Estimation of Future Earthquake Losses in California

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Purpose

Recent developments in earthquake hazards and damage modeling, computing, and data management and processing have made it possible to develop estimates of the levels of damage from earthquakes that may be expected in the future in California. These developments have been mostly published in the open literature, and provide an opportunity to estimate the levels of earthquake damage Californians can expect to suffer during the next several decades. Earthquake losses have increased dramatically within the recent decades, mostly because our exposure to earthquake hazards has increased. Table 1 summarizes the reported losses in California earthquakes within the past 30 years.

Table 1. Reported losses due to major earthquakes in California since 1971.

Earthquake	Date	Magnitude	Total Loss [1]
San Fernando	February 9, 1971	6.7	2,200 [2]
Imperial Valley	October 15, 1979	6.5	70 [2]
Coalinga	May 2, 1983	6.4	18 [2]
Whittier Narrows	October 1, 1987	5.9	5 22 [3]
Loma Prieta	October 17, 1989	7.0	10,000 [4]
Northridge	January 17, 1994	6.7	46,000 [5]
Petrolia	April 25, 1992	7.0	80 [3]
Landers	June 28, 1992	7.6	120 [3]
Hector Mine	October 16, 1999	7.4	"Minor"

[1] Estimates are in (2000) millions dollars

[2] Estimate is from FEMA (1997)

[3] Estimate is from U.S. Office of Technology Assessment

[4] Estimate is from NRC (1994)

[5] Estimate is from California Governor's Office of Emergency Services

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From Table 1, it is apparent that the most important factor affecting losses from earthquakes is not timing, or earthquake magnitude, but location. All but four of the earthquakes listed in Table 1 have occurred far from major population centers. Two, the Loma Prieta earthquake and the San Fernando earthquake, occurred on the edges of major populated areas. Loma Prieta, although it occurred beneath the Santa Cruz Mountains, caused significant damage in the nearby Santa Cruz and in the more distant, heavily populated, San Francisco Bay area. The 1971 San Fernando earthquake had an epicenter in the lightly populated San Gabriel Mountains, but caused slightly over $2 billion in damage in the Los Angeles area. As urban areas continue to expand, the population and the infrastructure at risk increase. When earthquakes occur closer to populated areas, damage is more significant. The relatively minor Whittier Narrows earthquake of 1987 caused over 500 million dollars in damage because it occurred in the Los Angeles metropolitan area, not at its fringes. The Northridge earthquake had fault rupture directly beneath the San Fernando Valley, and caused about $46 billion in damage. The vast increase in damage from the 1971 San Fernando earthquake to the 1994 Northridge earthquake, reflects the effects of both the location of the earthquake being directly beneath a highly populated area, and 23 years of continued development, resulting in greater exposure to potential damage.

The reported thirty-year (1970-2000) average annual loss for California is about $1.9 billion (2000 dollars). However, 70 to 80 percent of that loss is from the Northridge earthquake alone! Thus, past earthquakes may not provide a realistic estimate of future earthquakes' effects. The large earthquakes in lightly populated regions, such as Landers (June 28, 1992) and Hector Mine (October 16, 1999) give us a clear perspective on the potential earthquake shaking from a major earthquake, while the moderate earthquakes “closer to home”, particularly Northridge, give us a sense of our vulnerability to earthquake shaking. A major earthquake in or near one of California’s urban centers has the potential to produce unprecedented losses.

California policy-makers are frequently called upon to make decisions on development, redevelopment, and hazard mitigation priorities. Clearly, these decisions could profit from an understanding of the expected future losses from earthquakes. This understanding should begin on a regional scale, applicable to regional policy decisions. To this end, to provide a credible first order estimation of future earthquake losses in California, the California Geological Survey (CGS) has implemented an evaluation of expected earthquake losses in California. Of course, we cannot precisely predict when and where future earthquakes will occur, how big they will be, and what effects they will have. But, we can apply the current understanding of earthquakes and their potential impacts to make such an evaluation. This approach provides results that can be applied at regional scales to assist in the development and prioritization of mitigation, and response and recovery strategies. To this end, we include a short list of policy questions and issues that arise from the damage analysis.

Introduction

In this report we present a summary of our results of a detailed evaluation of future potential earthquake losses to the buildings in California. Our study consists of two parts: (I) scenario loss estimation, and (II) annualized loss estimation.

More specifically, the scenario earthquake loss estimates presented in the first part of this report, are based on sixty shakemaps for hypothetical earthquakes on known active faults in California, prepared and released by the USGS (http://earthquake.usgs.gov/shakemap).

In the second part of the study, we have made an estimate of the annualized losses in the State. For this part, an earthquake hazard model developed jointly by CGS and the USGS in 1996, and updated in 2002 has been used (http://www.conservation.ca.gov/CGS). Geologists and seismologists at CGS and USGS have worked in collaboration with others familiar with California's seismic hazards to include all known seismic sources in and near California into the model. The expected frequency of earthquake occurrence along each fault is estimated from the historical and geologic earthquake activity. The estimates of ground motion that can be anticipated from those earthquakes incorporate the variability of shaking from different earthquake sources.

The building damage that results from the ground shaking emanating from these earthquakes is estimated using HAZUS, a program developed by the National Institute of Building Standards (NIBS) for the Federal Emergency Management Agency (FEMA) to calculate levels of damage that can be expected from a variety of natural disasters (NIBS, 1997). The input to HAZUS can be a specific earthquake or an already developed ground motion map. The result is a damage and loss scenario, that is the level of damage and the amount of loss expected from a specific earthquake or specific distribution of ground motion. HAZUS can also incorporate the probabilities of the ground motions into the computation to produce an estimate of the expected loss per year (expected annual loss). This report uses HAZUS to produce estimates of losses expected from scenario earthquakes in the highly populated areas of the San Francisco Bay Area (SFBA) and the Los Angeles area, and also the estimates of annualized losses throughout the State.

In using the results of this study, it is important to keep in mind that the present version of HAZUS (Service Release 2) has crude databases, which are regional estimates only. In many cases HAZUS does not have any inventory for specific types of structures. The hazard data, such as the fault data, soil types, and liquefaction and landslide, the databases of the built environment, such as the building, highways and bridges, ports and utilities, and the demographic data, are all estimates and do not include detailed information on the specific features. Furthermore, most of HAZUS data, the building inventory and the demographic specifically, are based on the 1990 census. Consequently, the data does not reflect the changes in the exposure to risk within the past decade, of the population and the built environment. The results presented in this report are based on default inventories of the built environment and the demographic data.

To make estimates of losses within various size regions, we made many computer runs using ground motion hazard, building inventory, and population at census tract centroids[1]. The State of California consists of 5,858 census tracts, of sizes from significantly less than one square mile to almost 8,000 square miles, depending on the population density.

HAZUS (SR2) has the capability and the default data to compute the damage and loss brought about by ground motion only. However, using HAZUS, the additional damage and losses brought about by earthquake secondary effects, such soil liquefaction, landslides, and tsunamis, can only be estimated if data for such phenomena is prepared and fed into the program by the user. For the present study, the impact of liquefaction phenomenon on the estimated annualized losses was included in the analysis by preparing and using the liquefaction data in the computation. However, the damage and loss contributions from other secondary phenomena, that is, landslide and tsunami were not considered, because of the lack of such data.

[1] Census tract is the basic analysis unit in HAZUS, which is defined by the U. S. Census Bureau, as a geographic region of approximately 4,000 population, comprised of people of “similar characteristics”.

Concerning the built environment exposed to the ground motion hazard, only the building inventory was considered in the loss estimation. Other elements of the built environment, such as the lifeline facilities, utilities and the ports were not included in this study. The reliability and the completeness of the data-bases and the damage-loss analysis relations (fragility functions) for these latter facilities in HAZUS are lower than the inventories and fragility functions for the buildings.

The output of each run of HAZUS includes the expected dollar loss due to structural and nonstructural damages to the inventory of buildings within the census tracts comprising the study region. Contents loss, direct economic loss (losses of income and rental) and indirect economic losses are also calculated. The buildings are divided into 15 different structure types, each with its own response to ground shaking. Estimates of various levels of injury (from level I representing relatively small injury not needing hospitalization to level IV, representing loss of life) can also be made using HAZUS. Here, we report on structural and nonstructural damage only. In the analysis of the annualized losses, the probabilities of ground motions expected to occur during one year to produce an estimate of the expected annual loss, structural and nonstructural, to buildings in California have been computed and incorporated in the calculations.

The results presented here do not include the effects of catastrophic losses caused by damage to facilities such as dams, nuclear power plants, natural gas facilities, or military installations. We have not evaluated the losses due to fire and inundation following earthquakes, social losses, or the indirect losses that may result from the effects of the earthquake. These factors can all lead to significant losses. One recent study calculated total economic losses that would result if a major earthquake on the Hayward fault were to sever the Hetch Hetchy aqueduct (Bay Area Economic Forum, 2002). That study concluded that the loss of fire fighting ability, disruption to major industries and other direct and indirect effects would cost the economy of the bay area $28 billion. Because the economies of the San Diego, Los Angeles and San Francisco Bay areas all depend on supplies of water, gas, and electricity that come from great distances, crossing many faults, all should be considered vulnerable to severe economic disruption from damage to these lifelines. The estimates presented in this report represent losses from direct damage to buildings. These constitute a large part of the dollar damage potential from earthquakes, but total economic effects may run up to several orders of magnitude larger than as the damage to buildings, depending on the lifelines affected.

Once again, it is important to recognize that the results of loss estimations such as presented in this report have large uncertainties. First, the estimates of the hazard posed by individual faults or seismic sources are uncertain. There may be hazardous faults that have not been identified or adequately characterized (some blind thrust faults, such as the fault responsible for the 1994 Northridge earthquake, fall into this category). In general, there is always the uncertainty that the earth will not behave as we have anticipated. The levels of damage caused by the shaking are uncertain. In other words, the fragility curves used to convert the level of ground shaking into damage have a high level of uncertainty associated with them. As a part of this study we have attempted to evaluate the levels of uncertainty in the estimates that stem from different sources. Despite the significant level of uncertainty, the loss estimates presented in this report are very useful for various aspects of earthquake mitigation and response planning and implementation. Mitigation options considered, and response and recovery plans, should have the flexibility and capability to make accommodations for the uncertainties in the analysis without becoming unreasonable, unfeasible, or too expensive.

Data and Results

I. Scenario Loss Estimates

Following significant recent earthquakes in California, the USGS has prepared "shakemap"s. The USGS also has developed scenario shakemaps for a variety of feasible earthquakes on the active faults throughout California. Earthquake shakemaps show the distribution of strong ground motion in the general vicinity of the fault. Therefore, for the real earthquakes shakemaps show the recorded distribution and for the scenario earthquakes, they show the expected distribution of strong ground motion. As measures of ground motion for preparing real and scenario shakemaps, USGS uses peak ground acceleration, peak ground velocity, 0.3-second spectral acceleration, and 1-second spectral acceleration. They are prepared in different format, including data files and graphic files, which can be easily used as input in HAZUS. Table 2, is a summary of the California earthquakes for which such shakemaps exist. Table 3 and Table 4 list, respectively, the northern California and the southern California scenario earthquakes for which shakemaps have been prepared. The scenario earthquakes listed in the latter two tables are based on the present state of knowledge of the earthquake potential of the two regions in California – the San Francisco Bay Area (SFBA), and southern California, and many years of research and investigation and consensus building by a number of Geology-Seismology Working Groups (WG, 1995; WG, 2003).

We have carried out loss estimation studies for the two metropolitan regions of the State - SFBA and southern California, using the shakemaps listed in Tables 3 and 4. For each region we have selected ten counties. Tables 5 and 6 show the names of the selected counties for the northern California and southern California respectively. The expected total losses for these scenario earthquakes are summarized in Tables 3 and 4 (see http://www.consrv.ca.gov/CGS/rghm/loss/ for details). In many cases the shakemaps do not cover the entire study areas used in our estimates. In such cases, there will be no loss associated with such counties. It is important to also note that the scenario shakemaps are truncated in some cases and some areas of significant ground motion are not shown far enough from the epicenters. In other cases, notably the San Andreas fault, offshore segment in Table 3, the area of damage is mostly offshore, and outside of the ten-county bay area so we have not calculated the loss values. As was mentioned earlier, the loss estimates are for building damage only. Therefore, the losses from other types of property, including transportation, lifelines, and utilities are not included in the estimates.

Table 2. Recent Earthquakes in California for which shakemaps have been developed to show the distribution of ground motion.

	Magnitude
San Fernando, Feb 9 1971	6.6
Coyote Lake Aug 6 1979	5.7
Imperial Valley Oct 15 1979	6.5
Livermore Jan 24 1980	5.8
Livermore Aftershock Jan 26 1980	5.4
Coalinga May 2 1983	6.4
Coalinga Aftershock May 8 1983	5.2
Morgan Hill Apr 24 1984	6.2
North Palm Springs Jul 8 1986	6.0
Whittier Narrows Oct 1 1987	6.0
Loma Prieta Oct 17 1989	6.9
Sierra Madre Jun 28 1991	5.8
Petrolia Apr 25, 1992	7.2
Petrolia Aftershock 1 Apr 25, 1992	6.6
Petrolia Aftershock 2 Apr 26, 1992	6.6
Landers Jun 28 1992	7.3
Northridge Jan 17 1994	6.7
Hector Mine Oct 16 1999	7.1

Six example scenarios are briefly presented and discussed in this report: (i) a repeat of the 1906 earthquake on the San Andreas fault, (ii) a rupture of the Hayward fault, and (iii) a rupture of the

Rogers Creek fault in the San Francisco Bay Area and (iv) a rupture of the Puente Hills thrust fault, (v) a rupture of the Newport-Inglewood fault and (vi) a rupture of the southern San Andreas fault in southern California. The three examples from northern California span the Bay Area and show levels of damage that are as high or higher than most scenarios for most parts of the area. The three scenarios for southern California span most of the metropolitan Los Angeles region and show the potential hazards from a blind thrust fault, a relatively minor strike-slip fault, and the San Andreas fault.

The shakemaps for these six scenario earthquakes and the results are presented in Figures 1 through 18. Figure 1, taken from the USGS website (http://earthquake.usgs.gov/shakemap) shows the distribution of peak ground acceleration expected in a repeat of the 1906 earthquake. Using the shake-map data corresponding to Figure 1, we have computed the dollar losses for each census tract within the ten-county SFBA. The dollar losses by census tract for the 1906 San Francisco earthquake scenario are depicted in Figure 2. The distribution of dollar losses in this Figure reflect both the distribution of ground motions as indicated in Figure 1 and the areas of high density of buildings exposed to the ground motion. Next, we present the level and distribution of the loss in terms of the "Loss-Ratio" (LR), which is defined as the estimated dollar loss divided by the building replacement dollar value, both computed at the census tract. In contrast to the total loss, which represents the estimated loss only, with no with reference to the dollar value of the buildings suffering the loss, the loss ratio represents the amount of loss as a fraction of the building replacement value. Therefore, once the losses in regions of different building replacement value are compared in a relative sense, LR is a more useful measure of loss. The distribution of the loss ratio for the repeat of the 1906 San Francisco event is shown in Figure 3. This Figure clearly shows that the proportionate loss will be concentrated in areas along the fault and on the west margin of the bay, the areas of highest ground motion. The estimated losses, computed at the census tract level, have typically have large degrees of uncertainty and inaccuracy, especially for larger size census tracts of non-uniform hazard and/or non-uniform building exposure. Tow other useful measures of the estimated loss are the loss for individual counties and "Per-Capita" loss. The results for counties average out inaccuracies and variations in the building inventories for individual census tracts. Per-capita loss, that is the average loss per resident, has the advantage of reflecting the impact of the population density. It can be obtained on the census tract level or larger zones, such as the county level. The estimated losses for counties, and the associated per-capita losses for the six scenario earthquakes are also computed and the results are summarized in Tables 5 and 6.

