office.

Federal Emergency Management Agency (FEMA), 2001. Hazus®99 Estimated Annualized Earthquake Losses for the United States, Federal Emergency Management Agency Mitigation Directorate, FEMA 366, Washington, D.C.

Federal Emergency Management Agency (FEMA), 2008. Hazus®MH Estimated Annualized Earthquake Losses for the United States, Federal Emergency Management Agency, FEMA 366, Washington, D.C.

Federal Emergency Management Agency (FEMA), 2009. Unreinforced Masonry Buildings and Earthquakes, FEMA P-774, Washington, D.C., U.S. Government Printing Office.

Federal Emergency Management Agency (FEMA), 2012. Hazus-MH 2.1 Technical Manual: Earthquake Model, developed by Federal Emergency Management Agency, Mitigation Division, Washington, D.C.

Jaiswal K. S., Bausch D., Chen R., Bouabid J., and Seligson H., 2015. Estimating annualized earthquake losses for the conterminous United States, Earthquake Spectra, Volume 31, No. S1, pages S221–S243, December 2015.

National Earthquake Hazards Reduction Program (NEHRP), 2015. NEHRP Recommended

Seismic Provisions for New Buildings and Other Structures Volume I: Part 1 Provisions, Part 2 Commentary FEMA P-1050-1/2015 Edition. Prepared for the Federal Emergency Management Agency of the U.S. Department of Homeland Security by the Building Seismic Safety Council of the National Institute of Building Sciences, Washington, D.C.

National Earthquake Hazards Reduction Program (NEHRP), 2017. Earthquake Consortium and State Support Program Fact Sheet, FEMA, 2017, https://www.fema.gov/media-library/assets/documents/5772.

Northeast States Earthquake Consortium (NESEC), 2013. Pilot Project to Investigate the Feasibility of Using HAZUS-MH and High Resolution Satellite Imagery to Identify and Quantify Unreinforced Masonry (URM) Buildings in the United States, Wakefield, MA.

Kircher, C.A., Reitherman , R. K., Whitman, R. V., and Arnold, C., 1997. Estimation of earthquake losses to buildings, Earthquake Spectra, Vol. 13, No. 4, pp. 703-720.

Petersen, M. D., Moschetti, M. P., Powers, P. M., Mueller, C. S., Haller, K. M., Frankel, A. D., Zeng, Y., Rezaeian, S., Harmsen, S. C., Boyd, O. S., Field, E. H., Chen, R., Rukstales, K. S., Luco, N., Wheeler, R. L., Williams, R. A., and Olsen, A. H., 2014. Documentation for the 2014 update of the United States national seismic hazard maps, U.S. Geological Survey Open-File report 2014-1091, 243 pp., available at http://dx.doi.org/10.3133/ ofr20141091.

Petersen, M. D., Mueller, C. S., Moschetti, M. P., Hoover S. M., Shumway A. M., McNamara D. E., Williams R. A., Llenos A. L., Ellsworth W.L., Michael A. J., Rubinstein J. L., McGarr A. F., and Rukstales, K. S., 2017. 2017 One-year seismic-hazard forecast for the central and eastern United States from Induced and Natural Earthquakes, Seismological Research Letters, Volume 88, Number 3, May/June 2017, doi: 10.1785/0220170005.

RS Means, 2005. RS Means Square Foot Costs 2005 26th Edition, published by RS Means Company, http://www.rsmeans.com/.

RS Means, 2014. RS Means Square Foot Costs 2014 35th Edition, published by RS Means Company, http://www.rsmeans.com/.

Seyhan, E., and Stewart, J. P., 2014. Semi-empirical nonlinear site amplification from NGA-West2 data and simulations, Earthquake Spectra 30, 1241– 1256.

Siegel, Lee J., 2011. A Preliminary Survey by the Utah Seismic Safety Commission and Structural Engineers Association of Utah. Utah Seismic Safety Commission, February 2011.

U.S. Bureau of the Census, 2010. https://www.census.gov/2010census/data/.

A Glossary

Annualized Earthquake Loss (AEL) – The estimated long-term value of earthquake losses in any given single year in a specified geographic area.

