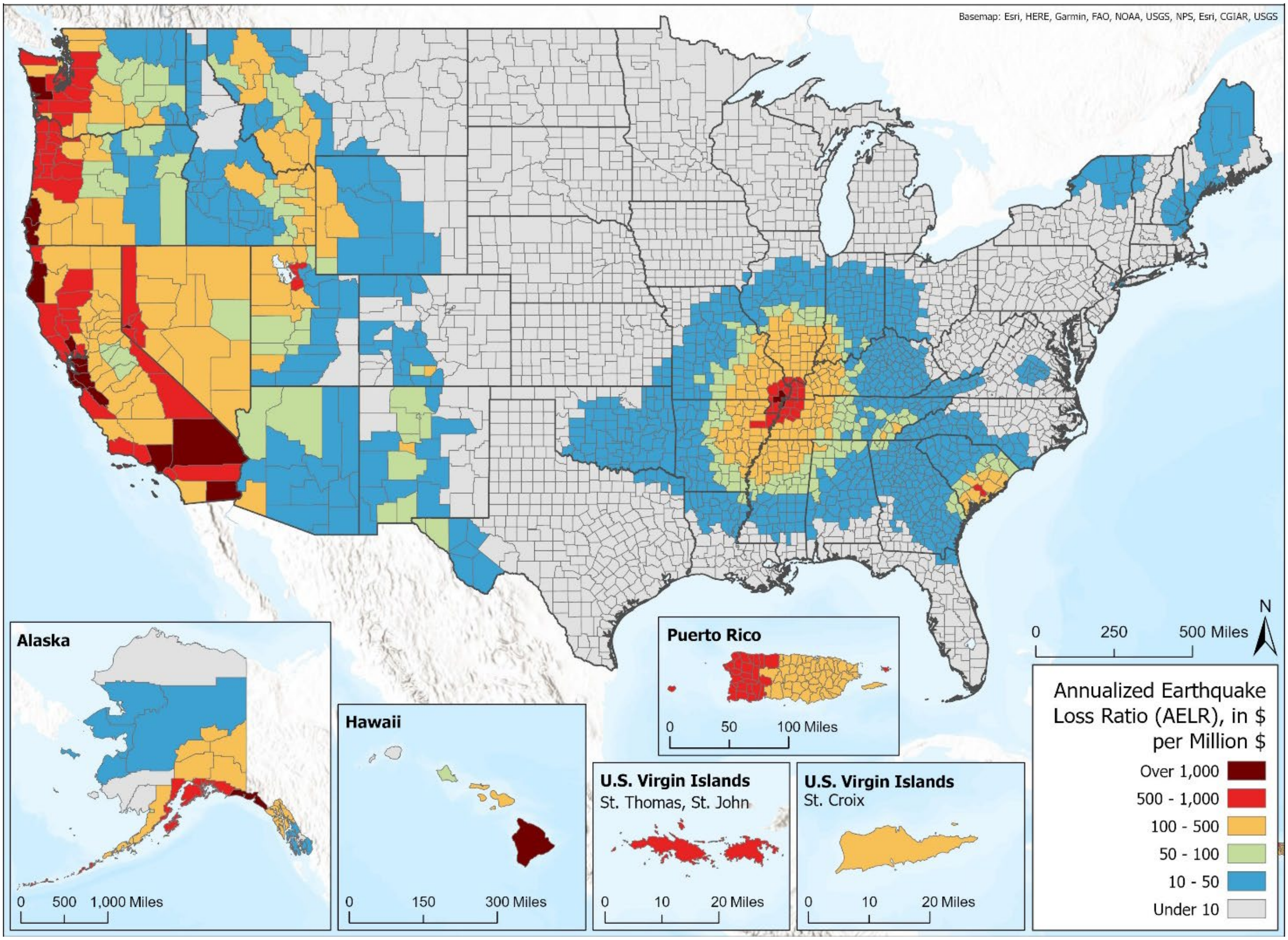

# Hazus Estimated Annualized Earthquake Losses for the United States

FEMA P-366 / April 2023

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# Acknowledgements

The Federal Emergency Management Agency (FEMA) acknowledges and appreciates the contributions of the following individuals and organizations who participated in the development of this report. This report is an update of FEMA P-366 Estimated Annualized Earthquake Losses for the United States study that uses previous versions namely FEMA 366 1999 and 2008 reports as a template. The authors have modified the specific sections pertaining to new investigation and the results/discussion based on new findings. We thank additional review comments and editorial suggestions from Dr. Ned Field, Dr. Brian Shiro, and the USGS Bureau Approving Official Ms. Janet Carter. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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# Executive Summary

The National Earthquake Hazards Reduction Program (NEHRP) Reauthorization Act of 2018 (Pub.L. 115−307) requires that the Federal Emergency Management Agency (FEMA) “shall support the implementation of a comprehensive earthquake education, outreach, and public awareness program, including development of materials and their wide dissemination to all appropriate audiences and support public access to locality-specific information that may assist the public in preparing for, mitigating against, responding to and recovering from earthquakes and related disasters.” As one effort to satisfy the mission, this joint FEMA-U.S. Geological Survey (USGS) report provides nationwide and state-by-state estimates of annualized earthquake losses (AELs) based on the latest census and building stock data, as well as USGS earthquake hazard information.

Earthquake risk continues to rise in the United States as a result of rapidly growing human and economic exposure, complemented by the fact that much larger fractions of built assets are in high earthquake hazard areas. Large earthquakes can cause social and economic disruption that can be unprecedented in any given community. Fully recovering from these impacts may or may not always be achievable. Recent worldwide earthquakes have claimed tens of thousands of lives and caused hundreds of billions of dollars of economic impact throughout the globe: $86 billion from 2008 M7.9 Wenchuan, China (USGS, 2008); ~$30 billion from 2010 M8.8 Maule earthquake in Chile (USGS, 2010); ~$220 billion from 2011 M9.0 Tohoku, Japan earthquake (NCEI, 2016); ~$25 billion USD from 2011 M6.3 Christchurch, New Zealand (RBNZ, 2018); ~$12 billion from 2016 M7.0 Kumamoto, Japan (USGS, 2016). The widespread destruction from the recent 2023 Central Turkey earthquake included at least 46,000 deaths and $100 billion in losses (Paykoç, 2023).

The United States has experienced 28 earthquakes of magnitude 6 and greater in the last decade alone (e.g., M6 2014 South Napa, California; M6.4 and M7.1 2019 Ridgecrest, California; M6.4 2022 Ferndale, California) that have caused considerable damage, loss of life, and economic disruption (California Earthquake Authority, 2023). The 2019-2020 Puerto Rico earthquake sequence consisted of an M6.4 mainshock leading to 80 residential buildings with complete or partial collapse and some 280 buildings with structural damage (Miranda et al., 2020). The 2018 M7.1 Anchorage, Alaska, earthquake resulted in more 750 homes and buildings that suffered substantial damage (DeMarban, 2018). Moderate earthquakes, such as the M5.7 2020 Magna, Utah, earthquake, resulted in more than $100 million in losses to public facilities, including schools, because of the presence of older, unreinforced masonry construction (USSC, 2022). Similarly, the damage and impacts from M5.8 2011 Mineral Virginia earthquake and M5.1 2020 Sparta, North Carolina, earthquake continue to highlight the earthquake risk faced by central and eastern United States (Figueiredo et al., 2022). The 1994 M6.7 Northridge earthquake in California remains the one of the costliest disaster in U.S. history (California Geological Survey, 2023).

Recent earthquakes show a pattern of steadily increasing damage and losses that are primarily due to four key factors: (1) substantial growth in earthquake-prone urban areas; (2) higher contribution due to non-structural damage, content, and functional losses; (3) vulnerability of aging building stock, including poorly engineered, non-ductile concrete and unreinforced masonry buildings; and (4) an increased interdependency in terms of supply and demand for the businesses that operate in different parts of the world results in economic impacts far beyond the impact areas. Understanding the seismic hazard requires studying earthquake characteristics and the locales in which they occur, whereas understanding the risk requires an assessment of the potential damage from earthquake shaking to the built environment and public welfare—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. This study and 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 United States such as Los Angeles, San Francisco, and Seattle is constantly improving. Other lower hazard regions, such as New York City and Boston, generally are still recognized as being 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 levels. An improved risk quantification requires rigorous local or regional level inventory compilation with detailed building-specific structural and nonstructural attributes. Similarly, new strategies for communicating earthquake risk in areas where earthquakes have not historically occurred could effectively engage the local community and inform improved 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 FEMA. The Hazus 6.0 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 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.

Although 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 the 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 damage to critical facilities and indirect economic loss.

In Hazus 6.0, the total estimated economic exposure (building stock as well as content) for the nation is approximately $107.8 trillion, of which more than 29% comes from California, Texas, New York, and Florida. According to the latest USGS seismic design categories D and above, the 10 states with the highest populations exposed to strong ground shaking levels are California, Washington, Oregon, Tennessee, Puerto Rico, Utah, Nevada, Missouri, Arkansas, and Hawaiʻi (see Appendix D). Together, these states account for more than 27% of the nation's total economic exposure. Although such a level of shaking is estimated to occur relatively infrequently, it could cause substantial damage and causalities. Within the central and eastern United States, the New Madrid seismic zone (NMSZ) and the Charleston, South Carolina, area pose substantial earthquake threat. The NMSZ covers parts of eight states: Illinois, Indiana, Missouri, Arkansas, Kentucky, Tennessee, Oklahoma, and Mississippi. Together, they amount to approximately 15% of the total national exposure.

The Hazus analysis indicates that the AEL to the national building stock is $14.7 billion per year. Most of the average annual loss of 65% ($9.6 billion per year) is concentrated in the state of California. Overall, the West Coast (California, Oregon, and Washington) accounts for 78% of the total average annual loss in the United States. The high concentration of loss in California is consistent with the state's high seismic hazard and large structural exposure. The remaining 22% ($3.1 billion per year) of annual loss is distributed throughout the rest of the United States (including Alaska, Hawaiʻi, Puerto Rico, and the U.S. Virgin Islands) as reflected in Figure E-1.

When casualties, debris, and shelter loss data are aggregated by state, California accounts for more than 75% of estimated debris generated, 77% of displaced households, and 76% of short-term shelter needs for the earthquake hazard with a 250-year return period.

Although most 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. Relatively high earthquake loss ratios are 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 (including Los Angeles, Long Beach, and Anaheim) and San Francisco (including San Francisco, Oakland, and Berkeley) Bay areas, account for 85% of the total AEL. Los Angeles area alone has about 23% 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, Alaska, Reno, Nevada, Carson City, Nevada, Longview Washington, Olympia-Lacey-Tumwater, Washington, and Corvallis, Oregon, 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 (to include San Jose, Sunnyvale, and Santa Clara) metro area and Napa. This observation supports the value for strategies that can reduce the current seismic risk. Strategies to reduce future losses throughout the nation that are closely integrated with policies and programs that guide urban planning and development would be beneficial.

Loss estimates are based on the best science and engineering available when the study was conducted (during 2022-2023); thus, future estimates based on new technology will differ from those presented herein. To demonstrate how risk has changed with time, comparisons are drawn across all four updates of FEMA 366, Hazus Estimated Annualized Earthquake Loss for the United States, prepared in 2001, 2008, and 2017, and most recently with this release.

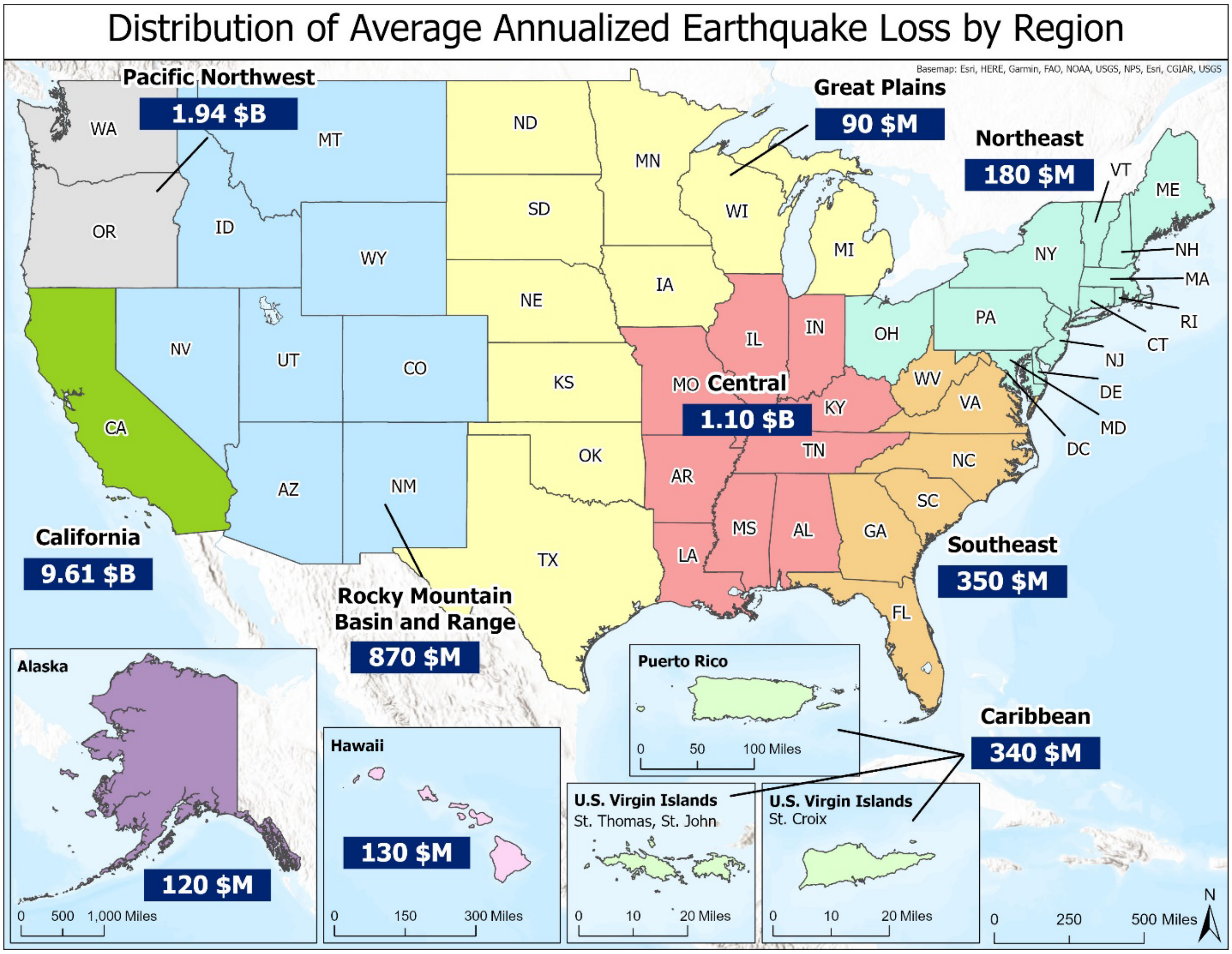


**Figure E-1. Distribution of Average Annualized Earthquake Loss by Region.**

This loss study is an important milestone in a long-term, FEMA-led effort to analyze and compare the seismic risk across regions of the United States. The study also contributes to the endeavor of NEHRP—to provide new knowledge and inform mitigation best practices and policies to reduce fatalities, injuries, economic losses, and other expected impacts 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. Evaluating the costs and benefits of seismic provisions in 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

## 1.1. Background

It is important that policies and practices associated with minimization of earthquake impacts are commensurate with the underlying risk that the community or region faces. Seismic risk assessment requires a systematic aggregation of the likelihood of potential future earthquake shaking and their resulting impacts on the built environment. In the United States, the seismic mitigation policies 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. Although hazard maps contribute to understanding earthquakes, analyzing and mapping earthquake risk in the United States would be beneficial. As urban development continues in earthquake-prone regions, there is growing concern about 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, critical infrastructure, 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 the 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. Understanding the consequences of earthquakes is critical to developing emergency operations plans for catastrophes.

This study uses Hazards U.S. (Hazus) Version 6.0, a desktop PC-based standardized tool that uses a uniform engineering-based approach to measure damages, casualties, and economic losses from earthquakes nationwide. FEMA released Hazus 6.0 in 2022 and it incorporates updates to the building valuation data using 2022 U.S. dollar values and the 2020 census, as well as enhanced geotechnical data. Appendix B contains an overview of Hazus 6.0.

## 1.2. Study Objectives and Scope

The objective of this study is to assess levels of seismic risk in the United States, Puerto Rico, and the U.S. Virgin Islands using Hazus 6.0 and nationwide data. The study updates Hazus 3.0 Estimated Annualized Earthquake Losses for the United States (FEMA, 2017; Jaiswal et al., 2015) and incorporates the 2018 updates to the USGS National Seismic Hazard Model (Petersen et al., 2020) and 2020 census data to estimate annualized economic losses, debris, shelter, and casualty estimates for all 50 states, Puerto Rico, and the U.S. Virgin Islands. Seismic risk associated with the other U.S. territories such as American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands is not included in the present investigation. This is mainly because the Hazus 6.0

software currently does not include building inventory and seismic vulnerability information for these territories.

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. The AEL accounts for the regional variations in risk. For example, the New Madrid seismic zone (NMSZ) located in southeastern Missouri, northeastern Arkansas, western Tennessee, western Kentucky and southern Illinois, is the most active seismic area in the United States east of the Rocky Mountains. The risk in the NMSZ 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 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. Although Hazus has the capability to do so, this national study is based on the potential for ground shaking only and does not include the impacts associated with potential earthquake-induced ground failure.

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, and supports the implementation of mitigation investments. 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 damage 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. Also, because it is normalized by replacement value, AELR can be directly compared across metropolitan areas, counties, or states. An AELR that decreases over time can help indicate that the losses relative to the increasing exposures are being reduced.

## 1.3. 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 6.0 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 response, as well as risk-reduction strategies.

Estimating casualties and 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 to improve life-safety and lessen the need for post-disaster shelter. Recent disasters continue to reinforce the critical nature of casualty and shelter planning. The ability to compare shelter needs for 250-year and 1,000-year return periods helps 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 Hazus versions and the 2002, 2014, and 2018 versions of the USGS seismic hazard maps for the continental United States (CONUS), 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 the 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

## 2.1. 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 on various locations at various magnitudes and frequencies. The probabilistic analyses allow for uncertainties and randomness in the occurrences of earthquakes.

To estimate average annualized loss, several hazard and building structural characteristics were input into the Hazus 6.0 earthquake model, as described in Table 2-1.

Computing AEL, 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 6.0. In the second step, the building inventory in Hazus 6.0 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 additional 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 2018 USGS National Seismic Hazard Model (NSHM) (Petersen et al., 2020), which provides 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. Similarly, the USGS 2021, 2007, and 2003 NSHMs were used for Hawaiʻi (Petersen et al., 2022), Alaska (Wesson et al., 2007), and Puerto Rico with the U.S. Virgin Islands (Mueller et al., 2003), respectively.<br>Ground motion parameters are area weighted within each census tract based on the USGS ground motion grids.<br>Ground-failure effects (liquefaction, landslide) were not included in the analyses due to the lack of a nationally consistent database. |
| Building Inventory Parameters | Basis for general building inventory exposure:<br>The National Structure Inventory (NSI) 2022 (USACE, 2022), HIFLD Open (HIFLD, 2022) and 2022 cost values derived from RSMeans data (Gordian, 2022) for all building replacement costs. Additional details for the 2022 inventory updates are available in the Hazus 6.0 Inventory Technical Manual (FEMA, 2022b). Building-related direct economic losses (structural and nonstructural damage based on replacement costs, contents damage, business inventory losses, business interruption, and rental income losses), debris, shelter, and casualties due to ground shaking were computed. Economic losses related to critical infrastructure are not included due to the lack of a nationally consistent database. |

## 2.2. 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 (http://www.usgs.gov/programs/earthquake-hazards/hazards). These were processed for compatibility with Hazus. The curves specify the average annual frequency that a level of ground motion, such as peak ground acceleration (PGA), peak ground velocity (PGV) and spectral acceleration (SA) will be exceeded in an earthquake. Examples of the USGS probabilistic hazard curves are illustrated in Figure 2-1 which shows average annual frequency of exceedance as a function of SA at 0.3 second for single points in seven major U.S. cities.

The USGS has developed these data for most regions of the United States (see Petersen et al., 2020 & 2022) 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. The 2018 USGS CONUS (Petersen et al., 2020), 2021 Hawai‘i (Petersen et al., 2022), 2007 Alaska (Wesson et al., 2007), and 2003 Puerto Rico and U.S. Virgin Islands (Mueller et al., 2003) data illustrate site-corrected 0.3 second and 1.0 second spectral ground motions for an average return period of 250 years and 1,000 years and are shown in Figures 2-2, and 2-3, respectively.

The 2018 USGS CONUS hazard curves were converted to a Hazus-compatible database of probabilistic ground shaking values available as a grid in Hazus 6.0. Note that the increases in U.S. seismic hazards due to induced seismicity are represented in the USGS 2017 one-year model (Petersen et al., 2017); however, this study does not account for earthquake risk due to induced seismicity. Probabilistic hazard data for the PGA, PGV, SA at 0.3 second (SA at 0.3), and SA at 1.0 second (SA at 1.0) were processed for each census tract for each of the eight different return periods listed in Table 2-1. Figure 2-4 compares a Hazus 6.0 seismic hazard (SA at 0.3) map for the 1,000-year return period for California to the USGS map for the same return period to illustrate that the remapping process does not substantially affect the estimated losses. To account for local site soil conditions, the USGS ground motions are computed by performing probabilistic hazard analysis for each grid point by specifying the shear wave velocity of the upper 30 meters of soils (Vs30) estimate at the grid site within the ground motion models. The Vs30 estimates are based on a global hybrid Vs30 map with a topographic-slope-based default and regional map insets (Heath et al., 2020). Notably in this update, insets based on a composite of shear wave velocity measurements and geologic data are incorporated for Utah, Oregon, and Washington. In addition, the Hawai‘i site soil amplification map was supplemented with data from Wong et al. (2011).

