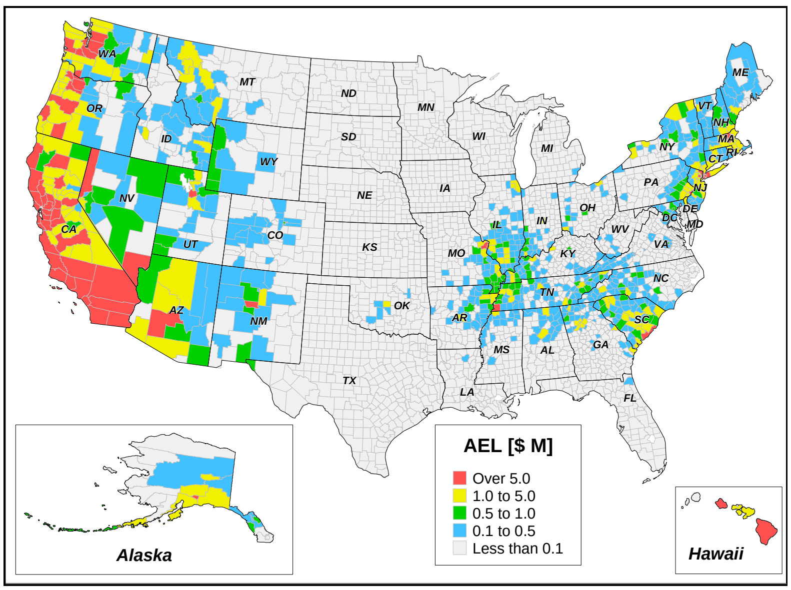
FEMA 366 / February 2001

HAZUS® 99 Estimated Annualized Earthquake Losses for the United States



NATURAL HAZARD LOSS ESTIMATION METHODOLOGY

Federal Emergency Management Agency
Mitigation Directorate

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Executive Summary

Recent earthquakes around the world show a pattern of steadily increasing damages and losses. The increases are due primarily to two factors: 1) significant growth in urban areas that are prone to earthquakes; and 2) the vulnerability of the older building stock, even buildings that were constructed within the past twenty years. In the United States, earthquake risk has grown substantially with development, while the earthquake hazard has remained relatively constant.

To understand the hazard, we study earthquake characteristics and locales in which they occur. To understand risk, we must include characteristics of the built environment in the locales where earthquakes occur, and we must assess potential damages to the built environment and the people who use it. That is a complex undertaking and one this study intends to advance.

It is important to estimate the varying degrees of seismic risk throughout the United States because we need that understanding in order to make informed decisions on mitigation policies, priorities, strategies and funding levels—in both the public and private sectors. We can reduce earthquake losses to older buildings by rehabilitating them, and we can reduce earthquake losses in new buildings by applying seismic codes to their design and construction. However, decisions to spend money on either of those solutions require evidence of risk. In the absence of a nationally accepted criterion and methodology for comparing seismic risk across regions, a consensus on optimal mitigation approaches has been difficult to reach.

We are all aware of regions with high hazard and high risk, such as Los Angeles, but there is growing recognition that some regions with low seismic hazard actually have high seismic risk, as is the case in New York City and Boston. This risk results, in part, from concentrations of buildings and infrastructure built without use of seismic codes or provisions. Additionally, mitigation policies and practices in the public and private sectors may not have been adopted because a community's earthquake risk was not clearly demonstrated, and neither was the value of mitigation measures in reducing that risk.

The low hazard/high risk problem exists in a number of areas in the U.S., where the infrequency of damaging earthquakes has been interpreted, wrongly, as lack of risk. While earth scientists work to increase knowledge about the hazard throughout the United States, structural engineers and other professionals work to enumerate the many factors that comprise risk.

This study is one result of that endeavor. It is based on loss estimates generated by Hazards U.S. (HAZUS), a Geographic Information System (GIS)-based earthquake loss estimation tool, developed by the Federal Emergency Management Agency (FEMA) in cooperation with the National Institute of Building Sciences (NIBS). The HAZUS tool provides an approach to quantifying future earthquake losses that is national in scope, uniform in application, and comprehensive in its coverage of the built environment.

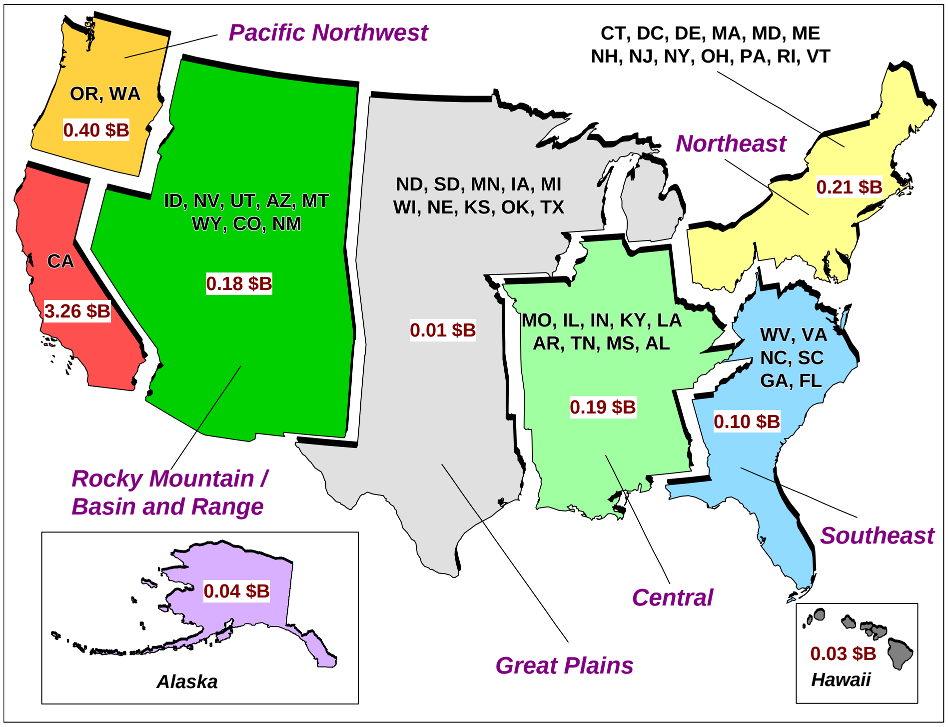


Figure 1. Comparison of U.S. Regional Seismic Risk by Annualized Earthquake Losses (AEL)

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

1) The Annualized Earthquake Loss (AEL), which is the estimated long-term value of earthquake losses to the general building stock in any single year in a specified geographic area (e.g., state, county, metropolitan area)

2) The Annualized Earthquake Loss Ratio (AELR), which expresses estimated annualized loss as a fraction of the building inventory replacement value

While building-related losses serve as a reasonable indicator of relative regional earthquake risk, it is important to recognize that these estimates are not absolute determinations of the total risk from earthquakes. The loss parameters used in this study address direct economic losses to the building inventory. Seismic risk also depends on other parameters, which have not been included herein, such as social losses and casualties, damages to lifelines and other critical facilities, and indirect economic loss.

The HAZUS analysis indicates that the Annualized Earthquake Loss (AEL) to the national building stock is $4.4 billion per year. The estimated losses are in two categories: 1) capital losses ($3.5 billion), which include repair and replacement costs for structural and nonstructural components, building content loss, and business inventory loss; and 2) income losses ($ 0.9 billion), which include business interruption, wage, and rental income losses.

The majority (84 percent) of average annual loss is located on the West Coast (California, Oregon, Washington), with 74 percent ($3.3 billion per year) concentrated in the state of California. The high concentration of loss in California is consistent with the state's high seismic hazard and large structural exposure. The remaining 16 percent ($0.70 billion per year) of annual loss is distributed throughout the rest of the U.S. (including Alaska and Hawaii), as reflected in Figure 1.

While the majority of economic loss is concentrated along the west coast of the United States, the distribution of relative earthquake risk, as measured by the Annualized Earthquake Loss Ratio (AELR), is much broader and reinforces the fact that earthquakes are a national problem. There are relatively high earthquake loss ratios throughout the western U.S., the central U.S. (states within the New Madrid Seismic Zone), and in the Charleston, South Carolina area.

Forty metropolitan areas, led by the Los Angeles and San Francisco Bay areas, account for 86 percent of the total annualized losses in the U.S.. Los Angeles county alone has about 25 percent of the total AEL. This observation supports the need for strategies to reduce the current seismic risk by focusing on rehabilitation of the existing building stock in our most at risk communities. Strategies to reduce future losses throughout the U.S. need to be closely integrated with policies and programs that guide urban planning and development.

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

- Improving our understanding of the seismic risk in the U.S.
- Providing a baseline for earthquake policy development and the comparison of mitigation alternatives.
- Supporting the adoption and enforcement of seismic provisions of building codes.
- Comparing the seismic risk with that of other natural hazards.

Chapter 1 — Introduction

Background

In the past, much of our perception of the “earthquake problem” in the United States has been shaped by our understanding of the earthquake *hazard*, which focuses on the location and type of faulting and ground failure, and the distribution of strong ground motion (shaking). Earthquake hazard databases and maps - produced by the U.S. Geological Survey (USGS), state geological surveys and other research institutions - provide increasingly consistent and useful data on the earthquake hazard in the U.S. (See the glossary in Appendix A for further explanation of all italicized words and phrases).

While hazard maps contribute to our understanding of the earthquake hazard, there is an increasing recognition among policy makers, researchers and practitioners of the need to analyze and map the earthquake *risk* in the U.S. As urban development continues in seismically hazardous regions of the nation, there is growing concern about the exposure of buildings, lifelines (e.g., utilities and transportation systems), and the population to the potential effects of earthquakes.

Earthquake *risk analysis* begins with *hazard identification*, but goes beyond that to determine the potential earthquake consequences to people and property, including buildings, lifelines, and the environment. Earthquake *risk assessments* add to the determination of consequences by pointing out their significance in the community or region under consideration. Only with a comprehension of all these factors can decisions be made at any governmental level about mitigation priorities and optimal approaches.

At the national level, the ability to compare risk across states and regions in the United States is critical to the management of the National Earthquake Hazards Reduction Program (NEHRP). At the state and community level, an understanding of seismic risk is important to the mitigation planning process, including the evaluation of costs and benefits associated with the adoption of building codes and other mitigation strategies. Finally, an understanding of seismic risk to business and industry is central to the adoption of risk reduction and business continuity measures in the private sector.

