Alaska

Hawaii

Puerto Rico

0   50   100 Miles

U.S. Virgin Islands
St. Thomas, St. John

0   10   20 Miles

U.S. Virgin Islands
St. Croix

0   10   20 Miles

0   500   1,000 Miles

0   150   300 Miles

0   250   500 Miles

N

Annualized Earthquake Loss Ratio (AELR), in $ per Million $

Over 1,000
500 - 1,000
100 - 500
50 - 100
10 - 50
Under 10

Hazus Estimated Annualized Earthquake Losses for the United States

FEMA P-366 / April 2023

U.S. DEPARTMENT OF HOMELAND SECURITY — FEMA

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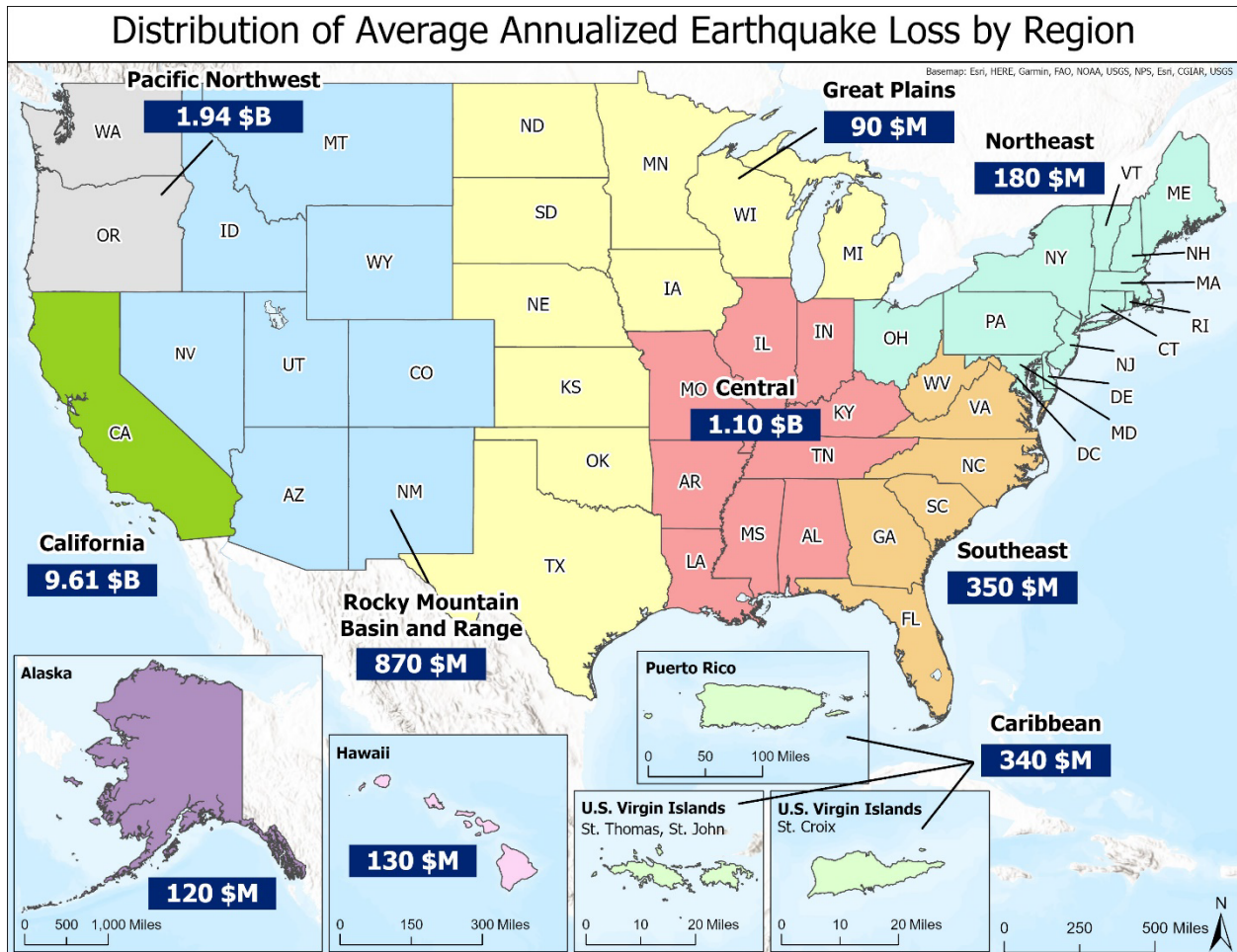
Figure E-1. Distribution of Average Annualized Earthquake Loss by Region.

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.
	Ground motion parameters are area weighted within each census tract based on the USGS ground motion grids.
	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:
	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 Hawaiʻi (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 Hawaiʻi site soil amplification map was supplemented with data from Wong et al. (2011).
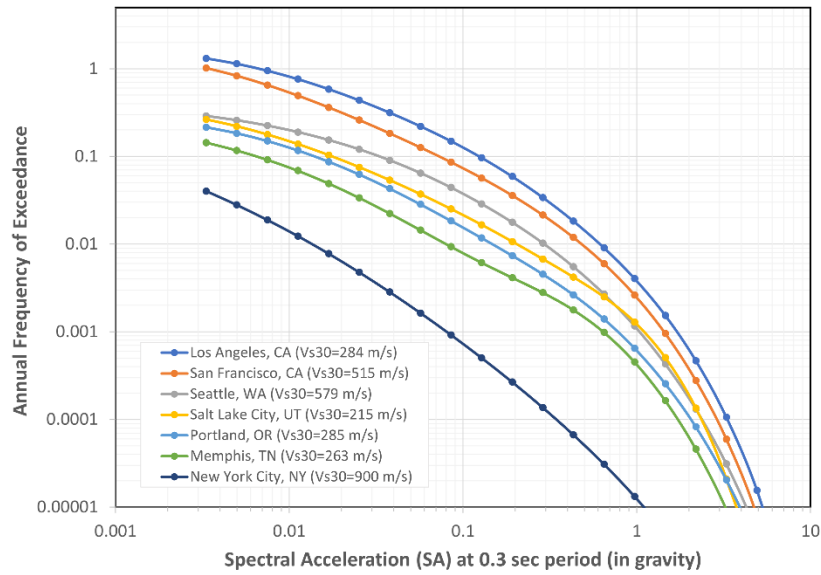
Figure 2-1. Average Annual Frequency of Site-Corrected Spectral Acceleration (0.3 second) for Seven Major Cities.