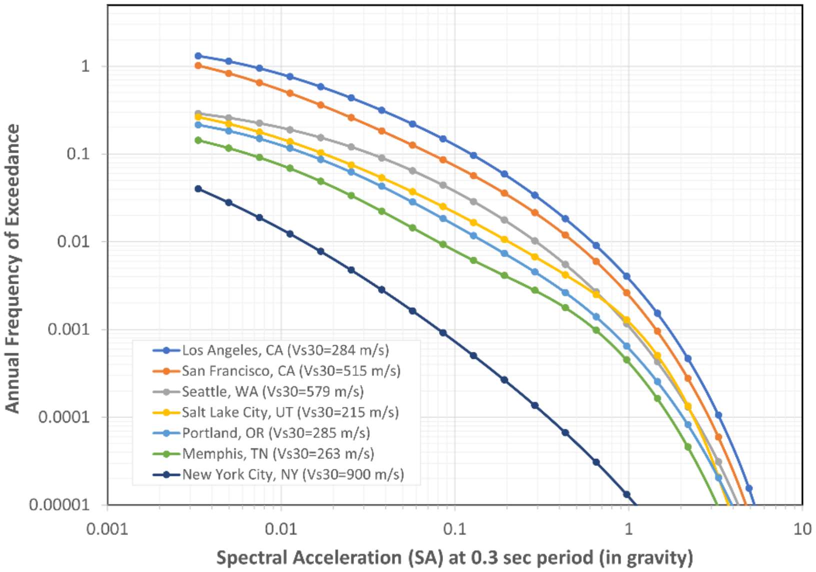
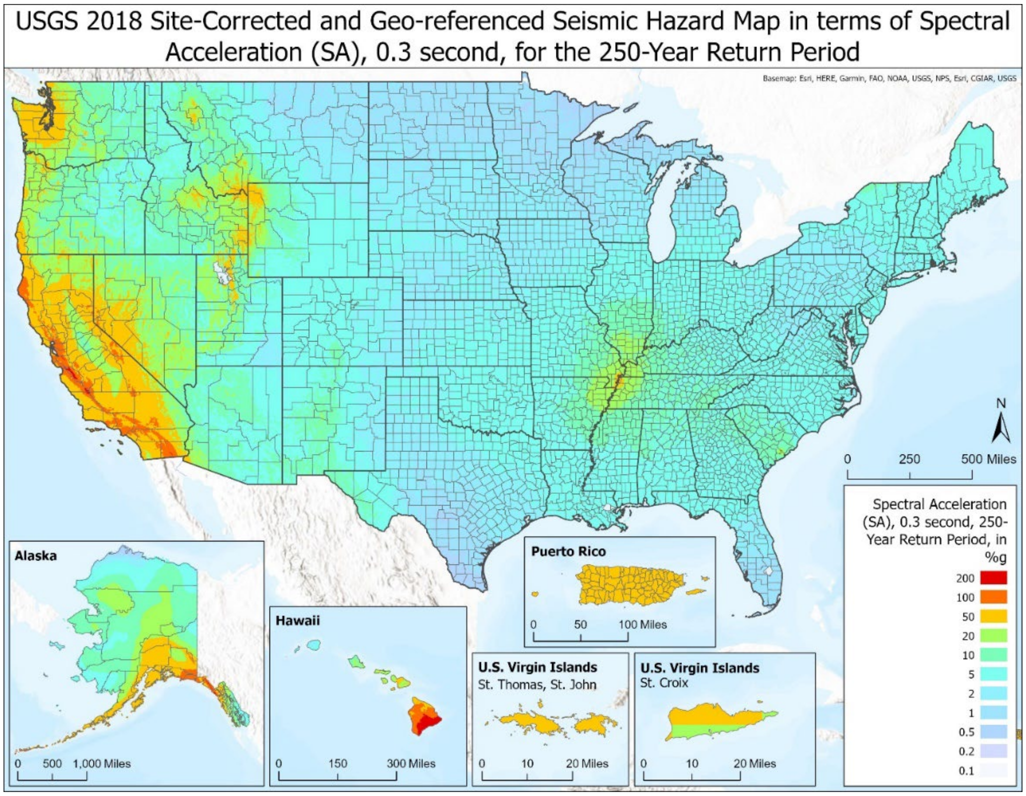


**Figure 2-1. Average Annual Frequency of Site-Corrected Spectral Acceleration (0.3 second) for Seven Major Cities.**

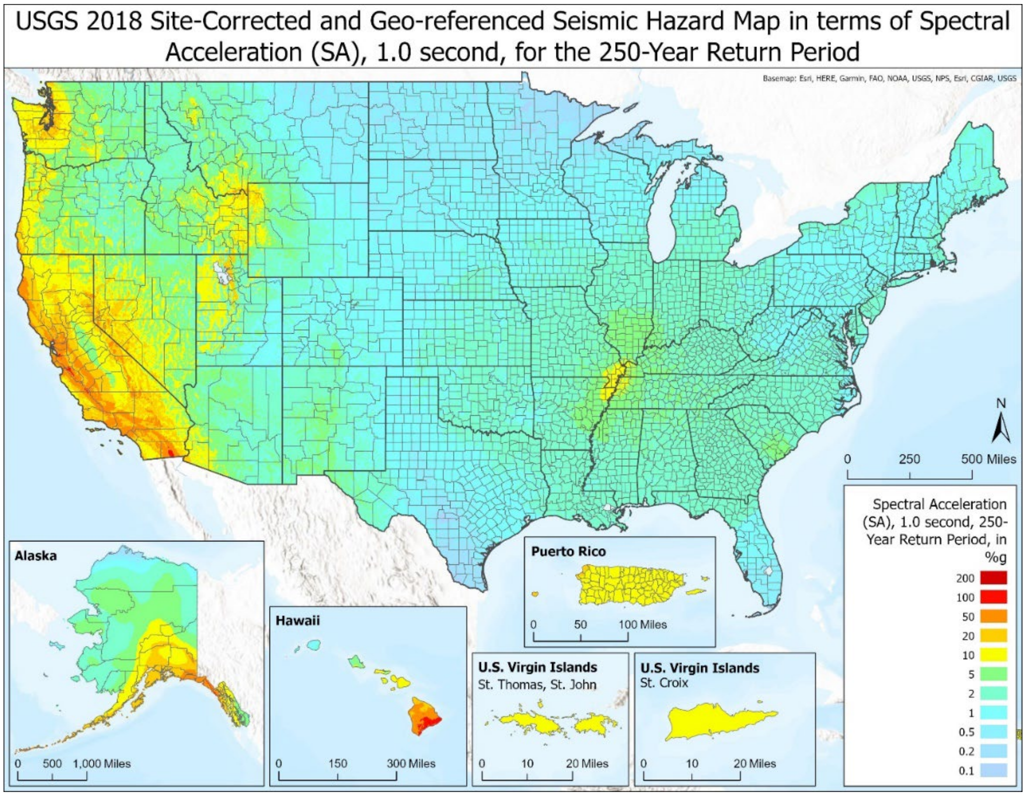
**Table 2-2. Comparison of major metro areas population and building exposure, ground-motion (spectral acceleration 0.3 seconds) and losses.**

| *Metro Area Name* | *Total Population (Census 2020)* | *Total Exposure ($Millions)* | *SA03 250-Year Event* | *SA03 1,000-Year Event* | *AEL ($Million)* |
|---|---|---|---|---|---|
| Los Angeles-Long Beach-Anaheim, California | 13,200,998 | 3,571,639 | 0.9758 | 1.7028 | 3,331 |
| San Francisco-Oakland-Berkeley, California | 4,749,008 | 1,572,151 | 0.7978 | 1.4383 | 1,795 |
| Seattle-Tacoma-Bellevue, Washington | 4,018,762 | 1,321,065 | 0.5221 | 1.0348 | 781 |
| Portland-Vancouver-Hillsboro, Oregon-Washington | 2,512,859 | 837,148 | 0.3177 | 0.781 | 403 |
| Salt Lake City, Utah | 1,257,936 | 321,716 | 0.4484 | 1.0986 | 174 |
| Memphis, Tennessee-Mississippi-Arkansas | 1,337,779 | 432,733 | 0.1989 | 0.6421 | 131 |
| New York-Newark-Jersey City, New York-New Jersey-Pennsylvania | 20,140,470 | 5,466,580 | 0.029 | 0.0808 | 49 |



USGS 2018 Site-Corrected and Geo-referenced Seismic Hazard Map in terms of Spectral Acceleration (SA), 0.3 second, for the 250-Year Return Period

Basemap: Esri, HERE, Garmin, FAO, NOAA, USGS, NPS, Esri, CGIAR, USGS



USGS 2018 Site-Corrected and Geo-referenced Seismic Hazard Map in terms of Spectral Acceleration (SA), 1.0 second, for the 250-Year Return Period

Basemap: Esri, HERE, Garmin, FAO, NOAA, USGS, NPS, Esri, CGIAR, USGS

**Figure 2-2. USGS 2018 Site-Corrected and Georeferenced Seismic Hazard Map in terms of spectral acceleration at 0.3 (Top) and 1.0 second (Bottom) for the 250-year Return Period.**

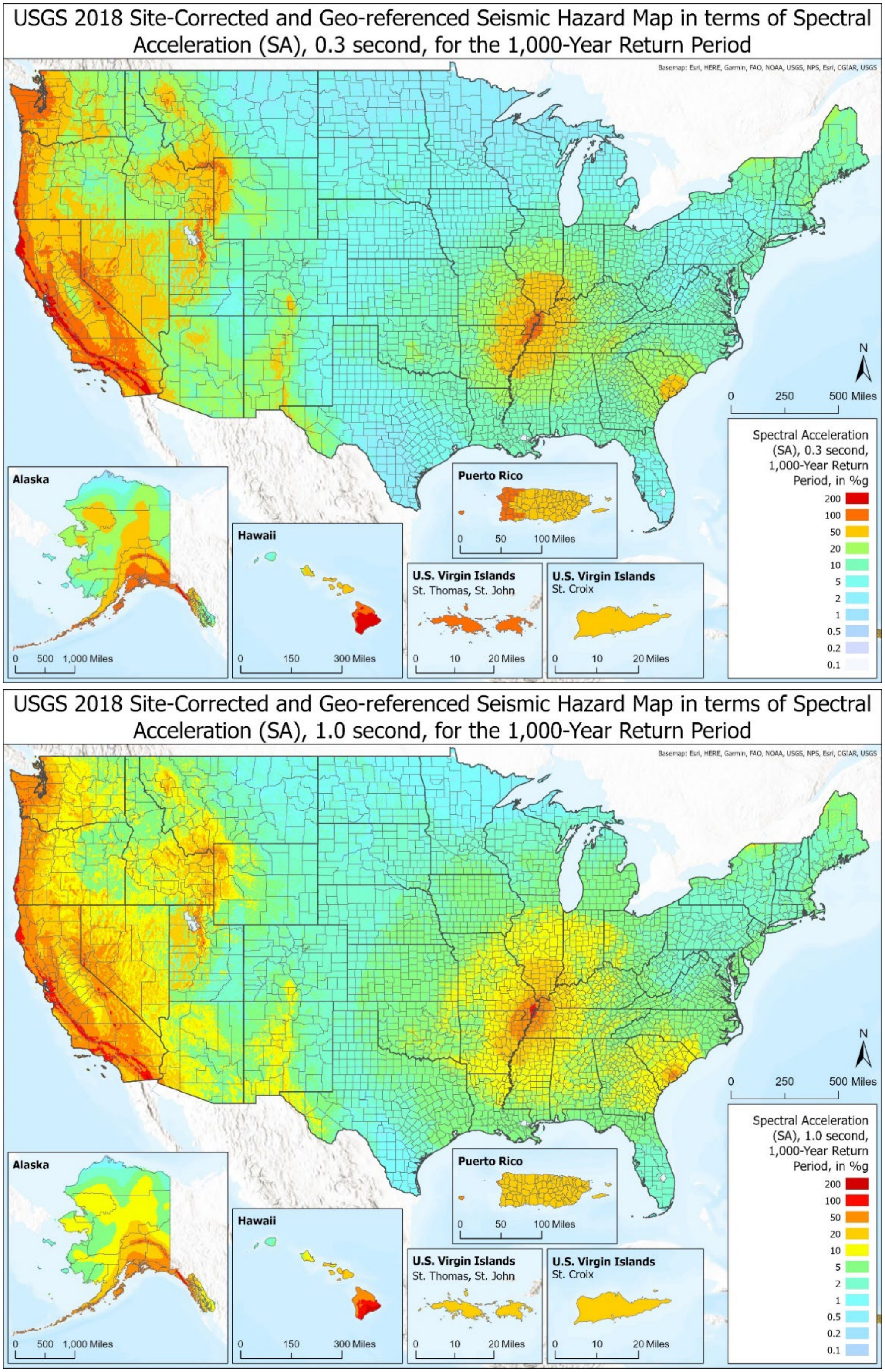


**Figure 2-3. USGS 2018 Site-Corrected and Geo-referenced Seismic Hazard Map in terms of spectral acceleration at 0.3 (Top) and 1.0 second (Bottom) for the 1,000-year Return Period.**

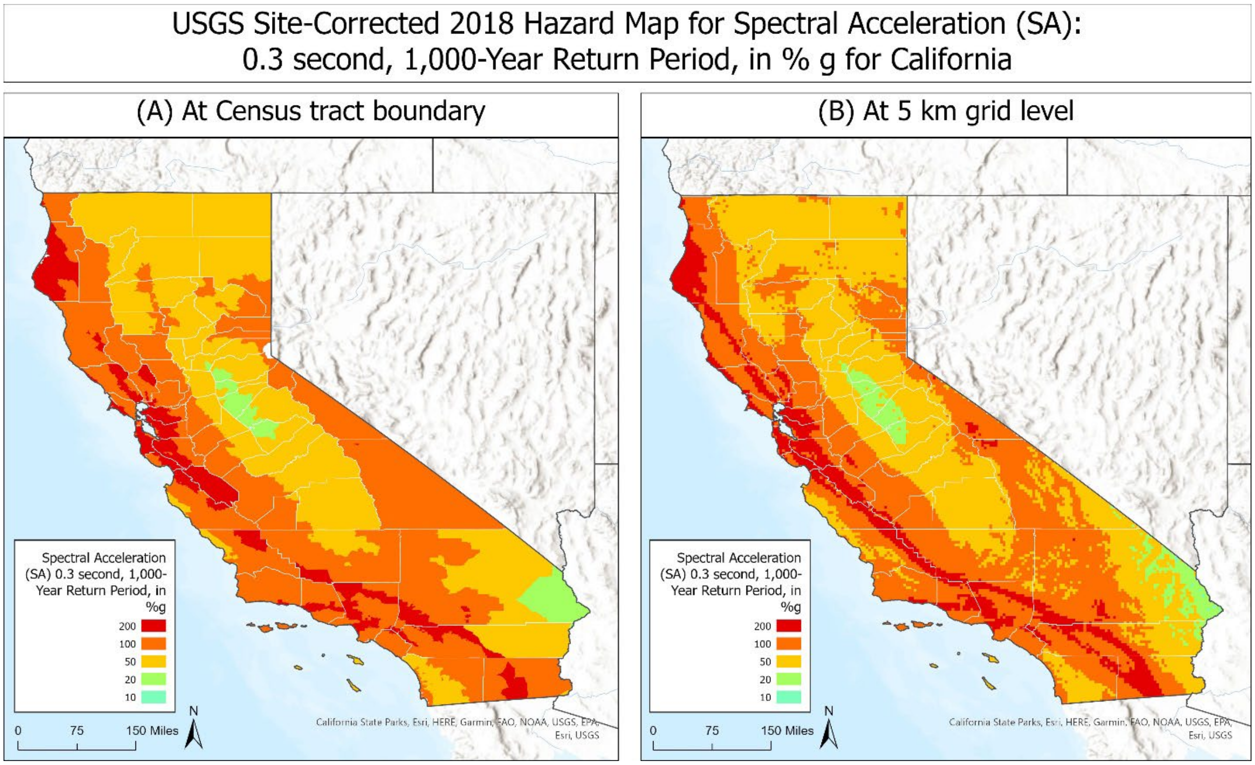


**Figure 2-4. USGS Site-Corrected Seismic Hazard Map for Spectral Acceleration (SA) 0.3 second, 1,000 Year Return Period in % g for California: (A) at the Census Tract Level, (B) at the 5-km Grid Level.**

## 2.3. 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 85,229 census tracts in the United States. These building-related losses serve as a reasonable indicator of relative regional risk, as described in Appendix B.

Damage and economic losses to critical facilities, transportation, and utility lifelines were not considered in this study. Although 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 are included for each county. A map illustrating the replacement value of buildings (by county) is shown in Figure 2-5. The replacement value 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 2-6 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.

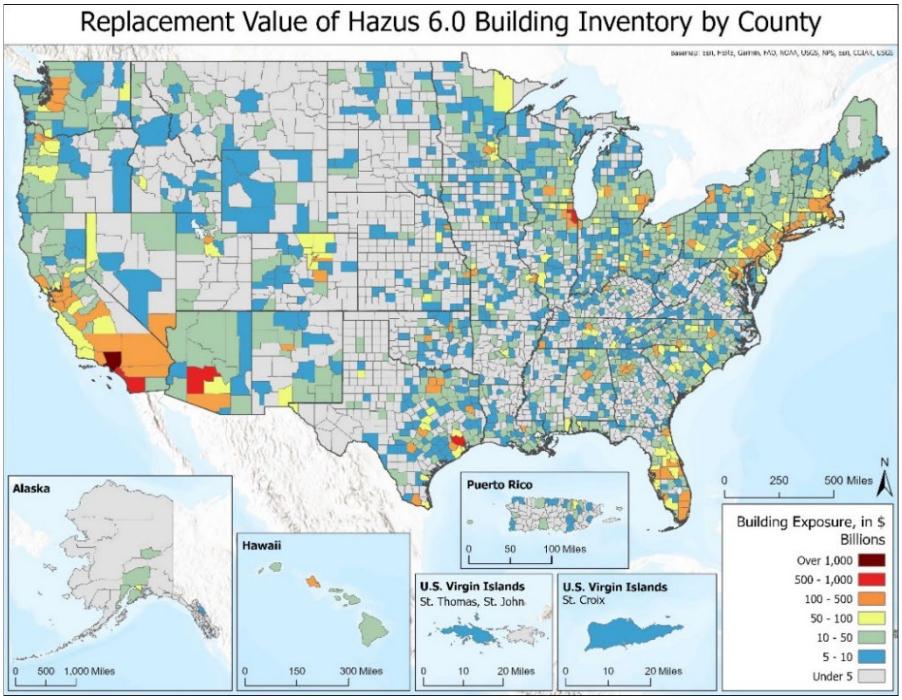


**Figure 2-5. Replacement Value of Hazus 6.0 Building Inventory by County.**

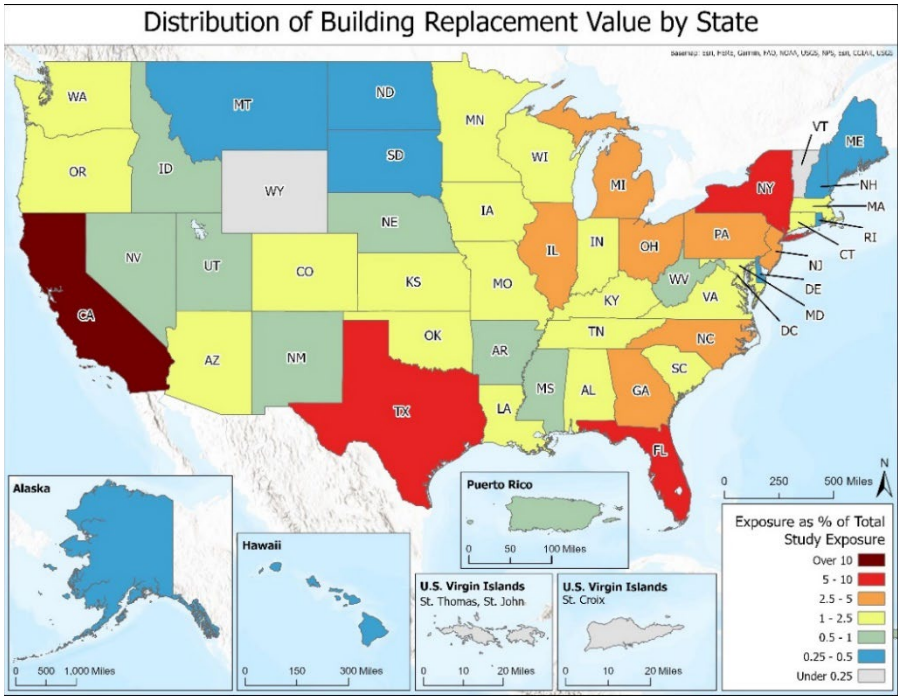


**Figure 2-6. Distribution of Building Replacement Value by State.**

**Table 2-3. Structural Exposure, Nonstructural Exposure, Contents Exposure and Total Exposure by State (in $millions, ranked by total exposure).**

| *Rank* | *State* | *Structural Exposure ($million)* | *Nonstructural Exposure ($million)* | *Content Exposure ($million)* | *Total Exposure ($million)* |
|---|---|---|---|---|---|
| 1 | California | 1,415,561 | 5,482,796 | 4,992,829 | 11,891,186 |
| 2 | Texas | 1,044,289 | 3,789,344 | 3,596,553 | 8,430,186 |
| 3 | New York | 652,015 | 2,693,171 | 2,385,084 | 5,730,270 |
| 4 | Florida | 676,331 | 2,577,206 | 2,290,426 | 5,543,962 |
| 5 | Pennsylvania | 580,397 | 2,131,703 | 2,006,215 | 4,718,315 |
| 6 | Illinois | 578,247 | 2,106,248 | 1,941,122 | 4,625,617 |
| 7 | Ohio | 513,622 | 1,867,946 | 1,816,746 | 4,198,313 |
| 8 | Michigan | 432,638 | 1,621,295 | 1,509,922 | 3,563,855 |
| 9 | Georgia | 415,678 | 1,578,095 | 1,456,246 | 3,450,020 |
| 10 | North Carolina | 425,970 | 1,581,511 | 1,435,538 | 3,443,020 |
| 11 | New Jersey | 370,757 | 1,383,896 | 1,275,777 | 3,030,429 |
| 12 | Virginia | 307,350 | 1,168,136 | 1,059,910 | 2,535,395 |
| 13 | Washington | 303,974 | 1,161,973 | 1,061,313 | 2,527,260 |
| 14 | Wisconsin | 304,119 | 1,115,544 | 1,012,881 | 2,432,543 |
| 15 | Indiana | 287,346 | 1,083,606 | 1,048,187 | 2,419,139 |
| 16 | Minnesota | 278,380 | 1,038,784 | 979,137 | 2,296,301 |
| 17 | Missouri | 278,587 | 1,037,357 | 957,877 | 2,273,821 |
| 18 | Massachusetts | 254,285 | 1,020,221 | 941,155 | 2,215,662 |
| 19 | Tennessee | 254,467 | 954,757 | 898,981 | 2,108,205 |
| 20 | Arizona | 252,503 | 958,244 | 847,725 | 2,058,472 |
| 21 | Colorado | 218,751 | 816,362 | 732,214 | 1,767,327 |
| 22 | Maryland | 215,541 | 819,077 | 725,035 | 1,759,652 |
| 23 | South Carolina | 211,983 | 801,354 | 710,716 | 1,724,053 |
| 24 | Alabama | 192,577 | 738,702 | 701,381 | 1,632,660 |

| *Rank* | *State* | *Structural Exposure ($million)* | *Nonstructural Exposure ($million)* | *Content Exposure ($million)* | *Total Exposure ($million)* |
|---|---|---|---|---|---|
| 25 | Oregon | 190,231 | 709,418 | 660,870 | 1,560,520 |
| 26 | Kentucky | 187,503 | 657,495 | 636,801 | 1,481,798 |
| 27 | Louisiana | 176,704 | 660,814 | 595,050 | 1,432,567 |
| 28 | Iowa | 161,299 | 597,231 | 564,671 | 1,323,201 |
| 29 | Connecticut | 145,108 | 561,133 | 514,726 | 1,220,967 |
| 30 | Kansas | 148,818 | 524,733 | 531,811 | 1,205,362 |
| 31 | Oklahoma | 135,180 | 501,033 | 476,963 | 1,113,176 |
| 32 | Nevada | 115,913 | 443,732 | 396,810 | 956,456 |
| 33 | Mississippi | 113,298 | 417,644 | 407,591 | 938,532 |
| 34 | Arkansas | 114,841 | 416,801 | 403,286 | 934,927 |
| 35 | Utah | 106,332 | 393,774 | 373,795 | 873,900 |
| 36 | New Mexico | 87,515 | 353,985 | 297,315 | 738,815 |
| 37 | Puerto Rico | 89,373 | 369,791 | 259,253 | 718,417 |
| 38 | District of Columbia | 66,704 | 318,476 | 327,624 | 712,805 |
| 39 | Nebraska | 88,047 | 322,380 | 298,216 | 708,643 |
| 40 | Idaho | 81,439 | 283,675 | 269,533 | 634,647 |
| 41 | West Virginia | 77,189 | 281,205 | 268,362 | 626,756 |
| 42 | Maine | 58,056 | 224,770 | 203,361 | 486,187 |
| 43 | Montana | 65,651 | 203,753 | 204,739 | 474,143 |
| 44 | South Dakota | 62,088 | 201,574 | 194,287 | 457,949 |
| 45 | New Hampshire | 52,580 | 207,185 | 196,047 | 455,811 |
| 46 | North Dakota | 60,885 | 184,715 | 196,417 | 442,017 |
| 47 | Hawai‘i | 44,257 | 183,605 | 158,267 | 386,129 |
| 48 | Delaware | 47,418 | 173,810 | 157,172 | 378,400 |
| 49 | Rhode Island | 38,102 | 151,677 | 140,979 | 330,758 |

| *Rank* | *State* | *Structural Exposure ($million)* | *Nonstructural Exposure ($million)* | *Content Exposure ($million)* | *Total Exposure ($million)* |
|---|---|---|---|---|---|
| 50 | Alaska | 36,263 | 142,803 | 129,166 | 308,232 |
| 51 | Vermont | 33,004 | 122,111 | 110,465 | 265,579 |
| 52 | Wyoming | 27,728 | 105,513 | 101,740 | 234,981 |
| 53 | U.S. Virgin Islands | 4,037 | 16,002 | 14,519 | 34,558 |

## 2.4. Step Three: Compute the Average Annualized Earthquake Loss

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, 2008).

## 2.5. Step Four: Compute the Average Annualized Earthquake Loss Ratios

The AEL is an objective measure of risk; however, because 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 influence 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, because annualized loss is expressed as a fraction of the building replacement value. For example, while Charleston, South Carolina, has a smaller AEL than Memphis, Tennessee ($119.4 million versus $131.1 million) (see Table 3.2), the former has a higher earthquake loss ratio ($477.1 versus $302.8) expressed in dollars per million dollars of exposure, because Charleston has less building inventory and building replacement value.

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

The Hazus 6.0 software can directly compute annualized casualty estimates. However, this automated capability does not exist for annualized debris and shelter estimates. In the present investigation, Hazus 6.0 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 (Kircher et al., 1997). This method does not include casualties that might occur during or after earthquakes that are not related to damaged buildings. These casualties can include 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. The Hazus shelter module supports the ability to consider age, ethnicity, income, and home ownership in estimating the rates that individuals from displaced households seek public shelter. By default, in Hazus 6.0 and this study, only income is used.

## 2.7. Study Limitations

The estimates provided by this study are not determinations of total risk because 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 critical facilities, as well as indirect economic losses sustained by communities and regions. Indirect economic losses may include losses due to changes in demand and supply of products, changes in employment, and changes in tax revenues.

There are also inherent uncertainties in computing losses using estimated building values, averaged building characteristics, spatial averaging of ground conditions such as soil response and ground motion across 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 for basins that are not included in the current USGS hazard model. For example, Field et al. (2020) demonstrates the influence of hazard model related uncertainties in estimating average annual loss in California.

The occurrence of a large earthquake in any given region may influence the likelihood of subsequent earthquakes (i.e., time dependence) and their associated impacts (e.g., change in vulnerability). The assumptions within the current methodology regarding building vulnerability may not be reflective of the latest code adoption and enforcement within a given jurisdiction. Further improvements maybe needed to accurately reflect the seismic vulnerability of new buildings.

