San Francisco Bay Area Catastrophic Earthquake Incident Scenario

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ACRONYMS

Acronyms and Abbreviations	
ACS	Auxiliary Communications Service
AWSS	Auxiliary Water Supply System
BART	Bay Area Rapid Transit
Caltrans	California Department of Transportation
CALWAS	California Warning Alert System
CESRS	California Emergency Services Radio System
CLEMARS	California Law Enforcement Mutual Aid Radio System
CLERS	California Law Enforcement Radio System
CMARS	California Multi-Agency Radio System
CONOP	Catastrophic Incident Base Plan, Concept of Operations
CONPLAN	San Francisco, Bay Area Earthquake Concept Plan
DHS	Department of Homeland Security
DMAT	Disaster Medical Assistance Team
EBMUD	East Bay Municipal Utility District
EOC	Emergency Operations Center
FEMA	Federal Emergency Management Agency
FIREMARS	Fire Mutual Aid Radio System
HF	High frequency
LMR	Land Mobile Radio
Mw	Moment Magnitude
NASA	National Aeronautics and Space Administration
NAWAS	National Warning Alert System
NGO	Non-Governmental Organization
OASIS	Operational Area Satellite Information
OES	Office of Emergency Services
OHS	California Office of Homeland Security
OSHPD	California Office of Statewide Health Planning and Development
PG&E	Pacific Gas & Electric Company
REOC	Regional Emergency Operations Center
RIMS	Response Information Management System
SEMS	Standardized Emergency Management System
SKYMARS	Statewide Mobile Satellite Mutual Aid Radio Network
SOC	State Operations Center
URM	Unreinforced Masonry
USGS	U.S. Geological Survey

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1 Introduction

According to the U.S. Geological Survey (USGS), there is a 62 percent probability of an earthquake Mw 6.7 or larger in the San Francisco Bay Area within the next 30 years. Various jurisdictional and agency-specific incident planning efforts must be coordinated in order to achieve a fully integrated, optimized, and effective plan to respond to a catastrophic earthquake.

The Federal Emergency Management Agency (FEMA) has retained the services of URS Corporation to facilitate catastrophic earthquake planning efforts, to include the development of a Catastrophic Incident Base Plan, Concept of Operations (CONOP), and Bay Area Earthquake Concept Plan (CONPLAN). Such planning efforts are highly complex and include various information gathering, coordination, and plan development steps. Fundamental to this process is the development of a potential earthquake scenario that is firmly rooted in the historical data as well as the latest seismological research and forecasting.

URS staff reviewed numerous sources of information ranging from historical accounts of past earthquakes in the Bay Area, to peer-reviewed journals, to the latest available data to arrive about the potential catastrophic earthquake scenario described in this document. This catastrophic earthquake scenario is based on a repeat of the 1906 San Andreas Fault earthquake—one of the most documented earthquakes in the United States—and focuses on the potential consequences of such an event including impacts on major infrastructure, housing, and Bay Area residents. This scenario will serve as the basis for developing the CONPLAN.

Damage, casualties, and losses for this document were estimated using HAZUS-MH™ – a standardized methodology and loss estimation software developed by FEMA. HAZUS-MH™ can produce potential loss estimates for physical damage to buildings, schools, critical facilities, and infrastructure; economic loss; and such societal impacts as displaced households and estimates of shelter requirements. The impacts described in this scenario are based on a HAZUS-MH™ study completed by Charles A. Kircher, Hope A. Seligson, Jawhar Bouabid, and Guy C. Morrow as part of a series of papers presented at the 100th Anniversary Conference on the 1906 San Andreas Fault Earthquake. The report was based on the most accurate data available at the time and the results were reviewed by peers. Additional analysis and data were prepared by Kircher, et al. for Golden Guardian 2006. That research was funded by Department of Homeland Security (DHS) and the California Office of Homeland Security (OHS).

Descriptions of damage in this scenario include impacts expected from an earthquake on the Hayward Fault, the other most likely source of a catastrophic event in the Bay Area. An earthquake on either the Hayward fault or San Andreas fault will damage the same critical infrastructure and will displace a similar number of people from their homes. To stress the severity of damage expected in a catastrophic Bay Area earthquake, certain effects of the well-documented Hayward Fault Earthquake scenario were included in the San Andreas scenario.

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2 Scenario Overview

The month and the time of the scenario earthquake were changed from those associated with 1906 to maximize an earthquake's potential impact on structures and individuals in the Bay Area. Map 1, in **Appendix A,** depicts the length of the San Andreas fault and shows the intensity of shaking felt in the Bay Area and surrounding counties. The following assumptions were used in developing this scenario earthquake:

- The scenario earthquake occurs in January, at 2:00 p.m. PST on a Tuesday.
- In similar fashion to the 1906 event, a foreshock precedes the earthquake, followed about 20-25 seconds later by the main shock lasting 45 to 60 seconds.
- The earthquake's epicenter is located just outside the mouth of the San Francisco Bay and ruptures the San Andreas fault for approximately 300 miles from the San Juan Bautista area in the south to the Mendocino Triple Junction in the north.
- The scenario earthquake measures an estimated Moment Magnitude (Mw) 7.7 to 7.9 with an instrumental intensity of VIII (moderate damage) to IX (heavy damage) for about 60 miles inland along the fault line.
- Shaking is felt as far north as Oregon, south to Los Angeles, and east to central Nevada.

The earthquake generates severe ground shaking and damage in 19 central California counties, extending from Monterey to Humboldt, and into the San Joaquin Valley, with the greatest amount of damage affecting the urban areas of Oakland, San Francisco, San Jose, and Santa Rosa.

Table 1 briefly summarizes the impact of the scenario earthquake. Numbers are listed for the 10 counties of the Bay Area.

Table 1. Earthquake scenario

Resulting Event	Number/Quantity
Fire ignitions	569
Debris created	25 to 40 million tons
Households without potable water service (E+1 day)	1,828,000
Households without electric power (E+1 day)	789,000
Roads closed	1,300
Residential buildings damaged (extensive to complete damage)	114,747
Commercial buildings damaged (extensive to complete damage)	10,051
Functioning hospitals	4
Schools damaged (extensive to complete damage)	55
Individuals with injuries	12,254
Individuals trapped and requiring rescue	1,718
Fatalities	3,322
Displaced households (people, assuming 2.7 per household)	650,859
People needing temporary shelter	125,529

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3 Primary Hazards

3.1 Ground Failure

The margin of the San Francisco Bay is characterized by extensive areas of thick, soft soil overlain in places by artificial fill and surrounded by hills underlain in many areas by weak rocks that are susceptible to slope failure or landslides. Secondary ground failures, notably differential settlements and shifting of the land surface due to liquefaction, will be common following the earthquake, particularly on filled ground around the Bay margins. These movements will damage various major infrastructures and lifeline facilities, notably highways, railroads, airport runways, port facilities, and utility pipelines.

Fault displacements resulting from the scenario earthquake can range from less than a few millimeters to several meters. The most dangerous displacements will occur in the highly populated areas of San Mateo County.

3.2 Seismically Induced Landslides

Hundreds to thousands of disrupted material landslides, primarily in the foothills of the East Bay and on the Marin and San Francisco Peninsulas, will follow the earthquake. Landslides along the coastal bluffs in the Daly City area will undermine houses built on the bluffs and may cause fatalities in the beach areas down below. Several hundred deep-seated landslides are also likely along the East Bay Hills, leading to extensive damage of thousands of single family homes. In Northern California, January is the month with the heaviest rainfall; hillside soils that absorbed considerable moisture in the winter rain season will be most susceptible to landslides triggered by ground motion.

Hillsides in Alameda, San Mateo, Santa Cruz, San Francisco, Marin, and Santa Clara Counties are vulnerable to this hazard. Map 2, in **Appendix A,** shows areas where landslides are likely. The eastern slope of the Santa Cruz mountains is particularly susceptible to landslide. The area includes the community of Los Gatos and Highway 17, a main access route to Santa Cruz County.

3.3 Liquefaction

Areas with the greatest susceptibility to liquefaction are generally underlain by soft soils, mud (along the Bay margin), and artificial fill. The extensive urban development of lowlands and landfill around San Francisco Bay will be especially hard hit, and liquefaction in many of these areas will intensify the damage to structures erected on them. Neighborhoods built on landfill such as the Marina District, the Mission, and South of Market areas in San Francisco, as well as Alameda and Treasure Island in the Bay will experience significant liquefaction-related damage.

The southern end of Alameda County and Santa Clara Valley areas of high population and a considerable number of industrial facilities are vulnerable to liquefaction. Map 3 depicts areas that will be most susceptible to liquefaction and the major transportation routes that cross them.

3.4 Aftershocks

Numerous aftershocks are expected to occur in the Bay Area and in surrounding counties following the scenario earthquake. In 1906, the largest aftershock, Mw 6.7, occurred about 60 miles west of Eureka. Other significant aftershocks included events near San Juan Bautista and

near Shelter Cove. **Table 2** shows the probability of aftershocks during the week following the scenario earthquake. Aftershocks will hamper emergency response and infrastructure restoration efforts. In addition, aftershocks may further damage buildings and infrastructure systems weakened in the original event and prevent thousands of residents from reoccupying their homes and businesses.

Table 2. Probability of aftershocks during the week following the scenario earthquake

Aftershock Magnitude	Probability of Occurrence (%)	Potential Number of Aftershocks (Range)
>5	100	46 (33-59)
>6	100	6 (1-10)
>7	50	1 (0-2)

Source: USGS 2006

The scenario earthquake may also trigger smaller events in southern California (including separate events in or near the Imperial Valley, the Pomona Valley, and Santa Monica Bay), in western Nevada, in southern central Oregon, and in western Arizona within a few days of the main shock.

3.5 Fault Rupture

Fault rupture describes the phenomena where ground on opposite sides of the earthquake fault is displaced in opposite directions, either vertically or horizontally. Displacement can be a few inches or several feet. Structures crossing a fault rupture suffer collapse or may be rendered unusable due to sudden misalignment. Damage from fault rupture will occur in areas where the San Andreas Fault is closely surrounded by structures and other development. Highway 280, from San Jose, north to Daly City, follows the main section of the fault. Ruptures will damage the elevated sections of Highway 280 in San Mateo County, along Crystal Springs Reservoir, as well as the Highway 92 interchange leading to Half Moon Bay and the Highway 17 junction in Santa Clara County. Communities that depend on those highways for access will be isolated. Sections of Highway 1 in Marin and Sonoma Counties are also vulnerable to fault ruptures.

4 Secondary Hazards

4.1 Fires

The scenario earthquake will likely be followed by destructive fires due to gas line breaks, electrical transmission disruptions, limited availability of water for firefighting, and restricted firefighter access. These factors can lead to fires spreading and causing extensive additional damage and burning entire neighborhoods. More than 500 fire ignitions are expected following the earthquake. **Table 3** shows the estimated number of fires expected in Bay Area counties following an Mw 7.9 San Andreas fault earthquake.

Table 3. Anticipated number of fire ignitions, by county

County	Number of Ignitions
Alameda	90
Contra Costa	38
Marin	29
Napa	4
San Francisco	90
San Mateo	93
Santa Clara	155
Santa Cruz	30
Solano	8
Sonoma	32
Total	**569**

Source: Kircher et al. 2006

The greatest challenge is in San Francisco because of intense shaking, building density, large number of wooden structures, and limited access to mutual aid resources. In addition to the regular municipal water supply used for firefighting in San Francisco, the Fire Department maintains a separate high-pressure nonpotable Auxiliary Water Supply System (AWSS). This system is capable of drafting seawater if the reservoirs cannot be refilled from the municipal water system. However, AWSS is seldom used, very complex, and too dangerous for use by outside firefighters responding under mutual aid. The system did not perform well in the past and does not serve the southwestern portion of the City, a heavily residential area of loosely packed homes, as well as the location of the City College of San Francisco. In addition, San Francisco's fire hydrants have nonstandard hose connections, requiring outside firefighters to use a special adapter. The other 47 counties in California comply with SEMS and use compatible hose fittings. Other Bay Area counties will have better access to mutual aid resources than San Francisco.