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
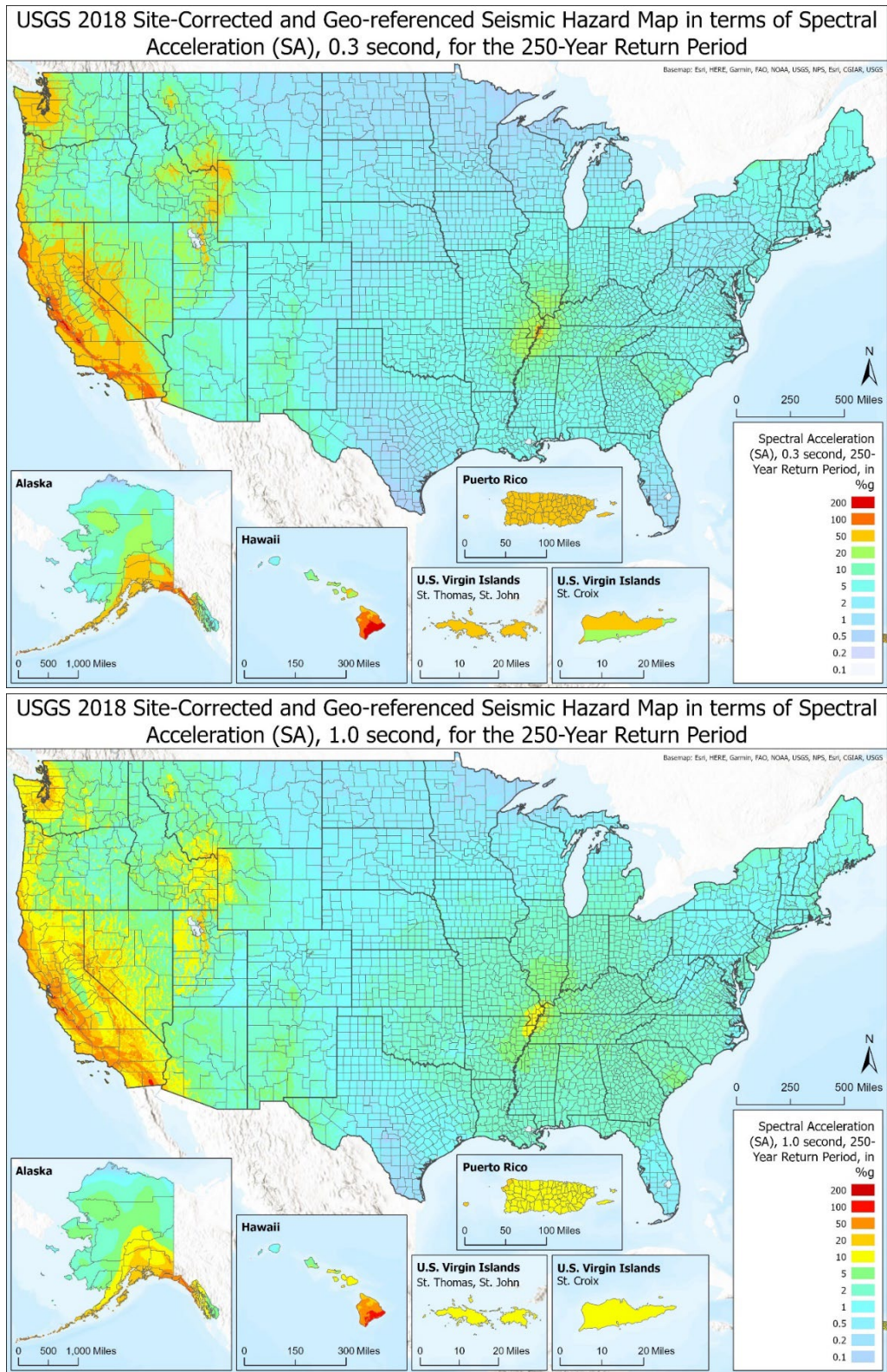
Figure 2-2. USGS 2018 Site-Corrected and Georeferenced Seismic Hazard Map in terms of spectral acceleration at 0.3 (Top) and 1.0 second (Bottom) for the 250-year Return Period.
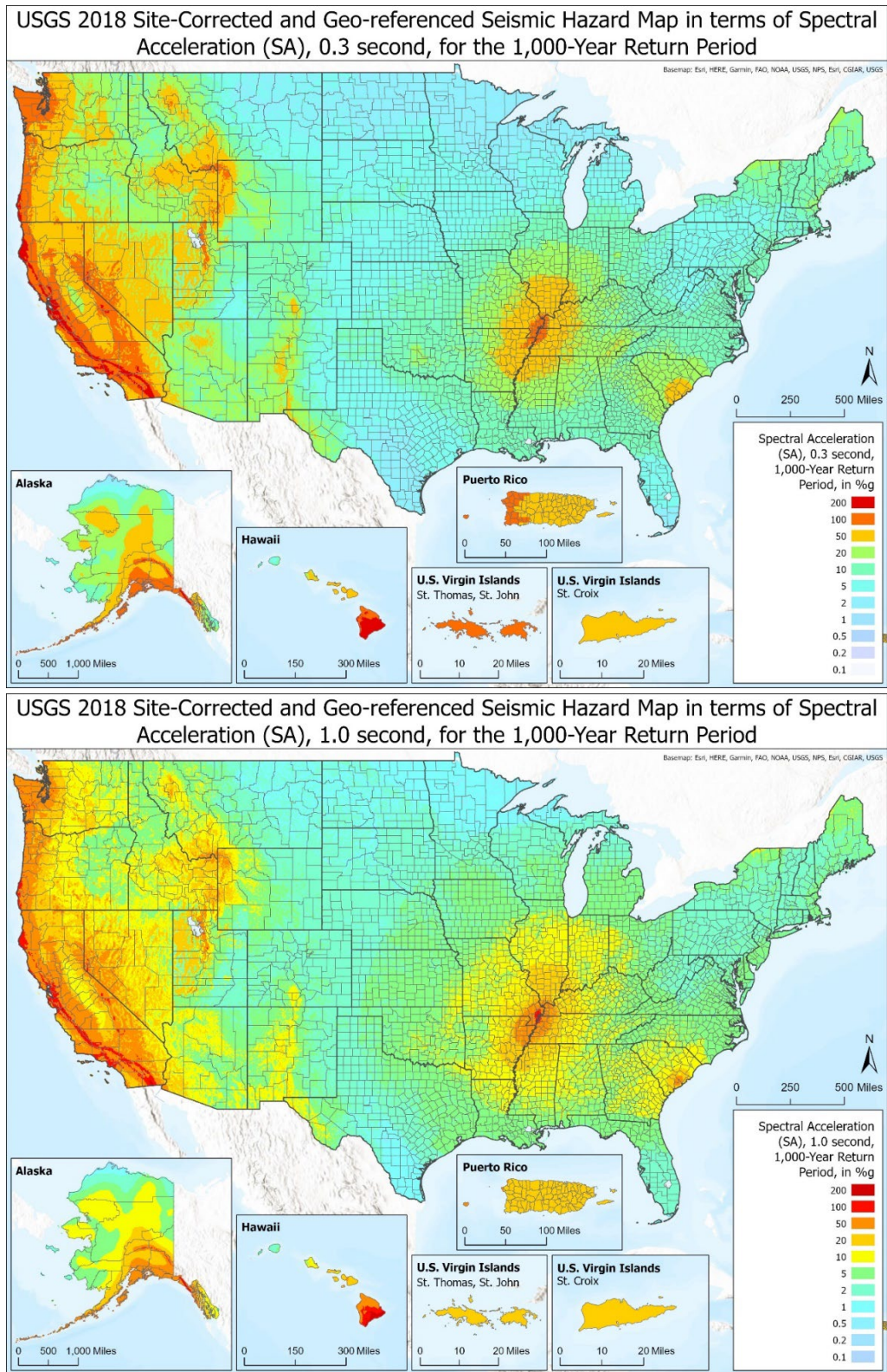
Figure 2-3. USGS 2018 Site-Corrected and Geo-referenced Seismic Hazard Map in terms of spectral acceleration at 0.3 (Top) and 1.0 second (Bottom) for the 1,000-year Return Period.

USGS Site-Corrected 2018 Hazard Map for Spectral Acceleration (SA): 0.3 second, 1,000-Year Return Period, in % g for California

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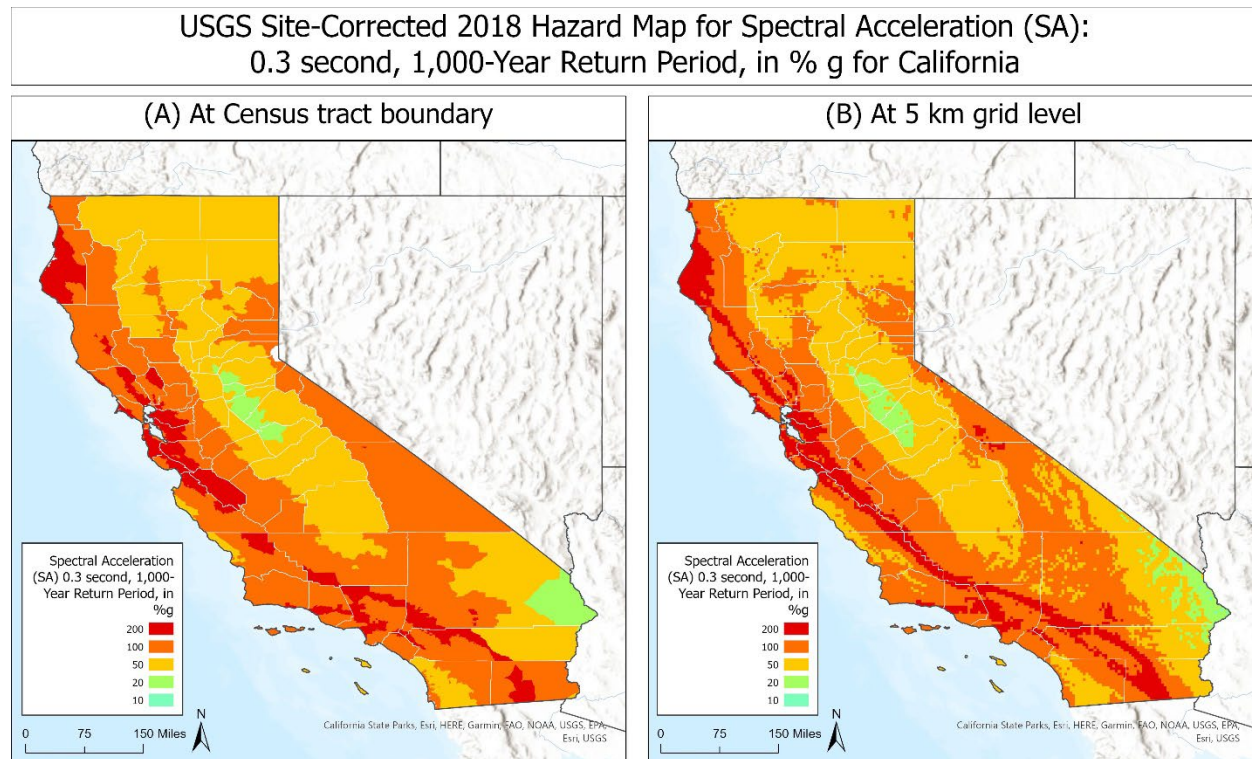
Figure 2-4. USGS Site-Corrected Seismic Hazard Map for Spectral Acceleration (SA) 0.3 second, 1,000 Year Return Period in % g for California: (A) at the Census Tract Level, (B) at the 5-km Grid Level.