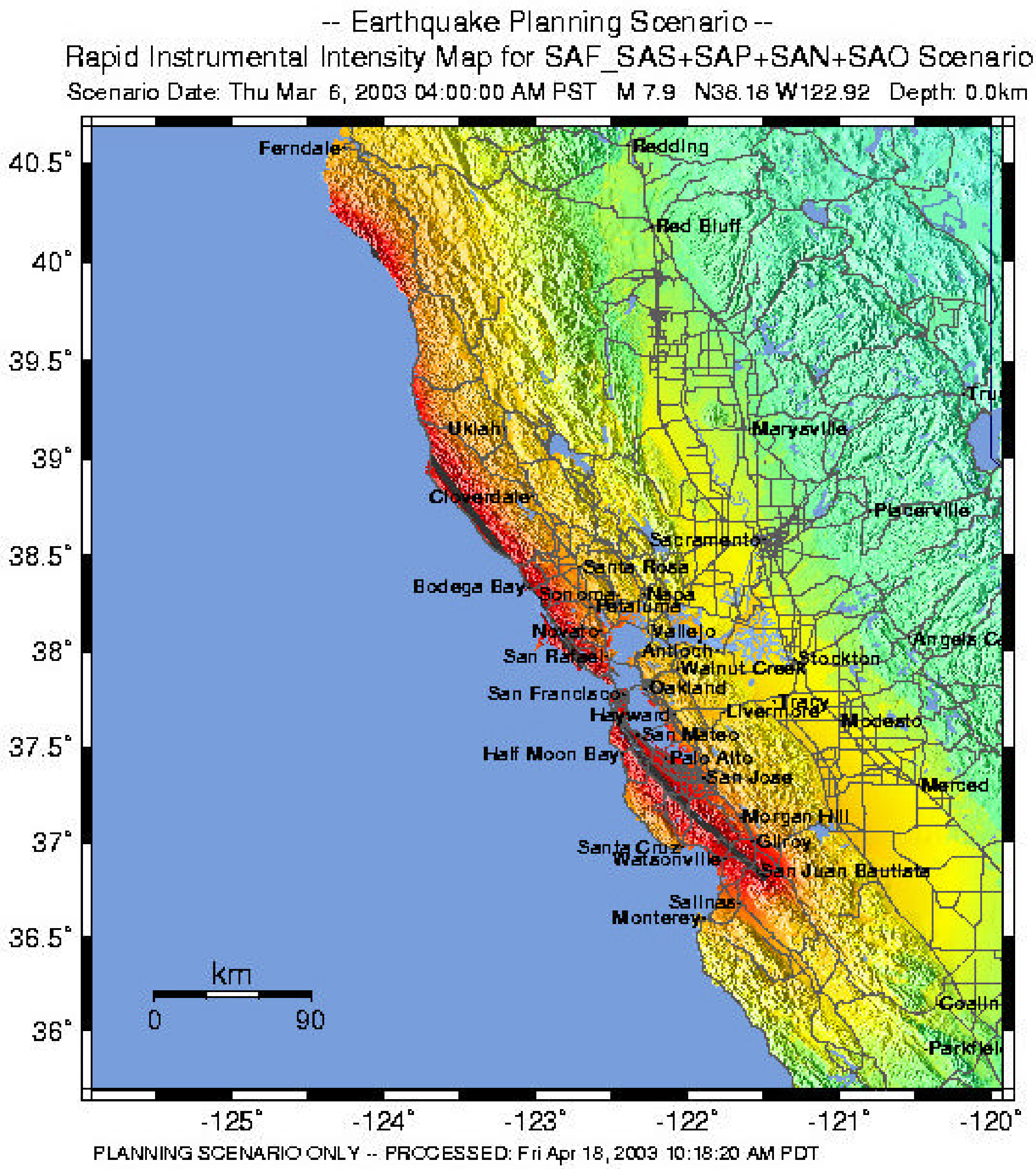
Computations similar to what described above, to estimate the losses in terms of total loss, loss-ratio, and per-capita loss, on the levels of census tract and county, have also been performed for the rest of scenario shakemaps. The results are summarized in Tables 3 through 6 of this report. The complete results, including summary tables and maps of loss distributions, can be seen on the CGS website (see, http://www.consrv.ca.gov/CGS/rghm/loss/).

Table 3. Scenario Earthquakes and associated losses for 10-county northern California.

Scenario Earthquake (USGS Scenario Name)	M	Estimated Building Damage Economic Loss ($M)
San Andreas Fault: Repeat of the 1906 San Francisco Earthquake (SAS+SAP+SAN+SAO)	7.9	54,000
San Andreas Fault: Santa Cruz + Peninsula + North Coast segments (SAS+SAP+SAN)	7.8	50,000
San Andreas Fault: Peninsula + North Coast + Offshore segments (SAP+SAN+SAO)	7.8	47,000
San Andreas Fault: Santa Cruz + Peninsula segments (SAS+SAP)	7.4	30,000
San Andreas Fault: Santa Cruz segment (SAS)	7.0	5,900
San Andreas Fault: Peninsula segment (SAP)	7.2	24,000
San Andreas Fault: North Coast + Offshore (SAN+SAO)	7.7	16,000
San Andreas Fault: North Coast segment (SAN)	7.5	15,000
San Andreas Fault: Offshore segment (SAO)	7.3	0.0
Southern Hayward: Repeat of the 1868 Earthquake (HS)	6.7	15,000
Northern Hayward (HN)	6.5	9,000
Southern Hayward + Northern Hayward (HS+HN)	6.9	23,000
Rodgers Creek (RC)	7.0	8,000
Northern Hayward + Rodgers Creek (HN+RC)	7.1	20,000
Southern Hayward + Northern Hayward + Rodgers Creek (HS+HN+RC)	7.3	34,000
Southern Calaveras (CS)	5.8	100
Central Calaveras (CC)	6.2	2,700
Southern Calaveras + Central Calaveras (CS+CC)	6.4	3,200
Northern Calaveras (CN)	6.8	10,000
Ccentral Calaveras + Northern Calaveras (CC+CN)	6.9	12,600
Southern + Central + Northern Calaveras (CS+CC+CN)	6.9	13,000
Concord (CON)	6.2	2,800
Southern Green Valley (GVS)	6.2	2,100
Concord + Southern Green Valley (CON+GVS)	6.6	7,000
Northern Green Valley (GVN)	6.0	600
Southern + Northern Green Valley (GVS+GVN)	6.5	3,200
Concord + Southern + Northern Green Valley (CON+GVS+GVN)	6.7	6,800
Southern Greenville (GS)	6.6	1,800
Northern Greenville (GN)	6.7	3,200
Southern + Northern Greenville (GS+GN)	6.9	5,000
Southern San Gregorio (SGS)	7.0	300
Northern San Gregorio (SGN)	7.2	13,000
Southern + Northern San Gregorio (SGS+SGN)	7.4	15,000
Mount Diablo thrust (MTD)	6.7	7,000

Table 4. Scenario Earthquakes and associated losses for 10-county southern California.

Scenario Earthquake (USGS Scenario Name)	M	Estimated Building Damage Economic Loss ($M)
Puente Hills	7.1	69,000
Newport-Inglewood	6.9	49,000
Palos Verdes	7.1	30,000
Whittier Fault	6.8	29,000
Verdugo Fault	6.7	24,000
San Andreas Fault: Southern Rupture	7.4	18,000
San Andreas Fault: Repeat of the 1857 Earthquake	7.8	17,000
Santa Monica	6.6	17,000
Raymond Fault	6.5	17,000
San Joaquin Hills	6.6	15,000
Rose Canyon	6.9	14,000
San Jacinto	6.7	7,000
North Channel Slope	7.4	4,000
Elsinore Fault	6.8	4,000
Coachella Valley	7.1	3,000
Imperial	7.0	1,000



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 1. Scenario Shakemap for a repeat of the 1906 earthquake, consisting of the Santa Cruz Mountains, San Francisco Peninsula, North Coast and Offshore segments (WG, 2002).

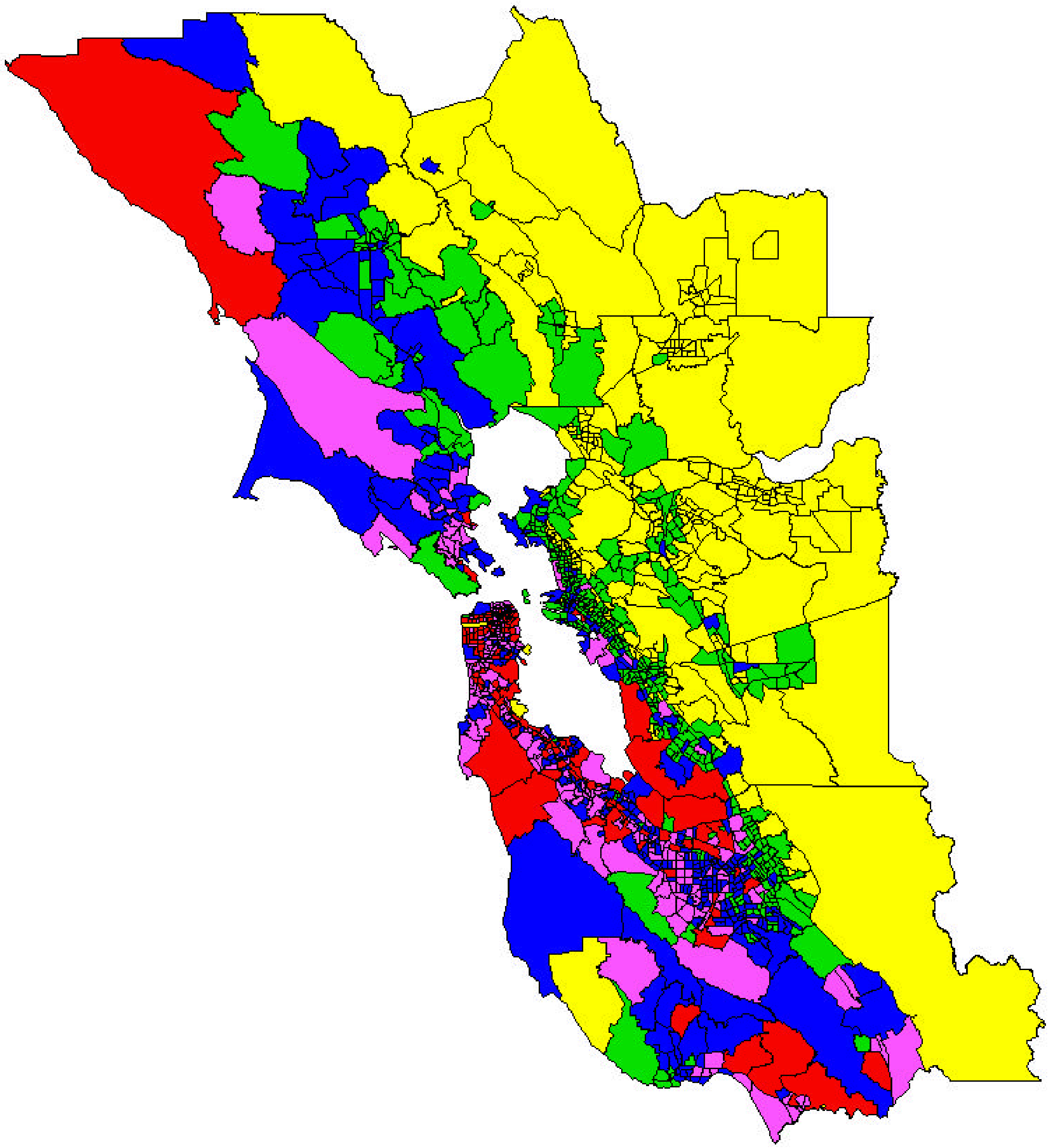


Figure 2. Estimated building damage economic loss by census tract ($M) for a repeat of the 1906 M7.9 San Francisco earthquake (in parentheses are the numbers of census tracts).

Red	> 100	(129)
Magenta	50 - 100	(233)
Blue	20 - 50	(309)
Green	5 - 20	(399)
Yellow	0 - 5	(392)