These variables warrant consideration when comparing the results of other loss studies based on Hazus or other methodologies.

# 3. Results of the Study

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

## 3.1 Nation

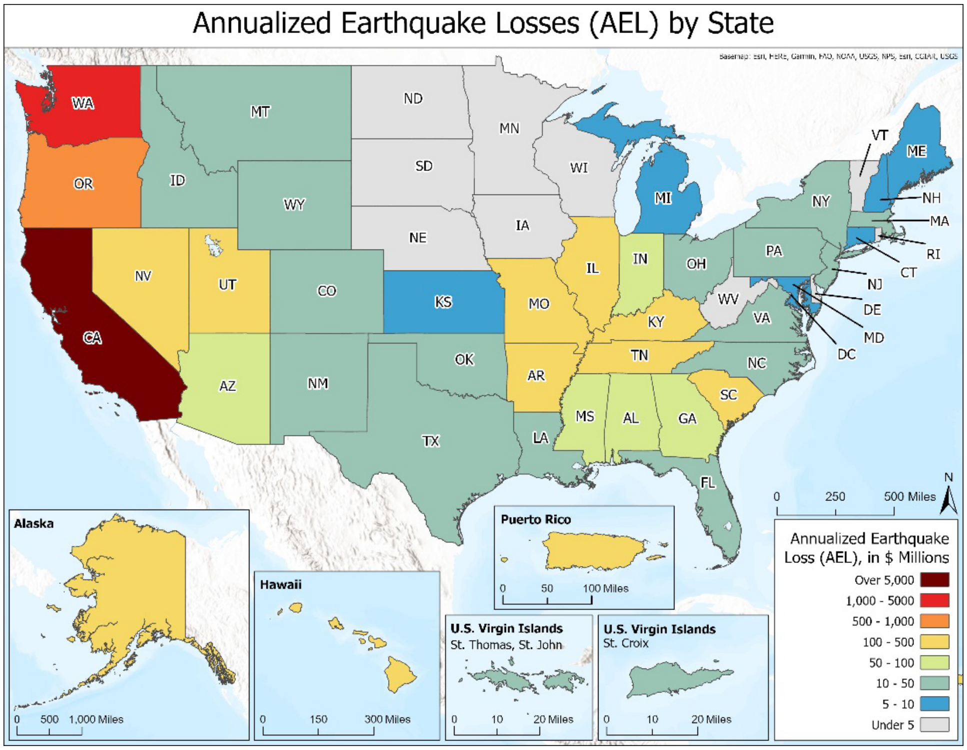
The analysis yielded an estimate of the national AEL as $14.7 billion per year. As previously stated, this does not include losses to lifeline infrastructure or indirect (long-term) economic losses, nor does it consider the risk/loss associated with induced seismicity; therefore, the AEL is a minimum 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.

## 3.2 States and Counties

Although 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 relative seismic risk severity between regions.

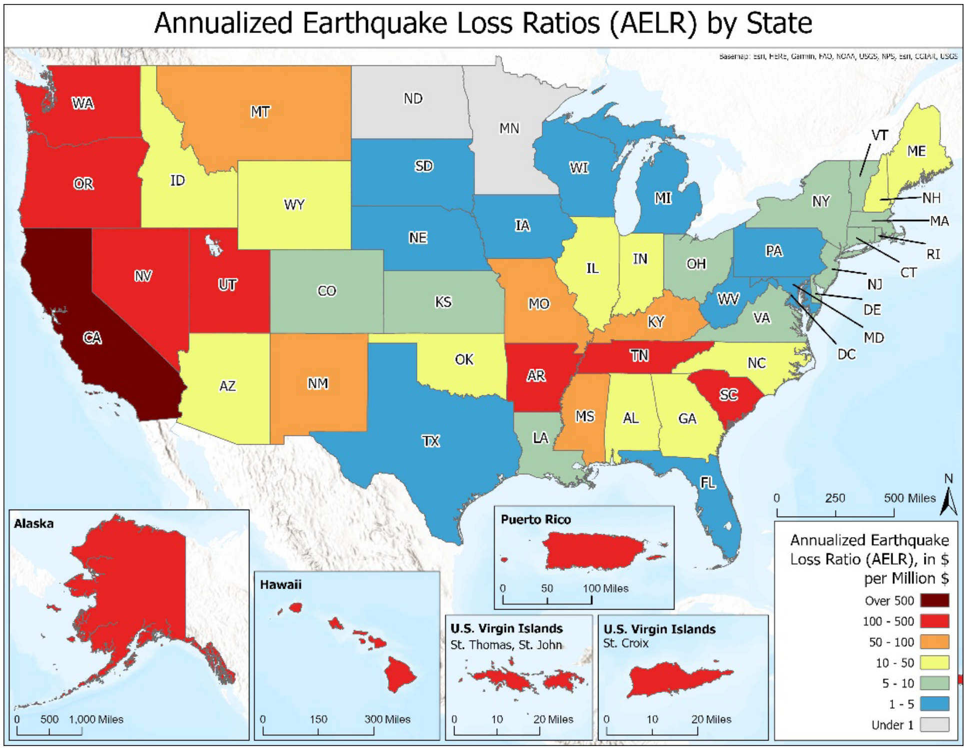
Figures 3-1 and 3-2 show the AEL and the AELR at the state level, and Figures 3-3 and 3-4 show the results at the county level. Relatively high earthquake-loss ratios exist throughout the western United States (including Alaska and Hawai‘i), the central U.S. states within the NMSZ, the Charleston, South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

Seventy-eight percent ($11.6 billion) of the national annualized losses occur in California, Oregon, and Washington. About 65% ($9.6 billion) of the national annualized losses 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 3-2 and 3-4).



Annualized Earthquake Losses (AEL) by State

**Figure 3-1. Annualized Earthquake Losses by State.**



Annualized Earthquake Loss Ratios (AELR) by State

**Figure 3-2. Annualized Earthquake Loss Ratios (AELR) by State.**

AEL and AELR values for the 50 states, Washington, D.C., Puerto Rico, and the U.S. Virgin Islands are shown in Table 3-1. Although California accounts for most of the losses, the regional distribution of annualized loss and loss ratios demonstrates that seismic risk is a national concern. The juxtaposition of New York and New Mexico 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., New Mexico).

Comparing the rankings of individual states and territories in the AEL and AELR columns of Table 3-1 shows that California and the Pacific Northwest region retain a high relative standing. Most of the states with the highest AELRs are in the western United States, whereas other significant concentrations occur in the Southeast (South Carolina), the central United States (Tennessee and Arkansas), and Caribbean (Puerto Rico and the U.S. Virgin Islands).

Figure 3-3 helps illustrate that the southern California coastal counties and Bay Area dominate the losses in California. Los Angeles County with $2.68 billion in annualized losses is more than three times greater than the second highest county (Santa Clara, California). The counties containing the Seattle, Portland, Salt Lake, and Memphis metropolitan areas also have relatively high AELs. Figure 3-4 illustrates when losses are normalized by total exposure (AELR), more rural counties such as Hawai‘i County, Hawai‘i , as well as coastal northern California, Oregon, and Washington counties, as well as counties in the NMSZ region rank relatively high. Urban counties in California such as Los Angeles rank very high in both AEL and AELR.

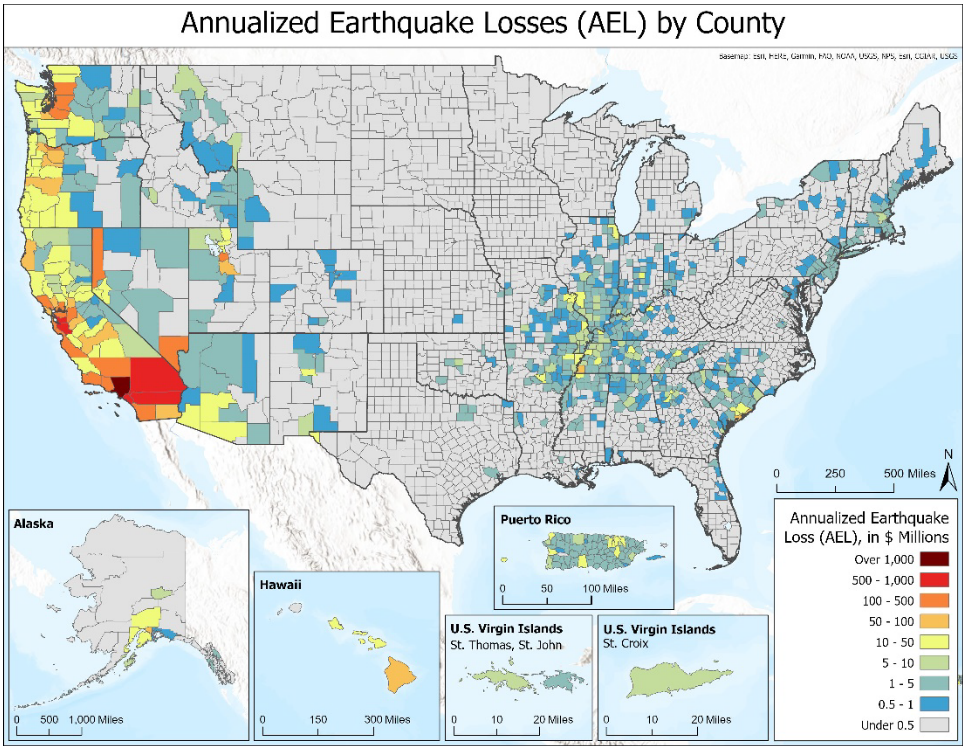


**Figure 3-3. Annualized Earthquake Losses (AEL) by County.**

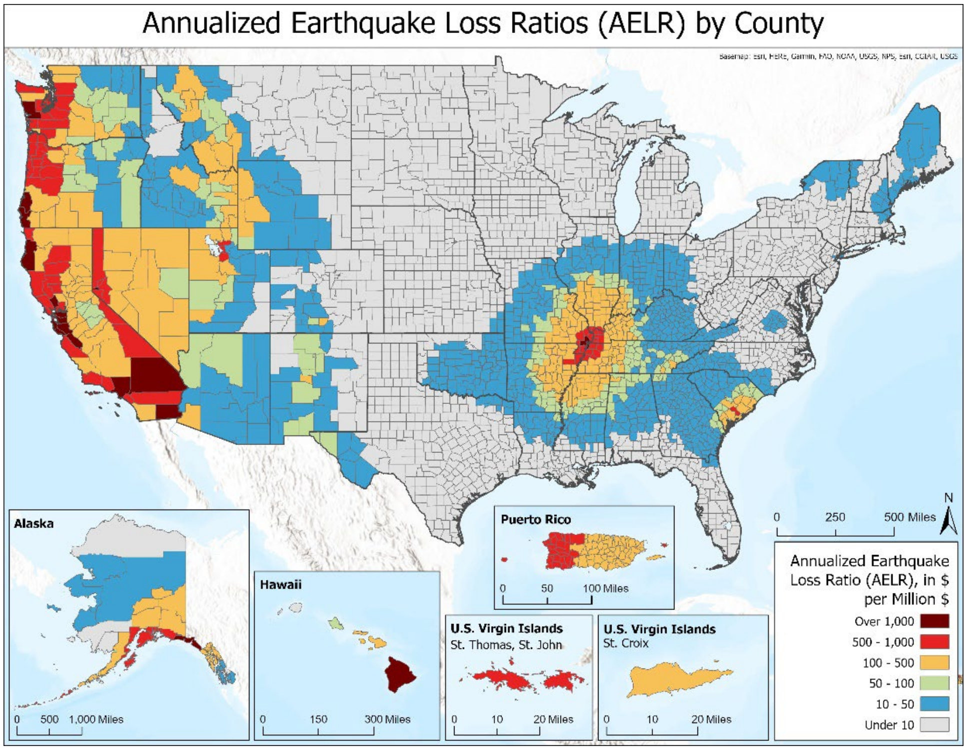


Figure 3-4. Annualized Earthquake Loss Ratios (AELR) by County.

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

| *Rank* | *State* | *AEL ($ x 1,000)* |
|---|---|---|
| 1 | California | 9,614,544 |
| 2 | Washington | 1,191,743 |
| 3 | Oregon | 744,979 |
| 4 | Utah | 366,714 |
| 5 | Puerto Rico | 326,809 |
| 6 | Nevada | 297,403 |
| 7 | Tennessee | 284,250 |
| 8 | South Carolina | 193,976 |
| 9 | Missouri | 188,476 |
| 10 | Illinois | 178,825 |
| 11 | Hawaiʻi | 126,956 |
| 12 | Alaska | 120,717 |
| 13 | Arkansas | 116,006 |
| 14 | Kentucky | 110,538 |
| 15 | Indiana | 87,362 |
| 16 | Georgia | 87,225 |
| 17 | Arizona | 86,095 |
| 18 | Mississippi | 69,937 |
| 19 | Alabama | 51,361 |
| 20 | New York | 45,353 |
| 21 | New Mexico | 41,071 |
| 22 | North Carolina | 36,133 |
| 23 | Texas | 35,610 |
| 24 | Ohio | 32,917 |
| 25 | Montana | 32,379 |
| 26 | Idaho | 26,898 |
| 27 | Oklahoma | 24,532 |
| 28 | New Jersey | 24,277 |

| *Rank* | *State* | *AELR ($/million $)* |
|---|---|---|
| 1 | California | 808.5 |
| 2 | Oregon | 477.4 |
| 3 | Washington | 471.6 |
| 4 | Puerto Rico | 454.7 |
| 5 | U.S. Virgin Islands | 451.3 |
| 6 | Utah | 419.6 |
| 7 | Alaska | 391.6 |
| 8 | Hawaiʻi | 328.8 |
| 9 | Nevada | 310.9 |
| 10 | Tennessee | 134.8 |
| 11 | Arkansas | 124.1 |
| 12 | South Carolina | 112.5 |
| 13 | Missouri | 82.9 |
| 14 | Kentucky | 74.6 |
| 15 | Mississippi | 74.5 |
| 16 | Montana | 68.3 |
| 17 | New Mexico | 55.6 |
| 18 | Wyoming | 46.6 |
| 19 | Idaho | 42.4 |
| 20 | Arizona | 41.8 |
| 21 | Illinois | 38.7 |
| 22 | Indiana | 36.1 |
| 23 | Alabama | 31.5 |
| 24 | Georgia | 25.3 |
| 25 | Oklahoma | 22.0 |
| 26 | New Hampshire | 15.2 |
| 27 | Maine | 14.1 |
| 28 | North Carolina | 10.5 |

| Rank | State | AEL ($ x 1,000) |
|---|---|---|
| 29 | Massachusetts | 21,642 |
| 30 | Pennsylvania | 17,360 |
| 31 | Virginia | 16,495 |
| 32 | U.S. Virgin Islands | 15,594 |
| 33 | Florida | 13,047 |
| 34 | Colorado | 11,919 |
| 35 | Louisiana | 11,499 |
| 36 | Wyoming | 10,956 |
| 37 | Michigan | 9,113 |
| 38 | New Hampshire | 6,932 |
| 39 | Maine | 6,851 |
| 40 | Kansas | 6,528 |
| 41 | Connecticut | 6,324 |
| 42 | Maryland | 6,171 |
| 43 | Iowa | 3,315 |
| 44 | Wisconsin | 2,929 |
| 45 | West Virginia | 2,855 |
| 46 | District of Columbia | 2,523 |
| 47 | Vermont | 2,440 |
| 48 | Delaware | 2,096 |
| 49 | Rhode Island | 1,671 |
| 50 | Nebraska | 1,082 |
| 51 | South Dakota | 661 |
| 52 | Minnesota | 612 |
| 53 | North Dakota | 132 |

| Rank | State | AELR ($/million $) |
|---|---|---|
| 29 | Massachusetts | 9.8 |
| 30 | Vermont | 9.2 |
| 31 | Louisiana | 8.0 |
| 32 | New Jersey | 8.0 |
| 33 | New York | 7.9 |
| 34 | Ohio | 7.8 |
| 35 | Colorado | 6.7 |
| 36 | Virginia | 6.5 |
| 37 | Delaware | 5.5 |
| 38 | Kansas | 5.4 |
| 39 | Connecticut | 5.2 |
| 40 | Rhode Island | 5.1 |
| 41 | West Virginia | 4.6 |
| 42 | Texas | 4.2 |
| 43 | Pennsylvania | 3.7 |
| 44 | District of Columbia | 3.5 |
| 45 | Maryland | 3.5 |
| 46 | Michigan | 2.6 |
| 47 | Iowa | 2.5 |
| 48 | Florida | 2.4 |
| 49 | Nebraska | 1.5 |
| 50 | South Dakota | 1.4 |
| 51 | Wisconsin | 1.2 |
| 52 | North Dakota | 0.3 |
| 53 | Minnesota | 0.3 |

## 3.3 Region

Figure 3-5 shows the distribution of AEL by generalized seismic regions. California, Washington, and Oregon account for $11.6 billion in estimated annualized earthquake losses, or 78% of the United States total. The remaining 22% of estimated annualized losses are distributed across the central United States ($1.10 billion), the northeastern states ($180 million), the Rocky Mountain/Basin and

Range region ($870 million), the Great Plains ($90 million), and the Southeast ($350 million). The states of Hawai‘i and Alaska have a combined AEL of $250 million, and the Caribbean has a combined AEL of $340 million.

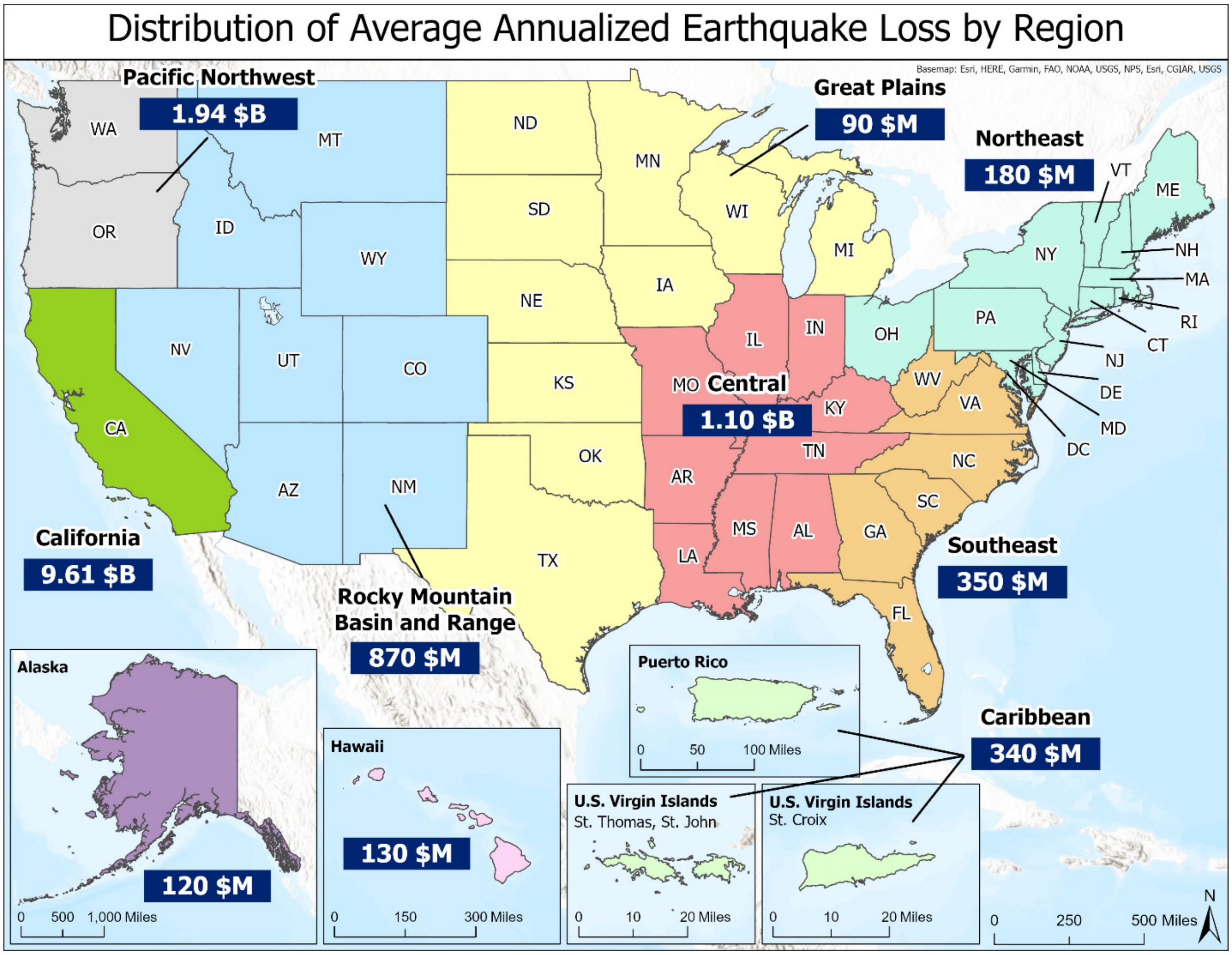


**Figure 3.5. Distribution of Average Annualized Earthquake Loss by Region.**

## 3.4 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, 2020). Metropolitan areas with annualized losses greater than $10 million are listed in Table 3-2.

These 87 metropolitan areas, led by the Los Angeles and San Francisco Bay areas, account for 87% of the total annualized losses in the United States. Los Angeles alone accounts for 23% of the national figure. Annualized earthquake loss values for selected metropolitan areas are listed alphabetically in Tables 3-2 and 3-3 and shown in Figures 3-6 and 3-7.

When losses for the 87 metropolitan areas are expressed as a fraction of total building value in the AELR column of Table 3-4, several cities rise in the rankings, notably El Centro, California, San Jose-

Sunnyvale-Santa Clara, California, and Carson City, Nevada. Again, this is a reflection of high seismic hazard and lower relative value of building inventory.

