CHAPTER 7. IMPLICATIONS FOR EARTHQUAKE HAZARD IN THE SAN FRANCISCO BAY REGION

Introduction

The foremost conclusion of our Bay Area earthquake probability study is that the likelihood of a future destructive earthquake somewhere in the region in the next 30 years is high, even though the precise probability value has a broad range of uncertainty. Relative to earlier studies, the most significant new result is that this probability is spread throughout the greater metropolitan region, not just restricted to areas surrounding San Francisco Bay. As growth and development have spread outward from the Bay margins during the past several decades, so has our recognition and definition of the earthquake hazard associated with strain accumulation and release on the 7 major fault systems that transect the region over a 75 km wide zone (see Figure 6.13).

By 2025, the population of the Bay Area is projected to exceed 8.2 million people--an increase of more than 1.4 million from the Census 2000 level (Fassinger et al., 2001). Nearly all of this growth is expected to occur in the East Bay and North Bay regions. Contra Costa, Alameda, and Santa Clara Counties are projected to experience a 15-20% increase in population. Solano and Napa counties are anticipated to show the highest growth, each adding more than 30 percent to their respective populations. This eastward and northward growth of the region will occur in areas of significant seismic hazard. As noted in Chapter 6, the cumulative 30 year probability of an earthquake of M>=6.7 occurring somewhere within this rapidly growing East and North Bay region alone is nearly 50% (P=0.46 [0.17 – 0.64].

Earthquake probabilities are, by themselves, only a partial description of the seismic hazard of a region. Most earthquake damage is the result of strong ground shaking, which depends on the earthquake size, distance from the causative fault, and local soil conditions as well as source to site path effects, duration of shaking, and rupture directivity . In this chapter we consider the distribution of shaking and damage that these earthquakes are likely to produce. It is important to note that these maps that do not attempt to characterize the complexity that will surely be characteristic of earthquake ground shaking and damage. These maps simply represent median ground motions and intensity levels that might occur from any of these earthquakes. Maps of expected intensity levels, as defined by the modified Mercalli intensity scale (MMI) can be created for a single earthquake, and these maps can be integrated to model the effects of a suite of future earthquakes. In general, MMI VII is characterized by damage to weak structures, MMI VIII is characterized by damage to engineered structures, and MMI IX is characterized by severe damage and partial collapse of some structures. Below, we present and discuss maps of expected shaking for the highest probability earthquakes in the WG02 study and aggregate shaking maps for the SFBR as a whole. Our goal in presenting this information is to inform policymakers and encourage mitigation and preparedness efforts to reduce the potentially devastating impacts of these future earthquakes.

Scenario Shakemaps: Anticipated Shaking Levels for High-Probability Future Earthquakes

To examine the implications of these future earthquakes, we have produced a series of MMI intensity maps, which we describe as scenario ShakeMaps, for the potential Bay Region rupture sources. We focus discussion on maps depicting MMI intensity values for the largest and most probable WG02 rupture sources (Table 7.1). The complete set of scenario ShakeMaps for all 35 potential rupture sources defined by WG02 can be downloaded from the website http://ncweb-menlo.wr.usgs.gov/research/strongmotion/effects/shake/archive/scenario.html.

The scenario ShakeMaps graphically illustrate the strength and regional extent of shaking that can be expected from a specific earthquake source. They are particularly valuable in assessing the hazard to a particular site from the set of scenario earthquakes. The ShakeMaps are determined from the peak ground acceleration and velocity estimated using the ground motion prediction equations of Boore and others (1997) and Joyner and Boore (1981), respectively. The source parameters required for these calculations are the seismic moment and the surface projection of the rupture area. The resulting ground motions are applied to the soils map developed by the California Geological Survey (Wills et al., 2001) to account for soil amplification. The site amplifications are determined by aggregating the surface geology into NEHRP site-classes and using the non-linear amplification equations of Borcherdt (1994). The maps of peak ground acceleration and velocity are combined to estimate the Instrumental Intensity, devised by Wald and others (1999) as a quantitative approximation for the Modified Mercalli Intensity.

The maps of Instrumental Intensity are presented in this chapter as scenario ShakeMaps. Alternative measures of ground motion in the form of contour maps of peak ground acceleration, peak ground velocity, and spectral response are also given on the website for all 41 rupture sources. It is important to note that these are median estimates: when a large earthquake actually occurs, the ground motions will exceed these estimates in many places. Furthermore, the ground motion prediction equations of Boore and others (1997) and Joyner and Boore (1981) do not include explicit directivity or near-fault amplification terms, so that it is possible that the ground motion near the surface trace of these rupture sources will be stronger than the estimates on these maps.

Table 7.1 Highest probability, large (M≥6.5) individual rupture sources identified by WG02

Rupture source	Magnitude	30 year Probability of Characterized eq
RC	6.98	15.20%
CN	6.78	12.40%
HN	6.49	12.30%
HS	6.67	11.30%
HS+HN	6.91	8.50%
MtD	6.65	7.50%
SAF floating M6.9	6.90	7.10%
CON+GVS+GVN	6.71	6.00%
SAS+SAP+SAN+SAO	7.90	4.70%
SAP	7.15	4.40%
SAS	7.03	2.6%

Scenario ShakeMaps for the most probable strike-slip earthquake rupture sources in the SFBR are described below. We cannot calculate a scenario ShakeMap for the floating SAF event because the location is unspecified. Table 7.1 again emphasizes the high hazard WG02 has identified for the east and north Bay, with 7 of the likeliest sources located in theseareas of the SFBR. We have included an actual ShakeMap (generated by incorporating the actual strong motion data) for the 1989 M6.9 Loma Prieta earthquake to provide a “ground truth” comparison for the scenario map for the Santa Cruz Mountain segment of the San Andreas fault (SAS). Perhaps the most important message from these maps is that even though the intensities are generally higher close to the rupture source, high intensities and associated damage occur throughout the SFBR for each of these events.

San Andreas fault

The largest anticipated earthquake affecting the SFBR is a repeat of the 473-long-1906 M7.9 rupture of the San Andreas fault. The immensity of the energy released by this earthquake is obvious when scenario ShakeMaps for this and two other San Andreas rupture sources, SAP and SAS, are plotted at the same scale (Figure 7.1). As is clearly demonstrated in Figure 7.1a, a repeat of the 1906 earthquake will have devastating effects throughout much of Northern California from the Central Valley west, producing a zone of structurally damaging shaking intensities (MMI≥VIII) over a 10,000 mi^2 zone (approximately 30 miles wide and over 330 miles long). Intensity VII shaking levels are anticipated to extend to the western part of the Central Valley.

A M7.2 event on the Peninsula segment of the San Andreas, possibly a repeat of the 1838 earthquake, would produce a significantly smaller region of strong shakingalong the Peninsula

(Figure 7.1b). However, this event also produces damaging ground motions (MMI-VIII) around much of the Bay margins.

A comparison of the scenario ShakeMap for a M7.0 rupture of the Santa Cruz Mountains segment (Figure 7.1c) with the actual ShakeMap for the Loma Prieta earthquake (Figure 7.1d) illustrates some of the uncertainties in our secenarios. Although the rupture source for the for the 1989 earthquake is not identical to the SAS, there is generally good agreement in distribution and levels of shaking from the 1989 event and the predicted shaking from a similar-sized earthquake (M7.0) in the Santa Cruz mountains. While the scenario ShakeMap underestimates the intensity to the north, in Oakland, San Francisco, and San Mateo, it overestimates the intensity in Morgan Hill, Gilroy, and Watsonville. These maps also serve as a reminder that even relatively remote quakes can have a significant impact on the Bay Area, as well as on the rapidly growing communities in the Monterey Bay and along the I101 corridor south of San Jose.

Hayward-Rodgers Creek fault

The most hazardous fault system in the Bay Area identified by WG02 is the Hayward-Rogers Creek, with a likelihood of 27% for a M≥ 6.7 earthquake in the next 30 years. This is greater than a 1 in 4 chance of a damaging larger earthquake somewhere along its extent. Figure 7.2a shows the expected distribution of shaking intensity for the highest probability large rupture source in the WG02 model, a M6.98 rupture of the Rodgers Creek Fault (P=0.15, Table 7.1). Shaking for this event will be severe to violent along the length of the fault through the highly developed Santa Rosa region as far north as Healdsburg, as well as on the soft sediments along the northern margins of San Pablo Bay. Very strong to severe shaking is also expected to occur in the Vallejo-Napa area, on the south side of San Pablo Bay, and along the Bay margins west of Oakland.

Rupture of the full Hayward fault (M6.91, P=0.09) shown in Figure 7.2b, would be the most devastating East Bay event because it would occur within the highly developed Interstate 880 corridor. This earthquake would generate structurally damaging ground motions (intensities VIII-X+) from the eastern margin of the Bay through the East Bay hills, and from Milpitas in the south to as far north as Petaluma. Structurally damaging shaking levels are also expected in the financial district of San Francisco. Very strong to severe shaking would occur throughout the Santa Clara valley and eastward into the San Ramon and Livermore valleys and the western part of the Delta.

Scenario ShakeMaps for the southern (P= 0.12) and northern P=0.11 segments of the fault are shown on Figures 7.2c and 7.2d, respectively. The southern Hayward rupture (M6.67, Figure 7.2c) is considered similar to the 1868 Hayward earthquake. The 1868 event caused considerable damage to soft soil and landfills both in San Francisco and along the east margins of the Bay (Lawson, 1908), consistent with the strong levels of shaking predicted in the scenario ShakeMap. The area of structurally damaging shaking intensities from a northern Hayward rupture (M6.5, P=0.11, Figure 7.2d) extends to north of San Pablo Bay, along the NE Bay margins, and eastward to the Walnut Creek area. Shaking intensities in the densely developed greater Oakland area would be in the VII to VIII range, and extensive structural damage is likely in this region.