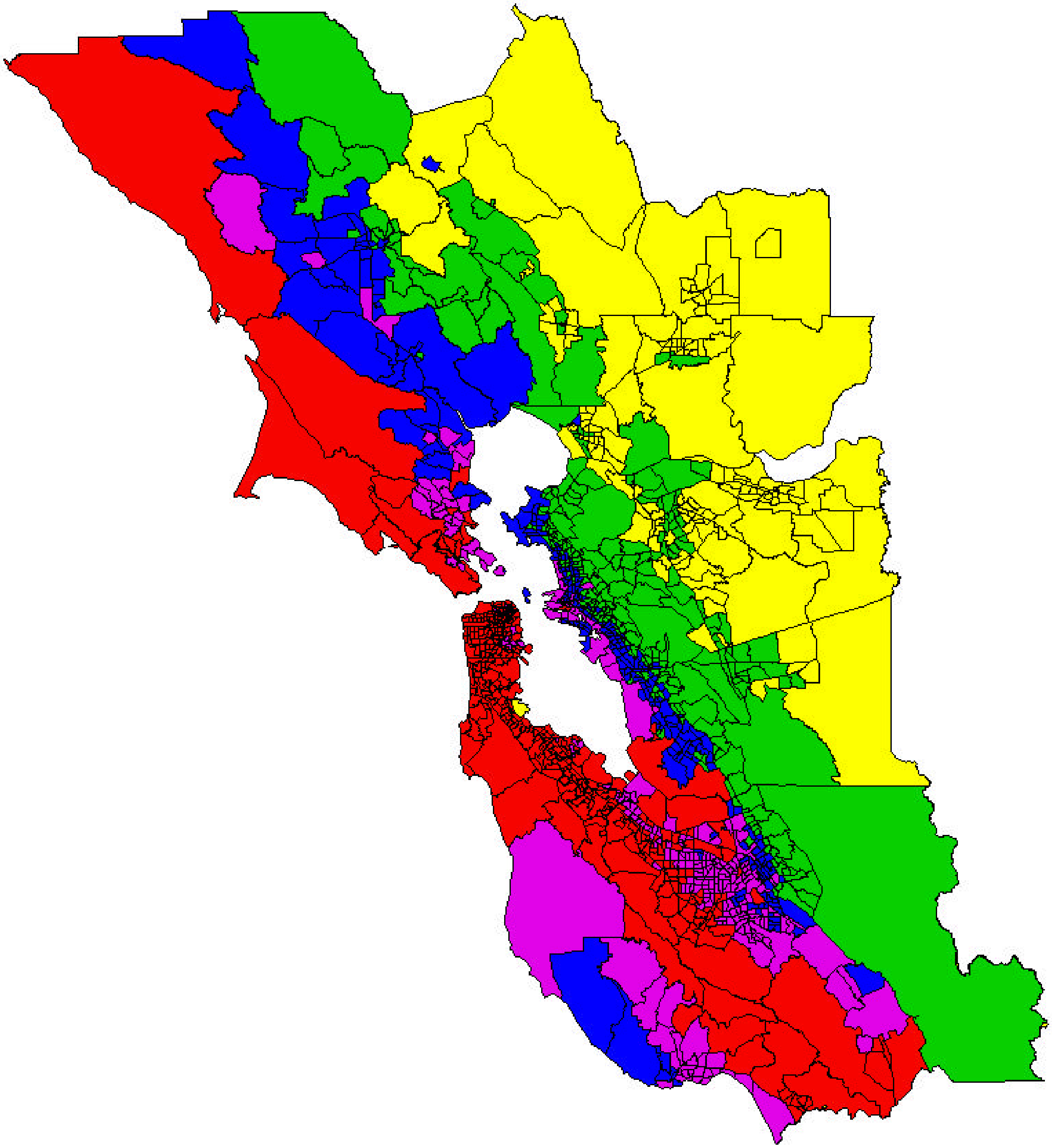
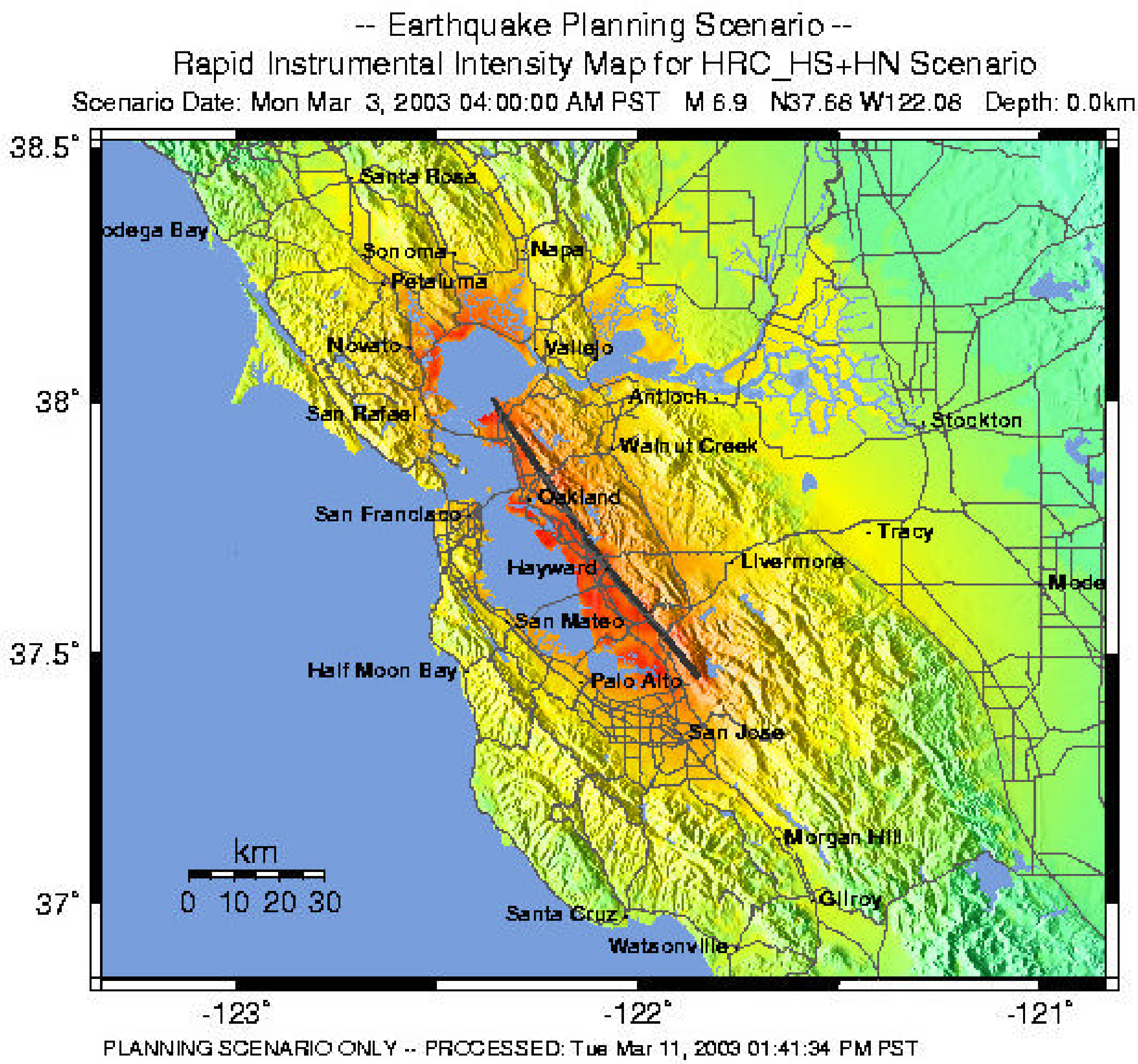


Figure 3. Estimated building damage economic loss as percentage of building replacement value by census tract for a repeat of the 1906 M7.9 San Francisco earthquake (in parentheses are the numbers of census tracts).

> 20	(389)
10 - 20	(250)
5 - 10	(267)
2 - 5	(262)
< 2	(294)

For each scenario we have shown the shakemap, the map showing the distribution of losses by census tract and the loss-ratio map. As can be seen from Figure 4, for the Hayward fault scenario the ground motion is most severe along the fault and eastern and southern margins of the bay. This is reflected in the total loss map (Figure 5) and the loss-ratio map (Figure 6). The Rogers Creek fault scenario affects the North Bay (Figure 7) with high loss and high loss ratio in the North Bay and relatively low loss ratios in San Francisco and on the peninsula (Figures 8 and 9). Note, however that because of the dense, high-value building inventory in San Francisco a low loss-ratio still translates into a substantial dollar loss, in this case nearly 1.5 billion dollars (Table 4). The Puente Hills thrust fault scenario in the south represents a “direct hit” from a buried thrust fault beneath central Los Angeles. Ground motions (Figure 10) and the total loss (Figure 11) and the loss ratio (Figure 12) are both substantial in an area of dense, high-value construction, resulting in losses to Los Angeles County of nearly 60 billion dollars (Table 6). The Newport-Inglewood scenario is for an earthquake on a strike-slip fault, similar but larger than the 1933 Long Beach earthquake. Like the Puente Hills scenario, ground shaking (Figure 13), total loss (Figure 14), and loss ratio (Figure 15) are concentrated in Los Angeles County. Earthquakes like the Puente Hills and Newport-Inglewood scenarios, or like the 1971 San Fernando and 1994 Northridge earthquakes, represent the major source of the hazard to urban Los Angeles. There are numerous thrust faults and strike slip faults across the area from Santa Barbara to Palm Springs and from Lancaster to Temecula. Most of these faults produce earthquakes capable of causing damage very infrequently, but collectively the chances of a M6.5 to M7 earthquake somewhere in the area is substantial. The last scenario presented in this report is a major rupture on the southern San Andreas fault. Ground shaking from this event would be concentrated from Salton Sea to Wrightwood (Figure 16) and the total loss and the loss ratio would also be highest along that zone (Figures 17 and 18). Despite the relatively low loss ratios in central Los Angeles, the high density of high-value construction leads to losses of over 4 billion dollars in Los Angeles County alone for this scenario (Table 6).



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 4. Scenario Shakemap for Hayward fault, including the northern and southern sections (WG, 2002).

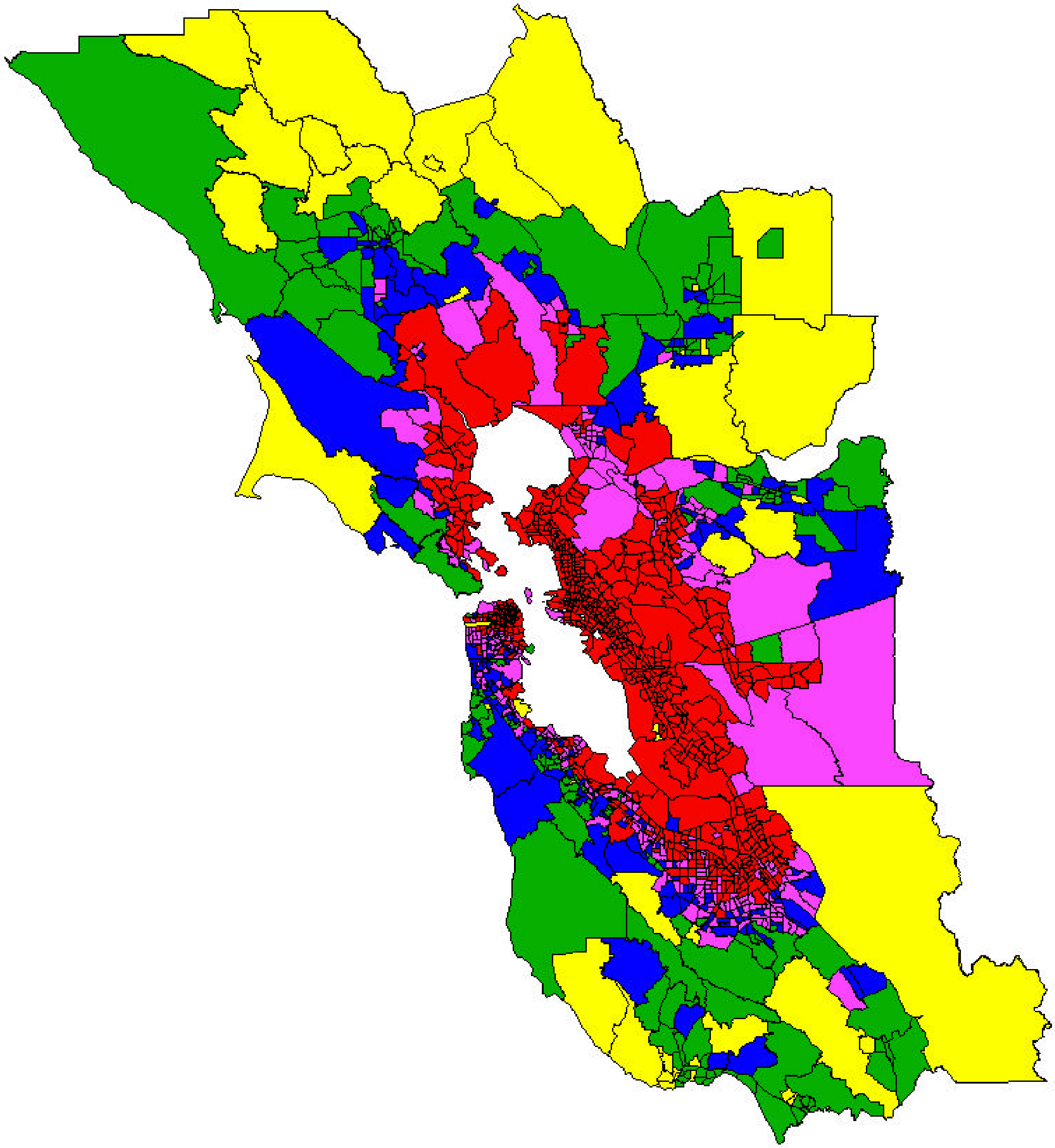


Figure 5. Estimated building damage economic loss by census tract ($1,000) for southern plus northern Hayward M6.9 scenario earthquake (in parentheses are the numbers of census tracts).

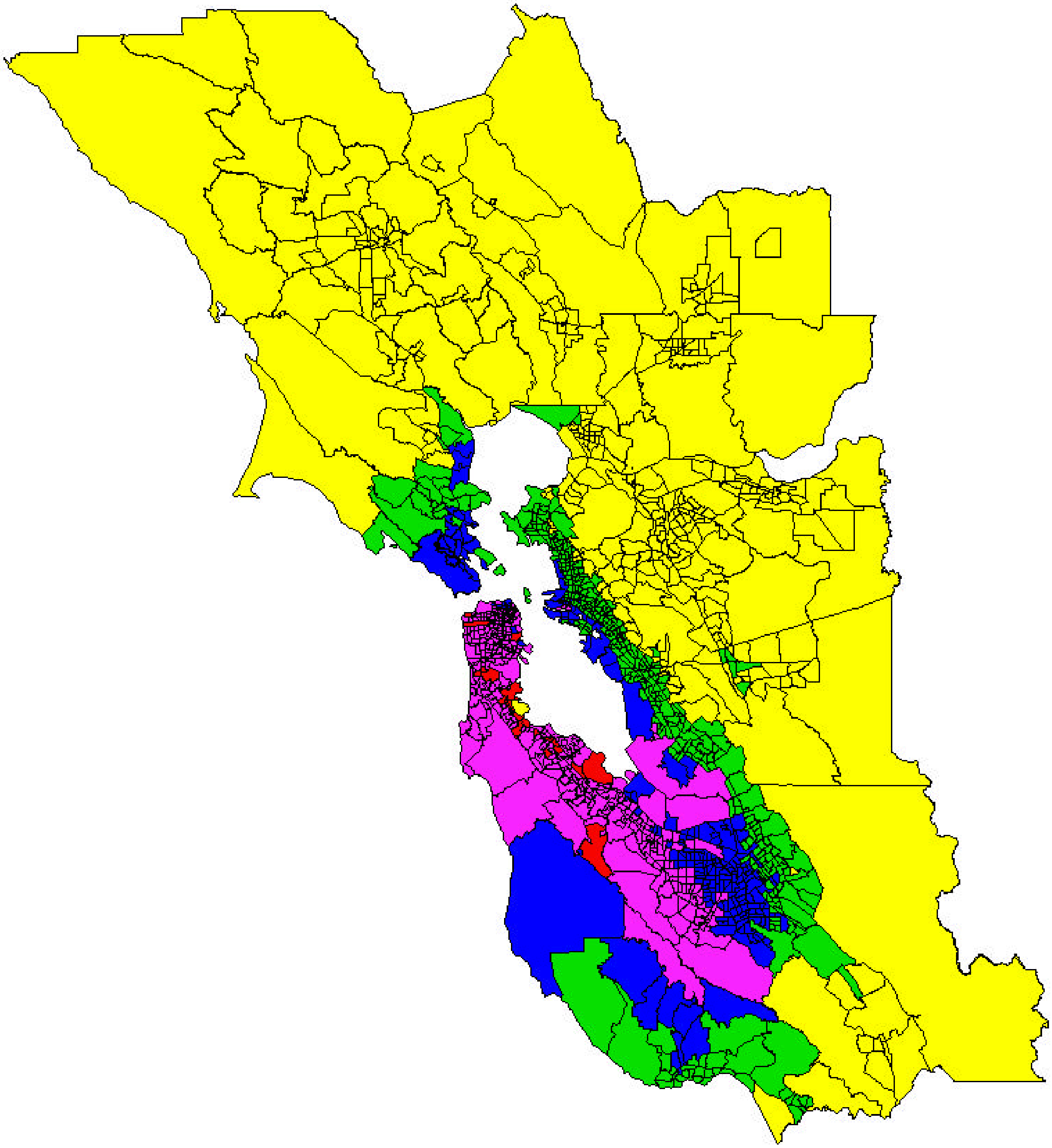
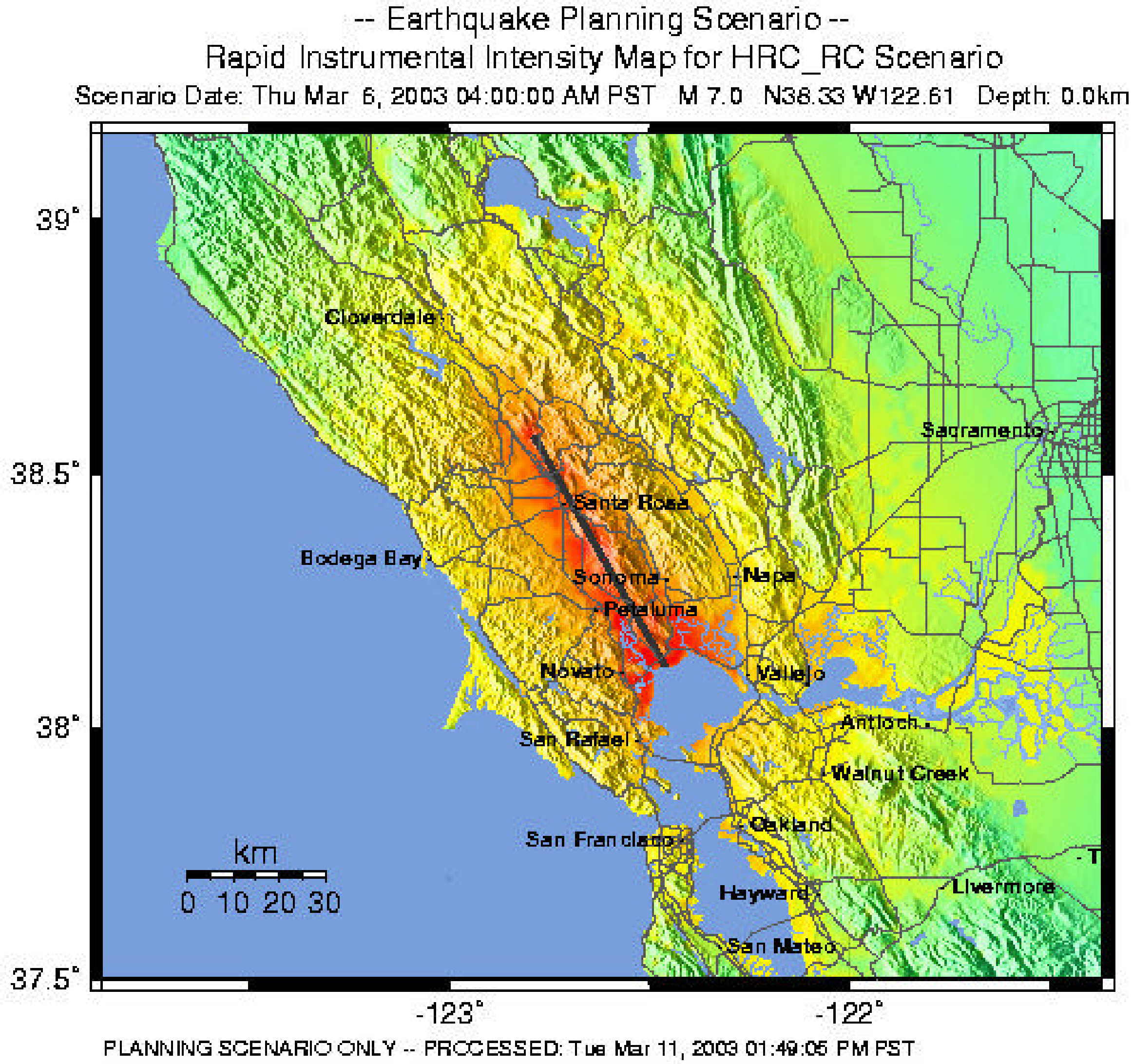


