CHAPTER 4: EARTHQUAKES AND LIQUEFACTION

4.3.0 RISK ASSESSMENT

4.3.1 IDENTIFYING EARTHQUAKE HAZARDS

3.1 Identifying Hazards – Requirement §201.6(c)(2)(i):

The risk assessment **shall** include a description of the type location, and extent of all natural hazards that can affect the jurisdiction.

An earthquake is a sudden release of built-up tension in the earth's crust and upper mantle, i.e., lithosphere. Caused by movement along fault lines, earthquakes vary in size and severity. The *focus* of an earthquake is found at the first point of movement along the fault line, and the *epicenter* is the corresponding point above the focus at the earth's surface.

Earthquake intensity is measured in various ways, the most familiar being the Richter magnitude scale which determines the amount of ground displacement or shaking that occurs near the epicenter; the Rossi-Forel scale which measures ground shaking intensity in terms of perception and damage; and the Modified Mercalli Intensity Scale which takes into account the localized earthquake effects.

Table 4-1 Modified Mercalli Intensity Scale

Intensity	Severity	Level of Damage	Richter Scale
1-4	Instrumental to Moderate	No damage.	</= 4.3
5	Rather Strong	Damage negligible. Small, unstable objects displaced or upset; some dishes and glassware broken.	4.4 – 4.8
6	Strong	Damage slight. Windows, dishes, glassware broken. Furniture moved or overturned. Weak plaster and masonry cracked.	4.9 – 5.4
7	Very Strong	Damage slight-moderate in well-built structures; considerable in poorly-built structures. Furniture and weak chimneys broken. Masonry damaged. Loose bricks, tiles, plaster, and stones will fall.	5.5 – 6.1
8	Destructive	Structure damage considerable, particularly to poorly built structures. Chimneys, monuments, towers, elevated tanks may fail. Frame houses moved. Trees damaged. Cracks in wet ground and steep slopes.	6.2 – 6.5
9	Ruinous	Structural damage severe; some will collapse. General damage to foundations. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground; liquefaction.	6.6 – 6.9
10	Disastrous	Most masonry and frame structures/foundations destroyed. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Sand and mud shifting on beaches and flat land.	7.0 – 7.3
11	Very Disastrous	Few or no masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Rails bent. Widespread earth slumps and landslides.	7.4 – 8.1
12	Catastrophic	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted.	> 8.1

Masonry Types

Masonry A: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B: Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C: Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D: Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

The harmful effects of an earthquake vary with the geologic composition and manmade infrastructure of the region, as well as the amount of accumulated energy released when the earthquake occurs.

Ground motion
Ground motion is the primary cause of damage and injury during earthquakes and can result in surface rupture, liquefaction, landslides, lateral spreading, differential settlement, tsunamis, building failure, and broken gas and other utility lines, leading to fire and other collateral damage.

The intensity and severity of ground motion is dependent on the earthquake's magnitude, distance from the epicenter and underlying soil and rock properties. Areas underlain by thick, saturated, unconsolidated soils will experience greater shaking motion than areas underlain by firm bedrock.

Fires and structural failure are the most hazardous results of ground shaking. Most earthquake-induced fires start because of ruptured power lines and gas or electrically-powered stoves and equipment. Structural failure is generally the result of age and type of building construction.

Liquefaction
Liquefaction is the transformation of loose, water-saturated granular materials (such as sand or silt) from a solid to a liquid state. Liquefaction commonly, but not always, leads to ground failure. Liquefaction potential varies significantly and site-specific analysis is needed to accurately determine liquefaction potential in earthquake prone areas.

Much of the downtown in the City of Santa Cruz flood plain experienced liquefaction during the 1989 Loma Prieta earthquake. Liquefaction and severe earth shaking have been the two primary causes of damage during earthquakes in Santa Cruz.

4.3.2 HAZARD PROFILE – EARTHQUAKES AND LIQUEFACTION

3.2 Profiling Hazards – Requirement §201.6(c)(2)(i):

The risk assessment **shall** include a description of the location and extent of all natural hazards that can affect the jurisdiction.

The plan **shall** include information on previous occurrences of hazard events and on the probability of future hazard events.

