PLANNING SCENARIO

IN HUMBOLDT AND DEL NORTE COUNTIES, CALIFORNIA FOR A GREAT EARTHQUAKE ON THE CASCADIA SUBDUCTION ZONE

SPECIAL PUBLICATION 115

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DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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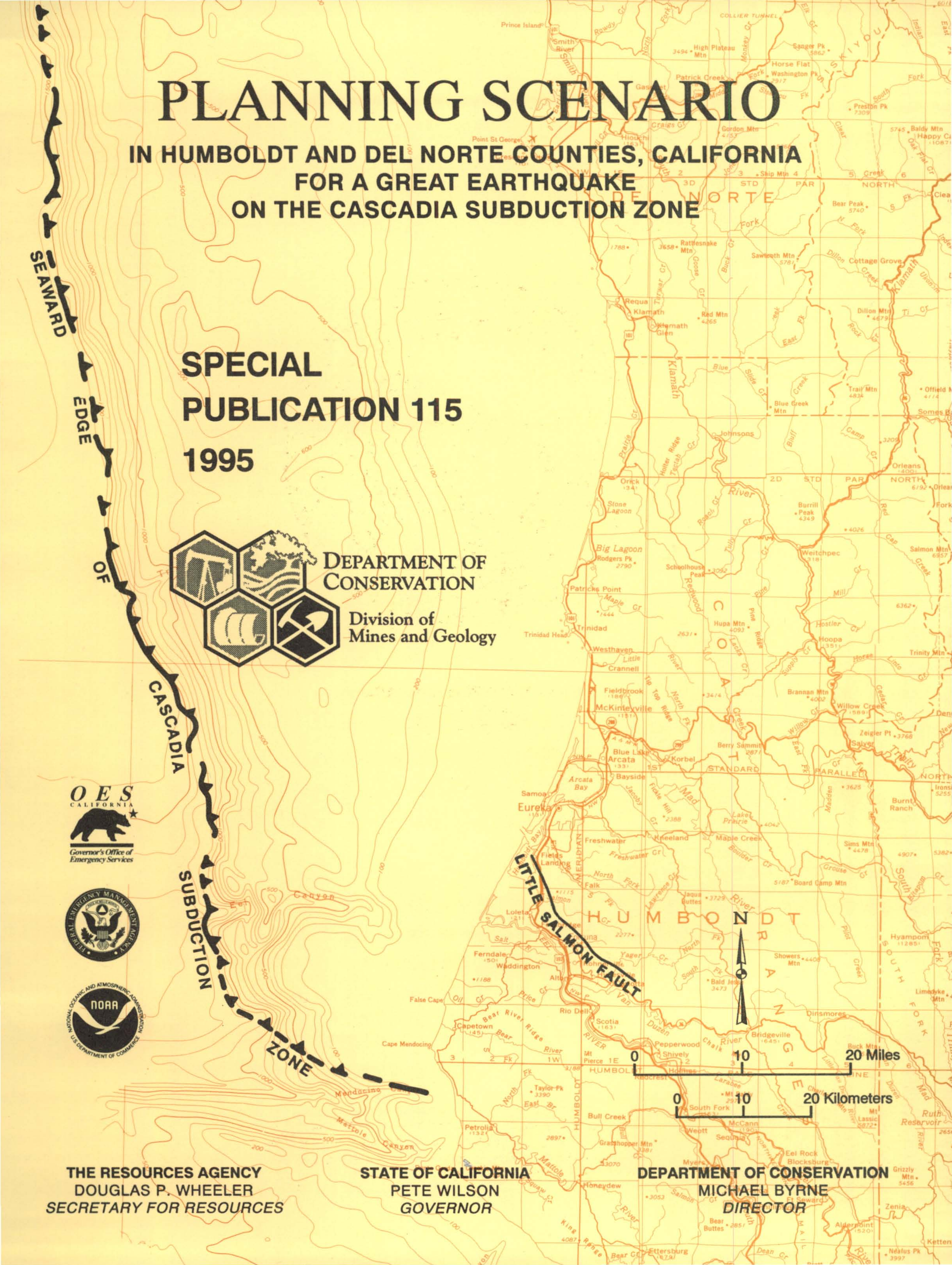

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PLANNING SCENARIO IN HUMBOLDT AND DEL NORTE COUNTIES, CALIFORNIA FOR A GREAT EARTHQUAKE ON THE CASCADIA SUBDUCTION ZONE

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INTRODUCTION

This report assesses the vulnerability of lifelines in northwestern California to a major earthquake on the Cascadia Subduction Zone (CSZ). The planning area, consisting of Humboldt and Del Norte counties, is about 50 miles (80 km) east to west and 140 miles (225 km) north to south. The area includes Eureka, Arcata, Crescent City, and many smaller communities. Over 150,000 people reside in the planning area, 127,000 in Humboldt County, and 29,000 in Del Norte County (Population Estimates, State of California, Department of Finance, 1.1.94, Report 94 E-1).

The regional geologic and seismologic basis for development of the scenario damage assessments includes the earthquake shaking intensities, the areas with potential for liquefaction, the areas subject to seismically induced landslides, and the generation of a seismic sea wave or tsunami. This information enables the reader to visualize the potential vulnerability of lifeline facilities.

The damage assessments illustrate a regional damage pattern that can result from an earthquake of magnitude (M) 8.4 on the Gorda segment of the CSZ. An earthquake of different magnitude or location on this fault, or an event on any of the other faults in the planning area, would result in different intensity and damage patterns.

The seismic intensity distribution from which the damage is assessed, is based on a particular model. There is no general agreement as to the most realistic model to be used for predicting intensity distribution, and a different model would yield a different intensity pattern. In addition, the quality of available information on which the seismic intensity distribution map is based varies throughout the planning area. Only general geologic information is available for most of the area. Modeling of ground shaking on a regional basis using this generalized geologic information produces plausible conclusions appropriate only for emergency planning. Conclusions regarding specific structures, such as the desirability of upgrading seismic resistance, require detailed engineering analysis and site-specific geologic information which are beyond the scope of this planning scenario. Likewise, the tsunami flooding scenario is based on an approximate model and is not site specific or accurate in detail.

While no planning scenario can be accurate in detail, it provides planners with a regional pattern of the types of problems that will confront emergency response personnel.

This planning scenario is intended to contribute to the efforts of the following users:

- Local, state, and federal officials with emergency planning responsibilities.

- Elected officials who need to visualize the threat in order to commit themselves to leadership in mitigating the hazard and planning for response.

- Private sector managers and planners who must understand the scope of the hazard to prepare for it.

- Educators, journalists, and others who must communicate to the public the character of the threat, and the importance of preparedness in mitigating its effects.

- The general public who need to support public mitigation efforts and develop personal strategies to minimize the effects of the earthquake on themselves and their families.

EXECUTIVE SUMMARY

The Cascadia Subduction Zone (CSZ) Gorda Segment

The CSZ is a 750 mile (1,200 km) long offshore major thrust fault zone extending from northern California to southern Canada. This planning scenario hypothesizes a M8.4 (moment magnitude) earthquake on the southernmost 150 mile (240 km) Gorda segment of the CSZ. This may not be the largest event that could occur along the CSZ, but it will produce within California about as much destruction as would a rupture of the entire zone. The probability of occurrence of the scenario earthquake is not known, but is sufficient to justify preparedness planning.

The Scenario Earthquake

The scenario earthquake is based on the following characteristics:

1. The Gorda segment of the CSZ, extending 150 miles (240 km) from Cape Mendocino to Cape Blanco ruptures in an earthquake of M8.4.
2. The ocean floor undergoes a maximum surface displacement of 26 feet (8 m), with the east side up, on a fault dipping 11 degrees to the east beneath Humboldt and Del Norte counties.
3. Sea floor deformation generates a destructive sea wave or tsunami.
4. Triggered offset along the Little Salmon fault averages 6 feet (2 m).
5. Potentially damaging ground shaking continues for about 60 seconds within 25 miles (40 km) of the fault. Humboldt and Del Norte counties are less than 25 miles above the CSZ fault plane which dips gently eastward, and are wholly within the zone of damaging shaking.
6. Potentially damaging aftershocks occur for several months following the main shock, with a few earthquakes in the M6 to M7 range.

Shaking Effects

Shaking intensities are generally greatest near the coast and decrease inland. This pattern is modified by the areal distribution of geologic materials that vary in their response to shaking. Overall, the intensities are high because the fault plane is directly beneath most of the coast at depths of 6 to 12 miles (10 to 20 km).

For alluvial sites, the Modified Mercalli Intensity (MMI) IX zone (MMI is described in Appendix A) extends inland from the coast about 45 miles (70 km) in southern Humboldt County, and about 6 miles (10 km) in northern Del Norte County.

The MMI VIII+ areas often surround the MMI IX areas, and cover the hills above Humboldt Bay and the Eel River Plain. Most of the three main population centers of the study area, Eureka, Arcata, and Crescent City, are in the MMI VIII+ area.

Local intensities could be greater than those from shaking only, mainly due liquefaction in alluvial areas, and landslides in hilly areas.

Tsunami

The scenario earthquake is assumed to generate a local seismic sea wave or tsunami that will arrive just minutes after the earthquake occurs. The lack of warning time from such a nearby event will result in higher casualties than if it were a distant tsunami source wherein the Tsunami Warning System for the Pacific Ocean could warn threatened coast areas in time for evacuation. **In low lying coastal areas, strong shaking should be taken as a warning of a potential tsunami, and individuals should immediately move to higher ground.** The tsunami model for this scenario was provided by the National Oceanic and Atmospheric Administration (Bernard and others, 1994).

In Humboldt County the greatest impact on populated areas will be the inundation of the Samoa Peninsula, and to a lesser degree the village of King Salmon, which faces the opening of Humboldt Bay (Map S-1). Earthquake damage to Highway 255 across the bay to Eureka and northward to Arcata will compound the tsunami problem by isolating the Samoa Peninsula. **A possible refuge from the tsunami might be afforded by a 1.5 mile-long by 300-foot-wide ridge of wooded dunes of elevation 40 to 70 feet just west of Manila, 2 miles north of Samoa, and 4 miles north of Fairhaven.** The tsunami impact on the village of King Salmon and the PG&E power plant will be less severe than on the Samoa Peninsula, but will compound the damage from intense ground shaking (MMI IX) and liquefaction. Humboldt and Arcata bays will be choked with debris from the Samoa Peninsula.

At Crescent City the tsunami destruction will exceed that which occurred from the 1964 Alaska tsunami. The 1964 run-up reached 4th Street, while this scenario postulates tsunami run-up reaching 8th Street. Crescent City experienced ten fatalities and over $7 million in damage from the tsunami caused by the M9.2 Alaska earthquake of 1964.

Damage Assessments

Damage assessments have been postulated for certain lifeline facilities. **The statements regarding the performance of facilities are intended for planning purposes only, and are not site-specific engineering evaluations.**

The scenario addresses primarily the initial 3 day response period. After 3 days, repairs and response will be dictated by the observed post-earthquake situation. The out of service times indicated below assume that equipment, repair materials, access to the damage site, and response personnel are available. If they are not concurrently available for all lifelines, then priorities must be set, and certain lifeline elements will be out of service for longer periods.

Schools and Colleges

The high schools and colleges will experience MMI VIII+ or IX ground shaking resulting in major nonstructural and some structural damage. Because of their size, location, and service facilities, public schools, and in particular high school buildings, are desirable as evacuation shelters and mass feeding centers.

For planning purposes, it is assumed that underground utility service lines such as water, natural gas, and sewage will be ruptured in soft ground areas. As a result, some schools will have functional impairments even if they remain structurally safe.

Humboldt State University, one of the system's older campuses, is located slightly north of Arcata and contains numerous buildings, varying greatly in age, type of construction, size, and occupancy. Some earthquake rehabilitation projects have been undertaken on the campus and others are yet to be completed.

The College of the Redwoods is new enough to have been built under the requirements of the Field Act, and no significant structural damage is expected from shaking. However, significant damage will occur because it is adjacent to the Little Salmon fault which will rupture in this scenario. Also, transportation and utility services will be interrupted where such systems traverse the fault.

Hospitals

While there are five hospitals in the main impact area, they have a total of only 348 beds. For response planning purposes, we anticipate that 119 (34 percent) will be unavailable for treatment of earthquake related casualties. This limited capacity plus the possibilities of damage, loss of utility services, disruption of roads, and the long distance to any other comparable facility, means that some of the most seriously injured may have to be evacuated by air to hospitals outside Humboldt and Del Norte counties.

Highways

Highway 101 will be unusable in most of Humboldt and Del Norte counties for at least the 3 day duration of this scenario and for up to a month later. The bridge between Eureka and the Samoa

Peninsula will also be unusable. Likewise easterly routes through the mountains (e.g. Routes 36, 299, 96, and 199) will be blocked by landslides and other damage. Planners need to identify access routes to communication centers, hospitals, airports, staging areas, fuel storage sites, and other locations necessary for emergency response. Highway outages will restrict emergency supplies from outside the area for 14 days.

Airports

Emergency air transport to and from the disaster area is vital to response activities, particularly during the first 3 days. The best options under the scenario conditions will be Arcata-Eureka Airport and McNamara Field in Crescent City, both of which can handle C-130 transport aircraft. The other small outlying airports in the planning area might be useable for small fixed wing and helicopter aircraft. They could be used to evacuate casualties and bring in key personnel and supplies. However, the condition of each would have to be determined before they are used as some may be damaged, require portable communications and air traffic control equipment, or be inaccessible due to damage to the connecting roads. Local emergency officials should consider these problems, by referring to the damage assessments listed in the Airports chapter.

Marine Facilities

Most of the docks in Eureka are supported on piles and are not expected to suffer severe damage from shaking. Tarmacs, aprons, access roads, and other paved surfaces placed over fill areas will fail due to settlement and spreading of soils owing to liquefaction induced by strong ground shaking. Humboldt/Arcata Bay is partially protected from tsunami damage by the Samoa Peninsula and South Spit. We expect the peninsula to be overtopped, and structures and lifelines there to be severely damaged. At Eureka harbor, debris from the tsunami and hazardous material spills will add to the earthquake damage.

In Crescent City severe damage to docks and other structures will be comparable to that experienced in the 1964 tsunami, causing loss of function for an extended period.

Railroads

The rail lines along the Eel River, Humboldt Bay, and Arcata Bay, will be disrupted by liquefaction and landslides and closed for repairs for several weeks. All movable span bridges in MMI VIII+ to IX zones are subject to misalignment due to heavy ground shaking. In general, we expect that many of the older bridges will be closed along the North Coast Railroad's right of way.

Electric Power

During the first 3 days after the earthquake the entire planning area will experience some loss of power, at least temporarily. The cities of Fortuna, Eureka, Arcata, and Crescent City are in strongly shaken areas (MMI VIII+ and IX) and will experience significant power outages. Service to most areas will be restored in 24 hours, but some parts of the cities and rural areas may experience outages lasting as long as 5 days.

The private power plants at Samoa and Fairhaven will be severely damaged by the tsunami. The PG&E power plant at King Salmon will be damaged by the earthquake more than by the tsunami.

Natural Gas

Sources of natural gas and propane that are outside the strongly shaken areas are not expected to be damaged or impaired by the scenario earthquake. Humboldt County is supplied by gas from Sacramento Valley and from Tompkins Hill gas field. Both transmission lines will be damaged where they cross the Little Salmon fault.

Numerous breaks and leaks will occur in service to mains connections and in the local distribution system throughout the strongly shaken area, especially wherever ground failure occurs as a result of liquefaction. Fires will break out in the downtown areas of Eureka, particularly where older wood frame buildings are clustered in areas of potential liquefaction. Local fires caused by gas appliance connections and in gas pipelines will occur in mobile home parks and other communities, particularly those experiencing MMI VIII or greater shaking.

The damage to water supply services will make firefighting difficult in these areas. Unless emergency water supply is immediately available, fire control could take from 48 to 72 hours.

Petroleum Products

Tanks bordering Humboldt Bay in Eureka will buckle and leak due to MMI IX shaking and liquefaction effects. Tanks in Crescent City will be destroyed by the tsunami, resulting in hazardous spills and fires. Given the area's dependence on imported supplies, and the vulnerability of Highway 101 and the local tank facilities, there will be a shortage of gasoline in the area.

Water Supply

The water supply from Humboldt Bay Water District intakes along the Mad River, and the Crescent City Water District intake along the Smith River will be reduced due to power outages and to transmission line breaks caused by liquefaction ground failures. There will be breaks in the distribution pipelines in residential areas. Localized fires will occur in some urban areas, and will be difficult to fight unless emergency water supplies are immediately available.

Waste Water

Soil liquefaction will be a major source of damage to treatment plants and to sewage lines. Untreated sewage will bypass damaged treatment plants and will be dumped into holding ponds, creeks, rivers, bays, or the ocean. The tsunami will damage treatment plants and outfall lines in Crescent City, Arcata, and Eureka.

PREVIOUS WORK

By the California Division of Mines and Geology

The Governor's Emergency Task Force on Earthquake Preparedness was established in February 1981. Some 30 committees were formed to deal with improvement of the many emergency response functions that would be needed in an earthquake emergency: communications, search and rescue, fire services, medical services, air transport, etc. A Threat Assessment Committee was also created to characterize the consequences of credible earthquakes as a basis for these emergency response planning efforts. Working with the Task Force, the Department of Conservation, Division of Mines and Geology developed two earthquake planning scenarios (Davis and others, 1982a, 1982b). These scenarios were based on a repeat of the 1906 San Francisco earthquake ($M \sim 8$) on the northern San Andreas fault and a repeat of the 1857 Fort Tejon earthquake ($M \sim 8$) on the south-central San Andreas fault.

With support from the National Earthquake Hazards Reduction program the Division of Mines and Geology also developed planning scenarios for the Hayward fault (Steinbrugge and others, 1987), and the Newport-Inglewood fault zone (Toppozada and others, 1988); with support from the Governor's Office of Emergency Services and the Federal Emergency Management Agency for the San Diego-Tijuana area (Reichle and others, 1990), the Riverside-San Bernardino area (Toppozada and others, 1993), and the northern San Francisco Bay area (Toppozada and others, 1994).

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Dr. Jack Evernden (USGS) provided critical discussion and input of the ground motion determination, and ran his model for a line source beneath Eureka for testing purposes.

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Jack McMillan (DMG) provided input and review for lifeline vulnerabilities in Eureka and Crescent City.

Robert Moskovitz (DMG) assisted with computing the distances from the surface to the dipping fault plane.

Ted Smith (DMG) reviewed the Geology and Seismology Chapter.

Claudia Hallstrom critically proofed and assembled the report.

Marialena Tabillo provided expert editing.

We are grateful to Joy Sullivan, Jim Williams, and Ross Martin for drafting the maps and to Jeffrey Tambert for supervising the publication.

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SECTION 1

GEOLOGY AND SEISMOLOGY

GEOLOGY AND SEISMOLOGY

This chapter outlines the geologic and seismologic input used to model the scenario earthquake, and to develop the map showing the shaking intensities and the areas susceptible to liquefaction and landslides. The generation of a local seismic sea wave, or tsunami, is also discussed.

We use **seismic intensity**, the **earthquake effects** on buildings, furnishings, etc. at a particular location, to evaluate damage. Intensity generally decreases with distance from the causative earthquake fault. Several intensity scales have appeared during the last century (Barosh, 1969). The Modified Mercalli Intensity (MMI) scale, used in this scenario, is reproduced in Appendix A.

Earthquake magnitude is an instrumental measure of **earthquake size**, regardless of location or intensity effects. Magnitude does not decrease with distance from the causative fault, because its calculation compensates for distance. Earthquakes of similar magnitudes can have different reported intensities because of population distribution and ground conditions. For example, the 1992 Landers earthquake (M7.5) had a maximum reported MMI of VIII, while the smaller 1994 Northridge earthquake (M6.7) had a larger maximum reported MMI of IX, because it occurred within a densely populated area.

The degree of ground shaking resulting from the scenario earthquake will depend on several factors. Among the most important is the distance from the fault plane and the site geology. Shaking generally diminishes with distance, and soft sediment can amplify ground motion increasing the potential for damage.

Earthquake Potential Along the Cascadia Subduction Zone (CSZ)

The CSZ is a 750 mile (1,200 km) long thrust fault extending offshore from northern California to southern Canada, and dipping gently eastward beneath North America (Figure S-1). On the south end, the CSZ intersects both the Mendocino fault and the San Andreas fault at the Mendocino triple junction. To the north, the fault zone intersects the Queen Charlotte fault, off the shore of British Columbia. The CSZ contains several plate segments that are subducting or thrusting beneath North America, as shown in Figure S-1. The southernmost segment is the 150 mile (240 km) long Gorda plate, which extends from Cape Mendocino to southernmost Oregon.

Geophysical measurements of the rocks on the sea floor indicate that the Juan de Fuca plate is being subducted or thrust beneath the North American plate along the CSZ at a rate of 1.6 inches/year (40 mm/yr) (Nishimura and others, 1984). Even though this movement or slip rate

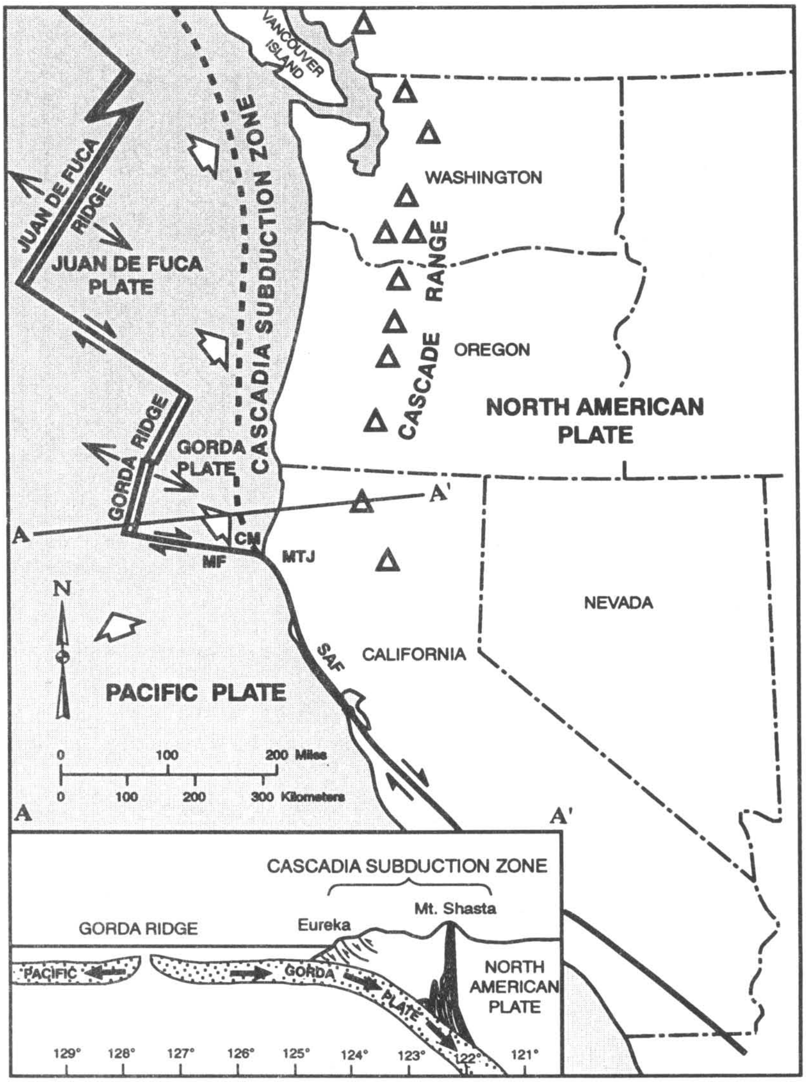

Figure S-1 Simplified map of northwestern California regional tectonics. To the south of the Mendocino triple junction (MTJ), the San Andreas fault system (SAF) is the transform (strike-slip) boundary between the Pacific and North American plates. North of Cape Mendocino (CM), the Juan de Fuca and Gorda plates are converging with the North American plate along the Cascadia subduction zone. West of Cape Mendocino, the Mendocino fault (MF) is the transform boundary between the Pacific plate and the Gorda plate. White arrows denote plate motion relative to North America; black arrows denote relative plate motion at plate boundaries. The inset is a simplified cross section of the southern Gorda plate being subducted beneath the North American plate in northern California. *Reproduced from Dengler and others, 1992.*

is comparable to the slip rate for the San Andreas fault in central California, the CSZ has generated no great earthquakes (M>8) and very few large earthquakes (M>6) during the 150 years of recorded history (Heaton and Kanamori, 1984; Heaton and Hartzell, 1987; Dengler and others, 1992). The 1992 Petrolia earthquake (M7) is the largest modern event associated with the CSZ (Oppenheimer and others, 1993).

Recent geodetic data indicate northeast convergence near the plate interface. Geologic investigations near the south end of the CSZ indicate a rapid 0.14 inch/yr (3.6 mm/yr) tectonic uplift along the coast, and that at least nine emergent terraces and beach ridges were formed during the past 5,000 years (Lajoie, 1983). For these nine terraces to form, the uplift (3.6 mm/yr x 5000 yr = 18 m) must have been episodic rather than gradual. It is possible they were created by nine large earthquakes occurring on average once every 500 years. The uplift of about 3 feet (1 m) produced during the M7 Petrolia event over a 6 mile (10 km) segment of the coast (Jayko and others, 1992; Stein and others, 1993) is significant in this regard.

Heaton and Kanamori (1984) observed that the CSZ shares many characteristics with other global subduction zones that have generated great earthquakes (e.g., southern Chile). Like the CSZ, these zones have young crust, shallow dips, weak gravity anomalies, and subdued trenches. Thus, by analogy, we expect that the CSZ could also rupture in a great earthquake.

The Gorda segment of the CSZ is composed of several fault strands that trend nearly north-northwest to south-southeast along most of the zone, changing to nearly east-west near Petrolia and the triple junction (Greene and Kennedy, 1989). The exact location of the southern boundary of the CSZ is not well established near the Mendocino triple junction. Although gravity and seismicity data have been interpreted as evidence that the CSZ extends southeast of Punta Gorda (Jachens and Griscom, 1983; Castillo and Ellsworth, 1993), other seismicity data and the 1992 aftershock pattern suggest that the seismogenic zone trends nearly due east of Punta Gorda (Smith and others, 1993; Oppenheimer and others, 1993). For this scenario we assume that the subduction zone extends southeast of Punta Gorda.

Little is known about the possible independent seismic activity of the Gorda segment of the CSZ. Offshore reflection and refraction data indicate that the CSZ crops out some 40 miles (60 km) west of Eureka in water 1.5 miles (2.5 km) deep (Greene and Kennedy, 1989). Clarke (1992) indicates that the earthquake-producing or seismogenic portion of the subducting plate may be distinguished by faults and folded sediments in the overriding plate that trend nearly normal to the direction of plate convergence. The seismogenic zone may also be distinguished by seismicity having compressional mechanisms. He suggests that the interface dips easterly at about 11 degrees, and that the seismogenic zone extends from about 12 miles (20 km) eastward of the surface trace of the CSZ at a depth of 5 miles (8 km) for about 50 miles (80 km), to a depth of about 14 miles (23 km), as indicated in Figure S-2.

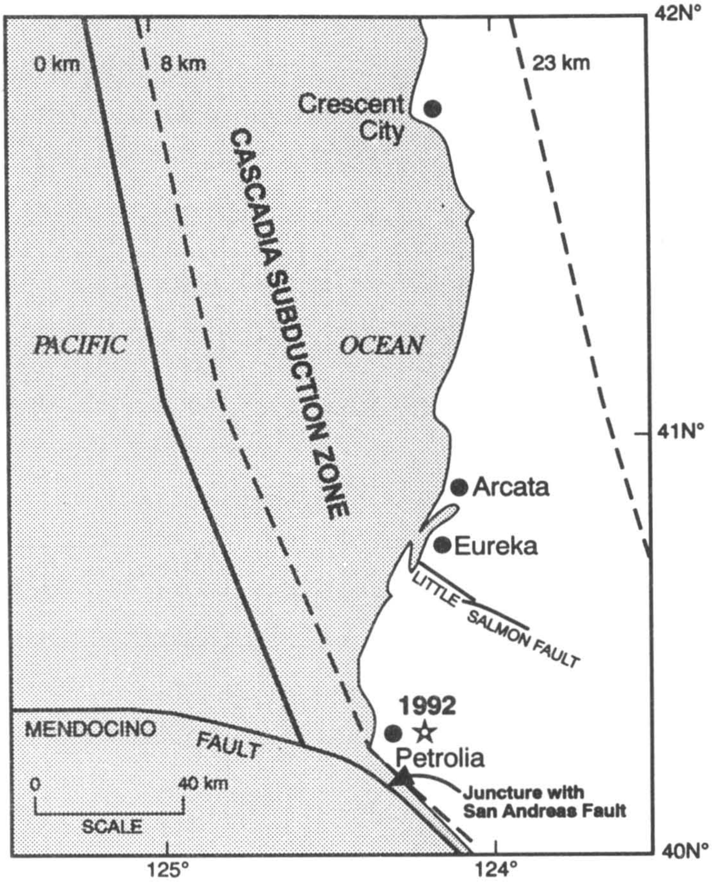

Figure S-2 The Gorda segment of the Cascadia Subduction zone (CSZ). The southern terminus is at the triple junction where it meets the Mendocino fault and the San Andreas, near the epicenter (star) of the 1992 Petrolia earthquake. The CSZ dips gently beneath Humboldt and Del Norte counties. It surfaces in the ocean bottom, indicated by 0 km. The earthquake-producing portion is between depths of 8 km and 23 km.

Earthquake History of Humboldt and Del Norte Counties

The April 25, 1992 Petrolia earthquake (M7) occurred along the CSZ and is a reminder of the potential for even larger events on this zone (Oppenheimer and others, 1993). This earthquake occurred at about 6 miles (10 km) depth and its aftershocks extended about 14 miles (22 km) north-south and 20 miles (32 km) east-west along a zone dipping shallowly to the east. The earthquake generated a small tsunami that arrived after the earthquake by 20 minutes at Eureka, and by 47 minutes at Crescent City. Waves continued to arrive for 10 hours, and the strongest wave (1.5 feet or 53 cm) arrived at Crescent City almost 4 hours after the earthquake (Oppenheimer and others, 1993; Gonzalez and Bernard, 1992). Damaging aftershocks of M6.6 and M6.7 occurred about 1½ and 5 hours after and 20 miles (30 km) west of the mainshock. They occurred beneath the CSZ, at a depth of 12 miles (20 km) on a strike-slip fault (Oppenheimer and others, 1992).

Earthquakes of M>6¼ that have caused damage (MMI>VI) in the planning area are listed in Table S-1, from the compilation of Dengler and others (1992).

TABLE S-1

EARTHQUAKES OF M>6¼ CAUSING DAMAGE IN HUMBOLDT AND/OR DEL NORTE COUNTIES

DATE	MAGNITUDE	MMI	LOCATION	REFERENCE
1873 November 22	6 3/4	VIII	Del Norte Co.	Toppozada & others, 1981
1906 April 18	8	VIII-IX	Mendocino Co.-Santa Cruz Co.	Toppozada & Parke, 1982
1909 October 28	6½	VIII	Cape Mendocino area	Toppozada & Parke, 1982
1922 January 31	7½	VI	60 km west of Arcata	Smith & Knapp, 1980
1923 January 22	7	VIII	Off Cape Mendocino	Smith & Knapp, 1980
1932 June 6	6¼	VIII	30 km W of Eureka	Toppozada & Parke, 1982
1941 October 3	6½	VII	40 km WNW of Cape Mendocino	Smith & Knapp, 1980
1954 December 21	6½	VIII	20 km NE of Arcata	TERA, 1977
1980 November 8	7	VII	50 km W of Trinidad	Berkeley Seism. Station
1992 April 25	7	VIII	Petrolia	Oppenheimer & others, 1993
1994 September 1	7	VI	140 km west of Petrolia	Dengler & others, 1995
1994 December 26	5.4	VI	16 km west of Eureka	----------

Paleoseismology

Since 1986, paleoseismic evidence has been accumulating for either a single large event (M9.5) or a series of smaller events (M8.4) having occurred along the CSZ about 300 years ago (Atwater, 1986, 1987, 1992; Atwater and Grant 1986; Carver and Burke, 1986, 1987a, 1987b, 1989, 1992; Burke and Carver, 1992; Clarke and Carver, 1992; Darienzo and Peterson, 1990; Grant and Minor, 1991). Current knowledge indicates that such events have a recurrence interval of 300 to 600 years (Wuethrich, 1994).

Geologic trench investigations near Eureka reveal that movement on the Little Salmon and similar faults may have occurred at the same time as the CSZ earthquakes (Carver and Burke, 1987a, 1987b, 1989, 1992).

Rationale for Selecting the Scenario Earthquake

The rationale for selecting the scenario earthquake is as follows:

1. Easterly movement of the Juan de Fuca at 1.6 inches/year (40 mm/yr) and Gorda plates beneath the North American plate continues to build strain that could be released in great earthquakes.

2. Coastal Humboldt and Del Norte counties are 6 to 12 miles (10 to 20 km) above the shallowly dipping CSZ.

3. Paleoseismic evidence suggests that large or great tsunami-generating earthquakes occur every 300 to 600 years along the CSZ in northern California.

4. CSZ earthquakes appear to be accompanied by movement on related land-based structures such as the Little Salmon fault.

5. The liquefaction, landsliding, strong ground shaking, and large local tsunami likely to be associated with the scenario event are hazards that can be mitigated through proper planning.

Characteristics of the Scenario Earthquake

This planning scenario assumes rupture of the 150 mile (240 km) Gorda segment of the CSZ (Figure S-2). Although this may not be the largest event that could occur along the CSZ, it would produce within California about as much destruction as a rupture of the entire zone.

Several empirical relations relate rupture length to average displacement for thrust earthquakes (e.g., Wyss, 1979; Scholz, 1982; Slemmons and Depolo 1986). From these relations, the average displacement predicted for the 240-km-long scenario rupture is between 16 and 26 feet (5 and 8 m). The displacement along the fault surface and the area of rupture determine the size of the earthquake. By using an average displacement of 8 m, and the plate rupture dimensions of 240 km length, and 80 km width (Clarke and Carver, 1992) we obtain a moment magnitude of 8.4.

The 1992 Petrolia earthquake is reported to have occurred on the CSZ. Oppenheimer and others (1993) indicate that the source of the 1992 Petrolia mainshock dipped about 13 degrees east, similar to previous interpretations of 10 to 15 degree dip from the seismicity along the CSZ (Smith and others, 1993; Clarke, 1992; Heaton and Kanamori, 1984, and Cockerham, 1984). For the scenario earthquake we use a rupture plane with a dip of 11 degrees and assume that the CSZ is at a depth of 6 miles (10 km) beneath the Petrolia earthquake epicenter, as indicated by Oppenheimer and others (1993).