Note that for all the Hayward fault scenarios, severe shaking is predicted to extend westward across San Francisco Bay onto the soft soil sites on the San Francisco Peninsula and the made land/artificial fill in San Francisco. In fact, San Francisco's financial district, which is largely built on pre-1906 bay fill, is approximately equidistant from the Hayward and the San Andreas faults, making it vulnerable to large earthquakes on both sides of the Bay.

Other East Bay faults

The newly characterized East Bay faults in the WG02 study transect the regions of the fastest growth of the San Francisco Bay area. We have included scenario ShakeMaps for four of the highest probability events in the eastern part of the study area-- rupture of the northern Calaveras, the entire Concord-Green Valley, the entire Greenville fault, and the Mt. Diablo thrust--to illustrate the potential impact of such events.

Figure 7.3 shows the distribution of shaking for the East Bay faults. The ShakeMap for the highest probability event in this region, a M6.78 earthquake on the northern Calaveras fault (P=0.12) is given in Figure 7.3a. This earthquake would severely affect the major cites in this part of the East Bay, from Livermore north to Walnut Creek. Intensities of VIII to X would be expected along the length of the rupture and eastward into the Livermore Valley. Severe shaking would also be produced along the east side of the Bay from Oakland south to San Jose.

A rupture of the entire Concord-Green Valley fault system (M6.71, P=0.06, Figure 7.3b) would produce violent shaking along the Vallejo-Suisun Valley corridor of Interstate 80 and in the Concord-Walnut Creek area. A full rupture of the Greenville fault (M6.94) is assigned a relatively low probability (P=0.02), however severe shaking from this event would strongly affect the Pleasanton-Livermore Valley region along Interstate 580 as well as the Concord-Walnut Creek area to the north (Figure 7.3c).

The Mt. Diablo thrust is the only thrust fault characterized in the SFBR by WG 02. The fault does not extend to the surface. Figure 7.3d shows the location of the modeled fault plane at depth (black rectangle) and the shaking estimated for a M 6.7 event. Very strong to severe shaking is expected to occur from the Livermore valley on the south northward to Vallejo and the western Delta. The margins of San Francisco Bay , particularly the eastern margin, is also expected to experience severe shaking.

All of these events generate strong to severe shaking in the western part of the Central Valley, particularly in the soft sediments in the Delta region south of Rio Vista. Despite their location in the eastern Bay region, large earthquakes on these faults will produce moderate to heavy shaking around the San Francisco Bay margins.

Regional Shaking Levels

Levels of shaking for a region can be calculated by combining the likelihood and magnitude of future earthquakes on specific fault segments with information on how seismic waves propagate through the region and on local soil conditions. These values are normally given in terms of the likelihood of exceeding a given level of shaking over a specific time interval. This approach, known as probabilistic seismic hazard assessment (PSHA) [Cornell, 1968], has been employed in developing the recent U.S. National Seismic Hazard Map .For the past several decades the U.S. Geological Survey (USGS) and the California Geological Survey (CGS) have jointly produced seismic hazard maps for California (Frankel et al., 1996; Petersen et al., 1996). These maps were used in developing the seismic design parameters for the 2000 International Building Code, setting insurance rates by the California Earthquake Authority in 1998, implementing California seismic hazard zones (1990 California Seismic Hazards Mapping Act), planning mitigation strategies (e.g., FEMA prioritization of structural retrofit following the 1994 Northridge earthquake), estimating seismic losses (FEMA-NIBS HAZUS loss estimation methodology) and calculating design ground motions for schools, hospitals, and other important structures (e.g., California Code of Regulations, Title 24, California Building Code; 1973 California Hospital Seismic Safety Act). New seismic hazard maps that use the updated WG02 SFBR earthquake sources area available at the website http://geohazards.cr.usgs.gov/eq.

Specific values of expected ground motion obtained from PSHA are of particular interest to engineers and architects. These values can be converted to earthquake intensity levels that are directly related to expected damage. We have calculated two intensity hazard maps (Figure 7.4) that depict the time-independent levels of shaking in the SFBR from the integrated earthquake sources included in the U.S. National Seismic Hazard maps (including the sources from this report) for a 30-year time window. In producing these hazard maps we have taken into account the uncertainties in the ground motions as well as the uncertainties in the damage associated with these motions. On both maps the intensity levels are color-coded using similar colors as the scenario ShakeMaps. The 10% map (Figure 7.4a) is time-independent and corresponds to the intensity that has a 1 in 10 chance (10%) in 30 years, or even odds (50%) chance in 200 years, of being exceeded. The 50% map(Figure 7.4b) shows the intensity that has a 50% chance of being exceeded in 30 years or a 99% chance of being exceeded in 200 years.

The 10% map depicts high intensities across the entire Bay area that would cause significant damage to both engineered and weak structures. The 50% probability map, which is more likely, indicates an expected intensity of about MMI VII on sites located on rock, causing damage to weak structures, and greater than MMI VIII on the soft soils surrounding the Bay and Delta, causing significant damage to engineered structures during the 30-year period. The strong shaking intensity levels on the Bay margins reflect the amplification effects of soft sediments and fill in these areas. In the past decade the Bay margins have experienced rapid commercial construction, particularly in the south Bay.

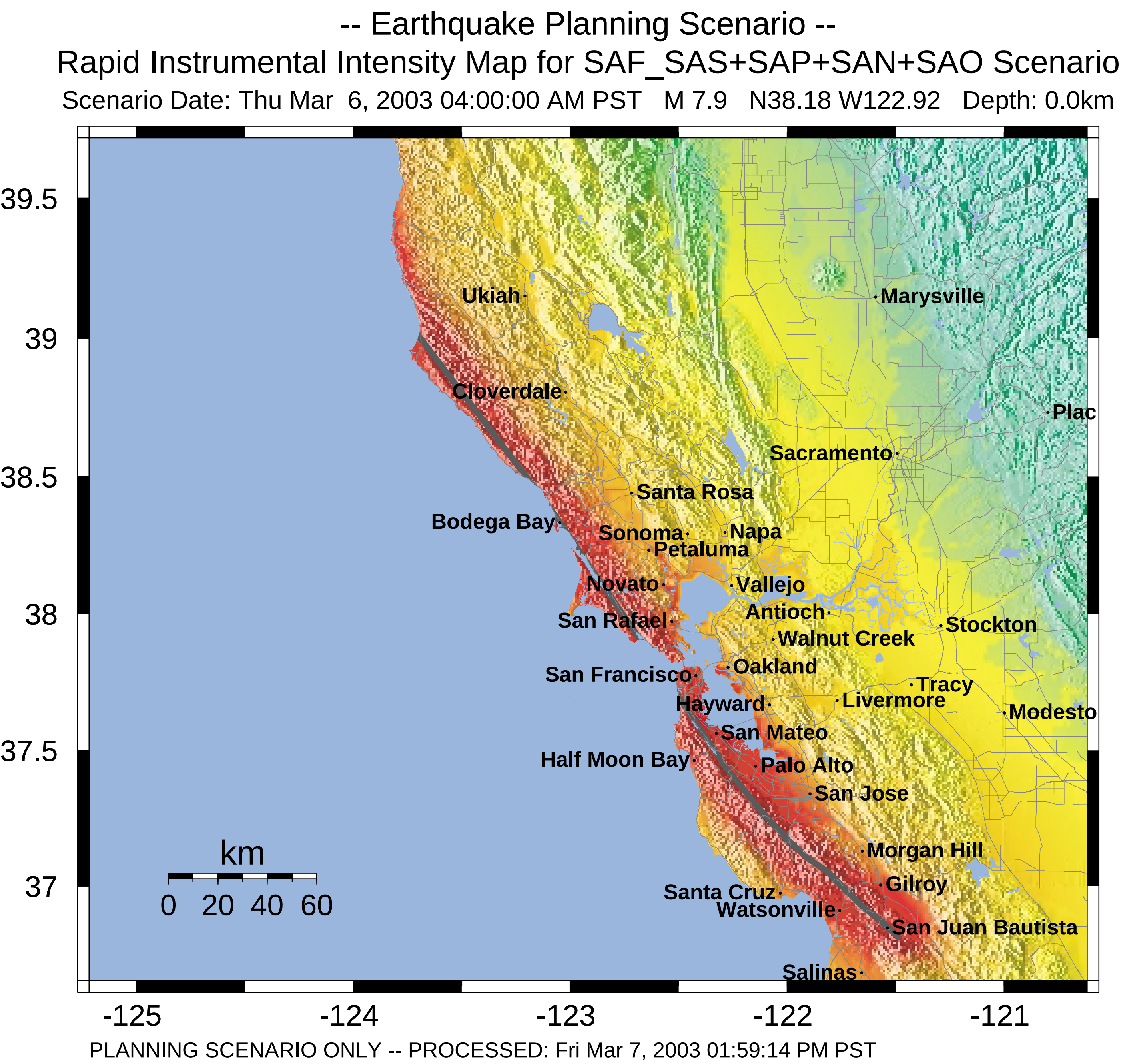
Historically, earthquake damage in the SFBR has been quite variable through the past couple of centuries. Residents of the Bay area have experienced little or no damage during decade long intervals of relative seismic quiescence and then have experienced significant damage from multiple earthquakes during long periods of seismic activity. For example, between 1830 and 1910 regional earthquake intensities were very high from at least 4 earthquakes with M>=6.5, culminating with the M 7.9 1906 San Francisco earthquake. However, during the subsequent 73-year period between 1907-1980 almost no damaging large earthquakes occurred in the region. More recently, during the past 23 years (1980-2003) the 1989 Loma Prieta earthquake (M 6.9) ruptured near the San Andreas fault in the Santa Cruz Mountains and the 1984 Morgan Hill earthquake (M6.2) ruptured along the Calaveras fault in the south Bay area. The 1989 earthquake caused considerable damage at sites that are underlain by soft soils (e.g., the San Francisco Marina district and Oakland) and at sites near the earthquake rupture beneath the Santa Cruz Mountains. Therefore, during some 30-year intervals over the past 170 years the SFBR has experienced shaking intensities similar to Figure 7.4a, in other 30-year intervals the SFBR experienced intensities similar to Figure 7.4b, and still others it experienced relatively low levels of shaking intensity. By analyzing intensity patterns from historical earthquakes back to 1800, Toppozada et. al (1991) conclude that the SFBR has experienced MMI VII or greater on average every 30 to 50 years. The regional probabilistic intensity maps are valuable because they allow assessment of impacts of future earthquakes at a given hazard level. While a 10% likelihood may be useful for many policy decisions, even the shaking intensity expected at the 50% likelihood level over the next 30 years represents a significant hazard.