A LOCATION

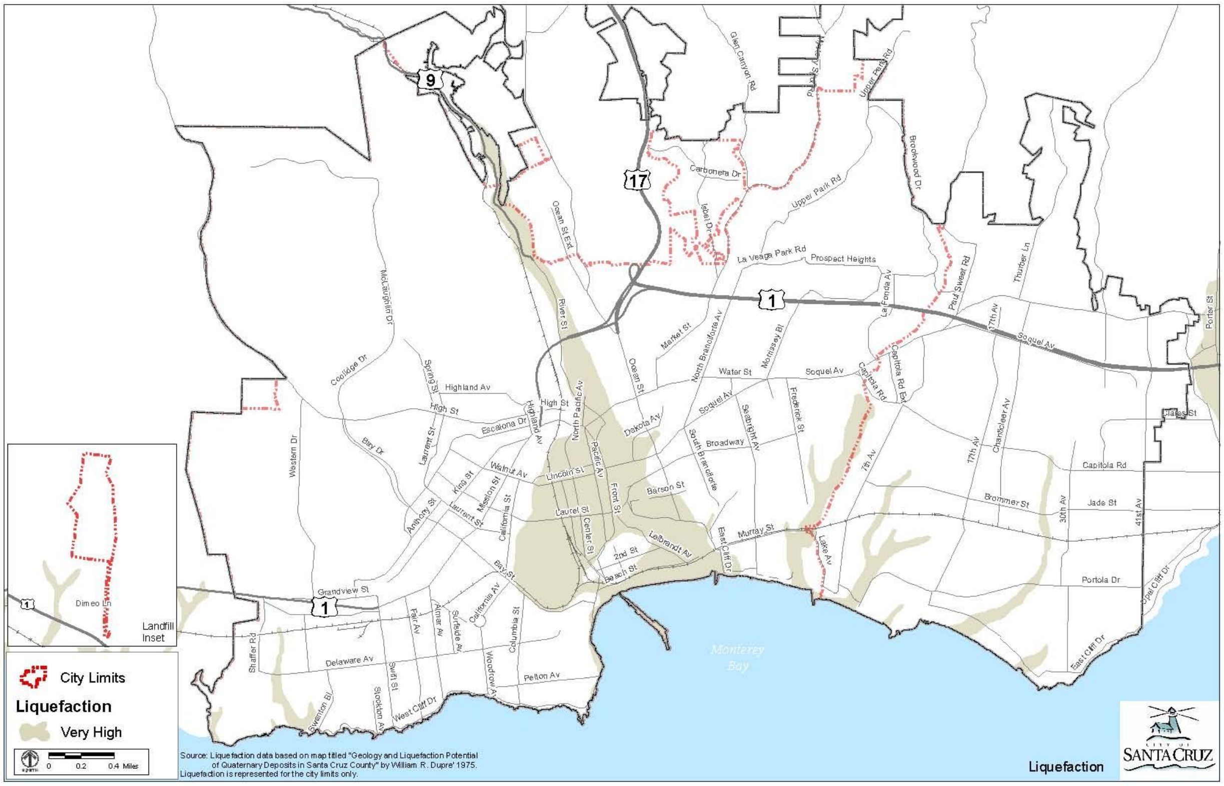


Figure 6 – Areas in Santa Cruz Potentially Vulnerable to Liquefaction

Past experience has shown that the entire community is vulnerable to earthquake. Within Santa Cruz County there are several active and potentially active faults. These include the San Andreas, San Gregorio, Zayante, Ben Lomond and Butano Faults, the Monterey Bay Fault Zone, as well as numerous fault complexes and branches of these major faults.

Santa Cruz lies within 15 miles of at least six major seismic faults and fault systems, placing it in an area of high seismic risk; however there is only one fault, the Ben Lomond Fault that actually passes through the city. The Ben Lomond Fault is not considered to have moved in historic time, however, and may be inactive.

B EXTENT: MAGNITUDE OR SEVERITY

Several of the faults located in the Santa Cruz Area are considered to be either possibly active (showing signs of recent geologic movement, within the last 10,000 years) or probably inactive (movement within the last two million years). However, the Hayward, Calaveras, San Gregorio and San Andreas faults are all considered historically active (movement within the last 200 years). Even a moderate earthquake in the area could result in deaths, property and environmental damage as well as the disruption of normal economic, transportation, government and community services.

The most active region and threat to the city is the San Andreas Fault zone which passes through the Santa Cruz Mountains 12 miles northeast of the city. Based on records from the 1906 San Francisco earthquake, it is estimated that the maximum credible earthquake likely to occur along the San Andreas Fault would equal 8.3 M, which represents more than 30 times the energy released by the 1989 Loma Prieta Earthquake. The city was one of the hardest hit communities during that earthquake. This is the highest magnitude earthquake expected in the region but it is estimated that the Hayward, Calaveras and San Gregorio faults are all capable of generating earthquakes greater than 7.4 M.

C PREVIOUS OCCURRENCES

The following is a list of previous events, dates, severity, level of damage, duration, sources of information used, and maps (where available) to show areas affected. While Santa Cruz has sustained numerous earthquakes throughout its history, the two most destructive ones were the 1906 San Francisco earthquake and the 1989 Loma Prieta earthquake.

April 18, 1906: (Richter Magnitude: 8.3)
No recorded deaths in Santa Cruz but the courthouse was almost destroyed; about 1/3 of the chimneys within the city were destroyed or damaged; there was major landsliding with gaping cracks in the earth, especially along the water; bridges were destroyed; and the water supply was shut off by broken mains and pipes.

October 1926: (Richter Magnitude: 6.1)
Two large earthquakes occurred during this year. Three of the aftershocks cracked plaster in Santa Cruz, almost bringing down the chimneys of numerous buildings. It broke plate glass windows along Pacific Avenue. The city water main broke at Laguna Creek and articles fell from shelves at stores.

October 17, 1989 (Richter Magnitude: 7.1)
Two people died in Santa Cruz as a direct result of this earthquake. In the greater San Francisco/Oakland Bay Area, there were sixty-two fatalities. The earthquake epicenter was located approximately 10 miles east of the City center. The earthquake destroyed much of the historic downtown and many areas of the City were very badly damaged. Roads in and out of the City were impassable and many residents lost power and water for up to a week.

Isoseismal Map — Santa Cruz Mountains (Loma Prieta), California
UTC (Local 10/17/1989) [6] Magnitude 6.9 Intensity IX