Until recently, there was no nationally consistent earthquake risk and loss estimation methodology for the U.S. That lack, combined with the absence of a national inventory of the built environment, hampered efforts to compare levels of earthquake risk across the U.S. and to craft regionally consistent mitigation strategies. In response to the need, and with the capacity provided by computer-based analyses, the Federal Emergency Management Agency (FEMA) began the development of *Hazards U.S. (HAZUS)* in cooperation with the National Institute of Building Sciences (NIBS). HAZUS is a standardized tool that uses a uniform engineering-based loss estimation approach to quantify damages, economic losses and casualties throughout the country (refer to Appendix B for a more detailed discussion of HAZUS). The economic loss estimates, in turn, form the foundation for the development of a consistent way to index or order risks nationally. That is the focus of this report.

Study Objectives and Scope

The goal of this study is to assess the level of seismic risk for various geographic units of the U.S. by using the basic level of the HAZUS methodology and the *basic building inventory*. The study is intended for policy makers, practitioners, and researchers in the public and private sectors who have roles in assessing risk, in developing strategies for managing risk, and in formulating plans for responding to and recovering from natural disasters.

The study uses results from HAZUS to perform a national seismic risk analysis that provides decision-makers with information useful in developing effective *risk management* programs for the U.S. Two interrelated parameters are used to characterize the seismic risk in the U.S.:

1) Annualized Earthquake Loss (AEL)

2) Annualized Earthquake Loss Ratio (AELR)

The estimated *Annualized Earthquake Loss (AEL)* addresses the two key components of seismic risk: the probability of ground motion occurring in the study area, and the consequences of the ground motion. Furthermore, the AEL takes into account that the seismic risk in the U.S. varies from region to region. For example, the level of seismic risk in the New Madrid Seismic Zone is measurably different from the seismic risk in the Los Angeles Basin, specifically with respect to: a) the probability of damaging ground motions, and b) the consequences of the ground motions, largely a function of building construction type and quality, and of the level of ground shaking and ground failure during the event.

There is regional variation in these components. For example, the earthquake hazard is higher in Los Angeles than in Memphis, but the general building stock in Los Angeles is more resistant to the effects of earthquakes. The AEL annualizes expected losses by averaging them per year. By annualizing estimated losses, the AEL factors in historic patterns of frequent smaller earthquake events with infrequent but larger events to provide a balanced presentation of seismic risk. This enables the user to compare the seismic risk between two geographic areas, such as Los Angeles and Memphis, or California and Oregon. The AEL values are also presented on a per capita basis, which provides another comparison of relative risk across regions.

The second parameter, *Annualized Earthquake Loss Ratio (AELR),* represents the AEL as a fraction of the replacement value of the local building inventory. For example, $10 million in earthquake damages in Evansville, Indiana represents a greater loss relative to the size of the city than a comparable dollar loss in San Francisco, a much larger city. The annualized loss ratio allows us to gauge the relationship between average annualized loss and building replacement value. This ratio can be used as a measure of relative risk between regions and, since it is normalized by replacement value, it can be directly compared across different geographic units such as metropolitan areas, counties, or states.

This report is organized into four chapters. 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 county, metropolitan, and state level in Chapter 3 through a series of maps and tables. The report concludes in Chapter 4 with a summary of the major findings, and recommendations for using results from this work. The Appendices contain more detailed technical information on terminology and methodology.

Chapter 2—Analyzing Earthquake Risk

Risk Parameters

Earthquake risk analysis involves making quantitative estimates of the damage, casualties, and costs likely within a specified geographic area over a certain period of time. A comprehensive risk analysis includes assessments of various levels of the hazard, as well as of consequences to structures and populations should the hazard occur. Appendix A defines terminology related to risk analysis.

There are two types of risk analysis - scenario and probabilistic. This study uses a probabilistic seismic hazard analysis to integrate the potential effects of earthquakes of varying location, magnitude, and frequency at a single site. In contrast to using a single scenario earthquake of a specific size and location, probabilistic analyses allow for uncertainties in the locations and rates of earthquake occurrence and levels of ground motion.

To arrive at estimates of the average annualized loss, a number of characteristics of the hazard and the vulnerable structures must be assessed and entered into the model. These are called geotechnical and building inventory parameters and are specified in Table 2-1.

The process of generating values for the Annualized Earthquake Loss and the Annualized Earthquake Loss Ratio is organized into four steps. In the first step, the USGS earthquake hazard data are processed into a format that is compatible with HAZUS.

In the second step, the basic building inventory in HAZUS is used to estimate loss data at the census tract level for specified return periods. Third, HAZUS computes the AEL. Fourth, the annualized loss values are divided by replacement value of building inventory to determine AELR values. Each of the four steps is described in detail below.

Step One:
Prepare Probabilistic Hazard Data

Probabilistic hazard curves specify ground motions, such as *peak ground acceleration (PGA)* and *spectral acceleration (SA)*, as a function of the *average annual frequency* that a level of motion will be exceeded in an earthquake. The *return period* is the inverse of the annual frequency of occurrence, and can be interpreted as the average number of years between occurrences of similar levels of ground motion.

The USGS has developed *probabilistic seismic hazard data* for the entire U.S. (see http://geohazards.cr.usgs.gov/eq/) as part of the National Earthquake Hazards Reduction Program (NEHRP). These data include seismic hazard curves developed for individual points in a

Table 2-1. Study

Software

HAZUS99 SR-1.

Geotechnical

NEHRP soil type 'D' (thick alluvium) used in all analyses.

USGS ground motion parameters for eight return periods between 100 and 2500 years (100, 250, 500, 750, 1000, 1500, 2000, 2500 years).

Ground motion parameters determined at the centroid of the census tract.

Ground failure effects (liquefaction, landslide) were not included in the analyses due to the lack of a nationally applicable database.

Building Inventory

Basis for general building inventory exposure: 1990 U.S. Census for residential buildings, 1996 Dunn & Bradstreet for non-residential buildings, and 1994 R.S. Means for all building replacement costs.

Building-related direct economic losses (structural and non-structural replacement costs, contents damage, business inventory losses, business interruption, and rental income losses) due to ground shaking only were computed. All other economic losses were ignored due to the lack of a nationally applicable database.

Building inventory loss estimates are calculated by census tract.

Losses reported in 1994 dollars

uniform grid that covers all 50 states and Washington, DC. Examples of the USGS probabilistic hazard curves are illustrated in Figure 2-1. The curves represent the average annual frequency of exceedance as a function of PGA for seven major U.S. cities.

A USGS map illustrating PGA for a single return period (1000 years) is shown in Figure 2-2. Appendix C describes in greater detail the process used to convert the USGS hazard curves to the HAZUS-compatible database of probabilistic ground shaking values.

Probabilistic hazard data for the PGA, spectral acceleration at 0.3 seconds (SA@0.3), and spectral acceleration at 1.0 second (SA@1.0) were processed for each census tract for each of the eight different return periods. Figures 2-3a and 2-3b compare a HAZUS seismic hazard (PGA) map for the 1000-year return period for California to the USGS map for the same return period and illustrates that the remapping process does not significantly change the hazard information.

The USGS-computed ground motions apply to rock (B/C soil) and have been used to modify the motions so they are applicable to a soil condition that, on average, is typical for populated metropolitan areas (D soil).

Step Two:
Compute Building Inventory Loss Estimates

The second step used HAZUS to generate damage and loss estimates for the probabilistic ground motions associated with each of the eight return periods. The analyses were completed for the entire HAZUS building inventory for each of the approximately 61,500 census tracts in the

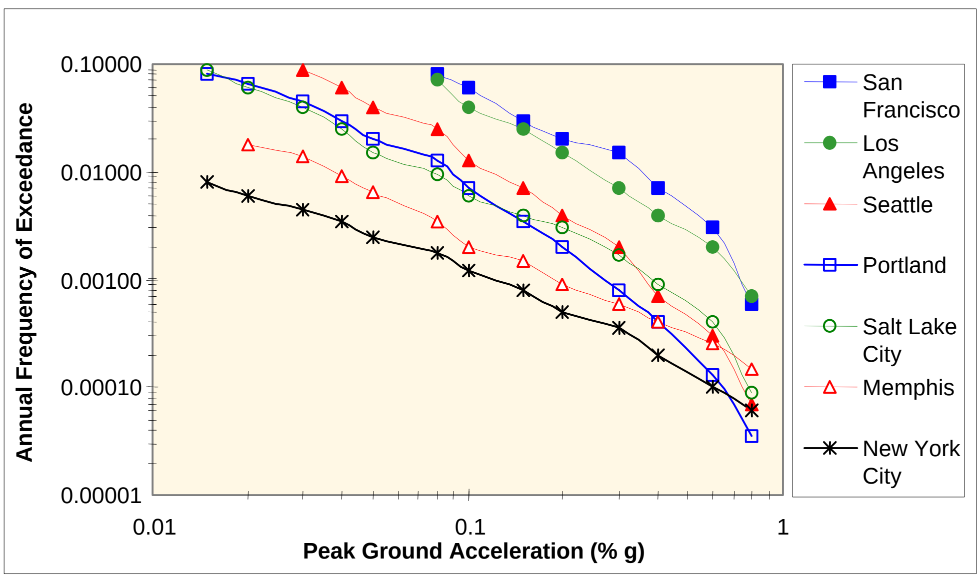


Figure 2-1. Average Annual Frequency of PGA for Seven Major Cities

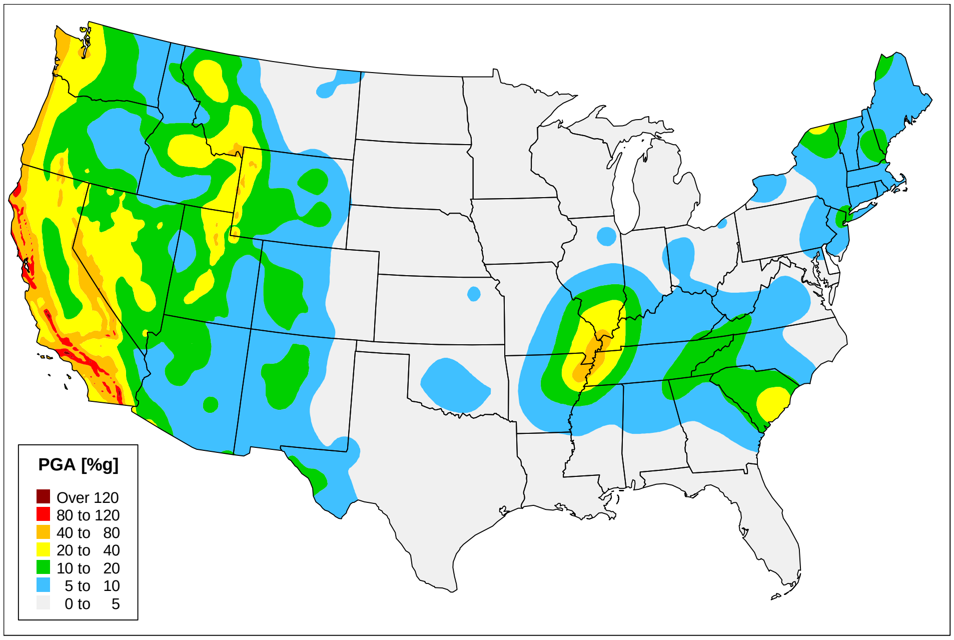
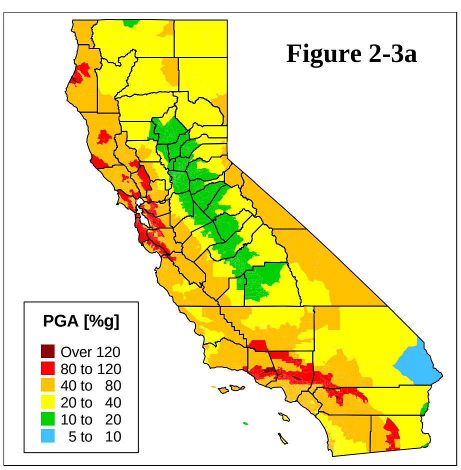