Annualized Earthquake Loss Ratio (AELR) – The ratio of the average annualized earthquake loss to the replacement value of the building inventory. This ratio is used as a measure of relative risk, since it considers replacement value, and can be directly compared across different geopolitical units including census tracts, counties, and states.

Average Annual Frequency – The long-term average number of events per year.

Basic Building Inventory – The national level building inventory incorporated into Hazus 3.0. The basic database classifies buildings by occupancy (residential, commercial, and industrial) and by model building type (wall construction, roof construction, height, etc.). The basic mapping schemes are state specific for single-family occupancy type and region specific for all other occupancy types; they are building age and height specific. The four inventory groups are general building stock, essential and high potential loss facilities, transportation systems, and utilities.

Hazard – A source of potential danger or an adverse condition. For example, a hurricane occurrence is the source of high winds, rain, and coastal flooding, all of which can cause fatalities, injuries, property damage, infrastructure damage, interruption of business, or other types of harm or loss.

Hazard Identification – Hazard identification involves determining the physical characteristics of a particular hazard—magnitude, duration, frequency, probability, and extent—for a site or a community.

Hazus – A standardized GIS-based loss estimation tool, developed by the Federal Emergency Management Agency (FEMA) in cooperation with the National Institute of Building Sciences (NIBS). See www.fema.gov/plan/prevent/Hazus for more information, or appendix B below.

Peak Ground Acceleration (PGA) – The maximum level of vertical or horizontal ground acceleration caused by an earthquake. PGA is commonly used as a reference for designing buildings to resist the earthquake movements expected in a particular location and is typically expressed as a percentage of the acceleration due to gravity (g).

Probabilistic Seismic Hazard Data – An earthquake ground motion estimate that includes information on seismicity, rates of fault motion, and the frequency of various magnitudes. Earthquake hazards are expressed as the probability of exceeding a level of ground motion in a specified period of time (e.g., 10% probability of exceeding 20% g in 50 years). See http://earthquake.usgs.gov/ for more information.

Return Period – The average time between earthquakes of comparable size in a given location. Equal to the reciprocal of the frequency.

Risk – The likelihood of sustaining a loss from a hazard event defined in terms of expected probability and frequency, exposure, and consequences, such as death and injury, financial costs of repair and rebuilding, and loss of use.

Risk Analysis – The process of measuring or quantifying risk. Risk analysis combines hazard identification and vulnerability assessment and answers three basic questions:

- What hazard events can occur in the community?
- What is the likelihood of these hazard events occurring?
- What are the consequences if the hazard event occurs?

Quantitative assessment of the overall significance of these consequences in the community or region is called the risk assessment.

Risk Management – The process of identification, assessment, and prioritization of risks leading to reduction of overall risk to an acceptable level. Risk management addresses three issues:

- what steps should be taken to reduce risks to an acceptable level (mitigation),
- the relative trade-offs among multiple opportunities (benefit/cost analyses, capital allocation), and
- the impacts of current decisions on future opportunities.

Spectral Acceleration (SA) – The acceleration response of a single degree-of-freedom, mass-spring dashpot system with a given natural period (e.g., 0.3 of 1 second) to a given earthquake ground motion. SA is most closely related to structural response and, therefore, indicates an earthquake's damage potential.

Vulnerability Assessment – The process of assessing the vulnerability of people and the built environment to a given level of hazard. The quantification of impacts (i.e., loss estimation) for a hazard event is part of the vulnerability assessment.

B Overview of Hazus

Acknowledging the need to develop a standardized approach to estimating losses from earthquakes and other hazards, FEMA has embarked on a multiyear program to develop a GIS-based regional loss estimation tool. FEMA released the first version of the Hazus earthquake model in 1997 followed by an updated version in 1999. In 1998, FEMA began the development of a multi-hazard methodology to encompass wind and flood hazards.

FEMA developed Hazus under agreements with the National Institute of Building Sciences. Hazus is a tool that local, state, and federal government officials and others can use for mitigation, emergency preparedness, response and recovery planning, and disaster response operations. The methodology in Hazus is comprehensive. It incorporates state-of-the-art approaches for characterizing hazards; estimating damage and losses to buildings and lifelines; estimating casualties, displaced households, and shelter requirements; and estimating direct and indirect economic losses.