Based on paleoseismic studies, the Little Salmon fault appears to generate 10 to 15 feet (3.5 to 4.5 m) of sympathetic coseismic slip during great CSZ earthquakes (Clarke and Carver, 1992). Therefore, we assume that the offset along the Little Salmon fault will be 12 feet (4 m) with the more prevalent average displacement at the ground surface being half the maximum value, or about 6 feet (2 m). The displacement is such that the northeast side of the fault is thrust over the southwest side along a plane dipping 15 degrees to the northeast. This will produce about 3 feet (1 m) of relative vertical movement along the Little Salmon fault, distributed across a deformed zone tens of feet wide.

We assume that potentially damaging ground shaking will continue for about 60 seconds within 25 miles (40 km) of the fault. Humboldt and Del Norte counties are less than 25 miles above the CSZ fault plane which dips gently eastward, and are wholly within the zone of damaging shaking. Potentially damaging aftershocks could occur for several months following the main shock, with a few earthquakes in the M6 to M7 range.

In summary, the scenario earthquake is based on the following characteristics:

1. The Gorda segment of the CSZ, extending 150 miles (240 km) from Cape Mendocino to Cape Blanco ruptures in an earthquake of M8.4.

2. The ocean floor undergoes a maximum surface displacement of 26 feet (8 m), with the east side up, on a fault dipping 11 degrees to the east, beneath Humboldt and Del Norte counties.

3. Sea floor deformation generates a destructive sea wave or tsunami.

4. The triggered offset along the Little Salmon fault averages 6 feet (2 m).

5. Potentially damaging ground shaking continues for about 60 seconds within 25 miles (40 km) of the fault. Humboldt and Del Norte counties are less than 25 miles above the CSZ fault plane which dips gently eastward, and wholly within the zone of damaging shaking.

6. Potentially damaging aftershocks occur for several months following the main shock, with a few earthquakes in the M6 to M7 range.

<u>Tsunami Hazard</u>

The scenario earthquake is assumed to generate a local seismic sea wave or tsunami that will arrive just minutes after the earthquake occurs. The lack of warning time from such a nearby event will result in higher casualties than if it were a distant tsunami source wherein the Tsunami Warning System for the Pacific Ocean could warn threatened coastal areas in time for evacuation. **In low lying coastal areas, strong shaking should be taken as a warning of a potential tsunami, and individuals should immediately move to higher ground.**

The tsunami model for this study was provided by the National Oceanic and Atmospheric Administration 1994 report entitled "Tsunami Inundation Model Study of Eureka and Crescent City, California" by Bernard, Mader, Curtis, and Satake. **That report produced 1:24,000 scale tsunami inundation maps for Eureka and Crescent City, but not for other coastal communities that are vulnerable to the tsunami.** Those maps are generalized on Maps S-1 and S-2 in Appendix B of the present report. The model did not examine the possibility of tsunami bores travelling up river valleys. Bores were a hazard in Alaska during the 1964 tsunami, and emergency planners should consider them a possible hazard in the present scenario.

The NOAA model assumes an incident wave 30 feet (10 m) high in water 150 feet (50 m) deep, based on historical tsunamis generated by earthquakes in the M8 to M9 range. The resulting approximate run-up is modeled at grid points separated by hundreds of feet, using topographic contours separated by tens of feet. This results in a plausible flooding scenario appropriate for emergency planning only. It is not intended as a site specific or accurate flooding scenario, because it is based on an incident wave of height estimated from the historical record, and an inundation model using a widely spaced grid on a rough topographic base. The nature of tsunami effects is discussed briefly in this section, as well as in the chapters on Buildings, Highways, Marine Facilities, Railroads, Electricity, Water Supply, Waste Water, and Petroleum.

In Humboldt County the greatest impact on populated areas will be the inundation of the Samoa Peninsula, and to a lesser degree the village of King Salmon, which faces the opening of Humboldt Bay (Map S-1). Earthquake damage to Highway 255 across the bay to Eureka and northward to Arcata will compound the tsunami problem by isolating the Samoa Peninsula. **A possible refuge from the tsunami might be afforded by a 1.5-mile-long by 300-foot-wide ridge of wooded dunes of elevation 40 to 70 feet just west of Manila, 2 miles north of Samoa, and 4 miles north of Fairhaven.** The tsunami impact on the village of King Salmon and the PG&E power plant will be less severe than on the Samoa Peninsula, but will compound the damage from intense ground shaking (MMI IX) and liquefaction. Humboldt and Arcata bays will be choked with debris from the Samoa Peninsula, and with spills of hazardous materials from the wood products processing facilities there.

At Crescent City the tsunami destruction will exceed that which occurred from the 1964 Alaska tsunami. Figure S-3 shows that the 1964 run-up reached 4th Street, while this scenario postulates tsunami run-up reaching 8th Street. Crescent City experienced ten fatalities and over $7 million in damage from the tsunami caused by the 1964 Great Alaska earthquake (M9.2). Serious damage can be expected to the part of the city and the unincorporated area of Del Norte County that lies to the southeast of Front and M streets along the shoreline, as happened in 1964. This area consists of hotels, motels, restaurants, marinas, commercial establishments, and some residences. In addition to the force of the wave, damage will result from water driven debris, such as logs, small boats, building materials, vehicles, etc. The following accounts from Crescent City of the 1964 tsunami are instructive:

> "At about 1:45 a.m. on the morning of March 28, the fourth and most destructive wave surged. ...Because the tsunami happened at night, the exact severity of the situation was not known until the following day. ...At Citizens Dock and the Crescent City Harbor, 26 boats had sunk like bathtub toys. The modern dock facility, built with pride only 14 years earlier, was a twisted mess. Fishermen on board their boats had to swim to safety amid lumber and driftwood as the waves surged and receded. ...The tsunami destroyed 29 city blocks in Crescent City, hurling mud, logs and cars into homes and

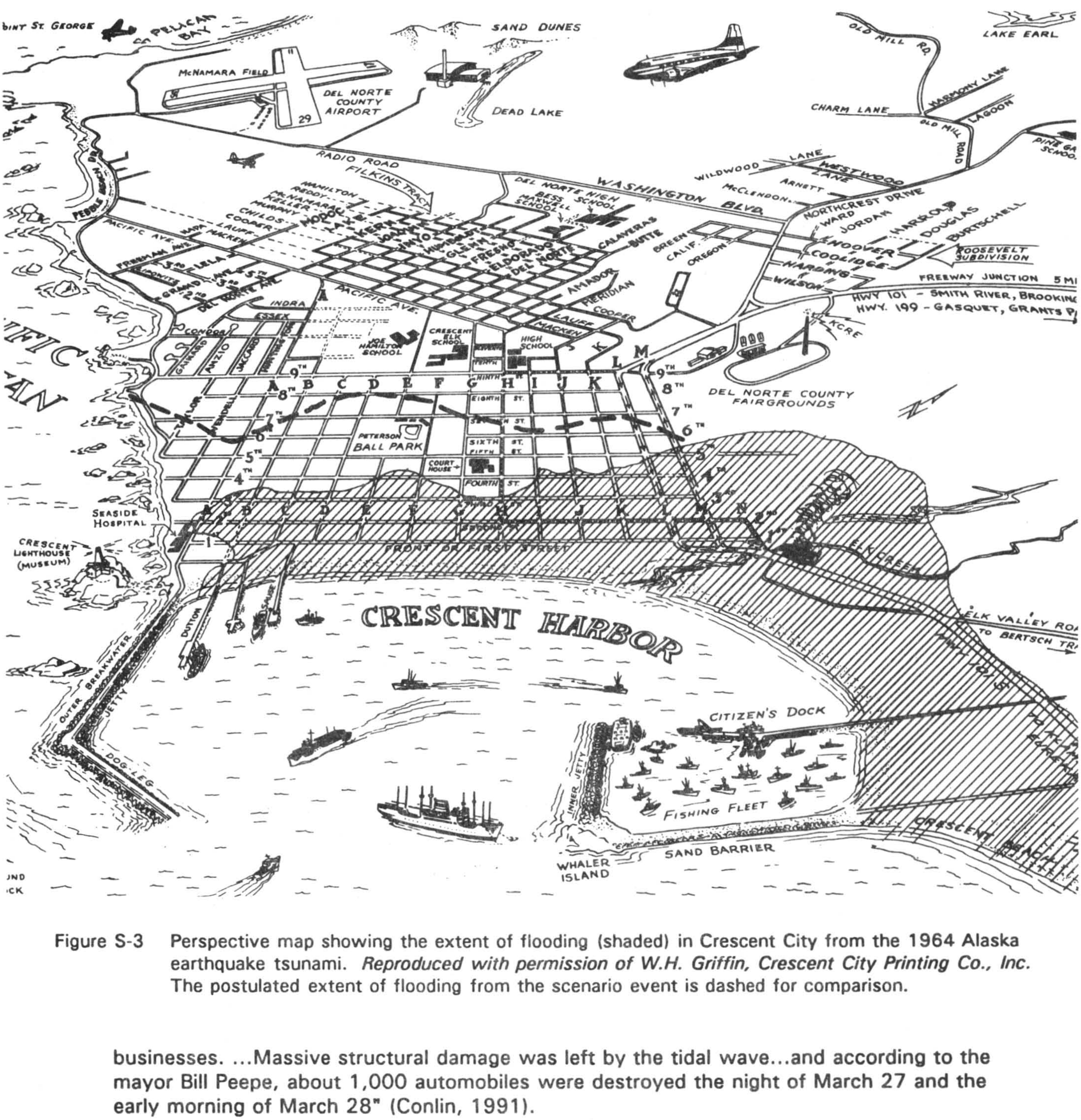

Figure S-3 Perspective map showing the extent of flooding (shaded) in Crescent City from the 1964 Alaska earthquake tsunami. *Reproduced with permission of W.H. Griffin, Crescent City Printing Co., Inc.* The postulated extent of flooding from the scenario event is dashed for comparison.

businesses. ...Massive structural damage was left by the tidal wave...and according to the mayor Bill Peepe, about 1,000 automobiles were destroyed the night of March 27 and the early morning of March 28" (Conlin, 1991).

"Crescent City harbor, especially facilities operated directly by the harbor district, or under direct jurisdiction of the harbor district, took a beating that left the area in a state of almost total devastation. The lumber wing of Citizens Dock was a shambles, and there were only enough piling standing along the main deck approach to the lumber and fish wings to keep the sagging floors from falling into the bay. The lumber wing resembled a washboard with planks from the dock floor and piling leaning crazily at all angles. The fish wing, newest portion of the dock, was in better shape, but had incurred extensive damage. ...Huge logs that, during floods on the rivers over the past years, had washed down onto the Del Norte beaches were brought in on the crest of the wave (engineers placed its highest crest at 20.78 feet) and used as battering rams to contribute to the fury of the force of the water. ...$1,250,000 was

> allocated for cleanup for health and safety reasons, including repair of the ocean outfall of the sewer system, replacement of a portion of the seawall, and repair or replacement of the devastated harbor facilities. ...Twenty-nine city blocks were left in total or partial ruins, and the devastation extended for a distance of approximately 2 miles (3 km) to the south of the city limits. Estimates of the cost or replacement of damage and destroyed public and private properties were later placed at $16 million" (Griffin, 1984).

These descriptions resulted from a tsunami originating in Alaska. A tsunami originating locally is expected to create more damage to an area that has just suffered intense earthquake shaking. The 1964 accounts illustrate the type of damage that can occur, and point out the danger of people returning to the evacuation zone after the first wave has receded. In 1964, the first damaging wave hit Crescent City at 11:03 pm, but the fourth wave that hit several hours later was the most destructive.

The 1992 Petrolia earthquake (M7) generated a small tsunami that arrived after the shaking by 20 minutes at Eureka and by 47 minutes at Crescent City. Tsunami waves continued to arrive for 10 hours, and the strongest wave arrived at Crescent City almost 4 hours after the earthquake (Gonzales and Bernard, 1992).

Ground Motion and Intensity

Shaking intensity maps have been prepared by the California Department of Conservation, Division of Mines and Geology and by Evernden of the U.S. Geological Survey for several large strike-slip earthquakes. This is our first scenario involving both a non-vertical fault and reverse slip. We developed a method to predict the seismic intensity distribution from previous subduction earthquakes elsewhere in the world (Petersen and others, 1993). The attenuation of ground motions and damage for a great earthquake along the CSZ would probably differ from an earthquake on a strike-slip fault due to the differences in fault geometry and radiation of seismic waves. Consequently, we have analyzed historical intensity data and peak acceleration attenuation relations derived from great earthquakes on subduction zones similar to the CSZ. We used two types of data from the global subduction earthquakes to produce an intensity map for the scenario earthquake.

1. Global Earthquake Analogy

We reviewed published maps of observed intensities and aftershock zones for large subduction earthquakes that occurred along the margins of the Pacific Ocean, using Pacheco and Sykes (1992) for moment magnitude and depth estimates. Crouse (1991) points out that subduction zones with characteristics similar to Cascadia exist in southwest Japan, Alaska, Central America, Colombia, Peru, and central and southern Chile. Intensity maps and aftershock studies are available for three earthquakes in Peru (Beck and Nishenko, 1990), one in Mexico (Reyes and others, 1979; Figueroa, 1973), and two in the U.S. (Algermissen and others, 1969; Oppenheimer and others, 1993; Stover and Coffman, 1993). We determined the configuration of the aftershock zone, estimated the trend of the trench, and measured on small scale maps the surface distance from the closest portion of the aftershock zone to each of the intensity zones.

Few of the published intensity data had a well defined MMI IX zone. Therefore, we analyzed the MMI IX zone from site-specific intensity data of the 1964 Alaska and 1992 Petrolia subduction earthquakes, as well as the 1906 San Francisco, and 1872 Owens Valley strike-slip earthquakes (Table S-2). During the 1964 Alaska earthquake, the city of Portage, Alaska experienced an intensity MMI IX. The best determined focal depths for aftershocks located near the city range from 6 to 18 miles (10 to 30 km). During the 1906 San Francisco earthquake, the city of Santa Rosa, about 17 miles (28 km) from the fault source also experienced MMI IX. Oppenheimer and others (1993) indicate that the city of Petrolia, which experienced MMI IX, was 6 miles (10 km) above the CSZ fault plane. In addition, several towns located about 12 to 15 miles (20 to 25 km) from the

TABLE S-2

INTENSITY-DISTANCE RELATIONS FOR SELECTED SHALLOW EARTHQUAKES OF DEPTH 10 TO 30 km

INTENSITY (MMI)	DISTANCE (km)[+]	INTENSITY (MMI)	DISTANCE (km)[+]
Owens Valley, 1872[x], M8.0		**San Francisco, 1906[x], M8.0**	
IX	25[*]	IX	28[*]
VIII	55[*]	VIII	70[*]
VII	120[*]		
Peru, 1942, M8.2		**Alaska, 1964, M9.2**	
VIII	70	IX	20[*]
VII	110	VIII	100
VI	220	VII	210
		VI	500
Peru, 1966, M8.1		**Mexico, 1973, M7.3**	
VIII	70	VIII	75
VII	140	VII	150
VI	200	VI	240
Peru, 1974, M8.0		**Petrolia, 1992, M7.0**	
VIII	75	IX	10[*]
VI	160	VIII	11
		VII	22
		VI	32

x The 1872 and 1906 earthquakes are mainly strike-slip events. The others six are subduction events.
+ Surface distance from aftershock zone to furthest extent of MMI value listed.
* Shortest distance to fault rupture plane.

1872 Owens Valley fault rupture also experienced MMI IX effects. Thus, even though not all sites close to the source experienced such high intensities, those sites experiencing MMI IX were generally within 12 miles (20 km) of the fault rupture plane.

We also analyzed the intensities from the April 13, 1949 (M7.1) and April 29, 1965 (M6.5) Seattle, Washington earthquakes that ruptured near the CSZ, but which are considered to be intraplate events (Crouse, 1991). Stover and Coffman (1993) showed that the intensity distributions for the 1949 and 1965 earthquakes were similar, although the 1949 event was more destructive. The intensity pattern for the 1949 event is asymmetrical and includes a MMI VII zone extending 25 to 45 miles (40 to 70 km) to the north and east, and 60 to 120 miles (100 to 190 km) to the south and west of the epicenter. The MMI VII zones for the Seattle earthquakes are of comparable dimensions to the MMI VII zones measured for the global subduction earthquakes we analyzed. The distances to each of the intensity zones are shown in Table S-2 and indicate that for each of the global earthquakes, the MMI VIII zone generally would extend entirely across the 50 mile (80 km) width of our planning area. We assume that the intensities reported from these earthquakes were primarily from soil sites, since few population centers are on rock sites.

2. Instrumental Estimates

Peak acceleration has been related to earthquake magnitude and distance from the fault. The peak horizontal acceleration attenuation relationships of Crouse (1991) and Youngs and others (1988) for subduction earthquakes on rock sites are generally compatible. These relations predict lower accelerations in the near field and considerably higher accelerations in the far field than the attenuation relationships for non-subduction earthquakes derived by Joyner and Boore (1988), and Boore and others (1993). The relationship of Youngs and others (1988) was particularly suited to our scenario earthquake because it uses the distance between the site and the fault plane. This relationship does not predict the high accelerations recorded during the 1992 Petrolia earthquake. Three of these exceeded 0.5 g or half the acceleration of gravity (Shakal and others, 1992), while the Youngs and others (1988) relationship for M7 would have predicted maximum accelerations for rock sites of only 0.17 g. This large discrepancy results partly from the effects of site geology and of topography. Consequently, we corrected for the geologic site effects.

We used the conversion relationship established by Trifunac and Brady (1975) from western United States earthquakes between MMI and peak horizontal acceleration. The conversion predicts intensity values that are well within the envelope formed by other conversion equations (Applied Technology Council, 1985). To test the applicability of the Trifunac and Brady (1975) relationship to the Cascadia subduction region, we converted the observed peak horizontal accelerations of the

1992 Petrolia earthquake (Shakal and others, 1992) to MMI and found reasonable correspondence with the MMI contours shown by Oppenheimer and others (1993).

For M8.4 and a distance of 12 miles (20 km), Youngs and others (1988) predict a shaking acceleration of 0.24 g (on rock-like material), which converts to MMI VIII according to Trifunac and Brady (1975). The MMI IX zone was commonly observed in past earthquakes at a distance of 12 miles (20 km) from the rupture as indicated in Table S-2. We used a site correction of one intensity unit to bring the MMI VIII on rock-like material (shear wave velocities (v_s) > 2,500 feet/sec or 750 m/s), up to MMI IX on alluvium. This assumes that rock-like material having v_s greater than 750 m/sec has a site correction that is halfway between hard rock (v_s > 5,000 feet/sec, Fumal and Tinsley, 1985) having zero correction, and alluvium (v_s < 1,200 feet/sec) having a correction of +2 MMI units (Table S-3). Thus the amplitudes of our intensity values are guided by the historical MMI data while their attenuation with distance follows the relationship of Youngs and others (1988).

To test the intensities that we derived for the scenario earthquake, we compared the intensities that would be expected from the Evernden and Thomson (1985) model and found reasonable agreement. Evernden (1993) ran his model for a line source at a depth of 15 km on the CSZ in the vicinity of Eureka, resulting in MMI IX on alluvium in coastal Humboldt and Del Norte counties, similar to our results. Our results are consistent with Heaton and Hartzell (1987), who used strong motion simulation methods to predict high accelerations of 0.6 g near the coast from subduction events, which corresponds to about MMI IX using Trifunac and Brady (1975).

Geologic Corrections

To account for the effects of geology, the intensity map was overlain by a geologic map for which each geologic unit was assigned a shaking intensity correction factor. The magnitude of this factor reflects the anticipated amplification of seismic shaking which occurs on geologic materials that are softer than crystalline bedrock. Table S-3 lists the geologic age and type of rocks in the map area and the shaking intensity correction factor assigned to each. Evernden and others (1981) have a range of 3 units for the correction factor, whereas we have a range of only 2 units because we consider liquefaction effects separately. Our classifications for some geological units also differ slightly from Evernden and others (1981). For instance, shear wave velocities have been found to be greater in Pleistocene deposits than in Holocene deposits (Fumal and Tinsley, 1985). Thus, we consider Pleistocene sedimentary deposits to be slightly more consolidated and to have slightly less intensity amplification (+1.8) than Holocene sedimentary deposits (+2.0). The anticipated MMI distribution for the scenario earthquake is determined by adding the correction factor to the intensity calculated for crystalline bedrock, and rounding to integer values. Half integers are shown only for

TABLE S-3

GEOLOGIC UNITS AND SHAKING INTENSITY CORRECTION FACTORS

GEOLOGIC UNITS	RELATIVE INTENSITY ADDITION FACTOR
Plutonic and Metamorphic Bedrock	0.0
Volcanic Rocks	0.3
Jurassic and Cretaceous Sedimentary Rocks	0.8
Late-Cretaceous to Eocene Rocks	1.2
Miocene Sedimentary Rocks	1.5
Mio-Pliocene to upper-Pliocene Sedimentary Rocks	1.7
Early to middle-Pleistocene Sedimentary Rocks	1.8
Holocene & Holo-Pleistocene Sedimentary Deposits	2.0

the MMI VIII range: 8- indicates 8.0 to 8.4, and 8+ indicates 8.5 to 8.9. The half integers help to differentiate between Late Cretaceous to Eocene rocks having a geological factor of 1.2 and rocks having geological factors of 1.7 (Mio-Pliocene) to 1.8 (Pleistocene), which will shake more strongly.

Intensities greater than MMI IX are not shown on Maps S-1, S-2, and S-3 because MMI X through XII are generally attributed to the secondary effects of ground breakage (faulting, liquefaction, landslides) which are identified separately.

Shaking Effects Predicted

Maps S-1, S-2, and S-3 show that shaking intensities are generally greatest near the coast and decrease inland. This pattern is modified by the areal distribution of geologic materials that vary in their response to shaking. For alluvial sites the MMI IX zone extends about 45 miles (70 km) inland from the coast in southern Humboldt County, and about 6 miles (10 km) inland from the coast in northern Del Norte County. For bedrock (v_s > 5,000 feet/sec or 1,500 m/s), the intensities are rarely above MMI VII. Overall, the predicted intensities are high because the fault plane is directly beneath most of Humboldt and Del Norte counties at depths of 6 to 12 miles (10 to 20 km).

The large MMI VIII+ areas generally are adjacent to and often surround the MMI IX areas and cover the hills above Humboldt Bay and the Eel River Plain. This zone also includes small parts of the southeast portion of the Smith River Plain, the Garberville-Redway area, and the alluvial river valleys on the east side of the study area. Most of the three main population centers of the study area, Eureka, Arcata, and Crescent City, are in MMI VIII+ to IX areas. The MMI VIII- area includes mountainous terrain of the southwest portion of the study area and includes the small towns of Shelter Cove, Honeydew, and Petrolia.

The MMI VII area is the largest intensity zone. It covers the mountainous terrain of the southeast and central portions, and the northern portion except the Smith River Plain. There are no large population centers in the MMI VII zone.

Local intensities could be greater than those from shaking only, mainly due to liquefaction in alluvial areas, and landslides in hilly areas.

Long period motion can shake tall structures at large distances from $M \geq 7$ earthquakes. For example, the M7 earthquake that occurred on the Mendocino fault in 1994 caused some concern to people in high rise buildings about 220 miles (350 km) away in Sacramento. The scenario earthquake would generate such long period motion as far away as Sacramento and San Francisco.

Ground Failure

Ground failure or ground breakage occurs when there is a permanent deformation of soil or rock. Ground failure, which can result in MMI>IX (Appendix A), can occur in isoseismal zones for which we would predict MMI values as low as VI based on shaking alone. Because ground failure results from special local conditions, we do not show MMI>IX on our regional maps. We present ground failure potential separately because it presents different engineering problems than does ground shaking alone.

Areas of potential ground failure on Maps S-1, S-2, and S-3 that could have intensities greater than MMI IX include:

a) Areas where the high water table and other ground conditions favor liquefaction.
b) Areas of potential landsliding, comprising much of the mountains in the planning area.
c) The areas of surface rupture on the Little Salmon fault.

Fault Rupture

The Alquist-Priolo Earthquake Fault Zoning Act

The Alquist-Priolo Earthquake Fault Zoning Act was enacted in 1972 to mitigate the hazard of surface fault rupture along active faults in California. The purpose of this Act is to avoid building structures for human occupancy across traces of active faults. Responsibilities for carrying out the provisions of the act are shared by State and local government. Specifically, the State Geologist (Department of Conservation, Division of Mines and Geology) is required to establish regulatory Earthquake Fault Zones (EFZs) for those faults considered to be "sufficiently active and well defined as to constitute a potential hazard to structures from surface faulting or fault creep." Cities and counties must regulate most building projects for human occupancy within the EFZs by requiring geologic investigations before issuing development permits. Some faults (Little Salmon, Hydesville, etc.) in the scenario area have been zoned under the Act.

The effectiveness of the Fault Zoning Act varies from place to place, depending largely on how well a particular fault is defined. Even so, the law only applies to new real estate development and to structures for human occupancy. Many structures, such as Highway 101 Overhead near Fields Landing and the southern part of the College of the Redwoods, sit astride or adjacent to the active trace of the Little Salmon fault. The extent of damage will depend on the amount of displacement that occurs locally on the fault and on measures taken to mitigate the hazard.

Rupture Postulated for the Little Salmon Fault

Displacement on the Little Salmon fault has likely accompanied previous large CSZ earthquakes (Clarke and Carver, 1992). Consequently, we assume that in addition to the main faulting on the CSZ, subsidiary faulting averaging 6 feet (2 m) and up to 12 feet (4 m) will occur on the Little Salmon fault across a zone tens of feet wide. This fault dips about 15° to the northeast. The EFZ extends from Highway 101 near the Fields Landing Overhead to College of the Redwoods and along the base of the hills northeast of Fortuna. This fault has been active during Holocene time and has a high potential for surface rupture in future major earthquakes on the CSZ (Carver, 1993; Wills, 1990; Carver and Burke, 1987b). The EFZs for the Little Salmon fault are appended to this scenario report.

Liquefaction

Areas with potential for ground failure due to liquefaction in this scenario earthquake were identified and plotted on Maps S-1, S-2, and S-3. Three factors must be present for liquefaction to occur:

1. A high water table.
2. Layers of loose sand.
3. Earthquake shaking of intensity greater than MMI VI.

Liquefaction susceptibility has been divided into two categories, high, and moderate to low. High susceptibility has been assigned to areas that have experienced liquefaction during past earthquakes and to alluvial areas having deposits of liquefiable sediments with groundwater within 10 feet (3 m) of the surface. These areas generally include artificial fills and natural deposits of bay mud, beach and dune sands, lake deposits, and active stream channels of Holocene age. Moderate to low susceptibility has been assigned to alluvial areas thought to contain limited liquefiable sediments where the groundwater table is at a depth of 10 to 30 feet (3 to 10 m). These areas include elevated river and marine terraces, older dune sand, and alluvial fans. Only scattered incidents of liquefaction are expected to occur in the moderate to low susceptibility areas.

The presence of a "free face" immediately downslope from a site increases the potential for liquefaction. In general, free faces exist along the banks of canals, rivers, channels, ponds, streams, lakes, and bays.

Seismic shaking will be sufficient to cause liquefaction in susceptible sediments throughout the study area. Much of the development in the southern half of the planning area is underlain by Holocene alluvial sediments which are susceptible to liquefaction. The areas delineated on Maps S-1, S-2, and S-3 as having high potential for ground failure include all deposits below high tide and fine fluvial deposits near the major rivers and creeks.

<u>Crescent City</u>

The northern half of the planning area is less susceptible to liquefaction because most of the area is underlain by consolidated sedimentary, igneous, volcanic, or metamorphic rock. The main population center is on the Crescent City platform. Although it is relatively flat land with a relatively high water table, the platform and its overlying beach deposits are of Pleistocene age (Davenport, 1982). Due to consolidation and cementation over time, deposits of this age in California have not been known to liquefy in modern times (Youd, 1994; Dwyer and Borchardt, 1994). There are only a few known cases of liquefaction in materials older than Holocene age. In the U.S., these have been associated with the Borah Peak, Idaho (1983), New Madrid (1911-1912), and Charleston (1886) earthquakes. Liquefiable deposits in the Crescent City area are confined mostly to the Holocene dune sands northwest of Lake Earl.

In preparing the intensity maps, we tentatively considered units Q (young alluvium) and Qs (dune sand) of Wagner and Saucedo (1987) to have high liquefaction potential and units Qby (late Pleistocene Battery Formation) and Qt (late Pleistocene river terrace) to have low liquefaction potential. Next, we modified this by using the water table data of Back (1957).

Judging mostly by the coarseness of the deposits, TerraScan (1976) considered liquefaction to be unlikely in the Smith River, Hiouchi, Gasquet, and Klamath-Klamath Glen areas. For Smith River, they wrote:

> "The possibility of liquefaction beneath the town of Smith River, or immediate environs, is considered minimal. Information from water wells in the area suggests that the area is underlain by fan deposits and terrace material that are not conducive to liquefaction. ...It is possible that liquefiable materials are present beneath the flood plain of the Smith River, but this remains conjectural"(p. 18-19).

For Klamath, they wrote:

> "Alluvial materials underlying the flood plain of the Klamath River and small tributary valleys are not likely to result in significant liquefaction because of their coarse consistency" (TerraScan, 1976, p. 21).

Humboldt Bay

In the Humboldt Bay area, the record of ground failure during earthquakes is substantial. Kilbourne and others (1980) show 42 localities, most of which experienced liquefaction in earthquakes that occurred in 1853, 1865, 1906, 1932, 1954, 1975, and 1980. The 1991 Honeydew earthquake (M6.2), triggered liquefaction along the Mattole River and Honeydew Creek channels (McPherson and Dengler, 1992). The M7 mainshock of the 1992 Petrolia earthquakes triggered extensive liquefaction in floodplain deposits of the Eel, Mattole, and Salt rivers (Prentice and others, 1992).

Our delineation of the zone of potential liquefaction was hampered by the lack of a water table contour map that we could use to distinguish between the zones of high and medium to low liquefaction potential within the alluvial units. The water well logs (Evenson, 1959) and geotechnical boring logs (Stevens, 1993) in the area generally show water levels in the young alluvial areas to be within 10 feet (3 m) of the surface at least part of the year.

Landslides

Nearly every large earthquake in a hilly area will produce seismically induced landslides (SIL), depending somewhat on the previous seasonal rainfall. The 1991 and 1992 earthquakes triggered hundreds of landslides, mostly associated with the road system, with one slide temporarily blocking Singley Creek (Dunklin, 1992). Lifelines are affected by two SIL effects: noncohesive falls and cohesive slides. Noncohesive falls include rock falls, soil falls, disrupted soil slides, and rock slides. Falls generally impact lifelines from above by depositing rocks that can cause disruption. Cohesive slides include rock slumps, soil slumps, rock block slides and slow earth flows. Slides generally affect lifelines from below by displacing supporting material.

During a great earthquake, such as the scenario event, the formation of large landslide dams across major streams poses yet another hazard. Monitoring this hazard via overland travel will be virtually impossible. As Dunklin (1992) wrote:

> "... [reconnaissance will be] difficult since many of the logging roads needed to reach remote areas are impassable due to fill failures, slumps, or rockslides" (p. 198).

Areas especially subject to SIL are shown on Maps S-1, S-2, and S-3. Not all the areas shown as susceptible to landslides will fail in this way, and some landslides could occur in areas not mapped as susceptible. Also, as a result of the scenario earthquake scattered landslides or rock falls will occur in susceptible areas outside of the scenario planning area, particularly during the rainy season. Techniques for analyzing SIL potential have been developed and used to produce a large scale map for San Mateo County (Wieczorek and others, 1986). These techniques can be applied on a site by site basis when the character of the bedrock is known (Wilson and Keefer, 1985), but for our regional analysis we used a more general approach. Three steps were taken to prepare the SIL overlay:

1. **Known Landslides**

   Large landslides were compiled from various references. Many of these previously mapped landslides are likely to be reactivated by the scenario earthquake (Carver, 1993).

2. **Potential Coherent Slides**

   Slopes of greater than 30 percent and less than 70 percent are shown as having a high potential for coherent slides in certain types of rock whenever the MMI is greater than VII. For most rock types the potential for coherent slides is moderate in MMI zones of VII or less. The potential for SIL usually increases with slope, but even the most unstable materials seldom experience SIL unless the slope is over 30 percent (Keefer, 1984). If the earthquake occurs in conjunction with unusually high moisture levels associated with the end of the rainy season or with improper drainage, even normally stable materials may fail. In the 1989 Loma Prieta earthquake (M7), most cohesive slides occurred in the area of MMI VIII or stronger shaking (Spittler and others, 1990; Manson and others, 1991). Because this scenario is for an M8.4 event of much longer duration (60 seconds vs. 15 seconds) than the 1989 event, we assume there will be some coherent slides in the MMI VII zone as well.

3. **Potential Noncoherent Slides**

   Slopes steeper than 70 percent are shown as having a potential for noncoherent falls. Loose materials at the angle of repose (typically 33 to 37 degrees, or 65 percent to 75 percent slope) require only a slight horizontal acceleration to cause them to tumble down slope. Falls are common in MMI zones as low as VI (Keefer, 1984). We expect most of the steep areas to have noncoherent falls. There also will be numerous falls from steep road cuts in both counties. Further, beneath each steep slope lies a "runout" zone of about half the height of the slope wherein noncoherent falls may impact (Keefer, 1991). Some of these slopes could be affected by coherent slides as well. Most of these steep zones are not near populated areas, and should have only localized effects on lifelines.

SECTION 2

BUILDINGS AND STRUCTURES

BUILDINGS AND STRUCTURES

Introduction

Seismic performance provisions in California building codes are intended to protect life and reduce the potential of property damage. Even though it is not yet possible to precisely forecast the exact magnitude, time, and location of the next earthquake, it is apparent that the existing building stock in California will be subjected to damaging earthquakes. By establishing the year 1933 (Long Beach earthquake) as an applicable baseline in the development of earthquake-resistant design, it has become possible to develop a general relative scale for an overall understanding of the seismic performance and vulnerability (i.e., hazard potential) of representative building classes to earthquakes. For a definitive source of building classification methods, refer to Algermissen and Steinbrugge (1978). In the development of seismic building codes and improved earthquake-resistant design since 1933, experience provides us with relationships between building classes, construction types, and their seismic performance that allows for the damage assessment of classes of structures on a collective, technical, and probabilistic basis.

Earthquake scenarios describing damage patterns and damage estimates are not precise predictions of what will occur, but are objective assessments developed for emergency planning. A statement that a building, facility, or lifeline system will survive, remain operable, or be severely damaged, can be given only in probabilistic terms.