The main water lines which supply water from Hetch Hetchy system to a large number of customers in the Bay Area cross major earthquake faults. Following an earthquake, critical pipelines, tunnels, bypasses, pumping stations, supply lines, and feeder mains will fail, making water for firefighting scarce.

4.2 Hazardous Materials

Local hazardous materials incidents will result from ground shaking. Building structural failures, dislodging of asbestos or encapsulated asbestos, laboratory spills, transportation accidents, pipeline breaks, storage tank failures, and industrial equipment problems will be the major sources of hazardous materials accidents following an earthquake. An extensive network of fuel pipelines serves the Bay Area; an earthquake of this magnitude will create hundreds of system failures likely to result in major hazardous materials releases. In addition, a catastrophic incident will lead to a significant number of animal deaths requiring special animal carcass disposal procedures.

4.3 Debris

Building and structural damage caused by a San Andreas Fault earthquake will generate massive amounts of debris that will overwhelm the daily waste management systems in the Bay Area. Various sources estimate that as much as 20 to 40 million tons of debris, consisting of building materials, personal property, and sediment will be generated by the earthquake. “Traditional” household waste volumes will also increase due to large amounts of spoiled food resulting from power outages and other debris from residential cleaning.

Equipment beyond the current capacity of the region’s private waste management companies will be needed to clear debris. Transportation routes will need to be cleared and restored to move debris out of damaged areas. Before heading to landfill or recycling areas, debris must be sorted at separate facilities. A key challenge will be the disposal of large amounts of contaminated, electronic, and hazardous materials waste. Landfill space is scattered throughout the region. Use of that space must be allocated to reduce the impact to host counties. **Table 4** shows a conservative estimate of the amount of debris to be generated by the scenario event.

Table 4. Estimated quantities of debris, by county

County	Brick, Wood, Other*	Concrete, Steel*	Total*
Alameda	359	1,186	1,545
Contra Costa	47	78	125
Marin	249	627	876
Napa	6	9	15
San Francisco	1,389	4,301	5,690
San Mateo	1,478	3,802	5,280
Santa Clara	1,409	3,498	4,907
Santa Cruz	337	670	1,007
Solano	7	8	15
Sonoma	143	267	410
Total	**5,424**	**14,446**	**19,870**

*In thousands of tons
Source: Kircher et al. 2006

5 Lifelines

The term "lifelines," as used in this scenario, includes systems for water, wastewater, gas, and electric utilities. Because of their network-like character, most systems for water and power generation and distribution are resistant to total failure, despite potentially severe local damage. Damaged components of the systems will cause serious local outages lasting from over a few weeks to months. In the first few days after the earthquake, there will be a greatly increased need for the utilities when lifesaving activities are paramount.

5.1 Water

Map 4 shows the major water transmission lines throughout the Bay Area, as well the transfer points where the various water authorities share water sources. One of the most vulnerable water transfer points is in Hayward, where East Bay Municipal Utilities District (EBMUD) receives water from the Hetch Hetchy system of San Francisco Public Utilities Commission. The transfer point is located in an area that will experience intense ground shaking and is vulnerable to liquefaction. The intertie between Hetch Hetchy and the Santa Clara Valley Water District, in Milpitas, is vulnerable for the same reason. Failure of these interties will interrupt water service to large portions of Alameda and Santa Clara Counties. The water utilities cannot be expected to support damaged water supplies in neighboring counties.

The Hetch Hetchy water system delivers water to 2.4 million people in San Francisco, as well as San Mateo, Santa Clara, and Alameda Counties. Business and institutional users account for more than one-quarter of Hetch Hetchy customers. Throughout the Bay Area, the system's largest individual customers include the University of California San Francisco Medical Center, Stanford University, Stanford Hospital, National Aeronautics and Space Administration (NASA) Ames Research Center, and San Francisco International Airport. Although Hetch Hetchy crosses at least five active faults, its key sections have largely not been seismically retrofitted and braced. Most facilities have little or no redundancy built into them so that in the event of a system failure, a tunnel, portal, pipeline, or siphon cannot be bypassed and the failure quickly isolated and repaired without interrupting service.

It is assumed that a San Andreas Fault earthquake would cause most critical pipelines, tunnels, bypasses, supply lines, and feeder mains from Newark in the southeast of the Bay, and up the Peninsula into San Francisco, to fail. Depending on the extent of damage, Peninsula, South Bay, and San Francisco customers will be fully or partially cut off from the Hetch Hetchy system. Pressure in the gravity-driven system will drop to that of the furthest upstream failure (about 300 feet), making it difficult to move supplies stored in the pipes beyond the break. System-wide leaks, particularly along pipelines in the liquefiable margins of the Bay, will exacerbate the low pressure problem and diminish supplies. In the first 24 hours, the average daily demand in directly impacted areas is expected to double.

Most of the locally stored water supplies from tanks and small reservoirs will be used up within 48 to 72 hours for fire, medical, and other critical services. At best, the time required for temporary repairs of various Hetch Hetchy facilities to restore partial service ranges is as follows:

- Pump stations – 2 days
- Water treatment plants – 3 to 6 days
- Storage tanks – 25 to 30 days

- Tunnels – 30 to 60 days
- Pipelines – up to 40 days

Power outages, employee absenteeism, access impediments, and other cumulative impacts of the scenario earthquake will lead to longer restoration times.

EBMUD serves Alameda County and has strengthened its water treatment plants and major aqueducts. Of particular concern, however, are underground pipes which distribute water from larger aqueducts to customers. The buried pipes will be particularly vulnerable to breakage in areas of major liquefaction such as in Richmond and Oakland along the Bay. Landslides threaten pipelines carrying water from the Claremont Tunnel aqueduct and the City of Berkeley, as well as aqueducts bringing water from the Upper San Leandro water treatment plant to East Oakland and San Leandro.

A similar but much smaller distribution system serves the North Bay counties of Marin and Sonoma. This system moves water from the Eel River to the Russian River to pumping stations north of Santa Rosa and from there to most of Sonoma County and into Marin. Transmission pipes in the liquefiable areas along Highway 101 are vulnerable to breakage.

Water systems in the Bay Area also depend on reservoirs to store water for gravity-driven transmission. Some reservoirs are subject to dam failure in a San Andreas Fault earthquake. More than 250 dams in the 10 counties in the Bay Area are within the jurisdiction of the State of California. A vast majority of these dams are earthen. It is likely that the scenario earthquake will cause at least one major dam to fail. **Table 5** lists major dams and the cities in the Bay Area that are at risk of inundation should those dams fail due to ground motions.

Table 5. Bay Area dams and inundation areas

Dam System	Vulnerable Areas
Calaveras/Del Valle (earthen)	South Hayward, Union City, Newark
Crystal Springs (gravel)	Southern San Mateo County
Lexington	San Jose
Lagunita (earthen)	Palo Alto
Upper San Leandro (earthen)	East Oakland and San Leandro
San Pablo/Briones (earthen)	Richmond
Temescal Lake (earthen)	Emeryville

5.1.1 Potable Water

Reservoirs along the San Andreas Fault, which supply San Francisco, San Mateo, and Santa Clara Counties, contain enough stored untreated water to meet demand in the event of an earthquake and subsequent system failure for 30 to 60 days. However, a number of technical difficulties—loss of pressure, pumping, and valve capacity, among others—will impede the delivery of water from these reservoirs to customers. As a result, while a limited amount of water may be available from major reservoirs, most of the water in the suburbs and parts of San Francisco will have to come from local storage and groundwater. Reservoir water will need to be disinfected and treated, but the water treatment plants in the area are likely not to be operational. At average demand, San Francisco's reservoirs and tanks contain 4 to 5 days' supply of treated water. Potable water rationing will be necessary to lower the rate of water depletion. **Table 6** shows the number of households expected to be impacted by potable water system failures in the days following the scenario event.

5.1.2 Wastewater

Interceptors (sewer pipes, as large as 10 feet in diameter, which form the backbone of the wastewater transport system) run along the margins of the Bay in areas of liquefiable soils. The interceptors will suffer major damage following an earthquake. Loss of electrical power will render pumping plants unusable, causing sewage backups and spills through the street access holes, posing potential public health concerns. Open trenches may be necessary to carry sewage for short distances. Sewer pipeline breaks may cause "sinkholes" that undermine roads and buildings.

A number of wastewater and sewage treatment facilities in the Bay Area are located in areas with liquefiable soils and will suffer significant structural damage in the earthquake. Limited access due to road closures and debris, lack of power, and reduced workforce will hamper restoration of these facilities. Moreover, facilities which experience minor or no structural damage may not be functional due to lack of power, limited accessibility, and reduced workforce. Partially treated raw sewage may need to be discharged into the Bay for up to 1 month.

Table 6. Expected potable water systems performance, by county

County	Number of Households Without Service		
	E+1 Day	E+7 Days	E+30 Days
Alameda	430,000	301,000	60,000
Contra Costa	57,000	40,000	8,000
Marin	89,000	62,000	12,000
Napa	0	0	0
San Francisco	323,000	226,000	45,000
San Mateo	249,000	174,000	35,000
Santa Clara	526,000	368,000	74,000
Santa Cruz	69,000	48,000	10,000
Solano	11,000	8,000	2,000
Sonoma	74,000	52,000	10,000
Total	**1,828,000**	**1,279,000**	**256,000**

Source: Kircher et al. 2006

5.2 Electrical Power

The majority of electrical power in the region is transmitted by Pacific Gas & Electric Company (PG&E). Smaller municipal agencies such as Silicon Valley Power and Palo Alto Electric Utility supply electricity to individual cities (Santa Clara and Palo Alto, respectively). Most of PG&E's electrical substations in the Bay Area were built in the 1900s and 1920s. Although mitigation efforts have been made, significant damage to these buildings is expected. Underground cables that cross liquefiable and weak soils are vulnerable. Immediately after the earthquake, PG&E is likely to initiate power shedding to balance the grid, followed by a progressive blackout of the Bay Area to prevent cascading power failure.

Damaged sections in the transmission and distribution system will need to be repaired or bypassed. Before electrical circuits are energized, inspections for gas leaks in impacted areas will be necessary. Under the normal circumstances, it takes 2 to 3 days to restore a transmission system. Impeded accessibility as well as workforce shortages will, at the minimum, double restoration times.

All portions of the Bay Area will experience some loss of electrical power following an earthquake. As much as a third of the customers in the area will be without power for at least 24 hours. Damage to other lifelines such as communications and highways will complicate power restoration efforts. Realistically, power will not be restored to most areas for several days or even weeks. Map 4 shows the main electrical transmission lines that serve the Bay Area. **Table 7** shows the number of households expected to be impacted by electrical system failures in the days following the scenario event.

Table 7. Expected electric power systems performance, by county

County	Number of Households Without Service		
	E+1 Day	E+7 Days	E+30 Days
Alameda	50,000	0	0
Contra Costa	4,000	0	0
Marin	34,000	9,000	2,000
Napa	0	0	0
San Francisco	222,000	68,000	17,000
San Mateo	199,000	77,000	22,000
Santa Clara	221,000	59,000	15,000
Santa Cruz	54,000	15,000	3,000
Solano	0	0	0
Sonoma	5,000	1,000	0
Total	**789,000**	**229,000**	**59,000**

Source: Kircher et al. 2006

5.3 Communications

The buildings and equipment of telecommunications systems owned by the private sector have been strengthened since the 1989 Loma Prieta earthquake with special emphasis on redundancy and power backup. The regional communication infrastructure in the Bay Area is highly diverse and incorporates the following statewide communication systems:

- Operational Area Satellite Information System (OASIS)
- California Multi-Agency Radio System (CMARS)
- California Emergency Services Radio System (CESRS, Statewide Repeater System)
- Operational Area Offices of Emergency Services (OES) Fire Radio System (OES Fire)
- California Law Enforcement Radio System (CLERS)
- White Fire
- OES High Frequency (HF)
- California Department of Forestry and Fire Protection (CAL FIRE Statewide LMR Repeater System)
- California Highway Patrol (CHP Statewide LMR Repeater System)
- Department of Fish and Game (Regional LMR Repeater Systems)
- Department of Parks and Recreation (Conventional Digital LMR Repeater System)
- Department of Transportation (CALTRANS Trunked LMR System)
- Bay Area Rapid Transit (BART Regional Trunked LMR Simulcast System)
- Response Information Management System (RIMS, Internet-based)
- Auxiliary Communications System (ACS)
- National Warning Alert System/California Warning Alert System (NAWAS/CALWAS)

- California Law Enforcement Mutual Aid Radio System (CLEMARS)
- Fire Mutual Aid Radio System (FIREMARS)
- SKYMARS (Statewide Mobile Satellite Mutual Aid Radio Network)

The diversity and redundancy of the systems in the Bay Area is likely to enable communication following the catastrophic earthquake. However, the physical damage to communication components as well as user overload will restrict communication capabilities in the region. In addition, diversity itself may limit interoperability.