Figure 2-2. USGS Seismic Hazard Map for 1000-year Return Period

U.S. The building damage estimates were the basis for the direct economic losses, which include building repair costs, the loss of contents and business inventories, costs of relocation, capital-related losses, wage losses and rental losses. These building-related losses serve as a reasonable indicator of relative regional risk (see Appendix B for more detail).

The damage and consequent economic losses to critical facilities, transportation and utility lifelines are not considered. While it is understood that these losses will have an effect on the relative risk of any region, they are not included in the present study because the default inventories currently available at a national scale are not comprehensive enough to yield meaningful estimates.

A map illustrating replacement value of the building inventory (by county) is shown in Figure 2-4. For this study, the replacement value is based on the value of the building components only and omits the value of the land



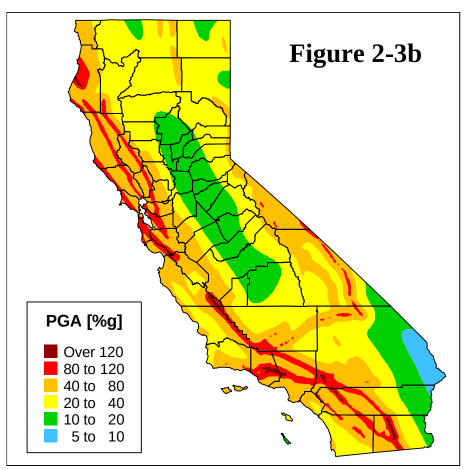


Figure 2-3a. HAZUS Seismic Hazard Map for 1000-year Return Period PGA for a B/C soil

Figure 2-3b. USGS Hazard Map for 1000- year Return Period PGA for a B/C soil

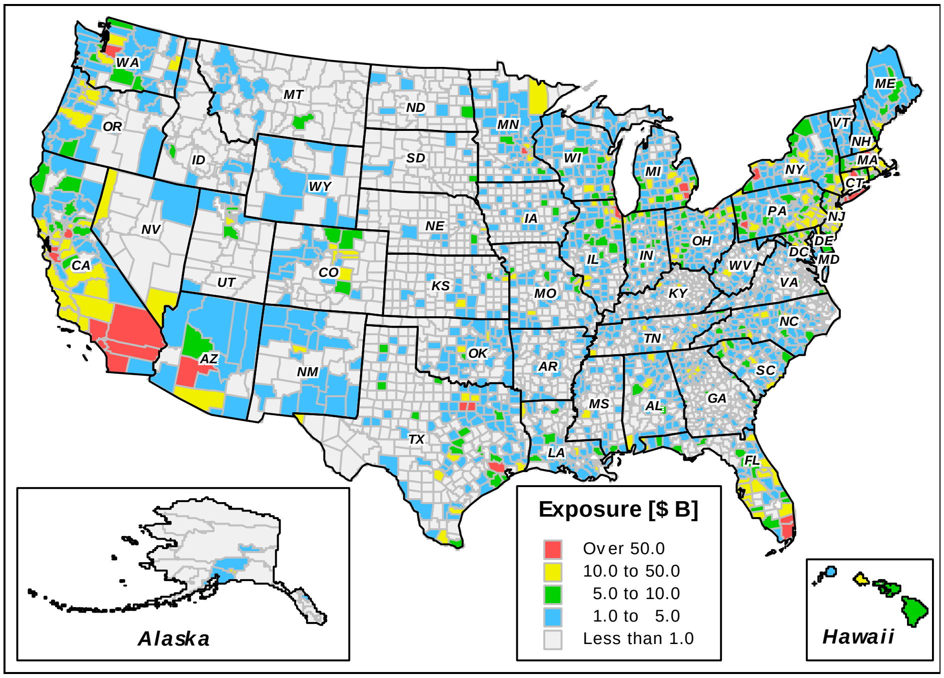


Figure 2-4.

Replacement Value of the HAZUS Building Inventory by County

the building is located on and the building contents. Building Components include piping, mechanical, and electrical systems; contents are fixtures, furnishings and equipment.

The inventory data can be aggregated at various levels to compare replacement value across different regions. For example, Figure 2-5 compares the replacement value by state as a percentage of total replacement value for the U.S. The inventory exposure data help to identify concentrations of replacement value, and thus potential areas of increased risk.

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

The HAZUS methodology computes the estimated AEL by multiplying losses from all potential future ground motions by their respective annual frequencies of occurrence, and then adding these values. Appendix C provides further details on this step.

Some important assumptions were made. First, the losses associated with ground motions having return periods greater than 2500 years are assumed to be no worse than the losses for the 2500-year event. Second, the losses for ground motions with less than a 100-year return period are assumed to be generally small enough to be ignored. In California, however, losses from ground motions with less than a 100-year return period are more significant, and can account for up to an additional 15 percent of the California AEL estimate.

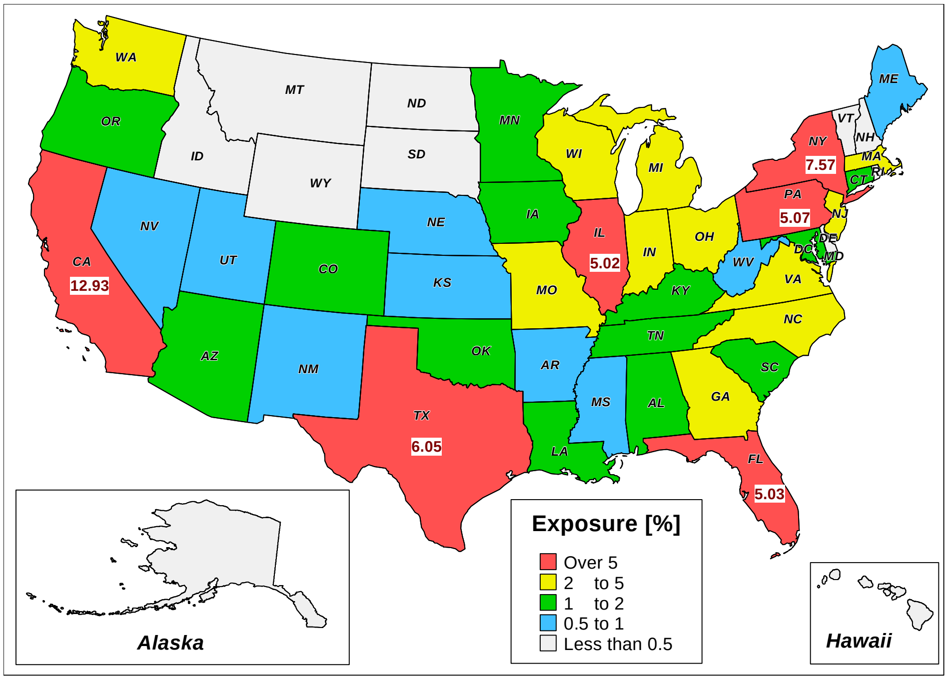


Figure 2-5. Distribution of Building Replacement Value by State

Step Four:
Compute Annualized Earthquake Loss Ratios (AELR)

The AEL provides an objective measure of risk among regions. However, since risk is a function of the hazard, building inventory, and vulnerability, variation in each of the three values determines the risk at any one site. Understanding how each of these values influences risk is key to developing effective risk management strategies. To facilitate that understanding for regional comparisons, it is useful to normalize the AEL by the building inventory exposure (e.g., a loss-to-value ratio). This ratio is termed the AELR and is expressed in terms of dollars per million dollars of building inventory exposure.

Between two regions with similar AEL, the region with the smaller building inventory typically has a higher relative risk, or AELR, than the region with a larger inventory, since annualized loss is expressed as a fraction of the building replacement value. For example, while Charleston, South Carolina and Memphis, Tennessee have similar AEL (see Table 3.3), the former has a higher earthquake loss ratio, since Charleston has less building inventory and building replacement value. In other words, while the seismic risk in Charleston and Memphis is roughly the same, a comparably sized earthquake would affect a significantly larger percentage of the building inventory in Charleston.

Study Limitations

It is important to realize that these estimates are not absolute determinations of the total risk from earthquakes. The loss parameters used in this study address direct economic losses to the building inventory. Seismic risk also depends on other parameters, which have not been included herein, such as social losses and casualties, damages to lifelines and other critical facilities, and indirect economic losses.

It must also be recognized that there are inherent uncertainties in any loss estimation analysis of this type. These uncertainties result from a number of factors, including the use of inferred building values and average building characteristics; spatial averaging of ground conditions, soil response and ground motion values (at the centroid of the census tract); and variables such as the magnitude and frequency of future events and variations in the attenuation of strong ground motion. These factors also need to be considered when comparing the results of different loss studies based on HAZUS or another methodology.

Finally, there are potentially valuable alternatives to using annualized losses for quantifying risk. Because there is potential for an enormous loss in any one year, the annual probability of exceeding a significant threshold of loss would also appear to be an important parameter for consideration in mitigation planning. Annualized risks averaged over many years may appear small and give the wrong impression of risk due to a single event.

Chapter 3 — Results of the Study

In this chapter, the estimated values of the Annualized Earthquake Loss and the Annualized Earthquake Loss Ratio are presented at four levels of geographic resolution: county, metropolitan, state, and regional.