Preparedness and Mitigation Now to Reduce Future Earthquake Losses

In the section above we have used our earthquake probabilities to estimate the expected distribution of shaking intensity for the SFBR as a whole. Earthquake risk (the consequences of an earthquake in terms of probable loss of life and property) is the product of the ground shaking hazard, the exposure (buildings, infrastructure inventories), and the structural vulnerability. A detailed examination of earthquake risk for the SFBR is beyond the scope of this report. However, the earthquake rupture scenarios developed by WG02 as well as the maps of integrated regional shaking intensity derived from the national Seismic Hazard map provide fundamental inputs to a variety of risk-related analyses.

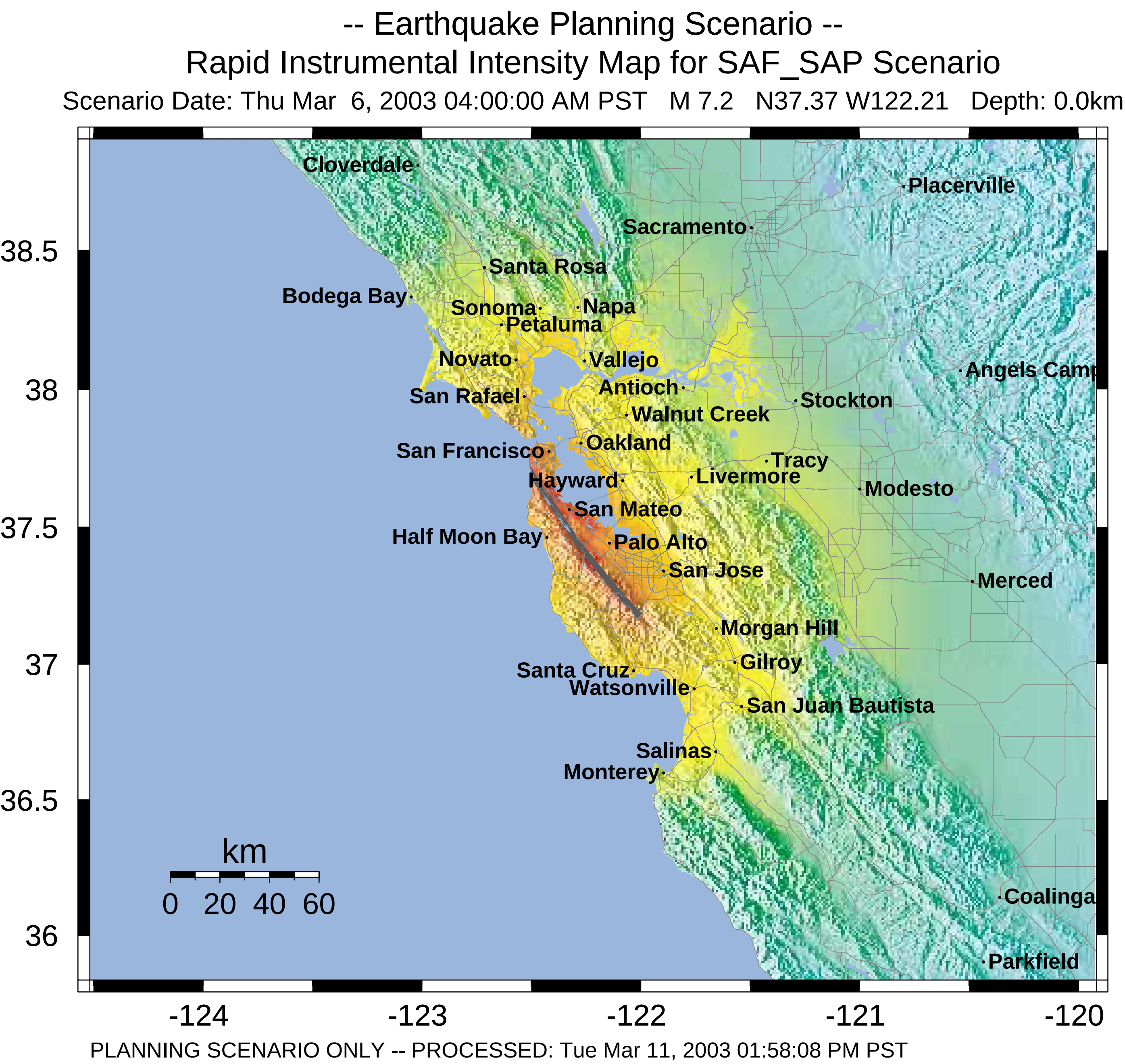
The scenario earthquake rupture sources described above can be particularly useful for loss estimation. FEMA has developed and made freely available an earthquake loss estimation software package called HAZUS .This program calculates a large number of loss parameters using ground motion inputs, including specification of the earthquake source. The required HAZUS input files for all 35 potential rupture sources in the SFBR are available on the web at: http://ncweb-menlo.wr.usgs.gov/research/strongmotion/effects/shake/archive/scenario.html . Estimates of earthquake loss for the SFBR using the most probable earthquake rupture sources as input to HAZUS have been calculated by Zoback et al (2003). The Association of Bay Area Governments (ABAG) has used the WG02 rupture sources for the scenario events to estimate the extent of liquefaction, the number of uninhabitable housing units, and impacts on the regional transportation system from future earthquakes (http://www.abag.ca.gov/bayarea/eqmaps/). To appreciate the potential scale of these effects ABAG has estimated that a southern Hayward event, for example, will result in 75,000 uninhabitable units and 170,000 displaced persons. Transportation losses include the effects of liquefaction, landslides, collapse of overpasses, and road closures due to surface fault rupture. ABAG estimates that a Northern Calaveras event (Figure 7.6) will close 363 roads, primarily in Alameda and Contra Costa Counties. A San Francisco Peninsula event is predicted to produce 879 road closures, principally in San Francisco and San Mateo counties and, for comparison, a repeat of the 1906 earthquake is expected to close more than 1330 roads throughout the region. In the SFBR the CGS has used scenario ruptures on the Hayward fault (CDMG, 1987) and Rodgers Creek fault (CDMG, 1994) to develop scenario maps and damage assessments for buildings and structures, transportation lifelines, and utility lifelines.

In releasing these shaking data, we urge cities, counties, regional authorities, and other groups to assess their exposure and vulnerability to the effects of future earthquakes. The high probability of M 6.7 or larger earthquake in the next 30 years, and the high probability of damaging ground motion shown on Figure 7.4, place lives, housing and critical infrastructure vital to the health and functioning of the entire Bay region at significant risk. The SFBR has been at the forefront of retrofitting its infrastructure. Since the 1989 Loma Prieta earthquake more than $12 billion spent to upgrade or replace bridges (Cal Trans); electrical substations, transmission lines, and gas pipelines (Pacific Gas and Electric Company); public transit (Bay Area Rapid Transit Authority); and water pipelines and distribution system (East Bay Municipal Utility District). And the City of San Francisco has approved a $4 billion bond measure for the rehabilitation and retrofit of the Hetch-Hetchy water system, for which losses are estimated to be as high as $38 billion for a repeat of the 1906 earthquake. Efforts such as these are important steps but there is much more required to prepare the region to ride through the effects of future large earthquakes. Both the high level of earthquake hazard and risk described here for the SFBR provide strong justification for accelerating retrofit programs, other mitigation strategies, and stronger preparedness measures.



