PLANNING SCENARIO
FOR A MAJOR EARTHQUAKE,
SAN DIEGO – TIJUANA METROPOLITAN AREA

SPECIAL PUBLICATION 100
1990

CALIFORNIA DEPARTMENT OF CONSERVATION
Division of Mines and Geology
PLANNING SCENARIO

for a Major Earthquake,

San Diego-Tijuana Metropolitan Area

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ACKNOWLEDGMENTS

This study was originally suggested by Dan Eberle, Director of the San Diego County Office of Disaster Preparedness (ODP). He and the ODP staff have provided a wealth of time and information on lifeline operators and lifeline inventories. Without their assistance, this scenario would have been much more difficult to complete.

We would like to thank the operators and disaster preparedness officers of the various lifelines in San Diego County. The cooperation and helpful assistance of the staff of the utilities and agencies that we contacted is gratefully acknowledged. In particular, Jim Hunt and John Burton of San Diego Gas and Electric Company; Gary Hogue, City of San Diego Water Utilities Department; Phil Shoemaker of Pacific Bell; and James H. Gates of the California Department of Transportation provided valuable information.

Dr. James N. Brune, University of California at San Diego; Dr. Gordon Gastil, San Diego State University; and Francisco Suarez and Alfonso Reyes of the Center for Scientific Investigation and Higher Education of Ensenada provided helpful information for the hazards evaluation and in the selection of the scenario earthquake.

Virginia Williams demonstrated great patience and ability during the typing and numerous revisions of the manuscript.

We thank Carol Allen for her skillful drafting of the figures and maps.

This study was partly funded by the U.S.-Mexico Earthquake Preparedness Project of Federal Emergency Management Association (FEMA) through the Southern California Earthquake Preparedness Project.
EXECUTIVE SUMMARY

Earthquake planning scenarios are prepared to provide a regional perspective on the plausible consequences of credible damaging earthquakes. The information is intended to be used by all who have responsibilities for emergency response and to facilitate both local and international efforts to prepare for such an occurrence. The scenario does not predict detailed patterns of damage that will follow the occurrence of the postulated earthquake. An assessment of the magnitude and types of damage to existing lifelines and other structures is placed in a regional context for general response planning purposes.

This planning scenario is based on the postulated occurrence of a magnitude 6.8 earthquake on the Silver Strand fault south of downtown San Diego. It was developed for a particular use, namely for international planning assuming an earthquake that could inflict significant damage to both the San Diego and Tijuana metropolitan areas. The scenario is a response to the need of the County of San Diego’s Office of Disaster Preparedness to better assess the consequences of a damaging earthquake along one of the faults within the metropolitan area. The scenario is also an outgrowth of the bi-national U.S.-Mexico Earthquake Preparedness Project (USMEPP), in which Federal, State, and local agencies from both sides of the border participate. However, damage assessments of the postulated earthquake are generally confined to U.S. facilities and lifelines.

San Diego, one of the oldest cities in California, is composed of many types and classes of buildings of diverse construction and age, including some built prior to the establishment of seismic building codes or their changes over the years. In general, this diversity of construction type and age also applies to certain parts of the lifeline systems and other physical facilities located in the area. Consequently, due to this diversity, the seismic performance of the buildings and other physical facilities will not be uniform throughout the study area. Anticipated damage patterns resulting from a severe earthquake in the San Diego area will change according to the number of building variables involved and the geological characteristics underlying their construction areas.
The Earthquake Threat

Historically, the San Diego area has been relatively free from damaging earthquakes. This has led the general public to believe that the area is "safe." But the short historical record is not indicative of the actual long-term seismic hazard. The occasional occurrence of a M4 to M5 earthquake offshore and of small earthquake swarms beneath San Diego Bay testifies to the potential for larger earthquakes along a number of local faults.

Major potentially active faults passing through, or close to, the San Diego metropolitan area include the Rose Canyon fault zone (which includes the Silver Strand fault), the La Nacion fault, the Coronado Bank fault, and the Vallecitos fault (San Miguel fault zone). Of these, the Rose Canyon fault is probably the most hazardous, followed by the highly active Coronado Bank and San Miguel fault zones. Historic seismic activity within the metropolitan area has been limited: damaging earthquakes occurred only in 1800, 1862, 1983, 1985, and 1986. None of these earthquakes produced serious damage.