The analysis yielded an estimation of the national AEL to the 1990's era general building inventory of $4.4 billion per year. The estimated losses occur in two categories: 1) capital losses ($3.5 billion per year) which include repair and replacement costs for structural and nonstructural components, building content loss, and business inventory loss; and 2) income losses ($0.9 billion per year) which include business interruption and rental income losses.

The AEL does not include losses to lifeline infrastructure or indirect (long-term) economic losses; therefore, the $4.4 billion represents a minimum estimate of the average annualized losses due to earthquakes in the U.S. Moreover, the estimate represents a long-term average. Actual losses in any single year may be much larger or much smaller than this estimate. A comparison of AEL results with other loss estimates is shown in Table 3-1 to give perspective on the range of thinking about this question.

The AEL quantifies the annualized earthquake losses in any single year; the AELR addresses seismic risk in relation to the value of the building inventory in the study area. By presenting annualized loss in relation to the replacement value of the study area, the AELR provides another perspective of seismic risk which facilitates comparison between regions.

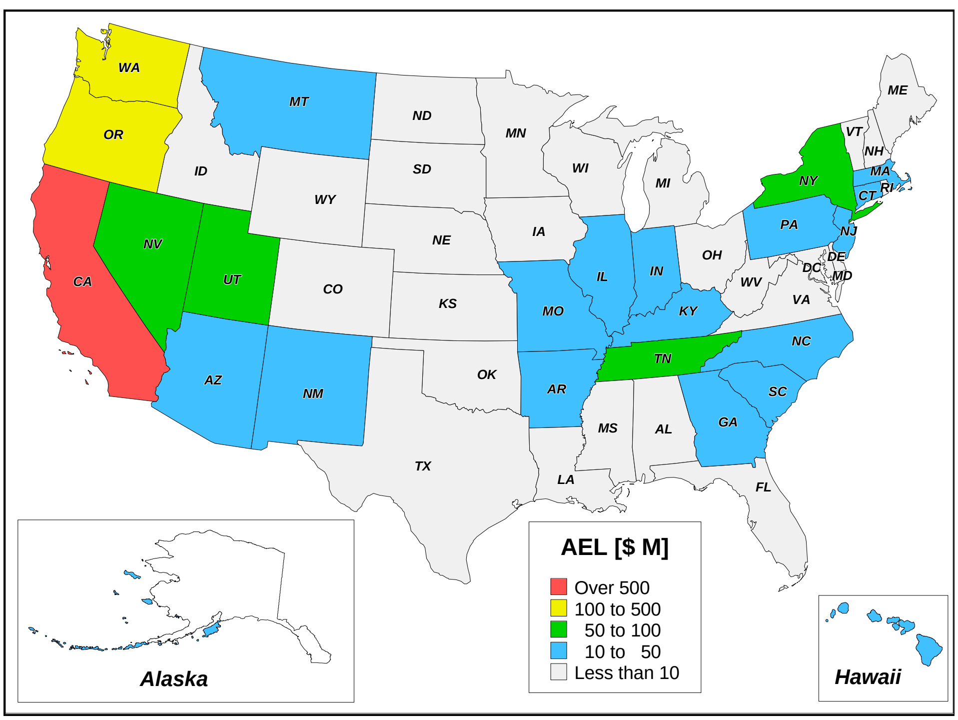


Figure 3-1. Annualized Earthquake Losses at the State Level

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

It is important to recognize that the nationwide and statewide losses are the result of averaging over time the losses caused by earthquakes occurring in different parts of the nation in different years.

The majority (84 percent) of the loss is located in California, Oregon and Washington, with 74 percent ($3.3 billion per year) concentrated in the state of California. The high concentration of AEL in California is consistent with the state's significant building inventory exposure and high earthquake hazard (see Figures 2-2 and 2-4).

AEL and AELR values for the 50 states and Washington, DC are shown in Table 3-2. While California accounts for 74 percent of total national AEL (or $3.3 billion in estimated annualized losses), the regional distribution of annualized loss and loss ratios demonstrates that seismic risk is a national concern. The juxtaposition of New York and Nevada in the AEL column of Table 3-2 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 those states with much greater hazards and smaller building inventories (e.g., Nevada).

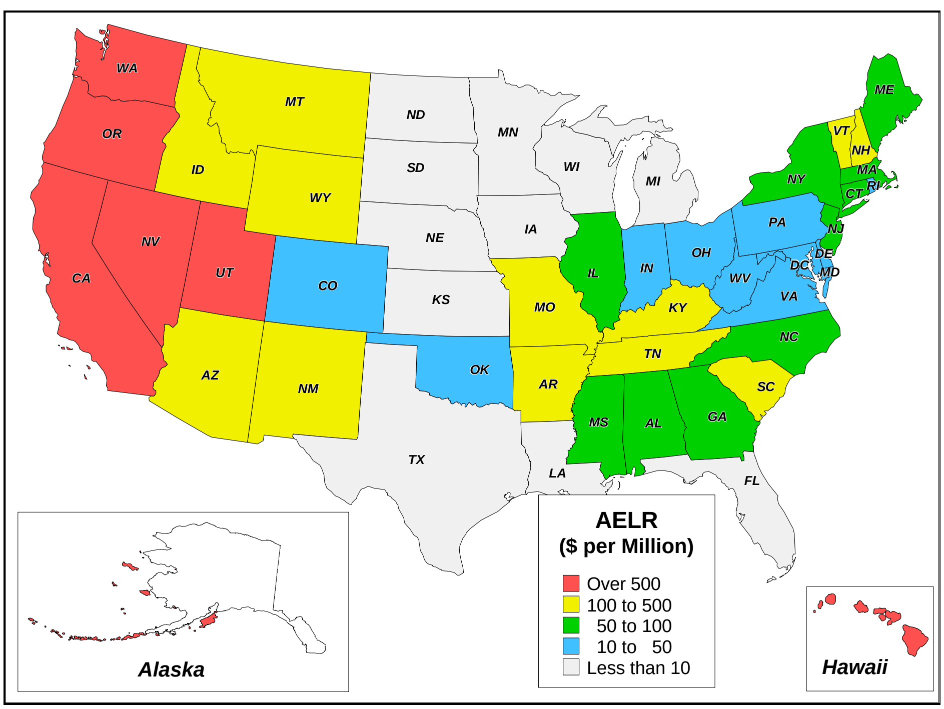


Figure 3-2. Annualized Earthquake Loss Ratios at the State Level

Table 3-1. Comparison of the HAZUS Loss Results with Other Loss Estimates

National:

Petak and Atkisson (1982) projection of direct and indirect annual economic loss in the year 2000: $1.55 billion (1970$) or $6.4 billion (1994 $). Petak, W.J. and A.A. Atkisson, 1982, Natural Hazard Risk Assessment and Public Policy, Springer Verlag, NY 489 pp.

Hayes (1990) estimate of annual earthquake losses $1 billion. Hayes, W., 1990, Perspectives on the International Decade of Natural Disaster Reduction, *Earthquake Spectra*, **6**, No. 129.

California:

California Division of Conservation, Division of Mines and Geology (2000), modified HAZUS estimate: $3.9 billion/year structural/nonstructural, and $4.7 billion/year with capital losses.

ftp://ftp.consrv.ca.gov/pub/dmg/pubs/Future_EQ_Losses.pdf.

California Earthquake Authority (CEA) estimates of losses to single-family residences: ~$2 billion/year, all residences: ~$1.6 billion/year EQECAT, 1995, CEA Residential Property Portfolio Earthquake Loss Modeling: Summary EQECAT, Inc., San Francisco, CA.

Reported losses in CA during 1970-2000 average $1-2 billion/year, 1989-1998 average $4-5 billion/year. Stover, C.W. and Coffman, F.L.,1993, Seismicity of the United States 1568-1989 (Revised), *US Geological Survey Professional Paper 1527*.

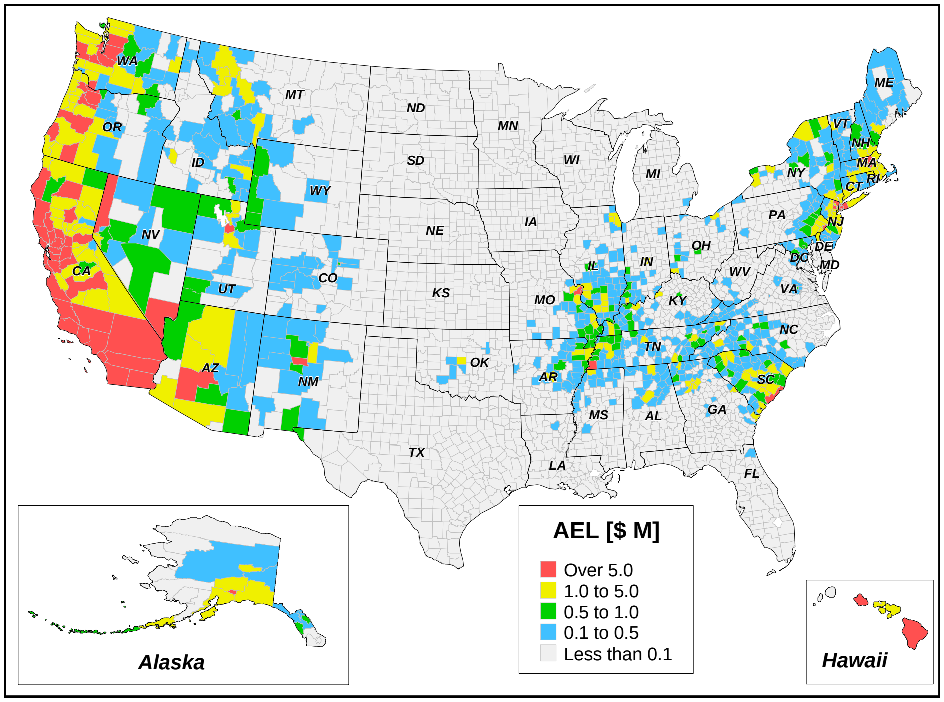


Figure 3-3. Annualized Earthquake Losses at the County Level

Comparing the standings of individual states in the AEL and AELR columns of Table 3-2 indicates that while California and the Pacific Northwest retain a high relative standing, New York and New Jersey, states with relatively low hazard and high inventory values, drop from 4th to 20th and 10th to 21st place, respectively. States such as Montana and New Mexico - with higher hazard and lower building inventory values - rise in the ordering from 22nd to 8th and 20th to 10th, respectively.

In other words, while the actual dollar amounts of estimated losses are lower, a significantly larger percentage of the building inventory is affected. Regionally, states with the highest AELR rankings are located in the western United States, however, other significant concentrations occur in the Southeast (South Carolina), Northeast (Vermont, New Hampshire), and the Central U.S. (Illinois, Kentucky, Tennessee, Arkansas, Missouri).