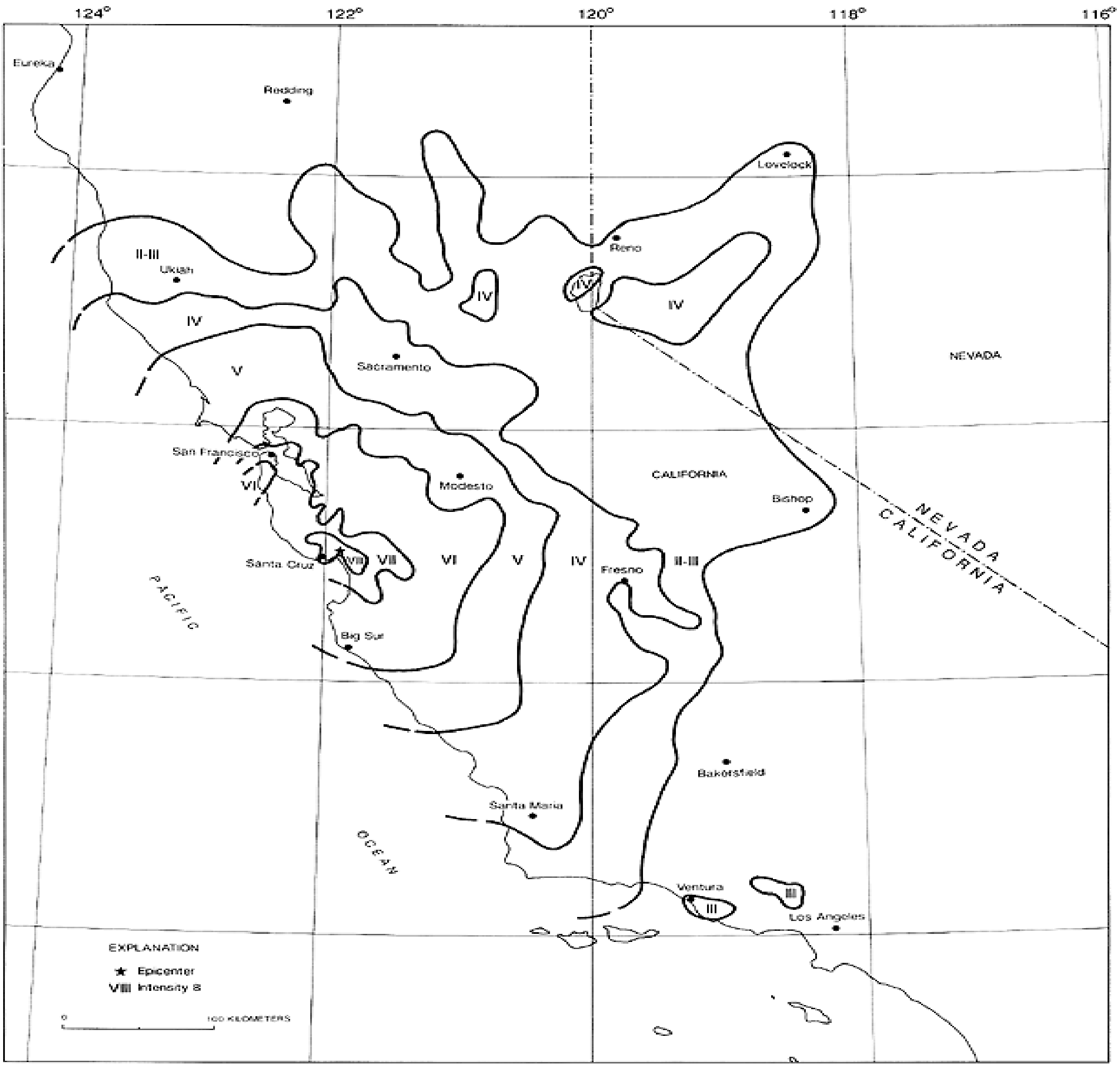


Figure 7 – Intensity and Magnitude of the 1989 Loma Prieta Earthquake in Santa Cruz

D PROBABILITY OF FUTURE EVENTS

The City lies within 15 miles of at least six (6) major seismic faults and fault systems, placing it in an area of high seismic risk. Because earthquakes can cause severe damage over a long distance, the Santa Cruz area remains at risk from continued seismic activity along the many faults in the region.

The reduction of seismic stresses that occurred in the Loma Prieta earthquake did nothing to relieve, and possibly increased, stresses within other faults, including other sections of the San

Andreas Fault. As a result, it is expected that Santa Cruz will be subjected to violent, earthquake-induced ground shaking in the future.

On the basis of research conducted since the 1989 Loma Prieta earthquake, U.S. Geological Survey (USGS) and other scientists conclude that there is a 62% probability of at least one magnitude 6.7 or greater quake, capable of causing widespread damage, striking the San Francisco Bay region (including Santa Cruz) before 2032. Major quakes may occur in any part of this region. This emphasizes the urgency for all communities in the region to continue preparing for earthquakes.[7]

The USGS, the California Emergency Management Agency, the California Geological Survey and the Association of Bay Area Governments jointly conducted a loss estimation study focused on the ten most likely damaging earthquakes. These earthquakes occur on six of the seven major fault systems in the area and range in size from a magnitude 6.7 on a blind thrust underlying Mt. Diablo to a magnitude 7.9 repeat of the 1906 rupture on the San Andreas Fault in northern California. Their 30-year probabilities range from a high of 15.2% for a M7.0 rupture of the Rodger's Creek fault to 3.5% for a M7.4 combined rupture of the Peninsula and Santa Cruz Mountains segment of the San Andreas. The ten most likely earthquakes and their 30-year probabilities are:[8]

Table 4-2 – Ten most likely damaging Earthquake scenarios in California

Ten most likely damaging Earthquake scenarios	30-year probability	Magnitude
Rodgers Creek	15.2%	7.0
Northern Calaveras	12.4%	6.8
Southern Hayward (*possible repeat of 1868 earthquake*)	11.3%	6.7
Northern + Southern Hayward	8.5%	6.9
Mt. Diablo	7.5%	6.7
Green Valley-Concord	6.0%	6.7
San Andreas: Entire Northern California segment (*possible repeat of 1906 earthquake*)	4.7%	7.9
San Andreas: Peninsula segment (*possible repeat of 1838 earthquake*)	4.4%	7.2
Northern San Gregorio segment	3.9%	7.2
San Andreas: Peninsula + Santa Cruz segment	3.5%	7.4

Because the ten most likely future earthquakes in the Bay Area occur on faults throughout the region, the impact and potential losses reported here reveal significant risk for the entire Bay Area region including the City of Santa Cruz.

4.3.3 ASSESSING VULNERABILITY: OVERVIEW

3.3 Assessing Vulnerability: Overview — Requirement §201.6(c)(2)(ii):
The risk assessment **shall** include a description of the jurisdiction's vulnerability to the hazards described in paragraph (c)(2)(i) of this section.
This description **shall** include an overall summary of each hazard and its impact on the community.

A OVERALL SUMMARY OF VULNERABILITY TO EARTHQUAKE

The vulnerability of a community to earthquake hazard is based on a variety of factors including proximity to active and inactive faults, the age of structures, the density of the population and development, the value of property and infrastructure, the construction materials used in residential and non-residential buildings, and the location of critical facilities in a community.

Recent history indicates that Santa Cruz has a very high vulnerability to earthquakes due to proximity to faults, density of population and downtown development in the San Lorenzo River floodplain which is subject to liquefaction. A number of buildings in the downtown were rebuilt or seismically retrofitted after the 1989 Loma Prieta Earthquake which damaged or destroyed much of the old downtown.

The October 17, 1989 Loma Prieta earthquake was responsible for 62 deaths (including three in the City of Santa Cruz) and 3,757 injuries. In addition, over $6 billion in damage was reported including damage to 18,306 houses and 2,575 businesses. Approximately 12,053 people were displaced.

The most intense damage was confined to liquefaction areas where buildings and other structures were situated on top of loosely consolidated, water saturated soils. Loosely consolidated soils tend to amplify shaking and increase structural damage. Water saturated soils compound the problem due to their susceptibility to liquefaction and corresponding loss of bearing strength.

During the Loma Prieta earthquake, extensive liquefaction occurred along the shoreline of the Monterey Bay. Most of the City of Santa Cruz downtown along the San Lorenzo River is in a liquefaction area. Liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading. Liquefaction has been responsible for tremendous amounts of damage in earthquakes around the world including the City of Santa Cruz.

Liquefaction occurs in saturated soils, that is, soils in which the space between individual particles is completely filled with water. This water exerts a pressure on the soil particles that influences how tightly the particles themselves are pressed together. Prior to an earthquake, the water pressure is relatively low. However, earthquake shaking can cause the water pressure to increase to the point where the soil particles can readily move with respect to each other. When liquefaction occurs, the strength of the soil decreases and, the ability of a soil deposit to support foundations for buildings and bridges is reduced.[9] Some examples of these phenomena are shown below.