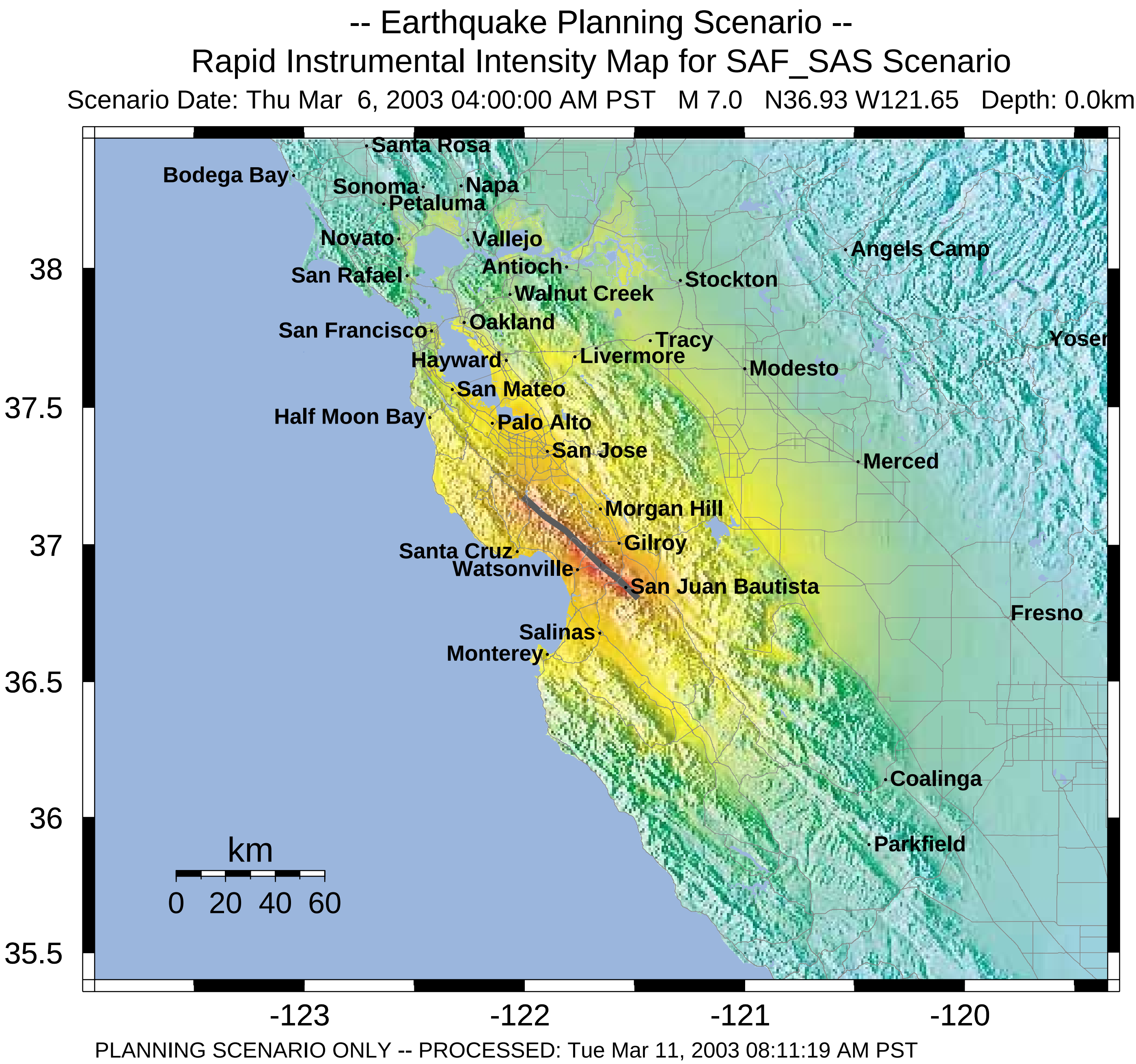
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1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

Figure 7.1a Scenario ShakeMap for rupture of all four fault segments in an event that is considered a repeat of the 1906 earthquake (P=0.05).



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Etreme
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 7.1b Scenario Shakemap for rupture of the San Francisco Peninsula segment in a M 7.2 event (P=0.04), believed to be a repeat of the 1838 earthquake on the Peninsula.

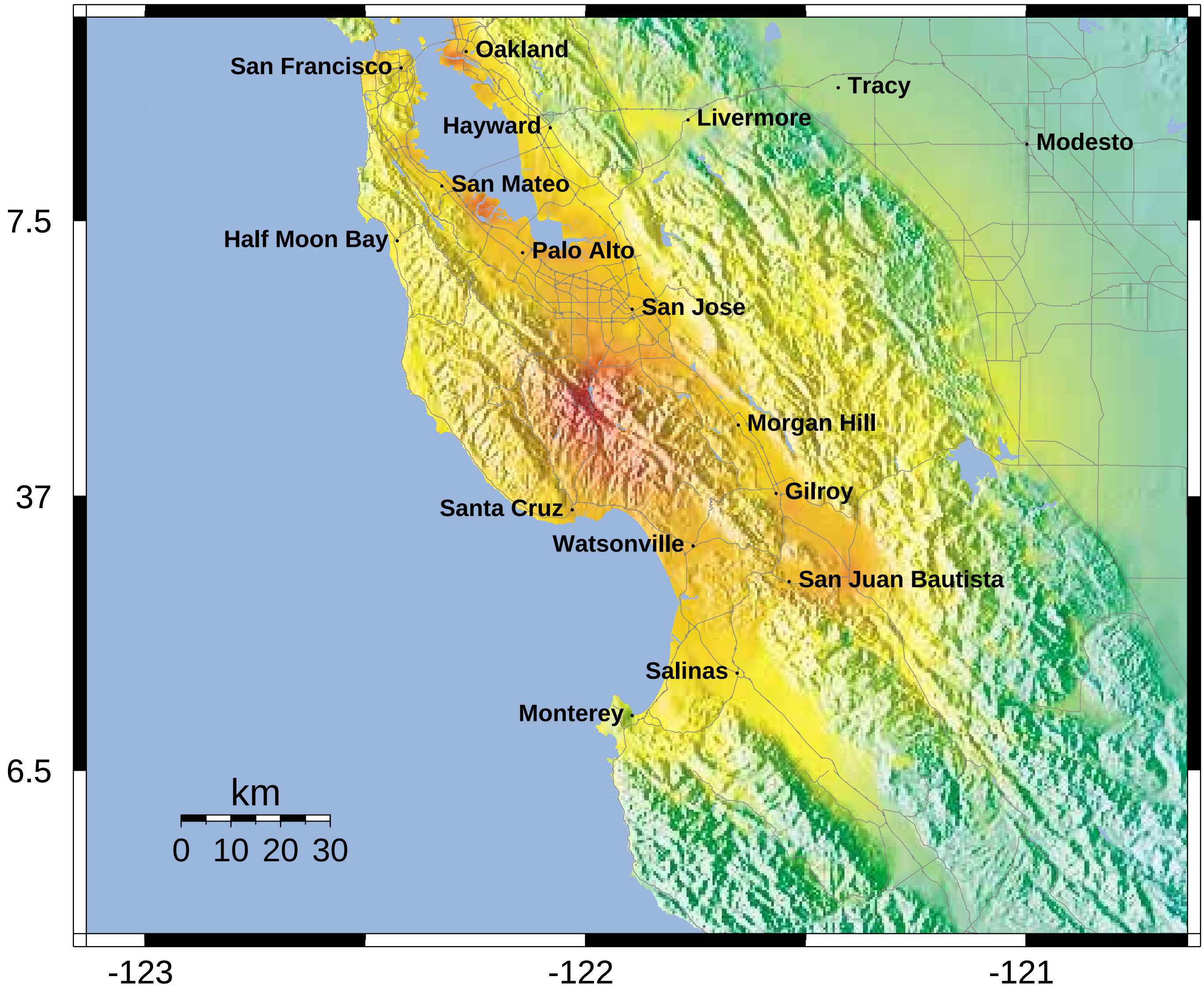


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Seere	iolent	Etreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	***<.17***	***.17-1.4***	***1.4-3.9***	***3.9-9.2***	***9.2-18***	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	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 7.1c Scenario ShakeMap for rupture of the Santa Cruz Mountains segment in a M 7.0 event (P=0.03), similar to the 1989 **M** 6.9 Loma Prieta event

USGS/UCB/CGS Rapid Instrumental Intensity Map for LP_1989 Earthquake

Tue Oct 17, 1989 05:04:00 PM PDT M 6.9 N37.04 W121.88 Depth: 18.0km ID:216859



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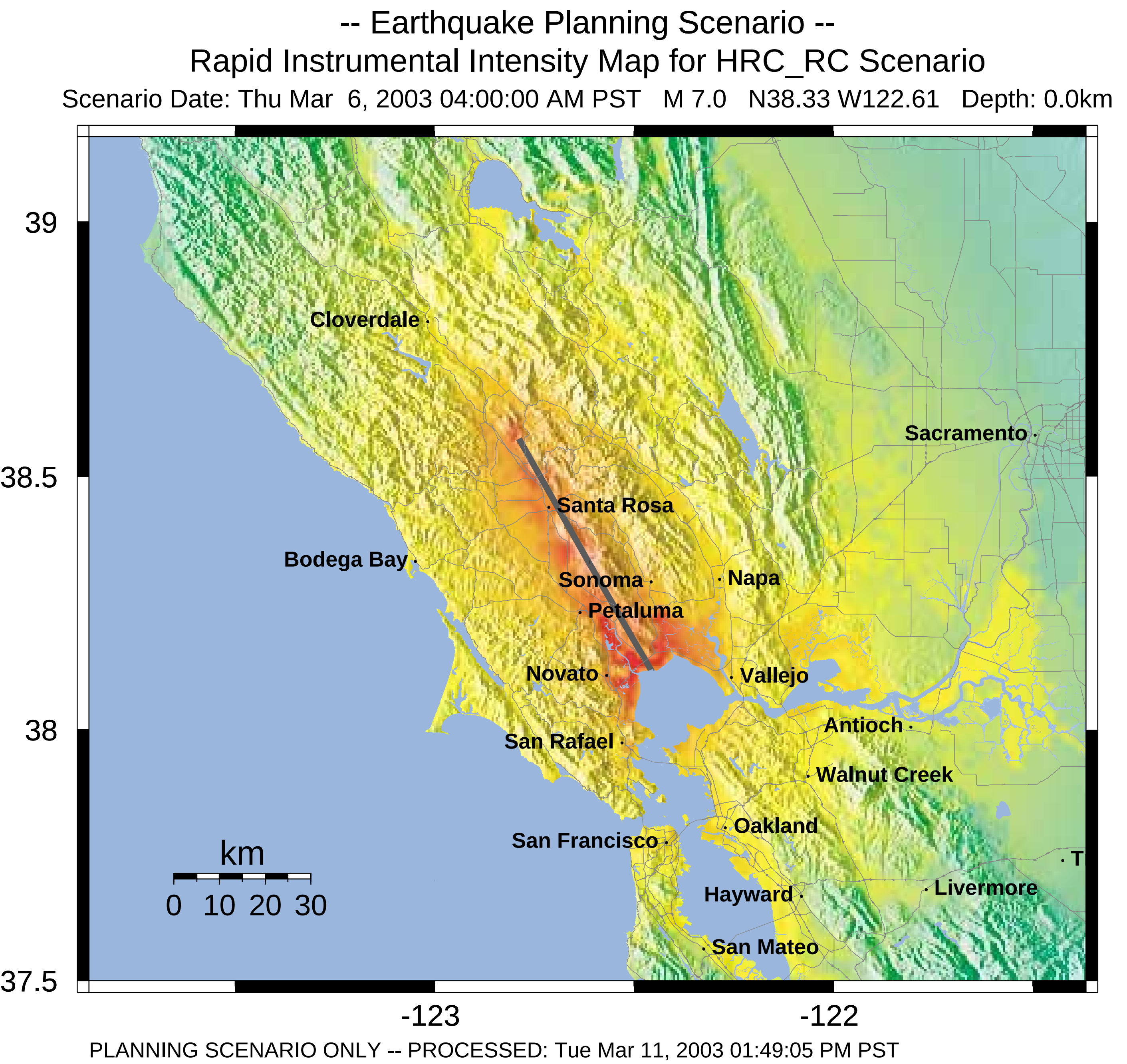
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1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