Figure 3-5 shows the distribution of AEL by region. Oregon, Washington, and California account for $3.7 billion in estimated annualized earthquake losses, or 84 percent of the U.S. total. The remaining 16 percent of estimated annualized losses are distributed across the Central U.S. ($0.19 billion per year), the Northeastern states ($0.21 billion per year), the Rocky Mountain / Basin and Range region ($0.18 billion), the Great Plains (($0.01 billion per year), and the Southeast ($0.10 billion per year). Hawaii and Alaska have a combined AEL of $0.07 billion.

Annualized losses can be aggregated at a variety of geo-political scales. County level data in Figure 3-3 can be aggregated to create

Table 3-2. Ordering of States by Annualized Earthquake Loss (AEL) and Annualized Earthquake Loss Ratio (AELR)

Order	State	AEL (x $1,000)
1	California	3,261,751
2	Washington	227,860
3	Oregon	167,496
4	New York	83,987
5	Nevada	55,041
6	Tennessee	52,117
7	Utah	51,448
8	Alaska	42,353
9	South Carolina	41,812
10	New Jersey	38,655
11	Missouri	38,400
12	Illinois	35,585
13	Hawaii	34,935
14	Massachusetts	24,896
15	Georgia	22,908
16	Pennsylvania	21,906
17	Arizona	20,602
18	North Carolina	18,742
19	Kentucky	18,680
20	New Mexico	17,729
21	Arkansas	16,669
22	Montana	15,609
23	Connecticut	12,189
24	Indiana	11,991
25	Virginia	8,640
26	Alabama	8,422
27	Ohio	8,169
28	Idaho	7,986
29	New Hampshire	6,828
30	Colorado	5,791
31	Mississippi	5,214
32	Maine	5,122
33	Oklahoma	4,681
34	Maryland	3,952
35	Vermont	3,446
36	Wyoming	3,269
37	Rhode Island	2,449
38	West Virginia	2,411
39	Delaware	1,467
40	Florida	922
41	District of Columbia	911
42	Texas	722
43	Louisiana	622
44	Michigan	300
45	Kansas	294
46	Wisconsin	121
47	Nebraska	93
48	Iowa	27
49	South Dakota	25
50	Minnesota	< 10
51	North Dakota	<10

Order	State	AELR ($ / Million)
1	California	2,049
2	Alaska	1,165
3	Oregon	1,063
4	Washington	878
5	Nevada	835
6	Utah	792
7	Hawaii	581
8	Montana	365
9	South Carolina	319
10	New Mexico	274
11	Tennessee	245
12	Idaho	172
13	Arkansas	171
14	Wyoming	164
15	Missouri	153
16	Arizona	121
17	Vermont	120
18	Kentucky	116
19	New Hampshire	114
20	New York	90
21	New Jersey	88
22	Georgia	86
23	Maine	80
24	North Carolina	69
25	Massachusetts	68
26	Connecticut	62
27	Illinois	58
28	Mississippi	54
29	Alabama	52
30	Indiana	44
31	Rhode Island	42
32	Delaware	40
33	Pennsylvania	35
34	Virginia	34
35	Colorado	34
36	Oklahoma	32
37	West Virginia	30
38	District of Columbia	23
39	Maryland	18
40	Ohio	15
41	Louisiana	4
42	Kansas	2
43	Florida	1
44	Nebraska	1
45	Texas	1
46	South Dakota	1
47	Michigan	1
48	Wisconsin	< 1
49	Iowa	< 1
50	Minnesota	< 1
51	North Dakota	< 1

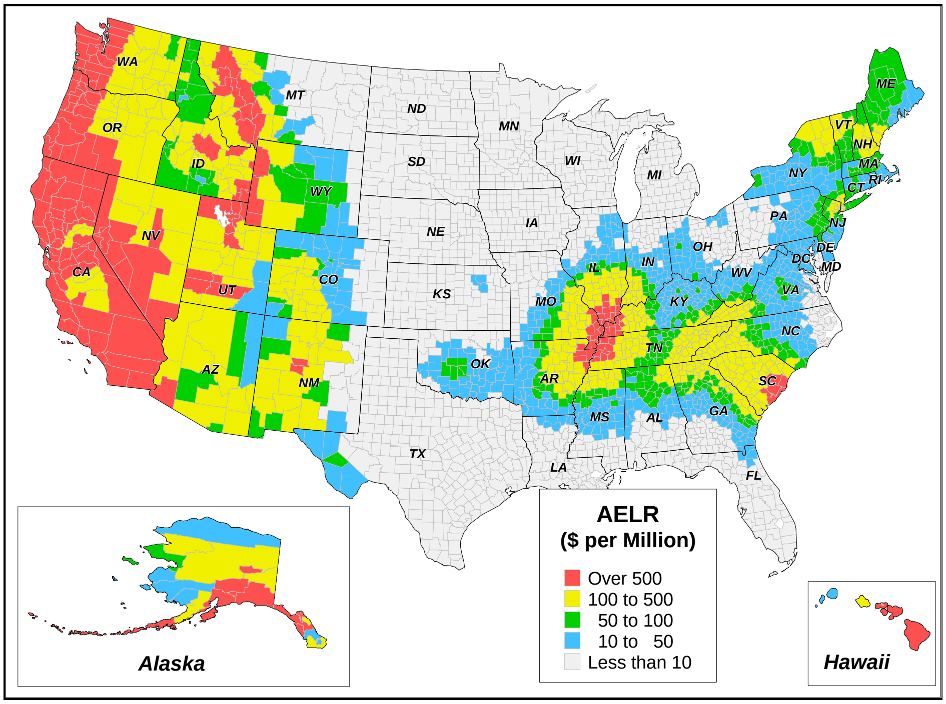


Figure 3-4. Annualized Earthquake Loss Ratios at the County Level

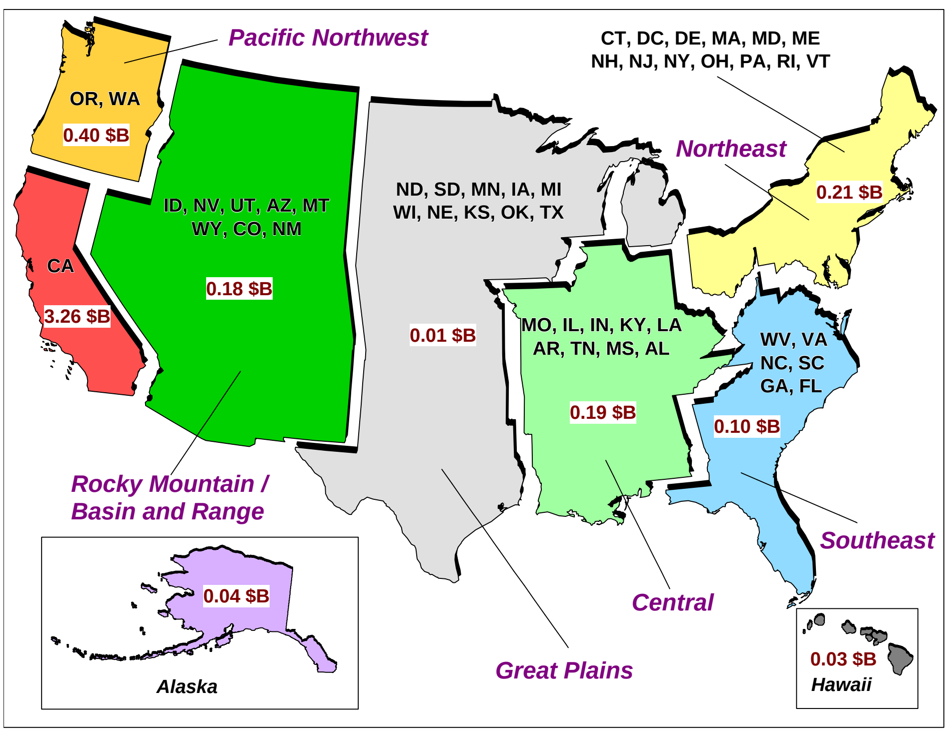


Figure 3-5. Distribution of Average Annualized Earthquake Loss by Region

loss estimates for metropolitan areas. These areas are the primary Metropolitan Statistical Areas (US Census, 1994). Metropolitan areas with annualized losses greater than $10 million per year are listed in Table 3-3. These 40 metropolitan areas, led by the Los Angeles and

Table 3-3. Annualized Earthquake Loss (AEL) and Average Earthquake Loss Ratios (AELR) for 40 Metropolitan Areas with AEL Greater Than $10 Million

Order	Metropolitan Area*	AEL ($Million)
1	Los Angeles, CA	1,069.0
2	Riverside, CA	356.7
3	**Oakland, CA**	348.7
4	San Francisco, CA	346.0
5	San Jose, CA	242.5
6	Orange, CA	214.4
7	**Seattle, WA**	128.4
8	San Diego, CA	127.5
9	**Portland, OR**	98.4
10	Ventura, CA	89.4
11	New York, NY	56.4
12	Vallejo, CA	52.7
13	Santa Rosa, CA	51.2
14	**Salt Lake City, UT**	39.5
15	Sacramento, CA	39.3
16	St. Louis, MO	34.1
17	Eureka, CA	33.8
18	Salinas, CA	33.1
19	**Santa Barbara, CA**	33.1
20	Santa Cruz, CA	32.9
21	Bakersfield, CA	30.6
22	Tacoma, WA	28.3
23	**Las Vegas, NV**	28.0
24	**Anchorage, AK**	24.9
25	Boston, MA	23.3
26	**Hilo, HI**	19.7
27	Stockton, CA	19.2
28	**Reno, NV**	17.8
29	Memphis, TN	17.2
30	Philadelphia, PA	16.8
31	San Luis Obispo, CA	15.6
32	Salem, OR	15.3
33	Fresno, CA	14.0
34	**Charleston, SC**	13.3
35	Albuquerque, NM	13.0
36	Newark, NJ	11.6
37	**Honolulu, HI**	11.6
38	Atlanta, GA	11.3
39	Modesto, CA	11.2
40	Redding, CA	10.3