According to Steinbrugge and others (1978, p. 79):

> "One cannot predict that a person who is driving under the influence of alcohol will certainly have an accident, but one can state that the probabilities are significantly higher than if he were not. Knowing building construction types and past earthquake performance of structures with given characteristics, realistic scenarios of probable damage can be developed for use in disaster response planning. ...The numerical values associated with each response planning topic represent reasonable maximum expected conditions. In other words, these values are credible; they have past data or experienced judgement behind them. The quality of the numbers vary depending upon the extrapolation of past data, the reliability of the assumptions supporting the calculations, and the quality of judgement behind the decisions."

The actual effects that earthquakes have on buildings and facilities depends on many variables, including:

1. Magnitude of the earthquake
2. Geological characteristics of the site
3. Location of earthquake
4. Severity and duration of ground shaking
5. Ground response according to soil types
6. Soil structure interaction

7. Code provisions in force at the time of the building's design
8. Building construction type, configuration, and size
9. Quality of construction
10. Proper building maintenance by the owner once the building is occupied.

One of the most important variables used to assess a building's seismic performance is its date of construction. Building code provisions are normally not retroactive and many existing buildings have not had the benefit of advanced performance standards that were developed after construction. For one recent exception to this, refer to the section on unreinforced masonry buildings.

Seismic Considerations

Building Damage and Ground Motions

The success with which a building responds to the dynamic loads induced by earthquake ground motions determines the level of its seismic performance. Seismic performance standards for buildings provide for life safety (i.e., to protect life) and are only partially directed toward damage control. Exceptions include the 1973 California Hospital Act and the 1933 Field Act.

The "life safety" approach is based on an underlining philosophy that earthquake-resistant design be used to develop the capacity of structures to "resist major earthquakes of the intensity or severity of the strongest experienced in California without collapse, but with some structural as well as nonstructural damage. In addition, the code indicates that "In most structures, it is expected that structural damage, even in major earthquakes, could be limited to repairable damage." Design for damage control usually encompasses life safety, however, design for life safety (i.e., minimum code standards), does not necessarily include damage control.

The following description of earthquake ground motions and building response is abstracted from Steinbrugge and others (1987, pp. 80-82).

> "Human observations as well as seismographic records show that the very rapid and violent ground oscillations (short period motions) in the epicentral regions are quickly damped and dispersed, leaving principally slower long-period motion at the greater distances from the earthquake source. The greater the distance, the slower the observed predominant oscillations. The predominant oscillations at large distances from the earthquake can be so gentle that they may not be felt by all persons, and yet be strong enough to cause water in reservoirs to oscillate with some destructive effects.
>
> Buildings respond differently to different kinds of ground motion. Each building has its own specific vibrational characteristics based on its stiffness. Each building will therefore respond to the particular ground motion at the site in a specific manner. One of these vibrational characteristics is termed the structure's natural period of vibration. In general, the taller the building, the longer is its natural period of vibration. If the building's natural period of vibration roughly coincides with a few cycles of the principal motions of the earthquake, quasi-resonance will occur. As a result, the vibratory motions of

the building may dramatically increase, along with damage. Damage from quasi-resonance is generally observed in taller buildings from distant earthquakes.

Based on the changes in ground motions as a function of increasing distance, observed damage patterns tend to reverse with distance. Damage to low, rigid (short-period) buildings predominate over high-rise (long-period) damage in the epicentral and energy-source regions nearer the fault. At distances over 100 miles, for example, high-rise building damage may predominate over that of even poorly built one-story structures. This was dramatically evidenced in Mexico City during the September 1985 earthquake.

The historical damage patterns are associated with short-period motions (i.e., rapid back-and-forth motions). Isoseismal maps are based on short-period effects. In general, light mass structures perform much better than do heavier mass structures. Conceptually, this is due to the fact that the ground moves away from the structure during an earthquake, and the structure must follow these movements. The heavier the mass of the structure, the greater will be the inertial (resisting motion) force on the structure. Therefore, a "heavy substantial" building which is not designed to be earthquake resistant is more likely to fail than a "flimsy" wood frame structure. Countless examples of this exist throughout the historic record.

Long-period motion principally affects high-rise buildings. An excellent example of long-period effects is demonstrated by the 1952 Kern County, California, earthquake. This earthquake resulted in numerous instances of nonstructural damage to multi-story steel or concrete frame buildings in Los Angeles and Long Beach, but essentially no damage to one- and two- story buildings of any kind in the same area. These cities are located 70 to 90 miles from the epicenter. Generally, the affected buildings were 10 to 12 stories high and had a measured natural period of vibration of 1 to 2 seconds, but buildings as low as 6 stories were also damaged. (The many modern high-rise structures of over 20 stories did not exist then.)"

Building codes have been one of the principal mechanisms used to reduce the damaging effects of earthquakes. The record indicates that earthquake-resistant designs are effective. Most major structures perform well. Exceptions have occurred when:

a) The design barely meets the minimum standards.
b) The building is not built according to the architect's or engineer's specifications.
c) The building owner modifies structural components of the building after its occupancy.

Special Earthquake Hazard Mitigation Legislation In California

The Field Act

After the 1933 Long Beach earthquake, the California Field Act for the safety of public schools was enacted and assigned to the Office of the State Architect. As evidenced by the 1952 Kern County, 1983 Coalinga, 1987 Whittier-Narrows, and 1989 Loma Prieta earthquakes, the resulting higher standards proved to be very successful. During the immediate emergency recovery period after the 1989 Loma Prieta earthquake, for example, the Marina Middle School successfully served as a shelter for the homeless and as an emergency services command post in the severely damaged Marina District of San Francisco.

The Field Act originally applied only to new public schools (private schools were not included in the mandate). As the act was not retroactive, all remaining older public schools throughout California continued to be used. However, in 1969, the Garrison Act was enacted as follow-up legislation to deal with the difficult task of abating the hazard posed by the older public schools still in existence, and required the abatement of hazardous older schools by 1978. Few non-Field Act public schools remain, although some older private schools still pose an earthquake hazard.

Hospital Act and Unreinforced Masonry Building Abatement Act

In addition to the Field Act, three other special California earthquake laws were enacted in 1973, 1986, and 1993:

1. The 1973 Hospital Act which was adopted after the 1971 San Fernando earthquake.
2. The Unreinforced Masonry (URM) Building Act (also known as Senate Bill 547 and later as Section 88-75) enacted in 1986.
3. An earthquake hazard disclosure requirement for residential dwellings adopted as part of the provisions in the Business and Professional Code (originally proposed as Assembly Bill 200) implemented in January 1993.

All three provisions are state mandated and developed to improve the seismic performance of buildings.

Potentially Hazardous Buildings

Certain types of buildings have had a much greater incidence of earthquake damage than others. These are often designated as potentially hazardous buildings. The most common types of potentially hazardous buildings found in the Humboldt and Del Norte County areas include:

1. Unreinforced masonry buildings
2. Pre-1940 wood frame houses
3. Tilt-up buildings
4. Pre-mid 1970s concrete frame buildings
5. Mobile home

Each of these is discussed below. Planners must be aware of the hazards that they present, including the consequences and impact of their failure on the local community.

Unreinforced Masonry Buildings

These are old brick buildings (Figure B-1) built in the 1930s or before. Some are historic structures. URM structures, particularly bearing-wall structures, are classified as one of the more hazardous

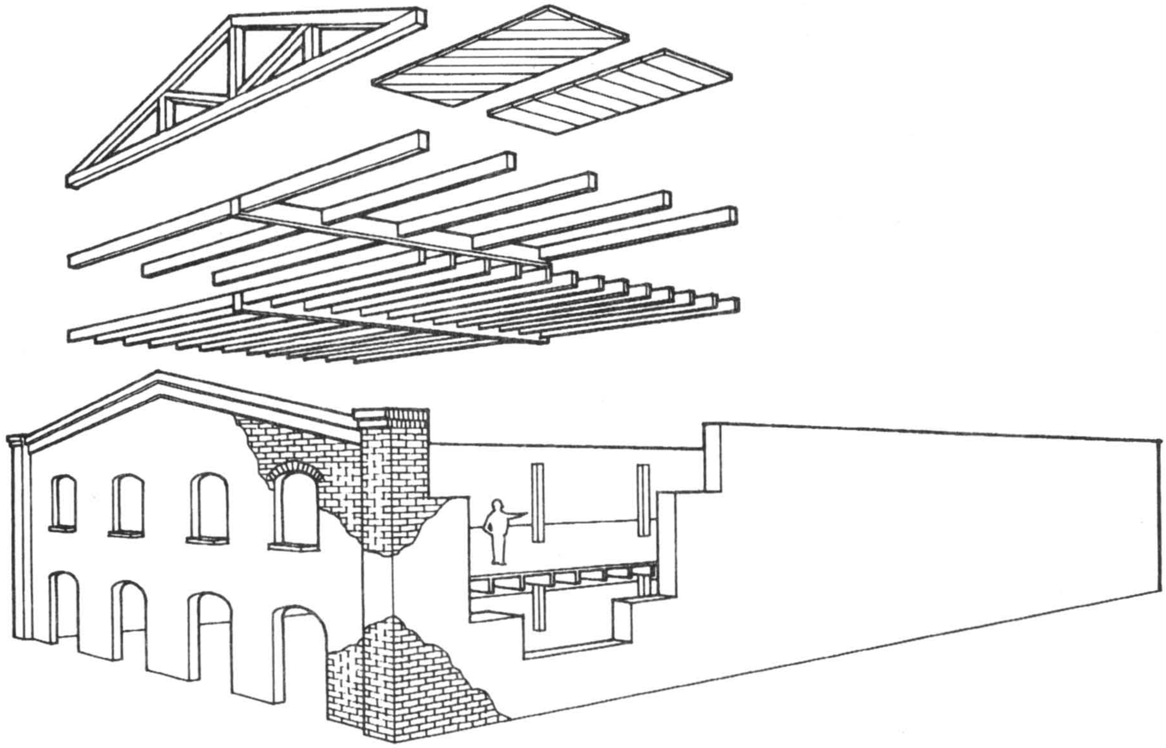

Figure B-1 Typical unreinforced masonry bearing wall building (URM). *From Lagorio and others (1986).*

forms of construction found in the United States. After a strong earthquake, those that have not collapsed are usually so heavily damaged that in many cases demolition is required.

URM buildings have several typical characteristics. First, they do not have steel reinforcing in the wythes of brick, hence the name "unreinforced masonry." Second, they are often built with weak mortar, or mortar that has deteriorated with age. Many also lack metal ties connecting the walls with floor or roof structural members. It is this latter characteristic, in particular, that makes these structures a hazard. During an earthquake, exterior walls often fall outward, creating a serious life safety risk to pedestrians or people running from the building (Photo B-1).

Cities in Uniform Building Codes Seismic Zone 4 in California are required by the state, under Senate Bill 547, to identify and mitigate the hazards of existing URM buildings in their jurisdiction.

<u>URM Buildings in the Study Area</u>

As in other older jurisdictions of California, principal cities in the study area also have an inventory of existing URM buildings. Typically, these URM buildings, which range from one to four stories, are

Photo B-1 Unreinforced brick buildings frequently lose parts of walls in earthquakes. Falling brick is a major life-safety concern. This structure was damaged in the 1987 Whittier earthquake.
Photo by Ronald Gallagher.

concentrated in the older downtown areas of cities. Occupancy of this building class tends to be related to industrial, commercial/mercantile (retail stores, offices, etc.), apartments, and hotel uses.

There are relatively few URM buildings in the study area because wood remains the principal building material. All principal cities (Eureka, Arcata, Fortuna, Crescent City) were visited and local building officials were consulted about the status of URMs in their communities. Eureka has approximately 25 URM buildings in the older waterfront/central business district area (refer to Figure B-2). The other communities have few or no URMs, and where they exist URMs are separated widely in the older areas of these towns. For example, Arcata has about three URMs located in the general vicinity of the city square.

EERI (1990, p. 127) gives the following description of URM damage:

> "Much of the spectacular building damage that resulted from the Loma Prieta earthquake was suffered to pre-code structures, principally the unreinforced masonry type (URM). Such

buildings, constructed of wood-frame roof and floor systems supported by thick unreinforced brick walls, were commonly constructed throughout California before the adoptions of building codes with provisions to make buildings seismic-resistant. ...Unreinforced masonry buildings

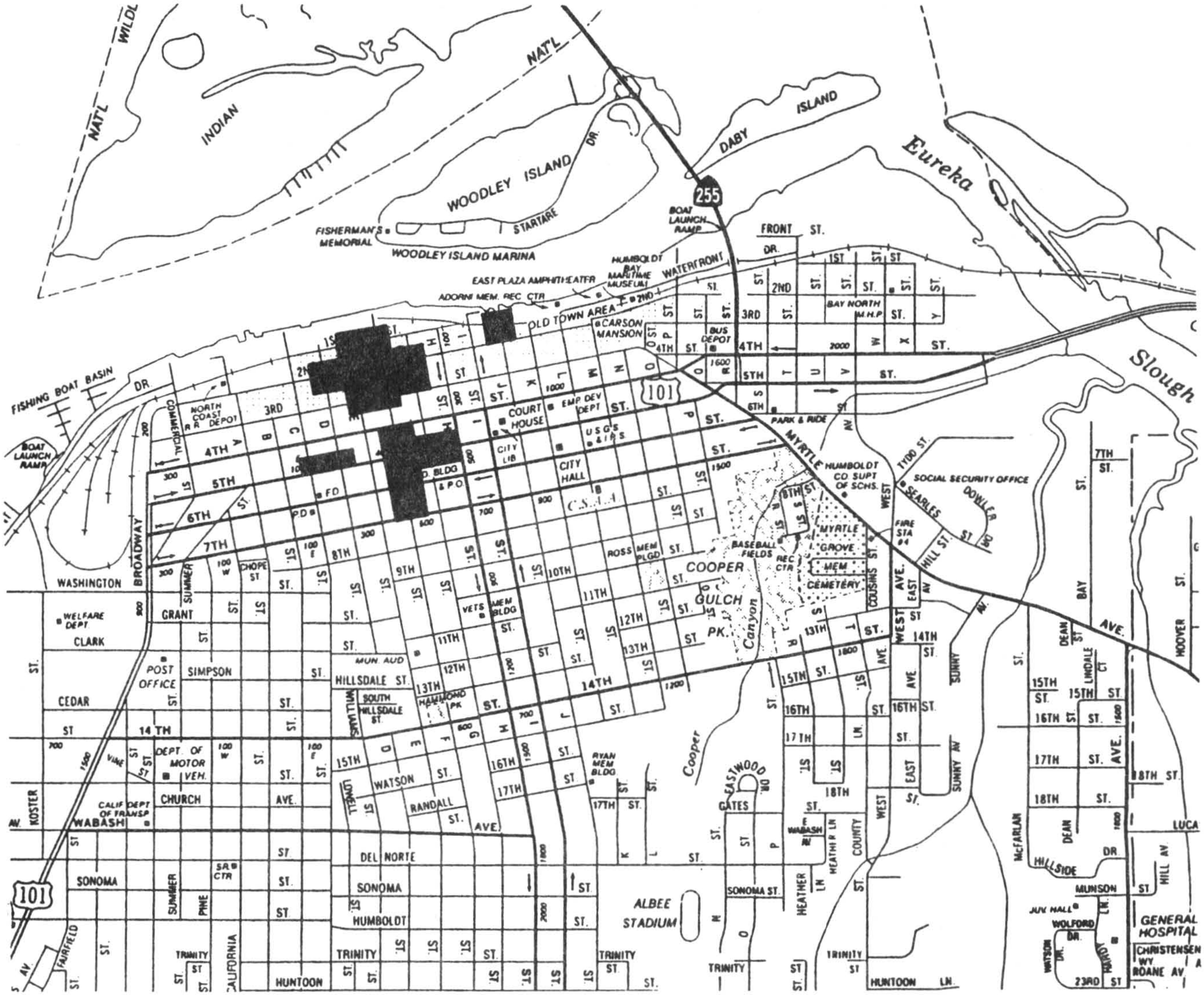

Figure B-2 Schematic distribution of URMs in Eureka.

failed in areas close to the earthquake epicenter and as far away as San Francisco and Monterey. ...The major shaking in and around Santa Cruz contributed to heavy damage to the unreinforced masonry buildings, particularly in the Pacific Garden Mall. Because unreinforced masonry buildings are non-ductile, brittle structures whose lateral systems are incapable of dissipating energy in an inelastic manner, the strength of these short-period buildings must exceed the product of their reactive weight and the peak ground acceleration in order to survive seismic shaking. Many of the buildings failed. The observed modes of failure were similar to those that occurred in other earthquakes: out-of-plane brickwork failure, diaphragm flexibility/failure, in-plane brickwork failure, and pounding."

Totals according to types of damage patterns suffered by URM buildings in the San Francisco experience are summarized below in Table B-1.

TABLE B-1

TYPES OF DAMAGE TO URM BUILDINGS IN THE CITY OF SAN FRANCISCO AFTER THE 1989 LOMA PRIETA EARTHQUAKE

Source: EERI, 1990, Table 5.1

TYPES OF DAMAGE	NUMBER OF BUILDINGS
Falling individual units or Trim	103
Veneer damage or delamination	100
Falling of portion of the wall	61
Falling of entire wall	36
"X" cracks in spandrels	125
Vertical cracks in spandrels	176
Pies or walls ("X" or stepped cracking)	198
Horizontal cracks at top/bottom of pier	201
Damage from debris from adjacent buildings	7
Roof or floor failure due to movement of exterior wall	13

For the 1954 Eureka earthquake (M6.5) Steinbrugge and Moran (1957) state:

> "Building damage was generally minimum or slight, with exceptions which are discussed later. There was practically no damage to reinforced concrete, reinforced hollow concrete block and wood frame buildings. Unreinforced brick masonry with sand lime mortar took the brunt of the damage. On the other hand, the authors saw no damage to brick masonry wherein cement mortar and reinforcing steel were used."

The Eureka experience is summarized in Table B-2.

During the 1994 Northridge earthquake, a further record was obtained on the performance of URM buildings by comparing retrofitted URM building with those still in their unretrofitted state:

> "Observations are that retrofitted URM buildings performed better than unretrofitted ones. Even so, some retrofitted buildings suffered parapet and wall damage, and a few wall collapses occurred. Unretrofitted URM buildings generally suffered more extensive damage, and a significant number of partial or complete collapses were observed. Typical damage to 2-story commercial/ residential unretrofitted URM construction included the falling of parapets, shear cracking of walls, the failing of walls loaded normal to their plane, and partial collapse because of the loss of corner piers" (EERI, 1994).

In this scenario, most cities with URM buildings will have strong ground shaking intensities of MMI IX. Damage to those URM buildings will be severe and extensive. For planning purposes, we assume that URM buildings in Eureka, Arcata, and Crescent City will partially collapse.

TABLE B-2

DAMAGE TO PRIVATE BUILDINGS WITH MASONRY WALLS IN EUREKA AFTER THE 1954 EARTHQUAKES

Source: Steinbrugge and Moran (1957)

WALL MATERIAL	NUMBER OF BUILDINGS DAMAGED		
	MINIMUM DAMAGE[A]	SLIGHT DAMAGE[B]	MODERATE DAMAGE[C]
Brick[D]	4	14	4
Reinforced concrete	8	5	0
Hollow concrete block[E]	7	1	0

[A]Incidental plaster damage, glass breakage, possibly small chimney damage. Some with no apparent damage.
[B]Same as "Minimum" except more extensive, especially with respect to plaster damage; no significant structural damage.
[C]Loosened and cracked masonry parapets; buildings readily repairable; loss usually less than 10 percent of building value.
[D]With sand-lime mortar and no reinforcing steel; not to be confused with reinforced grouted brick masonry construction which may be earthquake-resistant.
[E]Probably many are reinforced and have other than sand-lime mortar.

Pre-1940 Wood Frame Houses

Because of the history of the timber industry in the study area, wood frame buildings (Figure B-3) are the most common type of construction in Humboldt and Del Norte counties. Most wood frame structures are single-family dwellings with stud walls. Well-designed wood frame structures have a very good earthquake performance record, but an important class of wood frame dwellings has had major problems.

Wood frame dwellings built before 1940 often shift on or fall off their foundations during earthquakes. This has been due to lack of foundation anchorage, unbraced post and pier support, or weak cripple walls (cripple walls are those walls between the foundation and the first floor). The dwellings become unusable and may be posted "unsafe" by the local building department after a major earthquake. While the life-safety risk is low, repairs can be expensive, and the occupants must find new shelter during the reconstruction.

During the 1992 Petrolia earthquake (M7), damage to pre-1940 house was wide spread in the strongly shaken areas.

> "...most of the buildings that suffered damage in this earthquake were wood frame houses and one and two-story wood frame commercial buildings. Homes slid off foundations. Chimneys collapsed" (EERI, June 1992a).

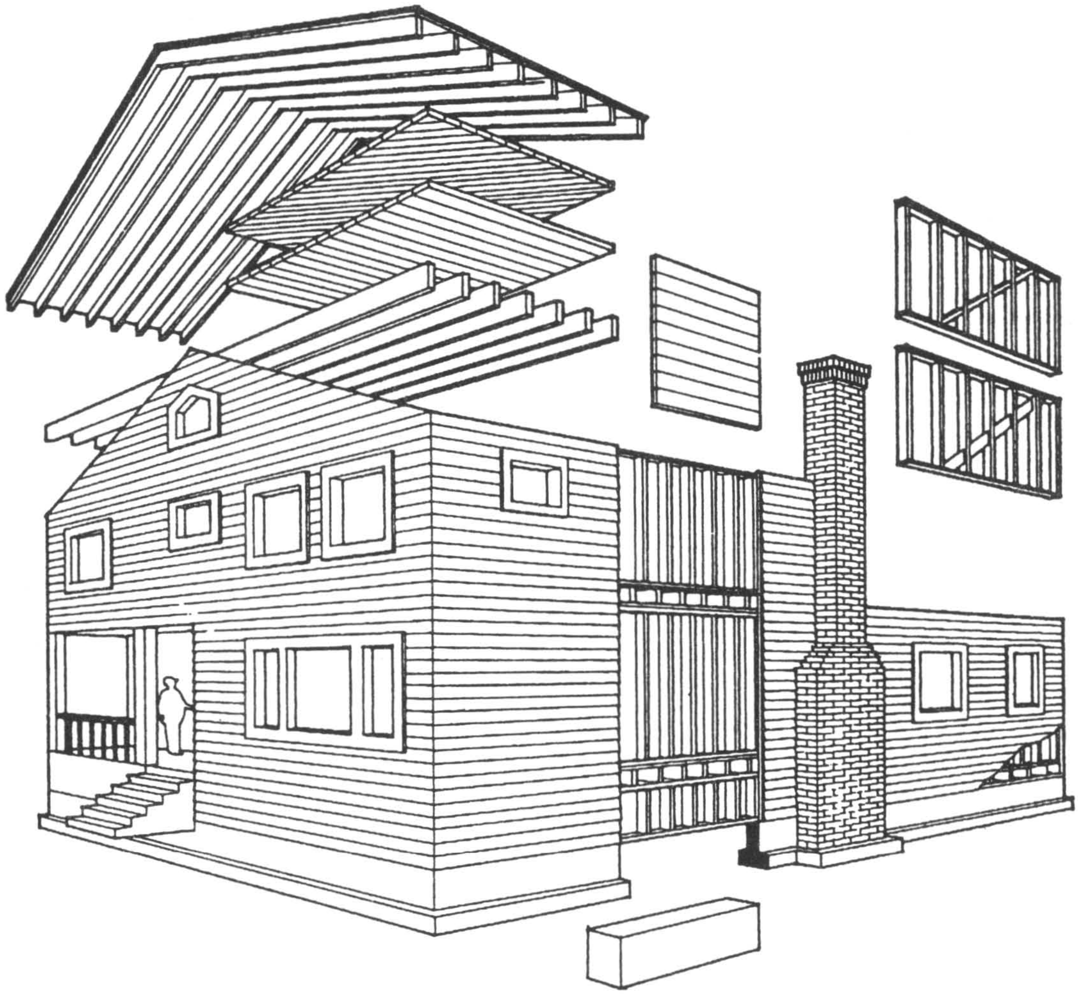

Figure B-3 Typical pre-1940 wood frame building. *Lagorio and others, 1986.*
NOTE: Foundations are commonly post and pier in Humboldt and Del Norte counties.

Elevated unbraced foundations collapsed on more than a dozen Ferndale houses (Photo B-2). While much of this damage was repairable, some houses were a total loss. This damage imposed an added burden on the community of finding shelter for the inhabitants at a time when community resources were already severely taxed.

The State of California recently enacted, under Assembly Bill 200, a requirement for earthquake hazard disclosure for residential dwellings. After January 1, 1993 (as required under provisions of the Business and Professional Code), all transferors of 1-to-4 unit dwellings of conventional wood frame construction must deliver to the purchaser a copy of the homeowners guide to earthquake preparedness. The transferor is required to complete the earthquake hazards disclosure part of the guide. This legislation is intended to identify such hazards as unanchored (i.e., unbolted) foundation plates, unbraced cripple walls, and inadequately anchored water heaters.

Photo B-2

The front door was at the top of the stairs before this Ferndale house was shaken off its foundation. *Photo by Kevin Bayliss.*

In the 1969 Santa Rosa earthquakes (M5.6, M5.7), the dollar losses to dwellings was placed at $4 million (1969 dollars). At the time, dwellings in Santa Rosa were generally one-story and two-story single family detached wood frame structures. The effect of period of construction is shown in Table B-3.

It is clear from Table B-3 that older dwellings suffered heaviest damage.

> "This follows historical patterns and is readily explainable by rot, general deterioration in the foundation area, and inadequate bracing by today's standard. Damage was almost equally divided between one-story and two-story buildings" (Steinbrugge and others, 1970).

TABLE B-3

SIGNIFICANTLY DAMAGED WOOD FRAME DWELLINGS IN 1969 SANTA ROSA EARTHQUAKES

Source: Steinbrugge and others (1970)

STATUS	AGE GROUP		
	PRE-1920	1920-1940	1940-1969
Demolished or probably will be demolished.........	18	8	0
Repairable or demolition questionable at this time	11	1	0
TOTAL	29	9	0

Where pre-1940 houses have not been retrofitted homelessness will be a problem after the earthquake. According to Lagorio (1990):

> "In the 1989 Loma Prieta earthquake, there were over 13,000 displaced persons (with some later estimates reaching as high as 20,000) and over 8,000 damaged or destroyed dwelling units (including single family homes, apartment buildings, and mobile homes). In the Watsonville area alone, approximately 2,000 residences were lost. Over 1,000 dwelling units were destroyed in Oakland. At the time, in San Francisco it was estimated that it would take roughly two years to replace and rebuild the estimated 5,000 housing units lost at a cost of about $191 million."

Accounts of the performance of wood frame buildings in the 1994 Northridge earthquake are also very informative:

> "Multi-story (mostly two or three stories) apartment and condominium buildings performed poorly compared to single family residences. Both the older non-engineered buildings and many newer buildings, especially those with the first level tuck-under parking, suffered extensive damage. In many cases the first story partially or completely collapsed. The Northridge Meadows Apartment Complex, where 16 inhabitants were crushed in apartments that shared the ground floor with tuck-under parking, is an example of a "soft story" apartment complex" (EERI, 1994).

<u>Other Potentially Hazardous Structures</u>

There are a variety of other hazardous structures. Generally, there are few of these in the planning area. These include tilt-up concrete buildings built before the mid-1970s non-ductile concrete frame structures built before the mid-1970s, and mobile homes (i.e., manufactured modular housing) of any age installed without seismic restraints between the undercarriage and the ground (Photo B-3).

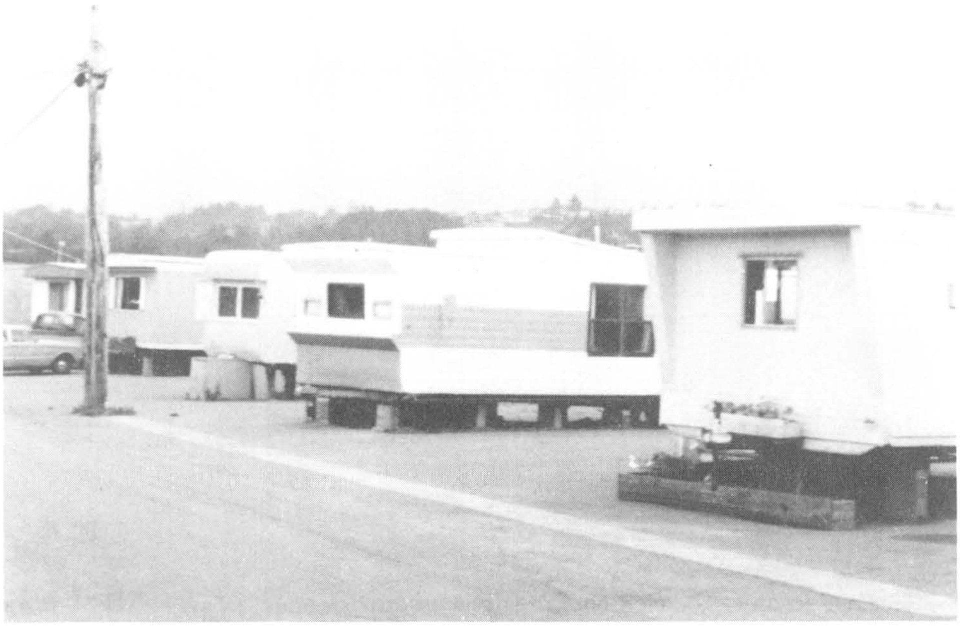

Photo B-3 Trailer home park in the village of King Salmon, south of Eureka.

Earthquake problems associated with tilt-up construction can be significant. Probably the most common cause of severe damage has been separation between the concrete tilt-up wall panels and the roof (Figure B-4). Many tilt-up buildings constructed before the mid-1970s have weak connections between walls and roof and between walls and floors. This can lead to collapse of the roof and floors and cause the wall panels to fall outward. The consequence of tilt-up building failure are both life-safety and economic. These buildings are often found in industrial parks, or are used as warehouses or even office buildings, and even one or two-wall failures can shut down entire buildings. A great many tilt-up buildings failed during the 1971 San Fernando earthquake.

Data collected on the performance of 17 pre-cast concrete structures used as parking garages during the 1994 Northridge earthquake indicate that:

> "Seven garages suffered partial to almost complete collapse of the parking structure. Two others experienced collapse of canopies over walkways leading to the top floors of the garages. An additional 17 garages, for a total of 34, have been reported to have sustained sufficient damage to require repair before they can be reopened. ...Six of the seven parking structures that partially collapsed were precast" (EERI, 1994).

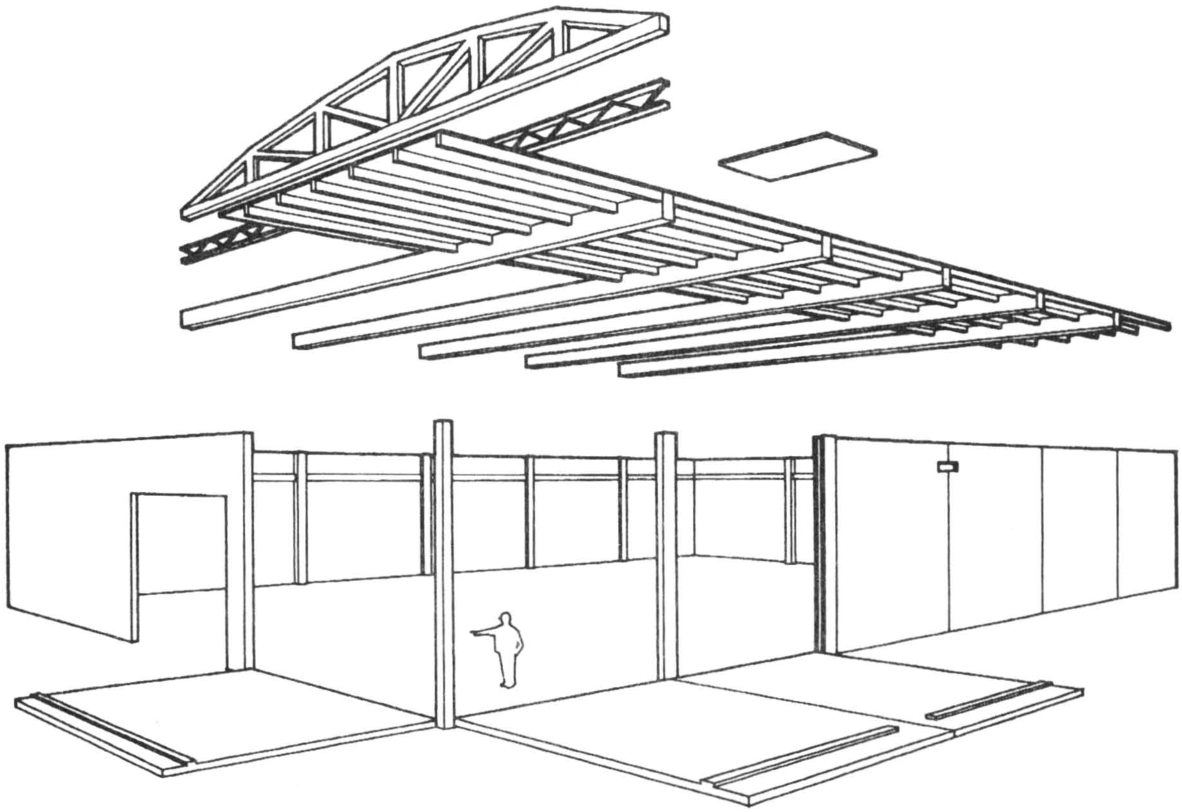

Figure B-4 Typical pre-1973 tilt-up construction. *From Lagorio and others, 1986.*

Structures with non-ductile concrete frames (Figure B-5) may collapse. These are typically old reinforced concrete frame structures without modern standards for detailing reinforcement in columns, beams, and joints. The strength and stiffness of these structures can degrade rapidly in an earthquake, causing serious damage or collapse (Photos B-4 and B-5). The Cypress viaduct, which collapsed in Oakland during the Loma Prieta earthquake with a loss of 42 lives, is an example of a non-ductile concrete structure which met code requirements when it was built (Photo H-1).

Several mobile home parks like those destroyed during the 1994 Northridge earthquake are in the planning area. Mobile homes installed without seismic foundation restraints are frequently damaged, often severely (Photo B-3). In 27 State of California regulated mobile home parks in San Benito, Santa Clara, and Santa Cruz counties, 24 percent of the homes (592 out of 2,434) went down during the Loma Prieta earthquake. In Santa Cruz County many parks had over 50 percent of their homes go down. Interestingly, there were no failures in state regulated parks, where the homes had properly installed state approved seismic restraints.