Since Hazus is a uniform national methodology, it serves as an excellent vehicle for assessing and comparing seismic risk across the United States. The Hazus technology is built upon an integrated geographic information system (GIS) platform that produces regional profiles and estimates of earthquake losses. The methodology addresses the built environment, and categories of losses, in a comprehensive manner.

Hazus is composed of six major modules, which are interdependent. This modular approach allows different levels of analysis to be performed, ranging from estimates based on simplified models and default inventory data to more refined studies based on detailed engineering and geotechnical data for a specific study region.

A brief description of each of the six modules is presented below. Detailed technical descriptions of the modules can be found in the Hazus technical manuals (FEMA 2012).

Module 1: Potential Earth Science Hazard (PESH)

The Potential Earth Science Hazard module estimates ground motion and ground failure (landslides, liquefaction, and surface fault rupture). Ground motion demands in terms of spectral acceleration (SA) and peak ground acceleration (PGA) are typically estimated based on the location, size and type of earthquake, and the local geology. For ground failure, permanent ground deformation (PGD) and probability of occurrence are determined. GIS-based maps for other earth science hazards, such as tsunami and seiche inundation, can also be incorporated. In the current study, hazard data from the U.S. Geological Survey are used.

Module 2: Inventory and Exposure Data

Built into Hazus is a national-level basic exposure database that allows a user to conduct a preliminary analysis without having to collect any additional local data. The general stock of buildings is classified by occupancy (residential, commercial, etc.) and by model building type (structural system, material and height). The default mapping schemes are state specific for the single-family occupancy type and region specific for all other occupancy types. They are age and building-height specific. The four inventory groups are general building stock, essential and high potential loss facilities, transportation systems, and utilities. The infrastructure within the study region must be inventoried in accordance with the standardized classification tables used by the methodology. These groups are defined to address distinct inventory and modeling characteristics. A description of the model building types can be further examined in Chapter 3 of the Hazus technical manual. Population exposure is based on the 2010 Census (U.S. Bureau of the Census, 2010) and estimates for building exposure are based on default values for building replacement costs (dollars per square foot) for each model building type and occupancy class, in addition to certain regional cost modifiers. Data also are drawn from Dun & Bradstreet (2006) and RS Means (2014).

Module 3: Direct Damage

This module provides damage estimates for each of the four inventory groups based on the level of exposure and the vulnerability of structures (potential for damage at different ground shaking levels).

A technique using building fragility curves based on the inelastic building capacity and site-specific response spectra is used to describe the damage incurred in building components (Kircher et al. 1997). Since damage to nonstructural and structural components occurs differently, the methodology estimates both damage types separately. Nonstructural building components are grouped into drift-sensitive and acceleration-sensitive components.

For both essential facilities and general building stock, damage state probabilities are determined for each facility or structural class. Damage is expressed in terms of probabilities of occurrence of specific damage states, given a level of ground motion and ground failure. Five damage states are identified—none, slight, moderate, extensive, and complete.

Module 4: Induced Damage

Induced damage is defined as the secondary consequence of an event. This fourth module assesses dams and levees for inundation potential, and hazardous materials sites for release potential. Fire following an earthquake and accumulation of debris are also assessed.

Module 5: Direct Losses

Unlike many previous loss estimation methods, Hazus provides estimates for both economic and social losses. Economic losses include structural and nonstructural building losses, costs of relocation, losses to business inventory, capital-related losses, income losses, and rental losses. Social losses are quantified in terms of casualties, displaced households, and short-term shelter needs. The output of the casualty module includes estimates for four levels of casualty severity at three daily time periods and for six occupancies and commuters. Casualties, caused by secondary effects such as heart attacks or injuries while rescuing trapped victims, are not included.

Shelter needs are estimated based on the number of structures that are uninhabitable, which in turn is evaluated by combining damage to the residential building stock with utility service outage relationships.

Module 6: Indirect Losses

This module evaluates the long-term effects on the regional economy from earthquake losses. The outputs in this module include income and employment changes by industrial sector (Brookshire et al. 1997).