Order	Metropolitan Area*	AELR ($ / Million)
1	San Francisco	3,167.5
2	San Jose	3,017.7
3	**Oakland**	2,954.3
4	Eureka Area	2,935.7
5	**Hilo**	2,825.4
6	Ventura	2,760.9
7	Riverside	2,673.3
8	Santa Cruz	2,628.9
9	Los Angeles	2,299.0
10	Santa Rosa	2,293.7
11	Vallejo	2,275.2
12	Salinas	1,819.0
13	**Santa Barbara**	1,690.1
14	Orange	1,666.2
15	**Anchorage**	1,640.1
16	Redding	1,287.9
17	**Reno**	1,246.2
18	San Luis Obispo	1,232.0
19	**Portland**	1,173.0
20	Bakersfield	1,155.1
21	**Seattle**	1,118.8
22	Salem	1,083.9
23	San Diego	992.6
24	Tacoma	983.8
25	**Salt Lake City**	954.7
26	Stockton	824.5
27	**Charleston**	722.2
28	Modesto	629.4
29	**Las Vegas**	599.4
30	Sacramento	523.2
31	Albuquerque	503.7
32	Memphis	387.6
33	Fresno	379.4
34	St. Louis	281.8
35	**Honolulu**	263.4
36	New York	125.4
37	Newark	108.7
38	Atlanta	86.9
39	Boston	74.7
40	Philadelphia	63.6

* FEMA *Project Impact* communities are designated in bold letters

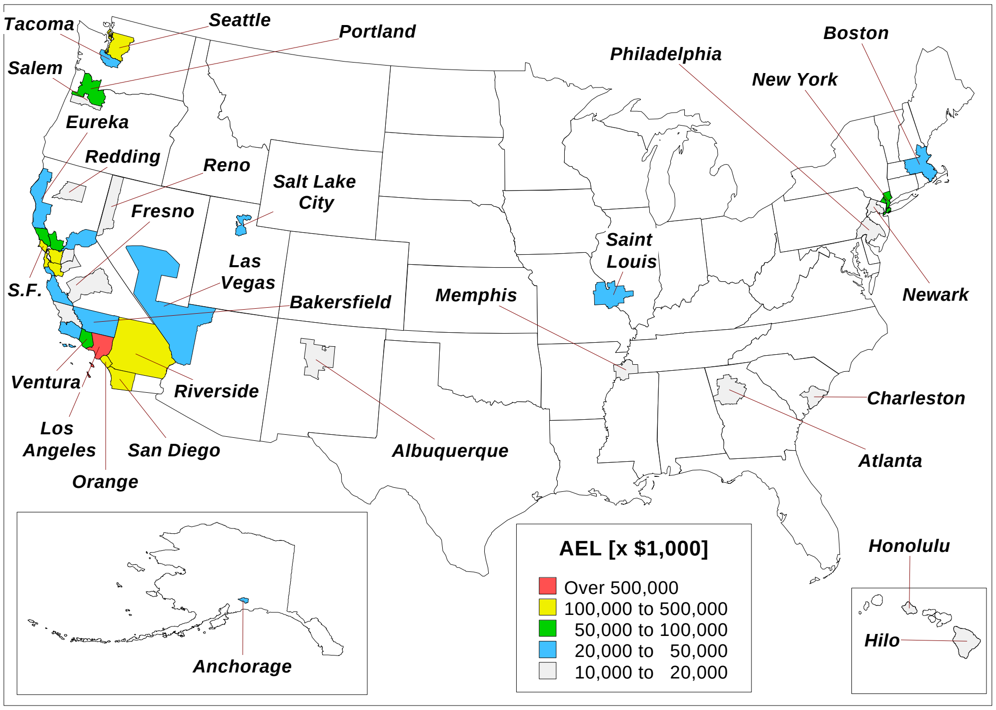


Figure 3-6. Metropolitan Areas with Annualized Earthquake Losses Greater than $10 Million

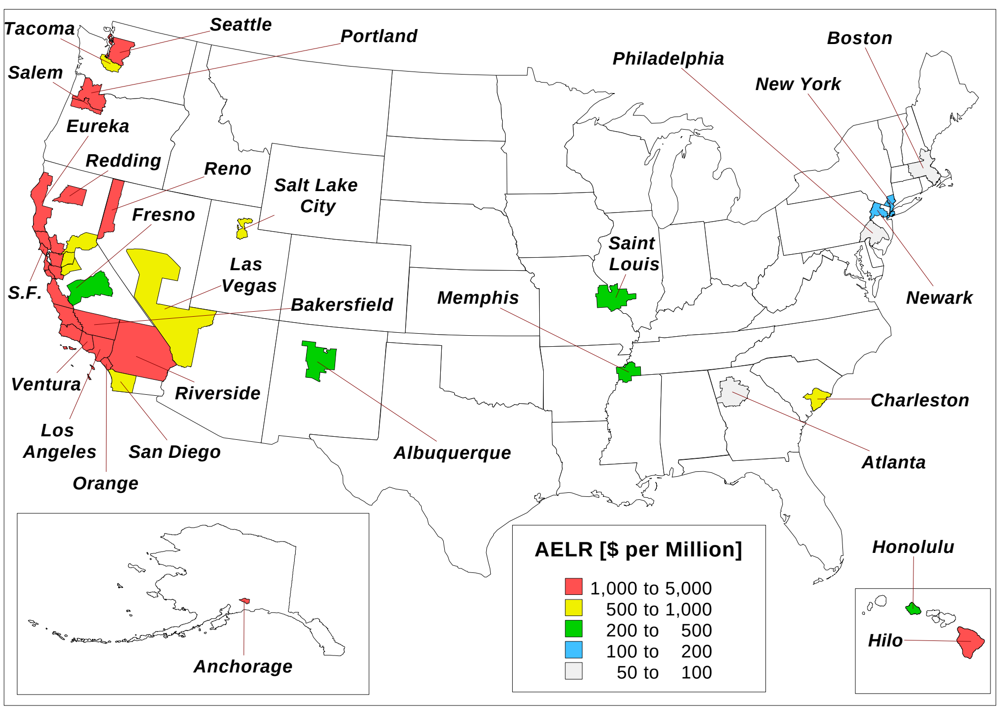


Figure 3-7. Annualized Earthquake Loss Ratios for Metropolitan Areas with Annual Losses Greater than $10 Million

San Francisco Bay areas, account for 86 percent of the total annualized losses in the U.S. Los Angeles county alone accounts for 25 percent of the total national AEL. Annualized earthquake loss values for selected metropolitan areas are shown in Figures 3-6 and 3-7.

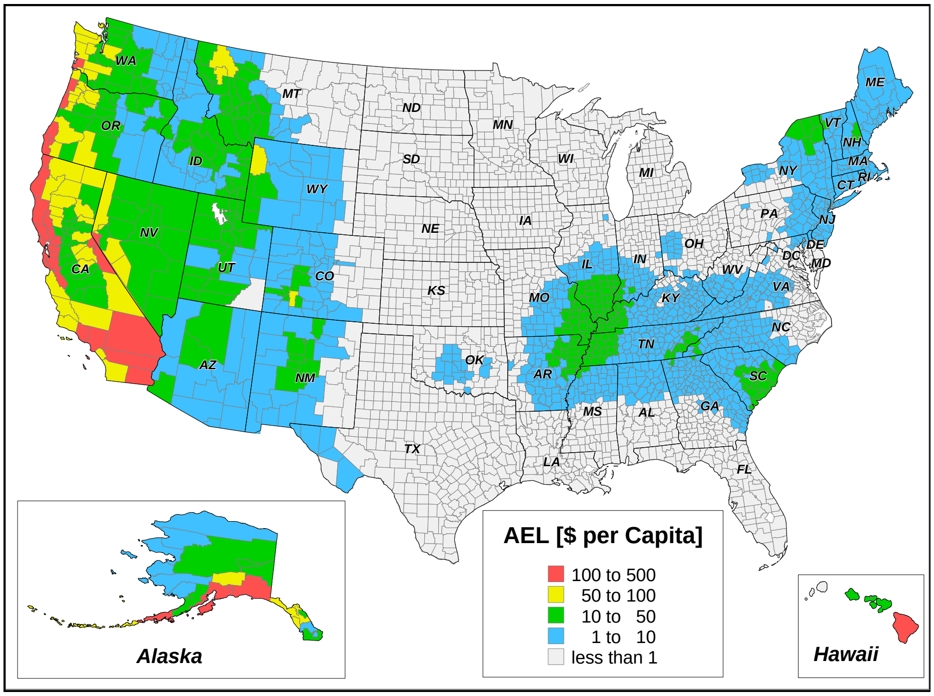


Figure 3-8. AEL Per Capita at the County Level

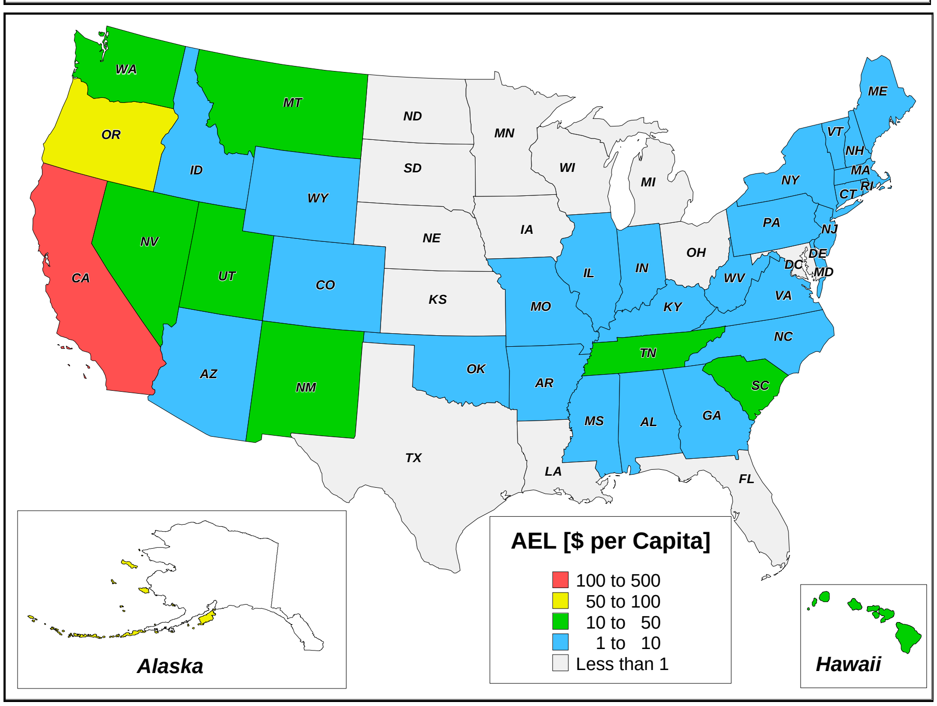


Figure 3-9. AEL Per Capita at the State Level

When losses for these 40 metro areas are depicted as a fraction of total building inventory value in the AELR column of Table 3-3, several cities rise in the rankings, notably Hilo, HI, Anchorage, AK, and Reno, NV. Again, this is a reflection of high seismic hazard and low value (relatively speaking) of building inventory.