Figure 7.1d Actual ShakeMap for the 1989 **M** 6.9 Loma Prieta event.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Etreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
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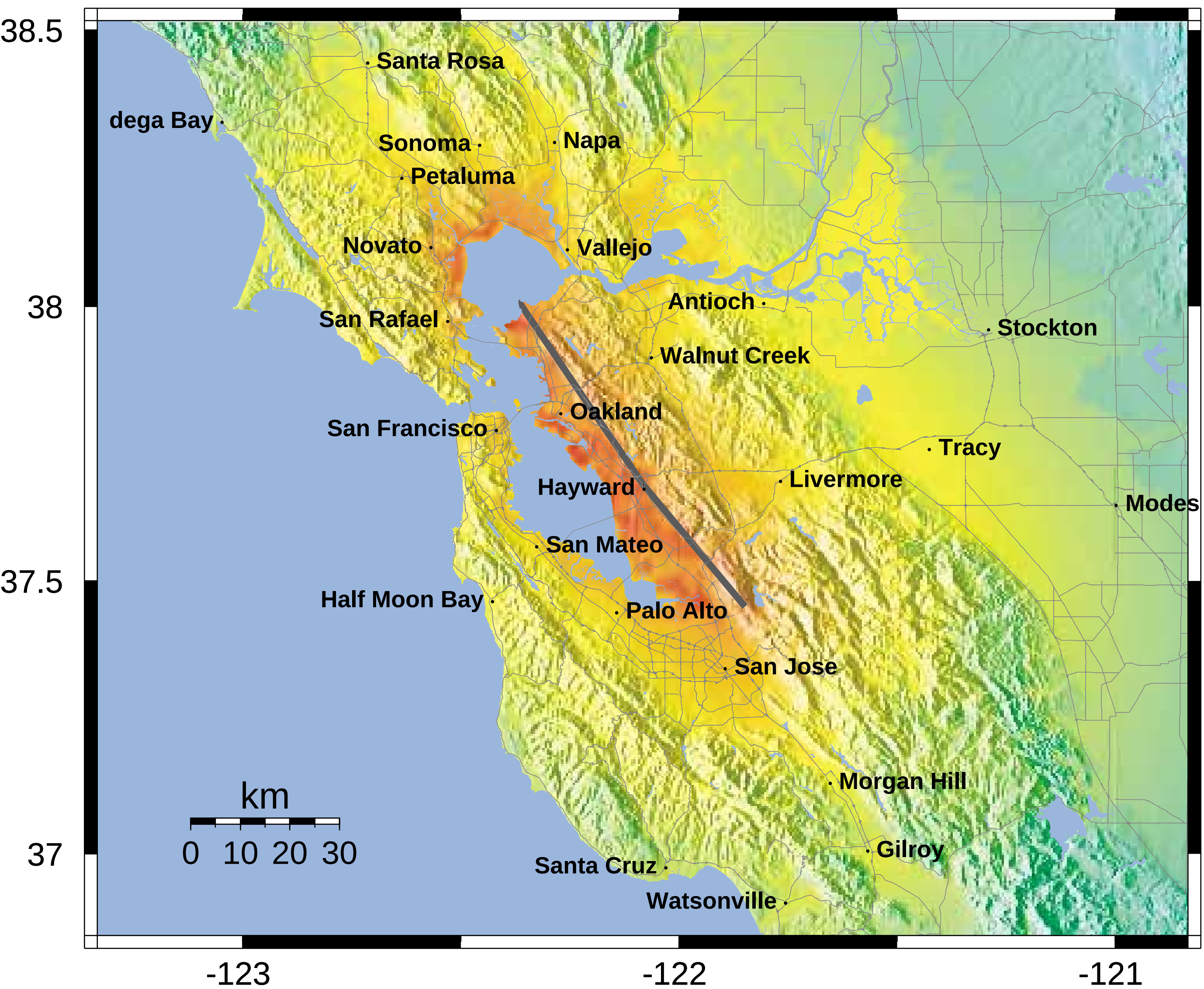
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	***16-31***	***31-60***	***60-116***	***>116***
INSTRUMENTAL INTENSITY	**I**	**II-III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X+**

Figure 7.2a Scenario ShakeMap for rupture of the Rodgers Creek segment in a M 6.98 (P=0.15) event.

-- Earthquake Planning Scenario --

Rapid Instrumental Intensity Map for HRC_HS+HN Scenario

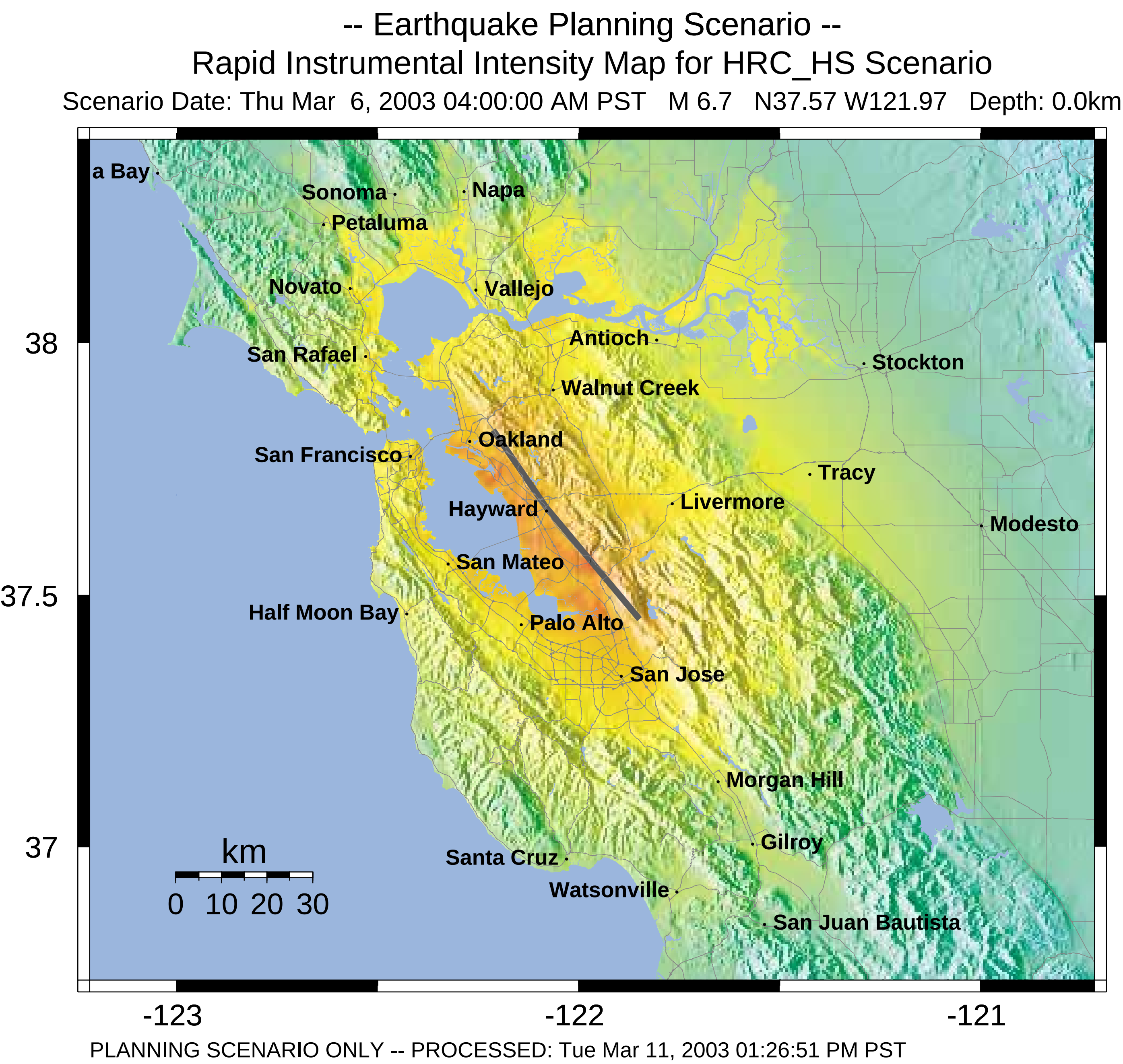
Scenario Date: Mon Mar 3, 2003 04:00:00 AM PST M 6.9 N37.68 W122.08 Depth: 0.0km



PLANNING SCENARIO ONLY -- PROCESSED: Tue Mar 11, 2003 01:41:34 PM PST

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 7.2b Scenario ShakeMap for rupture of the entire Hayward fault in a M 6.91 (P=0.09) event.