C Probabilistic Hazard Data Preparation and AEL Computation

The U.S. Geological Survey (USGS) provided the probabilistic seismic hazard data for the entire United States. A three-step process was used to convert the data into a Hazus-compatible format.

Step 1: Compute the PGA, SA@0.3 and SA@1.0 at each grid point for the eight return periods.

The latest 2014 national seismic hazard model of the USGS was used in the present investigation (Petersen et al. 2014). The hazard dataset consists of a set of 19 (or 20) intensity probability pairs for each of the 611,309 grid points used to cover the contiguous United States. The hazard models for Alaska, Hawaii and Puerto Rico were not up to date at the time of this investigation; hence, we relied on utilizing the 2007 model for Alaska, 1998 model for Hawaii and 2003 model for Puerto Rico.

Table C-1 provides an example of the USGS hazard data for an individual grid point. In the table, for each of the 18 (or 20) intensity-probability pairs, the intensity of the ground motion parameters (PGA, SA @ 0.3 sec. and SA @ 1.0 sec.) is shown along with the corresponding annual frequency of exceedance (AFE).

Table C-1. Example of the USGS Hazard Data

#	Ground Motion Data					
	PGA	AFE	SA(0.3 sec)	AFE	SA(1.0 sec)	AFE
1	0.0050	0.44320000	0.0050	0.702720	0.0025	0.589090000
2	0.0070	0.34746000	0.0075	0.542630	0.0038	0.437210000
3	0.0098	0.26823000	0.0113	0.404400	0.0056	0.312330000
4	0.0137	0.20393000	0.0169	0.294610	0.0084	0.215920000
5	0.0192	0.15156000	0.0253	0.208840	0.0127	0.143970000
6	0.0269	0.10967000	0.0380	0.143220	0.0190	0.093405000
7	0.0376	0.07706500	0.0570	0.094717	0.0285	0.058360000
8	0.0527	0.05222700	0.0854	0.060020	0.0427	0.035297000
9	0.0738	0.03431600	0.1280	0.036327	0.0641	0.020650000
10	0.1030	0.02195800	0.1920	0.021039	0.0961	0.011738000
11	0.1450	0.01342700	0.2880	0.011687	0.1440	0.006427700
12	0.2030	0.00797700	0.4320	0.006207	0.2160	0.003333100
13	0.2840	0.00454470	0.6490	0.003100	0.3240	0.001597500
14	0.3970	0.00244000	0.9730	0.001413	0.4870	0.000679480
15	0.5560	0.00119210	1.4600	0.000557	0.7300	0.000249660
16	0.7780	0.00051457	2.1900	0.000180	1.0900	0.000076200
17	1.0900	0.00018778	3.2800	0.000045	1.6400	0.000017270
18	1.5200	0.00005630	4.9200	0.000008	2.4600	0.000002589
19	2.2000	0.00001066	7.3800	0.000001	3.6900	0.000000198
20	3.3000	0.00000175			5.5400	0.000000002

Step 2: Modify the PGA, SA@0.3 and SA@1.0 at each grid point to represent site-soil conditions.

The USGS data were based on a National Earthquake Hazard Reduction Program (NEHRP) soil class type B/C (medium rock/very dense soil). To account for the difference in soil class types specific to each grid cell, the topography-based Vs 30 estimates available from the USGS website (https://earthquake.usgs.gov/data/vs30/) were used along with the NEHRP site soil correction factors (2015) to derive the site soil corrected PGA, SA@0.3 and SA@1.0 at each grid point.

Figure C-1 shows the site-corrected hazard curve for the site in downtown Los Angeles (Latitude: 34.05, Longitude: -118.25) with an approximate shear wave velocity estimate (Vs 30 value) of 364 cm/sec obtained from the topographic slope-based approach.

Step 3: Compute the PGA, SA@0.3 and SA@1.0 at each census tract centroid for the eight return periods.

For each grid point, a log-log interpolation of the data (Figure C-1) was used to calculate the ground motion values corresponding to each of the eight return periods used in this study (100, 250, 500, 750, 1000, 1500, 2000, and 2500 years). Table C-2 demonstrates the result of log-log interpolation of the hazard data for the site in downtown Los Angeles, California. Contrary to the linear interpolation that was applied in previous FEMA 366 updates, the present investigation relied on log-log interpolation which provides superior fit to the hazard and AFE data.