Under this scenario, satellite and microwave communications systems will be operational in the Bay Area after the earthquake. However, despite the State and local jurisdictions' microwave tower facilities collocation, there are currently no microwave system tie-ins between the State's microwave system in the Bay Area and local jurisdictions' microwave systems. While a number of critical microwave facilities will be functional after the scenario earthquake, they will require electrical power sources. Currently, these facilities have an 8-hour battery bank or onsite power generators with diesel or propane back-up power with up to 30 days fuel supply. Impeded access and fuel, vehicle, and staff shortages may compromise the ability of the Bay Area to replenish fuel supplies to the surviving microwave facilities.

An overload of post-earthquake calls in the region will make phoning difficult. Carriers will block the calls coming into the region to relieve circuit overloading. Outbound calls, as well as text messaging, are likely to be available. Customers located in areas subject to severe ground shaking and high probability of ground failure may lose land-based connections to the telephone system. Access for repairs in those areas will be a major problem. The cellular phone system relies on the integrity of antennas that are mostly located on building tops. Cell phone calls typically connect to the same landline systems that will be hampered by the expected overload of calls. The region's telecommunications companies will prioritize calls to allow emergency responders to communicate by phone.

State and OES plan for telephone outages in catastrophic disaster and use redundant communication systems, including radio, secure phone lines, satellite, and Internet to communicate between Emergency Operations Centers (EOCs) of various levels and to State agencies. The Fire and Law Enforcement Mutual Aid Systems use robust radio systems (OES Fire and CLERS, respectively) that link first responders, dispatchers, and EOCs at the local government, operational area, regional, and State levels.

The San Francisco Bay Area is an intensive user of advanced digital communications technologies. Most of these depend on high-speed Internet access. This access will also be severely disrupted in the region due to physical infrastructure failure as well as congestion. During the initial recovery period, efforts to increase telecommuting as a relief for overcrowded transportation systems may also suffer from this disruption and congestion.

5.4 Natural Gas and Liquid Fuels

PG&E is the provider of natural gas in the Bay Area. The main natural gas pipelines and facilities near major faults in the region were retrofitted and severe damage is not anticipated. However, the network of pipes beneath city streets is expected to suffer damage from ground failure. Hundreds of breaks in mains, valves, and service connections will occur. Broken gas mains could fuel street fires. Structural fires will occur as a result of broken service connections. Restoration of service could take as long as 2 months for customers because individual

connections will need to be inspected and appliances relighted. Most gas shutoffs are expected to be initiated by cautious customers. Map 5 shows how natural gas pipelines tend to follow the major highway systems from San Francisco, down to San Jose, and up along the shore of the East Bay. Emergency response and restoration of sections of highways vulnerable to ground shaking will be complicated by subsequent gas line failures in the same damaged areas. Trucks deliver most liquid fuel to retail stations, using the region's vulnerable highway systems. Damage to roads will delay transportation of fuel for distribution to the general public.

Six privately owned, major fuel refineries are located in the north of the Bay and large buried pipelines deliver liquid fuel to industrial customers. As Map 5 shows, the pipelines that supply fuel to the region's international airports are located in ground considered susceptible to strong shaking. Inspection of the systems and restoration of service may be prolonged and industrial customers may be without fuel for several weeks.

Refinery structures are expected to survive an earthquake. However, damage to storage tanks is anticipated. In past earthquakes, the footings of large storage tanks have failed, taking the tanks out of service until they are repaired and retrofitted. Major fuel storage tanks in the region are contained within berms or have provisions to mitigate spills, but fires caused by spills are a major concern of refineries. Private emergency systems to fight fires may be overwhelmed and fires involving hazardous materials will impact surrounding residential neighborhoods, requiring a substantial specialized response from governments. The refineries depend on the integrity of their port facilities and railroad lines. In Richmond, those transportation links are most susceptible to damage from intense ground shaking.

6 Transportation

Because the scenario earthquake will happen at 2:00 p.m. on a workday, hundreds of thousands of commuters in the Bay Area will be trapped in the places of their employment and will be unable to return home. The major transportation routes that traverse areas of severe liquefaction and shaking are depicted on Maps 3 and 6, respectively. Severity of damage may be relatively localized and not all transportation corridors will be equally impacted.

6.1 Roads

A repeat 1906 earthquake will cause approximately 1,300 road closures throughout the entire Bay region. More importantly, as many as 42 failures of key freeway sections are anticipated throughout the region. The majority of road closures will be located in Alameda, San Francisco, San Mateo, and Santa Clara Counties. Liquefaction will weaken the foundations of roads and elevated highway structures of Highway 880 in Alameda County. In San Francisco, building damage will be the most common cause of local road closures. Fault rupture will be the most common cause of road closures in San Mateo and Santa Clara Counties.

Fault rupture and accompanying landslides will close Highway 92 to Half Moon Bay and the west coast of San Mateo County, as well as Highway 17 across the Santa Cruz Mountains. Damage to these routes will limit access to rural communities along Highway 1. In San Mateo County, Highway 280 runs parallel to the fault source and will likely suffer severe damage at raised bridges due to collapsed foundations, and along cliffs susceptible to landslide. Highways 101 and 880 will suffer damage from fault rupture and/or liquefaction.

Particularly vulnerable sections of the region's highways exist in critical locations throughout the Bay Area. In Marin, the 580/101 interchange in San Rafael is raised over liquefiable soils. The Waldo Tunnel, the southern entry to Marin County from San Francisco, will likely close due to landslides triggered by ground shaking.

In the East Bay, the Caldecott Tunnel, the central link between Contra Costa and Alameda, carries Highway 24, as well as main electrical and gas, transmission lines beneath the roadway. Adjacent, separate tunnels are used for BART and water pipelines. The tunnels are vulnerable to closure due to landslide. If the utilities or mass transit below the roads are damaged, Highway 24 will be closed for months for reconstruction.

In Oakland, Highways 580, 880, 980, and 24, where they form the MacArthur Maze, a complex of elevated interchange structures, are built on liquefiable soils. Closure of sections of the Maze due to inspection or damage will restrict access into and throughout areas of need in the East Bay.

In San Francisco, the Central Freeway, the section of Highway 101 from the Bay Bridge to the intersection at Highway 280, provides various access points to the center of the city. It will be closed for weeks or months for inspection and repair.

The interchanges in the liquefiable region of Santa Clara Valley, including Highways 280, 101, and 880 may suffer ground failure, impacting access to the Peninsula and East Bay from counties south of the Bay Area.

6.2 Bridges

The cantilevered section of the eastern portion of Bay Bridge is not designed to withstand the expected seismic loads of the scenario earthquake. Doyle Drive, the aging southern approach to the Golden Gate Bridge, is elevated as it traverses an area of San Francisco that will experience extreme ground motions. The Golden Gate Bridge will not be accessible if Doyle Drive is closed for inspection and repair. Though the Richmond Bridge was recently retrofitted, the approach at the west end rests on liquefiable soils that will force closure of the bridge. The new Carquinez Bridge, between Contra Costa and Solano Counties, is not in an area expected to experience strong ground motions. All approaches to the San Mateo and Dumbarton Bridges cross highly liquefiable soils and are expected to suffer surface damage and connection failure.

Despite some new construction and extensive retrofits since the 1989 Loma Prieta Earthquake, all bridges and their approaches throughout the Bay Area will be closed for inspection in the days following the earthquake. The loss of just two bridges will effectively isolate Marin County. Map 3 shows where approaches to Bay Area bridges are located in expected liquefaction zones. Failure of bridge approaches for the San Mateo and Dumbarton Bridges will force traffic onto Highways 880 and 101, which will already be restricted to traffic due to damages and inspections.

Table 8 shows the number of all bridges (including elevated sections of highways and local roads) expected to suffer damage in the Bay Area.

Table 8. Expected damage to Bay Area bridges, by county

County	Total Number of Bridges	Number of Bridges with Structural Damage		
		Moderate	Extensive	Complete
Alameda	559	30	37	64
Contra Costa	499	14	21	20
Marin	189	16	24	54
Napa	145	2	5	5
San Francisco	107	10	15	27
San Mateo	306	29	52	131
Santa Clara	883	80	110	205
Santa Cruz	179	19	26	27
Solano	321	4	4	5
Sonoma	560	35	43	71

Source: Kircher et al. 2006

6.3 Airports

6.3.1 Major (International) Airports

Runways at the major Bay Area airports are generally constructed over landfill of varying depth. Liquefaction and differential settlement may render all or portions of many runways unusable by larger aircraft. In addition to runways compromised by liquefaction, San Francisco, San Jose, and Oakland International airports will suffer damage to traffic control towers and terminal facilities, as well as communication disruptions, and may only be available for limited use by small aircraft and helicopters until repairs are made. These airports run independently of the power grid and initially will not be severely affected by the loss of electrical power. San

Francisco International is accessed by Highway 101, which will suffer damage from fault rupture and liquefaction. Highway 880 serves Oakland International and is vulnerable to liquefaction. Both highways, as well as Highway 17 from Santa Cruz and coastal communities, serve San Jose International Airport and will be closed for inspection and repair. Access to Highways 101 and 880 will continue to be a problem for several days, until repairs are complete.

6.3.2 Regional Airports

General aviation airports in Hayward, Half Moon Bay, Concord, Napa, and Santa Rosa may suffer damage due to shaking and experience power and communication disruptions. However, these airports are less likely to suffer servicing roads closures and may serve as a point of delivery for emergency supplies. Airports outside of the immediate Bay Area, in Solano, Sacramento, and San Joaquin should plan for increased air and vehicle traffic, both immediately and long term, should the major airfields be impacted. Travis Air Base in Solano, however, will be restricted to government and military response operations. The general public needing access to a large airport will rely on Sacramento or will have to await the reopening of the Oakland or San Jose airports.

6.4 Ports

Ports located in vulnerable areas of the Bay Area are depicted in Maps 3 through 6. A San Andreas Fault earthquake will cause the most damage to the Port of Oakland, San Francisco's piers, and the port at Redwood City. Ports in the northern section of the Bay, from Richmond to Benicia, as well as the former Naval Base at Mare Island, will experience less shaking intensity, and are expected to remain viable; however, as mentioned earlier, damages to refinery structures that use the North Bay ports can incapacitate those facilities.

Earthquakes affect various types of port structures, such as piers, wharves, seawalls, container storage yards, marinas, cranes, and utilities. The land on which the ports of Oakland, San Francisco, and Redwood City are located is subject to lateral spreading, where subsurface soil liquefies and gravity and earthquake forces cause the land mass to move downward. Ground displacements of several feet are expected to damage structures such as cranes along the edge of piers. Collapse of the container cranes will cause additional structural damage to port facilities and require complex debris removal efforts. All piers in the Bay Area will initially suffer prolonged power loss and damage to truck and rail access routes. Other ports on the West Coast (Seattle and Long Beach) will experience an increased level of cargo traffic due to closure of the Port of Oakland.