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.
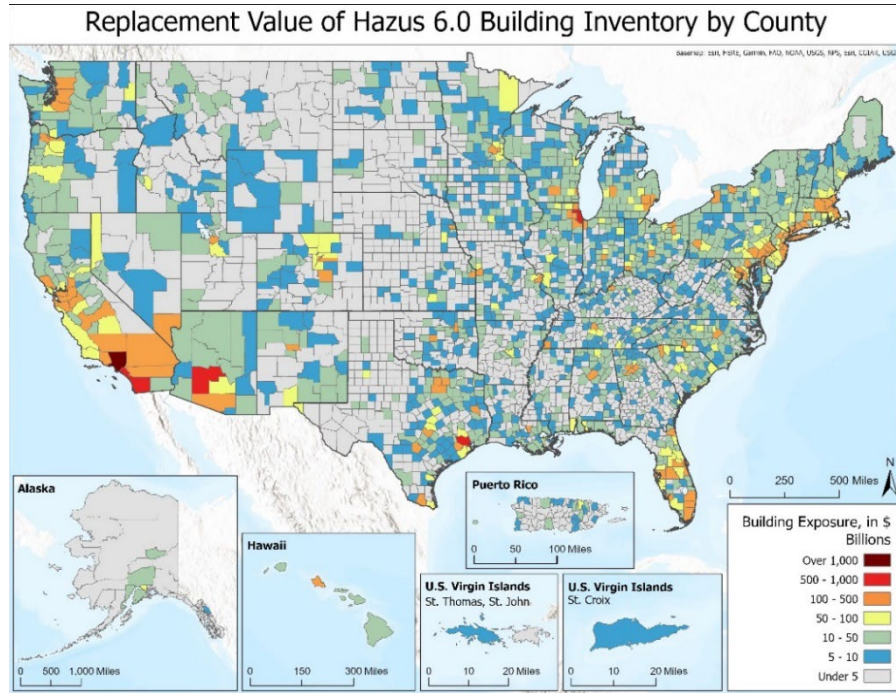
Figure 2-5. Replacement Value of Hazus 6.0 Building Inventory by County.
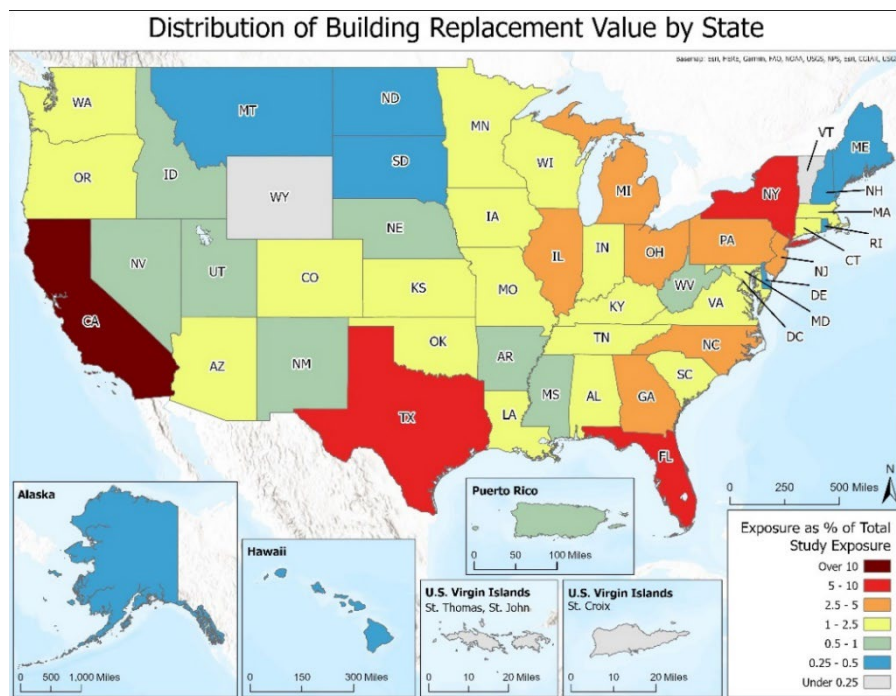
Figure 2-6. Distribution of Building Replacement Value by State.

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 Hawaiʻi), 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).
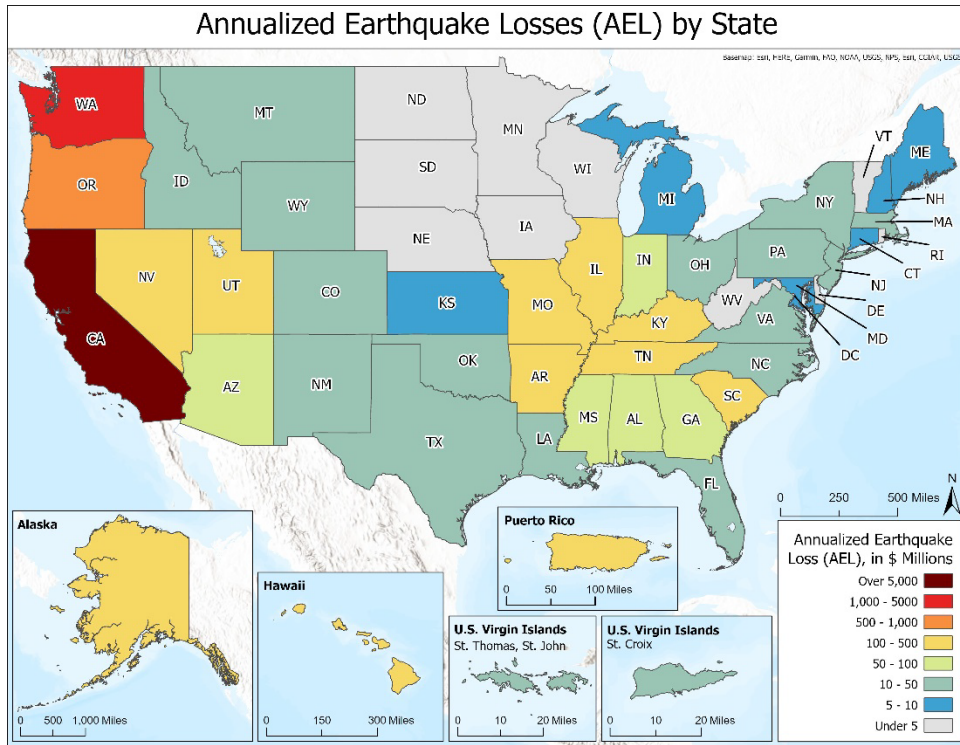
Figure 3-1. Annualized Earthquake Losses by State.
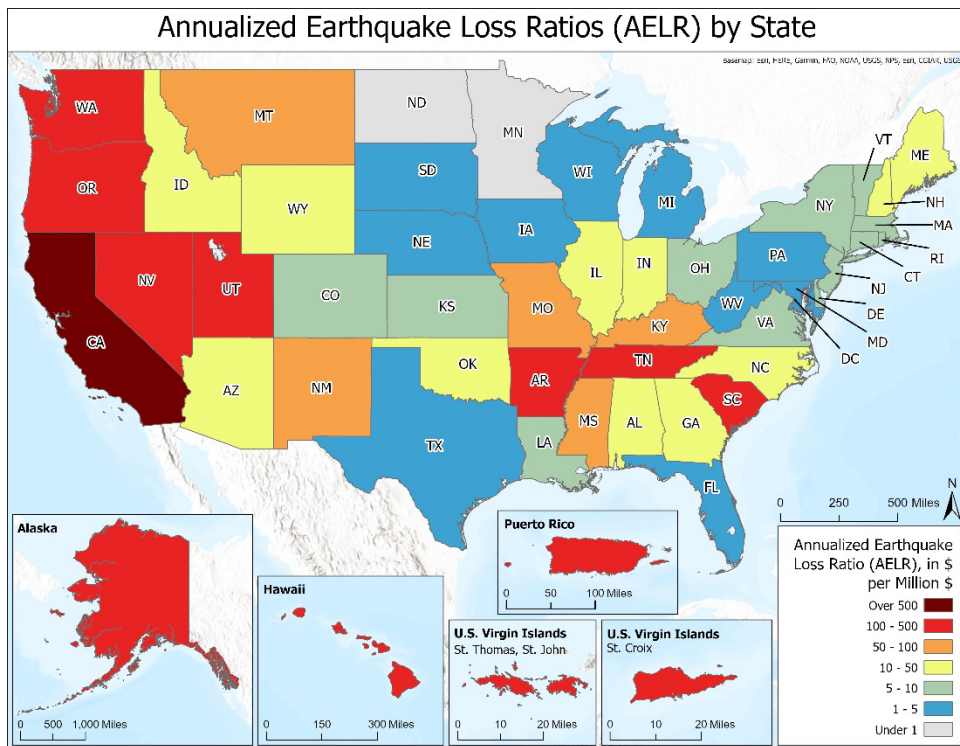
Figure 3-2. Annualized Earthquake Loss Ratios (AELR) by State.