For estimating losses to the building inventory, Hazus uses the ground shaking values calculated at the centroid of the census tract. To incorporate the USGS data into Hazus, the ground shaking values at the centroid were calculated from the grid-based data developed in Step 2.

Two rules were used to calculate the census-tract-based ground shaking values:

1. For census tracts that contain one or more grid points, the average values of the points are assigned to the census tract.
2. For census tracts that do not contain any grid points, the average value of the four nearest grid points is assigned to the census tract. Using this method, census-tract-based ground motion maps are generated for all eight return periods.

Table C-2. Result of the log-log Interpolation of the Site-Corrected USGS Hazard Data

#	Site-Corrected Ground Motion Data			
	AFE	PGA	SA(0.3 sec)	SA(1.0 sec)
1	0.01000	0.2376	0.4591	0.2161
2	0.00400	0.3817	0.7319	0.3703
3	0.00200	0.5164	0.9741	0.5198
4	0.00133	0.6067	1.1405	0.6219
5	0.00100	0.6805	1.2696	0.7001
6	0.00067	0.8002	1.4767	0.8261
7	0.00050	0.8961	1.6415	0.9105
8	0.00040	0.9656	1.7787	0.9819

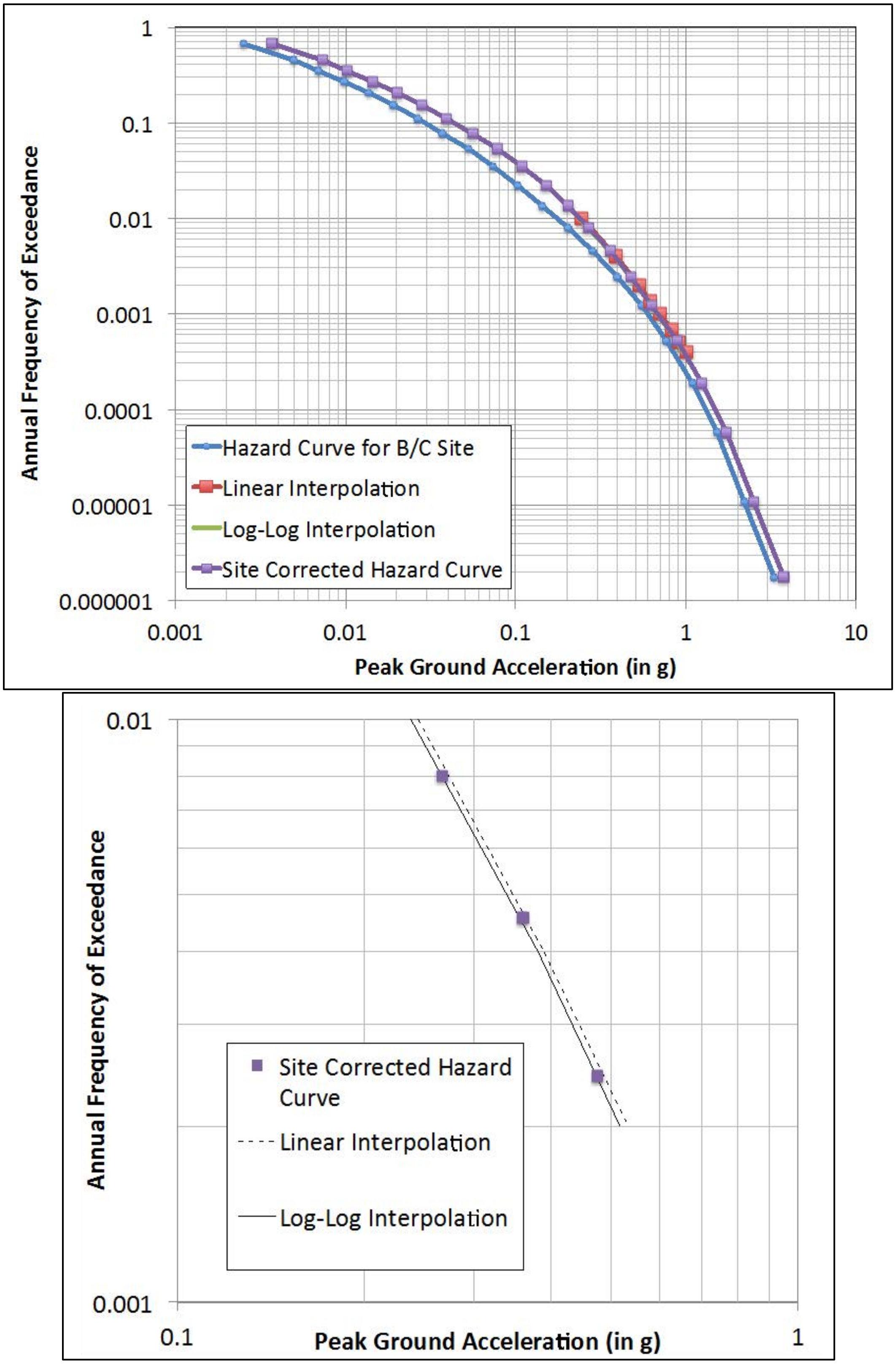


Figure C-1. Seismic Hazard Curve for the Site in Downtown Los Angeles, California and the Figure Below Shows a Zoomed Version Distinguishing the Linear Versus Log-Log Interpolation.

Average Annualized Earthquake Loss Computation

After the processing of hazard data, an internal analysis module in Hazus transformed the losses from all eight scenarios into an annualized earthquake loss (AEL).

The calculation of AEL is illustrated in Table C-2A for Los Angeles County, California. Hazus computes annual losses for eight probabilistic return periods as shown in the return period column. The annual probability of the occurrence of the event is 1/RP. The differential probabilities are obtained by subtracting the annual occurrence probabilities. Next, the average loss is computed by averaging the annual losses associated with various return periods as shown in the column average losses. Once average loss is computed, the average annualized Loss is the summation of the product of the average loss and differential probability of experiencing this loss. Table C-2B shows a sample computation for average annualized loss.