Thus, the seismic hazard in the San Diego area is difficult to quantify. Extensive development, a lack of well-dated Quaternary deposits onshore, and water cover offshore have limited both the quantity and quality of the data relating to the more recent geologic history of the area's faults. Critical parameters, such as geologic rate and sense of movement along local faults, recurrence times of damaging earthquakes, and recency of faulting are not well understood.
THE SCENARIO EARTHQUAKE

Description

For the scenario, an earthquake of M6.8 is assumed to occur, rupturing the entire Silver Strand fault. Surface fault rupture extends from the downtown San Diego area approximately 24 miles along the coast to the south, terminating approximately 16 miles south of the international border. Potentially damaging ground shaking continues for 10 to 15 seconds within 12 miles of the fault. Frequent aftershocks continue for several weeks, with events of M5.0 or larger possible.

While this planning scenario is based on a particular event on a particular fault zone, damage patterns would, in many areas, be similar for an event of similar magnitude located along one of several nearby faults. For example, a M6.0 event along the northern portion of the Silver Strand fault would inflict similar damage to downtown San Diego. A M6.9 earthquake on the Rose Canyon fault (approximately the maximum credible earthquake for that fault) would cause more damage along the coast north of San Diego than the scenario earthquake, but similar damage in the Mission Bay-San Diego Bay area.

Estimated Effects

Fault Rupture

Horizontal fault offset of up to two feet can be expected from a M6.8 earthquake. Largest offsets usually occur near the middle of the fault rupture. Generally, near the ends of the surface rupture (the only onshore portion of the scenario earthquake is at the northern end) smaller offsets occur. Because most of the scenario fault rupture is offshore, the effects of surface rupture are not expected to pose particularly serious problems.
Shaking Intensity Distribution

Areas subject to shaking of Modified Mercalli Intensity (MMI) IX (considerable damage to specially designed structures; great in substantial buildings with partial collapse; buildings shifted off foundations) include those areas of recent (Holocene) alluvium and artificial fill between the Tia Juana River Valley (California portion) and downtown San Diego/Coronado.

Areas subject to shaking of MMI VIII (considerable damage to ordinary substantial buildings; great in poorly built structures) extend from below Rosarito, Mexico, to Del Mar, California, along the coast, and as far as 36 km (23 miles) inland for poorest ground conditions. Intensity VIII has been subdivided (as shown in the shaking intensity map) into 8 (high VIII) and 8- (low VIII) to provide some differentiation between the firmer ground of, for example, Point Loma or Hillcrest and the more recent alluvial deposits and fill of Mission Bay and the areas bordering San Diego Bay. Intuition suggests that these areas will shake differently with less damage on firmer ground even though they all may lie within the area of MMI VIII.

Liquefaction

Earthquake-triggered ground failure, notably differential settlements and lateral spreading due to liquefaction, are expected to be common, particularly in areas of hydraulic fill in Mission Bay, Loma Portal, and along the margins of San Diego Bay. Also, areas of recent alluvium, particularly along river channels, such as the western reaches of Mission Valley and the Tia Juana and Otay River valleys, will experience moderate to severe liquefaction effects. (Note that the names Tia Juana River and the City of Tijuana, while possibly from the same root, are in fact different.)
Landslides

Seismically induced landslides pose an additional possible threat where steep slopes exist. Landslide problems will be greater during the rainy season than during the summer. Even though seismic induced landslides may not be pervasive, the implications of landslides along Pt. Loma, Mt. Soledad, Torrey Pines Mesa, along the north wall of Mission Valley, in Murphy Canyon, and along the canyons of Otay Mesa should be considered.
THE EARTHQUAKE IMPACT

Hospitals near the Fault

Four of the 29 San Diego area general acute-care hospitals (99 beds or more) are less than 1 1/2 miles from the postulated fault rupture of this scenario event. Of the 1,100 beds in these four facilities, less than 220 are in facilities constructed before 1972. Older facilities may be considerably damaged—not collapsed, but nonfunctional. One or more could become an added post-earthquake burden.

Public Schools

Public schools are fairly evenly distributed throughout the urbanized area. Post-Field Act schools generally perform well during earthquakes, as do private schools built to Field Act standards. Schools represent a tremendous resource for evacuation centers, mass care facilities, and so forth. At the same time, they contain a substantial student population at risk. Procedures for reuniting pupils with working parents—and for caring for the pupils until that time—must be carefully formulated. Access from outside the immediate area will be difficult where major arteries cross areas of poor ground.