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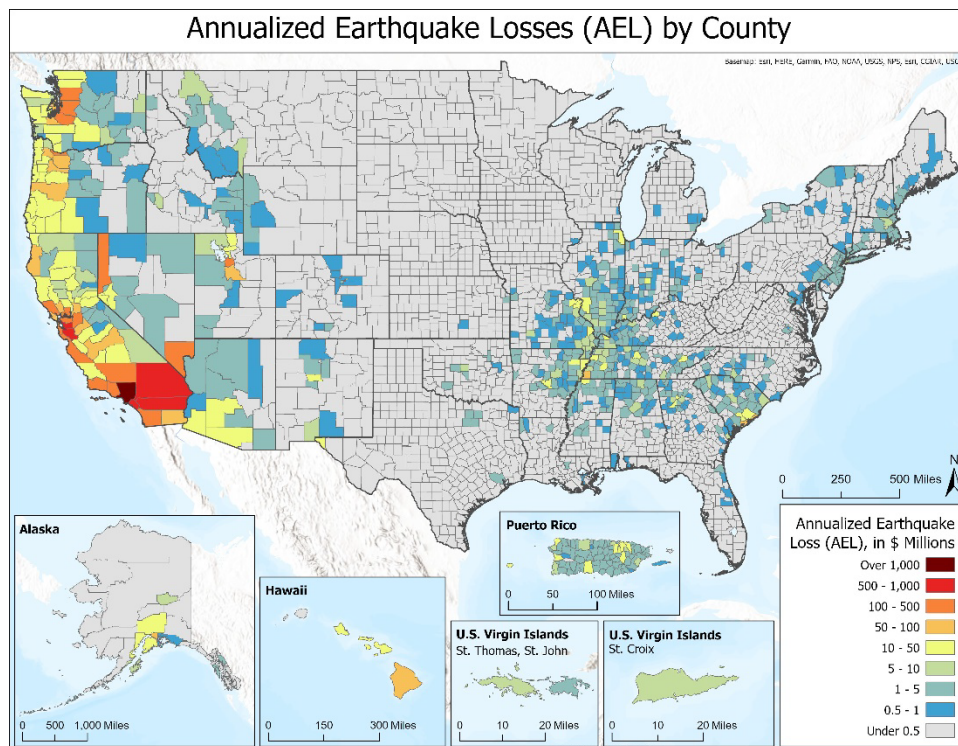
Figure 3-3. Annualized Earthquake Losses (AEL) by County.
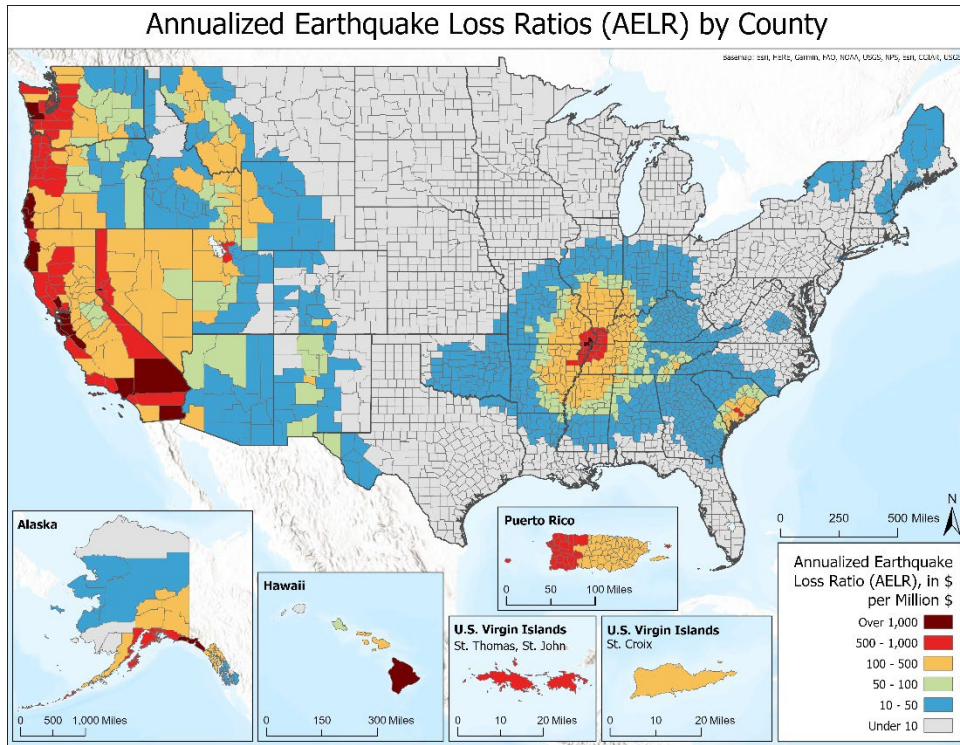
Figure 3-4. Annualized Earthquake Loss Ratios (AELR) by County.

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

Rank	State	AEL ($ x 1,000)		Rank	State	AELR ($/million $)
1	California	9,614,544		1	California	808.5
2	Washington	1,191,743		2	Oregon	477.4
3	Oregon	744,979		3	Washington	471.6
4	Utah	366,714		4	Puerto Rico	454.7
5	Puerto Rico	326,809		5	U.S. Virgin Islands	451.3
6	Nevada	297,403		6	Utah	419.6
7	Tennessee	284,250		7	Alaska	391.6
8	South Carolina	193,976		8	Hawai'i	328.8
9	Missouri	188,476		9	Nevada	310.9
10	Illinois	178,825		10	Tennessee	134.8
11	Hawai'i	126,956		11	Arkansas	124.1
12	Alaska	120,717		12	South Carolina	112.5
13	Arkansas	116,006		13	Missouri	82.9
14	Kentucky	110,538		14	Kentucky	74.6
15	Indiana	87,362		15	Mississippi	74.5
16	Georgia	87,225		16	Montana	68.3
17	Arizona	86,095		17	New Mexico	55.6
18	Mississippi	69,937		18	Wyoming	46.6
19	Alabama	51,361		19	Idaho	42.4
20	New York	45,353		20	Arizona	41.8
21	New Mexico	41,071		21	Illinois	38.7
22	North Carolina	36,133		22	Indiana	36.1
23	Texas	35,610		23	Alabama	31.5
24	Ohio	32,917		24	Georgia	25.3
25	Montana	32,379		25	Oklahoma	22.0
26	Idaho	26,898		26	New Hampshire	15.2
27	Oklahoma	24,532		27	Maine	14.1
28	New Jersey	24,277		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 Hawaiʻi and Alaska have a combined AEL of $250 million, and the Caribbean has a combined AEL of $340 million.
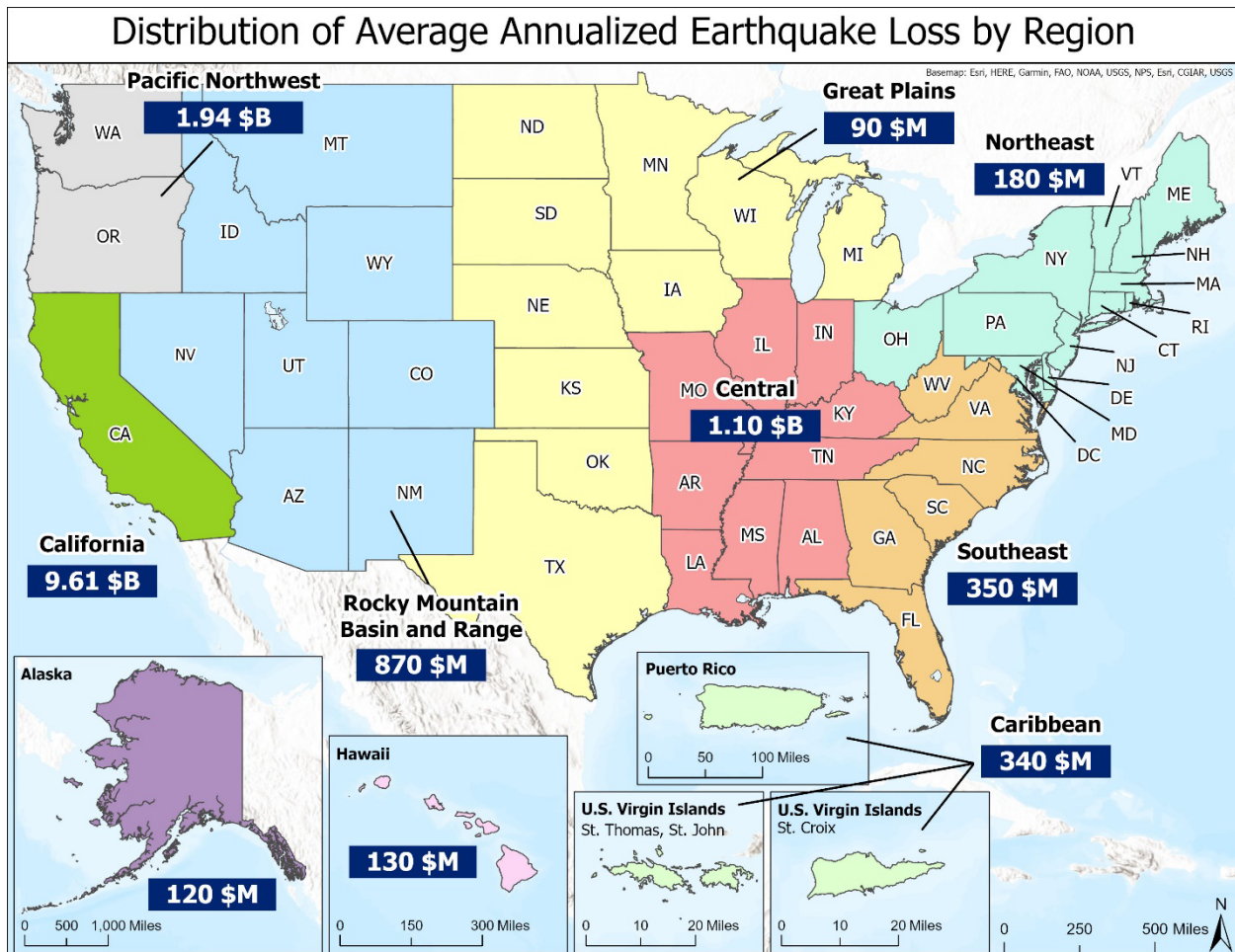
Figure 3.5. Distribution of Average Annualized Earthquake Loss by Region.