**Table 3-2. Metropolitan Areas (listed alphabetically) with Annualized Earthquake Losses Greater than $10 Million**

| *Map #* | *Metropolitan Area* | *AEL ($million)* | *Map #* | *Metropolitan Area* | *AEL ($million)* |
|---|---|---|---|---|---|
| 1 | Aguadilla-Isabela, Puerto Rico | 38.3 | 45 | Medford, Oregon | 28.4 |
| 2 | Albany-Lebanon, Oregon | 26.2 | 46 | Memphis, Tennessee-Mississippi-Arkansas | 131.1 |
| 3 | Albuquerque, New Mexico | 25.1 | 47 | Merced, California | 35.6 |
| 4 | Anchorage, Alaska | 81.6 | 48 | Modesto, California | 55.4 |
| 5 | Arecibo, Puerto Rico | 19.5 | 49 | Mount Vernon-Anacortes, Washington | 18.2 |
| 6 | Atlanta-Sandy Springs-Alpharetta, Georgia | 42.2 | 50 | Napa, California | 60.8 |
| 7 | Bakersfield, California | 125.3 | 51 | Nashville-Davidson--Murfreesboro--Franklin, Tennessee | 48.1 |
| 8 | Bellingham, Washington | 27.1 | 52 | New York-Newark-Jersey City, New York-New Jersey-Pennsylvania | 48.8 |
| 9 | Birmingham-Hoover, Alabama | 10.9 | 53 | Ogden-Clearfield, Utah | 94.3 |
| 10 | Boston-Cambridge-Newton, Massachusetts-New Hampshire | 19.5 | 54 | Oklahoma City, Oklahoma | 12.3 |
| 11 | Bremerton-Silverdale-Port Orchard, Washington | 53.1 | 55 | Olympia-Lacey-Tumwater, Washington | 65.9 |
| 12 | Cape Girardeau, Missouri-Illinois | 13.7 | 56 | Oxnard-Thousand Oaks-Ventura, California | 220.0 |
| 13 | Carbondale-Marion, Illinois | 19.7 | 57 | Philadelphia-Camden-Wilmington, Pennsylvania-New Jersey-Deleware-Maryland | 15.3 |

| Map # | Metropolitan Area | AEL ($million) | Map # | Metropolitan Area | AEL ($million) |
|---|---|---|---|---|---|
| 14 | Carson City, Nevada | 21.4 | 58 | Phoenix-Mesa-Chandler, Arizona | 40.1 |
| 15 | Charleston-North Charleston, South Carolina | 119.4 | 59 | Ponce, Puerto Rico | 19.7 |
| 16 | Charlotte-Concord-Gastonia, North Carolina-South Carolina | 15.0 | 60 | Portland-Vancouver-Hillsboro, Oregon-Washington | 402.8 |
| 17 | Chattanooga, Tennessee-Georgia | 11.8 | 61 | Provo-Orem, Utah | 74.4 |
| 18 | Chicago-Naperville-Elgin, Illinois-Indiana-Wisconsin | 27.5 | 62 | Redding, California | 43.3 |
| 19 | Chico, California | 32.7 | 63 | Reno, Nevada | 122.7 |
| 20 | Cincinnati, Ohio-Kentucky-Indiana | 10.4 | 64 | Riverside-San Bernardino-Ontario, California | 1341.8 |
| 21 | Clarksville, Tennessee-Kentucky | 12.9 | 65 | Sacramento-Roseville-Folsom, California | 153.8 |
| 22 | Columbia, South Carolina | 12.1 | 66 | St. Louis, Missouri-Illinois | 132.4 |
| 23 | Corvallis, Oregon | 24.8 | 67 | Salem, Oregon | 78.7 |
| 24 | El Centro, California | 92.7 | 68 | Salinas, California | 113.4 |
| 25 | El Paso, Texas | 14.6 | 69 | Salt Lake City, Utah | 173.6 |
| 26 | Eugene-Springfield, Oregon | 72.2 | 70 | San Diego-Chula Vista-Carlsbad, California | 284.5 |
| 27 | Evansville, Indiana-Kentucky | 24.4 | 71 | San Francisco-Oakland-Berkeley, California | 1794.9 |
| 28 | Fresno, California | 70.2 | 72 | San Germán, Puerto Rico | 13.4 |
| 29 | Grants Pass, Oregon | 10.7 | 73 | San Jose-Sunnyvale-Santa Clara, California | 917.0 |
| 30 | Greenville-Anderson, South Carolina | 10.7 | 74 | San Juan-Bayamón-Caguas, Puerto Rico | 200.9 |
| 31 | Hanford-Corcoran, California | 14.4 | 75 | San Luis Obispo-Paso Robles, California | 38.4 |

| Map # | Metropolitan Area | AEL ($million) | Map # | Metropolitan Area | AEL ($million) |
|---|---|---|---|---|---|
| 32 | Indianapolis-Carmel-Anderson, Indiana | 22.4 | 76 | Santa Cruz-Watsonville, California | 110.1 |
| 33 | Jackson, Tennessee | 26.1 | 77 | Santa Maria-Santa Barbara, California | 100.2 |
| 34 | Jonesboro, Arkansas | 18.9 | 78 | Santa Rosa-Petaluma, California | 178.7 |
| 35 | Kahului-Wailuku-Lahaina, Hawai'i | 13.7 | 79 | Seattle-Tacoma-Bellevue, Washington | 781.4 |
| 36 | Knoxville, Tennessee | 18.3 | 80 | Stockton, California | 108.4 |
| 37 | Las Vegas-Henderson-Paradise, Nevada | 112.7 | 81 | Tucson, Arizona | 11.4 |
| 38 | Little Rock-North Little Rock-Conway, Arkansas | 23.4 | 82 | Urban Honolulu, Hawai'i | 24.2 |
| 39 | Logan, Utah-Idaho | 16.2 | 83 | Vallejo, California | 122.3 |
| 40 | Longview, Washington | 25.6 | 84 | Visalia, California | 27.6 |
| 41 | Los Angeles-Long Beach-Anaheim, California | 3330.9 | 85 | Yakima, Washington | 16.6 |
| 42 | Louisville/Jefferson County, Kentucky-Indiana | 17.8 | 86 | Yuba City, California | 20.2 |
| 43 | Madera, California | 10.7 | 87 | Yuma, Arizona | 19.7 |
| 44 | Mayagüez, Puerto Rico | 13.6 | | | |

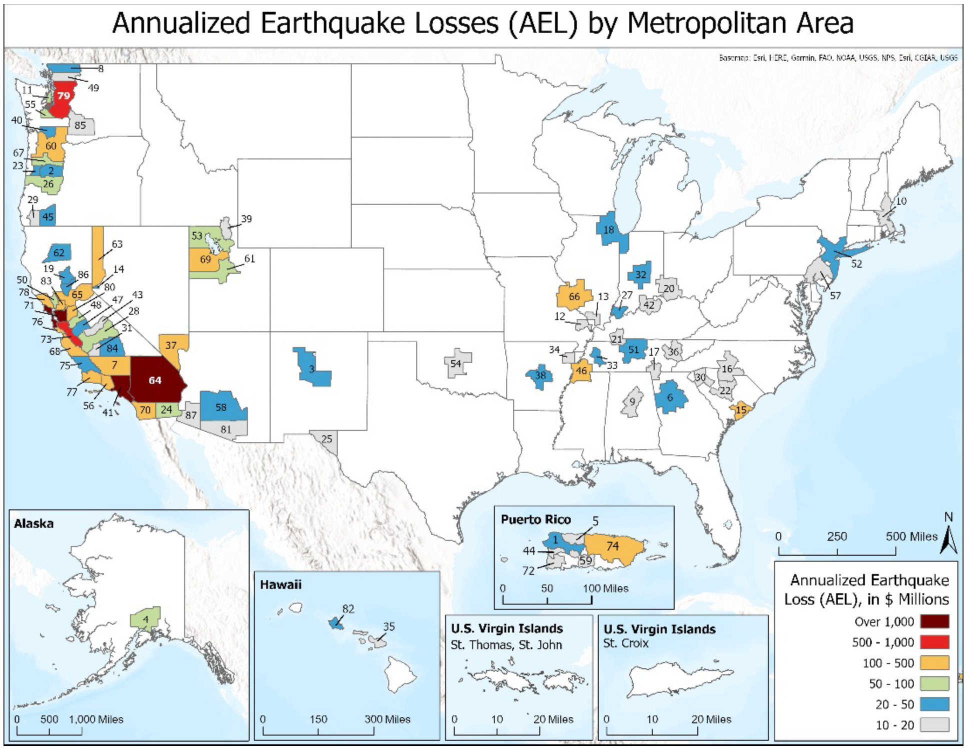


**Figure 3-6. Annualized Earthquake Losses (AEL) by Metropolitan Areas (Losses Greater than $10 Million).**

**Table 3-3. Annualized Earthquake Loss Ratios for Metropolitan Areas (listed alphabetically).**

| *Map #* | *Metropolitan Area* | *AELR ($/million$)* | *Map #* | *Metropolitan Area* | *AELR ($/million$)* |
|---|---|---|---|---|---|
| 1 | Aguadilla-Isabela, Puerto Rico | 625.1 | 45 | Medford, Oregon | 340.5 |
| 2 | Albany-Lebanon, Oregon | 574.1 | 46 | Memphis, Tennessee-Mississippi-Arkansas | 302.8 |
| 3 | Albuquerque, New Mexico | 95.3 | 47 | Merced, Calfornia | 385.4 |
| 4 | Anchorage, Alaska | 511.1 | 48 | Modesto, California | 314.3 |
| 5 | Arecibo, Puerto Rico | 543.9 | 49 | Mount Vernon-Anacortes, Washington | 389.5 |
| 6 | Atlanta-Sandy Springs-Alpharetta, Georgia | 21.8 | 50 | Napa, California | 1025.5 |
| 7 | Bakersfield, California | 482.6 | 51 | Nashville-Davidson--Murfreesboro--Franklin, Tennessee | 74.7 |

| ***Map #*** | ***Metropolitan Area*** | ***AELR ($/million$)*** | ***Map #*** | ***Metropolitan Area*** | ***AELR ($/million$)*** |
|---|---|---|---|---|---|
| 8 | Bellingham, Washington | 339.0 | 52 | New York-Newark-Jersey City, New York-New Jersey-Pennsylvania | 8.9 |
| 9 | Birmingham-Hoover, Alabama | 30.9 | 53 | Ogden-Clearfield, Utah | 529.5 |
| 10 | Boston-Cambridge-Newton, Massachusetts-New Hampshire | 12.4 | 54 | Oklahoma City, Oklahoma | 32.0 |
| 11 | Bremerton-Silverdale-Port Orchard, Washington | 645.5 | 55 | Olympia-Lacey-Tumwater, Washington | 672.6 |
| 12 | Cape Girardeau, Missouri-Illinois | 364.0 | 56 | Oxnard-Thousand Oaks-Ventura, California | 841.8 |
| 13 | Carbondale-Marion, Illinois | 377.0 | 57 | Philadelphia-Camden-Wilmington, Pennsylvania-New Jersey-Delaware-Maryland | 6.9 |
| 14 | Carson City, Nevada | 1180.6 | 58 | Phoenix-Mesa-Chandler, Arizona | 28.7 |
| 15 | Charleston-North Charleston, South Carolina | 477.1 | 59 | Ponce, Puerto Rico | 419.7 |
| 16 | Charlotte-Concord-Gastonia, North Carolina-South Carolina | 17.1 | 60 | Portland-Vancouver-Hillsboro, Oregon-Washington | 481.1 |
| 17 | Chattanooga, Tennessee-Georgia | 68.2 | 61 | Provo-Orem, Utah | 462.0 |
| 18 | Chicago-Naperville-Elgin, Illinois-Indiana-Wisconsin | 8.4 | 62 | Redding, California | 658.5 |
| 19 | Chico, Calfornia | 438.0 | 63 | Reno, Nevada | 776.5 |
| 20 | Cincinnati, Ohio-Kentucky-Indiana | 14.3 | 64 | Riverside-San Bernardino-Ontario, California | 982.8 |
| 21 | Clarksville, Tennessee-Kentucky | 158.6 | 65 | Sacramento-Roseville-Folsom, California | 204.2 |

| Map # | Metropolitan Area | AELR ($/million$) | Map # | Metropolitan Area | AELR ($/million$) |
|---|---|---|---|---|---|
| 22 | Columbia, South Carolina | 44.6 | 66 | St. Louis, Missouri-Illinois | 126.3 |
| 23 | Corvallis, Oregon | 683.2 | 67 | Salem, Oregon | 561.1 |
| 24 | El Centro, California | 1607.7 | 68 | Salinas, California | 855.6 |
| 25 | El Paso, Texas | 82.4 | 69 | Salt Lake City, Utah | 539.7 |
| 26 | Eugene-Springfield, Oregon | 506.5 | 70 | San Diego-Chula Vista-Carlsbad, California | 292.1 |
| 27 | Evansville, Indiana-Kentucky | 210.5 | 71 | San Francisco-Oakland-Berkeley, California | 1141.7 |
| 28 | Fresno, California | 250.6 | 72 | San Germán, Puerto Rico | 587.1 |
| 29 | Grants Pass, Oregon | 393.8 | 73 | San Jose-Sunnyvale-Santa Clara, California | 1359.8 |
| 30 | Greenville-Anderson, South Carolina | 34.6 | 74 | San Juan-Bayamón-Caguas, Puerto Rico | 421.2 |
| 31 | Hanford-Corcoran, California | 381.6 | 75 | San Luis Obispo-Paso Robles, California | 357.0 |
| 32 | Indianapolis-Carmel-Anderson, Indiana | 31.6 | 76 | Santa Cruz-Watsonville, California | 1163.9 |
| 33 | Jackson, Tennessee | 418.7 | 77 | Santa Maria-Santa Barbara, California | 736.1 |
| 34 | Jonesboro, Arkansas | 450.8 | 78 | Santa Rosa-Petaluma, California | 991.8 |
| 35 | Kahului-Wailuku-Lahaina, Hawai'i | 265.6 | 79 | Seattle-Tacoma-Bellevue, Washington | 591.5 |
| 36 | Knoxville, Tennessee | 71.7 | 80 | Stockton, California | 437.0 |
| 37 | Las Vegas-Henderson-Paradise, Nevada | 168.8 | 81 | Tucson, Arizona | 42.6 |
| 38 | Little Rock-North Little Rock-Conway, Arkansas | 110.7 | 82 | Urban Honolulu, Hawai'i | 97.1 |
| 39 | Logan, Utah-Idaho | 450.6 | 83 | Vallejo, California | 866.9 |
| 40 | Longview, Washington | 625.8 | 84 | Visalia, California | 211.0 |

| *Map #* | *Metropolitan Area* | *AELR ($/million$)* | *Map #* | *Metropolitan Area* | *AELR ($/million$)* |
|---|---|---|---|---|---|
| 41 | Los Angeles-Long Beach-Anaheim, California | 932.6 | 85 | Yakima, Washington | 191.7 |
| 42 | Louisville/Jefferson County, Kentucky-Indiana | 42.8 | 86 | Yuba City, California | 391.5 |
| 43 | Madera, California | 223.7 | 87 | Yuma, Arizona | 390.5 |
| 44 | Mayagüez, Puerto Rico | 557.4 | | | |

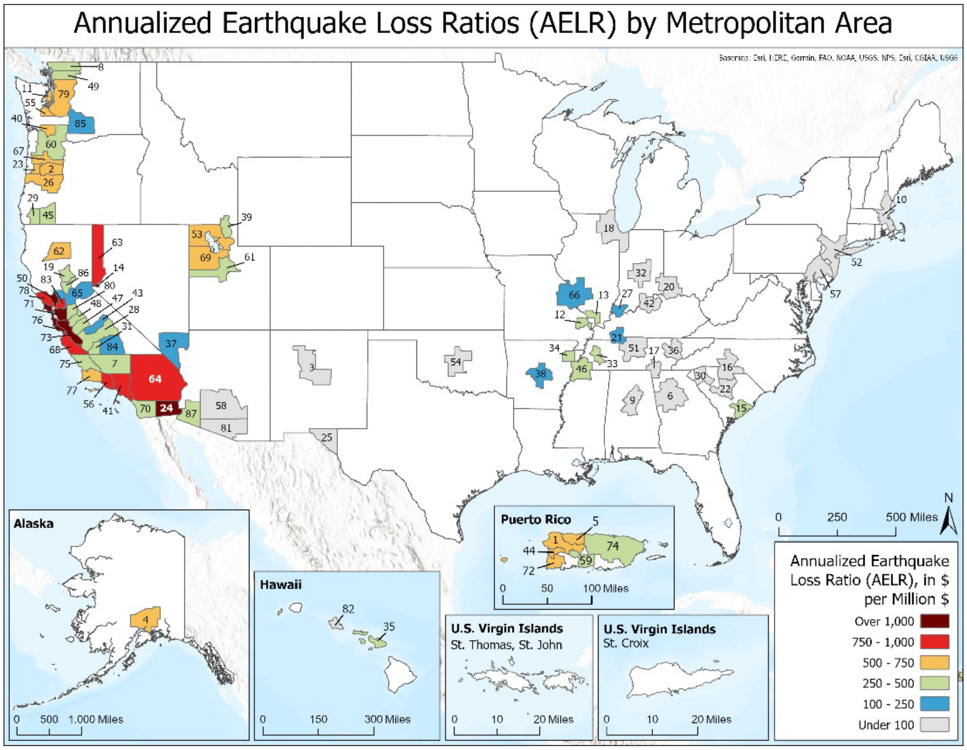


**Figure 3-7. Annualized Earthquake Loss Ratios (AELR) by Metropolitan Areas (Losses Greater than $10 Million).**

**Table 1-4. Annualized Earthquake Loss and Annualized Earthquake Loss Ratios for 87 Metropolitan Areas with AEL Greater than $10 Million.**

| *Rank* | *Metropolitan Areas* | *AEL ($ x 1,000)* |
|---|---|---|
| 1 | Los Angeles-Long Beach-Anaheim, California | 3,330.9 |
| 2 | San Francisco-Oakland-Berkeley, California | 1,794.9 |
| 3 | Riverside-San Bernardino-Ontario, California | 1,341.8 |
| 4 | San Jose-Sunnyvale-Santa Clara, California | 917.0 |
| 5 | Seattle-Tacoma-Bellevue, Washington | 781.4 |
| 6 | Portland-Vancouver-Hillsboro, Oregon-Washington | 402.8 |
| 7 | San Diego-Chula Vista-Carlsbad, California | 284.5 |
| 8 | Oxnard-Thousand Oaks-Ventura, California | 220.0 |
| 9 | San Juan-Bayamón-Caguas, Puerto Rico | 200.9 |
| 10 | Santa Rosa-Petaluma, California | 178.7 |
| 11 | Salt Lake City, Utah | 173.6 |
| 12 | Sacramento-Roseville-Folsom, California | 153.8 |

| *Rank* | *Metropolitan Areas* | *AELR ($/million$)* |
|---|---|---|
| 1 | El Centro, California | 1,607.7 |
| 2 | San Jose-Sunnyvale-Santa Clara, California | 1,359.8 |
| 3 | Carson City, Nevada | 1,180.6 |
| 4 | Santa Cruz-Watsonville, California | 1,163.9 |
| 5 | San Francisco-Oakland-Berkeley, California | 1,141.7 |
| 6 | Napa, California | 1,025.5 |
| 7 | Santa Rosa-Petaluma, California | 991.8 |
| 8 | Riverside-San Bernardino-Ontario, California | 982.8 |
| 9 | Los Angeles-Long Beach-Anaheim, California | 932.6 |
| 10 | Vallejo, California | 866.9 |
| 11 | Salinas, California | 855.6 |
| 12 | Oxnard-Thousand Oaks-Ventura, California | 841.8 |
| 13 | Reno, Nevada | 776.5 |

| *Rank* | *Metropolitan Areas* | *AEL ($ x 1,000)* |
|---|---|---|
| 13 | St. Louis, Missouri-Illinois | 132.4 |
| 14 | Memphis, Tennessee-Mississippi-Arkansas | 131.1 |
| 15 | Bakersfield, California | 125.3 |
| 16 | Reno, Nevada | 122.7 |
| 17 | Vallejo, California | 122.3 |
| 18 | Charleston-North Charleston, South Carolina | 119.4 |
| 19 | Salinas, California | 113.4 |
| 20 | Las Vegas-Henderson-Paradise, Nevada | 112.7 |
| 21 | Santa Cruz-Watsonville, California | 110.1 |
| 23 | Stockton, California | 108.4 |
| 24 | Santa Maria-Santa Barbara, California | 100.2 |
| 25 | Ogden-Clearfield, Utah | 94.3 |
| 26 | El Centro, California | 92.7 |
| 27 | Anchorage, Alaska | 81.6 |
| 28 | Salem, Oregon | 78.7 |
| 29 | Provo-Orem, Utah | 74.4 |
| 30 | Eugene-Springfield, Oregon | 72.2 |
| 31 | Fresno, California | 70.2 |

| *Rank* | *Metropolitan Areas* | AELR ($/million$) |
|---|---|---|
| 14 | Santa Maria-Santa Barbara, California | 736.1 |
| 15 | Corvallis, Oregon | 683.2 |
| 16 | Olympia-Lacey-Tumwater, Washington | 672.6 |
| 17 | Redding, California | 658.5 |
| 18 | Bremerton-Silverdale-Port Orchard, Washington | 645.5 |
| 19 | Longview, Washington | 625.8 |
| 20 | Aguadilla-Isabela, Puerto Rico | 625.1 |
| 21 | Seattle-Tacoma-Bellevue, Washington | 591.5 |
| 22 | San Germán, Puerto Rico | 587.1 |
| 23 | Albany-Lebanon, Oregon | 574.1 |
| 24 | Salem, Oregon | 561.1 |
| 25 | Mayagüez, Puerto Rico | 557.4 |
| 26 | Arecibo, Puerto Rico | 543.9 |
| 27 | Salt Lake City, Utah | 539.7 |
| 28 | Ogden-Clearfield, Utah | 529.5 |
| 29 | Anchorage, Alaska | 511.1 |
| 30 | Eugene-Springfield, Oregon | 506.5 |
| 31 | Bakersfield, California | 482.6 |

| *Rank* | *Metropolitan Areas* | *AEL ($ x 1,000)* |
|---|---|---|
| 32 | Olympia-Lacey-Tumwater, Washington | 65.9 |
| 33 | Napa, California | 60.8 |
| 34 | Modesto, California | 55.4 |
| 35 | Bremerton-Silverdale-Port Orchard, Washington | 53.1 |
| 36 | New York-Newark-Jersey City, New York-New Jersey-Pennsylvania | 48.8 |
| 37 | Nashville-Davidson--Murfreesboro--Franklin, Tennessee | 48.1 |
| 38 | Redding, California | 43.3 |
| 39 | Atlanta-Sandy Springs-Alpharetta, Georgia | 42.2 |
| 40 | Phoenix-Mesa-Chandler, Arizona | 40.1 |
| 41 | San Luis Obispo-Paso Robles, California | 38.4 |
| 42 | Aguadilla-Isabela, Puerto Rico | 38.3 |
| 43 | Merced, California | 35.6 |
| 44 | Chico, California | 32.7 |
| 45 | Medford, Oregon | 28.4 |
| 46 | Visalia, California | 27.6 |

| *Rank* | *Metropolitan Areas* | *AELR ($/million$)* |
|---|---|---|
| 32 | Portland-Vancouver-Hillsboro, Oregon-Washington | 481.1 |
| 33 | Charleston-North Charleston, South Carolina | 477.1 |
| 34 | Provo-Orem, Utah | 462.0 |
| 35 | Jonesboro, Arkansas | 450.8 |
| 36 | Logan, Utah-Idaho | 450.6 |
| 37 | Chico, California | 438.0 |
| 38 | Stockton, California | 437.0 |
| 39 | San Juan-Bayamón-Caguas, Puerto Rico | 421.2 |
| 40 | Ponce, Puerto Rico | 419.7 |
| 41 | Jackson, Tennessee | 418.7 |
| 42 | Grants Pass, Oregon | 393.8 |
| 43 | Yuba City, California | 391.5 |
| 44 | Yuma, Arizona | 390.5 |
| 45 | Mount Vernon-Anacortes, Washington | 389.5 |
| 46 | Merced, California | 385.4 |

| *Rank* | *Metropolitan Areas* | *AEL ($ x 1,000)* |
|---|---|---|
| 47 | Chicago-Naperville-Elgin, Illinois-Indiana-Wisconsin | 27.5 |
| 48 | Bellingham, Washington | 27.1 |
| 49 | Albany-Lebanon, Oregon | 26.2 |
| 50 | Jackson, Tennessee | 26.1 |
| 51 | Longview, Washington | 25.6 |
| 52 | Albuquerque, New Mexico | 25.1 |
| 53 | Corvallis, Oregon | 24.8 |
| 54 | Evansville, Indiana-Kentucky | 24.4 |
| 55 | Urban Honolulu, Hawai'i | 24.2 |
| 56 | Little Rock-North Little Rock-Conway, Arkansas | 23.4 |
| 57 | Indianapolis-Carmel-Anderson, Indiana | 22.4 |
| 58 | Carson City, Nevada | 21.4 |
| 59 | Yuba City, California | 20.2 |
| 60 | Carbondale-Marion, Illinois | 19.7 |
| 61 | Ponce, Puerto Rico | 19.7 |
| 62 | Yuma, Arizona | 19.7 |
| 63 | Boston-Cambridge-Newton, Massachusetts-New Hampshire | 19.5 |

| *Rank* | *Metropolitan Areas* | *AELR ($/million$)* |
|---|---|---|
| 47 | Hanford-Corcoran, California | 381.6 |
| 48 | Carbondale-Marion, Illinois | 377.0 |
| 49 | Cape Girardeau, Missouri-Illinois | 364.0 |
| 50 | San Luis Obispo-Paso Robles, California | 357.0 |
| 51 | Medford, Oregon | 340.5 |
| 52 | Bellingham, Washington | 339.0 |
| 53 | Modesto, California | 314.3 |
| 54 | Memphis, Tennessee-Mississippi-Arkansas | 302.8 |
| 55 | San Diego-Chula Vista-Carlsbad, California | 292.1 |
| 56 | Kahului-Wailuku-Lahaina, Hawai'i | 265.6 |
| 57 | Fresno, California | 250.6 |
| 58 | Madera, California | 223.7 |
| 59 | Visalia, California | 211.0 |
| 60 | Evansville, Indiana-Kentucky | 210.5 |
| 61 | Sacramento-Roseville-Folsom, California | 204.2 |

| *Rank* | *Metropolitan Areas* | *AEL ($ x 1,000)* |
|---|---|---|
| 64 | Arecibo, Puerto Rico | 19.5 |
| 65 | Jonesboro, Arkansas | 18.9 |
| 66 | Knoxville, Tennessee | 18.3 |
| 67 | Mount Vernon-Anacortes, Washington | 18.2 |
| 68 | Louisville/Jefferson County, Kentucky-Indiana | 17.8 |
| 69 | Yakima, Washington | 16.6 |
| 70 | Logan, Utah-Idaho | 16.2 |
| 71 | Philadelphia-Camden-Wilmington, Pennsylvania-New Jersey-Delaware-Maryland | 15.3 |
| 72 | Charlotte-Concord-Gastonia, North Carolina-South Carolina | 15.0 |
| 73 | El Paso, Texas | 14.6 |
| 74 | Hanford-Corcoran, California | 14.4 |
| 75 | Kahului-Wailuku-Lahaina, Hawai'i | 13.7 |
| 76 | Cape Girardeau, Missouri-Illinois | 13.7 |
| 77 | Mayagüez, Puerto Rico | 13.6 |

| *Rank* | *Metropolitan Areas* | *AELR ($/million$)* |
|---|---|---|
| 63 | Las Vegas-Henderson-Paradise, Nevada | 168.8 |
| 64 | Clarksville, Tennessee-Kentucky | 158.6 |
| 65 | St. Louis, Missouri-Illinois | 126.3 |
| 66 | Little Rock-North Little Rock-Conway, Arkansas | 110.7 |
| 67 | Urban Honolulu, Hawai'i | 97.1 |
| 68 | Albuquerque, New Mexico | 95.3 |
| 69 | El Paso, Texas | 82.4 |
| 70 | Nashville-Davidson--Murfreesboro--Franklin, Tennessee | 74.7 |
| 71 | Knoxville, Tennessee | 71.7 |
| 72 | Chattanooga, Tennessee-Georgia | 68.2 |
| 73 | Columbia, South Carolina | 44.6 |
| 74 | Louisville/Jefferson County, Kentucky-Indiana | 42.8 |
| 75 | Tucson, Arizona | 42.6 |
| 76 | Greenville-Anderson, South Carolina | 34.6 |
| 77 | Oklahoma City, Oklahoma | 32.0 |

| *Rank* | *Metropolitan Areas* | *AEL ($ x 1,000)* |
|---|---|---|
| 78 | San Germán, Puerto Rico | 13.4 |
| 79 | Clarksville, Tennessee-Kentucky | 12.9 |
| 80 | Oklahoma City, Oklahoma | 12.3 |
| 81 | Columbia, South Carolina | 12.1 |
| 82 | Chattanooga, Tennessee-Georgia | 11.8 |
| 83 | Tucson, Arizona | 11.4 |
| 84 | Birmingham-Hoover, Alabama | 10.9 |
| 85 | Grants Pass, Oregon | 10.7 |
| 86 | Greenville-Anderson, South Carolina | 10.7 |
| 87 | Madera, California | 10.7 |

| *Rank* | *Metropolitan Areas* | **AELR ($/million$)** |
|---|---|---|
| 78 | Indianapolis-Carmel-Anderson, Indiana | 31.6 |
| 79 | Birmingham-Hoover, Alabama | 30.9 |
| 80 | Phoenix-Mesa-Chandler, Arizona | 28.7 |
| 81 | Atlanta-Sandy Springs-Alpharetta, Georgia | 21.8 |
| 82 | Charlotte-Concord-Gastonia, North Carolina-South Carolina | 17.1 |
| 83 | Cincinnati, Ohio-Kentucky-Indiana | 14.3 |
| 84 | Boston-Cambridge-Newton, Massachusetts-New Hampshire | 12.4 |
| 85 | New York-Newark-Jersey City, New York-New Jersey-Pennsylvania | 8.9 |
| 86 | Chicago-Naperville-Elgin, Illinois-Indiana-Wisconsin | 8.4 |
| 87 | Philadelphia-Camden-Wilmington, Pennsylvania-New Jersey-Delaware-Maryland | 6.9 |

## 3.5 Socioeconomics

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 2020 population distribution and reveal two key 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., Hawaiʻi, Alaska, and the Caribbean); and
2. California, U.S. Virgin Islands, Oregon, Alaska, Washington, Utah, Puerto Rico, Nevada, and Hawaiʻi have the highest seismic risk when measured on a per capita basis at the state level.