The Port of San Francisco hosts the region's facilities for numerous cruise ship companies and will lose the structures needed to load and service the large ships. Plans to use cruise ships for transitional housing after the earthquake will be complicated because the ships will not be able to dock elsewhere along the Bay. Physical damage to the piers in San Francisco as well as to the Port of Oakland will make waterways unsafe for patient evacuation and supplies, equipment, and personnel deliveries.

6.5 Railroads

Rail service to the Bay Area will be curtailed due to fault ruptures, ground failures, and structural damages to numerous bridges. The Port of Oakland depends on intermodal railroads to move a majority of its cargo to California and other States. Port damage and closure of the rail system

due to damage and inspection will freeze movement of goods for days. Fuel processed in the region's refineries is shipped to the rest of California and other States by rail. Fuel supplies for customers dependent on the Bay Area refineries will be interrupted until inspections and repairs to rail lines are made.

Commuter train lines from San Jose to San Francisco could be closed for weeks due to displacement of rails caused by expected fault ruptures in the areas parallel to the San Andreas fault. Maps 3 and 6 show the commuter rail lines that cross liquefaction zones and areas of severe shaking. The rails of Caltrain, which carries commuters from San Mateo County to San Francisco, are vulnerable to the same ground failure risk that threatens Highway 101 and cannot be depended upon to relieve the increased commuter traffic needs that will result from impacts to the highway.

6.6 Ferries

Water will potentially be the only transportation system immediately available to move emergency responders to affected areas, evacuate population, and transport equipment and supplies following a large earthquake in the Bay Area. However, the current fleet lacks the capacity to make up for even one out-of-service bridge. Existing vessels are owned by and operated by various public and private owners and, although efforts have been made in this area, there is no plan or identified leader to coordinate them in a disaster. Terminals and piers in Marin, Oakland, and San Francisco will be subject to severe ground motions. Lateral spreading along waterside foundations will damage terminal structures and utilities.

6.7 Mass Transit System

BART is the major public transit system in the Bay Area. Although BART was constructed to high seismic standards for the 1960s and 1970s, severe earthquake-related damage could close parts of the 34 miles of its original elevated track, elevated stations, roads beneath these elevated structures, approaches to the Transbay Tube, and the BART tunnel through the East Bay hills. The Transbay Tube, set in soft soils beneath the Bay, will suffer severe displacement due to liquefaction of foundations. Following a catastrophic earthquake, portions of BART could be closed for repair for 2.5 years or longer, increasing roadway traffic by about 330,000 trips a day.

Other transit systems in the Bay Area will depend on the resiliency of roads. AC Transit buses in the East Bay will not be able to use the Bay Bridge. Road damage on routes along the margins of the Bay will further disrupt service. In San Francisco, local road closures due to building damage will disrupt MUNI service. Power outages will ground buses dependent on electricity. SamTrans in San Mateo County and the Valley Transit Authority in Santa Clara County will suffer route disruption due to the intense ground shaking expected along the Peninsula and in the South Bay. Fuel supplies will be restricted until pipelines, storage, and transit agency pumps are inspected and repaired.

7 Buildings

Tables 9a and 9b show the total number of buildings (both residential and commercial) expected to suffer damage in the earthquake. Appendix B contains tables showing information about building damages expected in each of the 10 Bay Area counties. Approximately one in six residential buildings in the Bay Area is considered a "soft story" building, a structural type that is particularly vulnerable to earthquake damage. A common construction type used for residences in the Bay Area, the soft story building is a multistory, multiunit building with a ground floor that is open, with minimal support, to provide commercial space or a garage for tenants.

Another typical and dangerous construction type in San Francisco is the older, unreinforced masonry (URM) building, constructed of bricks that are not reinforced to withstand earthquake damage. URM buildings will suffer extensive damage and may collapse. The debris from URM building failures will block streets and can injure people inside and outside of the buildings.

Table 9a. Region-wide building damage—inventory and estimated damage for all 10 counties

Building Type	Total Number of Buildings	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Residential buildings	2,078,108	317,065	81,664	33,083
Commercial buildings	51,579	12,584	6,919	3,132
All buildings	**2,141,252**	**335,700**	**90,528**	**37,025**

Source: Kircher et al. 2006

Table 9b. Region-wide building damage—estimated economic loss for all 10 counties

Building Type	Total Exposure (in billions of dollars)	Economic Loss Due to Ground Shaking/Failure (in billions of dollars)		
		Building	Contents	Total (with BI*)
Residential buildings	$579.8	$56.8	$7.7	$67.1
Commercial buildings	$158.4	$26.8	$6.1	$40.4
All buildings	**$791.0**	**$91.9**	**$16.5**	**$119.0**

*Business Interruption
Source: Kircher et al. 2006

7.1 Residential Structures

A repeat of the 1906 earthquake could damage as many as 432,000 residential buildings in the region. Neighborhoods in the western and southern areas of the City and along the Peninsula will bear the brunt of destruction, in large part because of the soil composition.

7.1.1 Single- and Two-Family Buildings

In the 10 Bay Area counties, about 5.2 million people (nearly 75 percent of total population) live in 1.8 million one- and two-unit dwellings. At least 200,000 of these buildings have "cripple walls," 85 to 95 percent of which will be damaged due to violent shaking. Older (usually pre-World War II) houses that were not retrofitted will be severely damaged. Homes with living area over a garage, on hillsides, or lacking adequate cripple wall bracing are most vulnerable. One- and two-story wood-frame structures with a minimally reinforced first floor, URM, and older, nonductile concrete frame structures are most vulnerable.

Mobile homes installed prior to 1995 will be responsible for 7 percent of the uninhabitable housing. These types of housing units house a disproportionate number of the elderly and poor, particularly in the North and South Bay areas.

7.1.2 Multi-Family Buildings

About 1.9 million people in the 10 Bay Area counties live in 90,000 multifamily buildings. About 15,000 of these buildings are soft-story structures. Moreover, more than 500,000 people in the Bay Area live in soft-story buildings. Multifamily wood-frame residential buildings will be responsible for 66 percent of uninhabitable housing following an earthquake. Individuals living in these types of homes tend to be poor and elderly, or children. These individuals will require shelters following an earthquake.

8 Essential Facilities

8.1 Hospitals

The most recent available data from the Office of Statewide Health Planning and Development indicate that there are 89 hospitals in the Bay Area with a total of 484 buildings (OSHPD 2001). Of these buildings, 14 percent are expected to be functional; 50 percent might not be functional or might have limited availability due to structural damage; and 36 percent pose a significant risk of collapse following an earthquake. Only four hospitals in the Bay Area are expected to remain functional with no structural damage and availability of electric power, water, and other utilities following a catastrophic earthquake.

Nonstructural damage to emergency power and medical equipment, loss of municipal water, or sewer services will reduce the number of hospitals available for immediate medical care. Following an earthquake, the Bay Area will also experience a shortage of medical transport vehicles, trained medical personnel, and medical and blood supplies. A rapid response by the Federal Disaster Medical Assistance Team (DMAT) will be required. To illustrate the impact on the medical response system, Appendix C shows the number of hospital beds that are expected to be available throughout the immediate Bay Area and surrounding counties. Hospital services will also be hampered by crowds of the "worried well"—people who may not need medical services but are seeking relief from their anxieties.

8.2 Fire Stations

Since the 1989 earthquake, 21 percent of fire stations throughout the Bay Area have been retrofitted to withstand earthquakes. However, 20 percent of Bay Area fire stations are located in areas mapped as having high to very high susceptibility to liquefaction. About 50 percent are located in areas with moderate or higher liquefaction susceptibility. About 67 percent of Bay Area fire stations are at moderate to high risk for loss of function due to earthquake effects. Jammed overhead doors and nonstructural damage can trap fire trucks inside of stations. Power failures will hamper dispatching, response, and staff support. Communication interruptions are also expected. Off-duty fire fighters reporting to their stations will encounter transportation problems en route. The expected damage to major roads and highways will slow fire response.

8.3 Police Stations

The heaviest damage occurs to police stations in counties closest to the San Andreas fault. The primary functions of police work are performed in the field; however, they depend on buildings for dispatch and logistics coordination. Stations will suffer structural and nonstructural damage due to ground shaking and will depend on the resiliency of utilities to remain viable. Damage to main transportation routes will impact police response. Telecommunication outages may have some impact on law enforcement response, but redundant radio systems are robust.

The earthquake's impact on jail and prison facilities is unknown; however, the County jail in San Francisco, adjacent to the Central Freeway, will probably be impacted by the severe damage expected to that highway. San Quentin, the Federal prison in Marin County, will experience extreme shaking. The old facility is located near to two particularly vulnerable and critical transportation structures (Highway 101 and the approach to the San Rafael Bridge) and response to emergency incidents in San Quentin will be restricted due to transportation disruption.

8.4 Schools

Since passage of the Field Act in 1933, school buildings in California have been continuously improved to withstand seismic hazards. However, more than 1,000 school buildings in the Bay Area are on California Division of State Architect's "vulnerable" list. These buildings provide questionable resistance to earthquakes. Local emergency planners depend on schools as a major resource for mass shelter and feeding. Even if they retain their structural integrity, a large number of schools may be functionally impaired due to disrupted utility services. Before they can be used as shelters, the schools will have to be inspected for structural integrity, thus delaying the availability of public shelters. **Table 10** depicts the damage expected to school buildings in the Bay Area.

Table 10. Impacts on schools in the Bay Area, by county

County	Total Number of Schools	Number of Facilities with Structural Damage		
		Moderate	Extensive	Complete
Alameda	519	25	3	1
Contra Costa	341	6	0	0
Marin	118	17	5	2
Napa	70	1	0	0
San Francisco	230	50	7	3
San Mateo	261	75	11	3
Santa Clara	542	82	12	3
Santa Cruz	101	20	1	0
Solano	135	1	0	0
Sonoma	227	12	2	0
Total	**2,544**	**289**	**42**	**13**

Source: Kircher et al. 2006

9 Impact on General Population

The scenario earthquake, occurring at 2:00 p.m. on a Tuesday, will prevent a large number of individuals from being able to return to their homes. In addition, large numbers of people will be trapped on public transportation, roads, bridges, and streets. These individuals will require shelter and care until they are able to return home to assess the damage and, depending on the extent of damage to their primary residences, long-term housing. Shaking will result in partial or complete collapse of thousands of buildings, possibly trapping occupants who cannot get out without being rescued. More than 50 percent of the estimated deaths following an earthquake will be due to the collapse of unreinforced masonry buildings, older reinforced concrete buildings, and other vulnerable structures. The more than 3,000 deaths expected from the earthquake will overwhelm the region's coroner system, requiring considerable support from the Federal Disaster Mortuary Team (DMORT). **Table 11** outlines the estimated number of injuries and fatalities following a catastrophic earthquake in the Bay Area.

Table 11. Injury and fatality estimates, by county

County	Treat and Release Injuries	Serious (Hospital Injuries)	Trapped Need Rescue	Immediate Deaths
Alameda	5,006	1,300	196	378
Contra Costa	506	96	11	21
Marin	1,490	404	62	121
Napa	39	5	0	1
San Francisco	13,569	3,977	430	823
San Mateo	10,788	3,218	521	1,013
Santa Clara	10,196	2,699	413	802
Santa Cruz	1,395	391	62	120
Solano	86	14	2	3
Sonoma	656	149	20	39
Total	**43,731**	**12,254**	**1,718**	**3,322**

Source: Kircher et al. 2006

More than 125,000 people are projected to need public short-term shelter. This projection includes not only people displaced from damaged homes, but also workers and visitors in the area who will need temporary shelter because failure of transportation modes will prevent them from returning to their homes. **Table 12** details the number of displaced households and temporary public shelter requirements. In urban areas, large numbers of people who are homeless before the earthquake will seek the services of disaster shelters. Currently, counties in the Bay Area have only limited resources for supplying mass care, which includes feeding and shelter. Supplies of the Red Cross and other nongovernmental organizations (NGOs) in the Bay Area cannot meet projected needs. In the first 3 days after the event, the State will not have the capability to meet the shelter needs of people in a San Andreas Fault scenario.