Figure 6. Estimated building damage economic loss as percentage of building replacement value by census tract for southern plus northern Hayward M6.9 scenario earthquake (in parentheses are the numbers of census tracts).

> 20	(21)
10 - 20	(347)
5 - 10	(225)
2 - 5	(385)
< 2	(484)



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 7. Scenario Shakemap for a rupture of the Rodgers Creek fault in the northern bay area (WG, 2002).

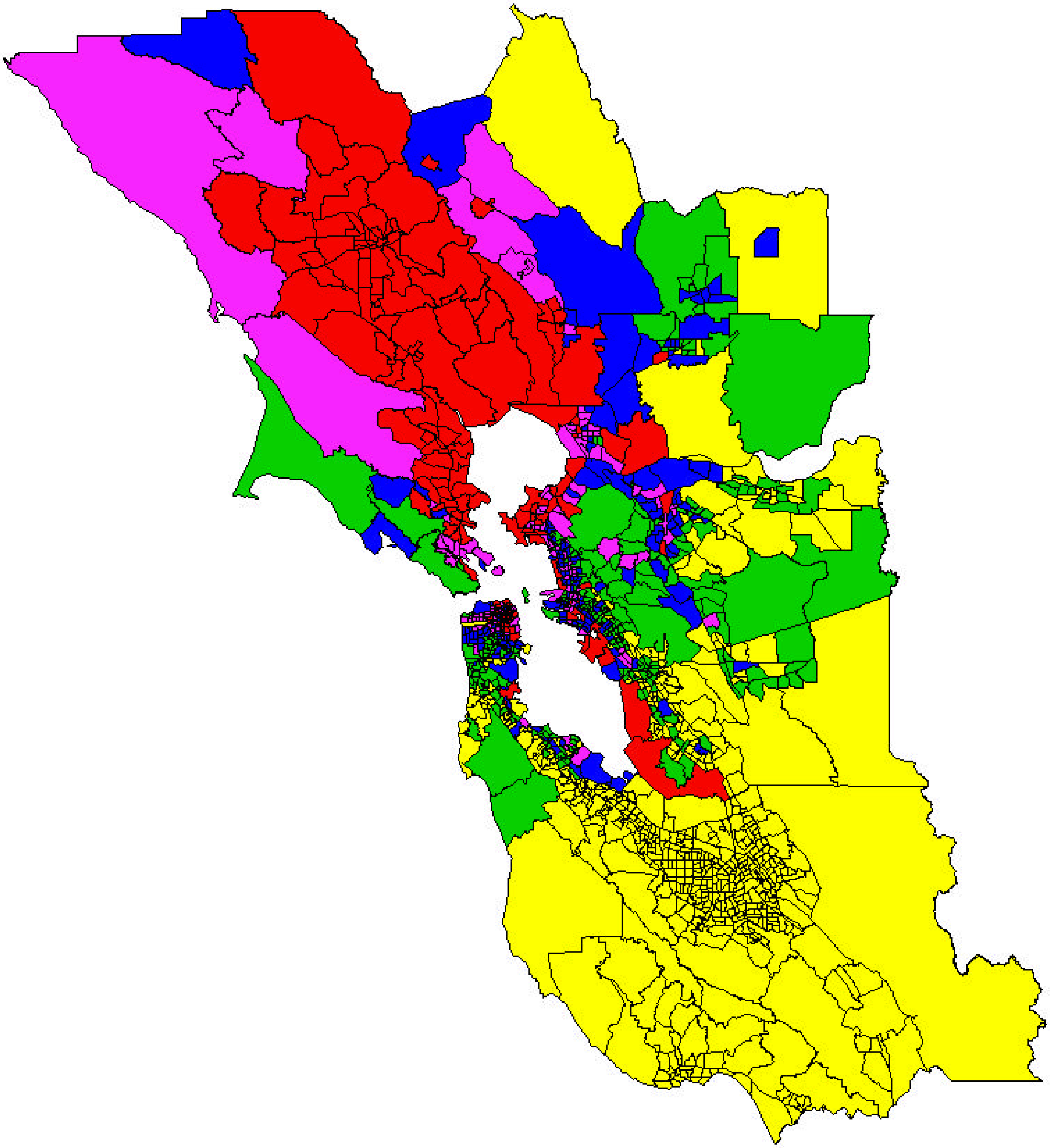


Figure 8. Estimated building damage economic loss by census tract ($1,000) for Rodgers Creek M7.0 scenario earthquake (in parentheses are the numbers of census tracts).

red	> 10,000	(171)
magenta	5,000 - 10,000	(139)
blue	2,500 - 5,000	(187)
green	1,000 - 2,500	(258)
yellow	< 1,000	(707)

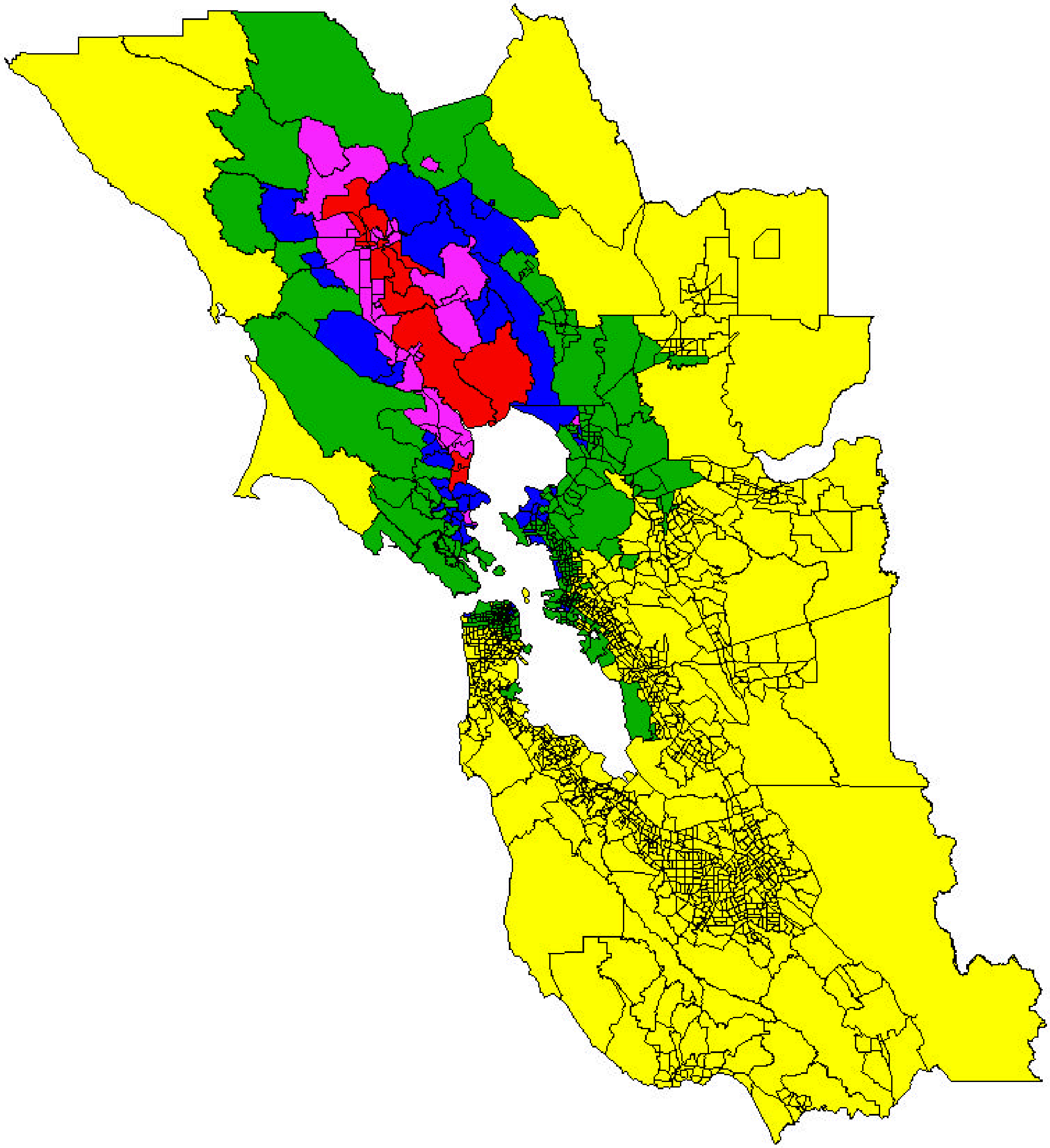


Figure 9. Estimated building damage economic loss as percentage of building replacement value by census tract for Rodgers Creek M7.0 scenario earthquake (in parentheses are the numbers of census tracts).

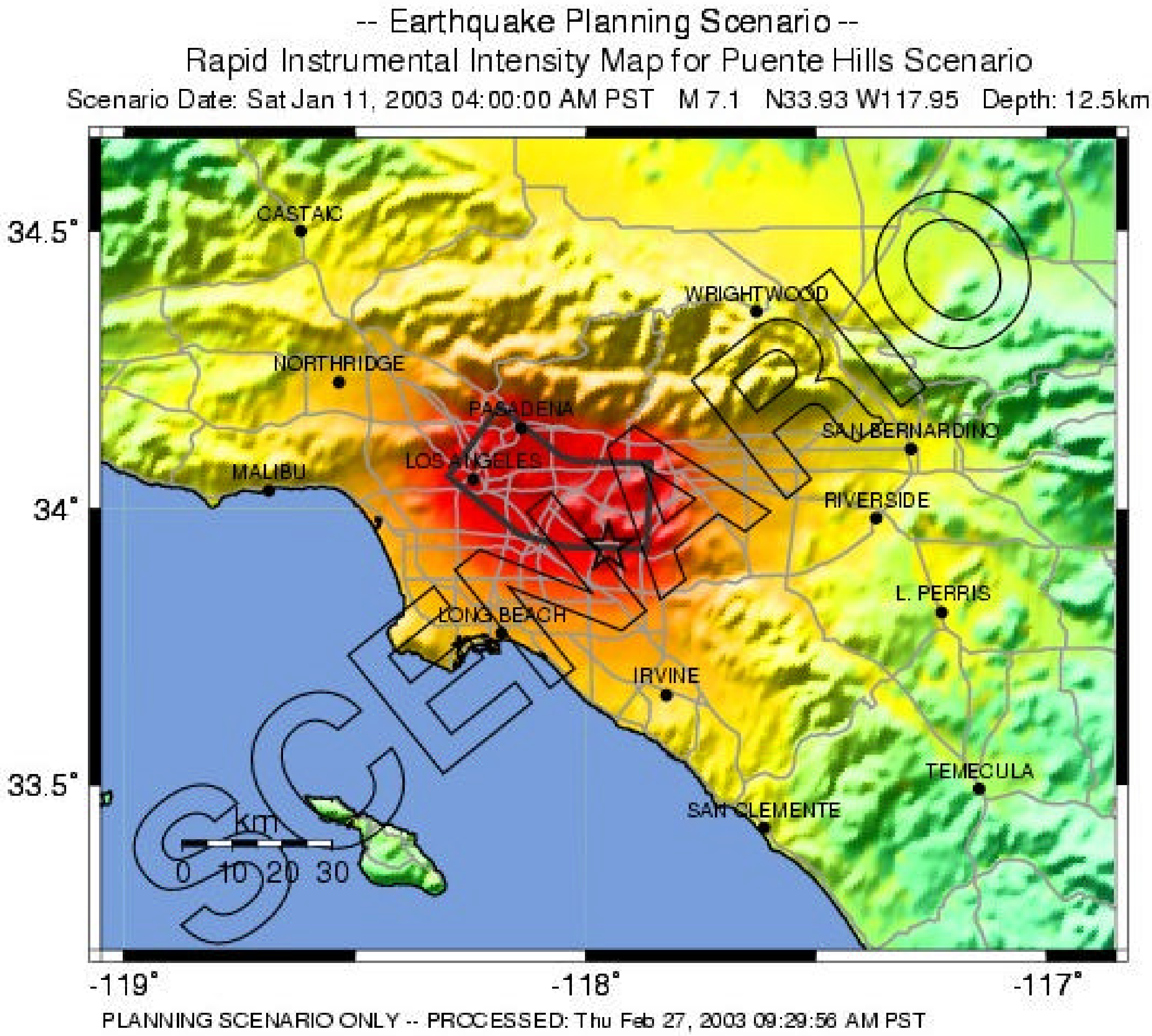
> 20	(16)
10 - 20	(38)
5 - 10	(50)
2 - 5	(298)
< 2	(1060)

Table 5. Ten-County Estimated Building Damage Economic Losses for Scenario Earthquakes.