Failure and cracks induced by liquefaction have been observed in the past (*see below*: photographers unknown). These images, probably from the 1906 event, show cracks formed by liquefaction at the San Lorenzo River.[10, 11]


See: http://www.es.ucsc.edu/~es10/fieldtripEarthQ/Damage1.htm

4.3.4 ASSESSING VULNERABILITY: IDENTIFYING STRUCTURES

A TYPES AND NUMBERS OF EXISTING BUILDINGS, FACILITIES AND INFRASTRUCTURE

Past experience has shown that the entire community is vulnerable to earthquake. The entire downtown commercial area is in a liquefaction hazard area. The remainder of the town is at risk for severe ground shaking as indicated by the maps below showing the probability of earthquake impacts to the Santa Cruz area within the next 50 years.

These estimates were formulated using HAZUS, a GIS-based, nationally standardized, loss estimation tool developed by FEMA. They are recent California Geological Survey maps and are limited to ground motion-induced losses to *buildings only*. In other words, the losses to other elements of the built environment, such as transportation, lifeline and communication facilities are not reported. Furthermore, the losses reported are only the *direct economic losses* due to building damage, which consist of *capital stock loss* and *income loss*.

This survey reviews 34 potential earthquake scenarios. Two of the ten most likely earthquake scenarios most damaging to Santa Cruz are shown on the following maps.

Scenario N-9 shows a possible repeat of the 1906 San Francisco earthquake and the intensity and potential damage to the City of Santa Cruz. The map indicates that the intensity would be up to IX or X which represents violent or extreme perceived shaking and very heavy potential damage. The next map shows the peak ground acceleration for this earthquake and the following two maps show the estimated building damage and economic loss as a result of the Sceniario-9 earthquake.

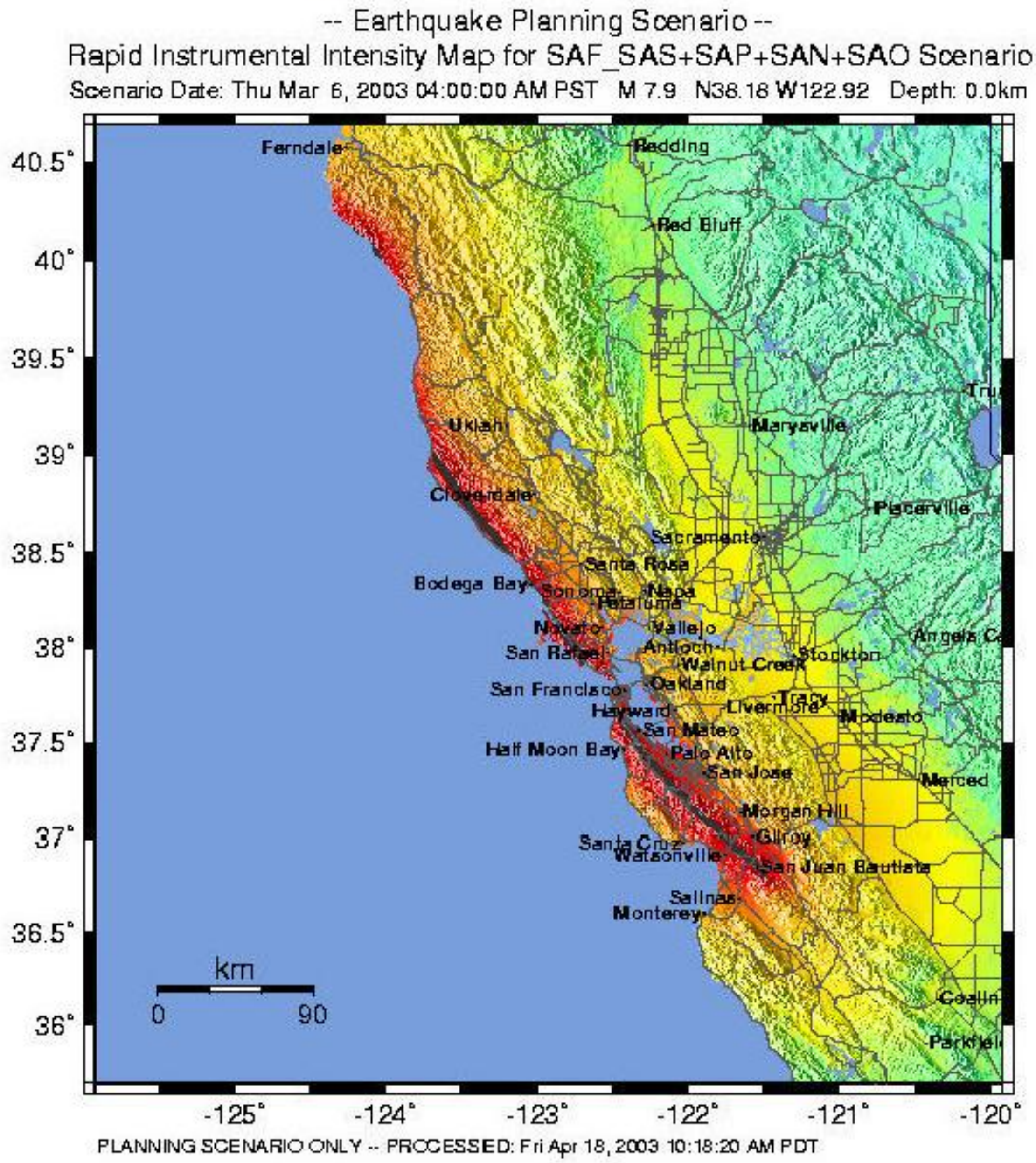
Scenario N-7 shows the projected impacts of an earthquake along the Santa Cruz Mountains + Peninsula + North Coast and the potential damage to the City of Santa Cruz. The map indicates that the intensity would be VIII or IX which represents severe to violent perceived shaking and moderate to heavy damage.

The next map shows peak ground acceleration for this earthquake scenario and the following two maps show the estimated building damage and economic loss as a result of the Scenario N-7 earthquake.