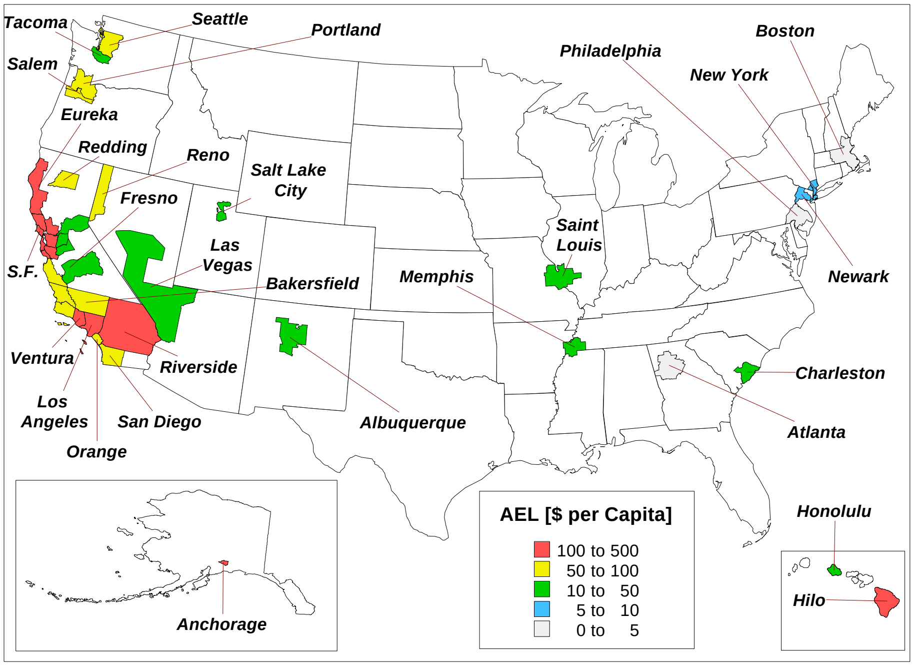


Figure 3-10. AEL Per Capita for Selected Metropolitan Areas

The ability to examine annualized loss in terms of demographic parameters such as population, ethnicity, age, and income is important to the development of policies, programs and strategies to minimize socio-economic losses from earthquakes. Figures 3-8 through 3-10 present the AEL results on a per capita basis by county, state, and metropolitan area. Whereas the AELR expresses annualized loss as a fraction of building replacement value, Figures 3-8 through 3-10 show annualized loss in relation to 1990 population distribution and reveal two important facts: 1) the high rankings include not only areas with high seismic hazard and high building exposure (e.g., Los Angeles and San Francisco Bay areas), but also areas with high seismic hazard and low building exposure (e.g., Hawaii and Alaska); and 2) California and Oregon have the highest seismic risk when measured on a per capita basis at the state level.

Chapter 4 —Interpretations and Applications

Officials at all governmental levels are frequently faced with the challenge of identifying areas that are susceptible to natural hazards; analyzing the potential future losses; and developing and implementing cost-effective risk management plans to minimize them. While there is a well-established body of information on how the earthquake hazard varies among regions, there is less understanding of how earthquake risk differs from one region to another. FEMA has long worked to improve the factual basis of seismic risk in the United States, and it believes that the data and analytical capacity in the HAZUS loss-estimation methodology provide the first, in-depth standardized comparison of regional seismic risk. This will assist FEMA and other organizations in promoting risk reduction, and motivate local, regional and state decision makers to implement it.

Study Findings

The annualized loss from earthquakes nationwide is estimated to be $4.4 billion per year, which includes both capital ($3.5 billion) and income-related losses ($0.9 billion). California, Oregon and Washington account for $3.7 billion (84 percent of U.S. total) in estimated annualized earthquake losses. The remaining 16 percent of estimated annualized losses are distributed among the Central U.S. ($0.19 billion per year), the Northeastern states ($0.21 billion per year), and the Southeast ($0.10 billion per year). Hawaii and Alaska have a combined $70 million in average annualized losses.

The study also helps define the urban dimension of the seismic risk in the U.S. In several states - including New York, South Carolina, Utah, Alaska, and Hawaii, as well as California, Oregon, Washington - estimated losses in metropolitan areas account for up to 80 percent of total state losses. More than 48 percent of the annualized losses in California, for example, are expected in three metropolitan areas: San Francisco, Los Angeles and San Diego. That these three metropolitan regions—with a combined population of 12 million (1994) - account for over 35 percent of the total estimated annualized earthquake loss in the U.S. has important implications for a national strategy to reduce seismic risk. These losses stem from the existing building stock. Strategies to reduce seismic risk in the U.S. must be closely integrated with policies that reduce the current risk through building rehabilitation and reduce future risks through urban planning and development, and the adoption and implementation of seismic building codes.

Applications

The information in this study can be used at least four ways:

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

The study gives policy makers, practitioners and researchers a consistent approach that will enable them to better understand the complexities and dynamics of risk, how levels of risk can be accurately measured and compared, and the myriad factors that influence risk. An understanding of these relationships is critical in balanced and informed decisions on managing the seismic risk, at the community, state and national level.

(2) To provide a baseline for earthquake policy development and the comparison of mitigation alternatives.

The information in this study is an integral component of a "national seismic risk baseline," aggregated at the metropolitan, state, and regional level. The data used for this analysis present an early to mid-1990's picture of seismic risk in the United States. Updating this seismic risk "snapshot" with more recent data, from the 2000 Census for example, will enable comparison of the changes in risk with time. Baselines of this type can support the objective analysis of policy and program options for seismic risk reduction in the U.S.

The methodology can be extended to other components of risk, including social losses or the economic consequences of losing transportation systems and utilities. An understanding of these other dimensions of risk can inform the decisions of policy makers to regulate and spend money. For example, as public funds are invested in the upgrading of our nation's infrastructure, it is increasingly important to understand the seismic risk of metropolitan areas.

Finally, the HAZUS methodology will be used as a decision-support tool by the National Earthquake Hazards Reduction Program (NEHRP) as it fulfills its responsibility to:

- Identify mitigation strategies and priorities that reflect the regional seismic risk.
- Promote seismic risk reduction to the private sector, through *Project Impact* and other community-based initiatives.
- Promote legislation that encourages seismic risk reduction, including the use of tax incentives and other mechanisms.

When the methodology described in this study becomes part of an integrated risk index for multiple hazards - including hurricanes, windstorms, floods, wildfires, and drought - policy makers will be able to compare risk, assess mitigation options, and implement balanced programs to reduce natural hazard losses.

(3) To support the adoption and enforcement of seismic provisions of building codes.

One of the greatest challenges for the National Earthquake Hazards Reduction Program (NEHRP) is to promote the adoption and enforcement of seismic building codes in regions of the U.S. that experience infrequent but damaging earthquakes. The uneven distribution of seismic risk across the U.S. militates against uniform adoption and enforcement. Typically, localities with infrequent earthquakes place a low priority on seismic code enforcement[(1)]. However, this study demonstrates the actual risk at each governmental level in terms of potential damage and economic loss.

The HAZUS data can be applied to evaluate the effectiveness of different mitigation strategies by comparing the risk values, including their uncertainties, before and after these strategies are implemented. For example, a FEMA study[(2)] concludes that if all of 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 (buildings, contents, and income). This is equivalent to avoiding about 40 percent of losses (when adjusting for additional costs to design and construct to higher seismic standards).

This information is invaluable in analyzing policy and program options in the development of long-term risk management measures, including those that address building code development, land use planning, and resource allocation.

(4) To compare the seismic risk with other natural hazard risks.

The Annualized Earthquake Loss figures - which include estimated losses in regions with infrequent earthquakes - can be compared with more frequent flood and wind-related losses. The ability to quantify the seismic risk relative to other natural hazards helps in a balanced, multi-hazard approach to risk management at each level of government. For example, government officials may choose to elevate structures in response to flood hazard when due respect to the earthquake risk would suggest better approaches to risk reduction. Future products in this integrated, multi-hazard approach include maps that allow the comparison of risk among natural hazards (e.g., hurricane, flood, earthquake, wildfires) at variable geographic scales (e.g., metropolitan, county, state, multi-state).

[(1)] Burby, Raymond and Peter May. Making Building Codes an Effective Tool for Earthquake Hazard Mitigation, *Environmental Hazards*, **1**, 1999, p. 27-37.

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

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, since it considers replacement value, and can be directly compared across different geopolitical units including census tracts, counties, and states.

Average Annual Frequency – The long-term average number of events in a unit of time.

Basic Building Inventory - The national level building inventory that was incorporated into HAZUS. The basic database classifies buildings by occupancy (residential, commercial, etc.) and by model building type (structural system and material, height). The basic mapping schemes are state-specific for single-family occupancy type and region-specific for all other occupancy types; they are building-age and height specific. The four inventory groups are: a) general building stock, b) essential and high potential loss facilities, c) transportation systems, and d) utilities.

Hazard - A source of potential danger or an adverse condition. For example, an earthquake occurrence is the source of strong ground shaking, faulting, liquefaction, and ground failure, 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.

Hazards U.S. (HAZUS) - A standardized GIS-based loss estimation tool, developed by the Federal Emergency Management Agency (FEMA) in cooperation with the National Institute of Building Sciences (NIBS). See www.fema.gov/hazus for more information.

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. PGA is typically expressed as a percentage of the acceleration due to gravity (g).

Probabilistic Seismic Hazard Data – earthquake ground motion estimate that include 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 www.geohazads.cr.usgs.gov/eq for more information.

Project Impact - A FEMA initiative to encourage communities to develop public-private partnerships to reduce losses from natural and technological disasters. See www.fema.gov for more details.

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: 1) what hazard events can occur in the community? 2) what is the likelihood of these hazard events occurring? 3) what are the consequences if the hazard event occurs? The overall significance of these consequences in the community or region is called the risk assessment.

Risk Management - The reduction of risk to an acceptable level. Risk management addresses three issues: 1) what steps should be taken to reduce risks to an acceptable level (mitigation), 2) the relative trade-offs among multiple opportunities (benefit/cost analyses, capital allocation), and 3) the impacts of current decisions on future opportunities.

Spectral Acceleration (SA) - A measure of the ground acceleration associated with an earthquake at a specific period (e.g., 0.3 second or 1 second). Acceleration is most closely related to structural response and, therefore, indicates an earthquake's damage potential.