County EQ Scenario	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Santa Cruz	Solano	Sonoma
SAF: Santa Cruz	483,442 (378)	69,383 (86)	17,222 (75)	2,668 (24)	251,344 (347)	341,907 (526)	3,739,808 (2,497)	963,417 (4,194)	10,772 (28)	9,052 (24)
SAF: Peninsula 1838	2,385,360	451,148	591,285	30,235	7,651,225	6,022,447	6,132,301	456,400	80,721	86,739
SAF: North Coast	2,082,445	620,801	1,675,867	84,858	7,740,538	1,526,220	499,956	21,329	129,074	960,147
SAF: Offshore	0	0	0	793	0	0	0	0	0	4,889
SAF: Santa Cruz, Peninsula	3,068,158	588,427	742,722	39,932	8,956,013	7,238,500	7,968,084	1,317,146	102,522	109,280
SAF: North Coast, Offshore	2,277,890	792,064	1,962,412	112,500	9,278,399	449,911	0	0	158,075	1,196,578
SAF: Santa Cruz,Peninsula, North Coast	4,734,194	909,139	2,071,855	115,447	14,435,965	11,715,703	12,299,960	2,040,249	164,451	1,240,207
SAF: Peninsula, North Coast, Offshore	4,809,214	931,688	2,147,772	131,015	15,037,737	12,043,337	10,701,120	0	173,601	1,319,226
SAF: Repeat of 1906 Event	4,907,228	970,291	2,262,991	138,467	15,830,849	12,563,669	13,287,955	2,209,491	182,294	1,353,929
Southern Hayward: Repeat of 1868	7,715,756	1,137,934	139,145	20,038	2,010,297	765,383	3,164,544	36,333	92,224	29,870
Northern Hayward (HN)	4,069,430	1,545,166	466,150	63,814	1,899,739	356,469	196,680	1,857	192,349	120,753
Southern + Northern Hayward	10,316,115	2,665,371	747,930	107,112	3,260,339	990,730	4,051,155	59,658	334,061	223,595
Rodgers Creek	899,506	717,254	879,669	293,963	1,484,691	192,624	0	0	329,227	3,144,960
Northern Hayward + Rodgers Creek	6,934,821	2,944,178	1,010,688	296,773	3,998,915	820,470	552,889	16,600	444,576	2,893,16
Southern+Northern Hayward + Rodgers Creek	13,946,525	3,641,525	1,113,014	346,093	4,140,661	1,384,070	5,525,159	89,515	498,520	3,312,127
Southern Calaveras	5,536	0	0	0	0	5,564	75,331	11,257	0	0
Central Calaveras	396,287	34,280	3,634	0	93,227	102,573	2,014,043	41,544	0	0

Table 5 (Cont.). Ten County Estimated Building Damage Economic Losses for Scenario Earthquakes.

County EQ Scenario	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Santa Cruz	Solano	Sonoma
Southern + Central Calaveras	499,848	39,759	3,259	0	116,396	130,623	2,397,236	54,160	0	0
Northern Calaveras	3,728,046	1,682,707	69,804	16,472	839,828	437,491	3,035,817	47,626	93,533	23,952
Ccentral + Northern Calaveras	4,214,206	1,881,387	84,757	8,693	994,646	502,143	4,695,544	149,895	90,417	14,953
Southern+Central +Northern Calaveras	4,293,241	1,964,699	87,156	8,693	1,029,469	520,299	4,796,044	150,279	90,859	14,953
Concord	667,209	1,446,191	40,080	22,654	279,825	82,145	106,649	988	181,251	19,044
Southern Green Valley	380,483	739,577	41,538	108,625	243,416	55,836	61,178	0	465,900	34,392
Concord + Southern Green Valley	1,194,971	2,336,890	82,714	178,303	511,079	151,079	201,454	50	742,251	70,196
Northern Green Valley	73,998	69,828	21,812	107,368	73,746	18,212	4,238	0	233,865	28,290
Southern + Northern Green Valley	566,740	1,012,912	57,018	239,978	409,893	86,382	27,260	0	676,416	69633
Concord + Southern + Northern Green Valley	1,468,808	2,705,042	106,031	298,496	688,185	205,463	272,691	0	895,263	116,607
Southern Greenville	699,997	218,931	15,285	4,003	151,415	103,031	587,135	15,659	20,269	4,543
Northern Greenville	1,155,967	955,591	34,844	14,226	335,795	149,448	467,302	14,553	80,296	16,378
Southern + Northern Greenville	1,691,023	1,309,600	56,377	19,924	481,740	217,180	970,848	40,872	112,769	26,496
Southern San Gregorio	0	0	0	0	0	2,100	20,308	295,224	0	0
Northern San Gregorio	1,605,074	385,199	509,395	23,383	5,169,139	3,047,282	1,562,369	522,387	72,129	83,779
Southern + Northern San Gregorio	1,789,521	461,924	616,071	29,238	5,576,265	3,524,053	1,886,847	615,932	83,005	52,207
Mount Diablo Single-Segment (Thrust) Fault	2,402,633	2,904,751	70,768	24,453	740,550	246,586	497,489	10,248	154,483	25,558



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 10. Scenario Shakemap for a rupture of the Puente Hills thrust fault, beneath the center of Los Angeles.

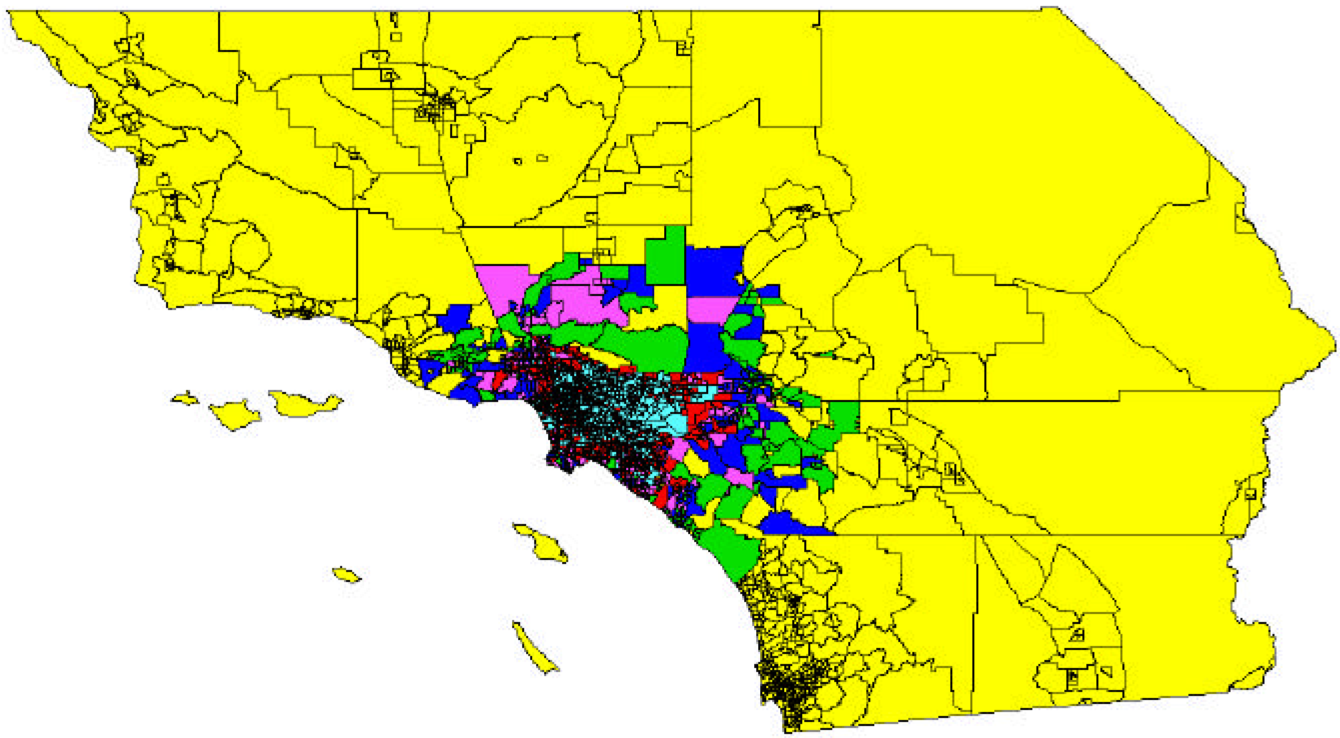


Figure 11. Estimated building damage economic loss by census tract ($1,000) for Puente-Hills M7.1 scenario earthquake (in parentheses are the numbers of census tracts).

> 30,000 (791)
10,000 - 30,000 (802)
5,000 - 10,000 (347)
2,500 - 5,000 (240)
1,000 - 2,500 (172)
< 1,000 (911)

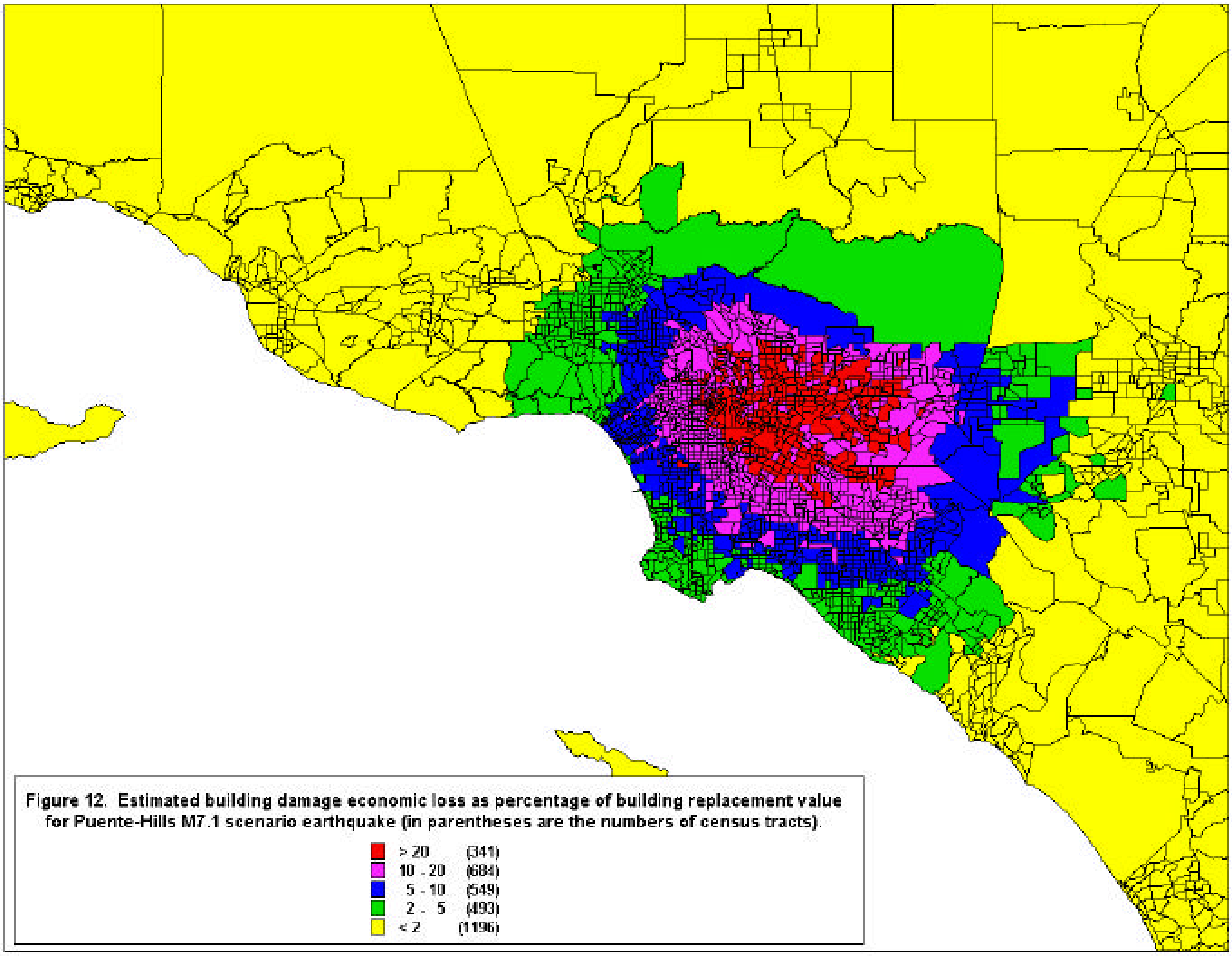
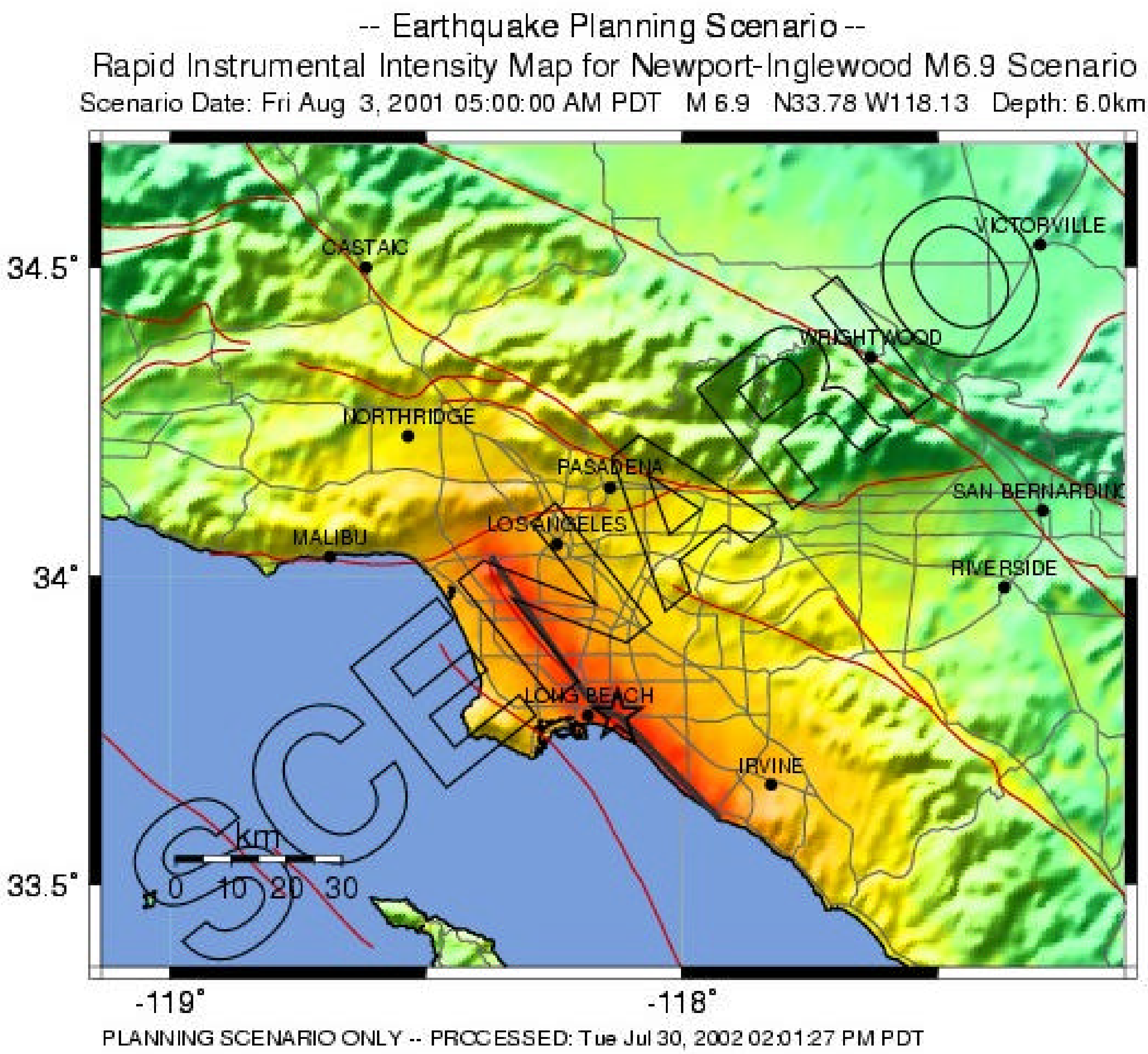


Figure 12. Estimated building damage economic loss as percentage of building replacement value for Puente-Hills M7.1 scenario earthquake (in parentheses are the numbers of census tracts).