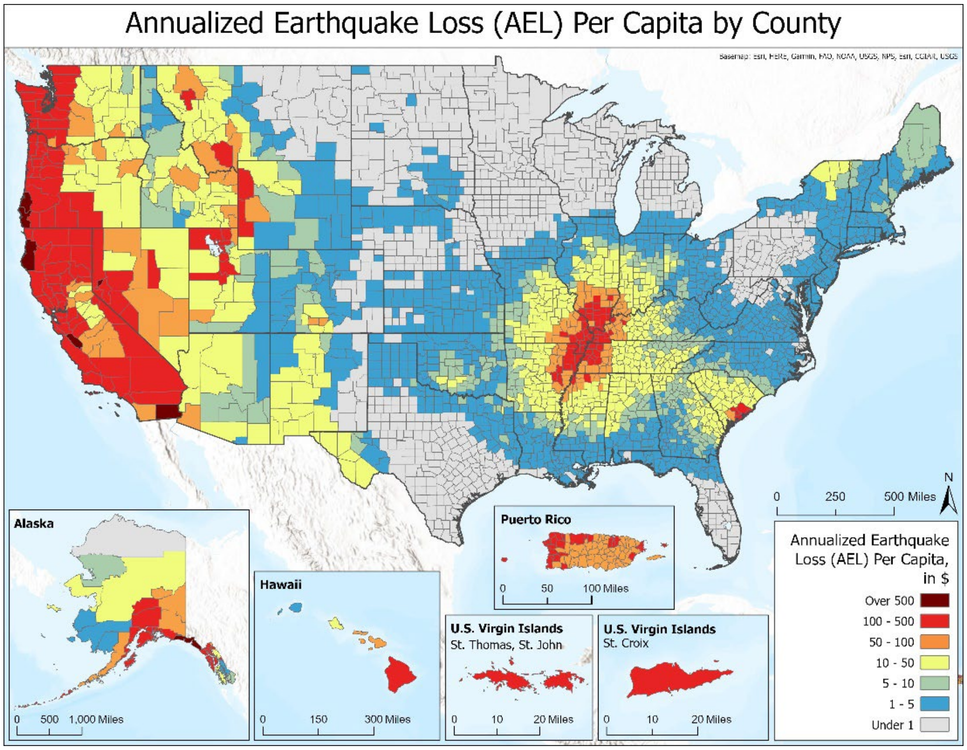


**Figure 3-8. Annualized Earthquake Loss (AEL) Per Capita by County.**

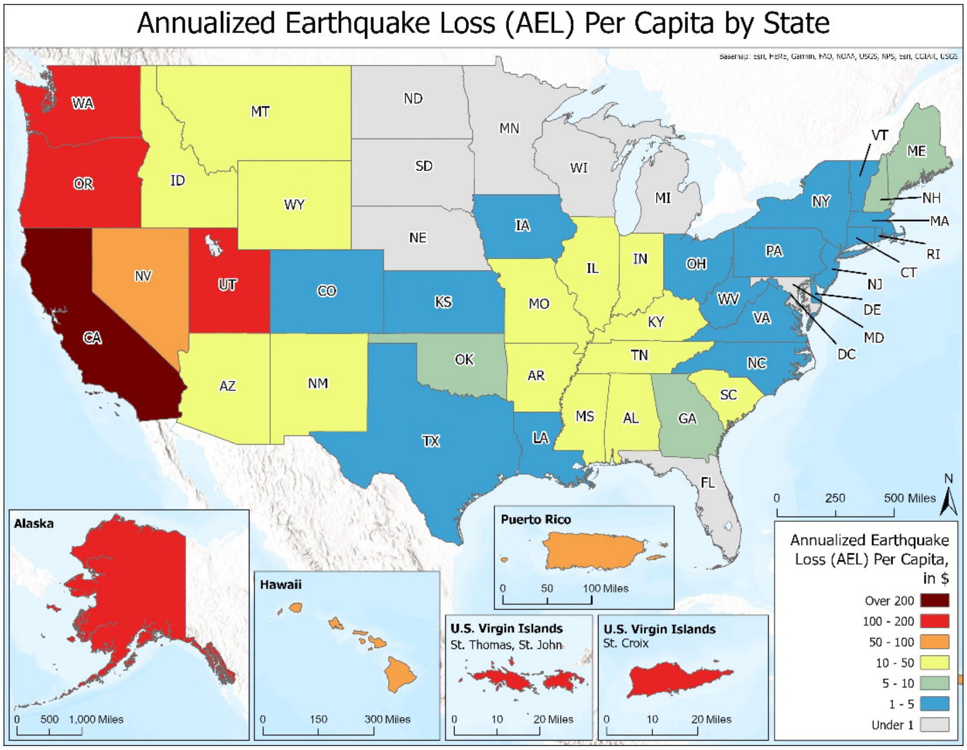


Figure 3-9. Annualized Earthquake Loss (AEL) Per Capita by State.

Table 3-5. AEL Per Capita for Selected Metropolitan Areas (listed alphabetically).

| *Map #* | *Metropolitan Area* | *AEL Per Capita* | *Map #* | *Metropolitan Area* | *AEL Per Capita* |
|---|---|---|---|---|---|
| 1 | Aguadilla-Isabela, Puerto Rico | 124 | 45 | Medford, Oregon | 127 |
| 2 | Albany-Lebanon, Oregon | 204 | 46 | Memphis, Tennessee-Mississippi-Arkansas | 98 |
| 3 | Albuquerque, New Mexico | 27 | 47 | Merced, California | 126 |
| 4 | Anchorage, Alaska | 205 | 48 | Modesto, California | 100 |
| 5 | Arecibo, Puerto Rico | 107 | 49 | Mount Vernon-Anacortes, Washington | 140 |
| 6 | Atlanta-Sandy Springs-Alpharetta, Georgia | 7 | 50 | Napa, California | 440 |
| 7 | Bakersfield, California | 138 | 51 | Nashville-Davidson--Murfreesboro--Franklin, Tennessee | 24 |
| 8 | Bellingham, Washington | 119 | 52 | New York-Newark-Jersey City, New York-New Jersey-Pennsylvania | 2 |

| Map # | Metropolitan Area | AEL Per Capita | Map # | Metropolitan Area | AEL Per Capita |
|---|---|---|---|---|---|
| 9 | Birmingham-Hoover, Alabama | 10 | 53 | Ogden-Clearfield, Utah | 136 |
| 10 | Boston-Cambridge-Newton, Massachusetts-New Hampshire | 4 | 54 | Oklahoma City, Oklahoma | 9 |
| 11 | Bremerton-Silverdale-Port Orchard, Washington | 193 | 55 | Olympia-Lacey-Tumwater, Washington | 224 |
| 12 | Cape Girardeau, Missouri-Illinois | 140 | 56 | Oxnard-Thousand Oaks-Ventura, California | 261 |
| 13 | Carbondale-Marion, Illinois | 147 | 57 | Philadelphia-Camden-Wilmington, Pennsylvania-New Jersey-Delaware-Maryland | 2 |
| 14 | Carson City, Nevada | 365 | 58 | Phoenix-Mesa-Chandler, Arizona | 8 |
| 15 | Charleston-North Charleston, South Carolina | 149 | 59 | Ponce, Puerto Rico | 88 |
| 16 | Charlotte-Concord-Gastonia, North Carolina-South Carolina | 6 | 60 | Portland-Vancouver-Hillsboro, Oregon-Washington | 160 |
| 17 | Chattanooga, Tennessee-Georgia | 21 | 61 | Provo-Orem, Utah | 111 |
| 18 | Chicago-Naperville-Elgin, Illinois-Indiana-Wisconsin | 3 | 62 | Redding, California | 238 |
| 19 | Chico, California | 154 | 63 | Reno, Nevada | 250 |
| 20 | Cincinnati, Ohio-Kentucky-Indiana | 5 | 64 | Riverside-San Bernardino-Ontario, California | 292 |
| 21 | Clarksville, Tennessee-Kentucky | 40 | 65 | Sacramento-Roseville-Folsom, California | 64 |
| 22 | Columbia, South Carolina | 15 | 66 | St. Louis, Missouri-Illinois | 47 |
| 23 | Corvallis, Oregon | 260 | 67 | Salem, Oregon | 182 |
| 24 | El Centro, California | 516 | 68 | Salinas, California | 258 |
| 25 | El Paso, Texas | 17 | 69 | Salt Lake City, Utah | 138 |
| 26 | Eugene-Springfield, Oregon | 189 | 70 | San Diego-Chula Vista-Carlsbad, California | 86 |
| 27 | Evansville, Indiana-Kentucky | 78 | 71 | San Francisco-Oakland-Berkeley, California | 378 |

| Map # | Metropolitan Area | AEL Per Capita | Map # | Metropolitan Area | AEL Per Capita |
|---|---|---|---|---|---|
| 28 | Fresno, California | 70 | 72 | San Germán, Puerto Rico | 107 |
| 29 | Grants Pass, Oregon | 122 | 73 | San Jose-Sunnyvale-Santa Clara, California | 458 |
| 30 | Greenville-Anderson, South Carolina | 12 | 74 | San Juan-Bayamón-Caguas, Puerto Rico | 97 |
| 31 | Hanford-Corcoran, California | 94 | 75 | San Luis Obispo-Paso Robles, California | 136 |
| 32 | Indianapolis-Carmel-Anderson, Indiana | 11 | 76 | Santa Cruz-Watsonville, California | 406 |
| 33 | Jackson, Tennessee | 145 | 77 | Santa Maria-Santa Barbara, California | 224 |
| 34 | Jonesboro, Arkansas | 141 | 78 | Santa Rosa-Petaluma, California | 366 |
| 35 | Kahului-Wailuku-Lahaina, Hawai’i | 83 | 79 | Seattle-Tacoma-Bellevue, Washington | 194 |
| 36 | Knoxville, Tennessee | 21 | 80 | Stockton, California | 139 |
| 37 | Las Vegas-Henderson-Paradise, Nevada | 50 | 81 | Tucson, Arizona | 11 |
| 38 | Little Rock-North Little Rock-Conway, Arkansas | 31 | 82 | Urban Honolulu, Hawai’i | 24 |
| 39 | Logan, Utah-Idaho | 110 | 83 | Vallejo, California | 270 |
| 40 | Longview, Washington | 231 | 84 | Visalia, California | 58 |
| 41 | Los Angeles-Long Beach-Anaheim, California | 252 | 85 | Yakima, Washington | 65 |
| 42 | Louisville/Jefferson County, Kentucky-Indiana | 14 | 86 | Yuba City, California | 112 |
| 43 | Madera, California | 68 | 87 | Yuma, Arizona | 96 |
| 44 | Mayagüez, Puerto Rico | 140 | | | |

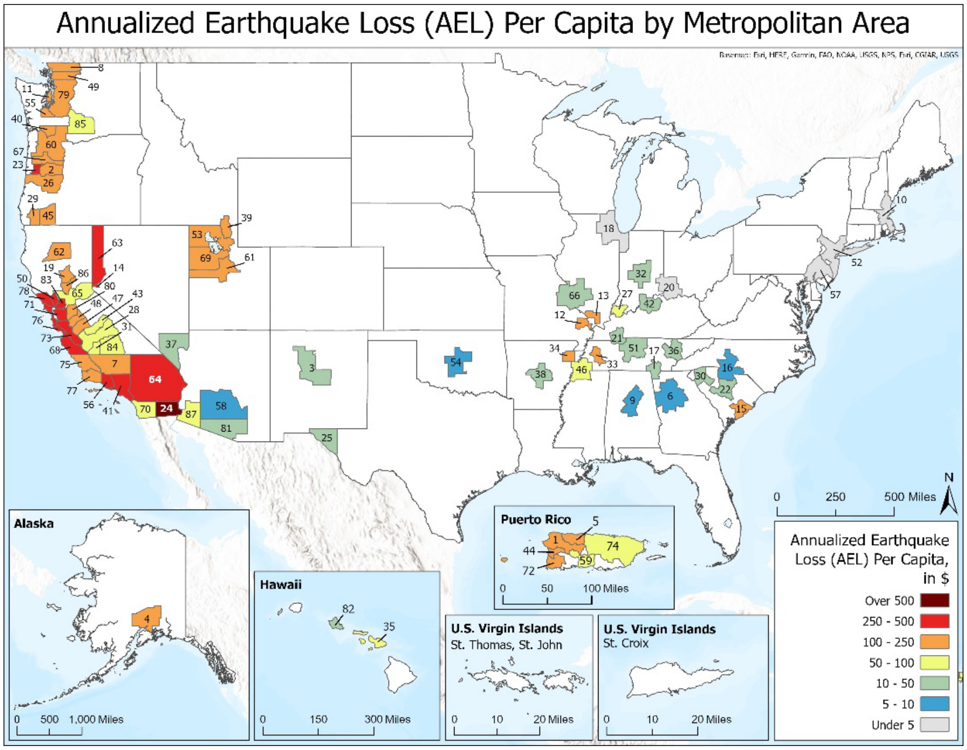


**Figure 3-10. Annualized Earthquake Loss (AEL) Per Capita by Metropolitan Area.**

## 3.6 Estimates of Debris, Displaced Households, and Shelter Requirements

Annualized casualty estimates and debris and shelter requirement estimates for 250- and 1,000-year return periods were derived using Hazus 6.0. Figures 3-11 and 3-12 and Table 3-6 depict the estimates of debris for 250-year and 1,000-year return periods, respectively. Estimating annualized losses for debris and shelter requirements include substantial post-Hazus analyses of data obtained from a series of at least 8 individual analyses; therefore, two return periods were selected and are presented.

Figure 3-12 illustrates that nine counties would produce more than 400 thousand truckloads of debris in the 1,000-year event. Los Angeles County produces almost 4 million truckloads, more than 3 times that of the second highest county (San Bernardino, California). Although seven of the nine counties producing over 400 thousand truckloads are in California, both Kings County, Washington, and Salt Lake County, Utah, also break the 400 thousand truckload threshold.

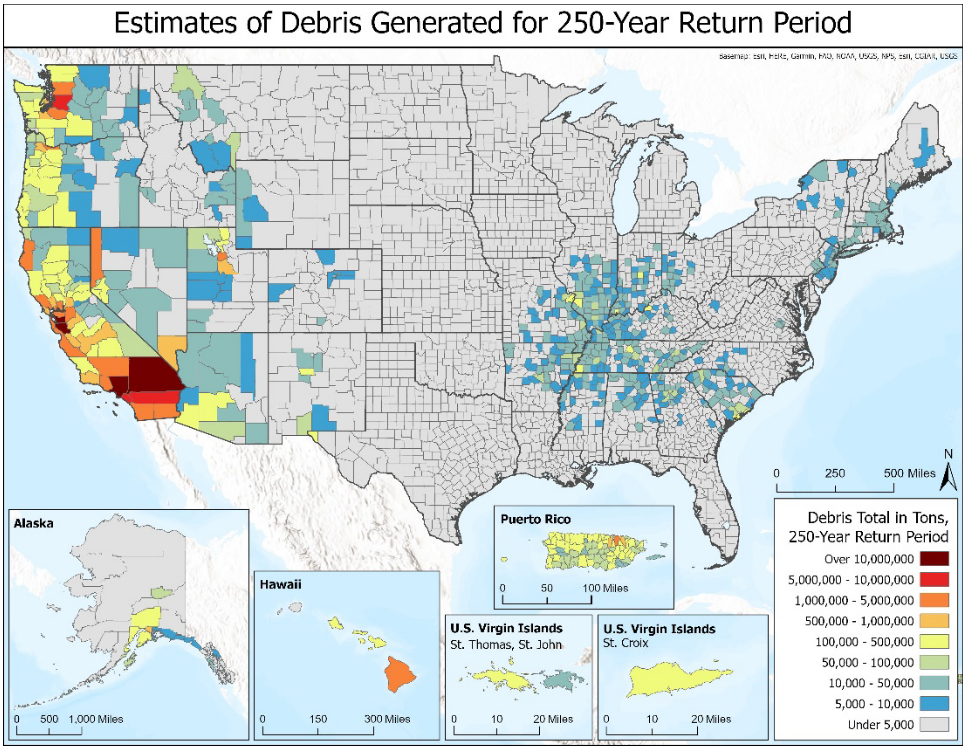


Figure 3-11. Estimates of Debris Generated for 250-Year Return Period.

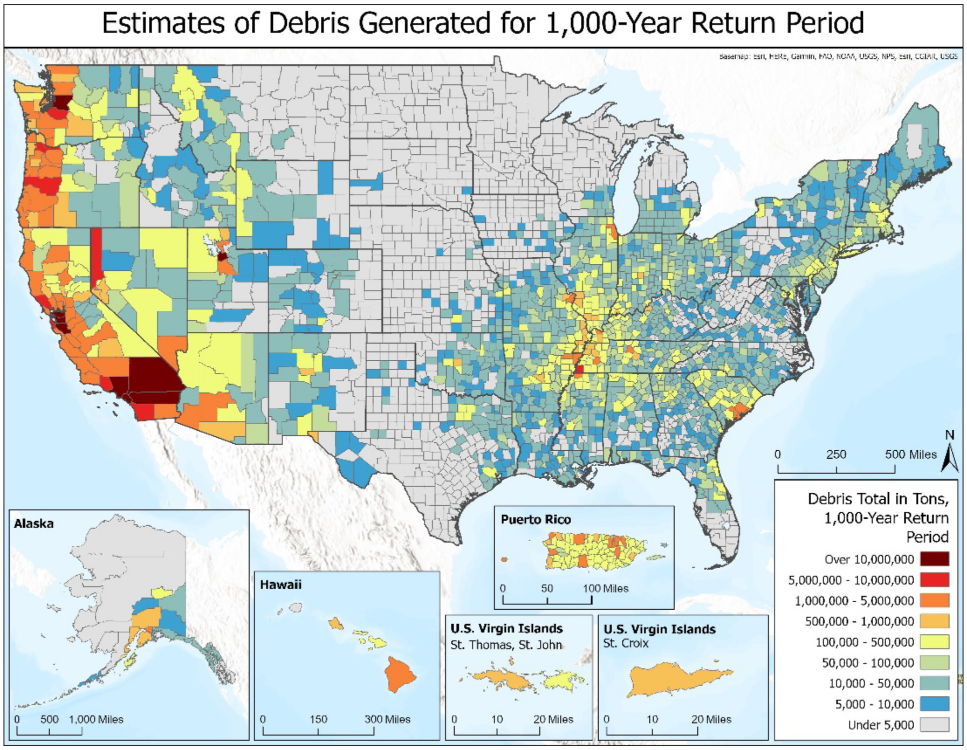


Figure 3-12. Estimates of Debris Generated for 1,000-Year Return Period.

**Table 3-6. Estimates of Debris for 250-year and 1,000-year Event (based on truckloads using 25 tons per load), ranked by 1,000-year Event).**

| *Rank* | *State* | *250-Year Event* | *1,000-Year Event* |
|---|---|---|---|
| 1 | California | 4,664,600 | 13,143,800 |
| 2 | Washington | 484,200 | 1,994,080 |
| 3 | Oregon | 208,440 | 1,932,000 |
| 4 | Puerto Rico | 513,120 | 1,347,120 |
| 5 | Utah | 128,160 | 936,800 |
| 6 | Tennessee | 69,360 | 736,560 |
| 7 | Nevada | 124,680 | 509,040 |
| 8 | Missouri | 44,800 | 501,960 |
| 9 | Illinois | 43,080 | 486,560 |
| 10 | South Carolina | 28,440 | 432,280 |
| 11 | Arkansas | 25,440 | 332,320 |
| 12 | Kentucky | 34,320 | 310,840 |
| 13 | Indiana | 29,280 | 239,800 |
| 14 | Georgia | 29,640 | 189,800 |
| 15 | Arizona | 35,240 | 184,160 |
| 16 | Mississippi | 13,640 | 181,960 |
| 17 | Hawai‘i | 61,520 | 165,520 |
| 18 | Alaska | 50,920 | 158,520 |
| 19 | Texas | 6,120 | 142,840 |
| 20 | Ohio | 13,480 | 131,600 |
| 21 | New York | 12,880 | 114,960 |
| 22 | Alabama | 12,840 | 107,320 |
| 23 | New Mexico | 9,240 | 83,320 |
| 24 | Oklahoma | 0 | 81,840 |
| 25 | Florida | 0 | 72,720 |

| *Rank* | *State* | *250-Year Event* | *1,000-Year Event* |
|---|---|---|---|
| 26 | North Carolina | 6,000 | 71,280 |
| 27 | Pennsylvania | 3,320 | 68,680 |
| 28 | Montana | 11,560 | 60,400 |
| 29 | Virginia | 4,680 | 58,200 |
| 30 | U.S. Virgin Islands | 20,640 | 55,520 |
| 31 | New Jersey | 6,120 | 54,240 |
| 32 | Michigan | 0 | 46,120 |
| 33 | Massachusetts | 6,640 | 45,880 |
| 34 | Louisiana | 160 | 45,840 |
| 35 | Idaho | 8,320 | 44,280 |
| 36 | Colorado | 3,400 | 28,680 |
| 37 | Maryland | 0 | 28,560 |
| 38 | Kansas | 0 | 28,000 |
| 39 | Wyoming | 3,880 | 20,680 |
| 40 | Iowa | 0 | 16,000 |
| 41 | Connecticut | 1,920 | 15,240 |
| 42 | Maine | 2,040 | 14,040 |
| 43 | Wisconsin | 0 | 14,000 |
| 44 | New Hampshire | 1,840 | 13,120 |
| 45 | West Virginia | 1,200 | 11,440 |
| 46 | District of Columbia | 0 | 10,200 |
| 47 | Delaware | 120 | 7,640 |
| 48 | Nebraska | 0 | 6,600 |
| 49 | Vermont | 760 | 5,160 |
| 50 | Rhode Island | 560 | 4,440 |
| 51 | South Dakota | 0 | 3,240 |
| 52 | Minnesota | 0 | 360 |

| Rank | State | 250-Year Event | 1,000-Year Event |
|---|---|---|---|
| 53 | North Dakota | 0 | 160 |

Table 3-7 provides the statewide estimates of displaced households based on the 250- and 1,000-year return periods. The default settings in Hazus used for this study base displaced households on 100% of those in the complete damage state for single and multi-family and include 90% of the households in the extensive damage state for multi-family only. States where the hazard is driven more by lower frequency events, such as Utah and Tennessee, will climb the rankings in the 1,000 versus 250-year, whereas states where higher frequency events such as Hawaiʻi will rank relatively higher in the 250- versus 1,000-year rankings.