As many as 1.5 million households in the 10-county Bay Area own a pet. Pet owners will be reluctant to leave their animals, impacting mass care facilities or risking their own lives in order to save a pet.

Table 12. Number of displaced households and number of people in need of shelter, by county

County	Total Number of Households	Number of Displaced Households	Number of People Needing Temporary Shelter
Alameda	523,366	38,955	20,785
Contra Costa	344,129	4,032	1,067
Marin	100,650	6,991	1,497
Napa	45,402	245	62
San Francisco	329,700	87,995	63,577
San Mateo	254,103	41,356	13,233
Santa Clara	565,863	52,911	23,194
Santa Cruz	91,139	5,216	1,303
Solano	130,403	502	132
Sonoma	172,403	2,855	678
Total	**2,557,158**	**241,059**	**125,529**

Source: Kircher et al. 2006

10 Economic and Business Impact

The Bay Area has the highest economic productivity in the Nation—twice the national average. The region hosts the Nation's largest concentration of national laboratories, corporate and independent research laboratories, and leading research universities. As many as 10,000 commercial buildings will sustain major structural damage. Damage to office buildings, plants, and other support facilities will interrupt business and industry. San Francisco's financial district, which is largely built on pre-1906 bay fill, is especially vulnerable to earthquakes and liquefaction that may follow. Disruption of transportation modes and routes throughout the region will reduce the number of workers needed to ensure rapid economic recovery.

The Port of Oakland is the fourth busiest port in the nation. Ninety-nine percent of containerized goods moving through Northern California are handled through the port. The region's international airports moved $109 billion worth of cargo in 1999. Local manufacturers, international traders, and the hub operations of national delivery companies such as FedEx and UPS depend on the resiliency of the airports and transportation systems that support them. Airports provided 470,000 jobs in 1999 and generated $37.7 billion in revenue. Tourism, an industry dependent on the airports, generated $473 million in taxes for the City of San Francisco in 2006. Economic recovery for the Bay Area will depend not only on the rapid restoration of infrastructure but on prompt and accurate public information aimed at national and international audiences.

Because of the damage to the telecommunication infrastructure following a catastrophic earthquake, established structures for financial transactions will be interrupted, affecting retail and other commerce related to response and reconstruction. Credit card, money transfers, and cash withdrawal transactions will be severely limited, delaying residential recovery efforts.

As shown in Map 1, in **Appendix A,** the repeat 1906 earthquake causes strong shaking in 19 counties surrounding the Bay Area. Farther away from the Bay, shaking is intense in regions surrounding bodies of water. Damage to transportation systems in and out of the Bay Area will interrupt commerce, especially the transport of agricultural products to ports and markets. Water systems in the neighboring counties of the Sacramento Delta, consisting mainly of earthen dams, are vulnerable to intense shaking and flooding of communities and industrial areas is possible.

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11 Emergency Response

Each of the 10 Operational Areas in the region has alternative sites for EOCs, should the original buildings suffer damage. It is not known if local governments have redundant EOCs. Under California's Standardized Emergency Management System (SEMS), the California Governor's OES manages a Regional Emergency Operations Center (REOC) from a high-rise commercial office building in Oakland. This facility is susceptible to failure due to structural damage, loss of utilities, or the inability of staff to travel to the EOC. There is currently no alternate REOC. Should the REOC fail, regional coordination would be undertaken by the State Operations Center (SOC) in Sacramento. FEMA Region IX's Regional Response Coordination Center is also located in a highrise in downtown Oakland. An earthquake occurring in the afternoon of a typical workday will impact the immediate response of FEMA Region IX staff. FEMA Region X, in Bellevue, Washington, will coordinate the initial Federal response. EOCs throughout the Bay Area may be unable to staff emergency management functions because the designated staff will also be victims of the earthquake.

Disruptions to dispatch and communication systems will significantly hamper first responders.

Logistics for establishing shelter systems will take 24 to 72 hours or more. Because accurate situational information will not be available for several days, initial resource and shelter needs may not be precise. Event-based modeling, such as the same HAZUS data that produced this scenario, may have to be used to make assumptions about resource and shelter needs.

Numerous people with varying degrees of injury will arrive at emergency shelters because they are accessible and they believe medical care will be available at the sites. Medical/health care resources, including trained personnel, equipment, supplies, and medications, will be in short supply. Churches and other organizations not normally involved in emergency planning will spontaneously set up additional shelters and may require the support of government or NGO mass-care providers to continue service.

12 Resources

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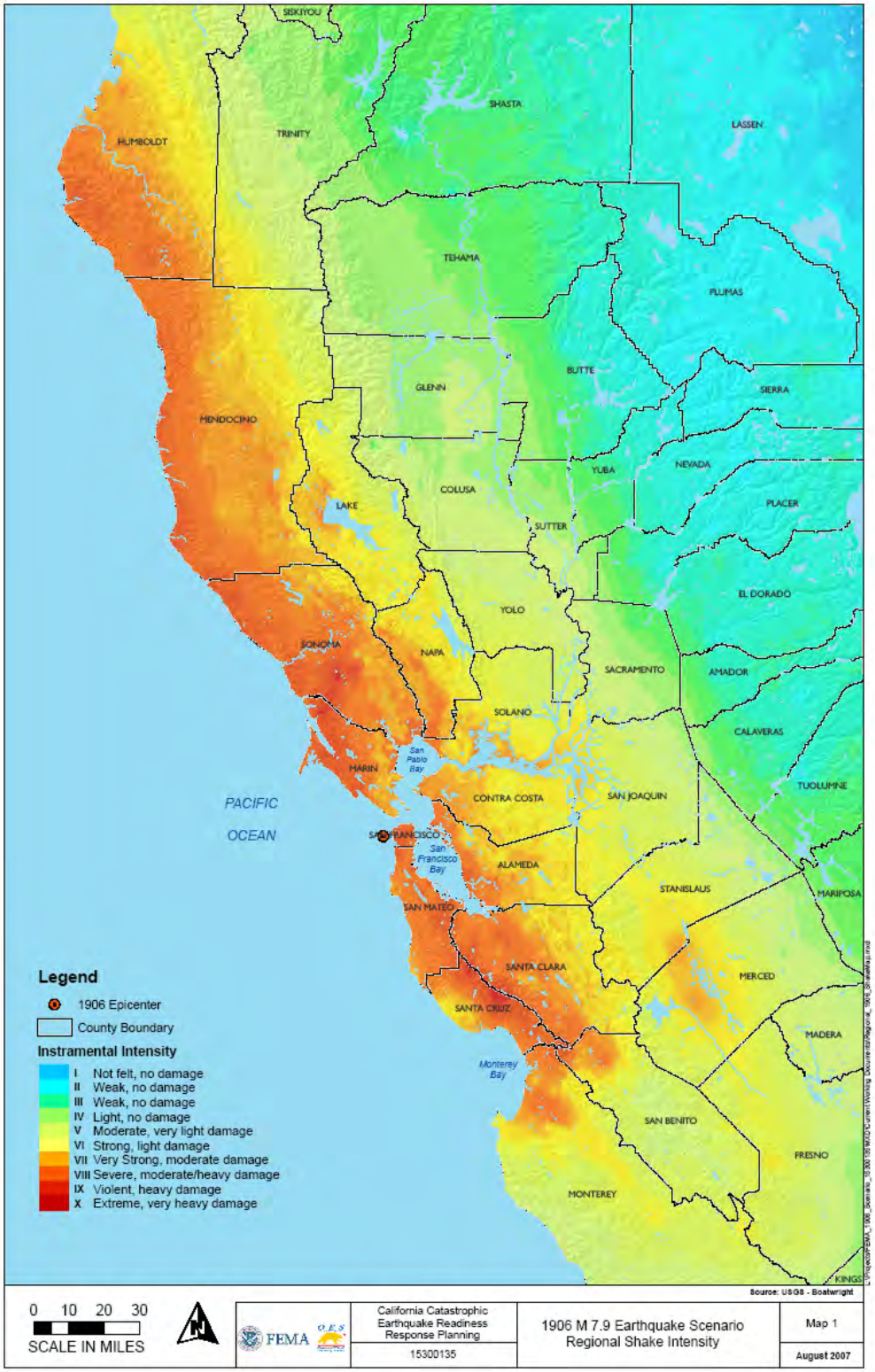
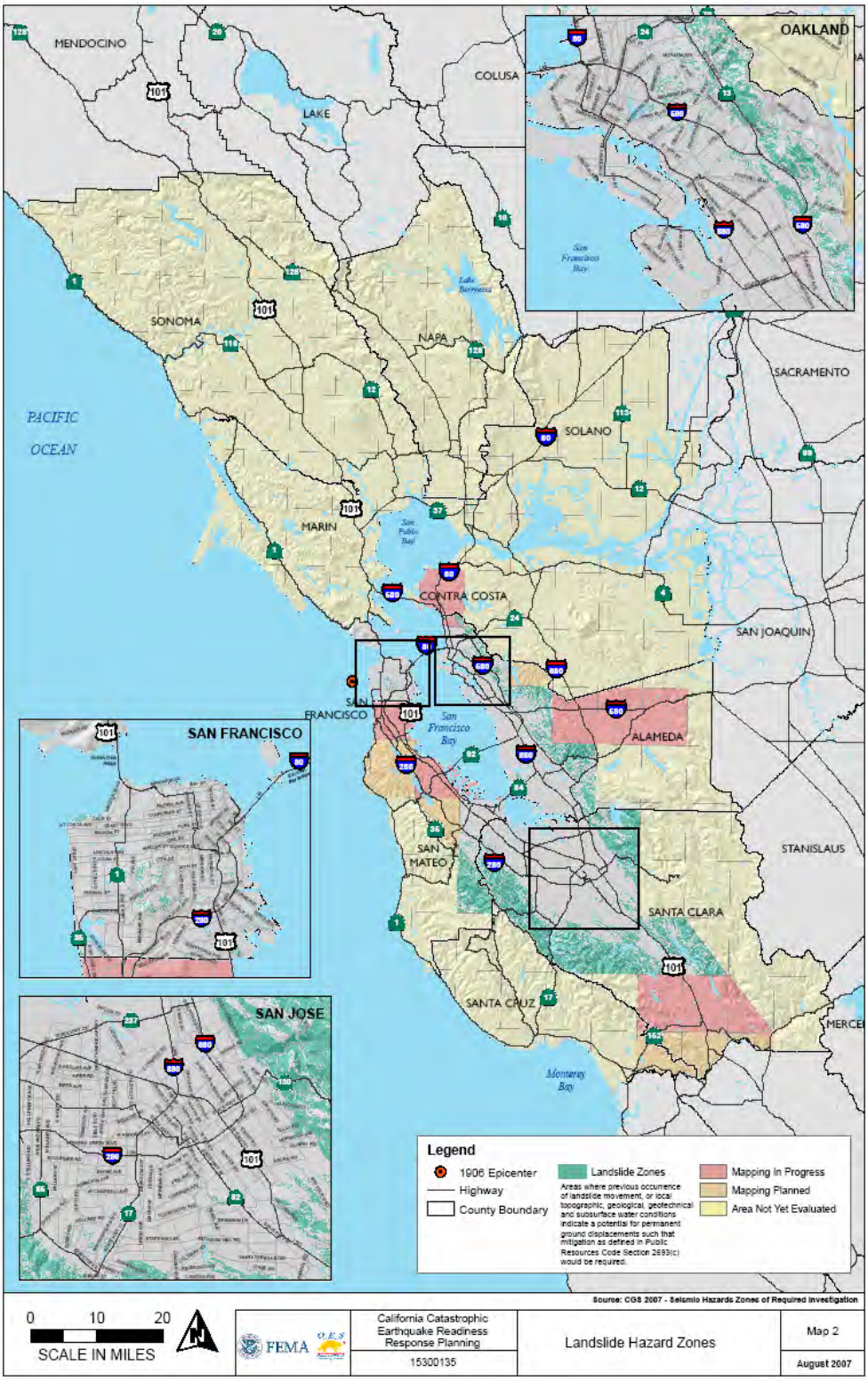
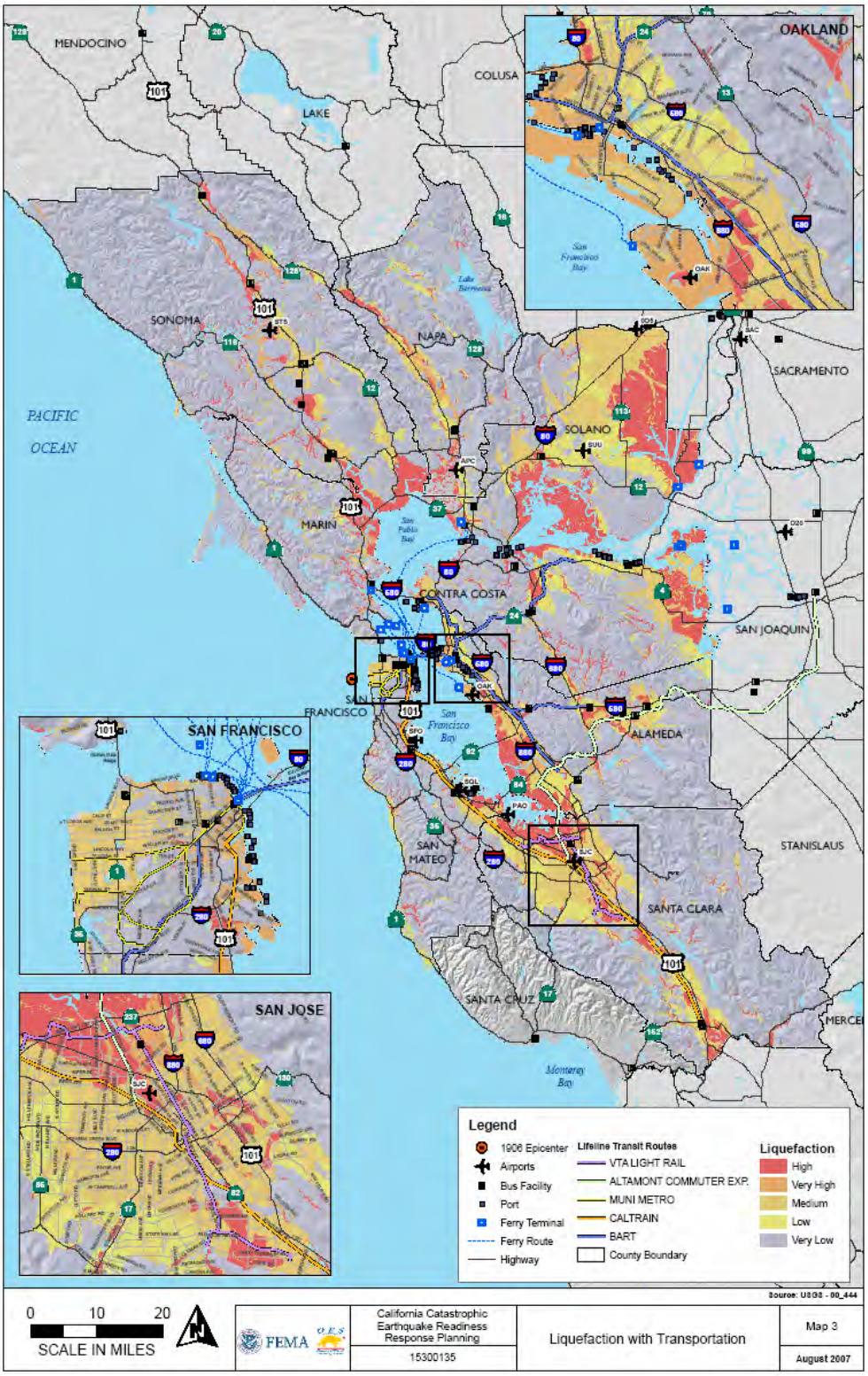
Appendix A: Maps