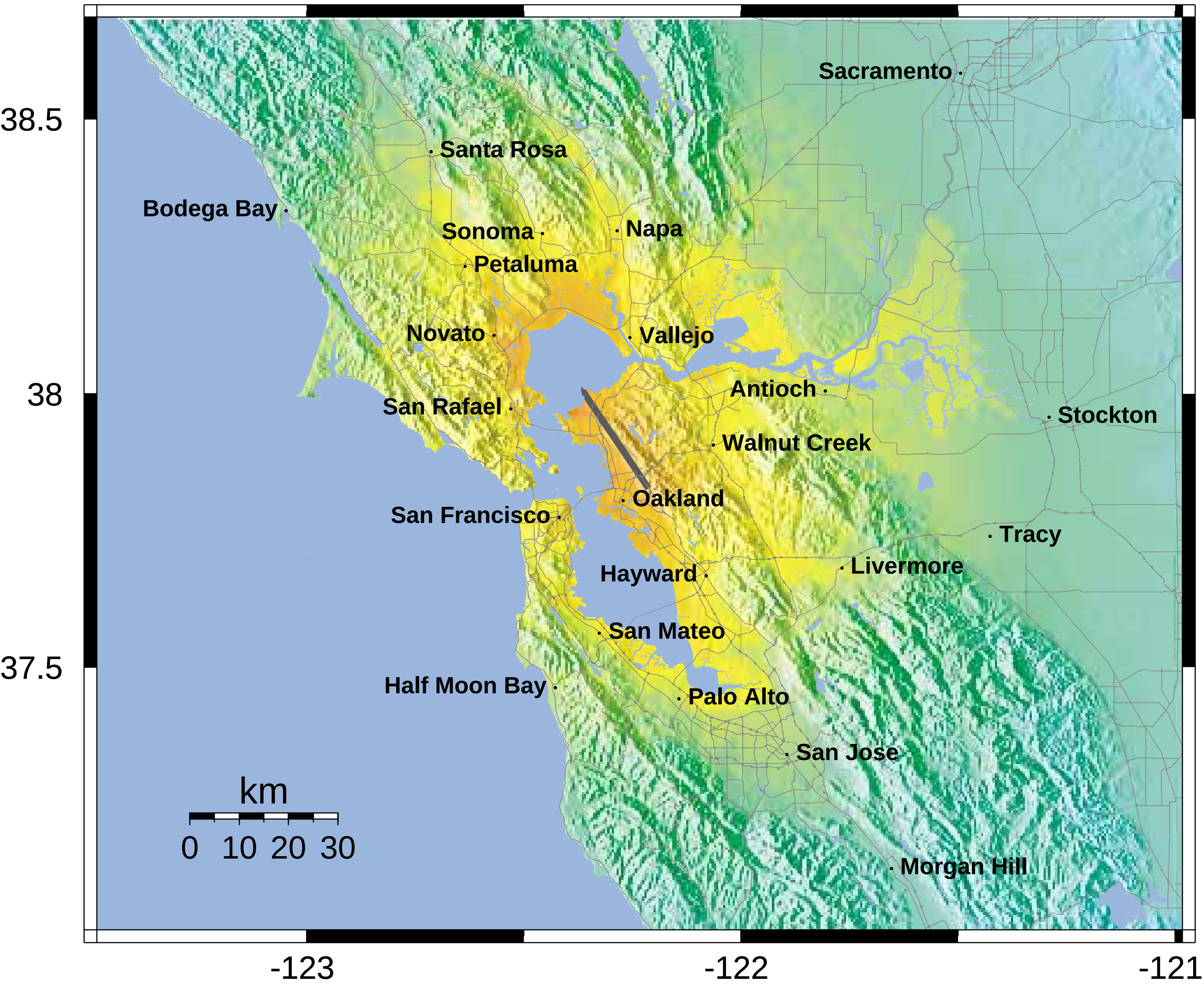
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	***<.17***	***.17-1.4***	***1.4-3.9***	***3.9-9.2***	***9.2-18***	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	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 7.2c Scenario ShakeMap for rupture of the Southern Hayward segment in a M 6.67 event, believed to be a repeat of the 1867 earthquake.

-- Earthquake Planning Scenario --

Rapid Instrumental Intensity Map for HRC_HN Scenario

Scenario Date: Thu Mar 6, 2003 04:00:00 AM PST M 6.5 N37.86 W122.24 Depth: 0.0km



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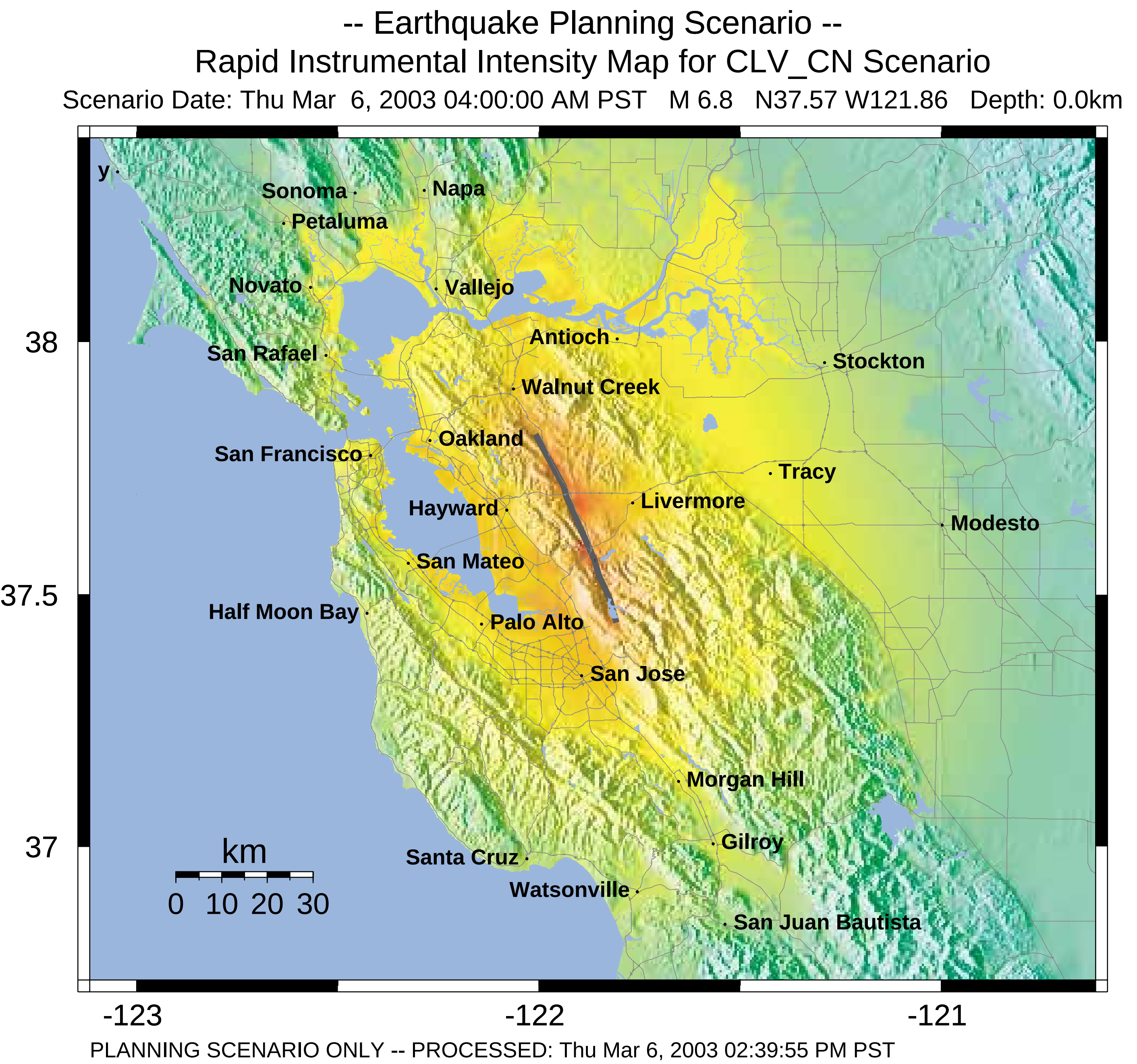
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	***<.17***	***.17-1.4***	***1.4-3.9***	***3.9-9.2***	***9.2-18***	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	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 7.2d Scenario ShakeMap for rupture of the Northern Hayward segment in a M 6.49 event (P=0.12).