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 13. Scenario Shakemap for a rupture of the Newport-Inglewood fault in an earthquake similar to, but larger than the 1933 Long Beach earthquake.

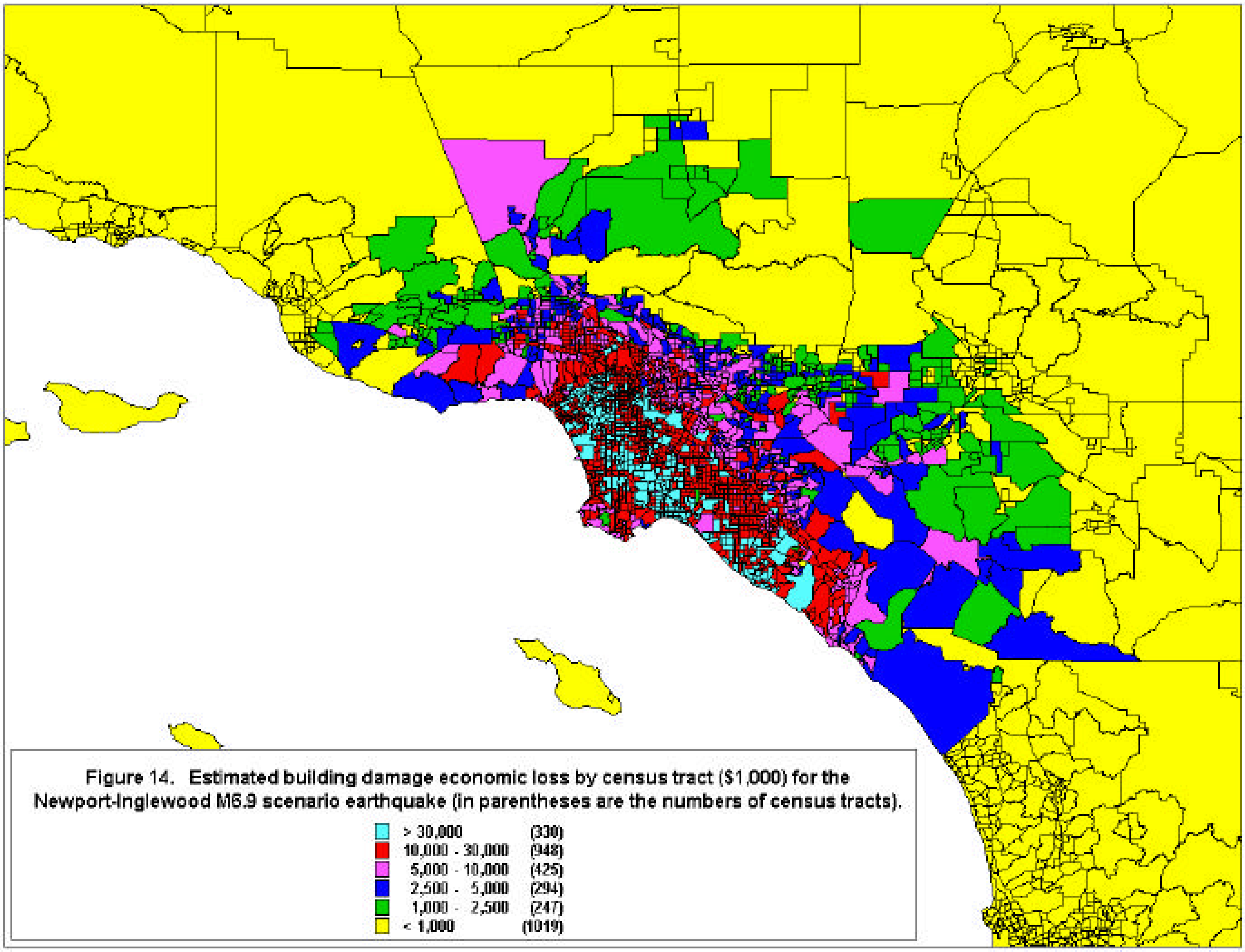


Figure 14. Estimated building damage economic loss by census tract ($1,000) for the Newport-Inglewood M6.9 scenario earthquake (in parentheses are the numbers of census tracts).

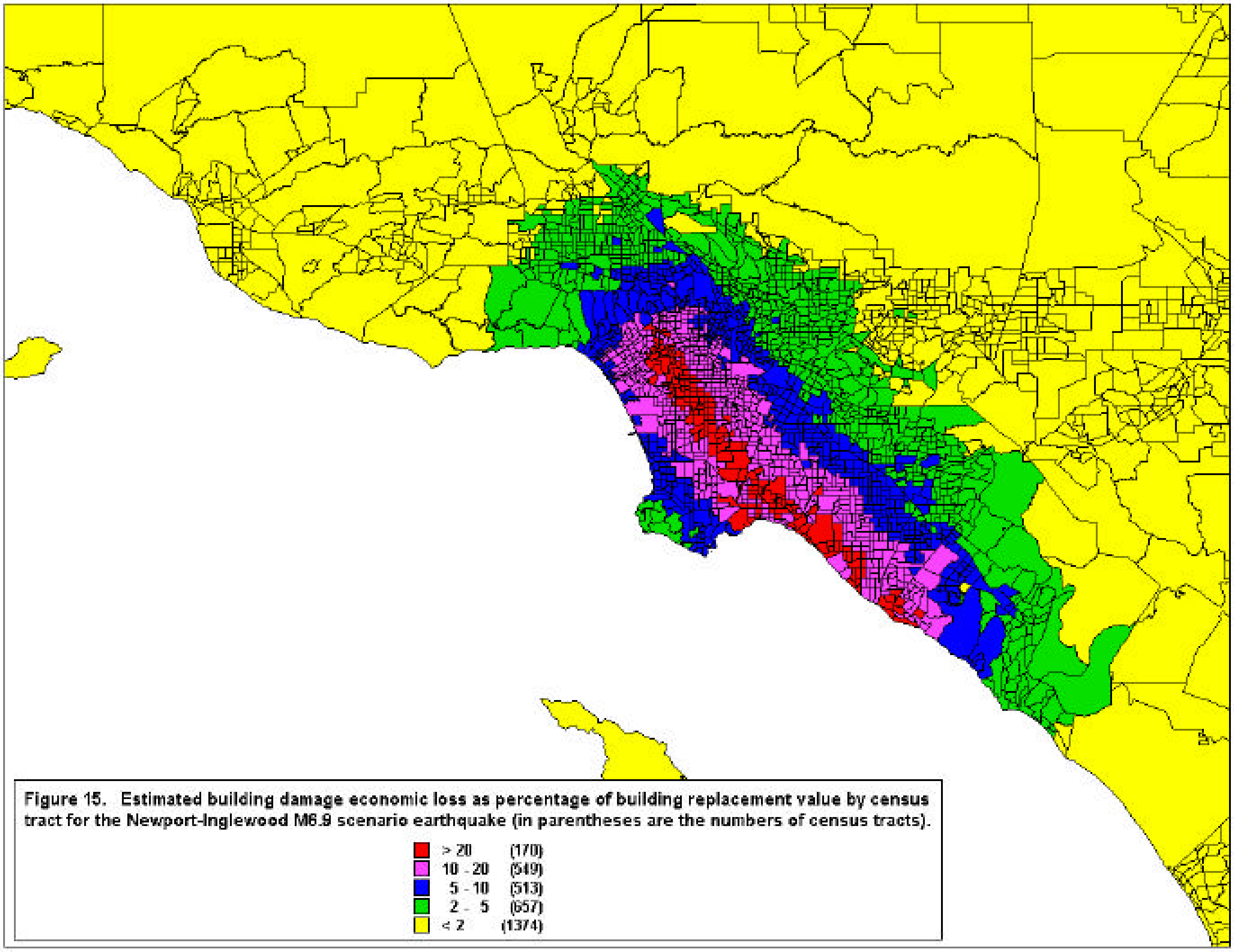
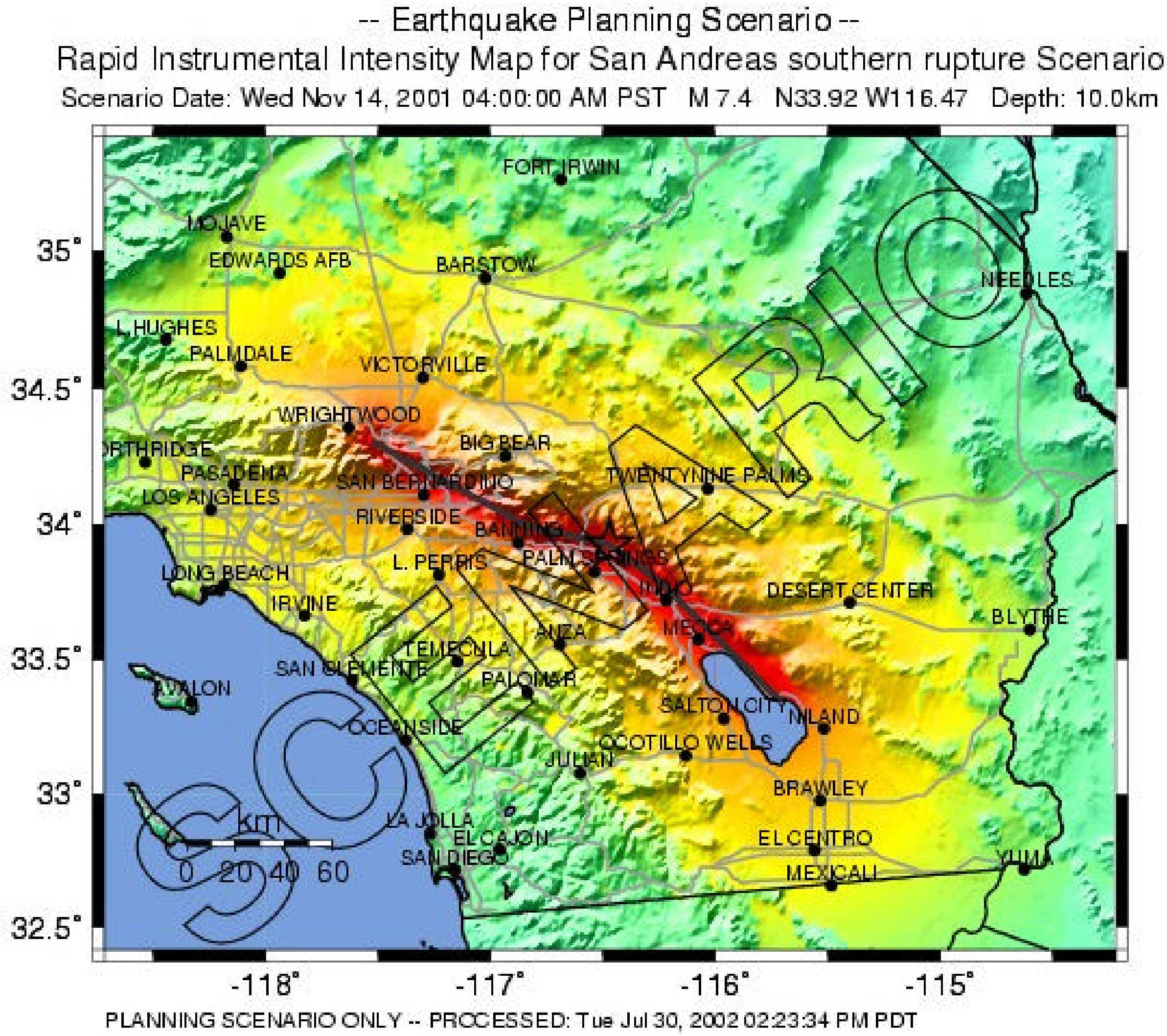


Figure 15. Estimated building damage economic loss as percentage of building replacement value by census tract for the Newport-Inglewood M6.9 scenario earthquake (in parentheses are the numbers of census tracts).



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 16. Scenario Shakemap for a rupture of the southern San Andreas fault from the Salton Sea to Cajon Pass.