Tsunamis and Buildings

It is beyond the scope of this report to predict tsunami damage to buildings, but we offer some general information. Single story buildings such as wood frame structures, mobile homes, and light weight steel frame buildings are highly susceptible to tsunami damage. The flow of water into

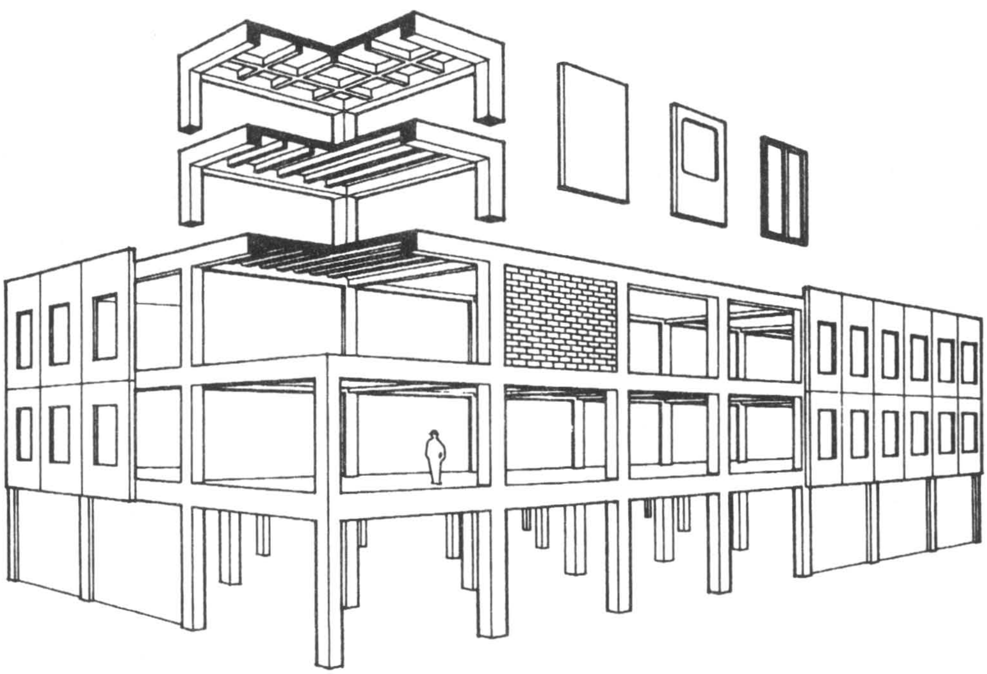

Figure B-5 Typical non-ductile concrete frame. *From Lagorio and others, 1986.*

Photo B-4 This non-ductile concrete parking structure suffered severe damage and partially collapsed in the 1987 Whittier earthquake. This type of construction is a collapse hazard under strong shaking. *Photo by Ronald Gallagher.*

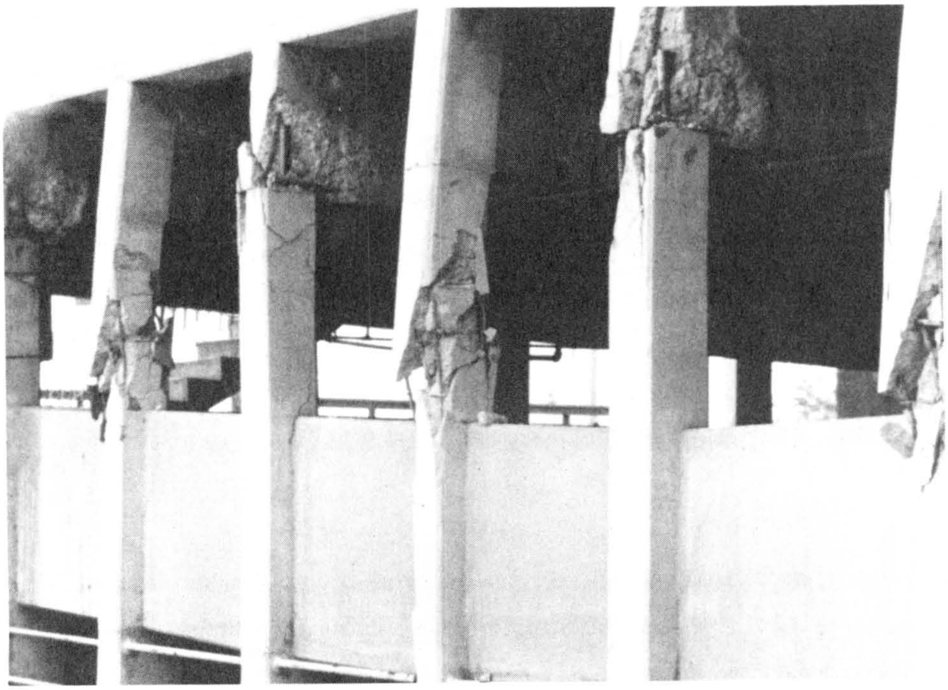

Photo B-5 Close-up of the parking structure showing structural failure of the non-ductile concrete columns. *Photo by Ronald Gallagher.*

structures will damage or destroy building contents (e.g., merchandise, equipment, furnishings, records, etc.). During the 1964 tsunami:

> "In Crescent City there were ten fatalities due to drowning. In the early hours of the disaster twelve people were hospitalized and twelve others were treated as outpatients. These numbers do not include the injuries sustained in the clean-up. The port facilities and 29 city blocks containing 172 businesses, twelve house trailers, and 91 homes were damaged or particularly hard hit and eight of the fatalities occurred there. Twenty one boats were sunk, due in part to being moored at both ends. ...A fire started at Nichols Pontiac and houses on the lower end of town floated off their foundations. ...The third and particularly the fourth waves picked up logs, cars, trucks, and other debris which acted as battering rams against buildings. One log penetrated the post office. The mail was sucked out but later most of it was painstakingly recovered. Fallen electric wires posed additional hazards and at least one person was burned by contact with wires while in the water" (Lander and others, 1993).

For thorough and definitive descriptions of tsunamis affecting the west coast of the United States refer to Lander and others (1993), or for a complete listing of all United States tsunamis refer to Lander and Lockridge (1989).

Planning Considerations

Response planners should verify and be knowledgeable of the URM buildings in their jurisdictions and develop appropriate contingency plans. A review of the performance of URM buildings during the 1989 Loma Prieta earthquake, particularly in Santa Cruz, Watsonville, and San Francisco's south of Market District, will be helpful.

Damage to pre-1940 wood frame dwellings and mobile homes will result in the need for shelters after the earthquake. Likewise, survivors of the tsunami on Samoa Peninsula and Crescent City will be homeless. A review of emergency housing needs after the 1989 Loma Prieta, 1992 Petrolia, and 1994 Northridge earthquakes will offer valuable insights for planners.

A shortage of equipment, supplies, food, drinking water, and other necessities will result after the earthquake.

Most of the larger governmental agencies and private corporations now have disaster response plans that include pre-arrangements with outside contractors for priority use of temporarily leased equipment during the post-earthquake recovery period (e.g., earth moving and other heavy construction equipment). In each case, the agency or corporation has stated that it expects the outside contractor to supply the required equipment on demand following an earthquake. Response planners should verify that their own outside suppliers do not have conflicting contract agreements with other agencies or corporations that, in effect, will cause "overbookings" during emergency periods.

Pelican Bay State Prison

The Pelican Bay State Prison is one of the largest maximum security prisons in the world. It is a multi-building reinforced concrete complex. It is about 8 miles (13 km) north of Crescent City, near Fort Dick and west of Highway 101. In this scenario, the prison is within an MMI VIII+ area, meaning that it will be shaken strongly. The prison is not located within the tsunami inundation area, nor is it expected to suffer damage from liquefaction.

No field survey or engineering analyses were conducted for the prison for this scenario. For emergency planning it should be assumed that at least nonstructural damage will occur, such as to utility services, interior elements, furnishings, and security systems. For example, damage in the 1971 earthquake to the juvenile detention center in San Fernando created several problems. They included the escape of inmates through an opening created by the partial failure of a yard perimeter wall; severe damage to interior walls, floors, and utility services due to the shaking and ground failure at the site. The loss of power to electric door locks and related security features made it difficult to open doors to release inmates from damaged buildings. Evacuation was hampered by barred windows which had to be pried or pulled off. Major damage to a Nicaragua maximum security prison following the 1972 Managua earthquake led to large scale escapes, a riot, and a gun battle between military forces and the inmates who were able to secure weapons from the guards and arms lockers.

Planning Scenario

While it is beyond the scope of this general planning scenario to identify specific buildings that could be damaged by this postulated event, a few general guidelines can be provided.

Unreinforced masonry buildings such as those in the older area of downtown Eureka and Arcata, will suffer severe to total damage.

Pre-1940 wood frame structures with cripple walls or unbraced post and pier foundations and those not tied down to their foundations will suffer the greatest losses.

Unrestrained mobile homes will be knocked from their foundations, causing fires from broken gas connectors. Mobile homes located in the tsunami run-up areas, will be knocked off their mountings by the force of the water.

Concrete tilt-up buildings, commonly located in newer light industrial and commercial areas, could experience severe damage. Often, this is due to inadequate connections between the roof diaphragm and the walls.

In general, it is damage to the area's building stock that creates the greatest long term recovery problems. Typical problems include temporary housing for displaced residents, closure of damaged commercial structures, loss of employment, loss of tax income to area governments and similar problems.

PUBLIC HIGH SCHOOLS AND COLLEGES

General Characteristics

According to data on the seismic performance of public education facilities throughout the State, public schools are normally found in a safe condition after an earthquake. Thus, because of their large sites, availability of ample parking spaces, cafeterias, gymnasiums, and other amenities, schools have strong potential to serve as a critical resource during the earthquake recovery period for mass shelter and feeding whenever homes are destroyed or otherwise rendered uninhabitable.

Because of the emphasis on the earthquake-resistant design of public school buildings in California ever since the 1933 Long Beach earthquake (M6.3), a wealth of information exists on the seismic performance of public school facilities. Among the many sources of data available, the following are especially pertinent:

"California Public School Directory," 1993 Edition, California Department of Education, Sacramento, CA, 1993.

"Unacceptable Risk: Earthquake Hazard Reduction in One East Bay School District," A. Chakos and S.K. Nathe, California State University, Hayward, CA, 1992.

"Performance of Public Schools in Loma Prieta Earthquake of October 17, 1989," J.F. Meehan, Office of the State Architect (OSA), Sacramento, CA, 1990.

"School Report - The Performance of Public School Plants During the San Fernando Earthquake," D.K. Jephcott and D.E. Hudson, Center for Research on the Prevention of Natural Disasters, California Institute of Technology, Pasadena, CA, September 1974.

"Loma Prieta Earthquake Reconnaissance Report" (EERI, 1990).

"Northridge Earthquake, January 17, 1994, Preliminary Reconnaissance Report" (EERI, 1994).

Engineering and planning consultants have developed extensive technical knowledge and experience in the seismic performance of public schools. We made general site location reviews of selected public high schools.

Maps SHM-1 and SHM-2 show the location of public high schools and colleges in the planning area. Public elementary schools, middle schools, and private schools are not shown. This chapter is applicable to schools of all class levels including institutions of higher education and private schools designed and constructed to Field Act standards. Table PS-1 lists the high schools, continuation schools, and colleges in the planning area.

TABLE PS-1

PUBLIC HIGH SCHOOLS & COLLEGES
HUMBOLDT AND DEL NORTE COUNTIES

COUNTY	SCHOOLS/COLLEGE	SITE LOCATION MM INTENSITY
Humboldt	Eureka Senior High	VIII+
	Arcata High	VIII+
	McKinleyville High	VIII+
	Zoe Barnum*, Eureka	VIII+
	Fortuna High	IX
	Ferndale High	IX
	College of the Redwoods	VIII+
	Cal. State Univ., Humboldt	VIII+
Del Norte	Del Norte High, Crescent City	VIII+
	Sunset*, Crescent City	VIII+

* Continuation School

Seismic Considerations

As mentioned, public schools in California have receivəd special legislative attention through the Field Act with respect to seismic safety following the 1933 Long Beach earthquake. Over the years, the Field Act has been successfully implemented by the Division of the State Architect through strictly enforced design and construction practices.

In the 60 years that have followed, the seismic design provisions of building codes, including those for school buildings, have been consistently improved. For example, our report issued in 1987 concerning an earthquake planning scenario for a M7.5 earthquake on the Hayward fault in the San Francisco Bay Area states that:

> "Looking back in time, it is fair to say that some of the Field Act Schools of 50 years ago would not comply with today's Field Act requirements, and indeed could not be built today without including significant improvements. While the overall performance of public schools will continue to be excellent, it is unreal to expect perfection, particularly in view of the large number of public schools in the near vicinity of the Hayward fault" (Steinbrugge and others, 1987).

The same report also states:

> "Public Schools constructed under the Field Act have performed excellently in all earthquakes. The performance of public schools has been far better than that for other buildings using similar construction materials, but this performance has not been perfect. For example, structural damage occurred to buildings at Arvin High School in the 1952 Kern County earthquake (M7.7). Structural damage also occurred in the West Hills Community College in Coalinga as a result of the 1983 Coalinga earthquake (M6.5) (Meehan, 1983). In no case was there a major life hazard, and costs of repair were a small fraction of the building's value. Experience shows that damage can occur to Field Act schools, and these buildings will not be useable until repairs are completed."

Reports issued on the seismic performance of public schools during the 1989 Loma Prieta earthquake (M7.0) again revealed that school facilities designed under the Field Act on the whole performed very well. Damage inspection conducted after the earthquake revealed the following:

1. "There was only minor structural damage to most public school buildings from the near field effects of the Loma Prieta earthquake. A preliminary survey of 1,544 public schools in the earthquake-affected region reveals an estimated $81 million in damage. Only five schools sustained severe damage.

   Fortunately, the Loma Prieta earthquake occurred after normal school hours. Hazards from unbraced and unanchored nonstructural items were evident in many school buildings. The following significant hazards continue to constitute a danger to classroom occupants during an earthquake: pendant-mounted light fixtures without safety cables; suspended acoustical ceiling systems installed without bracing or perimeter wires along with their unattached air-conditioning grilles; light lenses, and light fixtures; unanchored four-drawer file cabinets, unanchored shelving, and their contents" (EERI, 1990).

2. "Several school buildings in the area affected by the earthquake were constructed prior to the enactment of the Field Act. These buildings had been subsequently strengthened or retrofitted to meet building regulations which were less stringent than current building standards. The three-story Branciforte Elementary School in Santa Cruz was built about 75 years ago, well before the Field Act. This building was retrofitted in 1956. The structural system performed very well, but plaster fell in several locations where the plaster was supported by wood lath backing. Wood lath is no longer permitted in new construction and must be removed when public school rehabilitation projects are undertaken. Soquel Elementary School is about 50 years old and was constructed during the early years of the Field Act. This building also had plaster fall from old wool lath back. A heating radiator also fell off the wall.

   Watsonville High School's main building was constructed in 1917, prior to the Field Act; and some rehabilitation work was done in 1935. This building experienced extensive plaster damage where plaster was installed over wood lath. This building suffered damage to the heavy Spanish roof tile and large window glass areas. While the building was being surveyed to determine the extent of earthquake damage, it was learned that there were other structural deficiencies which will require correction or may lead to eventual abandonment of the building.

   After the earthquake, eighty-nine school buildings were investigated and found acceptable for operation as emergency shelters for people who had been displaced from their earthquake damaged homes. Many of these school buildings were used as shelters for several weeks after the earthquake.

Building codes have undergone significant changes based on recorded evidence from earthquakes in the last 20 years. Also, the construction industry has seen many changes in the use of the building materials since 1933. It would be prudent to examine all school buildings constructed or retrofitted during the early days of the Field Act. These buildings need to be examined to determine if they possess the necessary design and material strength and stiffness to perform adequately in future earthquakes or if the lack of proper maintenance or deterioration has reduced their strength" (Meehan, 1990).

As observed after the 1989 Loma Prieta earthquake, pre-Field Act buildings that were retrofitted between 1933 and the 1960s remain the most likely buildings to suffer structural damage. The seismic-resistant upgrade of these buildings focused on structural standards that were different and often less stringent than current requirements.

Owing to the high accelerations experienced in some areas during the 1994 Northridge earthquake (M6.7), general damage to public schools was heavier than anticipated. However, most of the damage was nonstructural. Structural damage to schools was not a major factor, e.g., there were no structural collapses. Accounts by the Division of the State Architect note that:

"A total of 22 structures were rated unsafe (Red Tag). However, further review revealed that, with the exception of the portable buildings, and some of the lunch centers, most structures tagged Red were not in danger of collapse. ...The most important damage consisted of wood roof beams slipping off seats because of connection failures aggravated by dry rot (e.g., wood decay), as well as effects from pounding with adjacent structures.

Some permanent buildings such as classrooms, gymnasiums, and administration buildings also experienced structural damage; most of these were constructed to pre-1971 building regulations. Potentially hazardous spalling of concrete and masonry, up to 5 pounds maximum weight per piece, occurred at localized areas on the outside of some buildings. Other damage included buckling of diagonal bracing rods, diagonal cracking of shear walls, concrete-column joint spalling, and ground cracking extending into buildings.

The Los Angeles Unified School District, which encompasses the entire city of Los Angeles, reported on Sunday, Jan. 23, that about 300 of roughly 800 campuses had sustained some damage, but fewer than 100 were not scheduled to open the following Tuesday. The district estimated total damage (structural and nonstructural) at $700 million. The schools hardest hit were in the portion of the San Fernando Valley west of the I-405 freeway, including Northridge, Granada Hills, and Encino. ...Schools in the central and east valley as well as in the remainder of the district experienced relatively minor damage. Hamilton High School, a URM in West Los Angeles that was built in 1931 and retrofitted after major damage in the 1971 earthquake, performed well despite damage to some exterior ornaments and pedestrian bridges between buildings. Similarly, a school located blocks away from the Santa Monica Freeway (I-10) collapse performed very well with nonstructural damage only" (EERI, 1994).

Planning Considerations

Almost all non-Field Act public schools are gone. Some private schools, however, still pose an earthquake hazard. By definition, therefore, all public school buildings in the study area have been designed to meet earthquake resistant design provisions required by the Field Act.

The Field Act covers public schools and community colleges. Private schools and state institutions of higher education generally have built their new buildings in conformance to the technical provisions which supplement the Field Act and have upgraded and strengthened some of their older existing buildings. Some old buildings still remain in use for purposes other than classrooms.

The high schools and colleges will experience MMI VIII+ or IX ground shaking resulting in nonstructural and some structural damage (Table PS-1).

Underground utility service lines that cross the Little Salmon fault near College of the Redwoods or areas of poor ground will be ruptured. As a result, some schools will have functional impairments even if their structures remain undamaged by the postulated earthquake.

California State University, Humboldt is one of the system's older campuses. It is slightly north of Arcata adjacent to Highway 101 on a steeply sloping site. The campus contains numerous buildings varying in age, type of construction, size, occupancy, and seismic resistance. Some earthquake rehabilitation projects have been undertaken on the campus and others are yet to be done. Further information can be obtained from the California State University's main offices in Long Beach, which is currently assessing the seismic performance of all California State University buildings.

The College of the Redwoods is new enough to have been built under the requirements of the Field Act, and no significant structural damage is expected there from shaking. However, significant damage will occur because it is adjacent to the Little Salmon fault which will rupture in this scenario. Also, transportation and utility services will be interrupted where such systems traverse the fault.

Planning Scenario

Because of their size, location, and service facilities, public schools are desirable as evacuation shelters and mass feeding areas for victims of the earthquake. They will be a critical resource, wherever damage to the existing housing stock is severe.

All wood-frame public schools are expected to survive without structural damage. These are mostly one-story elementary schools and high schools with one-story "open planning and exterior courtyards" (also referred to as the "open wing configuration") surrounding the classrooms and other facilities. There will be some functional restrictions owing to disrupted utility services, broken windows, fallen ceiling tiles, jammed doors, and other similar nonstructural effects to 10 percent of the classrooms. Typical damage will impair school functions for 2 to 7 days.

Contingency planners must identify the locations of pre-Field Act school buildings and Field Act buildings that were retrofitted between 1933 and the early 1960s. Professional damage assessments of all such facilities by engineers and architects will be required during the immediate post-earthquake period. We assume that damage to 25 percent of such retrofitted and strengthened schools buildings will occur. Evidence of structural damage will delay re-occupancy on a long-term basis.

Public school structures that are two or more stories high are often designed with construction systems that use reinforced concrete or other unit masonry wall materials. After the earthquake, these also will need to be inspected. If any significant cracking is found, occupancy will be delayed for repairs. The inspection will take from 2 to 3 days depending on the availability of inspectors, with repair taking up to several weeks depending on the extent of damage.

Immediately following the earthquake, road interruptions and closures could make local access to school sites a serious problem for school administrators and emergency response personnel. Alternative routes to reach schools with potential access problems must be established. In areas of expected high intensity ground shaking, contingency plans must include care for students for up to 10 hours after the event.

HOSPITALS

General Characteristics

When setting priorities among the many demands to be taken into consideration during the earthquake recovery period, the disaster response planner must give highest priority to saving lives and treating casualties. Hospital buildings, classified as critical emergency facilities, and the provision of acute health services are obviously vital in this regard. Staff personnel and medical resources, including medical supplies and equipment on-site and in warehouses and/or distribution centers, blood banks, ambulance services, clinical laboratories at hospitals, and other related critical elements of the medical system must be ready and available.

A major general acute care hospital provides specific medical services and includes an emergency room with facilities for intensive care, and surgery. Table H-1 lists all of the principal hospitals. These were surveyed in the field and reviewed for potential earthquake effects. Maps SHM-1 and SHM-2 show their locations in Humboldt and Del Norte counties. One small hospital (15 beds) is in Garberville at the southern end of Humboldt County. It was not visited during the preparation of this planning scenario.

For a complete inventory of all types of medical facilities in the planning area and throughout California, refer to the "Health Facilities Directory, July 1992," issued by the Licensing and Certification Division, California Department of Health Services.

A large percentage of the new major hospitals constructed in the state under the seismic performance standards established by the Hospital Seismic Safety Act of 1973 incorporated specific types of structural design, and many are composed of building configurations limited to four or five stories. These general building characteristics will be common to future hospitals constructed in the planning area. The implications of the planning and construction of medical facilities designed under the 1973 Hospital Act are described below in the Seismic Considerations and Planning Considerations sections which follow.

Seismic Considerations

The operational capacity and functional continuity of medical facilities are critically dependent on utility lifeline support systems (e.g., water supply, electric power, waste water disposal) and communication/transportation networks. This dependency on lifeline systems and the complexities

TABLE H-1

PRINCIPAL HOSPITALS IN HUMBOLDT AND DEL NORTE COUNTIES

HOSPITAL	CITY	COUNTY	NO. BEDS	SITE LOCATION MM INTENSITY	DATE	
					BUILT	ADDITION
Redwood Memorial	Fortuna	Humboldt	49	IX	1929	1955 & 1976
St. Joseph's	Eureka	Humboldt	92	VIII+	1972	1990
General	Eureka	Humboldt	83	VIII+	1965	1993
Mad River Community	Arcata	Humboldt	78	IX	1955	---
Sutter Coast	Crescent City	Del Norte	46	VIII+	1992	---
TOTAL			**348**			

found in components of hospital buildings make them vulnerable to disruptions and impairments including those commonly caused by major earthquakes:

1. Structural damage
2. Nonstructural damage
3. Failure of utility lifeline support systems
4. Damage to critical supplies, contents, and equipment
5. Accessibility of ambulances and emergency service vehicles to and from the site
6. Fire following earthquake

Hospitals built to the standards of the 1973 Hospital Act should perform well in a strong earthquake, particularly in comparison to ordinary buildings. Hospitals built in the 1950s and 1960s did not have the same amount of seismic resistance, and did not have the damage control features of those constructed under the 1973 Hospital Act. The Act also requires seismic design of equipment, nonstructural building components, and architectural elements. Before 1973, there were few or no such requirements. Currently, items such as emergency generators, battery racks, critical equipment, and large medical apparatus, for example, must be secured against sliding or overturning. This greatly increases the likelihood of the post-earthquake availability of medical facilities for the treatment of casualties and other emergency services.

During the aftermath of the 1971 San Fernando earthquake (M6.7) which caused significant damage to four major medical facilities (Indian Hills Medical Center in Los Angeles, Holy Cross Hospital in Los Angeles, Veterans Administration (VA) Hospital in Los Angeles County, and Olive View Hospital in Sylmar) the State of California adopted the Hospital Seismic Safety Act of 1973. This required higher seismic performance standards for hospital buildings than those required for ordinary buildings, to protect occupants from injury as well as to protect the functionality of hospitals. In the 1994 Northridge earthquake (M6.7) however, new and old hospitals were functionally impaired:

> "Nonstructural damage itself caused the temporary closure, evacuation, or patient transfer of Olive View Medical Center (the 1980s replacement hospital for the facility damaged in 1971), Holy Cross (a replacement for the original Holy Cross), Indian Hills (the same building that experienced the 1971 earthquake), and the Sepulveda VA Medical Center (in existence at the time of the San Fernando earthquake and distinct from the Sylmar VA facility where buildings collapsed in 1971). (The closure of St. John's Hospital in Santa Monica, although it suffered major nonstructural damage, was attributable to structural damage.)
>
> Major nonstructural element damage (heating, venting, air conditioning and piping) occurred in mechanical penthouses, and the penthouses themselves were severely damaged in some instances. In several facilities, large in-line supply fans were thrown through the exterior walls of the penthouse. The penthouses were often angle braced frames with no columns at one end to brace; thus, severe buckling failures occurred when overloaded.
>
> The most severe damage to healthcare facilities occurred in the Santa Monica area where a total of seven red tags were issued to five facilities. Four other red tags were issued to buildings in Los Angeles, and one more in San Pedro. Except for one warehouse, all the red tagged buildings were for patient care. Many of the red tags were issued because of severe diagonal cracking in concrete shear walls. Cracking extended through the entire thickness of those walls. Another red tagged building was evacuated because of the potential loss of vertical support capability resulting from column damage" (EERI, 1994).

A publication issued after the 1994 Northridge earthquake by the Central United States Earthquake Consortium (CUSEC) indicates that:

> "The Northridge earthquake is the most destructive earthquake in the U.S. since the 1906 San Francisco earthquake (M8.0). Direct economic losses are estimated currently at over $20 billion. ...One of the top priorities after the earthquake was an assessment of the damages to hospitals and Emergency Medical Service (EMS) System. These assessments were undertaken by local government (public health, emergency medical services, and emergency management), the State of California, and local officials in the Central States."

Table H-2 depicts the range of damages to hospitals in the Northridge/Los Angeles area, listed under five categories of damage and ability to function.

After the 1989 Loma Prieta earthquake (M7.0), an assessment report was issued by the Office of the California State Architect (OSA) on 17 hospitals in the East Bay and South Bay counties of the San Francisco Bay Area. Out of the total of 17 buildings inspected, five had no building damage, five had nonstructural damage but no structural damage, six had minor structural damage, and one had structural damage to an old tower wing built in 1927 "considered serious enough to compromise its capability to withstand another earthquake." The nonstructural damage reported by the five hospitals was generally limited to damaged elevators, equipment anchorage and pipe

TABLE H-2

NORTHRIDGE EARTHQUAKE - INITIAL IMPACT ON AREA HOSPITALS

CATEGORIES*	HOSPITAL	EPICENTER^x DISTANCE	DESCRIPTION
1	Olive View	>30	Evacuate 377 patients
1	Granada Hills	>10	Serious water damage, no communications, needs to evacuate
1	VA Sepulveda	>10	Evacuate 300 patients to Long Beach VA Hospital
1	Holy Cross	>10	Diverting ambulance patients, water leaks, will evacuate 17 ICU patients
2	Northridge Community	>10	Evacuate 23 neonatal patients, emergency services only
3	Kaiser/Pasadena	>10	Significant interior damage, unable to accept new patients via ambulance
3	Santa Monica	>30	Unable to accept new patients via ambulance
3	Simi Valley	>10	Unable to accept new patients via ambulance
4	St. Joseph's/Burbank	>30	Minor water damage
4	Henry Mayo/ Newhall	>30	-------
4	Valley Presbyterian	>10	No heating, venting, air conditioning
4	Encino	>10	Plaster cracking
4	Kaiser/Woodland Hills	>10	Minor nonstructural cracking
4	Kaiser/West L.A.	>30	No significant damage
4	Humana	>10	No water or emergency power
4	Pacifica	>30	Possible evacuation, no water or emergency power
4	Thompson Memorial	>30	Pipes loose
4	Glendale Adventist Memorial	>30	Minor cracks to interior
4	Huntington Memorial	>30	Elevator service out
4	Kaiser/L.A.	>30	Concrete spalling on adjacent parking structure
4	Cedars Sinai	>30	Expansion joint damage
4	St. Luke Medical	>30	Minor plaster cracking
4	Sherman Oaks	>10	Water pipes broken
4	Valley Hospital	>10	Minor water damage
4	Verdugo Hills	>30	Minor spalling/surface wall cracks
4	AMI Tarzana Regional	>10	Minor plaster cracking
5	Newhall Community	>30	Needs generator

*Status Categories:
1: Total major evacuation
2: Partial evacuation
3: Unable to accept new patients
4: Damaged but functional
5: Need help to remain operational

^x In miles

Source: THE CUSEC JOURNAL, vol. 2, no. 1, chart 1, p.

support damage, spalling and buckling at seismic joints, failure of vertical fan anchorage at roof level and minor cracks at ceilings and walls.

In the 1992 Petrolia earthquake "Preliminary observations by the USGS indicates that there were approximately six to seven miles of the Humboldt Coast that experienced a seismic uplift of one-half to one meter" (EERI, 1992a). One hospital in Fortuna, 15 miles (24 km) from the coastline, was the closest to the epicentral region of the 1992 Petrolia earthquake (M7.0), 30 miles (50 km) away. Typical nonstructural building damage was reported.

Planning Considerations

Hospitals close to surface fault rupture can be seriously affected by unusually strong shaking, by disruption of utilities, and by access problems. All hospitals in Humboldt and Del Norte counties will be within 7 to 12 miles (12 to 20 km) from the CSZ fault surface that dips eastward.

Hospitals not constructed to the standards of the 1973 Hospital Seismic Safety Act can be seriously damaged, even at some distance from the fault. In addition, those hospitals with unanchored emergency equipment (e.g., generators, battery racks) and with unsecured medical apparatus (e.g., laboratory equipment) can suffer serious impairment of operations.

In studying the post-earthquake operational capabilities of hospital facilities, planners should review the following:

1. Physical damage to buildings
2. Loss of life and injuries to personnel and patients
3. Loss of medical supplies and equipment
4. Loss of hospital functions from disrupted utilities and access

Because of the rural nature of Humboldt and Del Norte counties, getting the injured to hospitals may be difficult. If a local hospital is closed by earthquake damage, except for the two in Eureka, travel to the next closest hospital may involve distances of over 20 miles (32 km) on possibly damaged and congested roads. Much greater distances would be involved for residents of Del Norte County. Helicopter evacuation of the injured will be needed.

Planning Scenario

Roads and bridges will be damaged, and travel on them will be difficult or blocked. Utilities crossing the Little Salmon fault will be severed and out of service.

We assume that all five hospitals may have water outages for 3 days and power outages for 2 days (Table H-1). For planning purposes, we also assume that a medical facility constructed before enactment of the 1973 legislation will be disabled. We also assume that hospital facilities constructed since the Hospital Act of 1973 will remain functional.

While there are five hospitals in the main impact area, their combined bed capacity is comparatively small. This limited capacity plus the possibilities of damage, loss of utility services, disruption of roads, and the long distance to any other comparable facility, means that some of the most seriously injured may have to be evacuated by air to outlying locations. Planners should assume that victims and their relatives will converge on hospital facilities, whether they are operational or not.

Emergency response planners should note the locations of large acute health care facilities elsewhere in nearby counties. Planners also must realize the limited availability of overland routes (refer to Highways chapter), and provide helicopters or other means to move overflow casualties.

One of the hospitals has a portion built before 1972. It will be susceptible to damage from the scenario earthquake. Another hospital is composed of a set of one story wood frame buildings. It is a trauma center and was built according to the requirements of the Hospital Seismic Safety Act. While the buildings are expected to perform well, it is in an area moderate to low potential for liquefaction.

One way of examining the potential loss of facilities is to estimate hospital bed loss rather than building damage. A slightly damaged building evacuated for psychological or liability reasons will result in a critical loss of hospitals beds, just as it would for severe structural damage. For response planning purposes, we anticipate that out of 348 beds in the five hospitals, 119 (34 percent) will be unavailable for treatment of earthquake related casualties. As shown in the 1989 Loma Prieta earthquake and others, severe non-structural building damage to hospital facilities also will lead to loss of bed capacity. Up to 50 percent of the beds will be unavailable where ground shaking intensities of MMI IX are postulated, and 30 percent will be lost in the MMI VIII+ areas.

SECTION 3

TRANSPORTATION LIFELINES

HIGHWAYS

General Characteristics

The California Department of Transportation (Caltrans) was created in 1972 and is one of the leading organizations committed to the seismic design and research of highway bridges. Caltrans, which contributed to this chapter, is based in Sacramento and operates out of 12 district offices and has over 300 maintenance stations throughout the state.

This earthquake planning scenario considers the portion of the state highway system in Caltrans District 1, including over 250 structures on 12 state highway routes.

Seismic Considerations

The only identified fault crossing is Route 101 across the Little Salmon fault which will slip in conjunction with the M8.4 event. A Federal Highway Administration study (U.S. Department of Transportation, 1982) considers that normally those areas having MMI greater than VII will have significant damage to highway structures. The damaging effects from ground failure also must be considered independently in making performance assessments.

As a result of the 1971 San Fernando earthquake (M6.7), Caltrans implemented design criteria and details for bridges that improved seismic resistance. The most significant damage will occur in structures designed between 1946 and 1971 that have not yet been retrofitted. However, a legislative mandate following the 1989 Loma Prieta earthquake (M7), requires that all seismically deficient state structures be under contract for retrofit by December 1993.

The initial Caltrans retrofit program (1971-1985) involved the application of hinge restrainers to unrestrained superstructure expansion joints. The subsequent single column retrofit program concentrated on increasing the seismic resistance of single column substructures to current standards. By July 1992, all but 25 of the 271 single column bridges statewide had been advertised for retrofit. The detailed review of as-built plans for all state bridges is completed. The current retrofit program is to increase the seismic resistance of deficient bridge structures. Although retrofitting is no guarantee against collapse under the most intense shaking, it does improve the chances that a structure will survive with repairable damage. Examples of repairable damage include the tipping of short rocker bearings, minor cracking of piers and columns, and vertical displacements allowing an asphalt patch. Retrofitted structures may be significantly damaged and require road closure for repair, but they generally will not collapse.