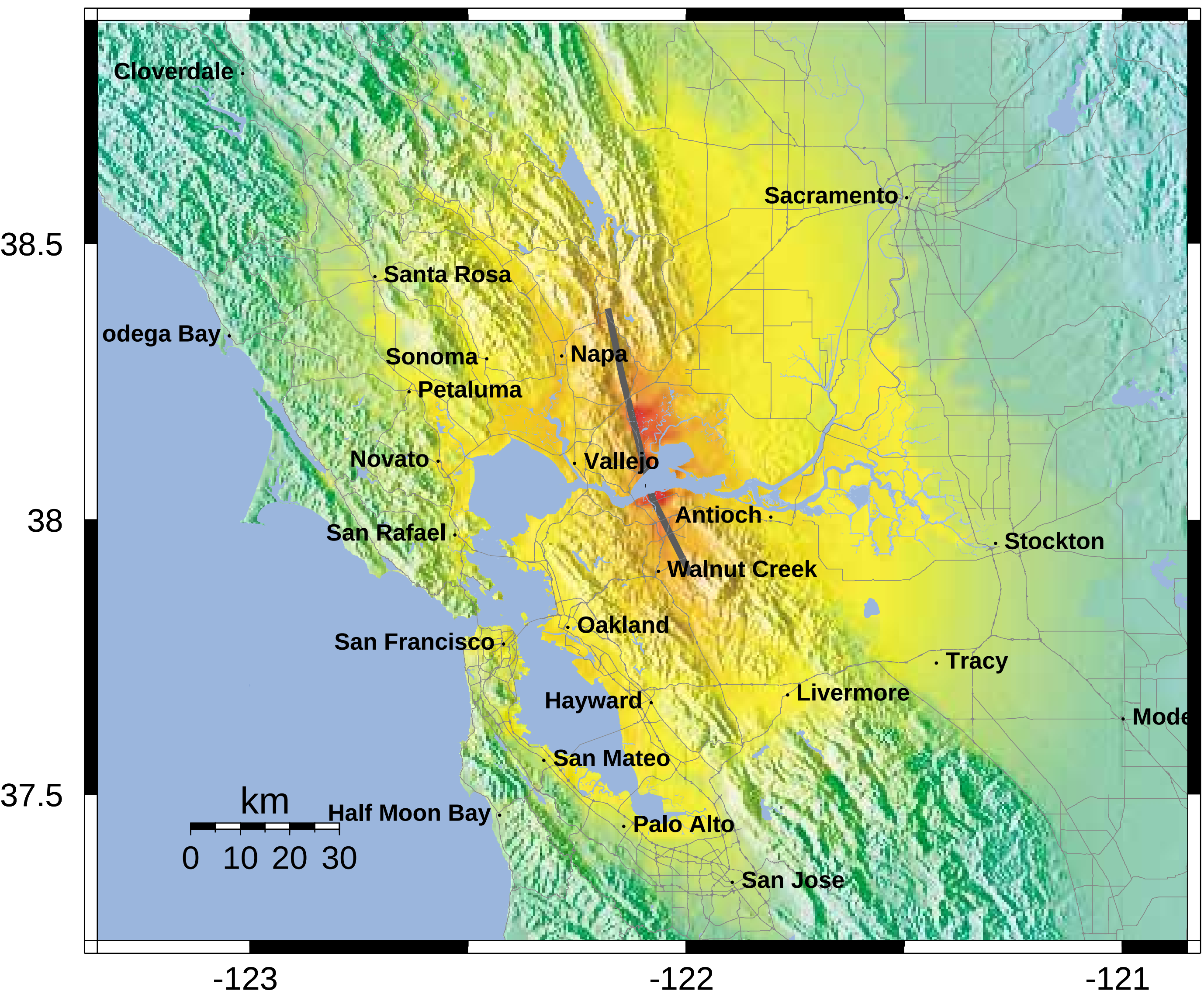
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1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

Figure 7.3a Scenario ShakeMap for rupture of the Northern Calaveras segment in a M 6.78 event (P=0.12).

-- Earthquake Planning Scenario --

Rapid Instrumental Intensity Map for CGV_CON+GVS+GVN Scenario

Scenario Date: Thu Mar 6, 2003 04:00:00 AM PST M 6.7 N38.06 W122.09 Depth: 0.0km



PLANNING SCENARIO ONLY -- PROCESSED: Tue Mar 11, 2003 01:19:26 PM PST

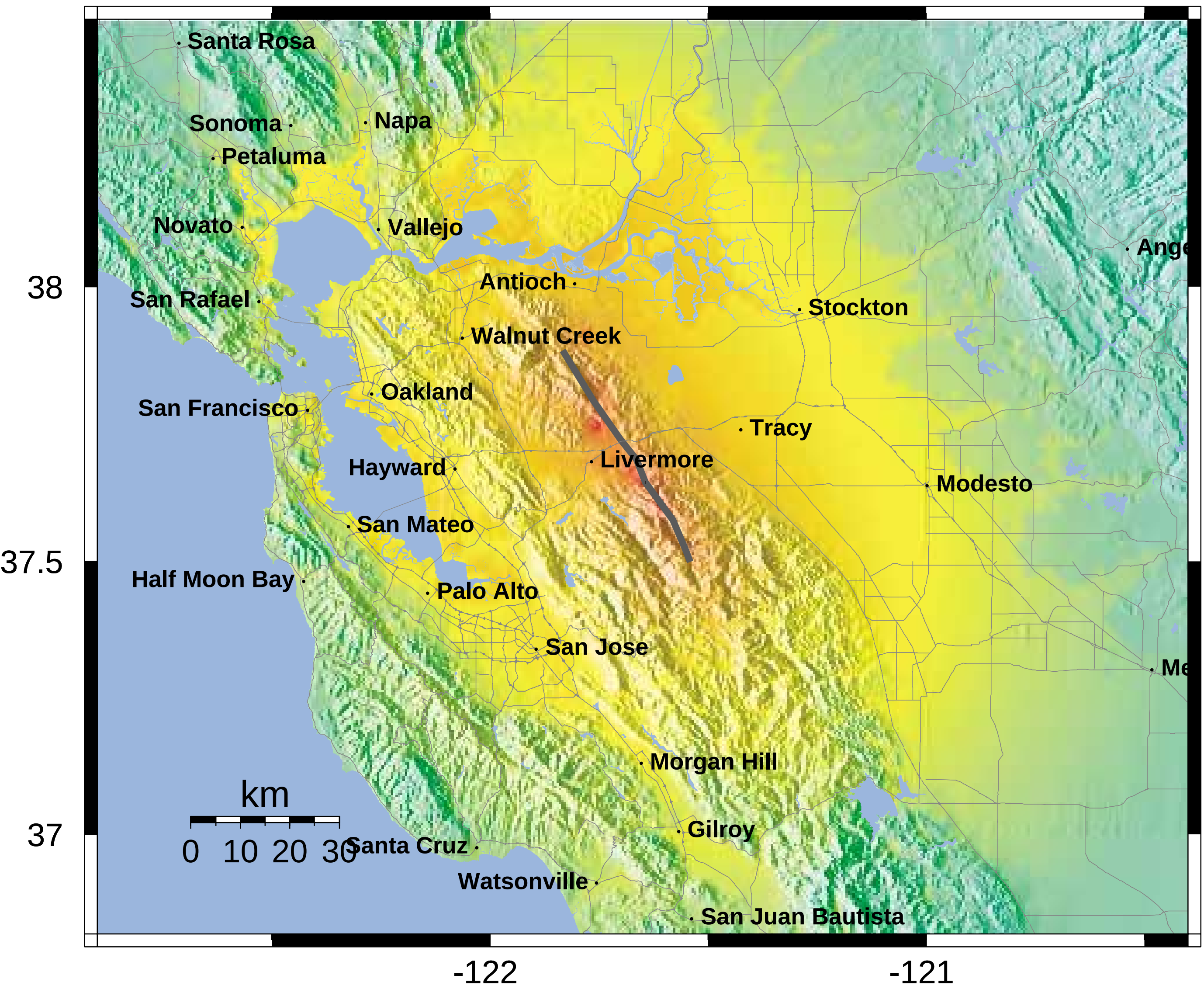
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Etreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1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

Figure 7.3b Scenario ShakeMap for rupture of the entire Concord - Green Valley in a M 6.71 (P=0.06) event.

-- Earthquake Planning Scenario --

Rapid Instrumental Intensity Map for GNV_GS+GN Scenario

Scenario Date: Thu Mar 6, 2003 04:00:00 AM PST M 6.9 N37.64 W121.64 Depth: 0.0km



PLANNING SCENARIO ONLY -- PROCESSED: Wed Mar 12, 2003 09:08:37 AM PST

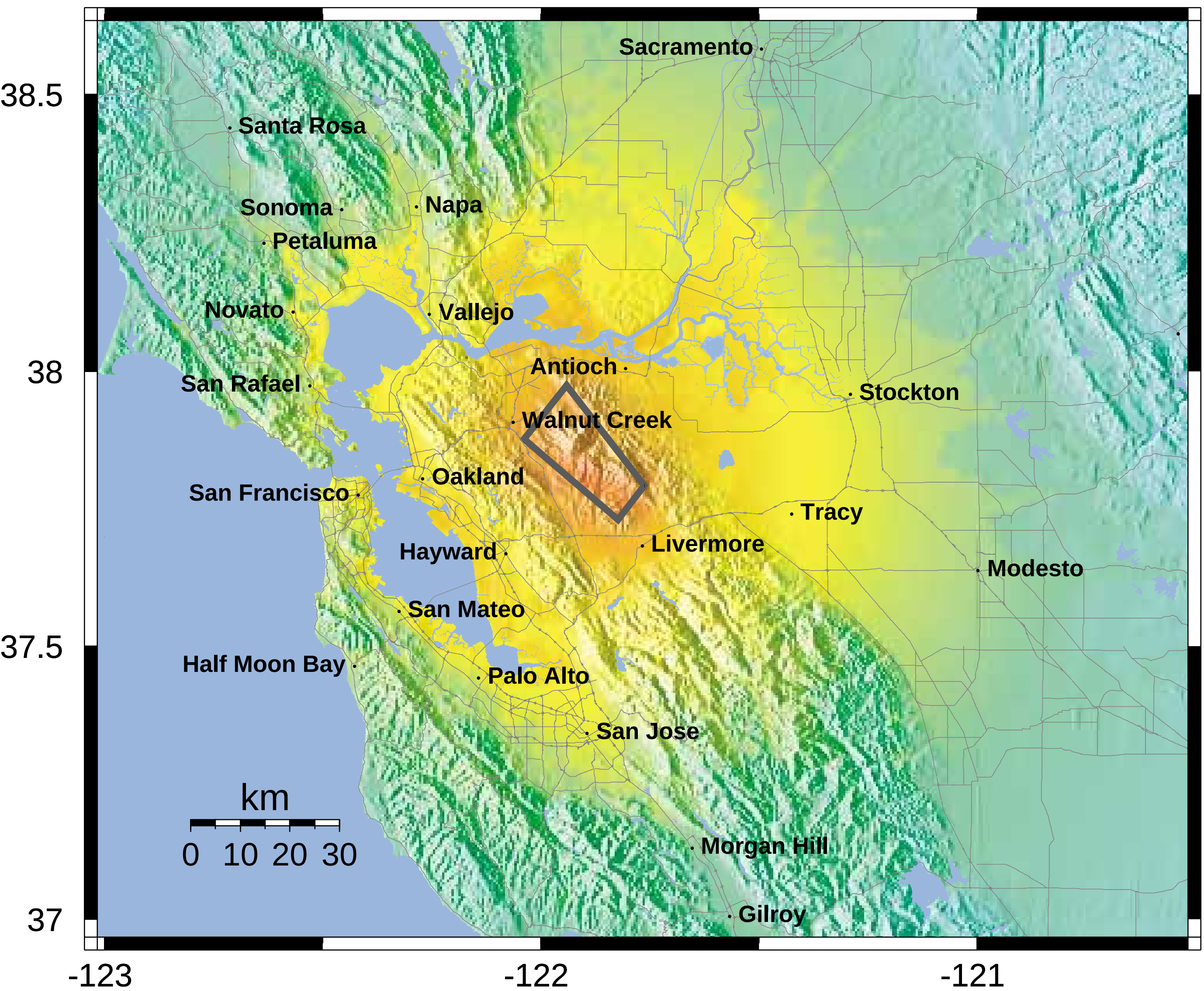
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Etreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1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

Figure 7.3c Scenario ShakeMap for rupture of the entire Greenville in a M 6.9 event (P=0.02).