Transportation Lifelines

Major Freeway Routes

Damage to the freeway system in the San Diego area will primarily result from ground failure because of liquefaction in areas of artificial fill and recent alluvial deposits and also because of failure of built-up embankments for road beds and on/off ramps. Interstate 5 (I-5) will be closed from Balboa Avenue on the north to Palm Avenue on the south. Both I-5 and old State Highway 101 will also be closed where they cross each of the coastal lagoons north to
Oceanside. Interstates 805, 15, and 8, and State Highways 163, 94, and 117 will generally be open except where they join I-5. Long delays along I-8 and Highway 163 will result from damage to their interchange. The Coronado Bridge will be closed. Access into Coronado on Highway 75 along the Silver Strand will be severely restricted. Although somewhat obstructed, major routes into and out of the greater San Diego area will be accessible. However, emergency vehicle transportation into and out of the most heavily damaged areas along the coast from Pacific Beach to Imperial Beach will be hampered by closures of all main arteries where they cross areas of poor ground.

We anticipate that the Otay border crossing will remain open. The San Ysidro border crossing will be severely damaged and closed.

Airports

With the exception of Lindbergh Field, most airports will remain accessible for at least some limited use. The runway at Lindbergh Field will be damaged by liquefaction-induced lateral spreading. Access will be extremely difficult for the first 48 to 72 hours. The Gillespie Field runway will be slightly damaged by liquefaction-induced lateral spreading. Other airport runways will be generally undamaged. However, Brown Field will be the only U.S. commercial field capable of receiving C-141 aircraft. Both Miramar and North Island naval air stations will be operational, although ground access to North Island will be extremely limited.

Railroads

Rail service will be interrupted by track damage in areas of liquefiable ground between Del Mar and the Tia Juana River Valley.
Port Facilities

Pile-supported docks are not expected to be heavily damaged by ground shaking. Quaywalls and the bordering areas of artificial fill will be heavily damaged around San Diego Bay. Access to and egress from these areas will be difficult. Port facilities should not be considered as supply-terminal resources in earthquake emergency response plans. A tsunami is not expected for the scenario earthquake.

Utility Lifelines

Communications

Telephone communications will be overloaded by post-earthquake calls and by telephones knocked off their hooks by the shaking. Physical damage to most modern switching facilities should be minimal. However, more severe damage may be expected at older facilities housing the older, high-rack switching gear. Telephone lines may be damaged where they cross areas of poor ground. As a result, routing options for Coronado, Point Loma, and Pacific Beach will be limited. Secondary communications networks will be required to provide supplementary communication, especially for police and fire departments, and for electrical and water utilities.

Electrical Power

Power plants, except for South Bay, and primary transmission lines, including the Southwest Power Link, will remain operational following the scenario earthquake. Thus, over most of the metropolitan area, limited power outages can be expected to result from the failure of transformers on poles and damage to ceramic insulators. In areas of strong shaking (IX and high VIII) and in areas of poor ground, substation damage and damage to underground lines
(where they cross areas of intense lateral spreading) will cause more extensive outages. Most severely affected will be Mission Bay and the Loma Portal-Lindbergh Field area. Access problems will prevent repair for 24 to 72 hours.

**Water Supply**

As with other utilities, water transmission aqueducts primarily occur inland from the areas of high damage expected for this scenario earthquake. All aqueducts and storage reservoirs are expected to be operational following the scenario earthquake. Assessments of San Diego area dams indicate that four require emergency planning attention.

Outside of areas of poor ground, the water distribution system will suffer only light to moderate damage. Western Mission Valley, the Tia Juana River Valley, and areas bordering Mission Bay and San Diego Bay will be most affected. Large portions of the coastal communities from La Jolla to the border will be without water for several days following the scenario earthquake. Operation of the primary waste water treatment facility in Point Loma will be severely hampered by loss of its water supply.

**Waste Water**

The primary waste water pipelines around San Diego Bay will be ruptured where they cross areas of liquefaction-induced lateral spreading. Pumping Plant Number 2 near Lindbergh Field is located on artificial fill. It will be out of service and without power for more than 72 hours following the scenario earthquake. Almost all of the waste water from the metropolitan area flows through this plant. Failure of the plant will necessitate waste water release into both Mission and San Diego bays. Pumping Plant Number 1 in the South Bay area is also located on liquefiable ground and will be damaged by the scenario earthquake.
The Point Loma treatment plant is not expected to be severely damaged, however, lack of water supply will cause major operational problems. Some damage to tanks will result from the sloshing of liquids and spillage of caustic chemicals, but the plants are expected to remain operational if power and water supplies are available. Nevertheless, because of failure of the primary pumping plants, little waste water will be reaching the plant for several days following the earthquake.