SCENARIO: N-9

All 4 segments: possible repeat of 1906 earthquake

(SAS+SAP+SAN+SAO)



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 8 – Scenario N-9 Repeat of 1906 Earthquake

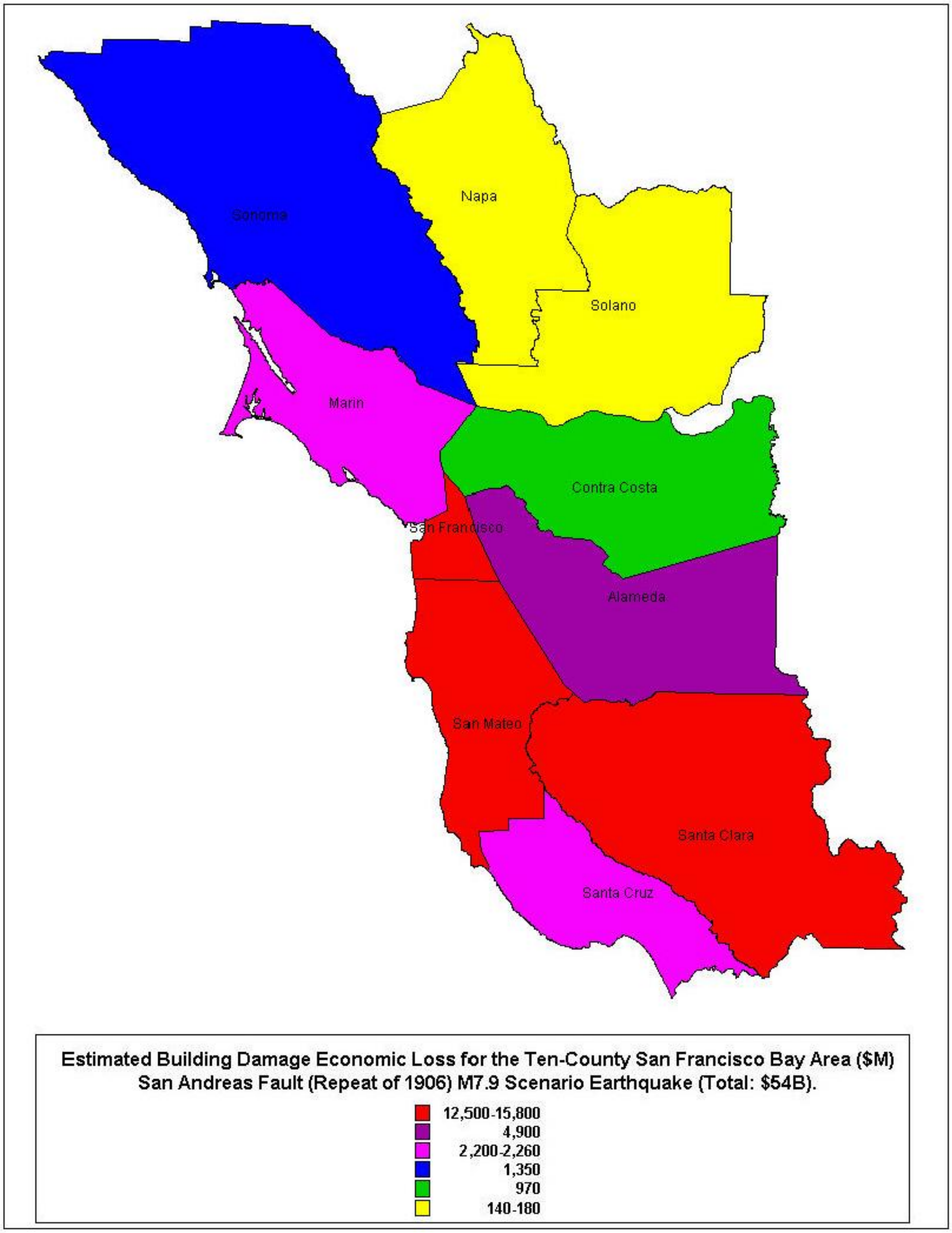


Figure 9 – Scenario N-9 Repeat of 1906 Earthquake - Building Economic Loss by County