Areas of potential liquefaction and seismically induced landslides will impact the highway system. The amount of movement due to liquefaction and landslides is erratic and difficult to predict. Most effects on the highway system involve blockage by rockfalls, settlement of sediment fills, and slumping of soils near streams and other water bodies.

We reviewed the general characteristics of the structures in light of their historic failure mechanisms. In particular, the damage patterns witnessed during the Loma Prieta earthquake were used for many of the predictions in this scenario. In some instances damage can occur in MMI VII zones far from the epicenter, when soil conditions and the period of a long structure lead to resonant amplification. Collapse of the Cypress Structure during the Loma Prieta earthquake is the classic example (Photo H-1).

Photo H-1 Collapsed steel rebar and concrete columns of the Cypress I-880 freeway structure, Oakland, California. A 1-mile lenght of this double-decked reinforced-concrete viaduct collapsed onto commuter traffic during the Loma Prieta earthquake. The failed column in the foreground supported the top deck. Built in the 1950s, the columns had vertical steel reinforcing rods but lacked the spiral reinforcing rods used in modern construction. *Photo by Michael Rymer, courtesy of the U.S. Geological Survey.*

Planning Considerations

Planners need to identify major emergency corridors that will have the least amount of damage in the earthquake. The best emergency routes are wide, at grade or on good ground, and should avoid adjacent tall buildings and power lines that could be damaged. Utility companies and local government agencies need to identify installations and facilities they will need to inspect, repair, operate, or access in the emergency. In general, routes that have sections crossing areas of both high and moderate liquefaction potential will have outages only in areas designated high liquefaction potential on the map. Critical facilities include communication centers, hospitals, airports, heliports, staging areas, fuel storage sites, and other locations essential for emergency response operations. Highway emergency response plans need to be coordinated with those developed for air and rail. Access to and travel through stricken areas will be difficult and will be limited to the highest emergency priorities.

Highway 101 will be unusable in most of Humboldt and Del Norte counties for at least the 3 day duration of this scenario and for up to a month later. The bridge between Eureka and the Samoa Peninsula will also be unusable. Likewise easterly routes through the mountains (e.g. Routes 36, 299, 96, and 199) will be blocked by landslides and other damage. Planners need to identify access routes to communication centers, hospitals, airports, staging areas, fuel storage sites, and other locations necessary for emergency response. Highway outages will restrict emergency supplies from outside the area for 14 days.

Highways and Bridges

Highway 101, the main thoroughfare along the California coast, extends through both Humboldt and Del Norte counties. A considerable portion of the highway in southern Humboldt County is inland from the coast, mostly notable where the highway follows along the Eel River, and many parts of the highway are in slide areas. There are also numerous bridges and overpasses along this highway, many of which were constructed before 1971. Bridges constructed at that time were not as well designed for lateral forces as those built in later years.

After the earthquake that occurred in southern California on February 9, 1971, Caltrans increased the seismic coefficient as a function of gravity to a higher level of lateral force design. Subsequently, bridges and overpasses were substantially increased in strength to resist lateral forces of earthquakes.

Along Highway 101, especially approaching the City of Fortuna, the land is closer to the Pacific Ocean and the wetlands and marshes become prevalent. The possibility of soil liquefaction becomes a potential problem for the many bridges and overpasses in these areas. Farther north in Eureka, Samoa Peninsula, Arcata, and areas between these locations, there are many marshlands and wetlands which are also in danger of liquefaction. Highways, bridges, and overpasses in these areas are particularly vulnerable to severe damage from liquefaction.

Highway 101 winds along the coast from Arcata to Crescent City through intermittent wetlands and marshes. These areas create potential problems for bridges and overpasses, especially where they span rivers and streams. Possible tsunami damage to highways is discussed briefly under *Damage Assessments*, although the tsunami runup was modeled only for limited parts of Eureka and Crescent City.

Damage Assessments

Damage assessments have been postulated for certain major facilities as set forth below. The statements regarding the performance of facilities are hypothetical and intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Outage and repair times assume that materials, equipment, and human resources are available concurrently for each damage locality. They will probably not be available concurrently, and outages could be much longer than estimated here. Locations of damage assessments are shown on Map H-1 (for nos. 1 to 8), Map H-2 (for nos. 9 to 28, and no. 37), and Map H-3 (for nos. 29 to 56). Routes not discussed may be assumed to be open with delays due to heavy traffic and obstructions.

<u>MAP NO.</u> <u>LOCATION</u>

1 **Route 101, Mendocino County Line to Benbow**

MMI VIII-

Potential for landslides

Closed for 3 days

This route was closed as a result of the 1964 storm. The damage to highway structures will be minor, with the blockage to the route being due to reactivation of known landslides. Movement of the Reed Mountain slide will block the Eel River to a shallow depth, but the highway will be unaffected. A slide north of Benbow Bridge will block the road.

2 **Route 101, north of Garberville**

MMI VII

Potential for landslides

Restricted for 1 day

The shaking intensity here will be just enough to reactivate the Bear Buttes landslide. The low relief on the ridge above slide suggests it will block the river to a shallow depth only. The effect on the road will be minor because the slide is west of river and road is east of the river.

3 **Route 101, Eel River Bridge north of Hooker Creek**

MMI VII

Open

This is a steel bridge on three concrete piers, with the two southern piers in the inactive channel. The northern pier has cable restrainers.

4 **Route 101, Phillipsville to Meyers Flat**

MMI VIII- to IX

Potential for landslides

Moderate potential for liquefaction

Closed for 3 days

There will be moderate structure damage and roadway damage from landslides. One landslide will block the highway as well as the river. Within 2 days the natural dam produced in the river will be close to failure, resulting in the need to evacuate the downstream area.

5 **Route 254, Alternate Route from Phillipsville to Meyers Flat**

MMI IX

Potential for landslides

Moderate potential for liquefaction

Closed for 3 days

There will be moderate structure damage along this route, and road closure from landslides.

6 **Route 254, Alternate Route from Meyers Flat to Jordan Road**

MMI VIII- to IX

Potential for landslides

Moderate potential for liquefaction

Closed for 3 days

Moderate structure damage similar to the damage that will occur on the parallel portion of Route 101.

7 **Route 101, Meyers Flat to Stafford Bridge, and Dyerville Loop Road along the Eel River**

MMI VIII- to IX

Potential for landslides

Moderate potential for liquefaction

Closed for 3 days

There will be moderate structure damage along this route. Failure of the concrete overpass on Route 101 for the road to Honeydew will block both Route 101 and Honeydew Road. One mile south of the Pepperwood exit, several earthflows will encroach on Route 101. There will be minor settlement at the north approach fill to the Stafford Bridge. This retrofitted bridge (over South Fork of Eel River) will be damaged.

8 **Secondary roads southwest of Route 101, Shelter Cove to Ferndale (not part of the state highway system)**
MMI VIII- to IX
Potential for landslides
Restricted for 3 days
Numerous landslides will restrict traffic to the small communities of Shelter Cove, Honeydew, and Petrolia. As in the 1980 earthquake, steep roadcuts will fail (Kilbourne and Saucedo, 1981, Figure 15). In 1992 "Strong ground shaking during the earthquakes triggered numerous landslides in steep mountainous areas. The widespread landslides blocked or impeded traffic on the limited number of roads that serve this rugged region. Tension cracks, due to soil compaction and downhill slumping, restricted traffic on the Mattole Road between Honeydew, Petrolia, and Ferndale" (Reagor and Brewer, 1992, p. 116).

9 **Route 283, Scotia to Eel River.**
MMI IX
Closed for 3 days
This 0.36-mile long segment of Route 283 includes the Eel River crossing. There will be major structural damage to the bridge.

10 **Route 101, Rio Dell (Stafford) Bridge northwest to Fortuna**
MMI IX
Moderate to high liquefaction potential
Closed for over 3 days
Due to strong ground shaking, there will be major structural damage to several bridges crossing the Eel and the Van Duzen rivers north of Rio Dell.

11 **Route 36, Alton to Hydesville**
MMI VIII+
Open
No structures will be affected and the surface cracks in the roadway will be small.

12 **Route 36, Hydesville to Bridgeville**

MMI IX

Moderate potential for liquefaction

Potential for landslides

Closed for 3 days

Fill failures will undermine the road and rock falls will cover it near Grizzly Creek Redwood State Park. The structure crossing Yager Creek will have major damage and it will take 3 days to provide temporary repairs necessary to carry emergency traffic. In other places there will be damage to structures and roadways from ground failure due to liquefaction.

13 **Route 36, Bridgeville to Larabee Valley**

MMI VII

Open

Minor and repairable structural damage. The old bridge crossing the Van Duzen River at Bridgeville was being replaced by a new structure in 1993. Existing slide in melange will not reactivate in this event.

14 **Route 36, Larabee Valley to Mad River**

MMI VII to VIII+

Moderate potential for liquefaction

Potential for landslides

Closed for 2 days

Moderate structure and roadway damage from liquefaction. Pavement cracks and separation will occur due to liquefaction. All structure damage can be repaired by using temporary shoring methods.

15 **Route 101, Fortuna Over-crossing**

MMI IX

Moderate potential for liquefaction

Closed for 3 days

Due to strong ground shaking, the Fortuna and the Twelfth Street over-crossings will be damaged. Alternative city routes in Fortuna will have to be used.

16 **Route 101, northwest Fortuna to Beatrice**

MMI VIII+

Restricted for 12 hours

There will be only minor structure damage along this route, mostly due to abutment settlement. The route will be open, but will have traffic delays for 12 hours.

17 **Route 211, Ferndale to Fernbridge**

MMI IX

High liquefaction potential

Closed for 3 days

This route will have moderate structure damage and pavement separation and settlement problems will develop due to liquefaction. The old bridge over the Eel River (Photo H-2) will be severely damaged.

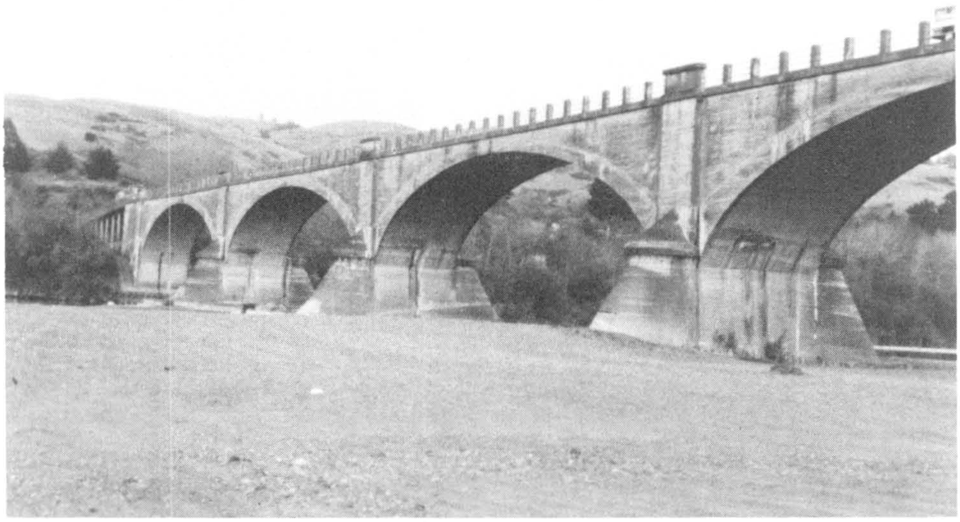

Photo H-2 The old bridge across the Eel River at Fernbridge.

18 **Route 101, Beatrice to Pine Hill**

MMI IX

High liquefaction potential

Potential for landslides

Closed for 3 days

There will be major structure and roadway damage north of Beatrice and either side of Spruce Point due to liquefaction. The landslides on Humboldt Hill east of the freeway will be reactivated and will close one of the four lanes. There will be minor damage to the southbound bridge across the Elk River near Pine Hill. Many possible detours will be available including the parallel bridge.

19 Route 101, Fields Landing Overhead

MMI IX

Little Salmon Fault Rupture

High liquefaction potential

Closed for more than 3 days

Two of the four spans of the Fields Landing Overhead (locally known as Tompkins Hill Road Overpass) collapsed in the 1980 M7.0 earthquake (Semans and Zelinski, 1980, photos 1 to 38; Kilbourne and Saucedo, 1981, photos 2 to 3). The two spans were replaced more or less according to the original design (Photo H-3) and both the old and the new spans were retrofitted with hinge restrainers to prevent future support failures.

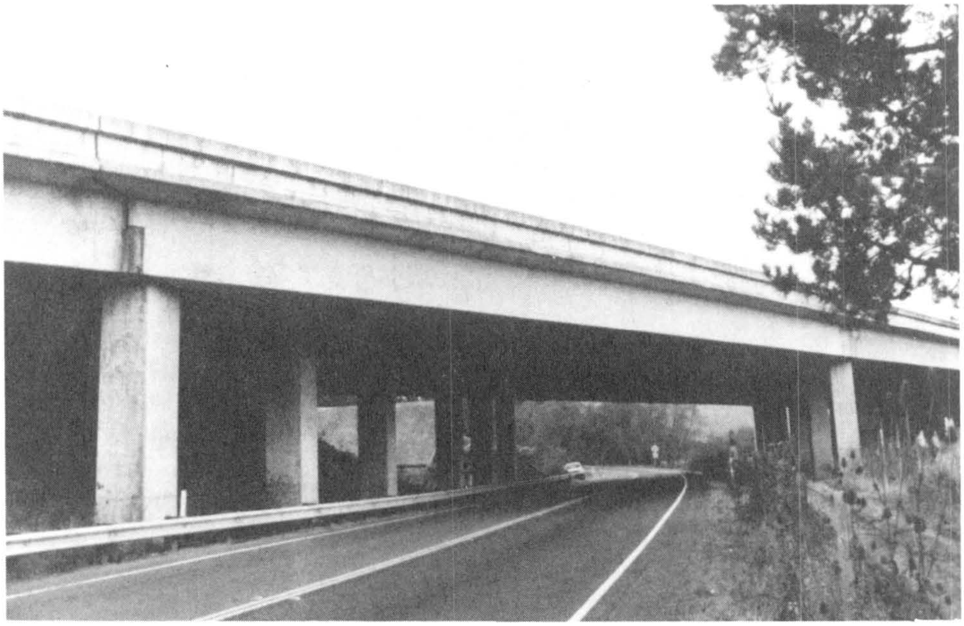

Photo H-3 Route 101 Fields Landing Overhead.

The superstructure has undergone up to 2 inches of progressive lateral movement between 1965 and 1980 (Semans and Zelinski, 1980, p. 2). Caltrans now expects this structure to perform much better and only suffer minor damage. In 1980, however, the intensity was only VII at Fields Landing (Kilbourne and Saucedo, 1981), whereas the scenario event will produce MMI IX with a shaking duration many times what it was in 1980. The bridge is founded in soft, saturated, sandy sediments and the scenario event will produce liquefaction and subsidence of many of the supports. The Little Salmon fault traverses the northern approach of the overhead (refer to Wills, 1990 for details). Slip along this fault will produce up to 12 feet (4 m) of thrust movement across a zone tens of feet wide (Carver, 1993).

20 **Route 101, Pine Hill to Route 255**

MMI VIII+

Restricted for 1 day

Highway 101 appears to be on a cut bench in Pleistocene sedimentary deposits. Although no large scale failures will occur, the road cuts on the east side of the highway in southwest Eureka will fail, closing the north bound lanes.

21 **Route 255 to Samoa**

MMI IX

High liquefaction potential

Tsunami inundation zone

Closed for 3 days

There will be major damage to the bridges across the Eureka, Middle, and Samoa Channel. The above three structures are under contract for special study and retrofit design, with the retrofit construction to be completed by 1999. However, the approaches and roadways connecting bridges are on shallow fill over mud. These will settle, making the bridges inaccessible. The west end of the bridge is in the tsunami runup zone.

22 **Route 255, Samoa to Arcata**

MMI IX

High liquefaction potential

Tsunami inundation zone

Closed for 3 days

This route will have moderate structure damage with roadway and pavement separation due to lateral spreading induced by liquefaction. The tsunami will block the road with debris.

23 **Route 101, Eureka to 255/101 Interchange, Arcata**

MMI IX

High liquefaction potential

Closed for 3 days

Moderate damage to structure with roadway and pavement separation due to lateral spreading induced by liquefaction.

24 **Route 255/101 Interchange, Arcata (Sunny Brae Over-crossing)**

MMI IX

High liquefaction potential

Closed for 3 days

Moderate damage to structure, with roadway and pavement separation due to lateral spreading induced by liquefaction. Detours to available surface streets in Arcata will be necessary.

25 **Route 101 from 101/255 Interchange to 101/299 Interchange**

MMI VIII+ to IX

Restricted for 1 day

There will be minor structure damage, with detours available for emergency traffic.

26 **Route 101 Bridges and Route 101/200 Interchange north of Arcata**

MMI IX

High liquefaction potential

Closed for 3 days

There will be structure damage to the parallel bridges across the Mad River and to the roadway interchange.

27 **Route 101 from 101/299 Interchange to 101/200 Interchange**

MMI IX

High liquefaction potential

Closed for over 3 days

There will be major structure damage including abutment cracking and fill settlement at the Route 101/299 interchange. This route will have moderate structure damage with roadway and pavement separation due to lateral spreading induced by liquefaction.

28 **Route 299 from 101/299 Interchange to Glendale**

MMI IX

Moderate to high liquefaction potential

Closed for 3 days

There will be liquefaction damage to the roadway.

29 **Route 299, Glendale to Blue Lake**

MMI VIII+ to IX

Potential for landslides

Moderate potential for liquefaction

Restricted for 2 days

Despite some preexisting right lateral offset at the east approach-span connection of the Mad River Bridge there will be no structure damage. Some existing landslides will be reactivated and will block the west-bound lanes and damage the roadway.

30 **Route 299, Blue Lake to Berry Summit**

MMI VIII+

Closed for 2 days

This area has many landslides that are too small to show at this map scale, (Carver, 1993) suggesting that the route will be closed in many places by small slides. There will be moderate structure damage to the bridge crossing the North Fork of the Mad River with the bridge being closed for 12 hours for repairs.

31 **Route 299, Berry Summit to Salyer**

MMI VII

Potential for landslides

Closed for 1 day

There will be no structure damage. Rock falls and landslides will block the roadway for 1 day.

32 **Route 299, Salyer to east edge of study area**

MMI VII

Open with delays

There will be minor structure cracking and settlement here, but the route will remain open, with delays due to rockfalls and small slides.

33 **Route 96, Willow Creek to Orleans**

MMI VII to VIII+

Potential for landslides

Closed for 3 days

There will be major damage to the bridge across the Trinity River, but other structures will suffer only moderate, repairable damaged. Only portions of the route will be closed for 3 days. Rockfalls will block the roadway for at least 1 day.

34 **Route 169, Weitchpec to Cappell Creek**

MMI VI

Open with delays

There will be no structure damage along this route. Rockfalls and small slides will cause traffic delays.

35 **Route 169, Cappell Creek to Johnsons**

MMI VII

Potential for rock falls

Closed for 1 day

Although there will be no structure damage, this route will be closed by extensive rockfalls that are too small to show on Map S-3 individually.

36 **Route 96, Dillon Mountain**

MMI VII

High potential for rock falls

Closed for 2 days

Moderate structure damage to the Klamath River Bridge and the Dillon Creek Bridge on Highway 96, about 15 miles (24 km) north of the Siskiyou County line. Rockfalls will block portions of this route.

37 **Route 200 from Route 200/101 Interchange to Route 200/299 Interchange**

MMI VII to VIII+

Closed for more than 3 days

In addition to major damage to the interchanges with Routes 101 and 299, the roadway will be damaged by shaking.

38 **Route 101 from Route 200 to Clam Beach**

MMI VIII+

Open with delays

No structure or roadway damage. Tsunami inundation is possible at Clam Beach.

39 **Route 101, at Little River Beach State Park**

MMI IX

High liquefaction potential

Closed for 3 days

There will be major structure damage at Little River Bridge, and liquefaction damage along this route.

40 **Route 101, Little River Beach State Park to Spruce Acres**

MMI VIII+

Closed for 3 days

There will be moderate structure damage to the bridge at Big Lagoon, which will be closed for 2 days for temporary repairs. A bluff failure north of Patricks Point State Park will undermine the highway, closing the south bound lanes. The north bound lanes will be closed by a slide at Big Lagoon.

41 **Route 101 from Spruce Acres to Stone Lagoon**

MMI IX

High liquefaction potential

Restricted for 3 days

There will be no structure damage here, but the road surface will be disrupted by lateral spreads produced by extensive liquefaction. Repairs such as fill and patch work will be necessary. Emergency traffic will be permitted to pass.

42 **Route 101, Freshwater Lagoon**

MMI VII

High liquefaction potential

Closed for 2 days

Lateral spreading can be repaired within 2 days. Alternate route available. Possible tsunami flooding.

43 **Route 101, north of Freshwater Lagoon**

MMI IX

High liquefaction potential

Closed for 3 days

There will be moderate structure damage with significant liquefaction effects. Emergency traffic permitted within 2 days.

44 **Route 101 (old segment), north of Freshwater Lagoon to Resighini Rancheria**

MMI VIII+

Open

There will be minor structure and roadway damage. The new segment to the east has large cut and fills in soft ground and could have ground displacements.

45 **Route 101, Resighini Rancheria to Klamath River**

MMI IX

High liquefaction potential

Restricted for 3 days

There will be liquefaction damage to the roadway, but no bridges will be affected. The route will remain open to emergency traffic, with all traffic being permitted within 12 hours.

46 **Route 101, Klamath River Bridge, Klamath**

MMI IX

High liquefaction potential

Closed for 3 days

There will be major damage to the bridge across the Klamath River. Liquefaction will lead to damage to the bridge foundation and to the surrounding roadway. Possible tsunami flooding.

47 **Route 169, to Klamath Glen**

MMI VII to IX

High liquefaction potential

Closed for 1.5 days

There will be moderate structure damage with repairs requiring temporary shoring and earthwork. There will be moderate damage to the road surface due to liquefaction.

48 **Route 101, Klamath River to False Klamath Cove**

MMI IX

Moderate to high liquefaction potential

Closed for 2 days

There will be major damage to the Panther Creek Bridge with liquefaction damage to the roadway. Repairs will include temporary shoring and earthwork. Possible tsunami flooding.

49 **Route 101, False Klamath Cove to southern Crescent City**

MMI VII

Restricted for 1 day

There will be no significant structure or roadway damage, but according to Carver (1993), parts of this stretch have many landslides that are too small to map at this scale.

50 **Route 101, southern Crescent City**

MMI VIII+

Potential tsunami inundation area

Moderate potential for liquefaction

Closed for 3 days

This part of the road is between 10 and 30 feet (3 to 9 m) above sea level and will be in the tsunami inundation area. Structures will be damaged and blocked by debris.

51 **Route 101, northern Crescent City to Route 101/199 Interchange**

MMI VIII+

Restricted for 2 days

There will be only minor structure damage here with emergency traffic able to use city streets as alternate routes.

52 **Route 101, 101/199 Interchange**

MMI VIII+

Moderate potential for liquefaction

Closed for 1.5 days

There will be only minor structure damage here with emergency traffic able to use city streets as alternate routes.

53 **Route 199 from Route 101 to Hiouchi**

MMI IX

Moderate potential for liquefaction

Closed for 2 days

There will be moderate structure and roadway damage.

54 **Route 199, Hiouchi to Cedar Springs**

MMI VII

High rockfall potential

Existing landslides

Closed for 2 days

The steep east facing slopes above this road have moderate fracture densities and the existing slides contain serpentinite and serpentinite breccia. Numerous local rockfalls and small slumps will close the route.

55 **Route 199, Cedar Springs to Washington Flat**

MMI VII

High potential for rock falls

Closed for over 3 days

This is one of only two roads leading into the study area from the north. The route has very steep slopes with numerous perched rocks above the roadway (Photo H-4). Rockfalls will block the roadway and the river in the narrow canyons, with the reservoir depth being a few tens of feet. Carver (1993) indicates that some of the abandoned river terraces above the active channel along the upper Smith River are fluvial or lake sediments deposited upstream of large landslide dams.

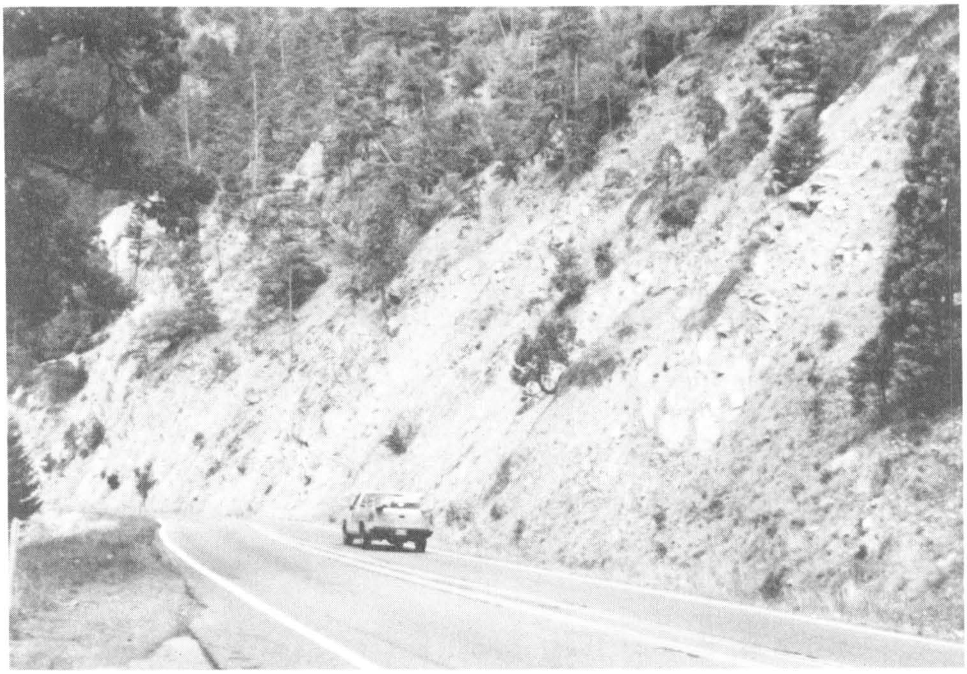

Photo H-4 Route 199 between Cedar Springs and Washington Flat.

56 **Route 199, Washington Flats to Oregon**

MMI VII

Open

The tunnel 3 miles (5 km) south of the Oregon border is well over 1,800 feet (550 m) long. It will likely suffer some minor cracking and settlement problems, but it will be open with only minor traffic delays.

57 **Route 101, Kings Valley**

MMI VIII+

Open

58 **Route 101, Smith River Bridge**

MMI IX

High liquefaction potential

Closed for 3 days

The area near this bridge is highly susceptible to liquefaction (Carver, 1993). There will be major damage to the bridge across the Smith River and liquefaction will damage the surrounding roadway.

59 **Route 197 along the Smith River**

MMI IX

Moderate to high liquefaction potential

Closed for 1 day

Only the lower reaches of this valley have high liquefaction potential. Because there are no structures along this route, the only possible damage will be pavement disruption from liquefaction.

60 **Route 101, Fort Dick to Smith River**

MMI IX

Moderate to high liquefaction potential

Closed for 2.5 days

There will be moderate structure damage here. Liquefaction will damage the roadway and structures.

61 **Route 101, Smith River to Smith River Rancheria**

MMI IX

Moderate to low potential for liquefaction

Open

62 **Route 101, Smith River Rancheria to the Oregon Border**

MMI VIII+

Open

There will be only minor structure cracking and movement along this route.

AIRPORTS

General Characteristics

Major and secondary airports in the planning area are shown on Map AR. The sites and facilities of the two major commercial airports served by regularly scheduled flights and the two largest secondary airports are listed in Table A-1. The Arcata-Eureka and McNamara airports were visited, surveyed, and reviewed for potential earthquake damage. Roads to and from the airports were also assessed for potential impairment to access and egress routes subject to liquefaction, landslides, and damage to bridges and overpasses. Eleven secondary local airports were also visited. In this scenario where surface transport will be severely curtailed, and the area will be accessible mainly by air, airports will be a valuable resource to receive supplies and transport casualties.

Only the Arcata-Eureka Airport and the McNamara Field in Crescent City are capable of handling C-130 aircraft, which require 5,000-foot runways for normal operations. Under special conditions, the C-130 type aircraft are capable of using unimproved runways or major roads.

Other major commercial and military airports available for emergency relief outside the immediate planning area are:

1. McClellan Air Force Base in Sacramento, Sacramento County, California
2. Travis Air Force Base in Fairfield, Solano County, California
3. Beale Air Force Base in Marysville, Yuba County, California
4. Medford-Jackson County Airport in Medford, Jackson County, Oregon

These airports are accessible to U.S. Interstate Highway 5, and are less than an hour's flight time from the planning area.

Seismic Considerations

Earthquake concerns for airports fit the following three categories:

1. Ground access and egress
2. Damage to runways and taxiways
3. Damage to buildings, including control towers

The minimum requirements for emergency operations are ground access and egress at the airport and usable runways and taxiways. Damage to or collapse of buildings, including the control tower, will not prevent emergency operations, particularly for military airlift operations. Ground access and egress implies that vehicles can come and go between the airport and the affected communities. Access problems can be created by collapse of adjacent freeway structures, road blockage by

TABLE A-1

COMMERCIAL AND MAJOR SECONDARY AIRPORTS

AIRPORT	CITY	COUNTY	RUNWAY LENGTH	SITE LOCATION MM INTENSITY
Arcata-Eureka	McKinleyville	Humboldt	6,000 and 4,500 feet	VIII+
McNamara	Crescent City	Del Norte	2 at 5,000 feet	VIII+-IX
Murray Field*	Eureka	Humboldt	3,000 and 2,000 feet	IX
Rohnerville	Rohnerville	Humboldt	4,000 feet	VIII+

* High liquefaction potential

nearby landslides, and settlement due to liquefaction. Access considerations also must include the operation of utilities such as power, telephone, and water. On-site aircraft fuel storage is another important consideration, especially if supplies have to be brought in from long distances.

Runway damage can render an airport unusable for emergency flights. The most serious threat to runways is damage from liquefaction of the underlying soils. Liquefaction can result in breaks in the pavement with differential settlements and lateral spreading of adjacent parts of runways. Federal Aviation Administration (FAA) regulations require the closing of a runway when there is a break (i.e., crack) in the pavement 3 or more inches wide. Damage to pavements from liquefaction can easily cause this much separation.

The 1964 Great Alaska earthquake (M9.2), provided an excellent test of airport operations during an emergency. Of 64 airports inspected after the earthquake, 13 had runway or taxiway damage. Nevertheless, virtually all were operational within hours after the event. Some resourcefulness, however, was required. For example, the collapse of the control tower at Anchorage International Airport required use of radios in a grounded plane for air traffic control.

During the 1989 Loma Prieta earthquake (M7), Oakland International Airport lost 3,000 feet of runway. Runway damage also closed Alameda Naval Air Station for over 2 months. San Francisco International Airport was closed for 13 hours. Its control tower suffered minor damage, a cargo building suffered major damage, and some passenger terminals experienced extensive nonstructural damage, including water damage from fire sprinkler heads impacted by swinging suspended ceilings (EERI, 1990).

Planning Considerations

As it did in the 1964 floods, air transport will play an important role in the earthquake and tsunami response operations because closure of the overland routes will isolate the area. Because the major population centers in the central planning area are in Eureka and Crescent City, the use of the Arcata-Eureka and McNamara airports will be crucial. The Crescent City Airport and the Arcata-Eureka Airport can take C-130 aircraft.

The use of helicopters to transport people and material for search and rescue, general damage assessment, and the movement of critical supplies and light equipment should be given a high priority in planning. The U.S. Coast Guard Station at the Arcata-Eureka Airport has helicopters and associated facilities. Unfortunately, as presently constituted, the Coast Guard Station on the Samoa Peninsula will be destroyed by the tsunami.

Planning Scenario

Emergency air transport to and from the disaster area is vital to response activities, particularly during the first 72 hours. The best options under these scenario conditions will be Arcata-Eureka Airport and McNamara Field in Crescent City. Most small outlying airports in the planning area will be useable for small fixed wing aircraft and helicopters. They could be used to evacuate casualties and bring in key personnel and supplies. However, the condition of each would have to be determined, as some may be damaged or inaccessible due to road damage. Local emergency officials should consider these problems by referring to the damage assessments listed below.

Damage Assessments

Damage assessments have been postulated for certain facilities as set forth below. The statements regarding the performance of facilities are hypothetical and intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Outage and repair times assume that materials, equipment, and human resources are available concurrently for each damage locality. They will probably not be available concurrently, and outages could be much longer than estimated here. The locations of airports are shown on Map AR.

MAP NO.	AIRPORT FACILITIES
A1	Shelter Cove (landing strip) MMI VIII+ Open

Runway:	3,400 feet long, 75 feet wide
Wheel Weight:	Single wheel 30,000 pounds
Fueling Facility:	None
Repair Facility:	None
Based Aircraft:	5 single or multiple engine

Reactivation of existing landslide to east and landslides in surrounding areas of landslide potential will damage local roads impeding access to airport.

A2 **Garberville**

MMI VIII+

Open

Runway:	3,050 feet long, 75 feet wide
Wheel Weight:	Single wheel 30,000 pounds
Fueling Facility:	Yes
Repair Facility:	None
Based Aircraft:	16 single engine

Airport is built on a thin fluvial terrace deposited on beveled sedimentary bedrock just east of the Eel River. The airport is only large enough for single and dual engine small aircraft and helicopters. Highway 101 will be closed for 3 days south of Benbow and north of Phillipsville due to landslides. Therefore, the airport will serve the local area only.

A3 **Dinsmores**

MMI VIII+

Open

Runway:	2,510 feet long, 48 feet wide
Wheel Weight:	
Fueling Facility:	None
Repair Facility:	None
Based Aircraft:	1 single engine

Highway 36 will be closed to the east and west for 2 days, impeding access to the airport.

A4 **Rohnerville**

MMI VIII+

Open

Runway:	4,005 feet long, 100 feet wide

Wheel Weight: Single wheel 30,000 pounds
Fueling Facility: Yes
Repair Facility: Yes
Based Aircraft: 35 single and multi-engine aircraft and 1 helicopter
Local roads will be open with access to portions of Highway 101.

A5 **Kneeland**
MMI VII
Open
Runway: 2,270 feet long, 60 feet wide
Wheel Weight: Single wheel 13,000 pounds
Fueling Facility: None
Repair Facility: None
Based Aircraft: 1 helicopter
Airport is remote from urban area but serves local residents. Local roads will be closed by reactivation of existing landslides and Highways 299 and 36 will be closed where local roads intersect highways.