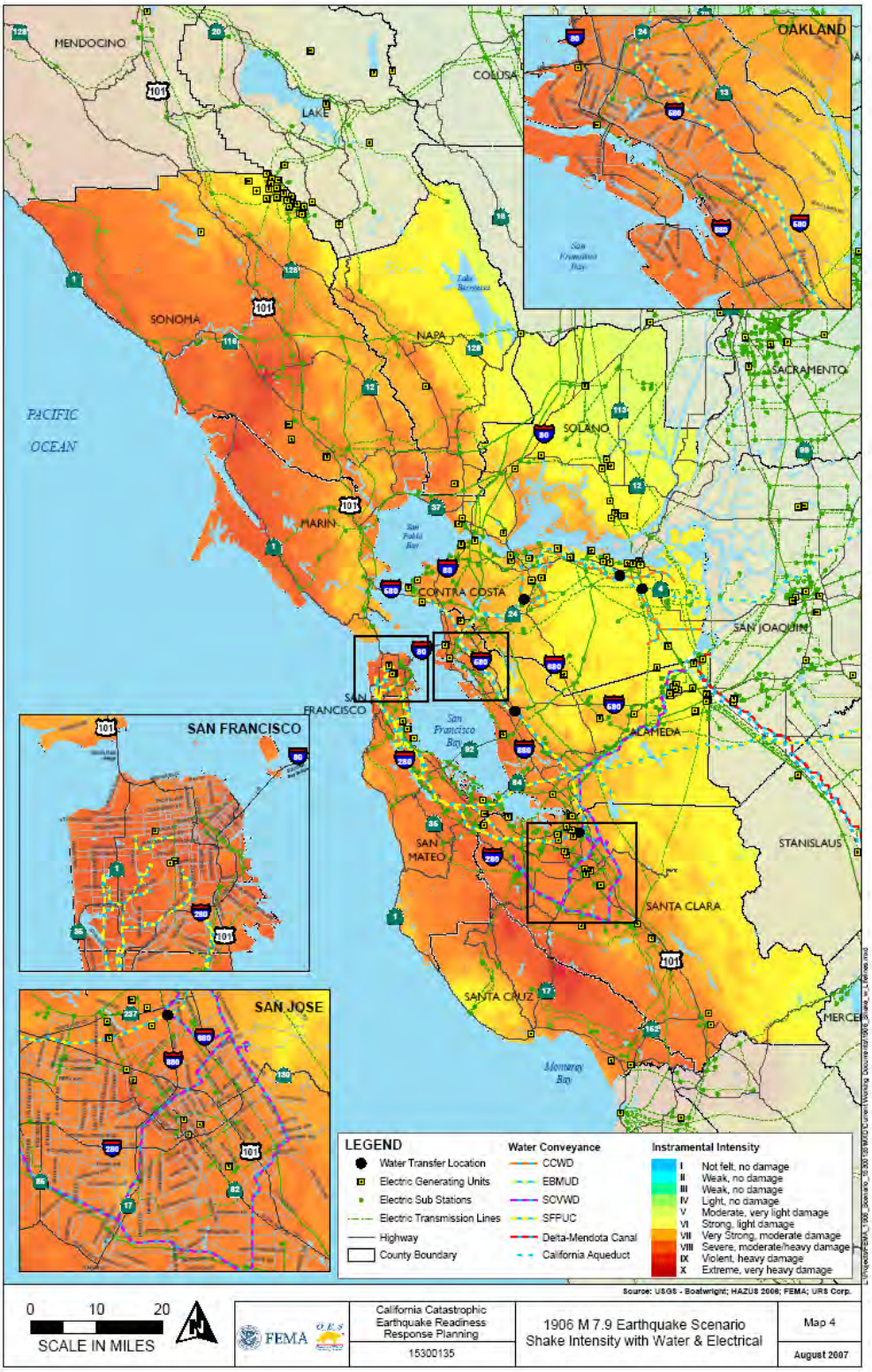
Map 1. Regional shake intensity



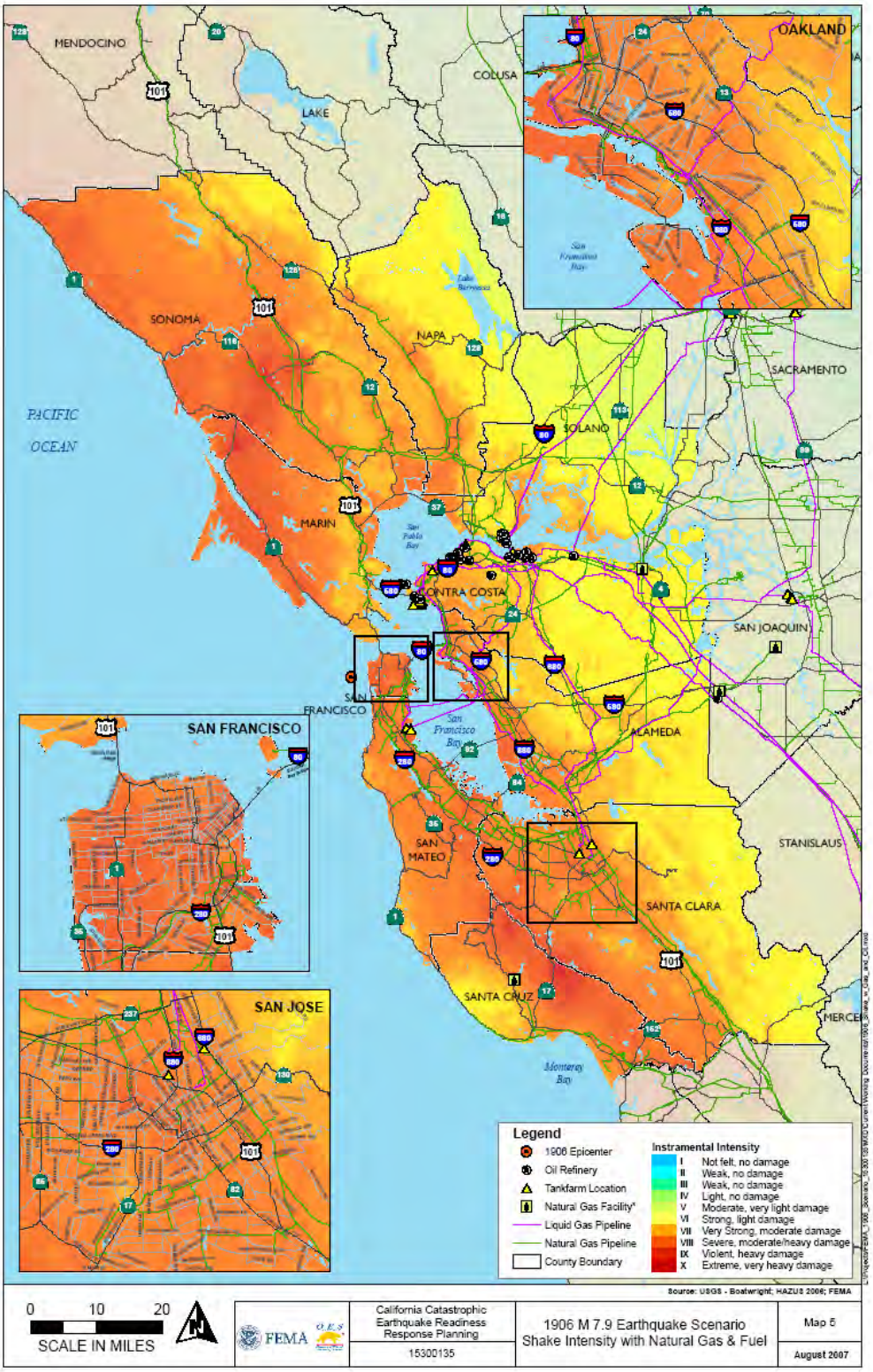
Map 2. Landslide hazard zones



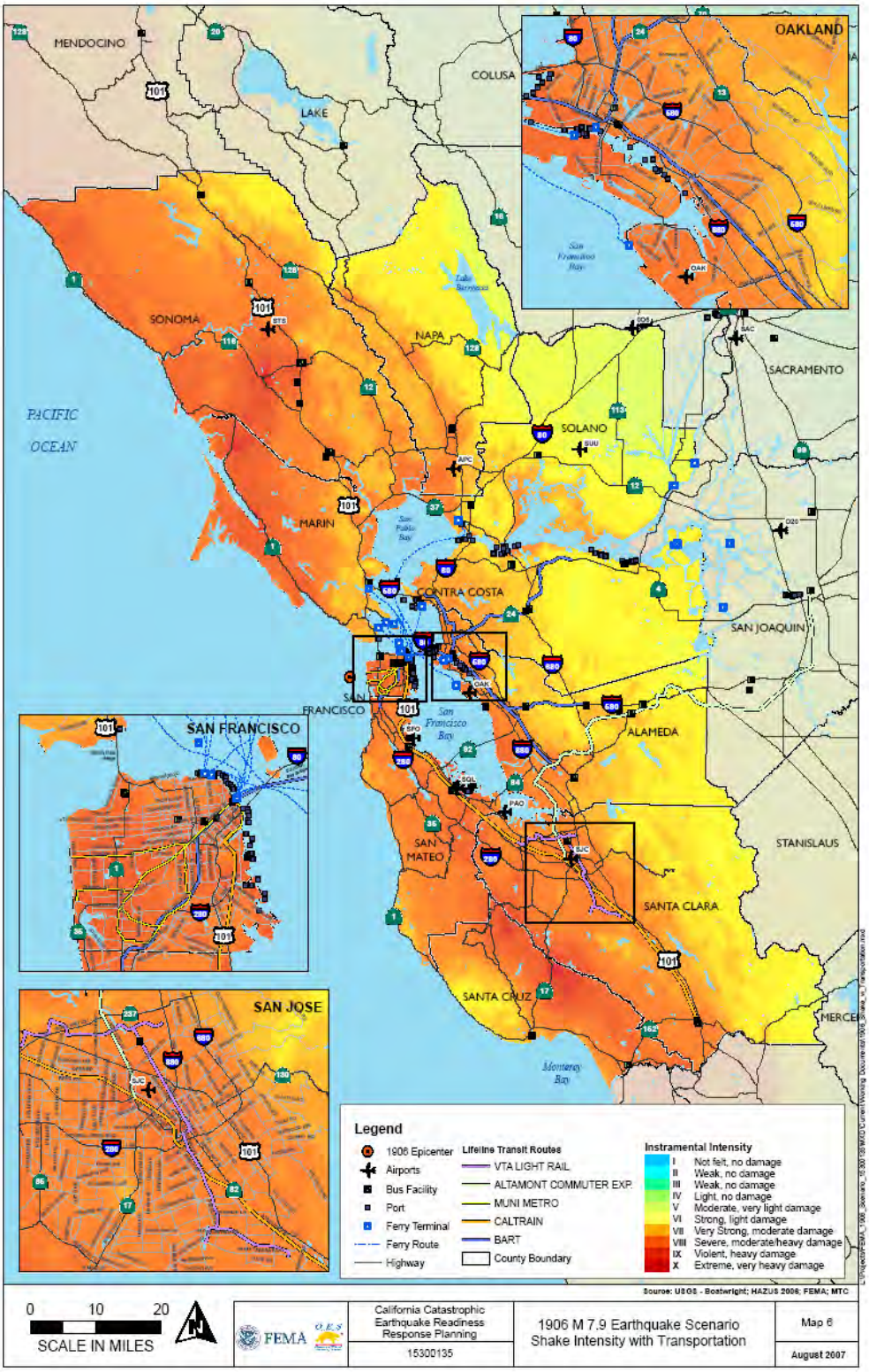
Map 3. Liquefaction with transportation routes



Map 4. Shake intensity with water and electrical transmission lines



Map 5. Shake intensity with natural gas and fuel lines



Map 6. Shake intensity with transportation routes

Appendix B: Estimate of Damaged Buildings, by County

Table B-1a. Summary of inventory and estimated damage to buildings in Alameda County

Building Type	Number of Buildings	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Residential buildings	399,561	41,702	12,433	3,705
Commercial buildings	10,667	2,422	1,011	296
All buildings	413,503	44,924	13,816	4,119

Source: Kircher et al. 2006

Table B-1b. Summary of inventory and estimated damage to essential facility types in Alameda County

Essential Facility Type	Total No. of Facilities	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Hospitals	22	6	3	1
Schools	519	25	3	1
Police stations, fire stations, and/or EOCs	43	5	1	1

EOC = Emergency Operations Center
Source: Kircher et al. 2006

Table B-1c. Summary of inventory and estimated damage in billions of dollars in Alameda County

Building Type	Total Exposure*	Economic Loss Due to Ground Shaking/Failure*		
		Building	Contents	Total**
Residential buildings	$111.0	$6.6	$0.8	$7.8
Commercial buildings	$30.9	$3.3	$0.7	$5.0
All buildings	$155.7	$11.4	$2.1	$15

* In billions of dollars
** Includes Business Interruption
Source: Kircher et al. 2006

Table B-2a. Summary of inventory and estimated damage to buildings in Contra Costa County

Building Type	Number of Buildings	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Residential buildings	314,850	9,294	1,132	183
Commercial buildings	5,726	486	86	10
All buildings	321,280	13,040	1,651	291

Source: Kircher et al. 2006

Table B-2b. Summary of inventory and estimated damage to essential facility types in Contra Costa County

Essential Facility Type	Total No. of Facilities	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Hospitals	10	1	0	0
Schools	341	6	0	0
Police stations, fire stations, and/or EOCs	49	2	0	0

EOC = Emergency Operations Center
Source: Kircher et al. 2006

Table B-2c. Summary of inventory and estimated damage in billions of dollars in Contra Costa County

Building Type	Total Exposure*	Economic Loss Due to Ground Shaking/Failure*		
		Building	Contents	Total**
Residential buildings	$82.4	$1,2	$0.2	$1.4
Commercial buildings	$16.9	$0.4	$0.1	$0.6
All buildings	$102.8	$1.7	$0.3	$2.2

* In billions of dollars
** Includes Business Interruption
Source: Kircher et al. 2006

Table B-3a. Summary of inventory and estimated damage to buildings in Marin County

Building Type	Number of Buildings	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Residential buildings	90,397	16,948	3,576	1,089
Commercial buildings	2,324	690	334	110
All buildings	93,195	17,772	3,987	1,229

Source: Kircher et al. 2006

Table B-3b. Summary of inventory and estimated damage to essential facility types in Marin County

Essential Facility Type	Total No. of Facilities	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Hospitals	4	1	1	1
Schools	118	17	5	2
Police stations, fire stations, and/or EOCs	23	5	2	1

EOC = Emergency Operations Center
Source: Kircher et al. 2006

Table B-3c. Summary of inventory and estimated damage in billions of dollars in Marin County

Building Type	Total Exposure*	Economic Loss Due to Ground Shaking/Failure*		
		Building	Contents	Total**
Residential buildings	$26.8	$2.7	$0.4	$3.1
Commercial buildings	$7.2	$1.2	$0.3	$1.8
All buildings	$36.1	$4.1	$0.8	$5.4

* In billions of dollars
** Includes Business Interruption
Source: Kircher et al. 2006

Table B-4a. Summary of inventory and estimated damage to buildings in Napa County

Building Type	Number of Buildings	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Residential buildings	43,756	781	51	3
Commercial buildings	991	66	9	1
All buildings	45,053	865	62	4

Source: Kircher et al. 2006

Table B-4b. Summary of inventory and estimated damage to essential facility types in Napa County

Essential Facility Type	Total No. of Facilities	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Hospitals	4	1	0	0
Schools	70	1	0	0