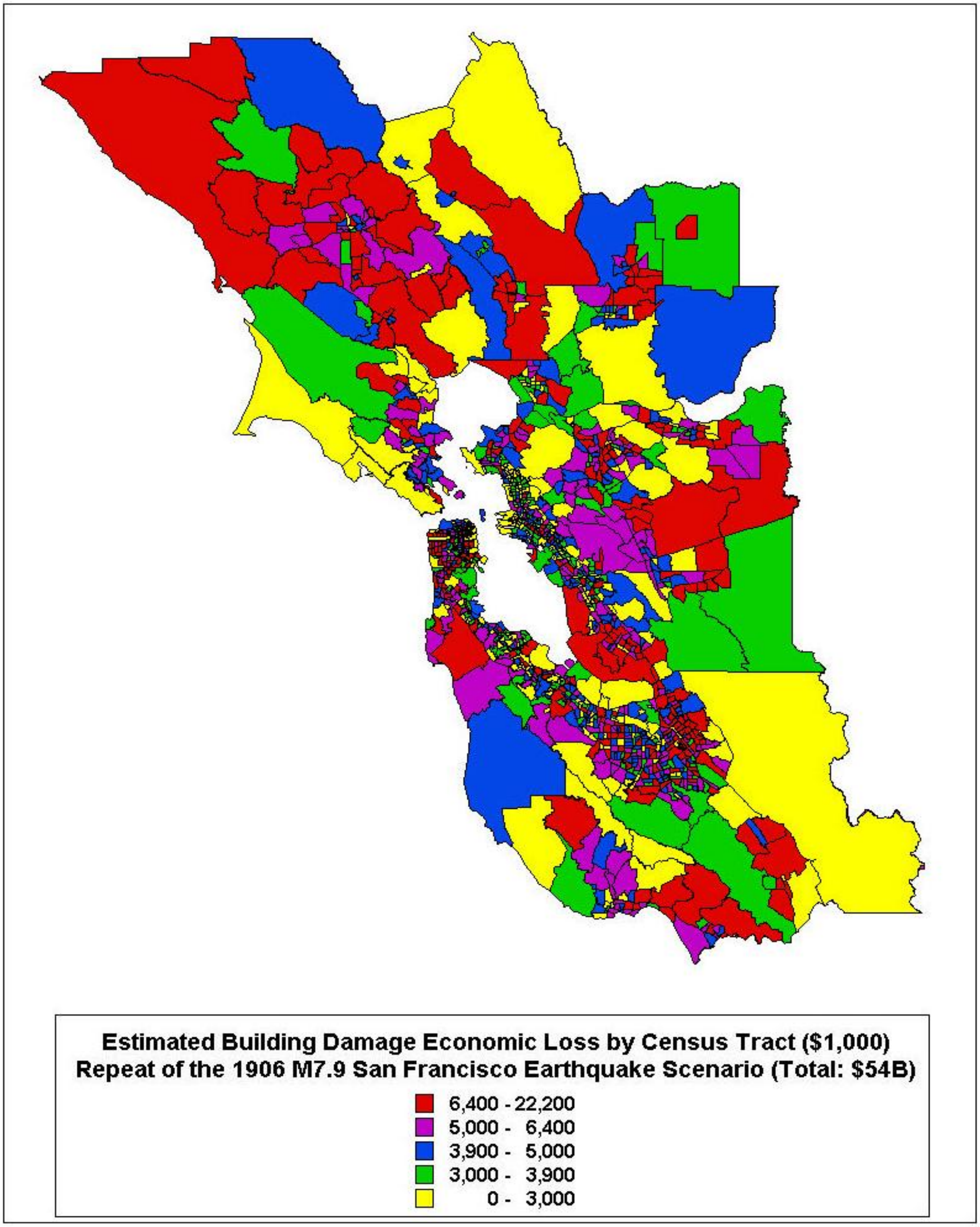
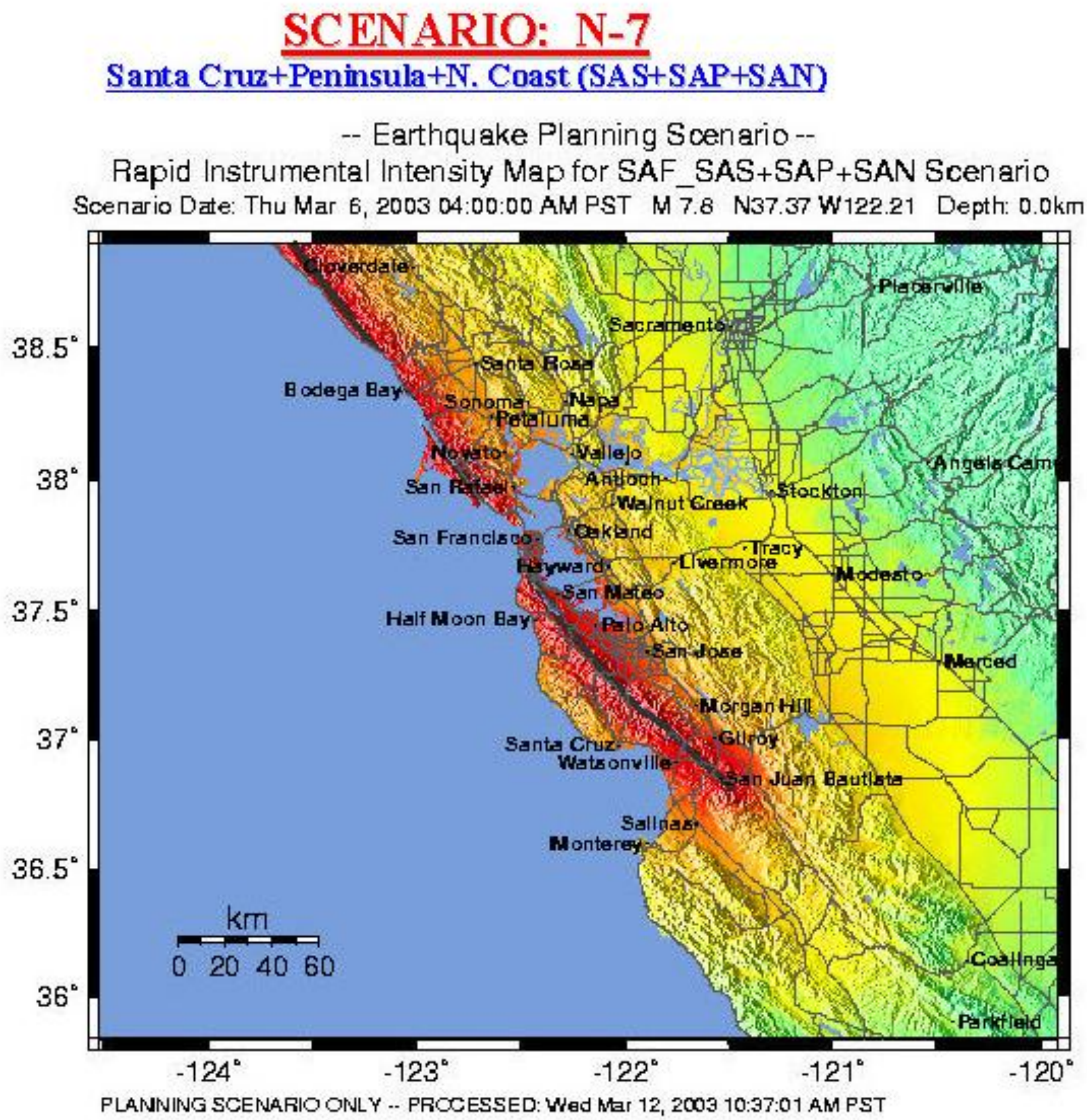


Figure 10 – Scenario N-9 Repeat of 1906 Earthquake Loss by Census Tract



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 11 – Scenario N-7 Santa Cruz Mountains