A6 **Eureka Municipal, Samoa Peninsula (landing strip)**
MMI IX
Tsunami inundation zone
High liquefaction potential
Closed for an extended period
Runway 2,700 feet long, 75 feet wide
Wheel Weight: Single wheel 10,000 pounds
Fueling Facility: None
Repair Facility: Yes
Based Aircraft: 5 single engine aircraft
Airport will be heavily damaged by liquefaction and tsunami inundation.

A7 **Murray Field, Eureka**
MMI IX
High liquefaction potential
Closed for over 3 days
Runways: 3,000 and 2,028 feet long, 75 and 50 feet wide
Wheel Weight: Single wheel 19,000 and 5,000 pounds

Fueling Facility:	Yes
Repair Facility:	Yes
Based Aircraft:	101 single and multi-engine aircraft

Highways and local roads will be closed by lateral spreading due to liquefaction.

A8 **Arcata-Eureka, McKinleyville**

MMI VIII+

Open

Runways:	5,998 and 4,500 feet long, 2 at 150 feet wide
Wheel Weight:	Single wheel 60,000 pounds, dual wheel 155,000 pounds, dual tandem 280,000 pounds
Fueling Facility:	Yes
Repair Facility:	None
Based Aircraft:	11 single and multi-engine aircraft, 3 helicopters, 2 military aircraft

This airport has runways sufficient for C-130 aircraft. There will be some damage to buildings and structures which will hinder, but not prevent, airport use for emergency purposes. The control tower will have nonstructural damage and will need to be inspected before resuming full operation. The local stretch of Highway 101 and local roads will be open, but Highway 101 to the south and north will be closed for 3 days.

A9 **Willow Creek**

This airport has been closed. Gravel mining has destroyed runway.

A10 **Hoopa Valley (landing strip)**

MMI VIII+

Open

Runway:	2,325 feet long, 50 feet wide
Wheel Weight:	Single wheel 10,000 pounds
Fueling Facility:	None
Repair Facility:	None
Based Aircraft:	None

This field is limited to small planes and helicopters. The airport will be damaged but usable. Routes 299 and 96 will be closed so access will be limited to the local area only.

A11 **Klamath Glen**

MMI IX

High liquefaction potential

Closed for over 3 days

Runway:	2,400 feet long, 50 feet wide
Wheel Weight:	Single wheel 12,000 pounds
Fueling Facility:	None
Repair Facility:	None
Based Aircraft:	None

Runway will be damaged by liquefaction.

A12 **McNamara Field, Crescent City**

MMI VIII+

Moderate to low liquefaction potential

Open

Runways:	2 at 5,002 feet long, 150 feet wide
Wheel Weight:	Single wheel 30,000 pounds, dual wheel 43,000 pounds , dual tandem 100,000 pounds
Fueling Facility:	Yes
Repair Facility:	Yes
Based Aircraft:	31 single and multi-engine aircraft

Some airport structures will be damaged. The tsunami will close roads in southern Crescent City for 3 days, but there will be access to a restricted part of Highway 101 north of the city. Local roads can be used to get around the closed 101/199 interchange.

A13 **Gasquet (Ward landing strip)**

MMI VII

Open

Runway:	2,990 feet long, 50 feet wide
Wheel Weight:	Single wheel 12,000 pounds
Fueling Facility:	None
Repair Facility:	None
Based Aircraft:	None

Route 199 will be closed to the east and west.

A11 **Klamath Glen**

MMI IX

High liquefaction potential

Closed for over 3 days

Runway:	2,400 feet long, 50 feet wide
Wheel Weight:	Single wheel 12,000 pounds
Fueling Facility:	None
Repair Facility:	None
Based Aircraft:	None

Runway will be damaged by liquefaction.

A12 **McNamara Field, Crescent City**

MMI VIII+

Moderate to low liquefaction potential

Open

Runways:	2 at 5,002 feet long, 150 feet wide
Wheel Weight:	Single wheel 30,000 pounds, dual wheel 43,000 pounds , dual tandem 100,000 pounds
Fueling Facility:	Yes
Repair Facility:	Yes
Based Aircraft:	31 single and multi-engine aircraft

Some airport structures will be damaged. The tsunami will close roads in southern Crescent City for 3 days, but there will be access to a restricted part of Highway 101 north of the city. Local roads can be used to get around the closed 101/199 interchange.

A13 **Gasquet (Ward landing strip)**

MMI VII

Open

Runway:	2,990 feet long, 50 feet wide
Wheel Weight:	Single wheel 12,000 pounds
Fueling Facility:	None
Repair Facility:	None
Based Aircraft:	None

Route 199 will be closed to the east and west.

A14 Smith River (Ship Ashore landing strip)

MMI IX

High liquefaction potential

Closed for over 3 days

Runway:	Approximately 2,400 feet long, width unknown
Wheel Weight:	Unknown
Fueling Facility:	Unknown
Repair Facility:	Unknown
Based Aircraft:	Unknown

Landing strip shown on USGS topographic maps, but not listed by FAA. Engineers at the Del Norte County Community Development Department are not aware of a facility there. Probably abandoned with unserviceable runways and no facilities. Liquefaction will damage runways. Route 101 open to north into Oregon and south to Route 101/197 interchange.

MARINE FACILITIES

General Characteristics

The two major marine facilities along the coastline of the planning area are at Eureka and Crescent City, and their locations shown on Maps SHM-1 and SHM-2. In addition, there are other small harbors such as Trinidad, for yacht clubs and pleasure craft. Vessels using the harbors are mainly commercial and private ships. Although Humboldt Bay has provided ship mooring for lumber and log exporting for many years, the volume of lumber and logs has recently declined. Since the days when redwood logging was of prime interest in Crescent City, and the Citizens Dock project in Crescent Harbor was built in 1950 "through community group efforts to save the lumber and fishing industries" (Conlin, 1991), the volume of its commercial shipping industry has diminished.

Except for the U.S. Coast Guard Reservation stations, no major military marine facilities are in the planning area in comparison to those found in other parts of California such as Hunter's Point Naval Shipyard in San Francisco or the U.S. Pacific Naval Base in San Diego.

The Humboldt Bay harbor is a natural harbor with the Samoa Peninsula protecting it from the ocean. The North and South jetties were constructed to reduce the hazard of entering the harbor. The jetties were originally constructed with large rocks hauled in by railroad. In recent years the two jetties have been rehabilitated by using concrete dolos to provide increased stability against heavy wave action.

Seismic Considerations

Information collected on the seismic performance of docks, jetties, warehouses, equipment, and support structures in previous earthquakes was extrapolated for this scenario.

Seismic events of particular interest to this section are:

a) The 1960 South Chile earthquake (M9.5) and the 1964 Great Alaska earthquake (M9.2), both of which generated tsunamis that hit Crescent City

b) The 1954 Eureka earthquake (M6.5)

In the 1954 Eureka earthquake, "The Hammond Lumber Company at Samoa had some of its structures on a hydraulic fill along the waterfront. The fill was said to have been placed about 1940. A large one story wood frame warehouse at this location settled vertically and lurched slightly toward the bay. Other wood frame buildings had some indications of damage, possibly due in part to settlement" (Steinbrugge and Moran, 1957).

The 1960 South Chile earthquake "triggered a small wave that travelled north in the Pacific for 15 hours. The surge reached 12 feet and lasted for 23 minutes, dumping water and debris on Crescent City streets. ...In that instance, two vessels were lost in the harbor, and about $30,000 in damage was reported" (Conlin, 1991).

The biggest seismic impact on Crescent City, however, occurred after the 1964 Great Alaska earthquake generated a tsunami that spread southward in the Pacific Ocean. Accounts of the impact of this event on Crescent City are summarized earlier in the report.

Other accounts of the vulnerability of harbors to unstable soils, liquefaction, and tsunamis are documented in reconnaissance reports on past seismic events in Alaska after the 1964 earthquake and the San Francisco Bay area after the 1989 Loma Prieta earthquake:

> "At Seward, Alaska, the 1964 earthquake was intense and of long duration. Docks apparently began sliding under the water surface soon after the earthquake began and continued during the shaking. One 200-ton wharf crane disappeared in the slide and was never found again. Another jumped its rails. The ground surface under Resurrection Bay at Seward drops off rapidly from the shoreline, being about 200 feet deep at about 900 feet from the shore. This steep gradient on unstable soils readily explains the landslide with its destruction of docks and the "lost" crane.
>
> Submarine landslides also destroyed the port facilities at Valdez and Whittier, Alaska, in the 1964 shock. Substantially lesser damage was sustained to the docks at Anchorage, Alaska, although a crane overturned at one of them. Damage also occurred at many other locations along the southern Alaska coastline.
>
> The damage to port facilities was compounded by the spectacular tsunami and its effects. ...Valdez also had tsunami damage due to submarine landsliding. The ship Chena was moored at the dock which collapsed. Lives were lost on the dock and the ship. ...The highest wave rose to 23 feet. Valdez has since been rebuilt on a different site with the view of minimizing the hazard from future submarine landslides and tsunamis" (Steinbrugge, 1982).

In the 1989 Loma Prieta earthquake (M7.0) at the Port of San Francisco and the Port of Oakland:

> "The primary cause of damage (at the Port of San Francisco) was liquefaction of the fill material, which resulted in the settlement of the piers supported by fill relative to the portions of the piers supported by piles. Settlement continued for several weeks after the earthquake. ...Because of significant structural damage at different locations along the waterfront, some buildings were condemned. Structural damage included cracked concrete walls and displaces asphalt decks in warehouses on Piers 45 and 48, caused by settlement of underlying fill; cracking and collapse of unreinforced clay tile walls in an office building on Pier 70; and the buckling of columns at the clock tower in the Ferry Building. ...Other damage at the port included many broken water mains, many broken batter piles, cracked decks above the piers, and damage to five container cranes.
>
> "As with the Port of San Francisco, the primary cause of damage (at the Port of Oakland) was liquefaction of fill and the resulting settlement and spreading of areas of fill relative to areas supported by piles. The many broken water and fire lines washed the fine materials from the soil, causing both settlement and uplift of the asphalt

pavement at numerous locations throughout the port. ...Wood piles with concrete followers were broken at Middle Harbor, resulting in condemnation of a building that was supported on these piles. The piles broke at the wood-concrete interface. Throughout the port, damage to piles and the settlement of fill occurred up to three weeks after the earthquake. ...At the Seventh Street terminals the crane rails that were on fill settled as much as 12-15 inches relative to the rail on piles, rendering the cranes inoperable. The rail spur serving Terminal 40 is...out of service because of horizontal and vertical displacement of the rails of fill relative to a portion of the spur supported by piles. Significant settlement and separation of the truck access road to Terminals 35-38 at the Seventh Street Complex occurred as a result of liquefaction. ...The Seventh Street Complex was finally shut down" (EERI, 1990).

As can be seen from accounts of past earthquakes, similar damage patterns appear in marine facilities due to ground settlement, liquefaction of soils due to strong shaking, and damage of port facilities and equipment due to tsunamis. Harbors along the coast of Humboldt and Del Norte counties have the same seismic considerations in terms of their vulnerability to earthquakes, and accordingly, should be expected to experience similar damage patterns.

Planning Considerations

Most of the docks in Eureka are supported on piles. While they are not expected to suffer severe damage from shaking, damage will result from tsunami effects. Moreover, tarmacs, aprons, access roads, and other paved surfaces over fill areas will fail due to settlement and liquefaction.

Pipelines, water utilities, storage tanks, and other facilities important to terminals and docks are susceptible to rupture where they cross areas of soft soil near the docks. Restricted egress and access to terminals and docks from liquefaction-damaged streets will be more common than liquefaction damage to pile supported docks. Finally, it is the tsunami that will severely impair the marine facilities. To facilitate access and to create fire breaks, earth moving equipment should be available for use after the tsunami. Fire was a major problem in the 1993 Japanese earthquake (EERI, 1993). Firefighters were unable to reach the fire due to the debris left by the tsunami.

Planning Scenario

We expect impacts due to the tsunami in Crescent City that are at least comparable to those that occurred in 1964. While the city prudently has restricted land use adjacent to the harbor area, new development south of town along the shoreline is vulnerable. Damage to docks and other structures will equal or exceed that experienced in 1964.

The Humboldt-Arcata Bay is partially protected from tsunami damage by the Samoa Peninsula and South Spit. We expect the peninsula to be overtopped, and all structures and lifelines to be severely damaged. Without sufficient warning time and evacuation, casualties could be heavy on the Samoa Peninsula, as was the case with a tsunami that struck an island west of Nicaragua in 1992. The earthquake and tsunami damage will release any hazardous materials used in the pulp mills on Samoa Peninsula, adding to the response problems.

The Samoa Peninsula will take the brunt of the tsunami damage in Humboldt Bay, allowing only minor waves to reach Eureka. No such barriers exist in Crescent City, leading to broad tsunami inundation and damage in the downtown area (Maps S-1 and S-2). We expect more severe liquefaction damage in the Humboldt-Arcata Bay area and more severe tsunami damage in Crescent City.

Usable docks in the heavily damaged areas will require emergency power and special off-loading capabilities. Truck traffic to and from the ports may have to be rerouted via undamaged access routes. Appropriate coordination efforts with other ground transport services will be required for efficient transfers. We expect marine transport will play minor roles in emergency response efforts. Air transport should be coordinated with ground transport to select the most effective means of providing needed equipment and supplies to the stricken area.

Serious disruption will last for a week, but problems could continue for up to a year. Typical problems include loss of electric power, damaged surface roads, debris from the tsunami, and damage to cranes and related facilities.

<u>Damage Assessments</u>

Damage assessments have been postulated for certain major facilities as set forth below. The statements regarding the performance of facilities are hypothetical and intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Outage and repair times assume that materials, equipment, and human resources are available concurrently for each damage locality. They will probably not be available concurrently, and outages could be much longer than estimated here. Locations of marine facilities are shown on Maps SHM-1 and SHM-2.

<u>MAP NO.</u> <u>MARINE FACILITIES</u>

M1 Humboldt Bay Harbor

MMI IX

High potential for liquefaction

Tsunami run-up zone

Closed for 7 days

Severe damage will result from strong ground shaking, liquefaction, and the tsunami.

M2 Crescent City Harbor

MMI IX

Tsunami run-up zone

Closed for an extended period

Crescent City's harbor directly faces the ocean, and the tsunami damage will be even greater than that experienced in 1964. Figure S-3 in the Geology and Seismology chapter compares the extent of inundation in the present scenario to that from the 1964 Alaska earthquake. The tsunami will heavily damage the pier areas and nearby structures, and will extend several blocks into the downtown area.

RAILROADS

General Characteristics

With the changes that have occurred over the last two decades in the economics and development of the timber industry, the role of railroads in hauling freight has diminished considerably throughout the planning area. As a result, transport by railway is now limited to the North Coast Railroad (NCRR). Based in Eureka, the NCRR operates from near Arcata on the north to the City of Willits in the south. It also provides occasional service to Fairhaven on the Samoa Peninsula. Selected locations, bridges, and railway facilities were surveyed in the field for potential earthquake damage.

The major active north-south railroad line in northwestern California closest to Humboldt and Del Norte counties is operated by the Southern Pacific Transportation Company (SPTCO) and is outside the planning area, 100 miles (160 km) due east of Eureka and Crescent City. This railway line runs parallel to Interstate 5 which stretches from San Diego near the Mexican Border, through Oregon, and north to Washington. Any emergency materials and equipment transported over this SPTCO line would have to be flown in from McClellan Air Force Base in Sacramento, Travis Air Force Base in Fairfield, Beale Air Force Base in Marysville, or Medford-Jackson County Airport in Oregon, to airports in Eureka and Crescent City, because highways into Humboldt and Del Norte counties from the Sacramento Valley and from Oregon will generally be impassable (refer to Highways Map H-3).

As shown on Map AR, there are three local railroad lines:

1. The apparently unused line from Arcata to the Samoa Peninsula.
2. The line that runs from Arcata, through Eureka, down to Fortuna, to Rio Dell and Scotia in the south, along the Eel River portion outside the planning area to Dos Rios and reaches its terminal at Willits.
3. The seldom used line that runs from the northern part of Arcata to the Mad River near the community of Korbel.

Over the years, segments of the North Coast Railroad line have not been maintained and are not in current use. Currently, there are no extensive railway lines in Del Norte County.

For planning purposes within the study area, Railroad access to the outside for post-earthquake emergency freight haulage (including heavy equipment and critical supplies) will be unavailable throughout the 3 day scenario. The route will be blocked by landslides and lateral spreading, and may not be totally functioning for a month or longer.

Seismic Considerations

The coastal railroad lines in the Eureka/Arcata marine terminal areas in Humboldt and Arcata bays, run along bay margins which are subject to liquefaction and tsunami effects. Rail lines located on such "poor ground" in low-lying areas are highly susceptible to severe damage. For an excellent source of information on damage patterns to be expected during a major earthquake, refer to the paper on the effects of the 1964 earthquake on the Alaska Railroad (McCulloch and Bonilla, 1970).

Railway bridges do not necessarily experience major damage except in areas subject to ground failure. However, when severe bridge damage does occur, it may involve a lengthy period for major repairs, which may last up to 14 days. The North Coast Railroad system has a roadbed line that crosses over the Little Salmon fault, bridges various sloughs, creeks and rivers including the Eel River, and runs along bay margins susceptible to liquefaction and tsunami run-up.

The 1964 Great Alaska earthquake produced tsunamis that severely damaged several coastal communities. One of the hardest hit was the City of Seward where railroad lines in waterfront dock areas were damaged:

> "A large swell broke over the Alaska Railroad dock area, lifting the flat cars off the tracks. ...An 80-car freight train on the tracks between the Standard and Texaco tanks was just ready to start moving north. Its last 40 cars were filled oil tankers and as the fire swept onto shore, the tankers caught fire in a chain reaction of exploding cars down the track toward the Texaco yard. ...The first seismic sea wave is reported to have spanned the width of the bay as it entered the Seward area and to have been 30 to 40 feet high as it neared the head of the bay. Burning oil covered much of its surface. Carrying boats, houses, and railroad cars collected from the Seward waterfront area, the wave crashed over the railroad embankment..."(Steinbrugge, 1982).

A brief written assessment of the impact of the 1992 Cape Mendocino earthquake (M7) on the North Coast Railroad indicates that little damage occurred on its lines to the City of Willits (EERI, 1992a):

> "The North Coast Railroad operated between Willits and Eureka transporting gravel and lumber. The two trains operating on the day of the first earthquake were stopped in accordance with company policy. Trains were cleared to proceed to their terminals after the tracks, tunnels, and bridges were inspected. On the next day, Sunday, a normal non-operating day, a more detailed inspection was made. The tracks were cleared of minor loose landslide material and were re-ballasted at one minor settlement. There was no settlement at bridge abutments. Train service returned to normal on Monday without loss of service."

During the 1994 Northridge earthquake (M6.7) in the greater Los Angeles region, "A 64 car freight train traveling through Northridge derailed at the time of the earthquake. There were 15 tank cars carrying sulfuric acid, and 8,000 gallons of acid spilled from one of the cars. Also, 2,000 gallons of diesel fuel spilled from the locomotive. Train service was restored by 2:00 a.m., January 19th, and the area was cleared of debris by January 21st (four days after the earthquake)" (EERI, 1994).

Railroad facilities and tracks are also subject to closure by major damage to freeway overpasses, bridges built over slough areas, and other traffic interchanges constructed over rail lines. As indicated by damage to the Struve Slough bridges during the 1989 Loma Prieta earthquake (EERI, 1990) and collapse of the Interstate 5/State Road 14 interchange during the 1994 Northridge earthquake (EERI, 1994), existing interchanges, overpasses, and bridges are vulnerable to significant damage and collapse. The Fields Landing overpass of Highway 101 which collapsed onto the North Coast Railroad line during the 1980 Gorda Basin earthquake (M7) is yet another example.

Planning Considerations

Privately owned railroads, because of their repair capabilities, including extensive use of outside contractors, are generally able to solve most of their reconstruction problems with little attention from governmental emergency response organizations. However, because the NCRR is a public agency, it may need to obtain outside resources through Humboldt County's Office of Emergency Services, and will most likely be eligible for state and federal disaster assistance.

Complete restoration of rail service throughout the area could take several weeks to many months. The relationships between the railroad, other systems of transport, and utility lifelines should be reviewed to identify likely response and service restoration problems and to set repair priorities before the scenario earthquake occurs.

Planning Scenario

The rail lines along the Eel River, Humboldt Bay, and Arcata Bay, will be displaced by liquefaction and landslides and closed for repairs for several weeks. All movable span bridges in MMI VIII+ to IX zones are subject to misalignment due to heavy ground shaking. Many of the older bridges will be closed along the NCRRs right of way.

Damage Assessments

Damage assessments have been postulated for certain major facilities as set forth below. The statements regarding the performance of facilities are hypothetical and intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Outage and repair times assume that materials, equipment, and human resources are available concurrently for each damage locality. They will probably not be available concurrently, and outages could be much longer than estimated here. The locations of the NCRR are shown on Map AR.

MAP NO.	RAILROAD LOCATIONS
R1	**North Coast Railroad, from the Mendocino County line to South Fork** MMI VII to IX Potential for landslides High potential for liquefaction Closed for more than 7 days Embankments will be damaged. The bridge over the Eel River at Dyerville will be misaligned and will be closed to traffic from 2 to 8 days. There will be numerous closures due to landslides which will block or misalign tracks and bridges.
R2	**North Coast Railroad, Dyerville loop** MMI VIII+ to IX Potential for landslides High potential for liquefaction Closed for more than 7 days Large slide with high relief on ridge above railroad indicates slide mass will close railroad above the Eel River.
R3	**North Coast Railroad, bridge at Scotia, South Fork Eel River** MMI VIII+ to IX Potential for landslides High potential for liquefaction Closed for more than 7 days Liquefaction and landslides will block or misalign the tracks, and the bridge across the South Fork Eel River (Photo R-1).
R4	**North Coast Railroad, beneath Fields Landing Overpass** MMI IX High potential for liquefaction Closed for more than 7 days The overpass on Route 101 could fall onto the tracks as occurred in 1980. Beneath the overpass the railroad tracks cross a drainage area underlain by fine sand which is subject to liquefaction (Photo R-2). Either or both situations will stop service on this segment.

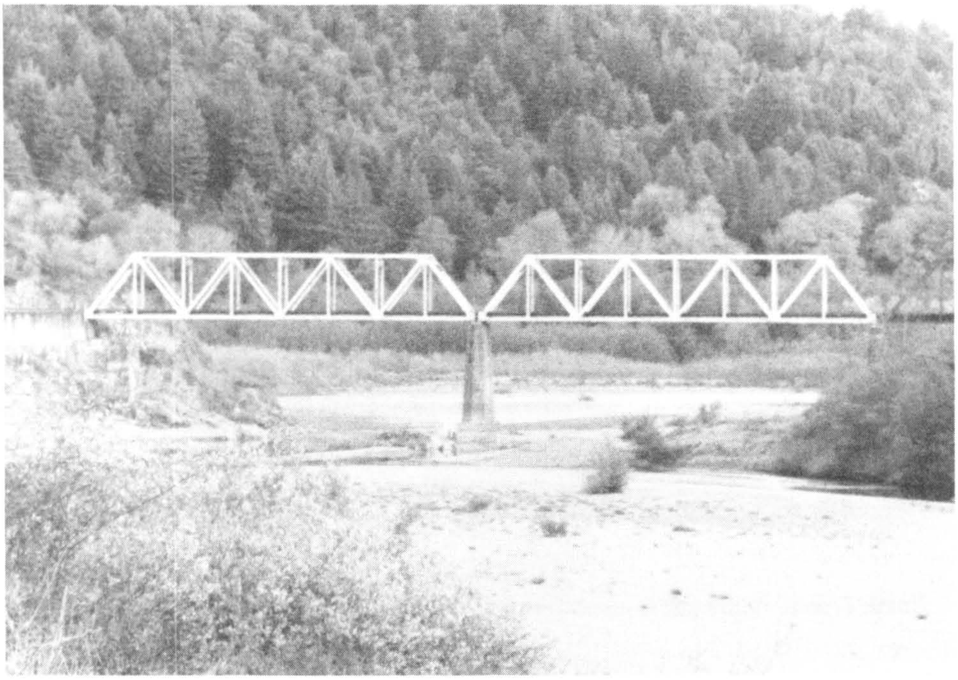

Photo R-1 Railroad bridge across South Fork Eel River at Scotia.

Photo R-2 Railroad tracks beneath Fields Landing overpass.

R5 **North Coast Railroad, north of Fields Landing to Eureka and Arcata**

MMI VIII+ to IX

High potential for liquefaction

Closed for more than 7 days

Line follows Humboldt Bay eastern shoreline, which is subject to liquefaction.

R6 **North Coast Railroad, Samoa to Arcata (non-operational)**

MMI IX

High potential for liquefaction

Tsunami run-up zone

Closed for an extended period

R7 **North Coast Railroad, Arcata to Blue Lake**

MMI VII to IX

High potential for liquefaction

This seldom used segment will be closed for more than 7 days

SECTION 4

UTILITY LIFELINES

ELECTRIC POWER

General Characteristics

Electric power is supplied to Humboldt County by Pacific Gas & Electric (PG&E) and to Del Norte County by Pacific Power and Light Company. Routes of transmission lines and the location of a major generating facility and substations that serve the area are shown on Maps EGP-1 and EGP-2 and AR. The major generating plant in the planning area and representative substations were reviewed for vulnerability to seismic effects.

Sources of electric power in Humboldt County are the PG&E fossil fuel generating plant near Buhne Point, three transmission lines from outside the area, and private cogeneration plants in the area. The Humboldt Bay Power Plant is fueled by natural gas produced at the Tompkins Hill Gas Field and by gas transmitted to the plant by a PG&E-operated 12-inch pipeline from Red Bluff.

Electrical power for the Crescent City area is managed by Pacific Power and Light Company. The supply lines come through Grants Pass substation in Oregon, with 90 percent of the power originating at the Jim Bridger Plant in Wyoming. The remaining 10 percent comes from two hydro-electric plants in Oregon at Klamath River and Tokedy. The power is distributed to the city starting from the Del Norte Substation, about 5 miles (8 km) north of town.

Table E-1 is a listing of the principal communities served by PG&E in Humboldt County and Pacific Power and Light Company in Del Norte County. In addition to the two major electric power companies listed in Table E-1, privately owned power plants (Fairhaven Power Company, Simpson Company, and the Louisiana Pacific Company on the Samoa Peninsula, and Ultra Power Company near Blue Lake) generate electric power for sale to PG&E.

Table E-2 lists the public and private electric power plants in the planning area. The PG&E power plant located on Humboldt Bay near Buhne Point is the sole public utility system that generates electric power within the planning area.

Within a complete electric power service system there are many critical elements including four primary components:

1. Generating power plants
2. High voltage transmission lines
3. Transformer and switchyard substations
4. Distribution lines

TABLE E-1

PRINCIPAL COMMUNITIES SERVED BY ELECTRIC POWER COMPANIES

UTILITY COMPANY	COUNTY	COMMUNITY
Pacific Gas & Electric	Humboldt	Eureka Arcata McKinleyville Blue Lake Trinidad Fortuna Hydesville Loleta Rio Del Bridgeville Miranda Weott Orick Petrolia Ferndale
Pacific Power and Light Co.	Del Norte	Crescent City Smith River Gasquet Klamath Fort Dick

TABLE E-2

ELECTRIC POWER GENERATING PLANTS IN THE PLANNING AREA

ELECTRIC POWER PLANT	LOCATION	SITE LOCATION MM INTENSITY
PG&E*	Buhne Point	IX
Fairhaven Power Co.**	Samoa Peninsula	IX
Louisiana Pacific Co.**	Samoa Peninsula	IX
Simpson Co.**	Samoa Peninsula	IX
Ultra Power Co.**	Blue Lake	VIII+

* The major electric utility company in Humboldt County
** Small, privately owned plant

Seismic Considerations

Large earthquakes generally disrupt electric power service. Sources of disruption may come from one or more of the following three elements:

1. Disruption of the source of supply
2. Damage to transmission facilities
3. Damage to switching and transformer facilities
4. Damage to the distribution system

Sources of electric power include generating plants, such as fossil, hydro and nuclear power plants, and power supplied from transmission inter-ties with power grids with many diverse power sources. Generating facilities are typically rugged. For instance, the Moss Landing Plant (2,000 MW) on Monterey Bay was shaken at MMI VII by the Loma Prieta earthquake (M7) but damage to the seven generating units was relatively modest (EERI, 1990).

Transmission facilities consist of high-voltage lines and substations. Generally, transmission towers and lines are resistant to damage from ground shaking, but they can be damaged by ground movements caused by surface fault rupture, liquefaction, or landslides. The effects of ground movements, however, are much more local than are ground shaking effects. Transmission facilities are vulnerable mainly at high-voltage substations ($\geq$220 kV). During the Loma Prieta earthquake, three such substations (Moss Landing, Metcalf, and San Mateo) suffered major damage. Within the Moss Landing substation (MMI VII), about 18 miles (29 km) from the epicenter, four live-tank circuit breakers were severely damaged as well as 10 of 12 current transformers (EERI, 1990). The type of damage experienced at Moss Landing, and the other two substations, is not without precedent. In fact, high-voltage substations generally are considered the least seismically resistant element in electric power supply systems.

At Seward, Alaska, the 1964 earthquake (M9.2) and tsunami caused great damage to the electric power system:

> "Some storage tanks at the Standard Oil tank farm broke open during the earthquake and the oil ignited. The nearby building, housing the standby generators, burned, and all the equipment was destroyed. The 69-kV transmission line across the freshwater lagoon was demolished. Power poles and spans of conductors were destroyed in the old townsite by slides, destruction of the dock, movement or destruction of buildings, and by waves. The only electric service available after the earthquake was from an emergency generator that provided a limited amount of power at the hospital" (NAS, 1973).

The Great Alaska earthquake also generated the tsunami that inundated Crescent City on March 27, 1964:

> "...a number of fires broke out in the harbor-front area in the city and south of town as electric lines were short circuited and oil tanks ruptured. However, water over Highway 101 prevented fire trucks from proceeding immediately to the burning tanks. ...There was a continuous crashing and crunching sound as the buildings gave way and splintered into rubble, and there were flashes from high powered electrical lines shorting out that resembled an electrical storm approaching from the east, except some of the flashes were blue" (Griffin, 1984).

At the PG&E generating plant during the 1992 Petrolia earthquake (M7) series:

> "The peaking unit operating at the time of the first event tripped off and could not be started again due to condenser tube leaks and low water levels in the steam drum. The other peaking unit was 'hot' and took 6 hours to reach operating output. It then tripped during the second event. Despite these events, there was adequate power supply because of the availability of the outside sources. Local outages were caused by transformer fires, wires welded together, wires slapping together, and wires burning down" (EERI, 1992a).

The 1992 Landers earthquake (M7.5) in San Bernardino County provides excellent evidence of the performance of high-voltage transmission towers during a major earthquake:

> "Power service was disrupted for approximately 600,000 customers throughout the greater southern California region, including customers as far way from the epicenter as Santa Barbara and Los Angeles, owing to localized damage within the distribution system. The region is served by approximately eight electric utilities. Most of the service disruptions were for a few seconds or minutes, and service was restored to most other customers within 24 hrs. of the earthquake. There was no operational damage to the high-voltage systems and generating facilities. ...Power was retained in all of the 230- and 500-kV transmission lines. Service was momentarily interrupted in a few 66- and 115-kV lines. Protective relays automatically trip circuit breakers open; however, the breakers close within a few seconds in case the electrical fault is merely transient. The electric utility in the epicentral area reported 29 of these momentary circuit interruptions in the high-voltage system. The surface rupture of the Landers event actually passed between the legs of a 230 kV steel truss transmission tower. The permanent horizontal ground displacement across the fault shifted one side of the tower base an estimated 8 ft (2.4 m) relative to the other side. As a result, the center of the tower twisted in torsion, buckling and breaking diagonal braces in the four legs. In spite of the distortion, the tower did not collapse and there was no disruption in service. The major source of power outage was distribution lines swinging together. Contact between distribution lines breaks the circuit either by burning out a nearby pole mounted fuse, which activates a circuit breaker, or by burning the conductor wire within the cable. Burning the conductor often causes the wire to separate and drop to the ground" (Lund, 1994).

In the recent 1994 Northridge earthquake (M6.7), lattice transmission towers fared worse than ductile steel towers. The footing movement resulted in serious deformation of the towers and came very close to producing some tower failures. Caissons 10 feet in diameter and approximately 40 feet in length were pulled 1 foot out of the ground. This scene will be duplicated in Humboldt County where lattice towers are in marshy areas.

The Southern California Edison Company substation at Valencia where the equipment and towers were damaged heavily by the Northridge earthquake was visited by a member of the research team. The equipment at the substation had been anchored for lateral forces of 0.5 g. This substation, however, was in a valley where the water table is 5 feet below grade, so the tower problems resulted from strong shaking and probable liquefaction.

Distribution systems operate at much lower voltages, have much greater redundancy, and are less vulnerable than transmission systems. There was relatively little damage to distribution systems after the Loma Prieta earthquake, with the damage described as being equivalent to that produced by a severe winter storm (EERI, 1990). The overall effect of the Loma Prieta earthquake on the electrical power system has been summarized as follows:

> "Approximately 1.4 million consumers suffered interruption of their electrical service as a result of the earthquake. Within 48 hours, service had been restored to all but 26,000 customers. Parts of Watsonville, however, were without electricity for 4 to 5 days" (McNutt, 1990).

According to Savage and Matsuda (1994):

> "The problems caused by distribution system damage due to lines burning down, pole-mounted transformers burning out or falling, or trees and buildings pulling lines down [are] generally quick to repair, there may be enough instances of this damage in both towns and remote rural areas that individual customers or small groups of customers could be without service for several days. From a planning standpoint, electric power customers should plan on surviving without power or using their own emergency power for several days."

The electric generating facilities listed in Table E-2, except that at Blue Lake, are within the tsunami run-up zone as shown on Maps EGP-1 and EGP-2. Tsunami damage will be extensive at the facilities on the Samoa Peninsula, but much less at Buhne Point where the run-up will extend only 1/4 mile beyond the facility.

Planning Considerations

Sources of power to the planning area other than the power plants listed in Table E-2 come from outside and will be unaffected by the scenario earthquake and tsunami. Disruption of power service to institutions, businesses, and residences will come from damage to substations and local distribution systems. Customers especially sensitive to loss of electric power should maintain their own emergency sources (e.g., generators or batteries).

Vital facilities and other lifelines discussed in the report, especially water supply, waste water treatment, and communications will be affected by interruptions in electrical power. Emergency planning for such facilities must recognize that power in certain areas can be out for extended periods. It is crucial that hospitals, emergency operations centers, water and waste water systems, and other vital facilities have their own emergency power sources. Those without emergency power sources must be identified, and appropriate procedures should be developed to compensate for this.