Figure C-2 illustrates schematically a Hazus example of eight loss-numbers plotted against the exceedance probabilities for the ground motions used to calculate these losses. Hazus computes the AEL by estimating the area under the loss probability curve as represented in Figure C-2. This area represents an approximation to the AEL and is equivalent to taking the summation of the differential probabilities multiplied by the average loss for the corresponding increment of probability. In effect, one is approximating the area under the curve by summing the area of horizontal rectangular slices.

The choice for the number of return periods was important for evaluating average annual losses, so that a representative curve could be connected through the points and the area under the probabilistic loss curve be a good approximation. The constraint on the upper bound of the number was computational efficiency vs. improved marginal accuracy. To determine the appropriate number of return periods, FEMA (2008) conducted a sensitivity study was completed that compared the stability of the AEL results to the number of return periods for 10 metropolitan regions using 5, 8, 12, 15, and 20 year return periods. The difference in the AEL results using 8, 12, 15, and 20 year return periods was negligible.

Table C-2A and B. Average Annualized Earthquake Loss Computation for Los Angeles County in California.

#	Return Period	Annual Probabilities	Differential Probabilities		Annual Losses	Average Losses	Annualized Loss
			Formula	Values			
1	2500	0.00040	P2500	0.00040	L2500	L2500	P2500 x L2500
2	2000	0.00050	P2000 - P2500	0.00010	L2000	(L2500+L2000)/2	(P2500 x P2500) x (L2500+L2000)/2
3	1500	0.00067	P1500 - P2000	0.00017	L1500	(L2000+L1500)/2	(P1500 x P2000) x (L2000+L1500)/2
4	1000	0.00100	P1000 - P1500	0.00033	L1000	(L1500+L1000)/2	(P1000 x P1500) x (L1500+L1000)/2
5	750	0.00133	P750 - P1000	0.00033	L750	(L750+L1000)/2	(P750 - P1000) x (L750+L1000)/2
6	500	0.00200	P500 - P750	0.00067	L500	(L750+L500)/2	(P500 - P550) x (L750+L500)/2
7	250	0.00400	P250 - P500	0.00200	L250	(L250+L500)/2	(P250 - P500) x (L250+L500)/2
8	100	0.01000	P100 - P250	0.00600	L100	(L100+L250)/2	(P100 - P250) x (L100+L250)/2
							Σ ( )