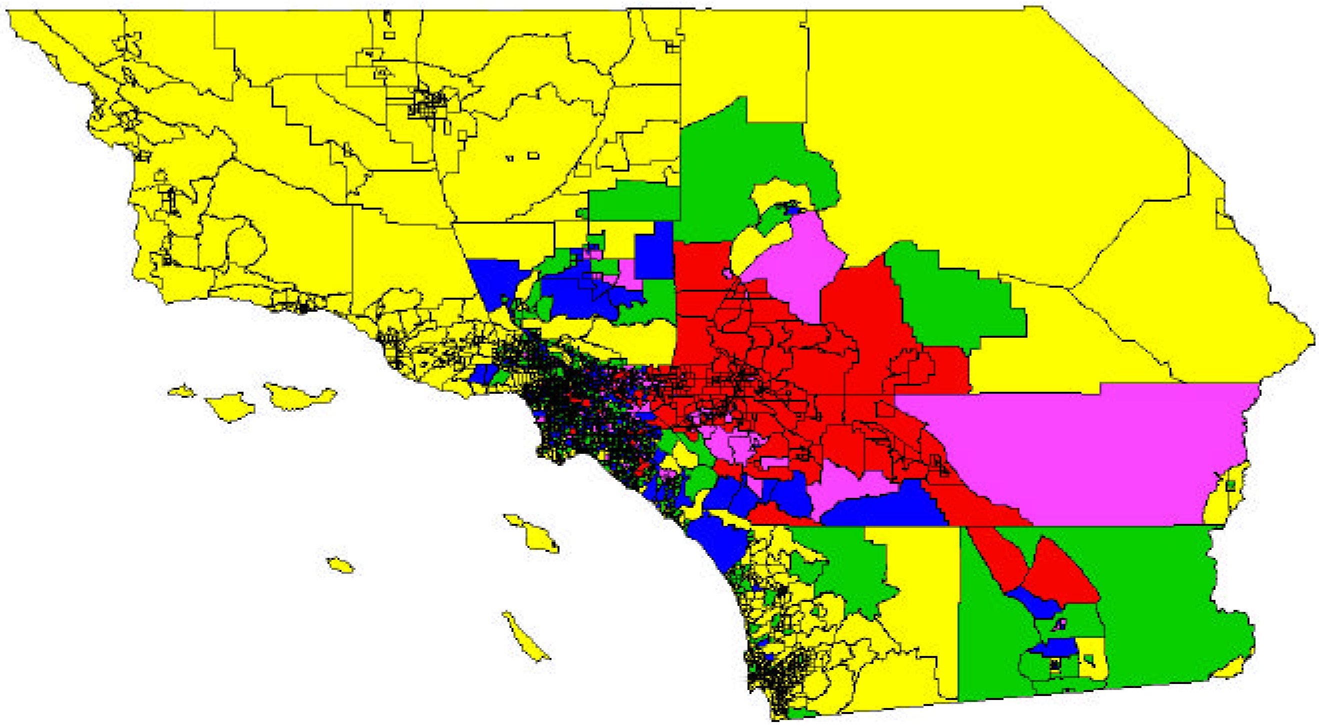


Figure 17. Estimated building damage economic loss by census tract ($1,000) for the southern San Andreas M7.4 scenario earthquake (in parentheses are the numbers of census tracts).

> 10,000 (290)
5,000 - 10,000 (182)
2,500 - 5,000 (414)
1,000 - 2,500 (1078)
< 1,000 (1299)

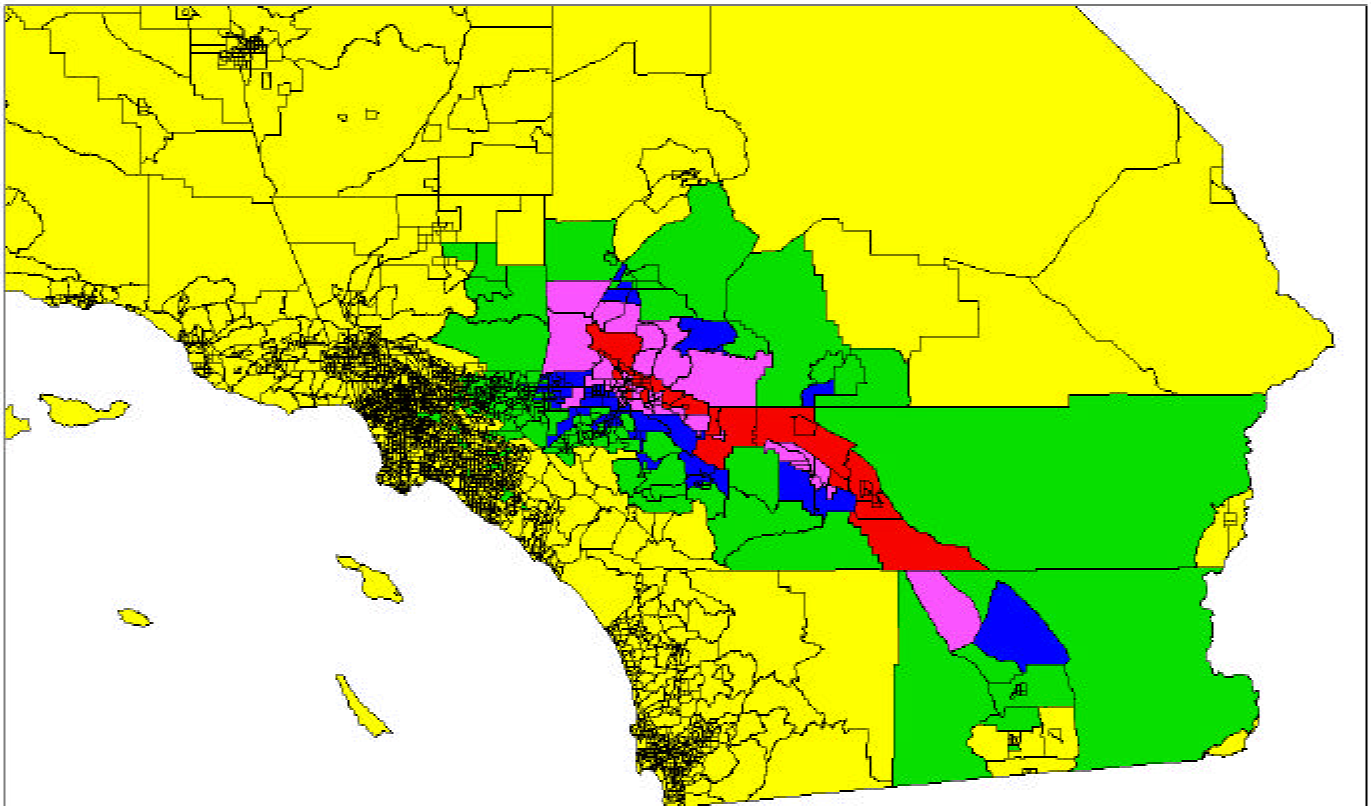


Figure 18. Estimated building damage economic loss as percentage of building replacement value for the southern San Andreas M7.4 scenario earthquake (in parenthese are the numbers of census tracts).

red	> 20	(42)
magenta	10 - 20	(66)
blue	5 - 10	(74)
green	2 - 5	(286)
yellow	< 2	(2795)

Table 6. Ten-County Southern California Estimated Building Damage Economic Losses for Sixteen Scenario Earthquakes.

County / EQ Scenario	Imperial	Kern	Los Angeles	Orange	Riverside	San Bernardino	San Diego	San Luis Obispo	Santa Barbara	Ventura
Rose Canyon	0	0	0	134,426	28,239	0	13,195,833	0	0	0
Santa Monica	0	0	16,434,973	195,615	0	0	0	0	0	236,595
Newport-Inglewood	0	0	38,044,398	10,438,365	170,382	215,816	6,947	0	0	118,871
Palos Verdes	0	0	25,102,592	3,594,039	88,741	148,961	75,986	0	0	294,354
San Jacinto	0	0	790,438	416,454	1,222,411	4,334,896	2,456	0	0	0
Verdugo	0	0	23,400,458	516,705	21,826	163,589	0	0	0	132,857
Coachella Valley	7,922	0	20,266	77,327	2,594,300	304,471	140,449	0	0	0
SAF Southern Rupture	95,287	9,304	4,029,639	1,162,088	5,025,289	6,802,229	227,826	0	0	4,814
Imperial	578,009	0	0	71	35,277	12,657	59,133	0	0	0
SAF Repeat of 1857 Event	0	650,963	10,520,468	1,255,926	674,698	3,073,999	0	201,767	192,724	372,351
Whittier Fault	0	0	17,816,507	8,217,555	1,252,063	1,543,581	8,386	0	0	34,543
Raymond	0	0	15,870,256	608,751	63,751	217,461	0	0	0	36,708
Elsinore Fault	87	0	573,355	919,180	1,204,397	275,395	992,244	0	0	0
San Joaquin Hills	0	0	2,668,811	11,128,986	226,842	197,063	115,010	0	0	0
Puente Hills	0	0	58,227,791	8,334,646	407,555	1,342,403	11,215	0	0	103,797
North Channel Slope	0	10,366	1,582	0	0	0	0	32,247	3,829,284	286,279

II. Annualized Loss Estimates

Scenario loss estimates, as discussed above, are valuable for planning and for understanding the types and magnitudes of the hazards faced by Californians. Unfortunately, the numbers and variations of all the potential earthquakes are so large that it is not possible to develop scenarios for all the feasible earthquakes, or to prioritize them by importance if they were developed. To make an assessment of the overall scope of the problem, and to determine which areas are most vulnerable to earthquakes another approach is needed. Fortunately an alternate approach based on probabilistic seismic hazard analysis (PSHA) is possible through HAZUS. PSHA attempts to calculate the overall probabilities of occurrence of different levels of ground motion in specified periods of time in the future, considering all possible earthquakes on all earthquake or seismic sources. PSHA uses several independent lines of evidence to estimate the (annual) rates of earthquakes on seismic sources, and then uses the rates of potential earthquakes to calculate levels of ground motion of specified probability at a point (or vise versa). The uncertainties in the estimates are also treated throughout the calculations. The resulting ground motions are expressed as a level of shaking of specified probabilities in given times, or of specified return periods (e.g., Figure 19). The ground motions currently specified in the building code for design are the ground motions with a 10% chance of being exceeded in 50 years. Stated another way, this is the level of ground motion with an average recurrence of about 475 years. The USGS and CGS have recently completed an update of the National Seismic Hazard Maps, which show, among others, the ground motion with 10% chance of being exceeded in 50 years (Frankel, et al., 2002, Cao, et al., 2003). The probabilistically calculated ground motions obtained from the PSHA, expressed in terms of peak ground acceleration, peak ground velocity, 0.3 second sectral acceleration and 1 second spectral acceleration (Figure 19 form the basis of our annualized loss estimate. The ground motions from USGS-CGS PSHA maps are for the “reference rock”, which for California is a relatively soft (BC rock in Wills, et al. classification). To take into account the highly variable soil amplification effect throughout the State, the ground motion values from the 2002 California Probabilistic Hazard Maps are modified using the consensus-based 1994-1997 NEHRP soil amplification factors and Wills et al. (2000) map. Next, in order to include the effects of soil liquefaction, which is expected to be significant in the areas of high population density of San Francisco Bay and the Los Angeles, we have prepared liquefaction data files, and used them as input to the HAZUS.

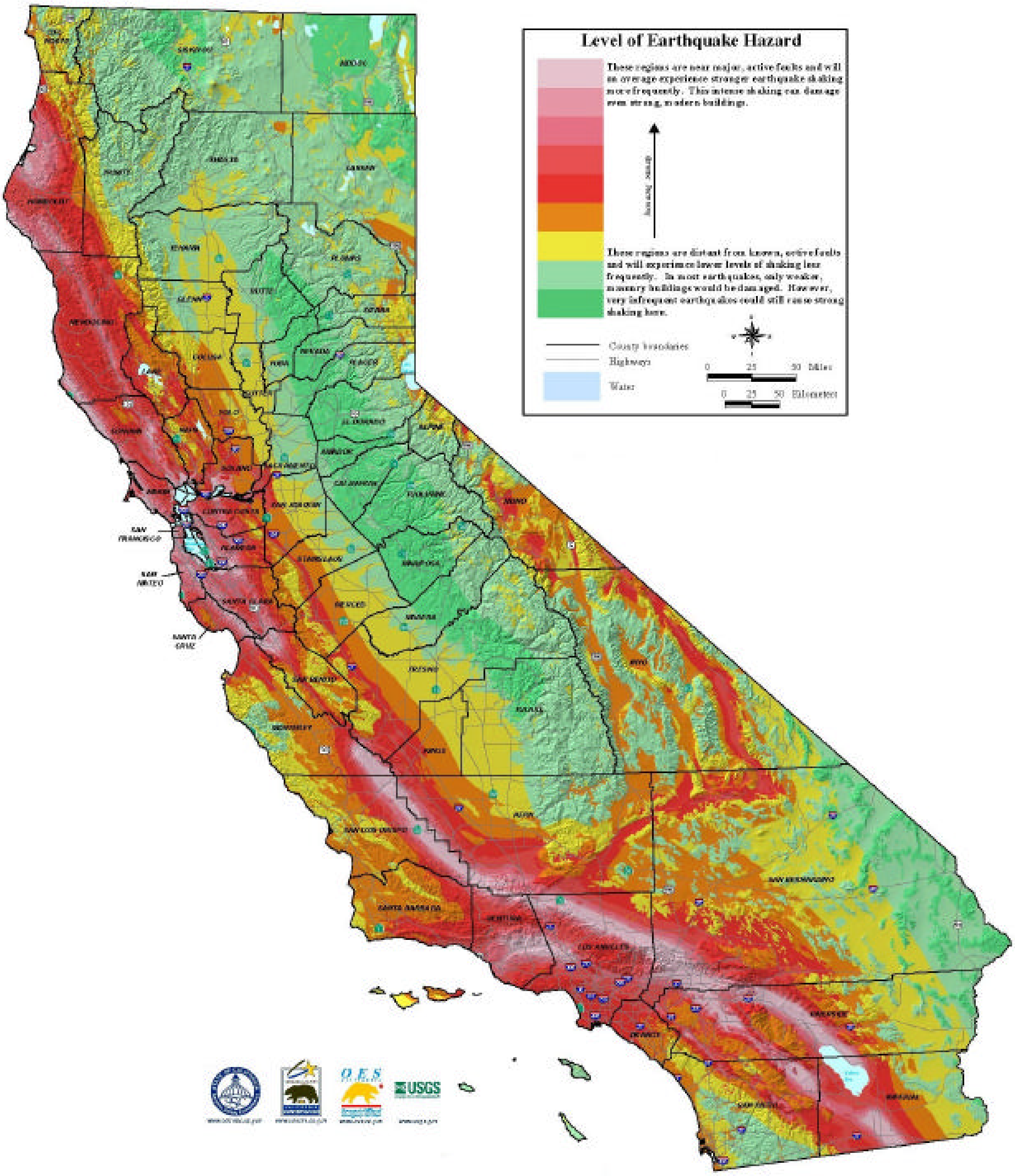


Figure 19 – Earthquake shaking hazard expressed in terms of 1-second spectral acceleration with 10% Probability of Exceedance in 50 Years. Values calculated by CGS from the USGS/CGS seismic shaking model (Frankel, et al., 2002) considering amplification in near surface soils as shown by Wills, et al. (2000) using the amplification factors recommended by the Building Seismic Safety Council (1997).

Using the data prepared as discussed above, we obtain $2.2 billion for the estimated annualized loss to the State of California. Like the scenario estimates, the annualized loss estimates presented in this section reflect only the structural and non-structural damage to buildings. The estimated annual loss by county is illustrated in Figure 20. Table 7 lists the 11 counties with the highest estimated annual loss. Counties most affected include Los Angeles, Alameda, Orange, Santa Clara, San Bernardino and San Francisco. Los Angeles has by far the largest expected annual loss, approximately 1/3 of the statewide total. Alameda follows with about 10% of the statewide total. Contrasting the estimated losses in these two counties, the differences in the estimated loss result from both a larger building inventory (exposure) in Los Angeles, and a greater hazard level in Alameda. In fact, the sum of expected annual losses for Los Angeles, Orange, and San Bernardino Counties is about 60% greater than that for the 5 San Francisco Bay area counties of Alameda, Santa Clara, San Francisco, Contra Costa and San Mateo.

Table 7 – Summary of data and annual loss results for 11 counties with the highest loss.