**Table 3-7. Estimates of Displaced Households for 250-year and 1,000-year Event (ranked by 1,000-year Event).**

| Rank | State | 250-Year Event | 1,000-Year Event |
|---|---|---|---|
| 1 | California | 378,824 | 1,251,172 |
| 2 | Washington | 39,993 | 180,644 |
| 3 | Puerto Rico | 28,588 | 102,436 |
| 4 | Oregon | 8,658 | 92,087 |
| 5 | Utah | 5,079 | 54,139 |
| 6 | Nevada | 7,977 | 39,288 |
| 7 | South Carolina | 1,268 | 33,219 |
| 8 | Tennessee | 2,125 | 32,837 |
| 9 | Missouri | 1,166 | 20,368 |
| 10 | Hawaiʻi | 4,993 | 18,389 |
| 11 | Illinois | 988 | 16,604 |
| 12 | Arkansas | 661 | 12,485 |
| 12 | Arkansas | 0 | 12,485 |
| 13 | Kentucky | 887 | 11,125 |
| 14 | New York | 656 | 9,593 |
| 15 | Alaska | 2,450 | 9,409 |
| 16 | Georgia | 932 | 8,614 |
| 17 | Arizona | 1,170 | 8,595 |

| Rank | State | 250-Year Event | 1,000-Year Event |
|---|---|---|---|
| 18 | Indiana | 574 | 6,772 |
| 19 | U.S. Virgin Islands | 1,811 | 6,095 |
| 20 | Mississippi | 325 | 5,789 |
| 21 | Alabama | 462 | 5,390 |
| 22 | Texas | 209 | 4,227 |
| 23 | Massachusetts | 335 | 3,567 |
| 24 | New Mexico | 170 | 3,369 |
| 25 | New Jersey | 206 | 3,259 |
| 26 | Ohio | 216 | 3,224 |
| 27 | Montana | 292 | 2,366 |
| 28 | Pennsylvania | 82 | 2,261 |
| 29 | Virginia | 83 | 1,940 |
| 30 | Idaho | 186 | 1,622 |
| 31 | Oklahoma | 0 | 1,573 |
| 32 | Louisiana | 3 | 1,482 |
| 33 | North Carolina | 65 | 1,474 |
| 34 | Florida | 0 | 1,397 |
| 35 | Michigan | 0 | 1,129 |
| 36 | Wyoming | 130 | 937 |
| 37 | Maryland | 0 | 920 |
| 38 | Maine | 83 | 859 |
| 40 | Connecticut | 62 | 847 |
| 39 | New Hampshire | 77 | 847 |
| 41 | Colorado | 39 | 681 |
| 42 | Kansas | 0 | 590 |
| 42 | Kansas | 661 | 590 |
| 43 | Wisconsin | 0 | 426 |

| Rank | State | 250-Year Event | 1,000-Year Event |
|---|---|---|---|
| 44 | Iowa | 0 | 359 |
| 45 | West Virginia | 22 | 326 |
| 46 | Rhode Island | 23 | 298 |
| 47 | Vermont | 26 | 274 |
| 48 | Delaware | 2 | 228 |
| 49 | District of Columbia | 0 | 161 |
| 50 | Nebraska | 0 | 127 |
| 51 | South Dakota | 0 | 64 |
| 52 | Minnesota | 0 | 3 |
| 53 | North Dakota | 0 | 1 |

Figures 3-13 and 3-14 and Table 3-8 show the estimate of the number of people looking for shelter (shelter requirements) based on ground shaking estimates corresponding to the 250-year and 1,000-year return period, respectively. The figures are aggregated at the county level.

The estimates of shelter requirements follow the trend of displaced households for the 1,000-year return period with California, Washington, Puerto Rico, Oregon, and Utah together accounting for over 85%, and California accounting for nearly 64% of the total. For this study, the public shelter seeking population is based on the income of the displaced households, ranging from a 62% rate of shelter seeking population where household income is less than $10,000 per year, to 13% when income is more than $40,000. As a result, the relative rankings will have differences between displaced households and public shelter seeking populations, such as Puerto Rico moving up to second in the shelter seeking population when demographics are considered over Washington, which is second in overall displaced households. A comparison of the standings of individual states in the Shelter and Shelter Ratio (# of people per million) columns of Tables 3-8 and 3-9 show that while California, Washington, and Oregon rank in the top tier, Puerto Rico and the U.S. Virgin Islands— with relatively high hazard throughout the entire territory, and vulnerable demographics— rise to the top of the rankings.

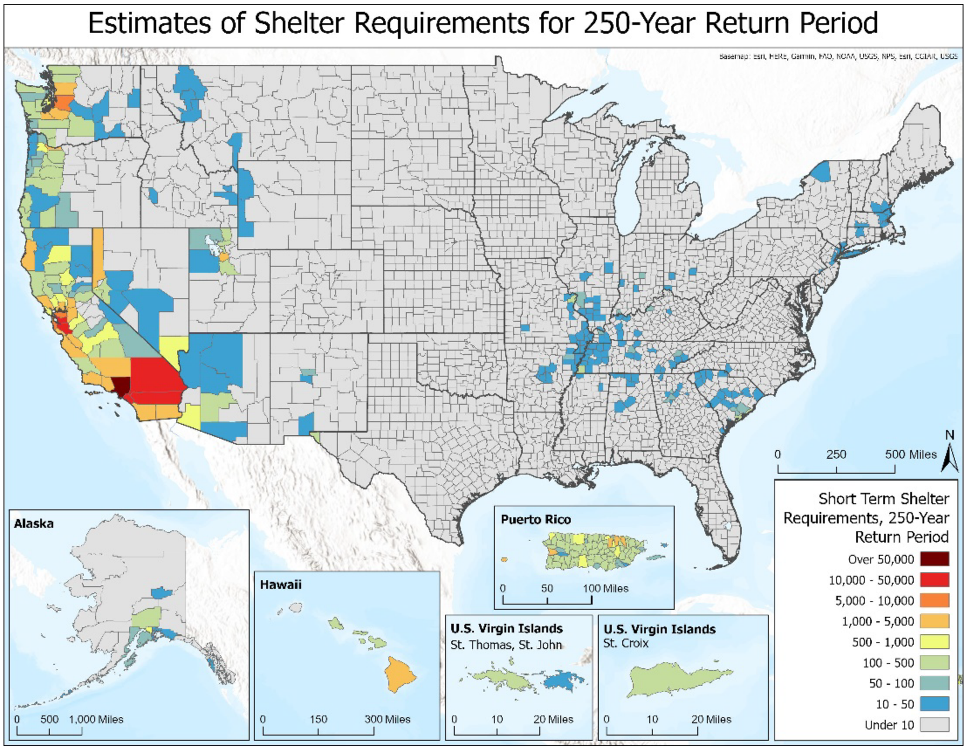


**Figure 3-13. Estimates of Shelter Requirements for 250-year Return Period.**

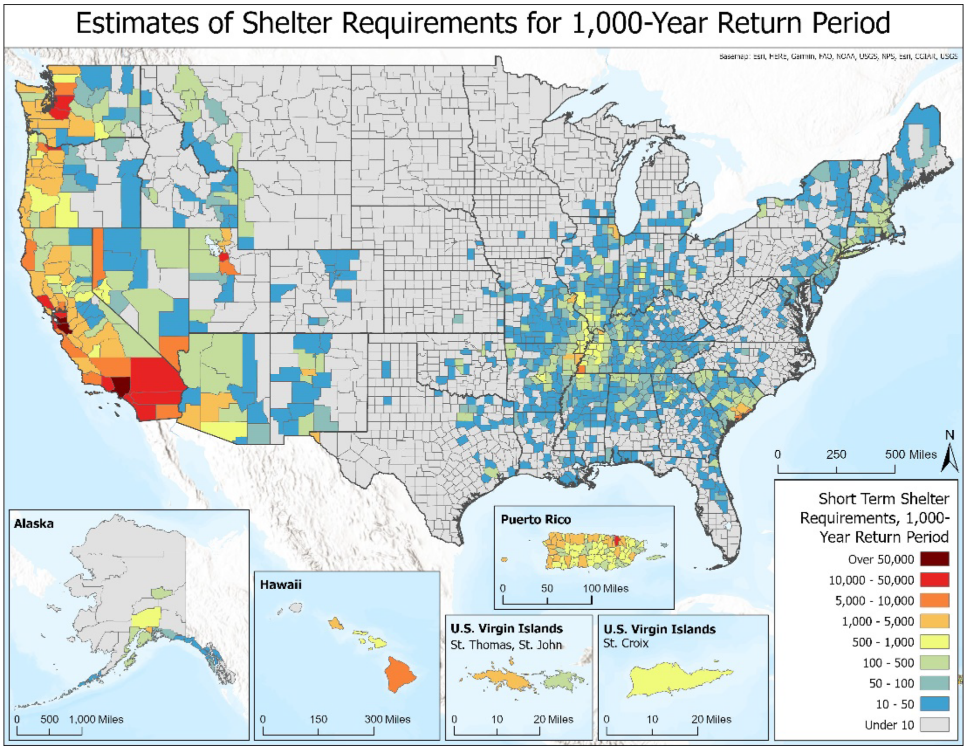


**Figure 3-14. Estimates of Shelter Requirements for 1000-year Return Period.**

**Table 3-8. Estimates of Short-Term Shelter Requirements for 250-year and 1,000-year Event (# of People, ranked by 1,000-year Event).**

| *Rank* | *State* | *250-Year Event* | *1,000-Year Event* |
|---|---|---|---|
| 1 | California | 213,023 | 700,699 |
| 2 | Puerto Rico | 24,740 | 89,144 |
| 3 | Washington | 18,229 | 83,889 |
| 4 | Oregon | 4,324 | 46,969 |
| 5 | Utah | 2,785 | 29,653 |
| 6 | Nevada | 4,171 | 21,475 |
| 7 | Tennessee | 1,213 | 19,109 |
| 8 | South Carolina | 686 | 17,582 |
| 9 | Missouri | 626 | 11,399 |
| 10 | Hawaiʻi | 2,954 | 10,635 |
| 11 | Illinois | 539 | 9,008 |
| 12 | Arkansas | 397 | 7,530 |
| 13 | Kentucky | 510 | 6,389 |
| 14 | New York | 373 | 5,419 |
| 15 | Arizona | 799 | 5,298 |
| 16 | Georgia | 516 | 4,857 |
| 17 | Alaska | 1,204 | 4,595 |
| 18 | Indiana | 310 | 3,634 |
| 19 | Mississippi | 201 | 3,558 |
| 20 | Alabama | 267 | 3,105 |
| 21 | Texas | 153 | 2,612 |
| 22 | U.S. Virgin Islands | 672 | 2,271 |
| 23 | New Mexico | 100 | 1,970 |
| 24 | Massachusetts | 171 | 1,815 |
| 25 | New Jersey | 110 | 1,749 |

| *Rank* | *State* | *250-Year Event* | *1,000-Year Event* |
|---|---|---|---|
| 26 | Ohio | 111 | 1,678 |
| 27 | Montana | 150 | 1,218 |
| 28 | Pennsylvania | 47 | 1,214 |
| 29 | Virginia | 45 | 986 |
| 30 | Idaho | 110 | 933 |
| 31 | Louisiana | 2 | 913 |
| 32 | Oklahoma | 0 | 887 |
| 33 | North Carolina | 34 | 779 |
| 34 | Florida | 0 | 760 |
| 35 | Michigan | 0 | 599 |
| 36 | Maryland | 0 | 450 |
| 37 | Connecticut | 34 | 448 |
| 38 | Wyoming | 59 | 430 |
| 39 | Maine | 41 | 422 |
| 40 | New Hampshire | 35 | 387 |
| 41 | Colorado | 20 | 343 |
| 42 | Kansas | 0 | 304 |
| 43 | Wisconsin | 0 | 219 |
| 44 | West Virginia | 13 | 190 |
| 45 | Iowa | 0 | 181 |
| 46 | Rhode Island | 13 | 159 |
| 47 | Vermont | 12 | 131 |
| 48 | Delaware | 1 | 115 |
| 49 | District of Columbia | 0 | 67 |
| 50 | Nebraska | 0 | 65 |
| 51 | South Dakota | 0 | 34 |

| Rank | State | 250-Year Event | 1,000-Year Event |
|---|---|---|---|
| 52 | Minnesota | 0 | 2 |
| 53 | North Dakota | 0 | 1 |

**Table 3-9. Estimates of Short-Term Shelter Ratio for 250-year and 1,000-year Event (# of People/Million, ranked by 1,000-year Event).**

| Rank | State | 250-Year Event | 1000-Year Event |
|---|---|---|---|
| 1 | Puerto Rico | 7,525 | 27,110 |
| 2 | U.S. Virgin Islands | 7,795 | 26,343 |
| 3 | California | 5,388 | 17,722 |
| 4 | Oregon | 1,020 | 11,085 |
| 5 | Washington | 2,366 | 10,887 |
| 6 | Utah | 851 | 9,064 |
| 7 | Hawai‘i | 2,030 | 7,308 |
| 8 | Nevada | 1,343 | 6,917 |
| 9 | Alaska | 1,641 | 6,266 |
| 10 | South Carolina | 134 | 3,435 |
| 11 | Tennessee | 176 | 2,765 |
| 12 | Arkansas | 132 | 2,500 |
| 13 | Missouri | 102 | 1,852 |
| 14 | Kentucky | 113 | 1,418 |
| 15 | Mississippi | 68 | 1,201 |
| 16 | Montana | 139 | 1,123 |
| 17 | New Mexico | 47 | 930 |
| 18 | Wyoming | 103 | 746 |
| 19 | Arizona | 112 | 741 |
| 20 | Illinois | 42 | 703 |
| 21 | Alabama | 53 | 618 |
| 22 | Indiana | 46 | 536 |

| ***Rank*** | ***State*** | ***250-Year Event*** | ***1000-Year Event*** |
|---|---|---|---|
| 23 | Idaho | 60 | 507 |
| 24 | Georgia | 48 | 453 |
| 25 | Maine | 30 | 310 |
| 26 | New Hampshire | 25 | 281 |
| 27 | New York | 18 | 268 |
| 28 | Massachusetts | 24 | 258 |
| 29 | Oklahoma | 0 | 224 |
| 30 | Vermont | 19 | 203 |
| 31 | Louisiana | 0 | 196 |
| 32 | New Jersey | 12 | 188 |
| 33 | Rhode Island | 11 | 145 |
| 34 | Ohio | 9 | 142 |
| 35 | Connecticut | 9 | 124 |
| 36 | Delaware | 1 | 116 |
| 37 | Virginia | 5 | 114 |
| 38 | West Virginia | 7 | 106 |
| 39 | Kansas | 0 | 104 |
| 40 | District of Columbia | 0 | 97 |
| 41 | Pennsylvania | 4 | 93 |
| 42 | Texas | 5 | 90 |
| 43 | North Carolina | 3 | 75 |
| 44 | Maryland | 0 | 73 |
| 46 | Colorado | 3 | 59 |
| 45 | Michigan | 0 | 59 |
| 47 | Iowa | 0 | 57 |
| 48 | South Dakota | 0 | 38 |
| 49 | Wisconsin | 0 | 37 |

| Rank | State | 250-Year Event | 1000-Year Event |
|---|---|---|---|
| 50 | Florida | 0 | 35 |
| 51 | Nebraska | 0 | 33 |
| 52 | North Dakota | 0 | 1 |
| 53 | Minnesota | 0 | 0 |

Table 3-10 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 3-10. 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, because severe damage and casualty rates are generally lowest in nighttime residential (primarily wood frames) occupancies for the majority of the United States. The one exception in the United States is Puerto Rico, where its high rate of masonry and concrete construction types for residential result in higher nighttime losses.

**Table 3-10. Annualized Estimates of Casualties (Day/Night ranked by daytime fatalities).**

| Rank | State | Day | | | Night | | |
|---|---|---|---|---|---|---|---|
| | | Minor | Major | Fatal | Minor | Major | Fatal |
| 1 | California | 2,720 | 95 | 184 | 1,177 | 22 | 41 |
| 2 | Washington | 406 | 14 | 27 | 120 | 2 | 4 |
| 3 | Oregon | 327 | 12 | 23 | 86 | 2 | 4 |
| 4 | Utah | 142 | 5 | 10 | 62 | 2 | 4 |
| 5 | Tennessee | 108 | 3 | 6 | 39 | 1 | 2 |
| 6 | Nevada | 94 | 3 | 6 | 30 | 1 | 1 |
| 7 | Puerto Rico | 102 | 3 | 5 | 162 | 4 | 9 |
| 8 | South Carolina | 76 | 2 | 5 | 31 | 1 | 2 |
| 9 | Illinois | 66 | 2 | 4 | 27 | 1 | 1 |
| 10 | Missouri | 64 | 2 | 4 | 33 | 1 | 2 |
| 11 | Arkansas | 49 | 1 | 3 | 18 | 0 | 1 |
| 12 | Kentucky | 44 | 1 | 2 | 13 | 0 | 1 |
| 13 | Hawaiʻi | 35 | 1 | 2 | 18 | 0 | 1 |

| Rank | State | Day | | | Night | | |
|---|---|---|---|---|---|---|---|
| | | *Minor* | *Major* | *Fatal* | *Minor* | *Major* | *Fatal* |
| 14 | Mississippi | 25 | 1 | 1 | 8 | 0 | 0 |
| 15 | Alaska | 23 | 1 | 1 | 9 | 0 | 0 |
| 16 | Arizona | 22 | 0 | 1 | 13 | 0 | 0 |
| 17 | Georgia | 21 | 0 | 1 | 8 | 0 | 0 |
| 18 | Indiana | 20 | 0 | 1 | 3 | 0 | 0 |
| 19 | New Mexico | 11 | 0 | 1 | 5 | 0 | 0 |
| 20 | Texas | 13 | 0 | 0 | 5 | 0 | 0 |
| 21 | Alabama | 13 | 0 | 0 | 4 | 0 | 0 |
| 22 | District of Columbia | 11 | 0 | 0 | 0 | 0 | 0 |
| 23 | Montana | 8 | 0 | 0 | 2 | 0 | 0 |
| 24 | Ohio | 8 | 0 | 0 | 5 | 0 | 0 |
| 25 | New York | 8 | 0 | 0 | 8 | 0 | 0 |
| 26 | Oklahoma | 6 | 0 | 0 | 4 | 0 | 0 |
| 27 | North Carolina | 5 | 0 | 0 | 3 | 0 | 0 |
| 28 | Idaho | 5 | 0 | 0 | 2 | 0 | 0 |
| 29 | New Jersey | 5 | 0 | 0 | 2 | 0 | 0 |
| 30 | Massachusetts | 4 | 0 | 0 | 2 | 0 | 0 |
| 31 | U.S. Virgin Islands | 4 | 0 | 0 | 4 | 0 | 0 |
| 32 | Virginia | 3 | 0 | 0 | 3 | 0 | 0 |
| 33 | Louisiana | 3 | 0 | 0 | 1 | 0 | 0 |
| 34 | Florida | 3 | 0 | 0 | 4 | 0 | 0 |
| 35 | Pennsylvania | 3 | 0 | 0 | 3 | 0 | 0 |
| 36 | Wyoming | 2 | 0 | 0 | 1 | 0 | 0 |
| 37 | Michigan | 2 | 0 | 0 | 1 | 0 | 0 |
| 38 | Colorado | 2 | 0 | 0 | 1 | 0 | 0 |
| 39 | Kansas | 2 | 0 | 0 | 1 | 0 | 0 |

| Rank | State | Day |  |  | Night |  |  |
|---|---|---|---|---|---|---|---|
|  |  | Minor | Major | Fatal | Minor | Major | Fatal |
| 40 | Maryland | 1 | 0 | 0 | 1 | 0 | 0 |
| 41 | Maine | 1 | 0 | 0 | 0 | 0 | 0 |
| 42 | Connecticut | 1 | 0 | 0 | 1 | 0 | 0 |
| 43 | New Hampshire | 1 | 0 | 0 | 1 | 0 | 0 |
| 44 | Iowa | 1 | 0 | 0 | 0 | 0 | 0 |
| 45 | Wisconsin | 1 | 0 | 0 | 0 | 0 | 0 |
| 46 | West Virginia | 1 | 0 | 0 | 1 | 0 | 0 |
| 47 | Delaware | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | Rhode Island | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | Vermont | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | Nebraska | 0 | 0 | 0 | 0 | 0 | 0 |
| 51 | Minnesota | 0 | 0 | 0 | 0 | 0 | 0 |
| 52 | South Dakota | 0 | 0 | 0 | 0 | 0 | 0 |
| 53 | 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, 2001, 2008, and 2017) 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 6.0 methods and data/2018 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, Hawaiʻi, Puerto Rico, and the U.S. Virgin Islands:

Hazus 6.0 methods and data/older (Alaska, 2007; Puerto Rico and U.S. Virgin Islands, 2003) and newer (Hawaiʻi, 2021) 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.

## 4.1 Study Parameters

Table 4-1 highlights the key changes in datasets and parameters between Hazus 99, Hazus-MH MR2, Hazus 3.0, and Hazus 6.0. The original earthquake loss study (FEMA, 2001) used the Hazus 99 methodology, the 1994 building data, population data from the 1990 census, and assumed site class D for all ground motions. 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 Hazus 3.0 study made use of 2014 CONUS seismic hazard models and incorporated Vs30-based, site-corrected ground motions as the basis for the annualized loss analyses. The present study using Hazus 6.0 makes use of new hazard models for CONUS (2018; Petersen et al., 2020) and Hawaiʻl (2021; Petersen et al., 2022). No hazard model changes were made to Alaska (2007; Wesson et al., 2007) and Puerto Rico (2003; Mueller et al., 2003), whereas the U.S. Virgin Islands are added for the first time.

**Table 4-1. Summary of Key Changes Incorporated into Hazus 6.0.**

| *Reference Data* | *Hazus 99 (FEMA, 2001)* | *Hazus-MH MR2 (FEMA, 2008)* | *Hazus 3.0 (FEMA, 2017)* | *Hazus 6.0 (FEMA, 2022)* |
|---|---|---|---|---|
| National Seismic Hazard Maps | 1996 National Seismic Hazard Maps (Frankel et al., 1996) | 2002 USGS National Seismic Hazard Maps (Frankel, et al. 2002) | 2014 USGS CONUS National Seismic Hazard Model (Petersen et al., 2014) | 2018 USGS CONUS National Seismic Hazard Model (Petersen et al., 2020) |

| ***Reference Data*** | ***Hazus 99 (FEMA, 2001)*** | ***Hazus-MH MR2 (FEMA, 2008)*** | ***Hazus 3.0 (FEMA, 2017)*** | ***Hazus 6.0 (FEMA, 2022)*** |
|---|---|---|---|---|
| Census Data | Loss estimates based on 1990 Census Data (U.S. Census, 1990) | Loss estimates based on 2000 Census Data (U.S. Census, 2000) | Loss estimates based on 2010 Census Data (U.S. Census, 2010) | Loss estimates based on 2020 Census Data (U.S. Census, 2020) |
| Building Inventory | 1994 Building Inventory and Occupancy to Building Type Distributions | 2002 Building Inventory (Dun & Bradstreet, 2002), RSMeans derived 2005 replacement costs, and updated Occupancy to Building Type Distributions | 2006 Building Inventory (Dun & Bradstreet, 2006), RSMeans derived 2014 replacement costs | NSI 2022 (USACE 2022), HIFLD Open (HIFLD 2022), RSMeans 2022 (Gordian, 2022) |
| Exposure | 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 | Building and Content Exposure based on General Building Stock datasets in the study region. |
| Reference Year ($ value for the loss) | Losses reported in 1994 values of dollars | Losses reported in 2005 values of dollars | Losses reported in 2014 values of dollars | Losses reported in 2022 values of dollars |

## 4.2 Comparison of AEL and AELR

In this study, we estimate a national AEL of $14.7 billion 2022 dollars, which also includes the losses estimated for Puerto Rico and the U.S. Virgin Islands. This is a 140% increase over the 2017 FEMA 366 estimate of $6.1 billion. However, if we adjust the 2017 FEMA 366 study results to reflect the current version values (2017 to 2022 dollars adjustment using Consumer Price Index, Inflation Calculator: https://www.bls.gov/data/inflation_calculator.htm), the FEMA 366 (2017) loss estimate would increase to $7.5 billion, which indicates that this update represents a large increase in the overall earthquake loss potential. This difference is mainly due to inventory updates, changes in the estimate of long-term earthquake hazard, and an improved site characterization model adopted in the present study. Since Hazus 3.0, which relied on year 2010 residential and 2006 non-residential building inventory, the national building inventory total replacement value increased by 42%, and the inflation-adjusted estimated earthquake loss ($7.5 billion to $14.7 billion) increased by almost 50%.

In the following sections, the reasons why the losses increased, due to overall increases in inventory and hazard, will be discussed.