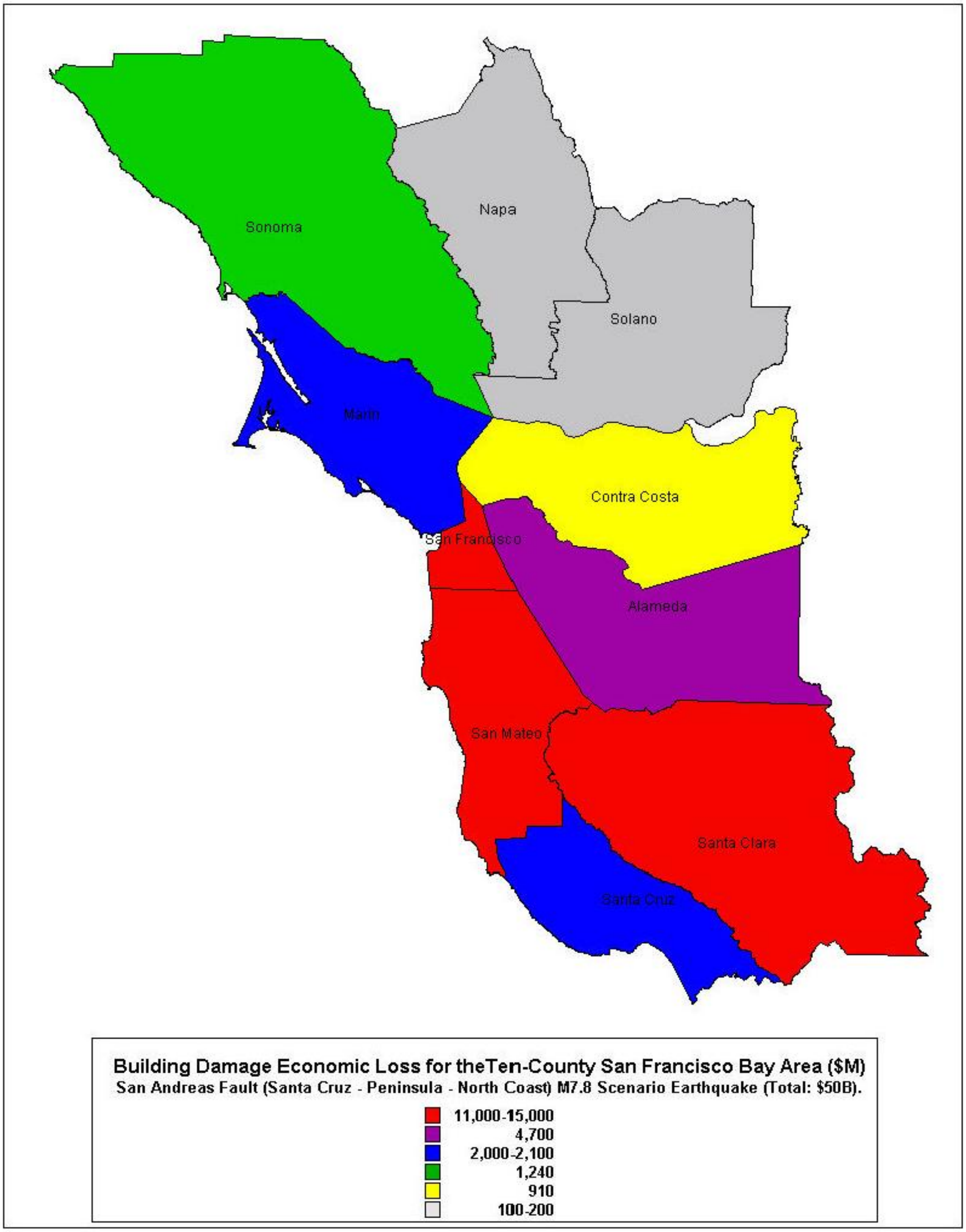


Figure 12 – Scenario N-7 Santa Cruz Mountains Building Economic Loss by County

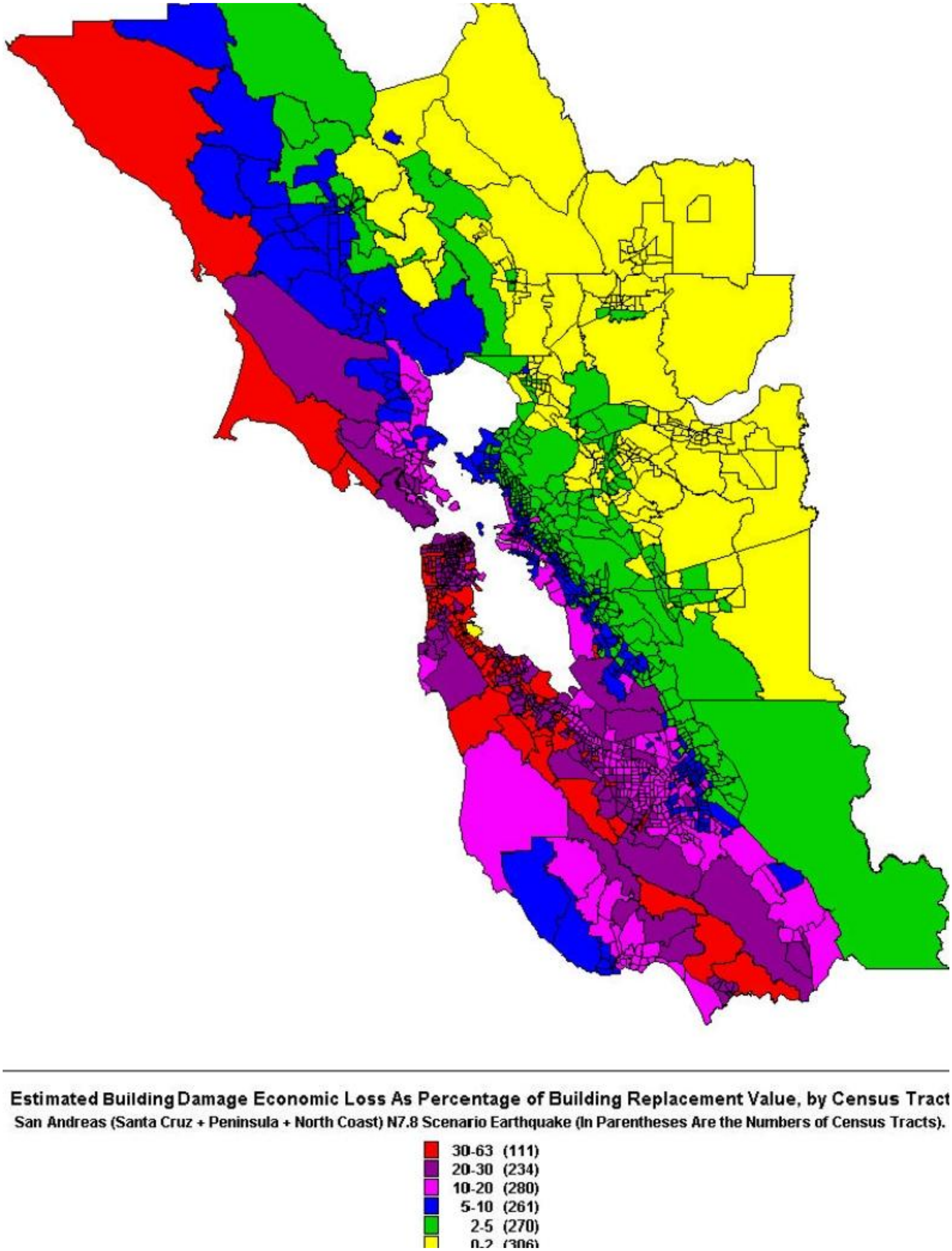


Figure 13 – Scenario N-7 Santa Cruz Mountains Building Economic Loss by Census Tract

4.3.5 ASSESSING VULNERABILITY: ESTIMATING POTENTIAL LOSSES

3.5 Assessing Vulnerability: Estimating Potential Losses: Requirement §201.6(c)(2)(ii)(B):

The plan **should** describe vulnerability in terms of an estimate of the potential dollar losses to vulnerable structures identified in paragraph (c)(2)(i)(A) of this section and a description of the methodology used to prepare the estimate.