-- Earthquake Planning Scenario --

Rapid Instrumental Intensity Map for MTD_MTD Scenario

Scenario Date: Thu Mar 6, 2003 04:00:00 AM PST M 6.7 N37.79 W121.76 Depth: 0.0km



PLANNING SCENARIO ONLY -- PROCESSED: Fri Mar 7, 2003 01:33:52 PM PST

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	ery strong	Seere	iolent	Etreme
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 7.3d Scenario ShakeMap for rupture of the Mt. Diablo blind thrust.

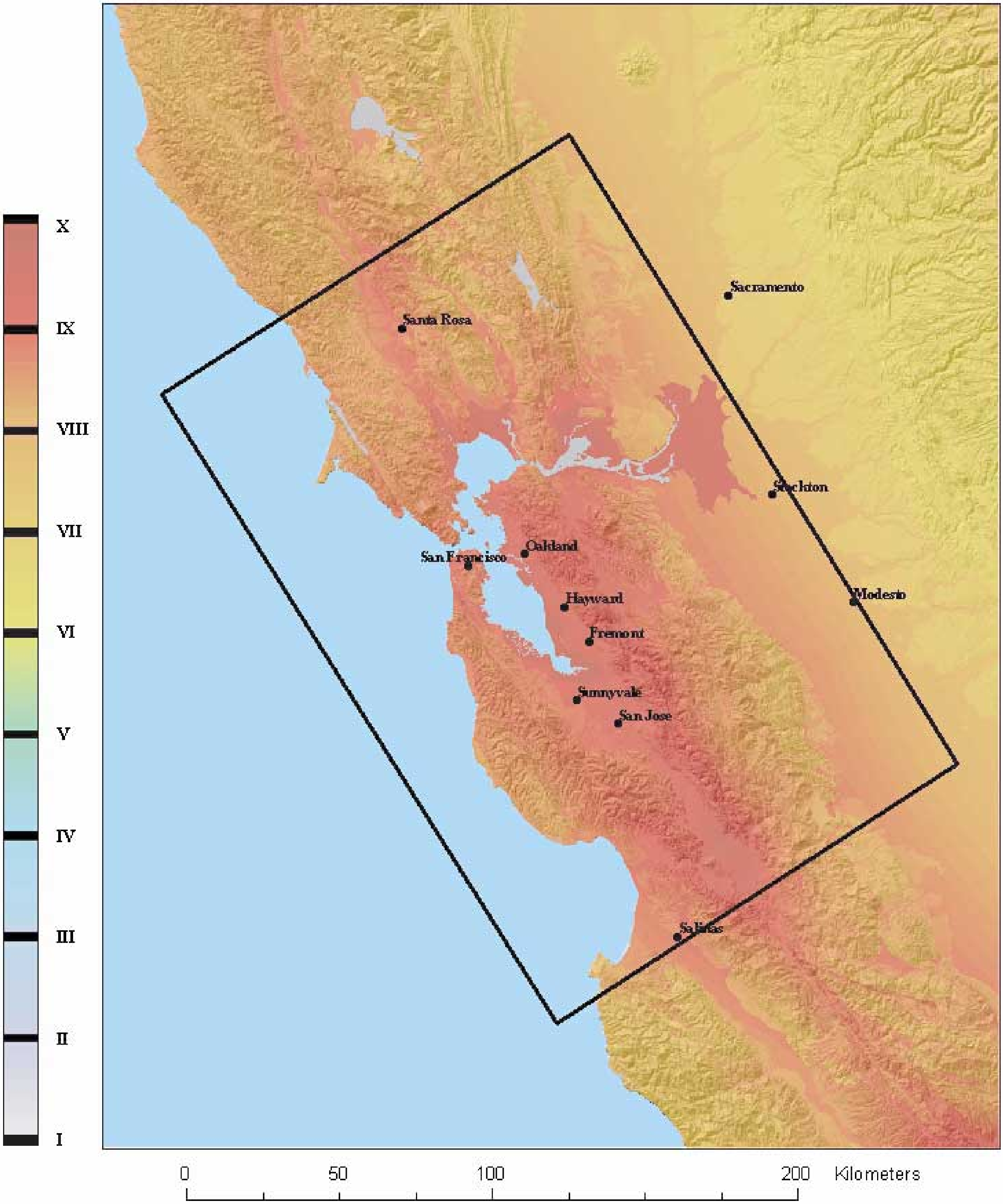


Figure 7.4a. Modified Mercalli intensity shaking levels for the SFBR with a 10% chance of exceedance in 30 years (time-independent).

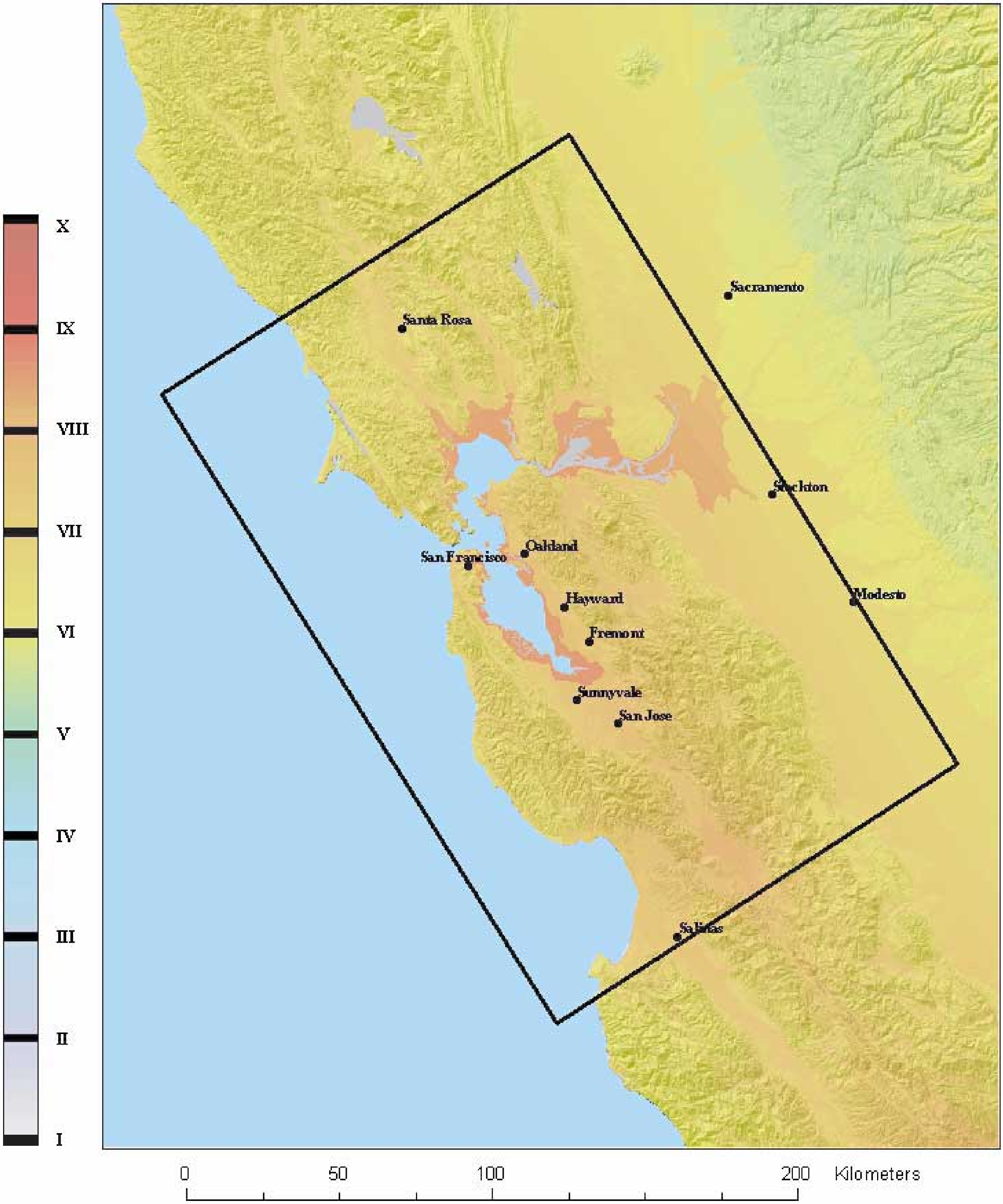


Figure 7.4b. Modified Mercalli intensity shaking levels for the SFBR with a 50% chance of exceedance in 30 years (time-independent).

Figure 7.5 Aerial view of the recently (2002) completed Interstate 680-Interstate 580 interchange at Dublin, CA. Note the location of surface trace of the northern Calaveras fault, which crosses I 580 here, and I 680 20 km to the south. All of the high-probability SFBR earthquake sources cross major transportation corridors.