## 4.3 Effect of a Change in Hazard

Figure 4-1A,B depicts the differences in hazard using the 0.3-second spectral ground accelerations with site soil amplification effects. By illustrating the 250- and 1,000-year return period, respectively, the figures show the negative values represent a decrease since the 2017 study (2014 CONUS hazard model), and the positive values represent an increase since the 2017 study. As described in Section 2, Hazus loss estimations for buildings are driven by the spectral ground accelerations at 0.3 and 1.0 second, and annualized losses are based on all eight return period earthquakes provided by the USGS. The change in ground motions vary by proximity to the earthquake source and return period of the earthquake. The ground motion difference shown in Figure 4-1A,B is considered representative of the spectral ground motions with the greatest impact on losses to the predominantly low-rise building types across the nation. The following patterns are noted:

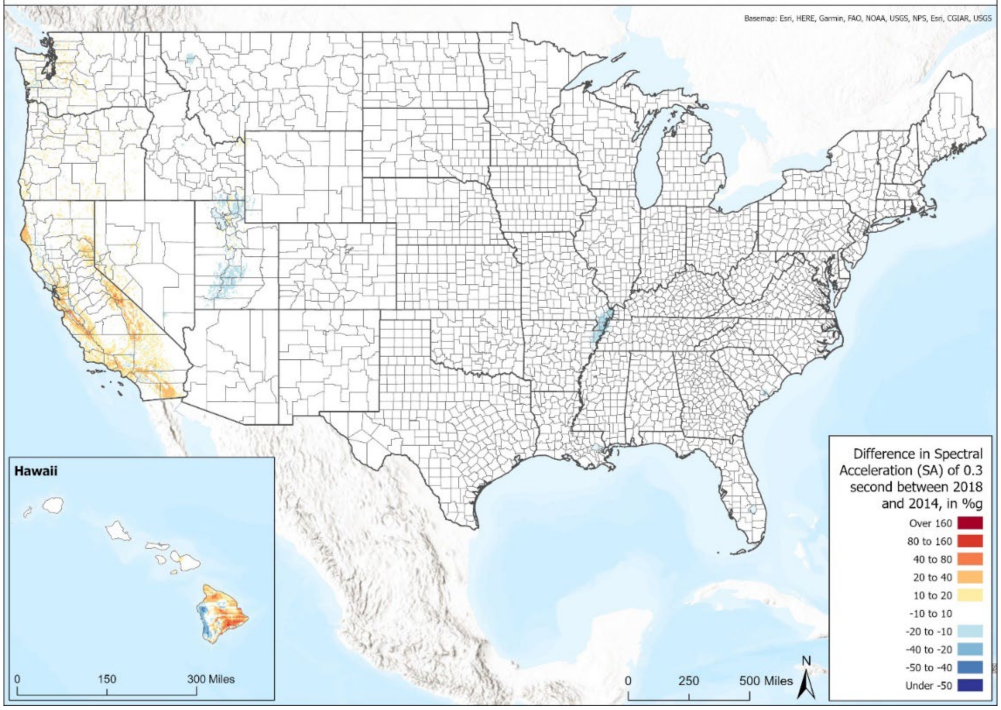
- More changes are in the western United States than in the central and eastern United States.
- The hazard increases in proximity to fault sources and decreases farther from fault sources in California.
- The coastal regions of northern California, Oregon, and Washington have increases.
- New composite site soil amplification mapping provided in the USGS Vs30 data highlight a pattern of change in Utah, Oregon, and Washington, where both increases and decreases occur. The 2018 USGS hazard model added basin effects for several places including Seattle Washington, Salt Lake City, Utah, and the Bay Area and Los Angeles, California. The basin effects increased the ground motions for long period buildings.
- Most of Utah shows a slight reduction in hazard; however, the more populated Wasatch Front and Salt Lake Valley has an increase in hazard.
- Western Colorado and most of western Montana and Wyoming have decreases in hazard.
- The New Madrid near-source areas have a slight decrease, while the hazard farther away from the source has increased.
- Relatively large ground motion increases are present for most of the Island of Hawaiʻi, except the Kona coast. The valley region of Maui has increases, and slight but notable increases occur on the southern coast of Oʻahu.
- Slight decreases are observed in eastern Tennessee, the Charleston, South Carolina, region, and northern Vermont.

The significance of the changes in probabilistic hazard estimates from the 2014 USGS model to the 2018 USGS model (while keeping the other analysis parameters constant) on annualized earthquake loss estimates is discussed below. In general, the results indicate a 160% increase in AELs for the highly seismic states of the western United States (California, Washington, and Oregon) driven by both increases in the inventory and the hazard. Increases are consistent but vary in importance for the central (129%) and northeast (6%) United States and are predominantly driven by the increase in inventory.

## 4.4 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. The older AEL studies in the United States including the FEMA 366 2001 and 2008 studies were based on the 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 substantially throughout the nation. Starting with FEMA 366 2017 and including this version, site soil corrections are included based on USGS data obtained from https://earthquake.usgs.gov/data/vs30/ that incorporate a composite of Vs30 mapping based on topography and shear wave velocity measurements (Heath et al., 2020).

A. Difference in the USGS Seismic Hazard Map between 2018 and 2014 for Spectral Acceleration (SA) of 0.3 second for 250-Year Return Period


Basemap: Esri, HERE, Garmin, FAO, NOAA, USGS, NPS, Esri, CGIAR, USGS

B. Difference in the USGS Seismic Hazard Map between 2018 and 2014 for Spectral Acceleration (SA) of 0.3 second for 1,000-Year Return Period

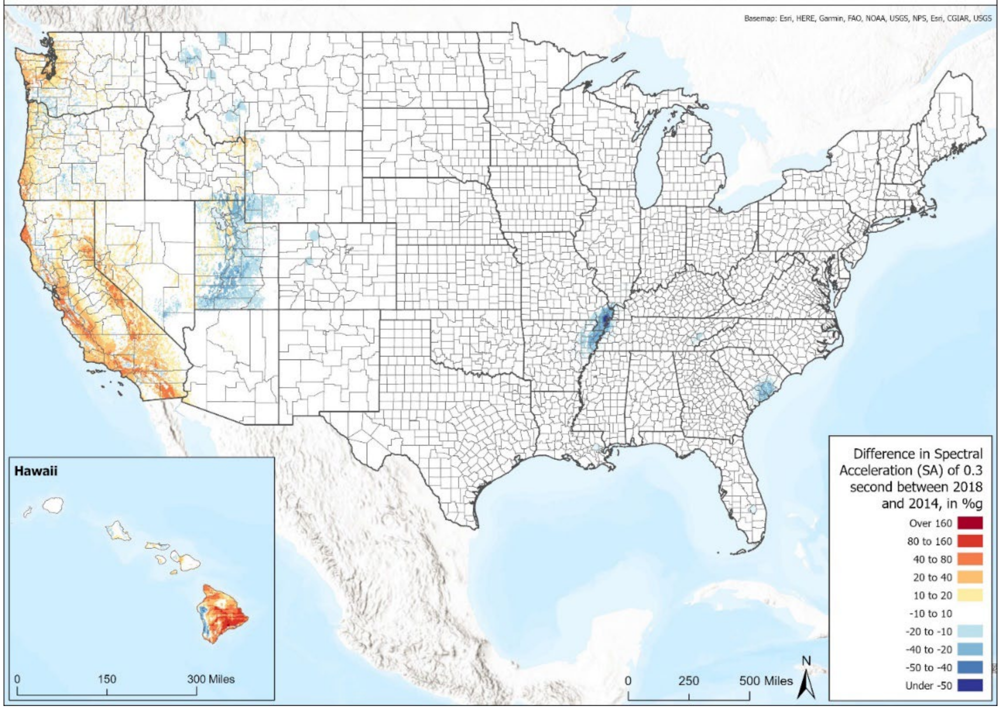

Basemap: Esri, HERE, Garmin, FAO, NOAA, USGS, NPS, Esri, CGIAR, USGS

**Figure 4-1A,B. Difference in the USGS National Seismic Hazard Model between 2018 and 2014 for Spectral Acceleration (SA) of 0.3 second for A. 250-Year Return Period and B. 1,000-Year Return Period. (Hawaiʻi represents 2021 compared to 1998, and no updates were made to the Alaska, Puerto Rico, or U.S. Virgin Islands hazard data.)**

The site soil amplification mapping for this update incorporates new data for Hawaiʻi (Wong et al., 2011), Utah, Oregon, and Washington that is reflected in Figure 4-2. Note that we applied these site amplification factors outside of Hazus directly to the 2018 (2021 for Hawai'i) USGS hazard curves. For the 2017 study, the site amplification factors were applied to the 2014 USGS B/C boundary category hazard curves. We used straight-line interpolation to obtain intermediate values of coefficients based on Vs30 values to derive the amplitude of ground motions. By default, Hazus now uses the site-amplified values for all probabilistic scenarios including the AEL performed for this study. However, if a user brings in a custom soil layer, the USGS B/C boundary conditions are used and amplified based on the 2015 NEHRP site soil amplification factors and the user's map.

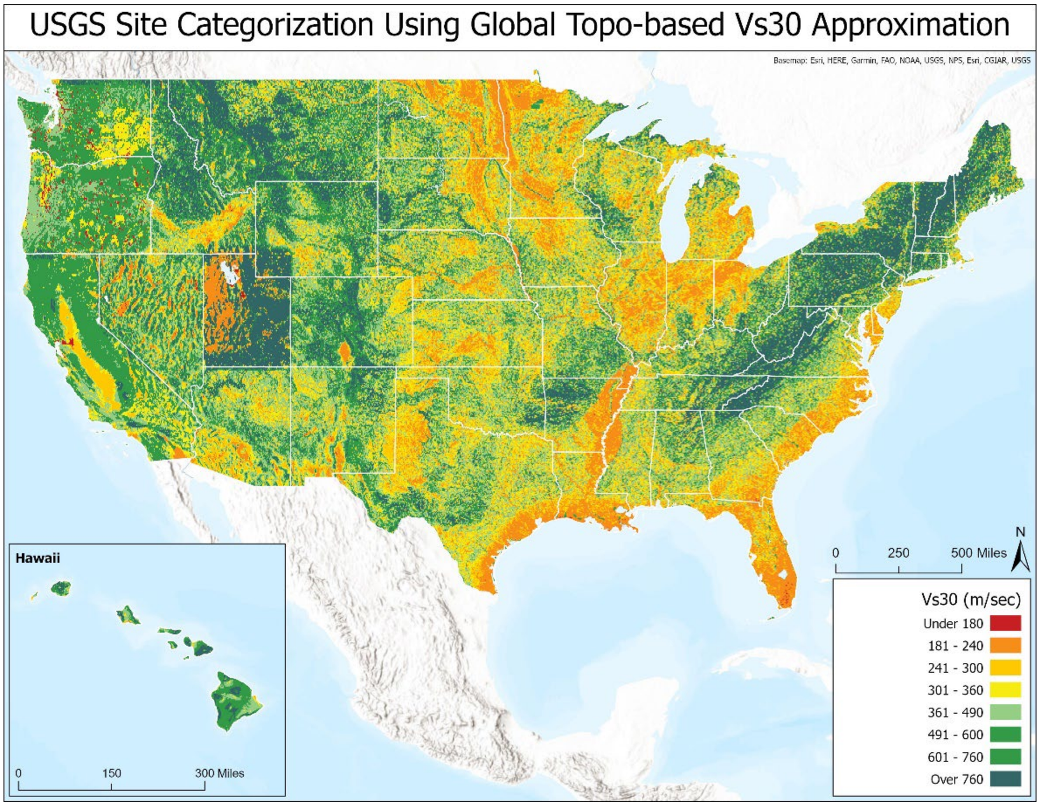


**Figure 4-2. USGS Site Categorization Using Global Topo-based Vs30 Approximation.**

Table 4-3 shows the annualized loss obtained from Hazus 6.0 using the 2018 CONUS hazard model (Hawai'i, 2021; Alaska, 2007; Puerto Rico and U.S. Virgin Islands, 2003) and the Hazus 3.0 analysis based on the 2014 CONUS USGS National Seismic Hazard Model (Hawai'i, 1998; Alaska, 2007; Puerto Rico and U.S. Virgin Islands, 2003) for all the states, including the percentage change. The negative values represent a decrease in losses. Analysis of the results reveals a general increase in AEL, with some exceptions. The 157% increase in California is notable and is mostly driven by the increase in inventory and valuation, and to a lesser degree (~22%) by an increase in the hazard data. In high hazard states, defined as having population exposed to seismic design category D or greater (Appendix D), three states have more than a 200% increase (Arizona, Idaho, and Mississippi) and 11 states with more than a 100% increase (Arkansas, California, Missouri, Montana, New Mexico, Nevada, Oregon, Tennessee, Utah, Washington, and Wyoming). In the western high hazard states, the increases are a combination of inventory, valuation, and hazard increases, whereas increases in the central and eastern states predominantly reflect the increase in inventory and valuations.

Many of the highest percentage increases occur in lower hazard states such as Kansas and Iowa where slight changes in the hazard can result in large percentage increases in losses, although they remain relatively low.

Table 4-4 lists the annualized loss ratio from 1996, 2002, 2014, and 2018 CONUS hazard models for all states. The reductions in AELR across nearly all states reflect the addition of substantial newer construction (new exposure), which is built to higher seismic design levels, newer code standards, and has reduced vulnerability. In addition, the continued reduction of AELR across all four versions of FEMA 366 since 2002 for all but a few states reflects the continued progress in reducing the overall vulnerability of the buildings in the United States. The reductions are a result of improving seismic hazard modeling, implementing advanced seismic provision through building codes, and adoption and enforcement of codes and standards for both new and existing buildings as demonstrated by FEMA's Building Codes Save project (FEMA, 2020a).

**Table 4-3. National Comparison of the AEL Values in $ by State for Hazus 6.0 (2018 CONUS hazard, and 2022 replacement cost) and Hazus 3.0 (2014 CONUS USGS Hazard Maps, and 2014 replacement cost).**

| *Rank* | *State* | *AEL 2018 CONUS Hazard (x $1,000)* | *AEL 2014 CONUS Hazard (x $1,000)* | *Percent Change* |
|---|---|---|---|---|
| 1 | California | 9,614,544 | 3,739,125 | 157 |
| 2 | Washington | 1,191,743 | 438,524 | 172 |
| 3 | Oregon | 744,979 | 271,113 | 175 |
| 4 | Utah | 366,714 | 124,637 | 194 |
| 5 | Puerto Rico | 326,781 | 252,911 | 29 |
| 6 | Nevada | 297,403 | 99,364 | 199 |
| 7 | Tennessee | 284,250 | 142,221 | 100 |
| 8 | South Carolina | 193,976 | 112,989 | 72 |
| 9 | Missouri | 188,476 | 83,762 | 125 |
| 10 | Illinois | 178,825 | 73,430 | 144 |
| 11 | Hawaiʻi | 126,956 | 106,825 | 19 |

| *Rank* | *State* | *AEL 2018 CONUS Hazard (x $1,000)* | *AEL 2014 CONUS Hazard (x $1,000)* | *Percent Change* |
|---|---|---|---|---|
| 12 | Alaska | 120,717 | 95,901 | 26 |
| 13 | Arkansas | 116,006 | 51,079 | 127 |
| 14 | Kentucky | 110,538 | 43,846 | 152 |
| 15 | Indiana | 87,362 | 34,888 | 150 |
| 16 | Georgia | 87,225 | 35,637 | 145 |
| 17 | Arizona | 86,095 | 26,751 | 222 |
| 18 | Mississippi | 69,937 | 23,299 | 200 |
| 19 | Alabama | 51,361 | 19,956 | 157 |
| 20 | New York | 45,353 | 59,352 | -24 |
| 21 | New Mexico | 41,071 | 15,205 | 170 |
| 22 | North Carolina | 36,133 | 15,380 | 135 |
| 23 | Texas | 35,610 | 13,334 | 167 |
| 24 | Ohio | 32,917 | 15,721 | 109 |
| 25 | Montana | 32,379 | 15,947 | 103 |
| 26 | Idaho | 26,898 | 8,231 | 227 |
| 27 | Oklahoma | 24,532 | 14,653 | 67 |
| 28 | New Jersey | 24,277 | 27,434 | -12 |
| 29 | Massachusetts | 21,642 | 26,264 | -18 |
| 30 | Pennsylvania | 17,360 | 12,929 | 34 |
| 31 | Virginia | 16,495 | 11,740 | 41 |
| 32 | U.S. Virgin Islands | 15,594 | NA | NA |

| Rank | State | AEL 2018 CONUS Hazard (x $1,000) | AEL 2014 CONUS Hazard (x $1,000) | Percent Change |
|---|---|---|---|---|
| 33 | Florida | 13,047 | 6,335 | 106 |
| 34 | Colorado | 11,919 | 10,978 | 9 |
| 35 | Louisiana | 11,499 | 3,671 | 213 |
| 36 | Wyoming | 10,956 | 4,837 | 126 |
| 37 | Michigan | 9,113 | 5,808 | 57 |
| 38 | New Hampshire | 6,932 | 7,301 | -5 |
| 39 | Maine | 6,851 | 5,689 | 20 |
| 40 | Kansas | 6,528 | 1,648 | 296 |
| 41 | Connecticut | 6,324 | 6,755 | -6 |
| 42 | Maryland | 6,171 | 5,767 | 7 |
| 43 | Iowa | 3,315 | 972 | 241 |
| 44 | Wisconsin | 2,929 | 1,295 | 126 |
| 45 | West Virginia | 2,855 | 1,456 | 96 |
| 46 | District of Columbia | 2,523 | 906 | 179 |
| 47 | Vermont | 2,440 | 1,894 | 29 |
| 48 | Delaware | 2,096 | 1,286 | 63 |
| 49 | Rhode Island | 1,671 | 1,944 | -14 |
| 50 | Nebraska | 1,082 | 584 | 85 |
| 51 | South Dakota | 661 | 374 | 77 |
| 52 | Minnesota | 612 | 383 | 60 |

| *Rank* | *State* | *AEL 2018 CONUS Hazard (x $1,000)* | *AEL 2014 CONUS Hazard (x $1,000)* | *Percent Change* |
|---|---|---|---|---|
| 53 | North Dakota | 132 | 58 | 129 |
| | **Total** | 14,723,809 | 6,082,388 | 83 |

**Table 4-4. National Comparison of the AELR Values by State for Each FEMA 366 Study using 2018, 2014, 2002 and 1996 USGS CONUS Hazard Models.**

| *Rank* | *State* | *AELR 2018 Hazard ($/million$)* | *AELR 2014 Hazard ($/million$)* | *AELR 2002 Hazard ($/million$)* | *AELR 1996 Hazard ($/million$)* |
|---|---|---|---|---|---|
| 1 | California | 808.5 | 971.5 | 1,452 | 1,580 |
| 2 | Oregon | 477.4 | 661.9 | 850 | 935 |
| 3 | Washington | 471.6 | 591.5 | 884 | 811 |
| 4 | Puerto Rico | 454.7 | 1,080.5 | NA | NA |
| 5 | U.S. Virgin Islands | 451.3 | NA | NA | NA |
| 6 | Utah | 419.6 | 498.6 | 817 | 802 |
| 7 | Alaska | 391.6 | 1,057.7 | 951 | 1,005 |
| 8 | Hawaiʻi | 328.8 | 708.4 | 488 | 531 |
| 9 | Nevada | 310.9 | 345.9 | 617 | 626 |
| 10 | Tennessee | 134.8 | 207.5 | 287 | 268 |
| 11 | Arkansas | 124.1 | 175.5 | 273 | 210 |
| 12 | South Carolina | 112.5 | 231.1 | 363 | 417 |
| 13 | Missouri | 82.9 | 118.0 | 218 | 190 |
| 14 | Kentucky | 74.6 | 94.0 | 151 | 140 |
| 15 | Mississippi | 74.5 | 83.1 | 117 | 98 |
| 16 | Montana | 68.3 | 147.6 | 304 | 332 |
| 17 | New Mexico | 55.6 | 82.7 | 205 | 245 |
| 18 | Wyoming | 46.6 | 78.4 | 187 | 214 |
| 19 | Idaho | 42.4 | 54.3 | 106 | 116 |

| *Rank* | *State* | *AELR 2018 Hazard ($/million$)* | *AELR 2014 Hazard ($/million$)* | *AELR 2002 Hazard ($/million$)* | *AELR 1996 Hazard ($/million$)* |
|---|---|---|---|---|---|
| 20 | Arizona | 41.8 | 42.4 | 79 | 108 |
| 21 | Illinois | 38.7 | 45.2 | 71 | 67 |
| 22 | Indiana | 36.1 | 45.8 | 73 | 70 |
| 23 | Alabama | 31.5 | 39.7 | 93 | 102 |
| 24 | Georgia | 25.3 | 33.2 | 77 | 102 |
| 25 | Oklahoma | 22.0 | 36.3 | 56 | 53 |
| 26 | New Hampshire | 15.2 | 43.3 | 92 | 128 |
| 27 | Maine | 14.1 | 35.0 | 74 | 101 |
| 28 | North Carolina | 10.5 | 14.7 | 62 | 80 |
| 29 | Massachusetts | 9.8 | 29.6 | 51 | 76 |
| 30 | Vermont | 9.2 | 23.3 | 103 | 149 |
| 31 | Louisiana | 8.0 | 8.0 | 12 | 14 |
| 32 | New Jersey | 8.0 | 24.1 | 63 | 97 |
| 33 | New York | 7.9 | 25.4 | 67 | 104 |
| 34 | Ohio | 7.8 | 11.0 | 26 | 30 |
| 35 | Colorado | 6.7 | 19.0 | 40 | 40 |
| 36 | Virginia | 6.5 | 11.6 | 32 | 47 |
| 37 | Delaware | 5.5 | 10.6 | 36 | 56 |
| 38 | Kansas | 5.4 | 4.9 | 14 | 11 |
| 39 | Connecticut | 5.2 | 13.8 | 45 | 71 |
| 40 | Rhode Island | 5.1 | 14.5 | 36 | 53 |
| 41 | West Virginia | 4.6 | 7.4 | 34 | 45 |
| 42 | Texas | 4.2 | 5.1 | 12 | 12 |
| 43 | Pennsylvania | 3.7 | 8.8 | 37 | 53 |
| 44 | District of Columbia | 3.5 | 9.6 | 28 | 38 |

| *Rank* | *State* | *AELR 2018 Hazard ($/million$)* | *AELR 2014 Hazard ($/million$)* | *AELR 2002 Hazard ($/million$)* | *AELR 1996 Hazard ($/million$)* |
|---|---|---|---|---|---|
| 45 | Maryland | 3.5 | 7.4 | 21 | 30 |
| 46 | Michigan | 2.6 | 4.6 | 6 | 6 |
| 47 | Iowa | 2.5 | 2.5 | 6 | 4 |
| 48 | Florida | 2.4 | 2.9 | 6 | 6 |
| 49 | Nebraska | 1.5 | 2.7 | 11 | 9 |
| 50 | South Dakota | 1.4 | 4.2 | 12 | 10 |
| 51 | Wisconsin | 1.2 | 1.7 | 4 | 4 |
| 52 | North Dakota | 0.3 | 0.7 | 2 | 2 |
| 53 | Minnesota | 0.3 | 0.5 | 1 | 1 |

## 4.5 Effect of Change in Building Inventory

These significant increases in projected annualized losses in all regions (Table 4-3) are 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.

Several examples highlight the benefits of identifying vulnerable structures, Utah Legislature, H.B. 278, Public Schools Seismic Studies, funded seismic safety evaluations for school buildings (Siegel, 2011). A statewide evaluation published by the Applied Technology Council (ATC, 2022) found 119 school campuses in 20 counties with URM construction where 72,126 children (or 12% of the total K-12 public school enrollment) spend some or all their school hours. Following FEMA's Rapid Visual Screening (RVS) methodology (FEMA P-154, 2015), the Central U.S. Earthquake Center (CUSEC) developed an RVS app (https://fema-p-154-rvs-cusec.hub.arcgis.com/) for multiple CUSEC states and beyond to develop their seismically vulnerable building inventories. As of 2022, the RVS application has been used by Tennessee to evaluate more than 50 critical facilities, by Missouri to inventory of more than 300 schools, and by the California Governor's Office of Emergency Services (OES) for inventory in Humboldt and Del Norte counties for more than 200 facilities and more than 1,000 individual buildings (CUSEC, 2023). CUSEC is hosting RVS data sites for Arkansas, Illinois, Indiana, Kentucky, and South Carolina for their RVS building inventory information. These states plan to develop building inventories in high hazard, earthquake-prone counties to prioritize retrofit of facilities exposed to potential seismic hazards (CUSEC, 2023).

In Hazus 6.0, default general building stock mapping schemes are used to map the building data by occupancy type to earthquake building types and design levels using mapping schemes. Although these schemes have not been updated with this study, the building distribution for the inventory of California changed substantially because the residential occupancy categories 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 (+23%) and a reduction in the amount of masonry, steel, and concrete buildings. This revision in the building distribution varies in other states. In Hazus 6.0, the default mapping scheme applied to the new National Structure Inventory (USACE, 2022)-based general building stock led to a further increase in wood-frame dwellings and a proportionate decrease in steel, concrete, and masonry buildings by count, as shown in Table 4-5. The proportion of manufactured homes and counts also have increased and these manufactured homes have been observed to continue to perform poorly in recent California earthquakes (Maison & Martinez, 2020). In the 2019 M7.1 Ridgecrest, California, earthquake, many manufactured homes fell off their foundations and ruptured gas lines causing fires.