Planning Scenario

During the first 72 hours after the earthquake virtually all parts of the planning area will experience some loss of power, at least temporarily. The cities of Fortuna, Eureka, Arcata, and Crescent City are in strongly shaken areas (MMI VIII+ and IX) and will experience significant power outages. Service to most areas will be restored within 24 hours, but some parts of the cities and rural areas may experience outages lasting as long as 5 days.

To continue high voltage service while repairs are being made, electric power will be distributed over alternate lines. The towers of high-voltage transmission lines crossing a large area of liquefaction along the marshlands of Humboldt/Arcata Bay will be damaged by settlement and subsidence.

According to Savage (1993):

> "Lower voltage substation equipment and transmission lines are typically not affected by earthquakes. Even in the Northridge earthquake, with "direct hit" ground motions of 0.6 to 0.9+g, damage to 115 kV and lower voltages was limited. There will be, however, some electric system damage at low voltage due to lines slapping together and burning down, a few broken poles supporting distribution transformers, and downed lines caused by falling trees. Such damage is expected to be highly sporadic and is usually repaired quickly by local crews, so customers should not be out of service for more than a few hours or a day or so."

Electric power supply is an absolute necessity in meeting today's societal needs. Unfortunately, electric power facilities are particularly vulnerable to major seismic events in areas of severe ground shaking (MMI VIII or IX), and/or deformation:

> "The time that it will take to restore full power under the best of conditions could be prolonged. While the resources may be available to rapidly deal with repairs to the system, the confusion and damage to such lifelines as communications and highways will create a substantial challenge. ...Emergency planning for power-dependent systems such as communication, water supply, fire fighting, and waste treatment should be cognizant of this likelihood" (Steinbrugge and others, 1987).

Damage Assessments

Damage assessments have been postulated for certain major facilities as set forth below. The statements regarding the performance of facilities are hypothetical and intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Outage and repair times assume that materials, equipment, and human resources are available concurrently for each damage locality. They will probably not be available concurrently, and outages could be much longer than estimated here. Locations of electric power transmission lines and major power generation and substation facilities are shown on Maps EGP-1 and EGP-2 and AR.

MAP NO.	ELECTRIC POWER FACILITIES
E1	**Carlotta Substation** MMI IX Out of service for 2 days
E2	**Fortuna Substation** MMI IX Moderate to low liquefaction potential Out of service for 2 days
E3	**Fernbridge Substation** MMI IX High liquefaction potential Out of service for 3 days
E4	**Humboldt Bay Power Plant and Substation** MMI IX High potential for liquefaction Tsunami run-up zone Out of service for 7 days At present, the Humboldt Bay Power Plant exclusively generates power from fossil fuel. Previously, power was generated from nuclear energy, however the nuclear power plant with its fuel rods now remains idle. The Humboldt Bay Power Plant is in the path of a tsunami and would immediately be shut down before its arrival. The earthquake will damage the plant before the tsunami arrives. Two fuel tanks and one water tank are vulnerable to earthquake forces. The water tank is a single wall steel tank with a 300,000 gallon capacity, and is used in producing electricity. The fuel tanks have cellular construction and are less vulnerable than the water tanks; however, a tsunami could spread spilled fuel.

Photo E-1 shows the power plant and part of the substation, and the cooling water channel which will be a free face during liquefaction. Damage to the equipment at the Humboldt Bay Power Plant substation will be substantial in this scenario earthquake.

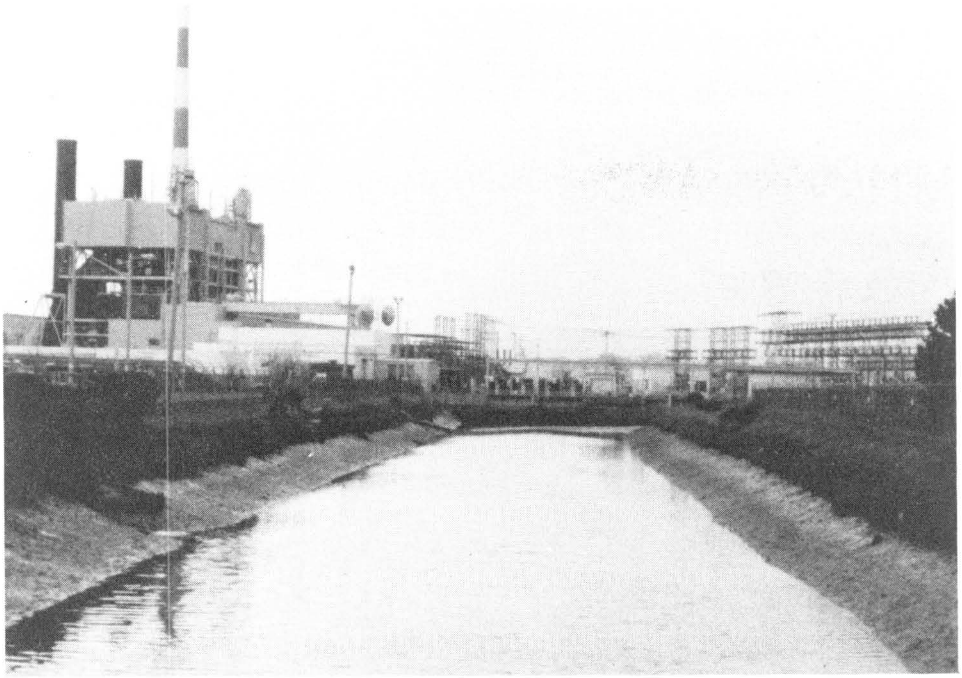

Photo E-1 Humboldt Bay Power Plant, cooling water channel and substation.

E5 **Eureka Substation**

MMI VIII+

Out of service for 2 days

The strong shaking will damage the high voltage equipment at this substation.

E6 **Fairhaven Power and Louisiana Pacific Power Plants**

MMI IX

High potential for liquefaction

In tsunami run-up zone

Out of service for an extended period

The Fairhaven and Louisiana Pacific Power plants are on the Samoa Peninsula on the western side of Humboldt Bay. These privately owned power plants sell electricity to PG&E. These are in the direct path of the tsunami, and will be seriously damaged.

E7 **Arcata Substation**

MMI IX

High potential for liquefaction

Out of service for more than 3 days

This substation is on the corner of Sixth and I streets, and the soils in this area are susceptible to liquefaction.

E8 **Janes Creek Substation**

MMI VIII+

Out of service for 1 day

E9 **Trinidad Substation**

MMI VIII+

Out of service for 1 day

E10 **Big Lagoon Substation**

MMI VIII+

Out of service for 1 day

E11 **Substation at Orick**

MMI IX

High potential for liquefaction

Out of service for 3 days

E12 **Substation near Smith River, north of Crescent City**

MMI IX

Moderate to low liquefaction potential

Out of service for 2 days

Strong ground shaking will damage the high voltage equipment.

E13 **Transmission Lines to Oregon**

MMI VII

Potential for landslides

Out of service for 2 days

Seismically induced landslides will disrupt the northern of these two lines near Gasquet.

NATURAL GAS

General Characteristics

Natural gas is supplied to Humboldt County by Pacific Gas & Electric (PG&E). The principal facilities and routes of the major gas transmission pipelines serving the area are shown on Maps EGP-1 and EGP-2 and AR. The planning area no longer has above-ground gas holders. Selected locations and facilities were reviewed in the field for earthquake damage potential. The principal areas in Humboldt County that have natural gas service available through PG&E are the same as those listed in Table E-1 (refer to Electric Power chapter).

In Del Norte County, Crescent City is served mainly by the two distributors Blue Star Gas and Suburban Propane. They provide about 97 percent of the service to the area, which they evenly split. The remaining 3 percent is provided by Farrelgas, a company based in Brookings, Oregon. Propane is trucked into the city for further local distribution. Blue Star Gas has a limited underground distribution system for the downtown area from their storage tanks. Blue Star's propane storage tank terminal in Crescent City consists of three tanks with capacities of 11,000, 17,000, and 30,000 gallons. Blue Star's remaining service and all of Suburban Propane and Farrelgas is delivered by truck to various local clients which include businesses, industry, and private residences. The reader should refer to the chapter on *Petroleum Products* for a discussion of typical storage tank performance.

Gas Field Operations

There are two commercial gas fields in the planning area, both in southwest Humboldt County. The Table Bluff gas field is about 2 to 3 miles (3 to 5 km) north-northwest of Loleta. This field consists of five wells, and produced gas from 1962 until the field was abandoned in 1968.

The Tompkins Hill gas field is the only currently active gas producing field in the planning area and has been operating since 1938. The field is on an east-west trending ridge named Tompkins Hill in Township 3 North, Range 1 West, Sections 14-17 and 20-24, with the west end of the field about 2 miles (3 km) north of Fortuna. Currently, this field consists of 34 active and 5 inactive wells which produced 1,760,000,000 cubic feet of gas in 1993. The gas is sold to PG&E, where a portion is used to partially fuel the Humboldt Bay Power Plant and the rest is distributed to utility customers in the Eureka-Arcata-McKinleyville area. The gas is shipped from the field in a 4 to 6 inch steel pipeline, which connects to the 12 inch pipeline operated by PG&E, that runs along the east side of Humboldt Bay.

The Little Salmon fault passes through the field, running diagonally across the southwest corner of section 15, across the northeast corner of section 22, diagonally across section 23 and through the southeast corner of that section.

Seismic Considerations

While gas supply systems are typically rugged and have performed well in past earthquakes, some damage has occurred, particularly to older components of transmission and distribution systems.

Transmission systems carry gas from production or storage fields in high pressure lines. This system may include terminals, compressor stations, and pressure limiting stations. Transmission pipelines can survive strong shaking, but can be damaged by permanent ground deformation. For example, during the 1971 San Fernando earthquake (M6.7), several pre-1940 gas transmission lines suffered numerous breaks in an area that experienced surface fault rupture. The lines ranged from 12 to 26 inches in diameter and were of welded steel construction. One 6 mile (10 km) length of pipeline had 52 breaks (NOAA, 1973).

The typical gas distribution system consists of a vast network of relatively small diameter (2 to 8 inches) underground lines and related above ground control facilities. Major earthquake vulnerabilities of distribution systems include permanent ground deformation and strong shaking affecting non-ductile distribution lines that are of older design or may have deteriorated with corrosion. New arc-welded steel lines and plastic lines are more ductile than the old lines and perform better. If permanent ground deformations occur, such as those caused by liquefaction, the old lines generally are much more vulnerable than the new lines, but both can be damaged.

During the 1989 Loma Prieta earthquake (M7):

> "The gas transmission lines and large diameter distribution mains experienced only three leaks due to the earthquake. Unstable soil in the Marina District of San Francisco caused damage that resulted in the replacement of approximately 10 miles (16 km) of cast iron and steel distribution mains with polyethylene plastic pipe. Also in the Marina, 1,500 services to 5,400 individual meters were replaced in less than 5 weeks. Three miles of distribution mains were replaced in Los Gatos and Watsonville. Other damage was scattered and minor.
>
> PG&E restored service to over 150,000 customers whose gas service had been turned off. A total of 1,100 service personnel participated in the relighting process, including 400 from other utilities in the west. Within a week, service was restored to all customers with undamaged piping" (EERI, 1990).

Gas lines can be damaged where they enter buildings or connect to water heaters. This sometimes causes localized outbreaks of fire as they did in the Marina District of San Francisco in the 1989 Loma Prieta earthquake.

In the 1992 Landers and Big Bear earthquakes of June 28, 1992 (M7.5 and M6.6):

> "Most gas service damage from the earthquake occurred in four mobile-home parks and a low-income housing project. About 60 percent of the damage to house gas lines occurred between meters and mobile homes when the homes shifted off their supports. Many water heater connections failed. Some water heaters slipped off their stands, fell out of cabinets, and broke restraining straps" (Lund, 1994).

During the 1992 Petrolia earthquake (M7.0):

> "Gas mains responded well in bridge structures even though the bridges were subject to slight displacement. There were no underground gas leaks in the distribution system; however there were some small leaks at meter risers due to falling debris. In Rio Del and Fortuna, approximately 50 service connections were shut off due to structural damage or leaks" (EERI, 1992a).

The fire in Scotia that burned the Post Office and General Store apparently was caused by the breaking of a gas line.

Relative to the 1994 Northridge earthquake (M6.7), two reports provide valuable insights on damage patterns to natural gas transmission lines:

1. "The natural gas supplier experienced about 150,000 outages, of which approximately 130,000 were unnecessary customer initiated closures. Preliminary reports on February 2 indicates that there were a total of 1,377 breaks and leaks in the piping system. Approximately 489 occurred in distribution lines, 35 in transmission lines, with the remaining 853 in service connection lines. The distribution systems consist of steel and plastic with pressures limited to 60 psi. No leaks or damages were suffered by the plastic piping. Restoration of customer service is very time consuming because of the need for gas service personnel to check internal gas piping and gas appliances before turning on the service. The transmission system service consists of steel pipe varying in diameter from 12 to 30 inches. The most visible failure occurred along Balboa Boulevard where a 22 inch line suffered two breaks, one in tension and the other in compression. These failures were located in parallel ground rupture zones crossing roughly perpendicular to the pipelines. The fire occurred at the northerly break where the gas pipe separated approximately 9 inches. In the Aliso Canyon Gas Storage Field, located in the Santa Susana mountains north of Granada Hills, a break occurred in a 10 inch gas line leaving the field, and there was damage to above ground pipe supports, displacement of runs of injection and withdrawal gas lines, and structural damage to fan units used to cool compressed gas prior to injection into the storage wells. The gas supply from Aliso Canyon was interrupted for approximately 5 days" (EERI, 1994).

2. "...ground deformation across Balboa Boulevard between Rinaldi and Lorillard streets...was responsible for breaks in one gas transmission and two water trunk lines. ...Gas escaping from Line 120 was ignited by sparks from the ignition system of a pick-up truck that had stalled in the area of tensile ground deformation flooded by the ruptured trunk lines. The gas fire spread to adjacent properties, destroying five houses and partially damaging another structure" (O'Rourke and others, 1994).

The propane storage tank terminal in Crescent City is outside the postulated tsunami run-up area. However, it is in an area with an expected MMI VIII+ which indicates that it will be subject to heavy ground shaking and potential damage.

Planning Considerations

Sources of natural and propane that are outside the strongly shaken areas are not expected to be damaged or impaired by the scenario earthquake. Humboldt County is supplied by gas from Sacramento Valley and from Tompkins Hill gas field. Both transmission lines will be damaged where they cross the Little Salmon fault (Map EGP-1). The extent of damage is difficult to predict because high pressure transmission lines are typically stronger and more rugged than distribution lines, but for planning purposes, the possibility of breaks and leaks at these locations must be considered. There are fewer lines involved in transmission than in distribution, and repairs to transmission facilities generally take less time.

Numerous breaks and leaks will occur in the local distribution system throughout the strongly shaken area, especially where ground failure occurs as a result of liquefaction.

While gas supplies to most of the Humboldt County planning area will be restored rapidly, distribution systems in areas of fault rupture or liquefaction could be without gas for several weeks. Restoration of the distribution system is a gradual process as described in the following:

> "Unlike electricity, which can usually be turned off and on at will, the restoration of gas service is an expensive and time consuming task. If a pipeline is broken, or part of a distribution network loses all pressure, every customer being supplied from that network must individually shut down before repressuring can begin. To prevent explosions, the entire system of mains, feeders, and service lines in the affected area must be purged before pilot lights can be relighted and service restored. In addition, extensive gas leak detection surveys may be needed, using flame ionization equipment throughout the affected area" (LNG Task Force, 1980).

Planning Scenario

For local areas within the MMI VIII+ and IX zones, gas service will be disrupted by the earthquake. The typical outage time will be 1 to 2 days, except in areas subject to ground failure. In areas faulting or liquefaction outages may last up to several weeks. We expect the maximum length of gas outage in areas not subject to ground failure to be 3 to 5 days.

As indicated in the Water Supply chapter, we expect fires to break out in the downtown areas of Eureka, particularly where older wood frame buildings are clustered in areas of liquefaction. Local fires caused by gas line breaks will occur in other communities, particularly those experiencing

MMI VIII or greater shaking. The damage to water supply services will make fire fighting difficult in these areas. Unless emergency water supply is immediately available, fire control could take from 2 to 3 days.

In Del Norte County, we expect local customer service to be disrupted by broken storage tank connections. We also expect several fires to result from this damage. Unless the winds are strong the fires most likely will be confined to the structure of origin.

<u>Damage Assessments</u>

Damage assessments have been postulated for certain major facilities as set forth below. The statements regarding the performance of facilities are hypothetical and intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Outage and repair times assume that materials, equipment, and human resources are available concurrently for each damage locality. They will probably not be available concurrently, and outages could be much longer than estimated here. Repair times can be lengthy because of the testing, repressurizing, and relighting procedures that must be followed. Approximately 2 weeks would not be unusual, and outside help from within the company or provided through a mutual aid arrangement often is required. Locations of storage and related facilities are shown on Maps EGP-1 and EGP-2 and AR.

MAP NO.	GAS FACILITIES
G1	**Transmission Line from the east** MMI VII Potential for landslides Open
G2	**Transmission Line through the Van Duzen River Valley** MMI IX Moderate to low liquefaction potential Open
G3	**Transmission Line through Fortuna** MMI IX Moderate to low liquefaction potential Open

G4 **Tompkins Hill Gas Field and Regulator Station**

MMI VIII+

Little Salmon fault rupture

Potential for landslides

Closed more than 3 days

Of the 39 active and inactive wells in the field, 17 are on the northeast side of the Little Salmon fault or very near the fault. The casings of these wells will be sheared by rupture along the Little Salmon fault, making the wells inoperable. Nine of these wells are also on active landslides. On the southwest side of the Little Salmon fault, five of the remaining 22 wells are on existing landslides which will reactivate, or on locally steep slopes that are subject to slope instability. These 5 wells will suffer damage to shallow or surface well components and piping, making them inoperable. Additionally, there will be damage to the gas collection piping at the field by ground shaking and deformation, causing a disruption of gas transmission from the field, a release of gas, and possible fires.

G5 **Tompkins Hill Road, east line**

MMI VIII+

Little Salmon fault rupture

Closed for 3 days

G6 **Humboldt Hill, east line**

MMI VIII+

Potential for landslides

Closed for 2 days

G7 **South of Tompkins Hill Overhead, west line**

MMI IX

High liquefaction potential

Closed for 3 days

G8 **Tompkins Hill Overhead, west line**

MMI VIII+

Little Salmon fault rupture

Closed for 3 days

G9 **Elk River Valley, west line**
MMI IX
High liquefaction potential
Closed for 2 days

G10 **Distribution Lines, Eureka**
MMI VIII+ to IX
Low to high liquefaction potential
Closed for over 3 days in a few local areas
Strong shaking will cause breaks in service gas lines in Eureka in the areas of liquefaction bordering the bay. There will be some post-earthquake fires due to service line breaks.

G11 **Distribution Lines, Arcata**
MMI VIII+ to IX
Low to high liquefaction potential
Closed for over 3 days
Strong shaking and liquefaction will cause breaks in service gas lines in the western part of Arcata. There will be post-earthquake fires due to service line breaks.

G12 **Crescent City Propane Tanks**
MMI VIII+
Closed for 2 days due to damaged piping and possible leaks

WATER SUPPLY FACILITIES

General Characteristics

Water supply, along with electric power and transportation, is one of the most critical lifeline systems for rapid post-earthquake response and recovery efforts. If major damage has occurred to any municipal or regional water supply system during an earthquake, it is essential that the system be restored as quickly as possible (Lagorio, 1994). The potential loss of water supply to urban areas is one of the most important concerns to be faced by municipal and county jurisdictions.

Major water supply systems and their primary sources for the conveyance of water to local communities in the planning area are shown on Maps W-1 and W-2. The two principal water supply agencies in Humboldt and Del Norte counties and their sources of water are listed in Table W-1. We visited representative dams, reservoirs, river intakes and storage tanks of both agencies. The remaining smaller communities throughout the planning area rely primarily on wells for water.

Humboldt Bay Municipal Water District (HBMWD), Humboldt County

The main water supply for the HBMWD system which serves 70,000 people comes from the Mad River whose source is in the Trinity National Forest approximately 65 miles (105 km) southeast of Eureka. HBMWD supplies approximately 50 million gallons of water per day to its service area, including the pulp mills on Samoa Peninsula. The major storage area for the water is Ruth Lake, impounded by Matthews Dam which is a closely monitored earth filled dam, 50 miles (80 km) southeast of Eureka (Photo W-1).

Downstream, with the riverbed acting as a filtration system, six pumping stations are spaced apart along the Mad River near Essex, 10 miles (16 km) north-northeast of Eureka. A booster pump station at Janes Creek supplies water to the City of Arcata and the industrial complex along the Samoa Peninsula. Arcata gets its water from the HBMWD. Two 42 inch diameter pipelines extend from Janes Creek south to the Samoa Peninsula and a small pipeline extends across Humboldt Bay near the Bayshore Mall. A one million gallon steel storage tank is on the Samoa Peninsula near Fairhaven.

Eureka water comes through 24 inch steel pipelines from the Mad River to a 20 million gallon storage reservoir and water treatment plant near Sequoia Park. An elevated 500,000 gallon water tank and a l,000,000 gallon ground level steel tank serve residential areas along Harris Street north of the Sequoia Park Reservoir. A 500,00 gallon ground level steel tank serves the Lundbar Hills area. The 20 million gallon storage reservoir will be out of service till late 1995 for repairs. Also,

TABLE W-1

WATER SERVICE AGENCIES AND SOURCES OF SUPPLY

DISTRICT	COUNTY	CITIES SERVED	MAJOR SOURCES
Humboldt Bay Municipal Water District (HBMWD)	Humboldt	Arcata Blue Lake Eureka McKinleyville Samoa Peninsula	Mad River Ruth Lake
Crescent City Water Supply District (CCWSD)	Del Norte	Crescent City	Smith River

Photo W-1 Matthews Dam and Ruth Lake.

the 24 inch line broke north of Eureka and was out of service for a few days. The 500,000 gallon elevated tank currently is limited to 250,000 gallons for earthquake safety reasons.

Crescent City Water Supply District (CCWSD), Del Norte County

The main water supply for the CCWSD is pumped from the bed of the Smith River, 8 miles (13 km) north of Crescent City.

All other communities within Humboldt and Del Norte counties are supplied by wells or other water supplies local to those communities.

Seismic Considerations

After an earthquake, water supply becomes a particularly vital resource to every community, as it is required for emergency firefighting, as well as for drinking, sanitation, medical emergencies, commercial functions, and industrial operations. In addition, prolonged water outages, even for a few days, can have serious economic and social consequences for a community. In these terms, strategies for the post-earthquake recovery of water supply systems must be a critical element in pre-disaster planning efforts of every community in areas of high seismicity.

During major earthquakes in the past, typical damage patterns to water supply system components have been documented as follows:

1. Damage to sources of supply: dams, reservoirs, main storage tanks, intakes at rivers*
2. Damage to transmission facilities connecting sources of supply to local communities: aqueducts,** canals
3. Damage to treatment facilities*
4. Damage to distribution system networks: localized storage tanks, pumping stations,* valves/mains

* Also dependent on availability of electric power.
** Includes open channels, tunnels, and large diameter steel or concrete pipe.

Damage to, and disruption of sources of supply can include dam, reservoir, or major storage tank failure. In the 1971 San Fernando earthquake (M6.7), the upstream face of the Lower Van Norman Reservoir slumped and almost resulted in a catastrophic dam failure. This 20,500 acre-foot capacity reservoir had to be drained on an emergency basis. Had dam failure occurred, thousands of homes and tens of thousands of people living in the area below the dam would have been flooded and the loss of life would have been high.

Significant disruption of water supply and delivery systems during an earthquake may also be caused by electrical power outages that impact service to pumping stations and river intake facilities, essentially closing down operations. The availability of emergency generators then becomes critical.

Historic accounts of the 1932 Eureka earthquake (M6.2) document damage to tall industrial brick chimney stacks, a steel elevated water tank, and the electric power system (Sparks, 1936). Similarity between the 1932 earthquake and the 1954 Eureka earthquake (M6.5) has been noted in other documents. In the 1954 earthquake, an MMI VII was recorded in Eureka. Damage to elevated water storage tanks and water supply lines was documented as follows:

> "There are many wooden elevated water tanks throughout the rural areas, and some at sawmills. The tank at the Valley Flower Cooperative Creamery near Ferndale is the only one known to have collapsed. A large wooden elevated water tank at a sawmill was reported to have sustained minor damage. ...The results of inspections of four steel elevated water tanks revealed that the only one damaged was at the plant of the Eureka Redwood Lumber Company. Six of its eight top panel rods were broken, and there were several slack rods elsewhere. The tank was in poor repair, as was indicated by excessive rusting. The present owners state that, as one of the employees recalls, similar damage occurred in 1932. ...The Pacific Gas and Electric Company's tank showed evidence of high stresses at anchor bolts and in the rods. The other two tanks showed no evidence of high stress.
>
> The Eureka water supply comes [in 1954] from the Sweasey Dam [which no longer exists] on the Mad River; the dam is about ten miles east of the city. The Division of Water Resources of the California Department of Public Works inspected and reported no damage to the 60 foot high variable radius arch concrete dam, which was built in 1938. They also reported that the dam was designed for an earthquake force of 10 percent of gravity.
>
> The water supply line to Eureka was damaged in three places [marked on Map W-1], with possible minor damage elsewhere. Leakage was considerable, but water continued to flow. The supply line consists of 36-in. wood-stave or 30-in. steel pipe, depending on the locality. There was damage north of Arcata when the wood-stave pipe pulled partly out of a concrete block; this location was a transition section between wood-stave (above ground) to steel pipe (below ground) to allow roadway passage. ...The central break, at Ganno Slough, occurred in a marsh area where the steel pipe went under a creek. Comparable damage occurred in a similar situation at the third rupture, just east of Eureka at Freshwater Slough. Repair to this last break was particularly difficult and finally required laying pipe on a new bridge crossing the creek; cost of this repair was about $25,000 and required that the pipeline be shut down for forty-eight hours. In the marsh areas the steel pipe was encased in concrete, laid underground, and supported on piling.
>
> Damage was done also to the main reservoir in Eureka, which consists of an excavation plus embankment, the embankments being constructed of earth removed from the excavation. The reservoir, divided into two compartments by a structural reinforced concrete wall, has a capacity of 20,000,000 gallons. The interior surfaces are lined with concrete reinforced mesh. The reservoir was leaking prior to the earthquake, and after the shock the leakage jumped to an estimated 1,700,000 gallons per day" (Steinbrugge and Moran, 1957).

The main difficulty in determining the extent of damage to distribution lines is that leaks may not be located until water pressure is restored. For this reason, it may take days or weeks to totally repair damage in densely populated, heavily impacted areas. Fresh water for domestic purposes often has to be supplied by tanker trucks or temporary above ground distribution lines during the immediate emergency and recovery period following a major earthquake.

The 1954 Eureka earthquake produced 30 breaks in the city's water mains (Louderback and others, 1955). Total cost of repairs to the water supply, storage, and distribution systems of Eureka was estimated at $44,000. A rolled earth fill dam, 50 feet high, on Jolly Giant Creek and owned by the City of Arcata, was undamaged according to the California Division of Water Resources. "There were four minor breaks in the Arcata water system, and because of temporary power failure the pumps were not able to keep up water pressure" (Steinbrugge and Moran, 1957).

In Alaska during the 1964 earthquake, a short documentation of tsunami damage to utility systems on Kodiak Island offers some useful data relative to the seismic performance of fire hydrants (Richardson, 1973):

> "Utilities were not materially affected by ground shaking, but were damaged by the tsunamis. A number of power poles and fire hydrants were broken off in the waterfront area, and sewer outfalls were washed away."

The 1992 Petrolia earthquake (M7) produced the following impacts to water supply systems and fire fighting capacities in the Humboldt County area (Varner and Varner, 1992):

> "The most significant loss of water service occurred in the City of Rio Dell when their 8-inch water main broke at the rise at the abutment of the southbound Eel River Bridge. The break caused the supply tanks to drain, leaving the city without a water supply. An emergency potable supply was provided by the American Red Cross, National Guard, and Anheuser Busch, Inc. Fire protection was supplied by contractor tank trucks. Water supply to the city was restored four days later on April 19th.
>
> Scotia, across the Eel River from Rio Dell, has separate water supply systems for domestic and fire protection. The fire protection (e.g., water) system was damaged and was inoperable. A fire destroyed Scotia's four-store shopping center after the second earthquake. The California Office of Emergency Services (OES) provided the town with a portable piping system and pump which was installed by the Scotia Volunteer Fire Department. It was available for service on April 28th. There was no reported damage to the domestic water system."

The recent 1994 Northridge earthquake (M6.7) in the Los Angeles area of Southern California offers additional insights on the seismic performance of water supply systems:

> "The earthquake disrupted all four pipelines from Northern California which serve the Santa Clarita and San Fernando Valleys and supply three water treatment plants. The pipelines are steel with diameters ranging in size from 54 to 120 inches. All suffered breaks but were repaired in two to ten days. The treatment plants have capacities of 25, 550, and 600 mg per day. They received minor damage, such as settlement around

> the plants, leaks at construction joints, leaks in plastic chlorine solution lines, and damage to wooden baffles in the basins. Supply was available in most areas from storage and other regional sources, but was not available to customers because of the damage to the distribution system.
>
> The most significant damage to the distribution pipeline network was within the epicentral area. Over 1,200 leaks in water lines and service connections in the San Fernando Valley and approximately 300 leaks in the Santa Clarita Valley have been identified as of February 8th [1994]. Pipes, some previously weakened by corrosion, were broken in compression and tension, most likely because of permanent ground deformations.
>
> An unusual concentration of eight systems occurred on Balboa Boulevard in Granada Hills. Located in the streets were three gas, three water, two sewer and one oil underground lines; 24.5 kV and 4.8 kV power, telephone, and cable TV overhead lines; and ornamental street lighting. Ground movement caused the breakage of some of the underground pipelines; a fire occurred that ultimately burned the overhead lines and five homes. ...The repairs were time consuming and required draining prior to repair, the repair itself, filling the pipe for testing, and chlorination. Invariably another leak was observed, after which the process was repeated, sometimes several times. ...There was damage to tanks which included rupture of inlet-outlet piping, buckling at the back of the tank (elephant's foot), shell buckling, ground settlement, and roof damage.
>
> Emergency water supply was provided by bottled water, beer and soft drink beverage companies, and water agencies provided water using rented tanker trucks. Mutual aid was provided by almost a dozen water agencies throughout the state and contractors familiar with water utility work. A number of fire department engine pumpers were used to pump water between fire hydrants to higher elevation service zones" (EERI, 1994).

During the 1989 Loma Prieta earthquake (M7), the Rinconada Water Treatment Plant (80 mgd capacity) suffered damage to three of its up-flow clarifiers. Wave action and differential movement damaged the interior metal structure. The fourth clarifier was empty at the time. The plants operated at 50 percent capacity until repairs could be made (EERI, 1990).

The supply of water to urban centers is one of the most important concerns facing local jurisdictions. Aqueducts, pumping stations, distribution lines and water treatment facilities have been damaged in past earthquakes by both ground displacement and shaking effects.

Planning Considerations

Firefighting efforts are easily hampered during the first 24 to 72 hours by blocked streets, insufficient personnel, structurally damaged fire stations, and the lack of water or power. Power outages affect water supplies wherever pumping is required for distribution. Gravity flow systems are better able to withstand power outages.

We expect the water systems within the planning region to suffer some damage. In areas of intense shaking or ground failure, pipeline breaks will be numerous. Breaks will be most common where water lines are corroded or otherwise deteriorated with age. Treatment facilities, structures, and equipment with poor seismic design will suffer damage and impairment.

The components of each water supply system--the source, aqueducts and transmission pipelines, local storage reservoirs, pumping stations, treatment facilities, and distribution lines--must be viewed in the context of the entire system and its performance. Impairment of any major element can seriously compromise the performance of the entire system. Effects on other systems, such as electric power and waste water treatment, must also be kept in mind.

It is essential that water agencies examine their transmission and distribution systems in detail to identify areas and facilities most likely to be impaired. Existing maintenance programs should be reviewed and new programs established to progressively upgrade facilities of questionable seismic resistance, particularly in areas of high vulnerability.

Stocks of materials and equipment to make emergency repairs must be readily available at all times. Mutual aid arrangements are extremely important in these cases, and might be especially important in this rural and relatively isolated area. The scale of earthquake damage to water lines will be much greater than non-seismic breaks and leaks normally experienced. Thus, water agencies must maintain an adequate stock of critical repair materials, that have long lead times for procurement.

In areas having a significant possibility of water outage, plans need to be developed for providing water via ground transportation. Generally, water supply cannot be restored to an area where sewer lines are still broken or not functioning. Emergency power sources must be provided for those vital elements (e.g., pumping stations) that lack a backup power supply.

Chlorine is applied at the Eureka treatment plant near Sequoia Park. Damage to the chlorination equipment or to the tanks could result in a hazardous material spill or leak.

Planning Scenario

The water supply from the HBMWD and CCWSD intake structures along the Mad River and Smith River, respectively, will be reduced due to power outages and pipe breaks caused by liquefaction ground failures.

In areas of intense shaking (e.g., MMI IX) or ground failure, two to four mains break in every residential block will be common where nonductile cast iron or asbestos cement pipe exists. In these areas, repairs of water supply lines could be delayed because of contamination from broken or severed sewer lines in the vicinity.

In areas of strong shaking (e.g., MMI VIII and greater) flat bottom water storage tanks will have failures sufficient to cause a loss of water. According the NAS (1973):

> "The behavior of large liquid storage tanks during earthquakes has an importance far beyond the mere economic value of the tanks and contents. If, for instance, a water tank collapses, as it did during the 1933 Long Beach earthquake (M6.3), the loss of public water supply can have serious consequences."

Typical damage patterns for large liquid storage tanks are:

1. Total collapse
2. Roof buckling
3. Damage to the connection between the roof and the shell
4. Shell wall buckling
5. Separation of shell from bottom plate (with loss of contents)
6. Separation in pipe-to-tank connections (with loss of contents)

Because of failures in local water distribution systems, many communities will be asked to use emergency supplies, boil their water, or take other measures against contamination for a week or longer.

For disaster response planning, authorities should expect localized fires to break out in the downtown areas of Fortuna, Eureka, Arcata, Crescent City, and in areas where older wood frame buildings are clustered. Because of damage to water supply and distribution lines, difficulties will be experienced in fighting fires in these areas. Unless an emergency water supply is immediately available, complete fire control will take up to 48 hours. Owing to the public's crucial need for water, it is assumed that highest priorities will be given to the restoration of electric power to all major pumping and treatment facilities.