A POTENTIAL DOLLAR LOSSES TO VULNERABLE STRUCTURES

Table 4-3 – Earthquake potential loss inventory

Inventory Assets				
EARTHQUAKE				
	# of Parcels	**# of Structures**	**Critical Structures**	**Loss in Value$***
Type	**Entire Community**	**Total**	**Total**	**Hazard**
Residential	14,808	17,128		$6,793,642,000
Commercial	1,480	1,293		$1,700,635,000
Industrial	257	321		$366,560,000
Agricultural	5	70		$22,438,000
Religious	57	89		$128,734,000
Government	216	27		$63,524,000
Education	228	57		$128,938,000
Total	**17,051**	**18,985**	**38**	**$9,204,471,000**
# of People	59,946			
DATE:	2010 Census			
Total number and values within the entire community is the same as hazard area for Earthquake				
The entire community is within the earthquake hazard area				
*Loss is based on Assessment Improvement values.				

B METHODOLOGY USED TO PREPARE ESTIMATE

Parcel Valuation:
Valuation of parcels within a hazard is based on improvement values only as collected by appraisers with the County of Santa Cruz assessor’s office. They don’t reflect sale value or replacement value. If a parcel intersected a hazard, the entire improvement value of that parcel was used.

Population:
Census population blocks were reduced to center points. If a hazard intersected a center point, that population was counted.

The losses to other elements of the built environment, such as transportation, lifeline and communication facilities are not reported. Furthermore, the losses reported are only the *direct economic losses* due to building damage, which consist of *capital stock loss* and *income loss*.

Indirect economic losses, representing the losses due to various forms of post-earthquake socioeconomic disruptions (such as employment and income, insurance and financial aids, construction, production and import-export of goods and services) are not included in the estimates reported. This is because of the higher level of uncertainty associated with the indirect losses, as compared to the direct losses. Therefore, it is expected that once the indirect building economic losses, the economic losses to non-building facilities, and the contributions of all earthquake hazards are taken into account, the estimated economic losses would be several times the numbers presented.[12]

Detailed results for all scenario earthquakes and for the State-wide annual losses are available on the CGS website.[13]

Among the 34 scenario earthquakes of the San Francisco Bay Area (SFBA), a repeat of the 1906 earthquake results in the largest economic loss for the ten SFBA counties. It would rupture four segments of the San Andreas fault and would cause approximately $54 billion of economic loss due to building damage. A number of other earthquakes on the San Andreas fault, rupturing different combinations of these four segments are also feasible. Should one occur, it would result in an estimated loss ranging from a few billion dollars to $50 billion. Other potentially damaging earthquakes in the SFBA are: A magnitude 6.9 event rupturing the entire Hayward fault causing $23 billion in losses; and, a magnitude 7.3 earthquake rupturing the entire Hayward fault and the Rodgers Creek fault causing $34 billion in losses.

Estimates were calculated using HAZUS version release 2.1 and uses 2010 census. This information in HAZUS is, for the most part, derived from 2010 national census data. Using this process the most severe potential earthquake near Santa Cruz estimates a loss of over $9 billion dollars for the county. The City of Santa Cruz represents 20 percent of that population and has within its boundaries significantly more than 20 percent of the structures as it is the commercial center of the county.

4.3.6 ASSESSING VULNERABILITY: ANALYZING DEVELOPMENT TRENDS

3.6 Assessing Vulnerability: Analyzing Development Trends — Requirement §201.6(c)(2)(ii)(C):

The plan **should** describe vulnerability in terms of providing a general description of land uses and development trends within the community so that mitigation options can be considered in future land use decisions.

C DESCRIPTION OF LAND-USES AND DEVELOPMENT TRENDS

The City of Santa Cruz is a compact urban community that is surrounded by natural barriers to outward expansion including the Santa Cruz Mountains, the Pacific Ocean and a designated greenbelt. "Ongoing population growth… has been mirrored by an increase in urbanization for the Monterey Bay area. Development patterns in the coastal zone since the 1970s confirm these overall urbanizing trends."[14]

New development has occurred within or adjacent to the urban services line (i.e., the boundary point for such infrastructure as gas, water, and sewage hook-ups). In Santa Cruz, most development is now infill or reuse development.

Since the 1989 Loma Prieta earthquake all commercial and public buildings have been replaced or seismically retrofitted. Seismic safety standards are a requirement for all building permits. As infrastructure is repaired or replaced updated seismic safety standards are incorporated.

4.4.0 MITIGATION STRATEGY

> **4.0 Mitigation Strategy – Requirement §201.6(c)(3):**
>
> The plan **shall** include a mitigation strategy that provides the jurisdiction's blueprint for reducing the potential losses identified in the risk assessment, based on existing authorities, policies, programs and resources, and its ability to expand on and improve these existing tools.

The primary mitigation strategy to avoid or reduce damage from earthquake is continuation of design review and code enforcement to meet current seismic standards, including adequate geotechnical monitoring protocols to insure structural integrity.

Mapping of liquefaction areas in Santa Cruz have been updated in this plan and represent a more accurate mapping of potential liquefaction areas. The inclusion of an updated liquefaction map was noted as an important goal of the 2007 LHMP.

4.4.1 MITIGATION GOALS

> **4.1 Local Hazard Mitigation Goals – Requirement §201.6(c)(3)(i):**
>
> The hazard mitigation strategy **shall** include a description of mitigation goals to reduce or avoid long-term vulnerabilities to the identified hazards.

Earthquake Goals:

Earthquake 1 — Avoid or reduce the potential for life loss, injury, property or economic damage to Santa Cruz from earthquakes.

Earthquake 2 — Encourage mitigation activities that increase disaster resilience to earthquake.

4.4.2 IDENTIFICATION AND ANALYSIS OF MITIGATION ACTIONS

4.2 Identification and Analysis of Mitigation Actions – Requirement §201.6(c)(3)(ii):

The mitigation strategy shall include a section that identifies and analyzes a comprehensive range of specific mitigation actions and projects being considered to reduce the effects of each hazard, with particular emphasis on new and existing buildings and infrastructure.

Earthquake Mitigation Actions:

Earthquake is one of the most significant threats to Santa Cruz. The following Actions (noted in parentheses), are listed in Part 4 – Chapter 13: Mitigation Strategies. They are critical to the future safety of Santa Cruz:

- Coordinate preparedness efforts with other agencies. (A-2)
- Upgrade sewer, water and other infrastructure to withstand seismic shaking. (A-10)
- Continue retrofitting all non-complying unreinforced masonry buildings. (C-8)
- Upgrade seismic safety of all emergency use and critical structures. (C-9)