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

Appendix B—Overview of HAZUS

Acknowledging the need to develop a standardized approach to estimating losses from earthquake and other hazards, FEMA has embarked on a multi-year program to develop a GIS-based regional loss estimation tool. FEMA first released HAZUS in 1997 followed by an updated version in 1999. FEMA developed HAZUS under a cooperative agreement with the National Institute of Building Sciences. HAZUS is a tool that local, state and federal government officials and others can use for earthquake-related mitigation, emergency preparedness, response and recovery planning, and disaster response operations. The methodology in HAZUS is comprehensive. It incorporates state-of-the-art approaches for 1) characterizing earth science hazards including ground shaking, liquefaction, and landslides; 2) estimating damage and losses to buildings and lifelines; 3) estimating fires following earthquake; 4) estimating casualties, displaced households, and shelter requirements; and 5) estimating direct and indirect economic losses.

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

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

A brief description of each of the six modules is presented below. Detailed technical descriptions of the modules can be found in the HAZUS technical manual[1].

Module 1:
Potential Earth Science Hazard (PESH)

The Potential Earth Science Hazard module estimates ground motion and ground failure (landslides, liquefaction, and surface fault rupture). Ground motion demands in terms of spectral acceleration (SA) and peak ground acceleration (PGA) are typically estimated based on the location, size and type of earthquake, and the local geology.

For ground failure, permanent ground deformation (PGD) and probability of occurrence are determined. GIS-based maps for other earth science hazards, such as tsunami and seiche inundation, can also be incorporated. In the current study, hazard data from the US Geological Survey is used (Step One).

(1) Federal Emergency Management Agency, HAZUS: Earthquake Loss Estimation Methodology, Technical Manuals I, II, & III, Prepared by the National Institute of Building Sciences for FEMA, 1999

Module 2:
Inventory and Exposure Data

Built into HAZUS is a national-level basic exposure database that allows a user to run a preliminary analysis without having to collect any additional local data. The general stock of buildings is classified by occupancy (residential, commercial, etc.) and by model building type (structural system and material, height). The default mapping schemes are state-specific for single-family occupancy type and region-specific for all other occupancy types. They are age and building-height specific.

The four inventory groups are: a) general building stock, b) essential and high potential loss facilities, c) transportation systems, and d) utilities. The infrastructure within the study region must be inventoried in accordance with the standardized classification tables used by the methodology. These groups are defined to address distinct inventory and modeling characteristics. A description of the four inventory groups and HAZUS default mapping schemes can be further examined in Chapter 3 of the HAZUS technical manual.

Population data is based on the 1990 United States Census(2), and estimates for building exposure are based on default values for building replacement costs (dollars per square foot) for each model building type and occupancy class, in addition to certain regional cost modifiers. Data was also drawn from Dun and Bradstreet and RS Means.

Module 3:
Direct Damage

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

For HAZUS, a technique using building fragility curves based on the inelastic building capacity and site-specific response spectra was developed to describe the damage incurred in building components(3). Since damage to nonstructural and structural components occurs differently, the methodology estimates both damage types separately. Nonstructural building components are grouped into drift-sensitive and acceleration-sensitive components.

For both essential facilities and general building stock, damage state prob-

(2) U.S. Bureau of the Census, "Standard Tape File 3", STF-3, May 1992

(3) Kircher, C.A., et. al., Estimation of Earthquake Losses to Buildings, *Earthquake Spectra*, **13**, No. 4, 1997, pp. 703-720.

abilities are determined for each facility or structural class. Damage is expressed in terms of probabilities of occurrence of specific damage states, given a level of ground motion and ground failure. Five damage states are identified - none, slight, moderate, extensive and complete.

Module 4:
Induced Damage

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

Module 5:
Direct Losses

Unlike many previous loss estimation studies, HAZUS provides estimates for both economic and social losses. Economic losses include structural and nonstructural damage, costs of relocation, losses to business inventory, capital-related losses, income losses, and rental losses. Social losses are quantified in terms of casualties, displaced households, and short-term shelter needs. The output of the casualty module includes estimates for four levels of casualty severity (minor to dead) by time (2:00 a.m., 2:00 p.m., and 5:00 p.m.) for four population groups (residential, commercial, industrial, and commuting). Casualties, caused by secondary effects such as heart attacks or injuries while rescuing trapped victims, are not included.

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

Module 6:
Indirect Losses

This module evaluates the long-term effects on the regional economy from earthquake losses. The outputs in this module include income change and employment change by industrial sector[4].

[4] Brookshire, D.S., et al., Direct and Indirect Economic Losses from Earthquake Damage, *Earthquake Spectra,* **13**, No. 4, 1997, pp. 683-702.

Appendix C—Probabilistic Hazard Data Preparation and AEL Computation

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

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

The USGS provided the hazard data as a set of 18 (or 20) intensity-probability pairs for each of the approximately 150,000 grid points used to cover the United States. For each grid point, a linear interpolation of the data was used

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	5.00E-03	2.49E-02	5.00E-03	3.28E-02	2.50E-03	2.85E-02
2	7.00E-03	2.07E-02	7.50E-03	2.89E-02	3.75E-03	2.37E-02
3	9.80E-03	1.65E-02	1.13E-02	2.40E-02	5.63E-03	1.84E-02
4	1.37E-02	1.25E-02	1.69E-02	1.85E-02	8.44E-03	1.34E-02
5	1.92E-02	8.76E-03	2.53E-02	1.30E-02	1.27E-02	9.24E-03
6	2.69E-02	5.86E-03	3.80E-02	8.45E-03	1.90E-02	6.25E-03
7	3.76E-02	3.87E-03	5.70E-02	5.29E-03	2.85E-02	4.23E-03
8	5.27E-02	2.64E-03	8.54E-02	3.36E-03	4.27E-02	2.95E-03
9	7.38E-02	1.90E-03	1.28E-01	2.27E-03	6.41E-02	2.14E-03
10	1.03E-01	1.43E-03	1.92E-01	1.63E-03	9.61E-02	1.60E-03
11	1.45E-01	1.08E-03	2.88E-01	1.19E-03	1.44E-01	1.18E-03
12	2.03E-01	7.73E-04	4.32E-01	8.28E-04	2.16E-01	8.08E-04
13	2.84E-01	5.06E-04	6.49E-01	5.03E-04	3.24E-01	4.83E-04
14	3.97E-01	2.88E-04	1.30E+00	1.30E-04	4.87E-01	2.36E-04
15	5.56E-01	1.35E-04	1.95E+00	3.84E-05	7.30E-01	9.04E-05
16	7.78E-01	4.88E-05	2.92E+00	7.62E-06	1.09E+00	2.60E-05
17	1.09E+00	1.32E-05	4.38E+00	9.76E-07	1.64E+00	5.08E-06
18	1.52E+00	2.80E-06	6.57E+00	8.61E-08	2.46E+00	6.62E-07

* AFE = Annual Frequency of Exceedence @ 1/ Return Period

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-1 below shows an example of USGS hazard data for an individual grid point.

Step 2: Compute the PGA, SA@0.3 and SA@1.0 at each census tract centroid for the eight return periods.

For estimating losses to the building inventory, HAZUS uses the ground shaking values calculated at the centroid of the census tract. To incorporate the USGS data into HAZUS, the ground shaking values at the centroid were calculated from the grid-based data developed in Step 1.

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

- For census tracts that contain one or more grid points, the average values of the points are assigned to the census tract.
- For census tracts that do not contain any grid points, the average value of the four nearest grid points is assigned to the census tract.

Using this method, census-tract-based ground motion maps are generated for all eight return periods.

Step 3: Modifying the PGA, SA@0.3 and SA@1.0 at each census tract centroid to represent site-soil conditions for a NEHRP soil class type D.

The USGS data were based on a National Earthquake Hazard Reduction Program (NEHRP) soil class type B/C (medium rock / very dense soil). For this study, NEHRP soil class type D (stiff soil) was assumed for all analyses. To account for the difference in soil class types, the data developed in Step 2 were modified. The procedure described in Chapter 4 of the HAZUS technical manual was used for the modification of the ground shaking values.

Average Annualized Earthquake Loss Computation

After the hazard data is processed, an internal analysis module in HAZUS is used to transform the losses from all eight scenarios into an Annualized Earthquake Loss (AEL). Figure C-1 below 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 integration, based on a best-fit curve for the points corresponding to the eight loss-probability pairs using two different curve-fitting approaches: a log-linear relationship and an exponential relationship. The shaded area under a loss-probability curve represents an approximation to the AEL[1]. Mathematically speaking, computing the area under the

[1] The horizontal axis in Figure C-1 has a non-linear scale, and thus the area shown is only a schematic representation of AEL. The actual AEL corresponds to the area under a plot of loss versus annual frequency of occurrence.

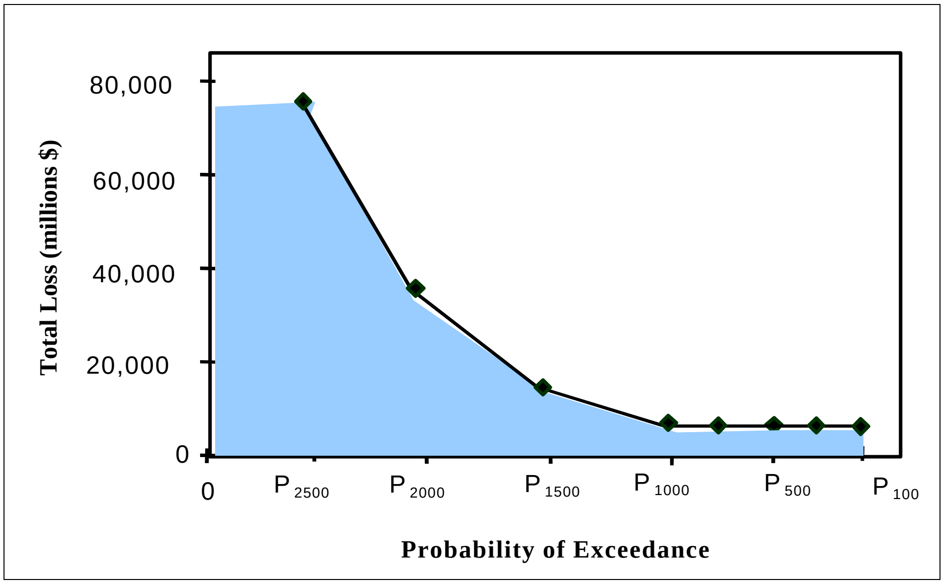


Figure C-1. Probabilistic Loss Curve

curve is equivalent to taking the summation of the losses multiplied by their annual probability of occurrence. Generally, the exponential relationship provides a better fit for states with a higher hazard, while the log-linear approach provides a better fit for states with a lower hazard.

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

It is important to note that losses in any given year could be substantially lower or higher than an average annual value.