Police stations, fire stations, and/or EOCs	16	1	0	0

EOC = Emergency Operations Center
Source: Kircher et al. 2006

Table B-4c. Summary of inventory and estimated damage in billions of dollars in Napa County

Building Type	Total Exposure*	Economic Loss Due to Ground Shaking/Failure*		
		Building	Contents	Total**
Residential buildings	$10.0	$0.1	$0.0	$0.1
Commercial buildings	$2.8	$0.0	$0.0	$0.1
All buildings	$14.6	$0.2	$0.0	$0.2

* In billions of dollars
** Includes Business Interruption
Source: Kircher et al. 2006

Table B-5a. Summary of inventory and estimated damage to buildings in San Francisco County

Building Type	Number of Buildings	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Residential buildings	161,972	47,846	20,596	14,076
Commercial buildings	9,527	3,046	2,363	1,197
All buildings	172,930	51,340	23,295	15,455

Source: Kircher et al. 2006

Table B-5b. Summary of inventory and estimated damage to essential facility types in San Francisco County

Essential Facility Type	Total No. of Facilities	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Hospitals	15	5	4	4
Schools	230	50	7	3
Police stations, fire stations, and/or EOCs	36	9	3	1

EOC = Emergency Operations Center
Source: Kircher et al. 2006

Table B-5c. Summary of inventory and estimated damage in billions of dollars in San Francisco County

Building Type	Total Exposure*	Economic Loss Due to Ground Shaking/Failure*		
		Building	Contents	Total**
Residential buildings	$62.3	$15.2	$1.8	$18.0
Commercial buildings	$32.1	$9.0	$2.0	$13.5
All buildings	$100.2	$26.0	$4.2	$33.8

* In billions of dollars
** Includes Business Interruption
Source: Kircher et al. 2006

Table B-6a. Summary of inventory and estimated damage to buildings in San Mateo County

Building Type	Number of Buildings	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Residential buildings	213,802	68,561	18,667	7,796
Commercial buildings	5,037	1,477	1,134	920
All buildings	219,814	70,301	20,025	8,947

Source: Kircher et al. 2006

Table B-6b. Summary of inventory and estimated damage to essential facility types in San Mateo County

Essential Facility Type	Total No. of Facilities	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Hospitals	9	3	2	3
Schools	261	75	11	3
Police stations, fire stations, and/or EOCs	44	14	4	1

EOC = Emergency Operations Center
Source: Kircher et al. 2006

Table B-6c. Summary of inventory and estimated damage in billions of dollars in San Mateo County

Building Type	Total Exposure*	Economic Loss Due to Ground Shaking/Failure*		
		Building	Contents	Total**
Residential buildings	$63.6	$12.9	$1.8	$15.1
Commercial buildings	$16.1	$5.9	$1.4	$8.7
All buildings	$84.3	$20.7	$3.7	$26.4

* In billions of dollars
** Includes Business Interruption
Source: Kircher et al. 2006

Table B-7a. Summary of inventory and estimated damage to buildings in Santa Clara County

Building Type	Number of Buildings	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Residential buildings	481,365	95,499	19,857	5,228
Commercial buildings	10,853	3,213	1,565	493
All buildings	495,280	99,585	21,836	5,851

Source: Kircher et al. 2006

Table B-7b. Summary of inventory and estimated damage to essential facility types in Santa Clara County

Essential Facility Type	Total No. of Facilities	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Hospitals	15	6	3	2
Schools	542	82	12	3
Police stations, fire stations, and/or EOCs	63	13	3	1

EOC = Emergency Operations Center
Source: Kircher et al. 2006

Table B-7c. Summary of inventory and estimated damage in billions of dollars in Santa Clara County

Building Type	Total Exposure*	Economic Loss Due to Ground Shaking/Failure*		
		Building	Contents	Total**
Residential buildings	$135.5	$14.3	$2.1	$17.0
Commercial buildings	$33.5	$5.5	$1.3	$8.4
All buildings	$183.3	$21.9	$4.2	$28.4

* In billions of dollars
** Includes Business Interruption
Source: Kircher et al. 2006

Table B-8a. Summary of inventory and estimated damage to buildings in Santa Cruz County

Building Type	Number of Buildings	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Residential buildings	88,130	22,541	3,639	690
Commercial buildings	1,657	561	252	76
All buildings	90,140	23,223	3,942	783

Source: Kircher et al. 2006

Table B-8b. Summary of inventory and estimated damage to essential facility types in Santa Cruz County