**Table 4-5. 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% |
| **Hazus 6.0** | 86% | 3% | 5% | 4% | 3% |
| **Percent Change (Hazus 6.0 vs Hazus 99)** | +23% | -7% | -6% | -9% | 0% |

Using the example for California, Table 4-6 indicates the broad range and types of economic losses that are related to building damage. Note that as a percentage of the total direct economic losses to buildings, most are nonstructural, including 51% of the total economic loss and 60% when compared to the building capital losses only. Structural damage to buildings is 13% of the total economic loss. Based on the direct building capital losses, total economic loss increases to 15%. This is a common observation as the nation continues to build stronger and safer buildings. However, economic losses remain high in both modeled and observed U.S. earthquakes because exposures continue to increase, and mitigation of nonstructural, content, and other loss types have not been prioritized. This observation warrants 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 could also contribute to reducing earthquake injuries. Improving functional recovery time for critical facilities and buildings has become a desirable consideration for new building design and existing building retrofits. Although the loss estimates reported in this study do not include functional recovery time, mitigation that addresses nonstructural and structural damage and losses could directly contribute to shortening functional recovery time.

Generally, wood-frame construction is less vulnerable to earthquake damage than other building types, so this change in inventory composition was expected to reduce the AELR for California. Consequently, because California accounted for almost two-thirds of the total AEL for the United States, this change was expected to have a substantial effect on the overall study. This study documents that 59% of the 140% increase in AEL from Hazus 3.0 to Hazus 6.0 was largely attributed to the increase in building inventory and valuations. The total exposure in Hazus 3.0 was $58.6 trillion, and in Hazus 6.0 the total exposure is now $107.9 trillion. In California, of the 157% increase in losses (Table 4-3), approximately 22% is a result of the increase in the probabilistic, site-corrected seismic hazard for California.

Figure 4-4 illustrates that changes in population across the country have influenced the increase in total household units that changes the built environment in many high-risk areas, especially in the western United States. The total population exposed to high seismic hazard by state is provided in Appendix D.

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

| *Economic Losses* | Hazus 6.0 Using 2018 Hazard (in thousands of dollars) | Percentage of Total Economic Losses | Percentage of Total Building Capital Losses |
|---|---|---|---|
| Building Loss Structural | 1,207,642 | 13% | 15% |
| Building Loss Nonstructural | 4,929,645 | 51% | 60% |
| Content Loss | 1,907,414 | 20% | 23% |
| Inventory Loss | 179,085 | 2% | 2% |
| Relocation Costs | 533,487 | 6% | Not Applicable |
| Income Loss | 259,799 | 3% | |
| Wage Loss | 331,272 | 3% | |
| Rental Income Loss | 266,199 | 3% | |
| **Total Loss** | **9,614,544** | 100% | |

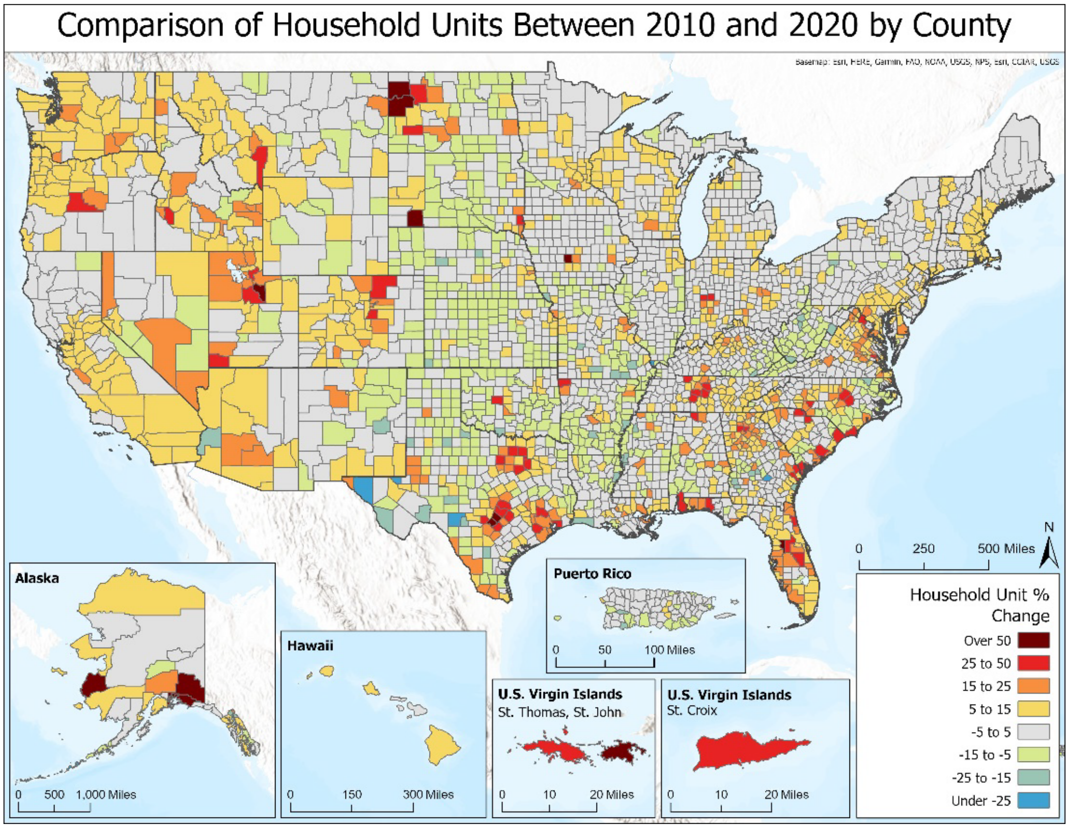


**Figure 4-4. Comparison of Household Units between 2010 and 2020 by County.**

# 5. Interpretation and Applications

Our understanding of the total distribution of earthquake risk to buildings continues to evolve through the work of NEHRP partner agencies in conducting and leveraging the latest scientific and engineering research on earthquake hazards and their effects on the built environment. The USGS remains at the forefront by providing the most up-to-date understanding of seismic hazard in the United States. The FEMA-initiated research and tools continue to shed light on the seismic vulnerability of existing and new buildings. These tools enable the latest data and information on building stock exposure to be integrated into FEMA's Hazus methodology for further application. FEMA P366 efforts during the past cycles (2001, 2008, 2017) and this one have merged the latest data and fostered cooperation between the NEHRP partner agencies to regularly evaluate the earthquake risk.  These efforts also highlight how risk may be affected by changes in the underlying hazard model and building stock exposure.

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 informing risk reduction strategies, seismic policy, and program development. Hazus methodologies and data are used in the recent landmark Building Codes Save study (FEMA, 2020a) to demonstrate that each $1 spent on building to higher standards results in $11 of future losses avoided.

## 5.1 Study Findings

- Although greatest on the West Coast, seismic risk exists in other areas of the United States.
    - The annualized loss from earthquakes nationwide is estimated to be $14.7 billion per year, with California, Washington, and Oregon accounting for $11.6 billion in estimated annualized earthquake losses, or 78% of the U.S. total. The remaining 22% of estimated annualized losses are distributed across the central United States ($1.10 billion), the northeastern states ($180 million), the Rocky Mountain/Great Basin region ($870 million), the Great Plains ($90 million), and the Southeast ($350 million). The states of Hawaiʻi and Alaska have a combined annualized loss of $250 million, whereas the Caribbean has an annualized loss of $340 million.
- An increase in building inventory will not always translate to a proportional increase in seismic risk.
    - In Hazus 6.0, even though the default general building stock mapping schemes remained the same, the building distribution for the inventory of California changed substantially because the residential occupancy categories like RES1 grew faster than others (Table 4-5). Wood-frame construction is less vulnerable to earthquake damage than other types of building construction types, such as masonry. This modification to the building type distribution was likely the primary reason for the reduction in the AELR for California [$808.5 (Hazus 6.0), $971.5 (Hazus 3.0), $1,452 (Hazus-MH MR2) and $1,580 (Hazus 99)]. AELR reductions were noted in all high earthquake hazard states, providing 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 several states—New York, South Carolina, Utah, California, and Washington—losses were estimated in metropolitan areas (Metropolitan Statistical Areas defined by the Office of Management and Budget [OMB]. For the purposes of this study, areas that also have an AEL greater than $10 million account for up to 97% of total state losses. This has important implications for the national strategy to reduce seismic risk. More than 55% 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 21.2 million (2022) and account for more than 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.
    - The spectral ground motions used by Hazus (0.3 and 1.0 second) in this study include increased site-corrected ground shaking in the western United States, as well as near four

urban areas (Los Angeles, San Francisco, Seattle, and Salt Lake City) overlying deep sedimentary basins in the western United States (Petersen et al., 2020).

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

1. To improve understanding of the seismic risk in the United States.

   This study builds on the knowledge gained from the original FEMA 366 studies (FEMA, 2001, 2008 and 2017) to incorporate new data that directly influences earthquake loss and mitigation. In particular, this study utilizes (1) the seismic hazard (2018 hazard data for CONUS [Petersen et al., 2020]); (2) inventory (National Structure Inventory [USACE, 2022] and 2022 building replacement cost derived from RSMeans values [Gordian, 2022]); (3) population at risk (2020 census data [U.S. Census, 2021]); and (4) estimated social losses. By continuing to improve these important parameters, this latest study provides a clearer picture of the role each data type plays in shaping seismic risk in the United States. 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 levels. 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.

   Information from this study directly feeds into the FEMA National Risk Index (FEMA, 2021) and serves as the earthquake hazard's expected annual loss factor. The National Risk Index is an online application that identifies communities most at risk to 18 natural hazards. This application visualizes natural hazard risk metrics and includes data about expected annual losses from natural hazards, social vulnerability, and community resilience. The results of this study and integration into the National Risk Index enable a refined understanding of earthquake hazard risk.

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

   AEL and AELR serve as 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.

   Addressing existing vulnerable buildings by adopting ordinances and requiring building owners to mitigate existing buildings is especially challenging because it can be expensive. There have been notable successes, including URM programs in Seattle and Salt Lake. In 2015, the City of Los Angeles adopted an ordinance 183893 to retrofit 14,000 pre-1978 wood-frame, soft-story buildings and non-ductile concrete buildings (LADBS, 2023). The City of Los Angeles has invested $1.3 billion in retrofitting over 8,000 buildings through 2022 (Lin, 2022). Although a large investment, the AEL estimated for Los Angeles County in this study is $2.68 billion.

3. To evaluate the costs and benefits of seismic building code provisions.

   One of the objectives of the NEHRP is to promote the adoption and enforcement of seismic building codes (Burby and May, 1999) in regions of the United States that experience infrequent but damaging earthquakes. Uniform adoption and enforcement could be beneficial because of the uneven distribution of seismic risk across the United States. 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 6.0 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 294 study (FEMA, 1997) concluded 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.

   In the more recent FEMA Building Codes Save study (FEMA, 2020a), it was shown that the recent adoption of the latest seismic provisions of the International Building Code (IBC) resulted in an average of $25 per structure in avoided loss per year across six western states (Alaska, California, Hawaiʻi, Oregon, Utah, and Washington). The differences were larger in states where weaker codes were in place prior to the IBC, such as Hawaiʻi, where the losses avoided per year because of recent code adoption is $56 per structure.

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 Framework (NRF). Such estimates are useful planning tools to identify and prioritize mitigation measures that address life, safety, and functionality of essential facilities. The ability to provide earthquake impacts in terms that are widely understood, such as social impacts including casualties and shelter needs, economic losses and debris helps enable all response partners to prepare for and provide a unified national response to future earthquake disasters.

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# Appendix

## 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 because 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.

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 – FEMA's Hazus Program provides standardized tools and data for estimating risk from earthquakes, floods, tsunamis, and hurricanes. See https://www.fema.gov/flood-maps/products-tools/hazus for more information, or appendix B below.

National Risk Index (NRI) – The NRI is an online application https://hazards.fema.gov/nri/ from FEMA that identifies communities most at risk to 18 natural hazards. This application visualizes natural hazard risk metrics and includes data about expected annual losses from natural hazards, social vulnerability, and community resilience. The results of this study and integration into the National Risk Index enable a refined understanding of earthquake hazard risk.

National Structure Inventory (NSI) – The NSI https://nsi.sec.usace.army.mil/downloads/ is a system of databases containing structure inventories of varying quality and spatial coverage. The purpose of the NSI databases is to facilitate storage and sharing of point-based structure inventories used in the assessment and analysis of natural hazards. Flood risk is the primary usage, but sufficient data exists on each structure to compute damages and life safety risk due to other hazard types.

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). In Hazus we also use PGV that represent the peak ground motions expressed by velocity and SA that represents the ground motion at a particular period of vibration (0.3 and 1.0 second).

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 or 1 second) to a given earthquake ground motion. SA is most closely related to structural response and, therefore, indicates an earthquake's damage potential.

Seismic Design Category (SDC) – An indicator of how much attention must be paid to the seismic design and construction of a building.

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

Hazus is a nationally standardized risk modeling methodology. It is distributed as free GIS-based desktop software with a collection of inventory databases for every U.S. state and territory. Hazus identifies areas with high risk for natural hazards and estimates physical, economic, and social impacts of earthquakes, hurricanes, floods, and tsunamis. The Hazus Program, managed by FEMA's Natural Hazards Risk Assessment Program, partners with other federal agencies, research institutions, and regional planning authorities to ensure Hazus resources incorporate the latest scientific and technological approaches and meet the needs of the emergency management community.

Hazus is used for mitigation, recovery, preparedness, and response. Mitigation planners, GIS specialists, and emergency managers use Hazus to determine potential losses from disasters and to identify the most effective mitigation actions for minimizing those losses. Hazus supports the risk assessment requirement in the mitigation planning process. Response planners use Hazus to map potential impacts from catastrophic events and identify effective strategies for response and preparedness. Hazus is also used during real-time response efforts to estimate impacts from incoming storms or ongoing earthquake sequences.

Hazus can quantify and map risk information such as:

- Physical damage to residential and commercial buildings, schools, critical facilities, and infrastructure.
- Economic loss, including lost jobs, business interruptions, and repair and reconstruction costs.
- Social impacts, including estimates of displaced households, shelter requirements, and populations exposed to floods, earthquakes, hurricanes, and tsunamis.
- Cost-effectiveness of common mitigation strategies, such as elevating structures in a floodplain or retrofitting unreinforced masonry buildings.

Full technical details regarding the loss estimation methodology in FEMA's Hazus earthquake model can be found in the Hazus Earthquake Technical Manual (FEMA, 2022a)

Hazus version 6.0 also included important baseline inventory dataset improvements to demographics, buildings, essential facilities, transportation and utility systems, and vulnerability information. Details can be found at https://www.fema.gov/sites/default/files/documents/fema_hazus-6-data-updates-factsheet.pdf and in the Hazus Inventory Technical Manual Hazus 6.0 (FEMA, 2022b).

## C. Probabilistic Hazard Data Preparation and AEL Computation

The 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 at 0.3, SA at 1.0, and PGV at each grid point for the eight return periods.

The latest 2018 CONUS and 2021 Hawaiʻi seismic hazard model of the USGS was used in the present investigation (Petersen et al., 2021). 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 continental United States. The hazard models for Alaska, Puerto Rico and the U.S. Virgin Islands were not up to date at the time of this investigation; hence, we relied on utilizing the 2007 model for Alaska and 2003 model for Puerto Rico and the U.S. Virgin Islands.

Table C-1 provides an example of the USGS hazard data for an individual grid point. In the table, for each of the 19 (or 20) intensity-probability pairs, the intensity of the ground motion parameters (PGA, SA at 0.3 second, and SA at 1.0 second) is shown along with the corresponding annual frequency of exceedance (AFE). Note that for the building losses presented in this report, Hazus only considers the spectral ground motion SA at 0.3 second and SA at 1.0 second in the loss computation. The USGS PGA and PGV values are used for other loss calculations including liquefaction potential and pipeline related losses, respectively.

**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 |

| *Ground Motion Data* | | | | | | |
|---|---|---|---|---|---|---|
| 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 | Not Applicable | Not Applicable | 5.5400 | 0.000000002 |

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

For CONUS and Hawaiʻi regions, the 2018 and 2021 USGS NSHM models were used to derive site-corrected hazard curves by using a reference global hybrid Vs30 values from Heath et al. (2020) for each grid location. For Alaska, Puerto Rico, and U.S. Virgin Islands, the USGS data were based on an 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 Vs30 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 at 0.3, and SA at 1.0 at each grid point.

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

For each grid point, a log-log interpolation of the data 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 area weights the ground shaking values provided by the USGS grid across each census tract. This method consists of calculating the area of each tract exposed to each level of ground shaking and weighting the ground shaking by area. For example, if 10% of the tract is exposed to ground shaking of 0.6 g and 90% is exposed to 0.4 g, the area weighted ground motion is $0.42\ g\ ((0.6\ g \text{ x } 10\%) + (0.4\ g \text{ x } 90\%))$.

**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 second)** | **SA(1.0 second)** |
| 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 |

## 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-2 for Los Angeles County, California. Hazus computes annual losses for eight probabilistic return periods (RPs) 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-3 shows a sample computation for average annualized loss where the summation of the contribution for each return period is $2.66B for Los Angeles County, by far the highest in the nation.

Figure C-1 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-1. 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 would be a good approximation. The constraint on the upper bound of the number was computational efficiency versus improved marginal accuracy. To determine the appropriate number of return periods, the 2008 version of FEMA 366 (FEMA, 2008) conducted a sensitivity study 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-2. Average Annualized Earthquake Loss Calculation for Los Angeles County in California.**

| # | *Return Period* | *Annualized Probabilities* | *Differential Probabilities* | | *Return Period Losses* | *Average Losses* | *Annualized Loss* |
|---|---|---|---|---|---|---|---|
| | | | *Formulas* | *Values* | | | |
| 1 | 2,500 | 0.00040 | P2500 | 0.00040 | L2500 | L2500 | P2500 x L2500 |
| 2 | 2,000 | 0.00050 | P2000 – P2500 | 0.00010 | L2000 | (L2500+L2000)/2 | (P2500 x P2500) x (L2500+L2000)/2 |
| 3 | 1,500 | 0.00067 | P1500 – P 2000 | 0.00017 | L1500 | (L2000+L1500)/2 | (P1500 x P2000) x (L2000+L1500)/2 |
| 4 | 1,000 | 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 |
| | | | | | | Total | Σ ( ) |

**Table C-3. Average Annualized Earthquake Loss Computation for Los Angeles County in California.**

| # | *Return Period* | *Annualized Probabilities* | *Differential Probabilities* | *Return Period Losses (Billions of $)* | *Average Losses (Billions of $)* | *Annualized Loss (Billions of $)* |
|---|---|---|---|---|---|---|
| 1 | 2,500 | 0.00040 | 0.00040 | $1,136.79 | $1,136.79 | $0.4547 |
| 2 | 2,000 | 0.00050 | 0.00010 | $1,040.91 | $1,088.85 | $0.1089 |
| 3 | 1,500 | 0.00067 | 0.00017 | $913.57 | $977.24 | $0.1629 |
| 4 | 1,000 | 0.00100 | 0.00033 | $564.09 | $738.83 | $0.2463 |
| 5 | 750 | 0.00133 | 0.00033 | $476.35 | $520.22 | $0.1734 |
| 6 | 500 | 0.00200 | 0.00067 | $361.93 | $419.14 | $0.2794 |
| 7 | 250 | 0.00400 | 0.00200 | $163.25 | $262.59 | $0.5252 |
| 8 | 100 | 0.01000 | 0.00600 | $72.34 | $117.80 | $0.7068 |
| | | | | | Total | **$2.6576** |

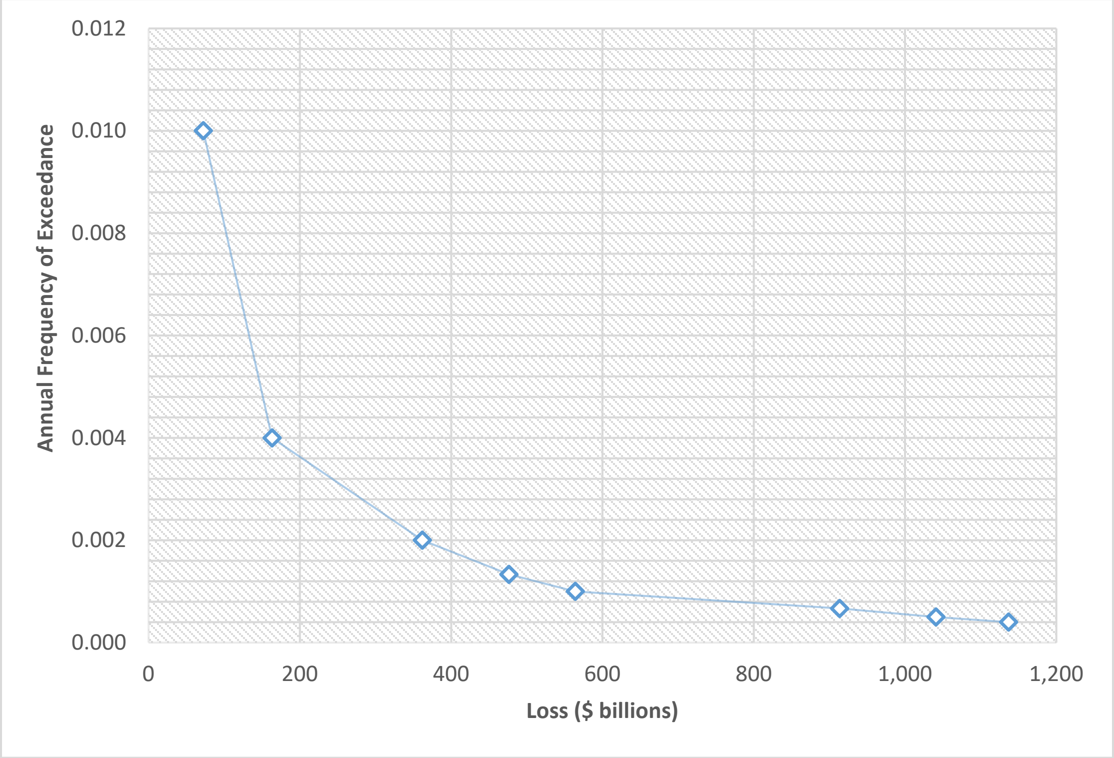

**Figure C-1. Probabilistic Loss Curve for Los Angeles County, California.**

## D. Population Exposure by State to High Seismic Design Categories

In addition to estimating earthquake losses, another important application of the USGS earthquake hazard maps is to inform the latest seismic building codes. The USGS collaborates with organizations that develop model building codes to make seismic design parameter values available to engineers. Based on the 2020 *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures* (FEMA P-2082, [FEMA, 2020b]) and ASCE 7-22 Minimum Design Loads and Criteria for Buildings and Other Structures, the Seismic Code Support Committee (SCSC) and USGS produced Seismic Design Category (SDC) maps for the 2024 International Building Code (IBC) and International Residential Code (FEMA P-2192-4 [FEMA, 2023]). The SDC D corresponds to areas expected to experience severe and destructive ground shaking, and are not located close to a major fault, whereas SDC E represents high risk areas that are also near major active faults. The SDC D or E represent high seismic hazards for potential building collapse and damage. An assessment of total population and land areas exposed to SDC D or E per maps for 2024 IBC by state is presented in Table D-1, below.

**Table D-1. Population Exposure by State to Seismic Design Categories (SDC) D or E**

| *State* | *SDC D or E* | *Developed Land Area (sq. km.)* | *Land Area (sq. km.)* |
|---|---|---|---|
| California | 39,538,223 | 14,584 | 646,400 |
| Washington | 6,966,185 | 4,200 | 315,192 |
| Oregon | 4,152,460 | 2,775 | 458,298 |
| Tennessee | 4,110,419 | 3,309 | 89,333 |
| Puerto Rico | 3,285,874 | 1,436 | 9,910 |
| Utah | 3,178,870 | 1,672 | 280,063 |
| Nevada | 3,104,614 | 1,331 | 477,410 |
| Missouri | 2,875,678 | 2,361 | 107,356 |
| Arkansas | 1,667,895 | 1,851 | 118,027 |
| Hawaiʻi | 1,381,973 | 493 | 17,056 |
| Illinois | 1,296,573 | 1,591 | 76,303 |
| South Carolina | 1,239,371 | 1,017 | 35,423 |
| New Mexico | 1,170,446 | 803 | 88,898 |
| Mississippi | 884,693 | 1,082 | 61,819 |
| Kentucky | 884,128 | 1,222 | 50,099 |
| Alaska | 728,457 | 536 | 8,129,971 |

| *State* | *SDC D or E* | *Developed Land Area (sq. km.)* | *Land Area (sq. km.)* |
|---|---|---|---|
| Montana | 614,261 | 747 | 303,195 |
| Idaho | 525,035 | 585 | 261,134 |
| Indiana | 524,741 | 577 | 23,150 |
| Arizona | 398,028 | 324 | 132,587 |
| Alabama | 336,317 | 452 | 16,233 |
| Guam | 153,898 | 71 | 586 |
| Oklahoma | 86,296 | 76 | 5,585 |
| U.S. Virgin Islands | 86,213 | 64 | 387 |
| Wyoming | 78,614 | 134 | 112,013 |
| American Samoa | 49,757 | 21 | 229 |
| Northern Mariana Islands | 47,331 | 22 | 327 |
| Texas | 39,901 | 32 | 33,953 |
| Colorado | 10,549 | 32 | 23,802 |
| Maine | 2,745 | 6 | 16,718 |
| **Grand Total** | **79,419,545** | **43,406** | **11,891,457** |