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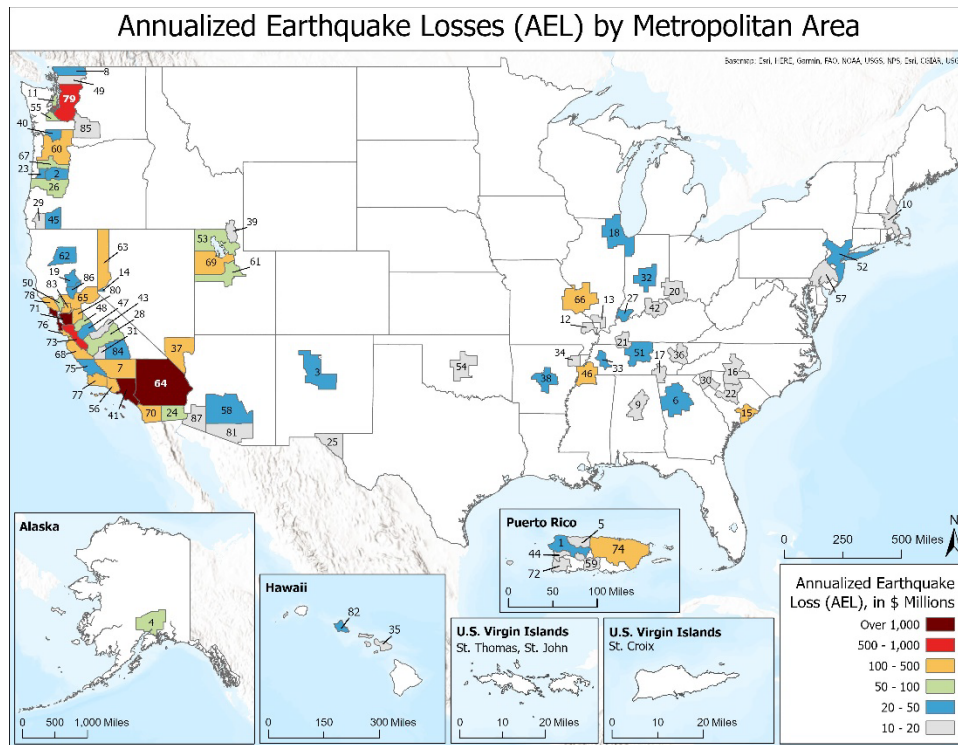
Figure 3-6. Annualized Earthquake Losses (AEL) by Metropolitan Areas (Losses Greater than $10 Million).

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

35

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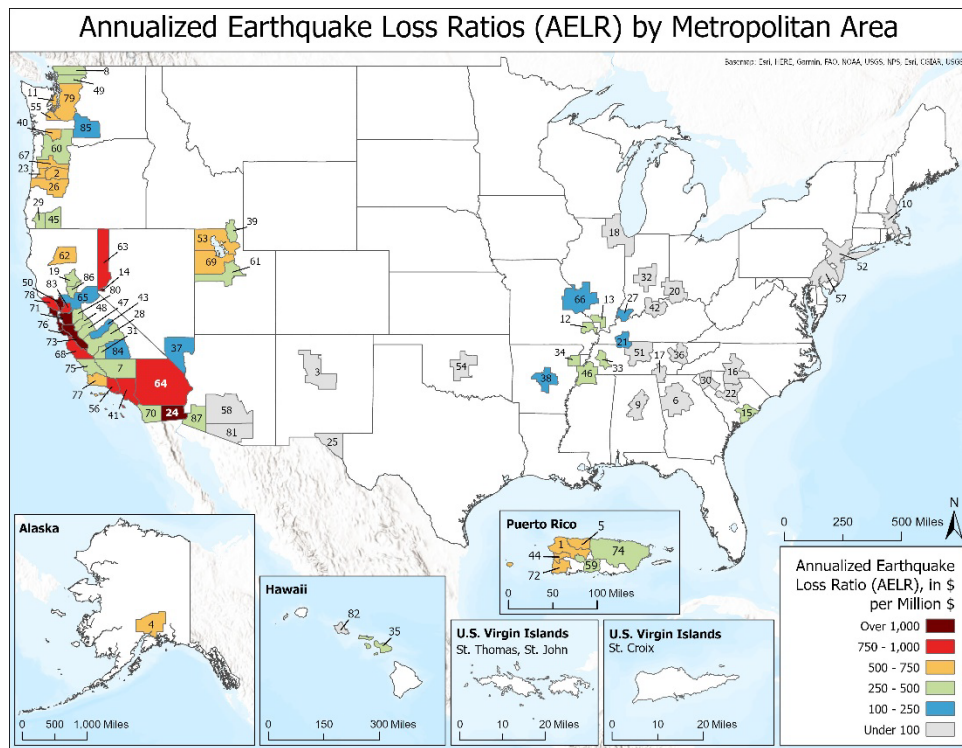
Figure 3-7. Annualized Earthquake Loss Ratios (AELR) by Metropolitan Areas (Losses Greater than $10 Million).

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., Hawai'i, Alaska, and the Caribbean); and

2. California, U.S. Virgin Islands, Oregon, Alaska, Washington, Utah, Puerto Rico, Nevada, and Hawai'i have the highest seismic risk when measured on a per capita basis at the state level.
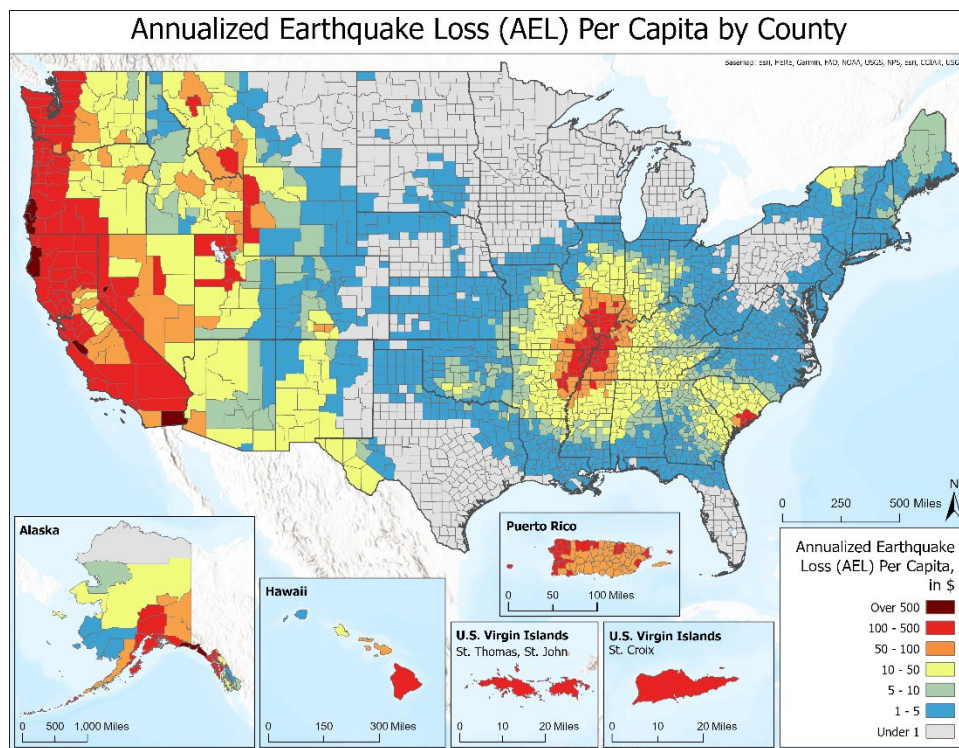
Figure 3-8. Annualized Earthquake Loss (AEL) Per Capita by County.
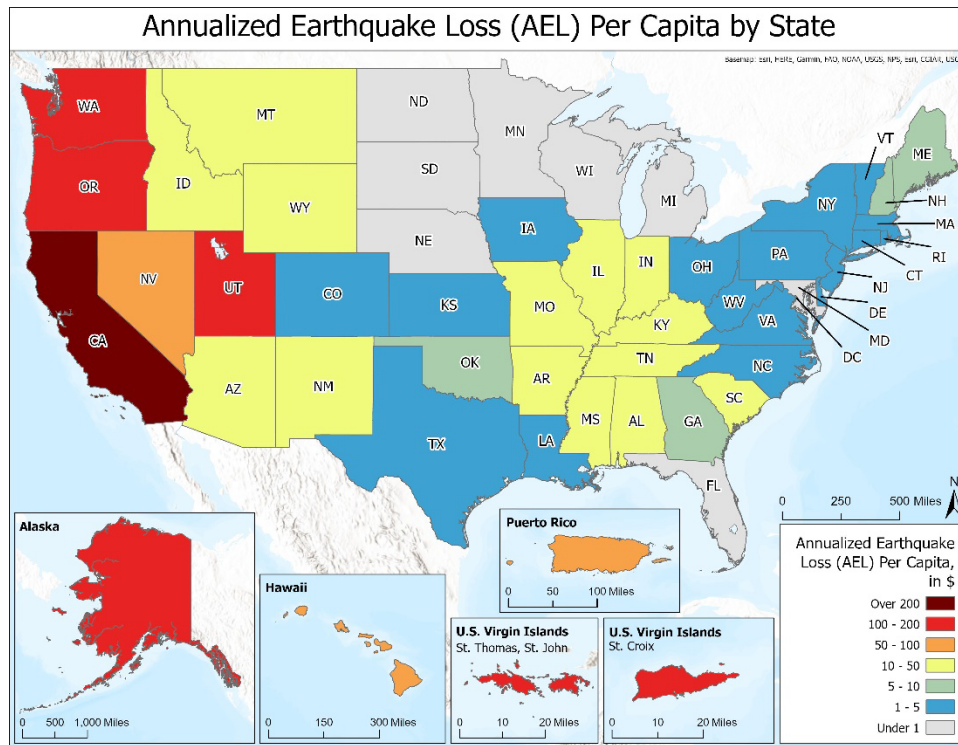
Figure 3-9. Annualized Earthquake Loss (AEL) Per Capita by State.