County	Total Loss ($k)	Population (1990 Census)	Per-Capita Loss ($)	Building Value ($M)	Loss Ratio (%)
Los Angeles	734,236	8,863,164	83	464,970	0.158
Alameda	198,313	1,279,182	155	74,980	0.264
Orange	154,073	2,410,556	64	128,690	0.120
San Bernardino	153,995	1,418,380	109	72,310	0.213
Santa Clara	146,675	1,497,577	98	80,340	0.182
San Francisco	141,042	723,959	195	58,500	0.240
Riverside	109,711	1,170,413	94	61,140	0.179
Contra Costa	80,995	803,732	101	43,030	0.188
San Mateo	77,981	649,623	120	36,270	0.214
San Diego	67,559	2,498,016	27	128,410	0.053
Ventura	66,394	669,016	99	32,380	0.205
Sum/Average (% of State)	1,930,974 (87)	21,983,618 (74)	104	1,181,020 (74)	0.183

From a different viewpoint, the average annual loss for the five San Francisco Bay area counties combined, with a total population (in 1990) of about 5 million, is only slightly smaller than the total for Los Angeles, with a population of over 12 million. So, when the population of each county is taken into account, the picture changes somewhat. In order to capture the impact of population density ”per-capita” loss is also computed. Figure 21 shows the per capita average annual loss (loss divided by population) by county. Table 7 summarizes the results for the eleven counties with the highest estimated annual loss. In terms of the earthquake impacts on the individual rsidents of the county, San Francisco rises to the top (with its high level of hazard, large building inventory, and relatively small population), with a per capita annual loss of $195, followed by Alameda county with $155 average annual per-capita loss. Los Angeles falls to the tenth level because of its high population density.

The estimated total value of the building inventory in the HAZUS database is $1.6 trillion, of which $1.2 trillion represents the value of residential buildings. Thus, the annualized total damage estimate represents approximately 0.15%, of the total building exposure. Next, in order take into consideration the effect of building inventory value in more detail, we compute the estimated annualized loss as a percentage of the building-replacement dollar-value, i.e., in terms of the Annual Loss Ratio (ALR). Figure 22 and 23 indicate, respectively, the State-wide distribution of the ALR by county and by census tract. The estimated ALRs for the eleven counties with the highest losses are summarized in Table 7. In terms of the estimated annual loss ratios, the two counties with the highest ALR are Alameda (ALR=0.264%) and San Francisco (ALR=0.240%). The ALR values are shown for each census tract in Figure 23 because this ratio of the expected losses to the replacement value is expected to reduce the errors caused by incomplete or incorrect data in the HAZUS inventory of structures. The census tract ALR values show a range up to 0.75%, largely reflecting the areas of highest ground motion hazard.

Additional results, including summary tables and maps of State-wide annual loss distributions, can be seen on the CGS website (http://www.consrv.ca.gov/CGS/rghm/loss/).

Figure 20. Estimated annual building damage economic loss by county in $M, based on the 2002 PSHA maps, weighted average soil, with liquefaction effect (in parentheses are the numbers of counties).

- 500 - 900 (1)
- 100 - 200 (6)
- 50 - 100 (4)
- 20 - 50 (4)
- 10 - 20 (5)
- 5 - 10 (7)
- 3 - 5 (6)
- 1 - 3 (7)
- 0 - 1 (18)

Figure 21. Annual, per-capita building damage economic loss by county, based on the USGS-CGS 2002 PSHA maps, weighted average soil, and liquefaction effect ($).

Figure 22 - Annual building damage economic loss as percentage of building replacement value by county, based on the 2002 PSHA maps, weighted average soil, with liquefaction effect.

- > 0.25
- 0.20 - 0.25
- 0.15 - 0.20
- 0.10 - 0.15
- 0.05 - 0.10
- < 0.05

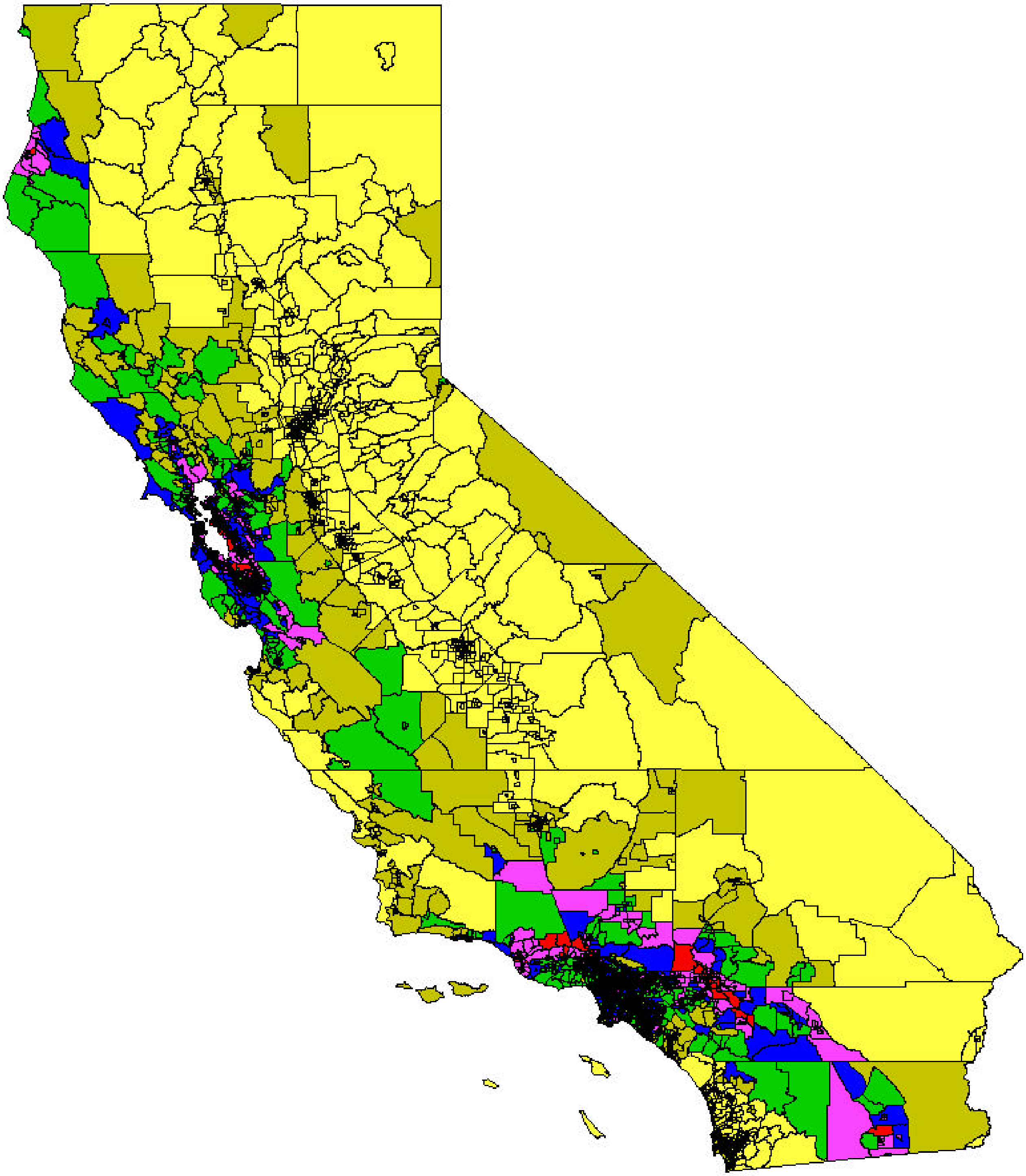


Figure 23. Annual building damage economic loss as percentage of building replacement value by census tract, based on the 2002 PSHA maps, weighted average soil, with liquefaction effect (in parentheses are the numbers of census tracts).

0.30 - 0.75	(137)
0.20 - 0.30	(833)
0.15 - 0.20	(1205)
0.10 - 0.15	(1445)
0.05 - 0.10	(880)
< 0.05	(1124)

Uncertainties

We have made some analysis of the uncertainty in the estimate of annual expected losses. It is important to note that the uncertainty in the estimated losses is large. However, the large uncertainty does not negate the significance and usefulness of the estimate itself. However, any decision based on the estimated losses, whether scenario or annual, must be able to take into account the uncertainty.

One source of uncertainty that we have attempted to resolve is the differences in the loss estimates are obtained when using two different releases of HAZUS. We conducted numerous detailed comparison calculations using of the two releases of HAZUS (the recent release, SR2 and the previous release, SR1), and found that with the same ground motion and inventory default data, there are consistent differences in the resulting loss values from the two versions. In general, the loss estimates made based on HAZUS-SR2 are approximately 15% lower than the HAZUS-SR1 estimates. These differences in estimated losses can solely be attributed to a possible change in the loss estimation methodology within HAZUS. However, we cannot examine the (source) code in either version of HAZUS; so we cannot determine the nature of the differences. In view of the fact that no documentation on the changes in the damage analysis methodology in HAZUS (from SR1 to SR2) has been released, it may be concluded that the more recent lower estimate of the loss is not necessarily more reliable than the older estimate.

Another major source of uncertainty is the modification of the ground motion values to consider the effects of soil amplification. The values in the National Seismic Hazard Maps are for a uniform "firm rock" site conditions. To include the effects of soil amplification in the ground motions we applied the NEHRP soil correction factors, which uses the map of soil conditions developed by CGS (Wills, et al., 2000). We then ran repeated tests to compare the values calculated using the NEHRP values with another widely used soil amplification factors from Boore, et al. (1997), which had been used in previous CGS loss estimation studies. We consistently found a decrease of about 30-40% in the estimated annual losses, obtained using the NEHRP factors, compared to estimates using the factors from Boore, et al. (1997). Using the soil amplification factors of Boore, et al (1997) and the earlier version of HAZUS (SR1), the State-wide estimated annual loss is roughly $ 3.3 billion, about 50% higher than the $2.2 billion, obtained using the NEHRP factors and HAZUS-SR2.

Relative numbers are probably less uncertain. That is, it makes sense, because of the known seismic hazards and because of the population, and the build environment at risk, that Los Angeles and the San Francisco Bay area would have the greatest expected losses. Results can be compared for areas smaller than counties. However, as the area gets smaller, uncertainties will grow, because the default inventory incorporates assumptions that do not apply to individual census tracts, although they may be appropriate for the aggregate.

Comparison with other published estimates

We have compared the results of our analyses with previously published results. For the scenario losses, the RMS study of the potential losses for a repeat of the San Francisco earthquake of 1906, of moment magnitude 7.9, estimates a total loss in the range of $170-225 billion (RMS, 1995). This estimate reflects all potential losses, with the secondary effects, such as fire and toxic releases also considered. Of this range, RMS estimate for the losses due to residential and commercial/industrial property and contents is $60-85 billion each, which seem to be an order of magnitude larger than the results presented in this report. The $54 billion estimated potential loss, does not however consider the potential losses due to secondary effects.

Hayes (1990) had estimated that earthquake losses in the United States would average about $1 billion per year. Most of those losses would occur in California. But his estimate was made before the 1994 Northridge earthquake, which radically changed our view of potential earthquake damage. It is now widely held that, even if the rate of occurrence of natural disasters may not be increasing, the potential damage and the economic losses will be increasing as the population, and the built environment exposed to the hazards, grow.

In 1996, the California Earthquake Authority published an estimate of expected annual loss due to single-family residences in California that have earthquake insurance (EQECAT, 1995). Expanding their estimate to all residences gives $2 billion loss per year. Our estimated annualized loss to residential buildings is around $1.4 billion, which constitutes about 61% of the total loss. Of the $1.4 billion loss to residential buildings, close to $1 billion is the loss due to single family residential buildings. These two numbers, given the uncertainties and reasonable differences in the two analyses, are close. In 1983, the Applied Technology Council published ATC-13, did a survey and compilation of expert opinion on the damageability of various types of structures as a result of earthquake ground shaking (ATC, 1985). We have examined what ATC-13 would estimate for earthquake damage to low-rise, wood-framed structures, the predominant structure type in California. ATC-13 does not base its damage estimates on any ground shaking parameter, but rather on Modified Mercalli Intensity (MMI), a scale that reflects the effects of an earthquake. Depending on how the conversion from MMI to ground shaking is done, losses from $0.8 to $2.6 billion are obtained from ATC results. Separating this structure type in our analysis gives 0.9 billion, which falls within the ATC-13 range. It is interesting to note that fully half of the anticipated earthquake damage in California will be to low-rise, wood-framed dwellings, which includes nearly all single-family residences and low-rise commercial structures.

The Federal Emergency Management Agency (FEMA, 2001) has released an estimate for average annual earthquake losses for the whole country, based on the first release of HAZUS (SR1), which uses the old (1996) USGS-CGS PSHA maps. The FEMA estimate of the average annual loss for the State of California is $3.2 billion, in contrast with our estimate of $2.2 billion, which is based on the new release of HAZUS (SR2) and the new (2002) USGS-CGS PSHA maps. There appear to be two main reasons for the difference between these two estimates: A roughly15% difference between the two estimates based on the two versions of HAZUS (SR1 and SR2), and a larger difference due to the soil amplification factors used for the sites. FEMA's results are based on the default (Type4, alluvium) soil throughout the state, while in our analysis, the type of soil could be any of seven types. Those portions of California not alluvium are mostly built on soils that would shake less than alluvium (the exception being the San Francisco Bay mud located around the fringes of San Francisco Bay and the soft fills found in the older developments along coastal areas). This difference would cause FEMA's estimate to be higher than ours, leading to slightly more conservative results. Based on these, we conclude that the $2.2-3.2 billion, as the range of economic loss caused by building damage is reasonable for mitigation planning and prioritizing, and is of similar order of magnitude as estimates made with other loss estimation studies.

Conclusions and Issues

The estimates presented here lead to a number of questions, both technical and policy-related. Some of the technical questions relate to magnitude and the distribution of the losses. Several questions have arisen that we are able to answer:

- How much of the loss results from the largest earthquakes (e.g. repeats of the 1906 or 1857 magnitude 7.8 events) and how much results from the more frequent magnitude 6 to 7 or 7.5 events?
- Which faults generate earthquakes that produce the highest losses.
- What is the range of dollar losses that could occur should a large earthquake occur in a metropolitan area?

With the aid of the results, a sample part of it is presented in this report, we are able to answer the above questions, and generally questions on the expected magnitude and distribution of losses due to earthquakes in California. The level of certainty of the answers, however, needs further investigation. In that connection, other technical questions the arise include: Can the uncertainties be reduced? If so, how? How can we better estimate the uncertainties in the calculation. Although we have presented an expected annual loss, what is the largest loss (probable maximum loss?) that might occur in a given year in California?

Policy questions abound. The expected annual loss from structural and non-structural damage to buildings only, amounts to a cost to each Californian of about $100 each year. And these costs to not reflect those additional costs associated with injuries to occupants. Damaged buildings (and contents) are more likely to injure the occupants than undamaged buildings (and contents). Efforts to reduce that cost should have high priority. Given that it will be impossible to mitigate expected damage to zero, how much of the expected damage can be effectively mitigated and at what cost? How should the society plan to recover from the residual losses? What kinds of structures contribute most to the cost? Is structural mitigation a cost-effective approach to reducing the damage? What role should earthquake insurance have? If a building owner does nothing to reduce or cover the damage, should the owner be penalized or rewarded by the government during recovery? How should the financial community incorporate this level of expected losses into its operations? The damage is principally an existing structure problem, not a new structure problem. Is there a role for the financial community? What role does local, regional, and State government have in identifying specific hazards, and in encouraging or forcing reduction of building damage?

These questions are undoubtedly but a sample of the kinds of questions that should arise from consideration of the level of earthquake damage that may be expected in the coming years in

California. We hope that this report will stimulate the asking of those questions and lead to ongoing discussion on how to answer them.

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