Essential Facility Type	Total No. of Facilities	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Hospitals	4	1	1	1
Schools	101	20	1	0
Police stations, fire stations, and/or EOCs	18	4	1	0

EOC = Emergency Operations Center
Source: Kircher et al. 2006

Table B-8c. Summary of inventory and estimated damage in billions of dollars in Santa Cruz County

Building Type	Total Exposure*	Economic Loss Due to Ground Shaking/Failure*		
		Building	Contents	Total**
Residential buildings	$21.3	$2.3	$0.3	$2.7
Commercial buildings	$5.1	$0.9	$0.2	$1.3
All buildings	$28.4	$3.5	$0.7	$4.5

* In billions of dollars
** Includes Business Interruption
Source: Kircher et al. 2006

Table B-9a. Summary of inventory and estimated damage to buildings in Solano County

Building Type	Number of Buildings	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Residential buildings	118,655	1,505	240	51
Commercial buildings	1,810	89	21	4
All buildings	120,823	1,608	264	56

Source: Kircher et al. 2006

Table B-9b. Summary of inventory and estimated damage to essential facility types in Solano County

Essential Facility Type	Total No. of Facilities	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Hospitals	6	1	0	0
Schools	135	1	0	0
Police stations, fire stations, and/or EOCs	32	1	0	0

EOC = Emergency Operations Center
Source: Kircher et al. 2006

Table B-9c. Summary of inventory and estimated damage in billions of dollars in Solano County

Building Type	Total Exposure*	Economic Loss Due to Ground Shaking/Failure*		
		Building	Contents	Total**
Residential buildings	$28.1	$0.2	$0.0	$0.2
Commercial buildings	$5.2	$0.1	$0.0	$0.1
All buildings	$34.8	$0.3	$0.1	$0.4

* In billions of dollars
** Includes Business Interruption
Source: Kircher et al. 2006

Table B-10a. Summary of inventory and estimated damage to buildings in Sonoma County

Building Type	Number of Buildings	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Residential buildings	165,621	12,387	1,474	260
Commercial buildings	2,988	534	144	25
All buildings	169,235	13,040	1,651	291

Source: Kircher et al. 2006

Table B-10b. Summary of inventory and estimated damage to essential facility types in Sonoma County

Essential Facility Type	Total No. of Facilities	Number of Buildings with Structural Damage		
		Moderate	Extensive	Complete
Hospitals	10	2	1	0
Schools	227	12	2	0
Police stations, fire stations, and/or EOCs	31	3	1	0

EOC = Emergency Operations Center
Source: Kircher et al. 2006

Table B-10c. Summary of inventory and estimated damage in billions of dollars in Sonoma County

Building Type	Total Exposure*	Economic Loss Due to Ground Shaking/Failure*		
		Building	Contents	Total**
Residential buildings	$38.7	$1.3	$0.2	$1.6
Commercial buildings	$8.7	$0.5	$0.1	$0.8
All buildings	$50.9	$2.1	$0.4	$2.7

* In billions of dollars
** Includes Business Interruption
Source: Kircher et al. 2006

Appendix C: Hospital Bed Availability

Table C-1. Number of hospital beds expected to be available in the Bay Area and surrounding counties following a repeat of the 1906 earthquake scenario

County	Total No. Beds	E+1 Day		E+3 Days		E+7 Days		E+30 Days		E+90 Days	
		No. Beds	%	No. Beds	%	No. Beds	%	No. Beds	%	No. Beds	%
Alameda											
Large hospital	3,182	2,338	73.48	2,355	74.01	3,082	96.87	3,173	99.71	3,176	99.81
Medium hospital	553	430	77.72	432	78.20	539	97.38	551	99.68	552	99.78
Small hospital	42	35	82.50	35	82.90	41	98.50	42	99.90	42	99.90
Total County	**3,777**	**2,942**	**77.90**	**2,960**	**78.40**	**3,686**	**97.60**	**3,768**	**99.80**	**3,771**	**99.80**
Contra Costa											
Large hospital	1,084	896	82.63	900	83.03	1,064	98.17	1,081	99.70	1,081	99.77
Medium hospital	460	425	92.33	425	92.48	458	99.48	460	99.90	460	99.90
Total County	**1,544**	**1,351**	**87.50**	**1,355**	**87.80**	**1,526**	**98.80**	**1,541**	**99.80**	**1,541**	**99.80**
Lake											
Medium hospital	54	52	97.00	52	97.00	54	99.70	54	99.90	54	99.90
Small hospital	40	40	99.00	40	99.00	40	99.90	40	99.90	40	99.90
Total County	**94**	**92**	**98.00**	**92**	**98.00**	**94**	**99.80**	**94**	**99.90**	**94**	**99.90**
Marin											
Large hospital	180	78	43.50	80	44.40	141	78.50	156	86.40	163	90.50
Medium hospital	179	92	51.15	93	51.95	156	87.10	169	94.50	172	96.35
Small hospital	33	20	61.40	20	62.10	31	94.30	33	99.80	33	99.80
Total County	**392**	**204**	**52.00**	**207**	**52.80**	**340**	**86.60**	**367**	**93.60**	**375**	**95.60**
Mendocino											
Medium hospital	124	85	68.65	86	69.25	118	94.90	124	99.80	124	99.85
Small hospital	28	27	95.00	27	95.10	28	99.70	28	99.90	28	99.90
Total County	**152**	**124**	**81.80**	**125**	**82.20**	**148**	**97.30**	**152**	**99.90**	**152**	**99.90**
Merced											
Large hospital	158	157	99.10	157	99.10	158	99.90	158	99.90	158	99.90
Medium hospital	101	100	99.10	100	99.10	101	99.90	101	99.90	101	99.90
Small hospital	29	28	97.70	28	97.80	29	99.80	29	99.90	29	99.90
Total County	**288**	**284**	**98.60**	**284**	**98.70**	**288**	**99.90**	**288**	**99.90**	**288**	**99.90**

County	Total No. Beds	E+1 Day		E+3 Days		E+7 Days		E+30 Days		E+90 Days	
		No. Beds	%	No. Beds	%	No. Beds	%	No. Beds	%	No. Beds	%
Monterey											
Large hospital	532	381	71.53	384	72.13	511	96.03	531	99.87	531	99.90
Small hospital	42	40	95.30	40	95.40	42	99.70	42	99.90	42	99.90
Total County	**574**	**479**	**83.40**	**481**	**83.80**	**562**	**97.90**	**573**	**99.90**	**573**	**99.90**
Napa											
Large hospital	1,867	1,735	92.93	1,738	93.08	1,858	99.53	1,865	99.90	1,865	99.90
Total County	**1,867**	**1,735**	**92.90**	**1,738**	**93.10**	**1,858**	**99.50**	**1,865**	**99.90**	**1,865**	**99.90**
Sacramento											
Large hospital	2,800	2,795	99.83	2,795	99.83	2,797	99.90	2,797	99.90	2,797	99.90
Medium hospital	333	332	99.78	332	99.78	333	99.90	333	99.90	333	99.90
Small hospital	32	32	99.80	32	99.80	32	99.90	32	99.90	32	99.90
Total County	**3,165**	**3,159**	**99.80**	**3,159**	**99.80**	**3,162**	**99.90**	**3,162**	**99.90**	**3,162**	**99.90**
San Benito											
Medium hospital	71	35	49.10	36	50.00	64	90.10	71	99.70	71	99.80
Total County	**71**	**35**	**49.10**	**36**	**50.00**	**64**	**90.10**	**71**	**99.70**	**71**	**99.80**
San Francisco											
Large hospital	4,130	1,942	47.01	1,981	47.97	3,631	87.91	4,044	97.92	4,074	98.64
Medium hospital	54	27	50.30	28	51.20	49	90.60	54	99.70	54	99.80
Small hospital	20	10	48.00	10	48.90	18	87.70	19	96.90	20	98.00
Total County	**4,204**	**2,036**	**48.40**	**2,075**	**49.40**	**3,731**	**88.70**	**4,127**	**98.20**	**4,154**	**98.80**
San Joaquin											
Large hospital	482	477	98.90	477	98.90	482	99.90	482	99.90	482	99.90
Medium hospital	374	368	98.30	368	98.30	373	99.80	374	99.90	374	99.90
Small hospital	35	35	98.90	35	99.00	35	99.90	35	99.90	35	99.90
Total County	**891**	**879**	**98.70**	**880**	**98.70**	**890**	**99.90**	**890**	**99.90**	**890**	**99.90**
San Mateo											
Large hospital	687	253	36.83	260	37.80	545	79.30	640	93.17	655	95.30
Medium hospital	367	143	39.10	147	40.13	302	82.40	352	95.90	357	97.20
Small hospital	12	6	48.20	6	49.10	11	87.80	12	96.90	12	98.10
Total County	**1,066**	**441**	**41.40**	**451**	**42.30**	**887**	**83.20**	**1,016**	**95.30**	**1,033**	**96.90**

County	Total No. Beds	E+1 Day		E+3 Days		E+7 Days		E+30 Days		E+90 Days	
		No. Beds	%	No. Beds	%	No. Beds	%	No. Beds	%	No. Beds	%
Santa Clara											
Large hospital	3,869	2,005	51.82	2,039	52.70	3,465	89.55	3,788	97.92	3,817	98.66
Medium hospital	236	115	48.70	117	49.70	211	89.20	233	98.65	234	99.20
Total County	**4,105**	**2,063**	**50.30**	**2,102**	**51.20**	**3,669**	**89.40**	**4,035**	**98.30**	**4,061**	**98.90**
Santa Cruz											
Large hospital	275	142	51.50	144	52.40	251	91.10	274	99.70	274	99.80
Medium hospital	130	60	46.20	61	47.20	116	88.90	130	99.70	130	99.80
Small hospital	30	15	50.60	15	51.50	27	90.80	30	99.70	30	99.80
Total County	**435**	**215**	**49.40**	**219**	**50.40**	**393**	**90.30**	**434**	**99.70**	**434**	**99.80**
Solano											
Large hospital	686	666	97.13	667	97.20	685	99.80	685	99.90	685	99.90
Medium hospital	293	272	92.83	272	93.00	292	99.50	293	99.90	293	99.90
Small hospital	43	42	97.50	42	97.50	43	99.80	43	99.90	43	99.90
Total County	**1,022**	**979**	**95.80**	**980**	**95.90**	**1,019**	**99.70**	**1,021**	**99.90**	**1,021**	**99.90**
Sonoma											
Large hospital	1,221	982	80.40	987	80.80	1,198	98.10	1,219	99.85	1,219	99.85
Medium hospital	610	468	76.78	471	77.25	593	97.28	607	99.50	608	99.70
Small hospital	97	79	81.00	79	81.40	95	98.05	97	99.90	97	99.90
Total County	**1,928**	**1,531**	**79.40**	**1,539**	**79.80**	**1,886**	**97.80**	**1,923**	**99.80**	**1,924**	**99.80**
Stanislaus											
Large hospital	966	951	98.43	952	98.50	965	99.90	965	99.90	965	99.90
Medium hospital	148	147	99.10	147	99.10	148	99.90	148	99.90	148	99.90
Total County	**1,114**	**1,100**	**98.80**	**1,101**	**98.80**	**1,113**	**99.90**	**1,113**	**99.90**	**1,113**	**99.90**
Yolo											
Medium hospital	103	102	99.20	102	99.30	103	99.90	103	99.90	103	99.90
Small hospital	48	48	99.10	48	99.10	48	99.90	48	99.90	48	99.90
Total County	**151**	**150**	**99.20**	**150**	**99.20**	**151**	**99.90**	**151**	**99.90**	**151**	**99.90**
Total State	**26,840**	**20,797**	**77.50**	**20,908**	**77.90**	**25,592**	**95.40**	**26,561**	**99.00**	**26,648**	**99.30**
Study Region	**26,840**	**20,797**	**77.49**	**20,908**	**77.90**	**25,592**	**95.35**	**26,561**	**98.96**	**26,648**	**99.28**

Source: OSHPD (2001)

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