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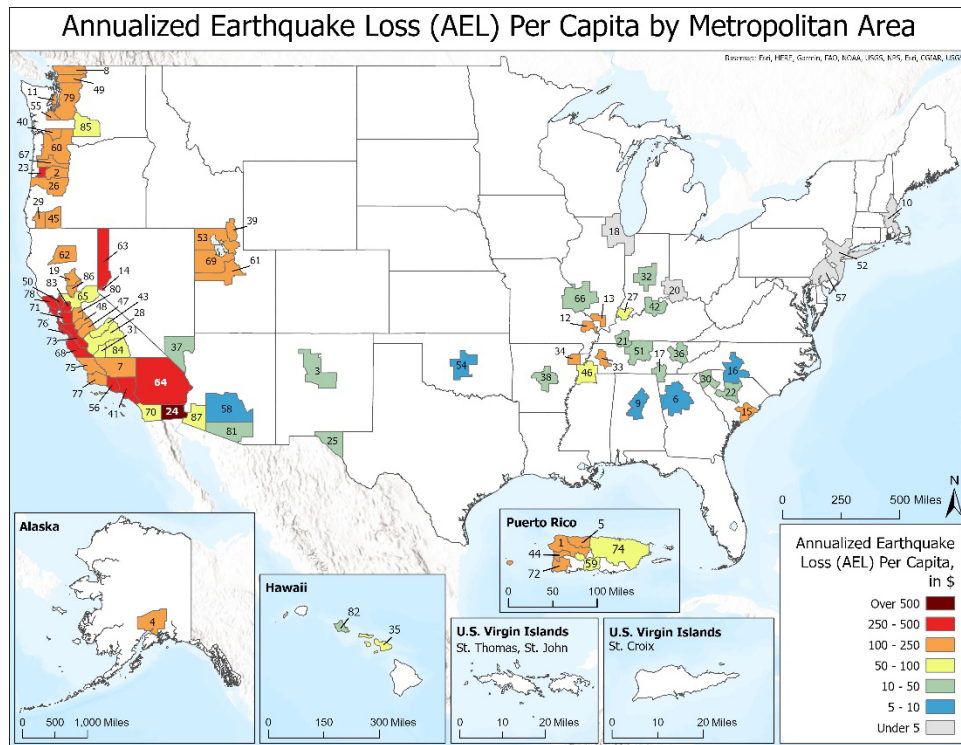
Figure 3-10. Annualized Earthquake Loss (AEL) Per Capita by Metropolitan Area.

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.
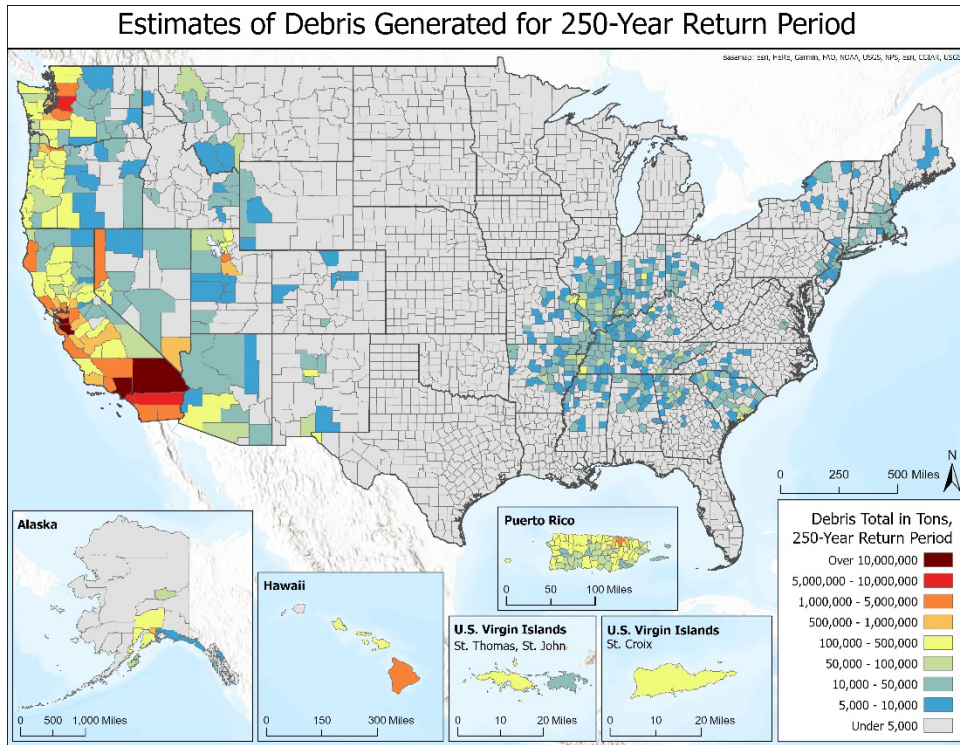
Figure 3-11. Estimates of Debris Generated for 250-Year Return Period.
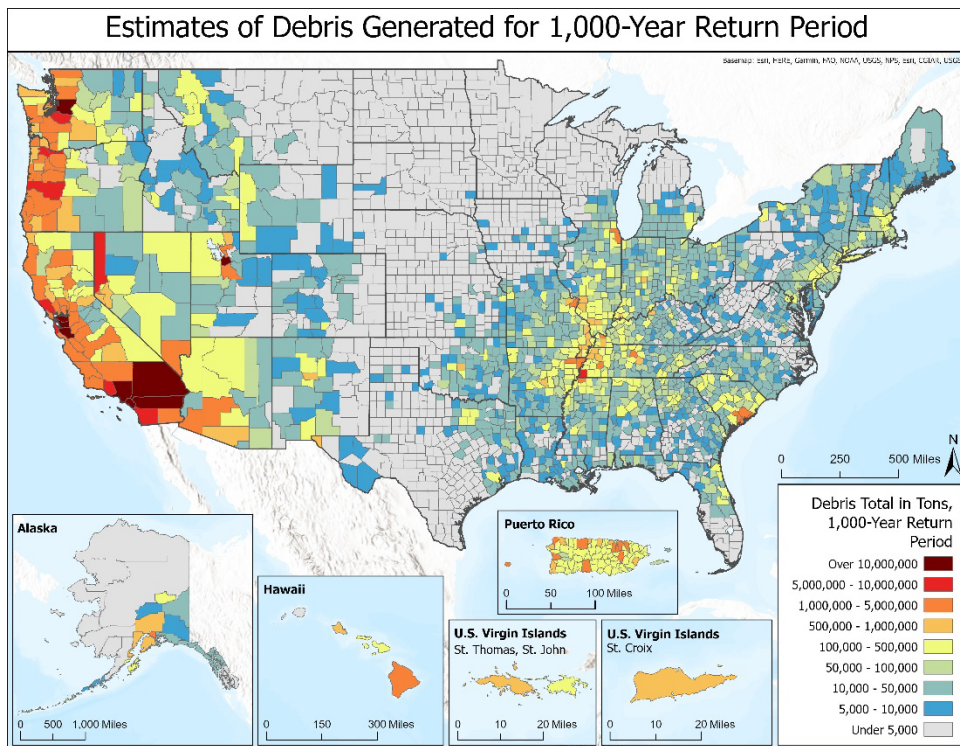
Figure 3-12. Estimates of Debris Generated for 1,000-Year Return Period.