	Return Period	Annual Probabilities	Differential Probabilities	Annual Losses	Average Losses (Billions of $)	Annualized Loss (Billions of $)
1	2500	0.00040	0.00040	465.65	465.65	0.1863
2	2000	0.00050	0.00010	418.40	442.02	0.0442
3	1500	0.00067	0.00017	361.88	390.14	0.0663
4	1000	0.00100	0.00033	222.57	292.23	0.0964
5	750	0.00133	0.00033	187.87	205.22	0.0677
6	500	0.00200	0.00067	145.46	166.67	0.1117
7	250	0.00400	0.00200	73.82	109.64	0.2193
8	100	0.01000	0.00600	33.83	53.82	0.3229
						1.1148

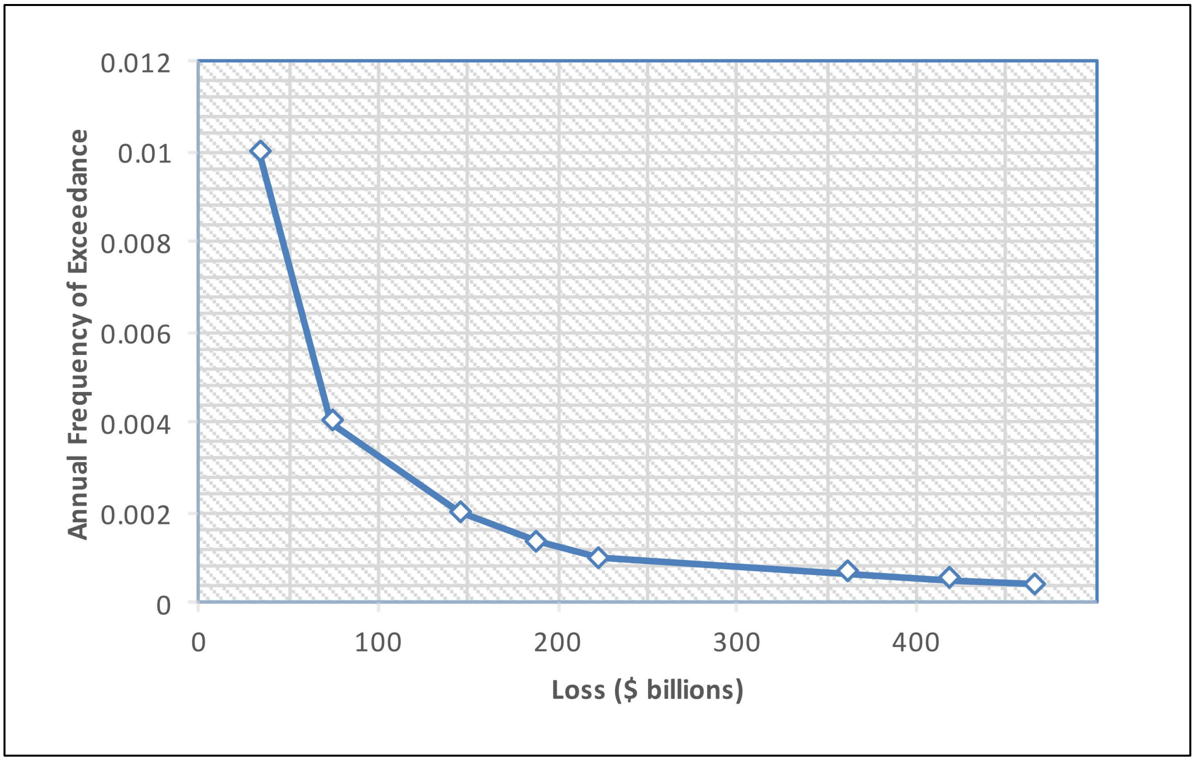


Figure C-2. Probabilistic Loss Curve for Los Angeles County, California

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