<u>Damage Assessments</u>

Damage assessments have been postulated for certain major facilities as set forth below. The statements regarding the performance of facilities are hypothetical and intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Outage and repair times assume that materials, equipment, and human resources are available concurrently for each damage locality. They will probably not be available concurrently, and outages could be much longer than estimated here. Locations of water supply facilities are shown on Maps W-1 and W-2.

MAP NO.	WATER SUPPLY FACILITIES

W1 **Ruth Lake/Matthews Dam on the Mad River in Trinity County**

MMI VIII

Open

Only minor damage is expected at this earth fill dam (Photo W-1), which is 50 miles (80 km) southeast of Eureka.

W2 **Fields Landing**

MMI VIII+

Little Salmon fault rupture

Closed for an extended period

The water line to the College of the Redwoods will be disrupted by faulting.

W3 **Lundbar Hills and City of Eureka Tanks**

MMI VIII+

Closed for more than 3 days

Damage to both ground level tanks is expected by buckling due to sloshing.

W4 **20 Million Gallon Reservoir and Filtration Plant, Eureka**

MMI VIII+

Closed for 2 weeks

Fed by the HBMWDs 24 inch line, this facility is expected to suffer extensive damage due to strong ground shaking.

W5 **Elevated Tank and Ground Level Tank, Eureka**

MMI VIII+

Closed for more than 3 days

Serious damage to the elevated tank may include collapse. The ground level tank will also be damaged.

W6 **Lines across Humboldt Bay**

MMI IX

High liquefaction potential

In tsunami inundation zone

Closed for more than 3 days

The two 42 inch lines crossing Humboldt Bay on pilings from the Samoa Peninsula will suffer serious damage, and will be out of service for several weeks.

W7 **Fairhaven Water Tank**

MMI IX

High liquefaction potential

In tsunami run-up zone

Closed for an extended period

The one million gallon storage tank near Fairhaven is expected to be destroyed by the earthquake and tsunami.

W8 **Main Line at Ryan Slough**

MMI IX

High liquefaction potential

Closed for more than 3 days

The 24 inch line crossing Ryan Slough and Freshwater Slough is expected to suffer severe damage as it did in the 1954 earthquake.

W9 **Main Line south of Sunny Brae**

MMI IX

High liquefaction potential

Closed for more than 3 days

The 24 inch line will be damaged between Sunny Brae and Bayside, as happened in the 1954 earthquake (refer to Steinbrugge and Moran, 1957).

W10 **Main Line northeast of Arcata**

MMI IX

High liquefaction potential

Closed for more than 3 days

The line will be damaged near Korbel, as happened in the 1954 earthquake.

W11 **Ranney Wells and Pumps near Essex**

MMI IX

Low to moderate liquefaction potential

Closed for more than 3 days

The Mad River contains 6 wells and 15 pumps. Electrical power will be lost and the tower structures will be damaged.

W12 **Storage Tanks (1,000,000 and 1,500,000 gallons), Crescent City**

MMI VIII+

Closed for more than 3 days

There will be elephant foot buckling due to sloshing of water in these ground level tanks. This will be accompanied by broken connections. These effects will result in serious losses of water for the city. Other damage could occur to booster pumps, the chlorination facility, and other parts of the water system.

W13 **Elevated Tank (50,000 gallons), Crescent City**

MMI VIII+

Closed for 1 week

This tank will be seriously damaged and could collapse.

W14 **Ranney Wells and Pumps in the Smith River**

MMI IX

High potential for liquefaction

Closed for more than 3 days

Expect loss of electrical power and damage to the tower structure in the riverbed.

WASTE WATER

General Characteristics

The major waste water treatment jurisdictions in the planning area are:

1. Elk River Sewage Treatment Plant, Eureka
2. Arcata Waste Water Treatment Facility, Arcata
3. Water Pollution Control Facility, Crescent City

Major agencies were visited and selected facilities in Humboldt and Del Norte counties were inspected for potential earthquake damage.

The major treatment plants are located along bay margins as shown on Maps W-1 and W-2. Other small facilities are located in interior regions of the planning area with outfall lines near rivers. Some of these systems involve gravity flow from the service area to the treatment plant with discharge in an outflow line, and others require pumping for all or part of their operation.

In general, waste water treatment plants have only limited storage capacity either in the form of basins or holding ponds. If the treatment sequence cannot be restored before storage capacity is surpassed, it will be necessary to discharge waste water by using emergency methods of treatment to reduce the risk of pollution. The importance of storage capacity is significant after an earthquake. For example, during the 1992 Landers and Big Bear earthquakes (M7.5 and M6.6), considerable damage occurred within a secondary treatment plant of a regional waste water collection agency in the Big Bear Lake area. But with adequate storage, the biological treatment process was maintained, and there was no operational loss (EERI, 1992a).

Damage and loss of power at critical facilities along the Bay margins, river delta regions, or other areas with a high potential for soil liquefaction, will necessitate sewage discharge directly into bays, deltas, rivers, or creeks at designated bypass locations. This will be accompanied by pollution at most waterways, which may pose a public health risk, depending on their location relative to populated areas.

In some cities, it is common to find waste water collection lines in the same trench as water distribution lines. Damage to both lines may occur in areas of high ground shaking or ground failure, resulting in contamination of water supplies. This occurred in the City of Watsonville during the 1989 Loma Prieta earthquake (M7), where leakage from damaged sewage lines contaminated water supply distribution lines in the same trench. In general, the water supply cannot be restored in areas where sewer lines remain broken or are not functioning (refer to Water Supply chapter).

Seismic Considerations

The impact of an earthquake on waste water systems can be considered from three standpoints:

1. Damage to the collection systems
2. Damage to treatment plants and outfalls
3. Discharge of untreated or poorly treated sewage into holding ponds, rivers, or bays.

Table WW-1 shows the anticipated MMI and liquefaction potential for the scenario earthquake at sites of the major waste water treatment facilities.

TABLE WW-1

MAJOR TREATMENT FACILITIES

WASTE WATER TREATMENT FACILITY	CITY	MM INTENSITY	LIQUEFACTION POTENTIAL
Municipal Treatment Plant	Fortuna	IX	High
Municipal Treatment Plant	Ferndale	IX	High
Elk River Sewage Treatment Plant	Eureka	IX	High
Arcata Waste Water Treatment Facility	Arcata	IX	High
Fisher Treatment Plant	McKinleyville	VIII+	None
Water Pollution Control Facility	Crescent City	VIII+	None

Waste water collection systems are primarily susceptible to earthquake damage as a result of broken underground pipelines. Lines typically made from relatively brittle clay, asbestos cement, or concrete pipe generally tolerate little movement without fracture. Damage tends to be greatest where permanent ground movements occur due to surface fault rupture, landslide, or liquefaction. The distribution of damage usually is similar to that suffered by other buried conduits, such as those carrying water, natural gas, and petroleum products. Because most sewer lines are not pressurized, broken lines are not readily detected unless blockage or severely restricted flow is experienced. Television cameras may be used to find cracks and broken lines.

Data collected and reported by the National Academy of Sciences (NAS) after the 1964 Great Alaska earthquake (M9.2) offer excellent insights on the impact that tsunamis had on sewer systems on poor soils in the City of Seward:

> "When the shaking had subsided, tsunamis started to come in, and for several hours they continued to damage as high as 31 feet above mean lower low water. The waves washed mud and silt into sewers and broken water lines, and the hydraulic pumping effect of continuous wave action packed mud into the lines. ...Along the bayside of the old townsite, large areas of ground slid into the bay, carrying away buried utilities,

> including the sewer outfall. The remaining ground cracked 100-200 feet inland in places, breaking sewer lines. Tsunamis and waves from slides and seiches pumped mud and silt into sewer lines and manholes; some manholes overflowed and mud rose above the inverts in others. The Clearview outfall traversed part of the lagoon area that sank several feet during the earthquake, and the bay end of the outfall was washed away by the waves" (NAS, 1973).

A brief description of the damage to waste water treatment facilities at El Centro that occurred during the 1979 Imperial Valley earthquake (M6.4) follows:

> "The damage to the secondary clarifiers were primarily related to failure of the center wells and their impact on rake arms, drive shaft, skimmers and sludge withdrawal piping. The contents of the clarifiers experienced significant sloshing, with mixed liquid spills evident at both clarifiers in a northwesterly direction in line with the probable epicenter location. The north clarifier had more extensive damages than the south clarifier. In the north clarifier, the center well support frame failed causing the center well to drop onto the sludge collector rake arms. As the center well fell, it hit sludge withdrawal pipes, causing them to be pulled apart at the flexible hose connection elbow. Also sludge skimmers were pulled from their tracks and fell to the bottom of the tank" (EERI, 1980).

During the 1971 San Fernando earthquake (M6.7), the sewage collection system was damaged in the Sylmar area, particularly in areas of fault rupture and permanent ground movement. In a 15 square mile (39 sq. km) area that included Sylmar, over 126,000 feet of mainline sewer had to be reconstructed. The damage consisted of crushed and cracked pipe, broken (compression failure) and pulled (tension failure) joints, and damage to manholes. The latter consisted of shifting of rims as well as some cracking of the manholes themselves (NOAA, 1973). Treatment facilities have also been closed due to equipment failures and power outages.

During the 1989 Loma Prieta earthquake wave action at the 40 mgd Palo Alto Waste Water Treatment Plant caused fiberglass scum troughs to fall onto the sludge sweeping scraper in the bottom of a clarifier, causing it to jam. Two days were required to repair this clarifier, but fortunately the plant was back in operation in 2 hours because an empty clarifier was available (EERI, 1990).

Regional waste water treatment plants in San Francisco and Oakland lost power but suffered no major structural damage during the Loma Prieta earthquake. There were some short time releases of sewage into San Francisco Bay and the Pacific Ocean. The Oakland plant lost commercial power for 7 hours (EERI, 1990).

Reports on the 1992 Petrolia earthquake (M7) indicate that:

> "The water and sewer systems in Ferndale continued to function. In Fortuna, there was a power loss to a sewer pumping plant, but there were no reported sewer spills" (EERI, 1992a).

In the area impacted by the 1994 Northridge earthquake (M6.7) in southern California, two water reclamation plants that provide tertiary treatment of waste water were damaged:

> "Both plants lost power. The smaller plant did not have an emergency generator as it operates on a bypass of the main outfall sewer. At the large plant the emergency generator started automatically; however the operator was concerned about the generator's operation and shut it down. Although both plants lost power from 7 to 8 hours, they did not lose their biological systems. The plants received minor damage, not significant enough to hinder operation when power was restored. Typical damage included dislodged sludge scrapers, broken auxiliary piping, broken windows, fallen ceiling tiles, and toppled warehouse supplies" (EERI, 1994).

Planning Considerations

Damage to collection systems will be similar to that experienced by water supply and distribution systems. Soil liquefaction in the poor ground areas will be a major source of damage (refer to Maps W-1 and W-2). To a much lesser extent, landslides, particularly at the end of a prolonged wet season, will cause damage to the collection systems in hilly areas. In areas of water outage or breaks in sewer lines, temporary facilities, such as the portable sanitary facilities used on construction sites, will have to be provided as they were after the 1971 San Fernando and the 1989 Loma Prieta earthquakes.

Buildings and other special structures found at treatment plants are usually earthquake resistive, particularly those built since the mid-1970s. In poor ground areas, large buildings and other major structures are normally on pilings and should survive without any major structural damage. Internal appurtenant piping and equipment are generally earthquake braced and intended for heavy duty. Building entry by pipes or conduits will be likely points of damage. Electric power outages will affect those treatment facilities and pumping or lift stations without emergency generators.

Damage is likely in structures containing rotating equipment or other moving devices, with the damage being due to the wave action of sloshing liquids. Differential settlements will occur between underground piping and the connected buildings. The result of these differential settlements is to crack or break the pipe where it joins the building. This is a particular concern for pressurized lines (e.g., force mains).

The quantity of waste water flowing to treatment plants will diminish immediately after the earthquake due to the closure of industrial plants and the reduction in the supply of fresh water.

Treatment plant buildings, tanks, piping, machinery, and equipment are all subject to earthquake damage. If a treatment plant becomes inoperable, untreated sewage must bypass the plant and be dumped into holding ponds, creeks, rivers, bays, or the ocean. The discharge of raw or poorly treated waste water may be necessary, and will cause public concern. This should be reviewed beforehand with the appropriate environmental agencies. Public announcements should also be readied for distribution immediately after the earthquake. Review of the adequacy of chlorination tank storage, piping, and machine tie downs is of utmost concern. Adequate chlorine spill control programs are vital for all affected waste water stations.

The time required for assessing damage and making repairs to a damaged collection system depends on the availability of personnel, equipment, and materials. In the relatively small area affected by the 1971 San Fernando earthquake, 90 miles (145 km) of sewer lines were surveyed by pulling television cameras through them. From a practical standpoint however, until water supply is restored, discharge of sewage into sewer connection lines will be significantly reduced.

Planning Scenario

Waste water lines that cross the Little Salmon fault will be severed and unable to carry waste water. Where major trunk lines are severed, open trenches may be needed to carry raw sewage for short distances. Alternatively, emergency planners will have to provide either temporary emergency housing arrangements for neighborhoods heavily impacted by the earthquake or temporary sanitary facility units.

The flow capacity of the collection system in the poor ground areas as shown on Maps W-1 and W-2 will be reduced by 50 percent. The main collectors in these areas will be damaged, but will retain 75 percent of their capacity in those sections where gravity flow is possible. Main effluent lines of the Eureka, Arcata, and Crescent City systems will be interrupted by breaks where they cross areas of liquefaction. Thirty days will be needed to restore service.

Immediately after the earthquake, treatment plants without emergency power will shut down. Power requirements will diminish as the quantity of arriving waste water diminishes. Restoration of power will be a function of priorities. For instance, initial preference will be given to direct life support operations such as hospitals and water systems. This, in turn, will require emergency treated raw sewage to be discharged into holding ponds, creeks, rivers, and the bays for up to 1 week.

Depending on the number of tsunami waves and their height at the locations of the three treatment plants, there could be damage comparable to that experienced in 1964 in Seward, Alaska. This included damage to the outfall, inundation of the plant and lines with silt and mud, ground failures that damaged utilities, and other problems noted earlier.

Waste water treatment plants are generally located on poor ground that is highly susceptible to earthquake induced ground failure. This seldom results in damage to massive individual structures that are well designed and supported by piling or engineered fills. Instead, differential motion between structures and inlet and outlet lines often causes damage. In general, the contiguous trunk lines and outfalls also are in areas prone to ground failure. Gravity flow of waste water could be impaired by vertical deformation accompanying the earthquake, which will exceed the 4.5 feet (1.4 m) uplift observed in the 1992 Petrolia earthquake and reported by Jayko and others (1992) and Stein and others (1993).

Damage Assessments

Damage assessments have been postulated for certain major facilities as set forth below. The statements regarding the performance of facilities are hypothetical and intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Outage and repair times assume that materials, equipment, and human resources are available concurrently for each damage locality. They will probably not be available concurrently, and outages could be much longer than estimated here. Locations of waste water facilities are shown on Maps W-1 and W-2.

MAP NO.	WASTE WATER FACILITIES
WW1	Fortuna Treatment Plant MMI IX High liquefaction potential Closed for more than 3 days Damage to the plant and loss of water and power will result in discharge of untreated sewage into the Eel River.
WW2	Ferndale Treatment Plant MMI IX High liquefaction potential Closed for more than 3 days Damage to the plant and loss of water and power will result in discharge of untreated sewage into the Salt River.
WW3	Elk River Sewage Treatment Plant, Eureka MMI IX High liquefaction potential Closed for an extended period

While this facility is newer than the one serving Arcata, severe damage can be expected resulting in discharge of sewage into Humboldt Bay.

WW4 **Arcata Waste Water Treatment Facility**

MMI IX

High liquefaction potential

Closed for an extended period

Severe damage can be expected to this facility on the north shore of Arcata Bay resulting in discharge of sewage into the bay.

WW5 **Fisher Treatment Plant, McKinleyville**

MMI VIII+

Closed for 3 days

Damage will result in discharging sewage to Mad River slough and the ocean.

WW6 **Water Pollution Control Facility, Crescent City**

MMI VIII+

In the tsunami inundation zone

Closed for an extended period

The combination of strong ground shaking and tsunami damage will destroy this facility. Of special concern are unanchored chlorine bottles which could break and spill. This would create a dangerous chlorine gas cloud, requiring the evacuation of the nearby area.

PETROLEUM PRODUCTS

General Characteristics

Petroleum products are delivered by barge and truck to local distributors' facilities in the two-county planning area. The principal distributors' facilities are along the eastern Humboldt Bay shoreline and on the southeastern edge of Crescent City.

Representative storage tank terminals in Humboldt and Del Norte counties were visited in the field and assessed for earthquake damage potential.

Historical Oil Field Operations

Deposits of oil and natural gas have been recognized in the Bear River-Mattole-Briceland area of southwestern Humboldt County by settlers since 1860. Indications of petroleum such as seeps, led to the first California oil well being drilled about 3.5 miles (6 km) northeast of Petrolia in 1865. Since then, about 185 oil and gas wells have been drilled in southwestern Humboldt County, between Eureka and Garberville, and two near Crescent City in Del Norte County. However, only small quantities of oil were discovered and only one commercial oil field and two commercial gas fields were developed. The Petrolia oil field is about 3 miles (5 km) north of Petrolia. The field consists of two wells that produced oil from 1953 until the field was abandoned in 1971. There are currently no active petroleum producing fields in the planning area.

Seismic Considerations

In general, earthquake damage to petroleum facilities falls in two categories:

1. Damage may occur to transportation or dock facilities for incoming petroleum products.
2. Tank farms and distribution facilities may:
    a) Suffer direct damage such as broken piping, ruptured storage tanks, and damage to buildings and pumping equipment
    b) Suffer serious secondary damage from post-earthquake fire
    c) Become nonfunctional due to loss of water or electric power
    d) Become inaccessible due to liquefaction and ground failures where such facilities are on soft ground.

The few remaining active petroleum storage tank farms along the shoreline of Humboldt Bay are in areas of soft soil, in MMI IX zones, and are highly subject to liquefaction. Some are also along the bay margins which are within the postulated tsunami run-up area (e.g., Buhne Point).

There have been isolated instances of fires resulting from damaged storage tanks such as those at petroleum tank farms along the Seward waterfront following the 1964 Alaska earthquake (NAS, 1973). One particular account of tank damage after the Great Alaska earthquake details that:

> "In Seward, Alaska, burning oil on the surface of surging water in Resurrection Bay (due to tsunami-ruptured tanks after the 1964 earthquake) was spectacular" (Steinbrugge, 1982).

Damage to storage tanks come from sidewall buckling, bottom plate separation from sidewalls, and from the sloshing of liquids. Sloshing often damages or destroys fixed or floating tank tops. Rigidly connected piping also often breaks when the tank rocks because the piping does not possess sufficient flexibility. While spillage of oil from such damage may be spectacular, it has not been serious when contained within dikes and kept free of ignition sources.

There were many reports of tank damage following the 1989 Loma Prieta earthquake (M7). Damage was primarily related to uplift of unanchored tank walls and typically occurred at soft soil sites (Tuttle and others, 1990). Major leaks occurred in several tanks, but the spillage remained within containment dikes. No fires occurred (EERI, 1990).

During the 1994 Northridge earthquake (M6.7) two accounts of damage to storage tanks were recorded as follows:

> "Of approximately 12 oil storage tanks (e.g., at the Aliso Canyon Gas Storage Facility), six were damaged. One tank collapsed and another at the same location sustained a split seam. Damage at other oil storage tanks was relatively minor and consisted of buckling and warping of seams" (O'Rourke, 1994).

> "At an oil pumping site, there was severe damage to oil tanks. Contents escaped but were retained within containment dikes. ...Contents were lost at an 800,000 gallon water tank near Valencia after the piping ruptured. The tank also suffered roof damage and elephant's foot buckling at its base. ...An anchored waste oil tank (approx. 10,000 gal.) pulled its anchors and shifted, breaking the discharge pipe and emptying its contents. A 250,000 gal. unanchored fire-water tank experienced an 'elephant's foot' failure around the entire base circumference. The tank discharge pipe was damaged, apparently by tank uplift, and the tank lost its contents" (EERI, 1994).

Planning Considerations

During the 1989 Loma Prieta event numerous nearly full, unanchored tanks on soft ground, with height to width ratios of greater than 0.5 were damaged. Three tanks leaked, but the material was trapped by containment dikes. No fires occurred. Most facilities were back in operation within 6 days after the earthquake (EERI, 1990, pp. 218-238).

Facilities used for the manufacture, processing, and storage of various petrochemicals warrant special attention to reduce the risk of post-earthquake fire and the release of toxic substances. For example, unanchored tanks at soft soil sites at tank terminals are especially susceptible to damage and leaks. Leaks may also result from breaks in rigidly connected piping. Because of the possibility of post-earthquake fire and environmental damage, tanks should be given detailed seismic evaluations.

The low earthen embankments used as retention dikes around fuel and oil storage tanks, evaporation ponds and waste containments are subject to failure from earthquake shaking and deformation. Also, if valves in the dikes are left open during the rainy season, fuel from damaged tanks will escape. The locations of these types of structures, their vulnerability, and the consequences of failure need to be examined as part of any emergency planning program. This is especially true in the Humboldt Bay area where such tanks exist on the Bay's margins, and also may be subject to tsunami damage as was the case in Alaska.

Ground failures resulting from liquefaction can result in abrupt differential ground movements that cause pipe ruptures. Pipe connections at terminal facilities are also vulnerable due to the differing responses of buried pipes and rigid structures.

Shut-off valves are frequently installed in many facilities and on pipelines. These function automatically when the line pressure drops below a particular threshold, such as would occur in the case of a pipe rupture. Some of these valves depend on electrical power, however, and will not function if power is lost. Should a petroleum pipe rupture during the dry season, a post-earthquake fire could be a serious problem. This threat is also present during the rainy season should escaping fluids be ignited as storm waters wash them into sewers.

All of the petroleum product storage and distribution facilities in the area should be examined in detail relative to their vulnerability to ground failure. The adequacy and locations of automatic shut-off valves should also be examined for post-earthquake functioning. Locations for temporary storage of emergency fuel supplies, including those for aviation fuels, should be predetermined and emergency procedures established to ensure that these supplies will be available when needed.

Planning Scenario

Damage can be expected, such as ruptured tanks, buckled steel racks and pumping platforms, stretched anchor bolts, stretched or buckled bracing in support structures, broken and cracked piping, and piping shifted off its supports. Steel tanks that are not anchored to their foundations will rock or shift, rupturing some tanks and breaking attached rigid piping. For planning purposes, we assume at least 10 percent of the flat bottom tanks in the planning area will rupture and leak. Further damage is unlikely but could result from the tsunami generated by this scenario earthquake.

Most tsunami damage will occur along the Samoa Peninsula west of Humboldt Bay and the Buhne Point area near Eureka. In Crescent City, expected tsunami inundation reaches Eighth Street, and thus will affect petroleum tanks there.

Given the north coast's dependence on long haul petroleum product supply, and the vulnerability of marine facilities, Highway 101, and the local tank facilities, there will likely be a gasoline and diesel shortage in the planning area. This could necessitate the activation of energy shortage contingency plans at the county and state levels.

Damage Assessments

Damage assessments have been postulated for certain major facilities as set forth below. The statements regarding the performance of facilities are hypothetical and intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Outage and repair times assume that materials, equipment, and human resources are available concurrently for each damage locality. They will probably not be available concurrently, and outages could be much longer than estimated here. Locations of petroleum products storage and facilities are shown on Maps EGP-1 and EGP-2.

MAP NO.	PETROLEUM FACILITIES
P1	**Chevron Tank Farm, southwest of Eureka** MMI IX High liquefaction potential Bordering tsunami run-up zone Closed for more than 3 days Chevron Oil has tank farms at the south end of Eureka adjacent to Bayshore Mall. Due to strong ground motion and liquefaction, pipe breaks will occur in the facility and in the tank manifold system. Tank ruptures will occur from the sloshing of liquids, leading to spills and the possibility of fire.
P2	**Unocal Tank Farm, west of Eureka** MMI IX High liquefaction potential Bordering tsunami run-up zone Closed for more than 3 days Buckling and leakage of contents will result in contamination and possible fires.

P3 **Tank Farms, southeast of Crescent City**

MMI VIII+ to IX

High liquefaction potential

Tsunami inundation zone

Closed for an extended period

Both tank farms on Highway 101 will be severely damaged by the tsunami, resulting in spills and possibly fire.

P4 **Chevron Tank Farms, in Crescent City**

MMI VIII+

Tsunami inundation zone

Closed for an extended period

The local Chevron Oil Company distributor has two facilities near downtown Crescent City. One at Battery and A streets has five large vertical tanks, and the other at 2nd and D streets has five smaller ones. Both facilities will be severely damaged by the tsunami, resulting in spills and possibly fire.

GLOSSARY

ALLUVIUM	Surficial sediments consisting of poorly consolidated gravels, sands, silts, and clays deposited by flowing water.
BEDROCK	A general term for coherent, usually solid rock, that underlies soil or other unconsolidated surficial material.
DEFORMATION	A general term for the processes of folding, faulting, shearing, compression, or extension of rocks.
EARTHQUAKE	Vibratory motion propagating within the earth or along its surface caused by the abrupt release of strain from elastically deformed rock by displacement along a fault.
FAULT	A fracture (rupture) or a zone of fractures along which there has been displacement of adjacent earth material.
FAULT LINE	A scarp that has been produced by differential erosion along an old fault line.
GROUND FAILURE	Permanent ground displacement produced by fault rupture, differential settlement, liquefaction, or slope failure.
GROUND RUPTURE	Displacement of the earth's surface as a result of fault movement associated with an earthquake.
ISOSEISMAL AREA	An area composed of points of equal earthquake intensity on the earth's surface.
INTENSITY	A measure of the effects of an earthquake at a particular place. Intensity depends on the earthquake magnitude, distance from epicenter, and on the local geology.
LIFELINES	Facilities such as highways, bridges, tunnels, major airports, electrical power lines, fuel pipelines, communication lines, water supply lines, marine terminals and railroads.
LIQUEFACTION	The transitory transformation of sandy water- saturated alluvium with properties of a solid into a state possessing properties of a liquid as a result of earthquake shaking.
MAGNITUDE	A measure of the size of an earthquake, as determined by measurements from seismographic records.
MODIFIED MERCALLI INTENSITY SCALE	Refer to Appendix A.
REINFORCED MASONRY	Masonry construction with steel reinforcement.

GLOSSARY (cont.)

ROSSI-FOREL INTENSITY SCALE	Refer to Appendix A.
WATER TABLE	The upper surface of ground water saturation of pores and fractures in rock or surficial earth materials.

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SECTION 5

APPENDIXES

APPENDIX A

Modified Mercalli Intensity Scale of Wood and Neumann, and its Relation to the Rossi-Forel Scale

The numbers in parentheses in the left margin and the initials R.F. refer to the Rossi-Forel intensity scale.

I — Not felt—or, except rarely under especially favorable circumstances.
Under certain conditions, at and outside the boundary of the area in which a great shock is felt:
[I R.F.] sometimes birds, animals, reported uneasy or disturbed;
sometimes dizziness or nausea experienced;
sometimes trees, structures, liquids, bodies of water may sway–doors may swing very slowly.

II — Felt indoors by few, especially on upper floors or by sensitive or nervous persons.
Also, as in grade 1, but often more noticeably:
[I to II R.F.] sometimes hanging objects may swing especially when delicately suspended;
sometimes trees, structures liquids bodies of water may sway, doors may swing very slowly;
sometimes birds animals reported uneasy or disturbed;
sometimes dizziness or nausea experienced.

III — Felt indoors by several, motion usually rapid vibration.
Sometimes not recognized to be an earthquake at first.
[III R.F.] Duration estimated in some cases.
Vibration like that due to passing of light or lightly loaded trucks or heavy trucks some distance away.
Hanging objects may swing slightly.
Movements may be appreciable on upper levels of tall structures.
Rocked standing motor cars slightly.

IV — Felt indoors by many, outdoors by few.
Awakened few, especially light sleepers.
[IV to V R.F.] Frightened no one unless apprehensive from previous experience.
Vibration like that due to passing of light or lightly loaded trucks.
Sensation like heavy body striking building or falling of heavy objects inside.
Rattling of dishes, windows, doors; glassware, and crockery clink and clash.
Creaking of walls, frame, especially in the upper range of this grade.
Hanging objects swung in numerous instances.
Disturbed liquids in open vessels slightly.
Rocked standing motor cars noticeably.

V — Felt indoors by practically all, outdoors by many or most: outdoors direction estimated.
Awakened many or most.
[V to VI R.F.] Frightened few—slight excitement, a few ran outdoors.
Buildings trembled throughout.
Broke dishes, glassware to some extent.
Cracked windows—in some cases, but not generally.
Overturned vases, small or unstable objects, in many instances with occasional fall.
Hanging objects, doors swing generally or considerably.
Knocked pictures against walls or swung them out of place.
Opened or closed doors, shutters, abruptly.
Pendulum clocks stopped, started, or ran fast, or slow.
Moved small objects, furnishings, the latter to slight extent.
Spilled liquids in small amounts from well-filled open containers.
Trees, bushes shaken slightly.

APPENDIX A (cont.)

VI Felt by all indoors and outdoors.
Frightened many, excitement general, some alarm, many ran outdoors.
[VI to VII R.F.] Awakened all.
Persons made to move unsteadily.
Trees, bushes shaken slightly, moderately.
Liquid set in strong motion.
Small bells rang—church, chapel, school, etc.
Damage slight in poorly built buildings.
Fall of plaster in small amount.
Cracked plaster somewhat, especially fine cracks; chimneys in some instances.
Broke dishes, glassware in considerable quantity, also some windows.
Fall of knick-knacks, books, pictures.
Overturned furniture in many instances.
Moved furnishings of moderately heavy kind.

VII Frightened all–general alarm all ran outdoors.
Some or many found it difficult to stand.
[VIII - R.F.] Noticed by persons driving motor cars.
Trees and bushes shaken moderately to strongly.
Waves on ponds, lakes, and running water.
Water turbid from mud stirred up.
Incaving to some extent of sand or gravel stream banks.
Rang large church bells, etc.
Suspended objects made to quiver.

Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc.
Cracked chimneys to considerable extent walls to some extent.
Fall of plaster in considerable to large amount, also some stucco.
Broke numerous windows, furniture to some extent.
Shook down loosened brickwork and tiles.
Broke weak chimneys at the roof-line (sometimes damaging roofs).
Fall of cornices from towers and high buildings.
Dislodged bricks and stones.
Overturned heavy furniture with damage from breaking.
Damage considerable to concrete irrigation ditches.

VIII Fright general–alarm approaches panic.
Disturbed persons driving motor cars.
[VIII+ to IX - R.F.] Trees shaken strongly–branches, trunks broken off, especially palm trees.
Ejected sand and mud in small amounts.
Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters.
Damage slight in structures (brick) built especially to withstand earthquakes.
Considerable in ordinary substantial buildings, partial collapse, racked, tumbled down, wooden houses in some cases; threw off panel walls in frame structures, broke off decayed piling.
Fall of walls.
Cracked, broke, solid stone walls seriously.
Wet ground to some extent, also ground on steep slopes.
Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers.
Moved conspicuously, overturned, very heavy furniture.

APPENDIX A (cont.)

IX Panic general.
Cracked ground conspicuously.
[IX+ R.F.] Damage considerable in (masonry) structures built especially to withstand earthquakes:
threw out of plumb some wood-frame houses built especially to withstand earthquakes;
great in substantial (masonry) buildings, some collapse in large part;
or wholly shifted frame buildings off foundations, racked frames;
serious to reservoirs; underground pipes sometimes broken.

X Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks.
[X R.F.] Landslides considerable from river banks and sleep coasts.
Shifted sand and mud horizontally on beaches and flat land.
Changed level of water in wells.
Threw water on banks of canals, lakes, rivers, etc.
Damage serious to dams dikes, embankments.
Severe to well-built wooden structures and bridges, some destroyed.
Developed dangerous cracks in excellent brick walls.
Destroyed most masonry and frame structures, also their foundations.
Bent railroad rails slightly.
Tore apart, or crushed endwise, pipe lines buried in earth.
Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI Disturbances in ground many and widespread, varying with ground material.
Broad fissures, earth slumps, and land slips in soft wet ground.
Ejected water in large amount charged with sand and mud.
Caused sea-waves (tidal waves) of significant magnitude.
Damage severe to wood-frame structures, especially near shock centers.
Great to dams, dikes, embankments, often for long distances.
Few if any (masonry) structures remained standing.
Destroyed large well-built bridges by the wrecking of supporting piers or pillars.
Affected yielding wooden bridges less.
Bent railroad rails greatly, and thrust them endwise.
Put pipe lines buried in earth completely out of service.

XII Damage total–practically all works of construction damaged or greatly destroyed.
Disturbances in ground great and varied, numerous shearing cracks.
Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive.
Wrenched loose, tore off large rock masses.
Fault slips in firm rock with notable horizontal and vertical offset displacements.
Water channels, surface and underground, disturbed and modified greatly.
Dammed lakes, produced waterfalls, deflected rivers, etc.
Waves seen on ground surfaces (actually seen, probably, in some case).
Distorted lines of sight and level.
Threw objects upward into the air.

APPENDIX B

MAPS OF SEISMIC INTENSITY AND LIFELINES

SCALE x1000	MAP NO.	DESCRIPTION
100	S-1*	Seismic Intensity Distribution
100	S-2*	Seismic Intensity Distribution
250	S-3*	Seismic Intensity Distribution
100	SHM-1	Public Schools, Hospitals, and Marine Facilities
100	SHM-2	Public Schools, Hospitals, and Marine Facilities
100	H-1	Highways
100	H-2	Highways
250	H-3	Highways
250	AR	Airports, Railroads, Electric Power and Natural Gas
100	EGP-1	Electric Power, Natural Gas, and Petroleum
100	EGP-2	Electric Power, Natural Gas, and Petroleum
100	W-1	Water Supply and Waste Water
100	W-2	Water Supply and Waste Water

* "1" indicates Eureka area, "2" indicates Crescent City area, "3" indicates Humboldt and Del Norte counties.

NOTES

The 100,000-scale intensity maps generally show more detail for the Eureka area (Map S-1) and the Crescent City area (Map S-2) than the 250,000-scale Map S-3.

Narrow coastal strips of MMI IX, such as that northwest of Crescent City on Map S-2, should show high liquefaction potential.

On the 250,000-scale maps S-3, H-3, and AR, the labels for old and new Highway 101 near the Humboldt-Del Norte County line should be reversed.

Map AR should show Kneeland Airport (A5) as open, and Willow Creek Airport (A9) as closed.