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 Hawai'i 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	Hawai'i	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.
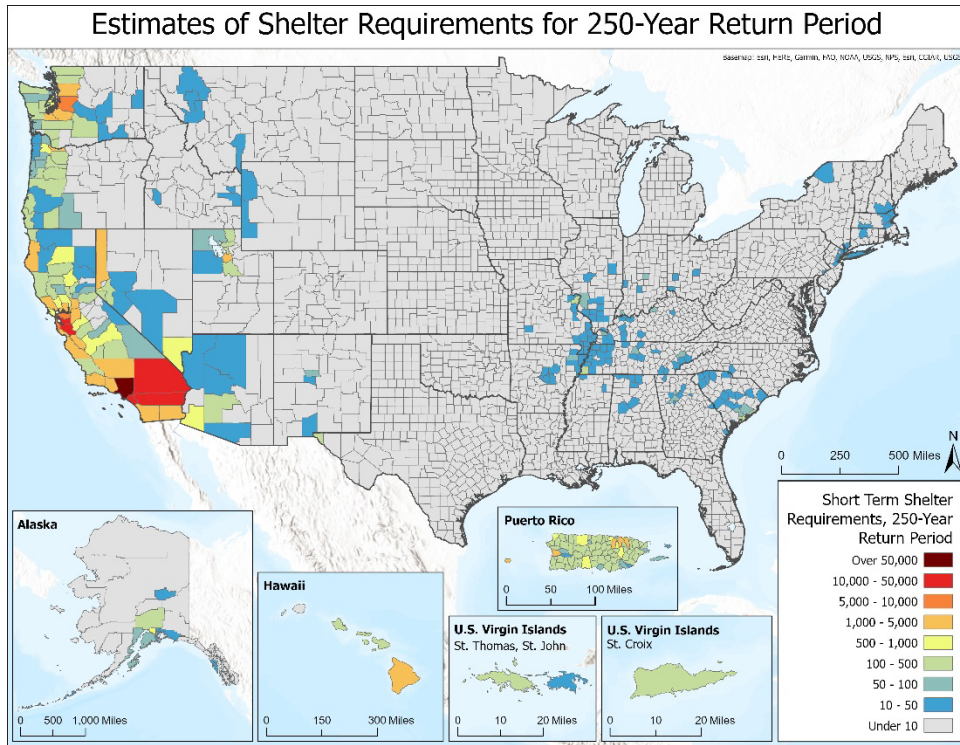
Figure 3-13. Estimates of Shelter Requirements for 250-year Return Period.
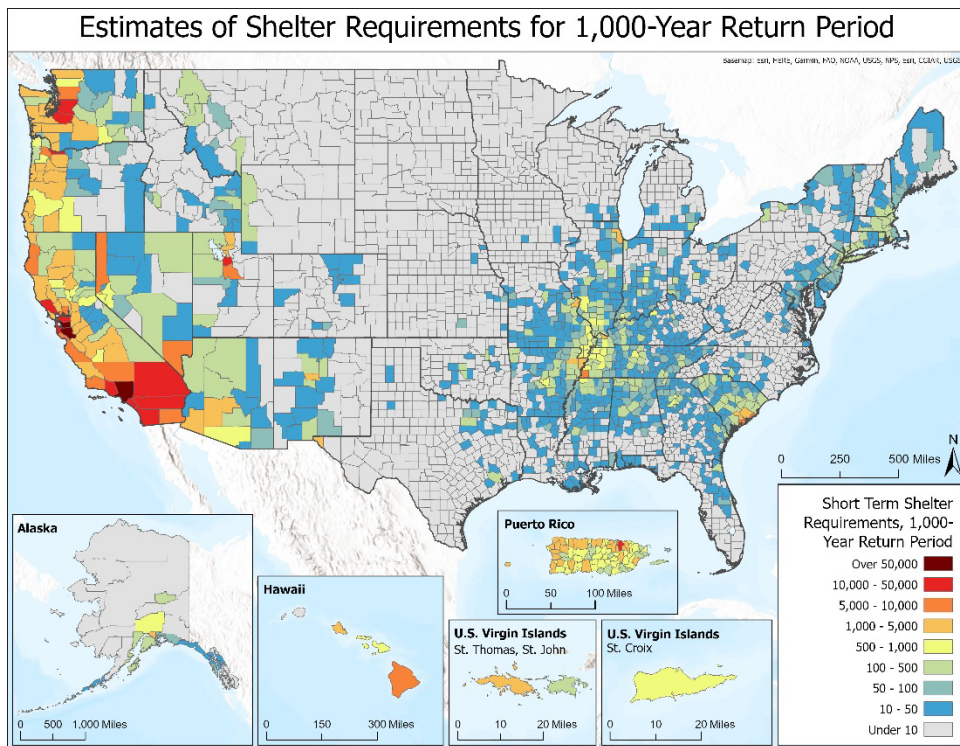
Figure 3-14. Estimates of Shelter Requirements for 1000-year Return Period.

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	Hawai'i	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	Hawai'i	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, Hawai'i, 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 (Hawai'i, 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 Hawai'I (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 Hawai'i, except the Kona coast. The valley region of Maui has increases, and slight but notable increases occur on the southern coast of O'ahu.

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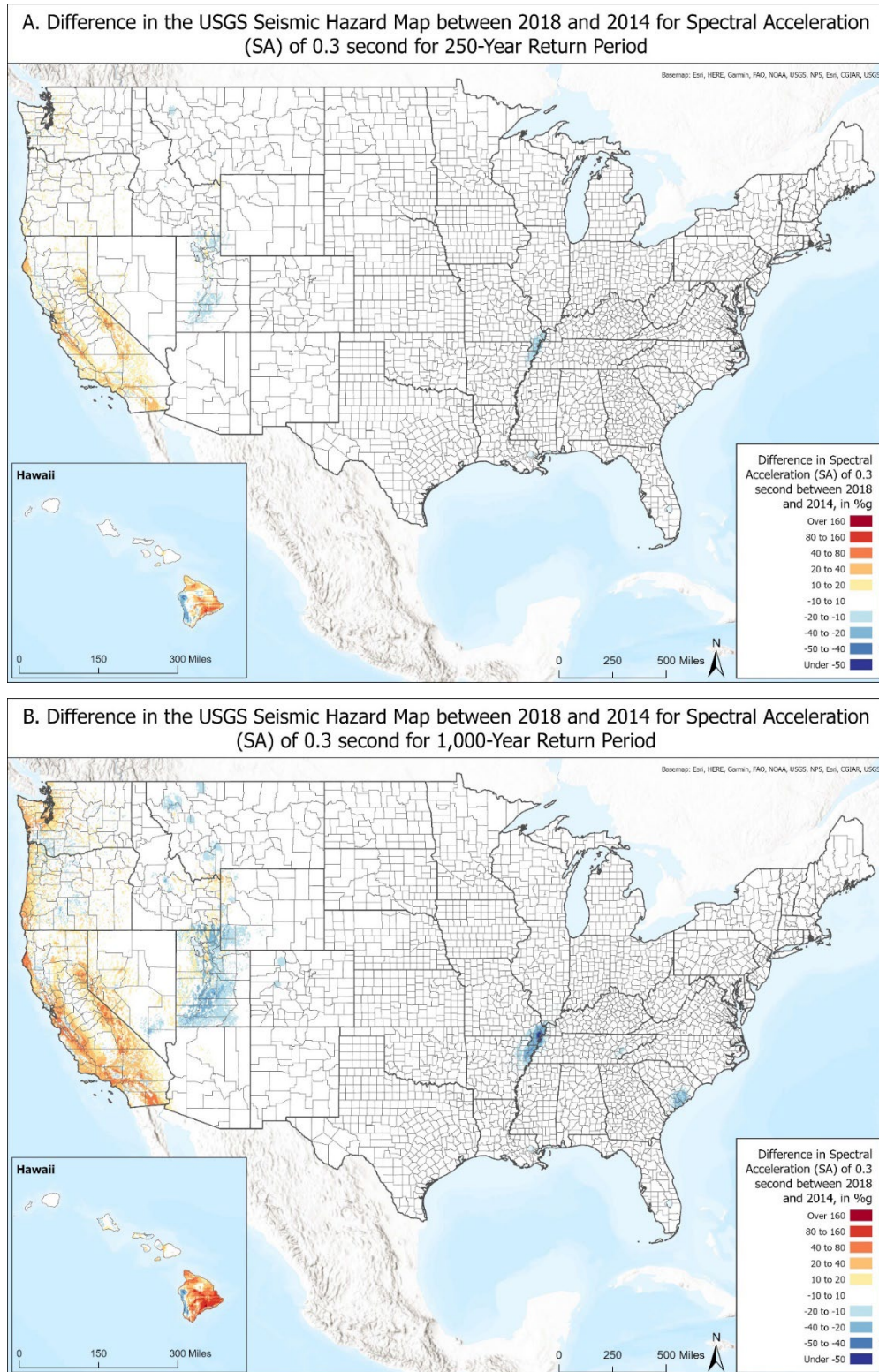
Figure 4-1A,B. Difference in the USGS National Seismic Hazard Model between 2018 and 2014 for Spectral Acceleration (SA) of 0.3 second for A. 250-Year Return Period and B. 1,000-Year Return Period. (Hawaiʻi represents 2021 compared to 1998, and no updates were made to the Alaska, Puerto Rico, or U.S.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

The site soil amplification mapping for this update incorporates new data for Hawai'i (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.
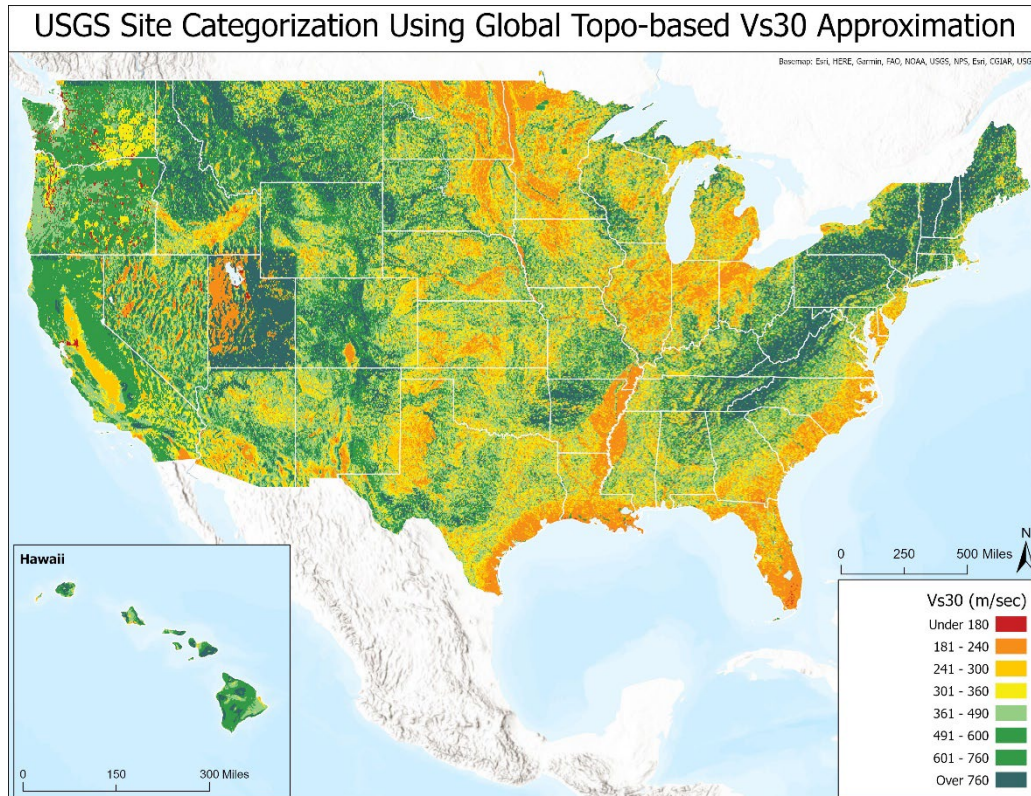
Figure 4-2. USGS Site Categorization Using Global Topo-based Vs30 Approximation.

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	Hawai'i	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	Hawai'i	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
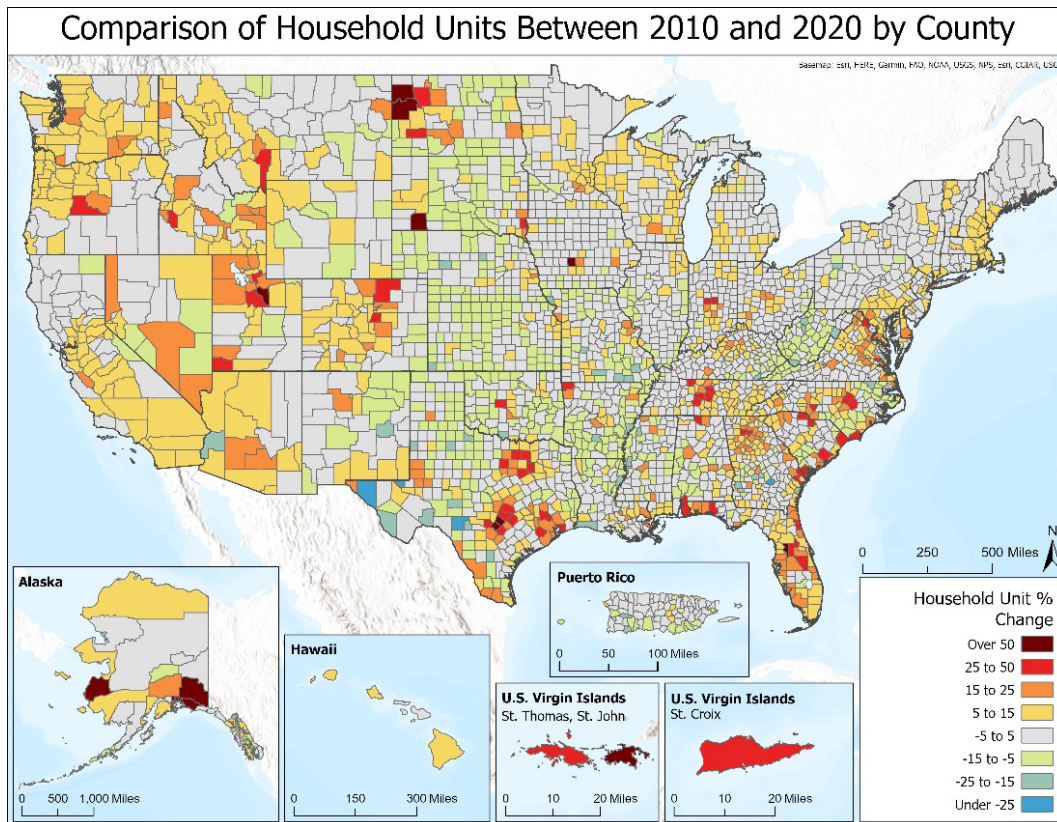
earthquake injuries. Improving functional recovery time for critical facilities and buildings has become a desirable consideration for new building design and existing building retrofits. Although the loss estimates reported in this study do not include functional recovery time, mitigation that addresses 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.

  o 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.

  o 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.

  o 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.

  o 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 x 10%) + (0.4 g 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
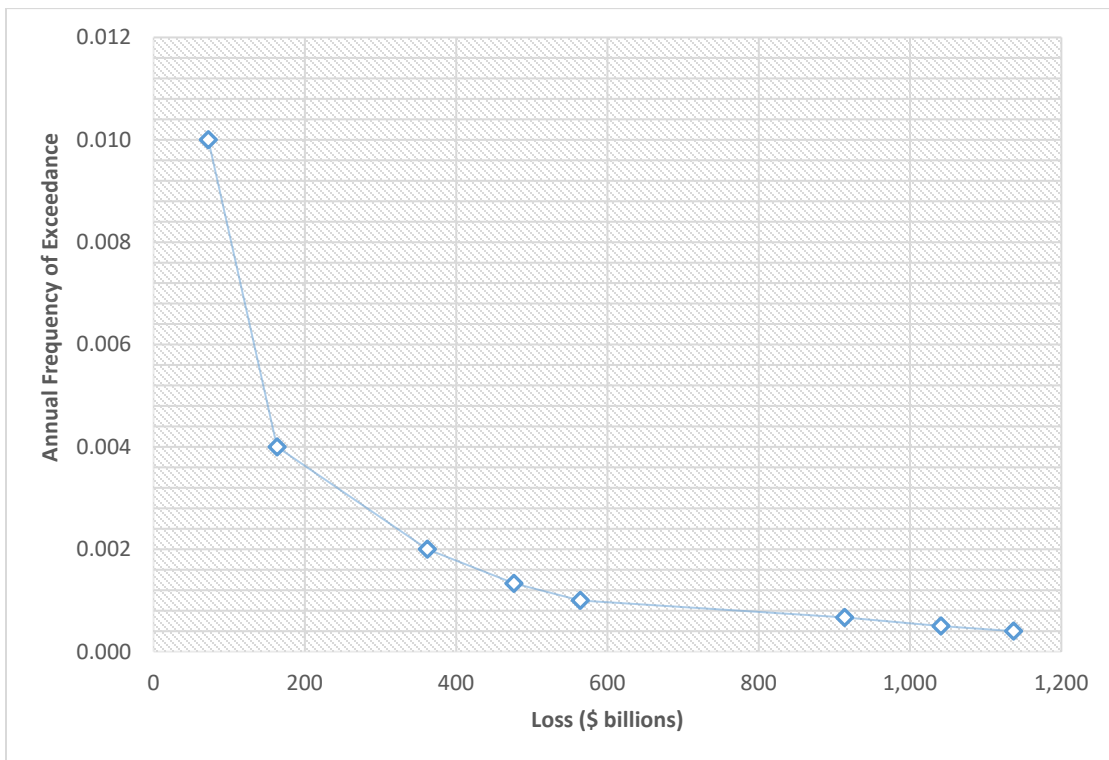
Figure C-1. Probabilistic Loss Curve for Los Angeles County, California.

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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
Hawai'i	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**