**Natural Gas**

Three transmission pipelines convey natural gas to the San Diego area from the north. Two are located inland, running along the mesas. These will not be seriously affected by the scenario earthquake. The third runs along the coast and crosses several areas of high to very high liquefaction susceptibility. This pipeline will be damaged by lateral spreading at Soledad (Sorrento) Valley and by landslides along Torrey Pines Grade. It will be out of service for more than 72 hours.

The scenario earthquake will primarily impact the gas distribution system where it crosses areas of high intensity and ground failure. In Pacific Beach, Point Loma, and downtown San Diego, repairs will be completed within 72 hours, but complete service restoration (relight) will take one to two weeks. Coronado could be without service for two to four months until a new pipe is installed across the Bay.

**Petroleum Products**

The petroleum products pipeline like most of the utilities' transmission facilities from the north is routed primarily along the inland mesas, and should be operational after the event. The tank farm is located on liquefiable alluvium near the north wall of Mission Valley, susceptible to some landsliding. Because of its distance from the earthquake source, the tank
farm should not have severe damage. Fires may result at lines broken where they meet the tanks. The tanks themselves may be damaged from sloshing liquids.

The Navy fuel pipeline to Point Loma will be damaged where it crosses the Mission Bay-Loma Portal area of high liquefaction susceptibility. The Tenth Avenue Marine Terminal fuel pier will be heavily damaged from lateral spreading of the liquefied fill along the margins of San Diego Bay. Access to the fuel terminal and to the damaged portions of the Navy pipeline will be difficult and limited, delaying repair for several days.
Section 1.

THE EARTHQUAKE PLANNING SCENARIO
THE EARTHQUAKE PLANNING SCENARIO

Introduction

This planning scenario for the San Diego area resulted from two related needs. San Diego County, through its Office of Disaster Preparedness, requested that the California Department of Conservation’s Division of Mines and Geology (DMG) undertake a seismic hazard analysis and lifelines scenario for the San Diego metropolitan area to assist in its emergency response planning. This was followed by the Federal Emergency Management Agency’s (FEMA) implementation of a U.S.-Mexico bi-national agreement on earthquake planning in the border area, beginning in the San Diego-Tijuana metropolitan area. This planning process involves FEMA, the State of California Office of Emergency Services, County of San Diego’s Office of Disaster Preparedness, other Federal, State and local agencies, and their Mexican counterparts. The objective of the planning effort is a projection of the potential damage that could result from the occurrence of a large earthquake in the vicinity of the Border and the identification and implementation of appropriate measures to mitigate that damage and respond effectively. Although this scenario’s title refers to both San Diego and Tijuana, damage assessments for Mexican facilities or lifelines generally have not been conducted. The scenario does provide estimates of ground shaking in Mexico from the scenario earthquake and estimates of liquefaction susceptibility for a portion of the Tia Juana River Valley. Thus, the needs and the sources of mutual emergency response assistance can be identified and agreements can be developed to assist the local response capabilities in both countries. Though chosen to fulfill this particular planning need, the forecasted damage distribution does approximate the damage that would occur in the San Diego area from a large earthquake on any of the near-border faults. The particular event chosen for this planning scenario should not be taken as the most probable damaging earthquake that could occur in the area.
It is hoped that this planning scenario will contribute to the efforts of the following users:

- Elected officials who must be able to visualize the threat in order to assume the leadership roles needed to cope with the earthquake.

- Local, State and Federal officials with emergency planning responsibilities.

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

- Educators, journalists, and other public opinion leaders who must appreciate the threat and communicate it to motivate citizen understanding and commitment to preparedness.

- The citizens of the San Diego and Tijuana metropolitan areas who are asked to support mitigation efforts and to develop personal earthquake safety strategies for themselves and their families.

Earthquake planning scenarios are used to provide a regional perspective of plausible consequences of credible damaging earthquakes. This information facilitates the efforts of planners in preparing emergency response plans to cope with such an event. Previous earthquake planning scenarios for the Los Angeles and San Francisco metropolitan areas (Davis and others, 1982a, 1982b; Steinbrugge and others, 1987; Toppozada and others, 1988) were based on the assumed repeat of or extrapolation of damaging historical earthquakes. The San Diego area has not experienced a large, damaging historical earthquake for which the causative fault can be identified. This does not imply that the San Diego area is free of seismic hazards. The hazards simply are not as well understood as those in other parts of California.
Scenarios postulating damage and damage patterns are not precise predictions of what will occur. A statement that a building will survive or will collapse can be given only in probabilistic terms as one cannot predict that a person driving under the influence of alcohol will have an accident, but the probabilities are significantly higher. Because building construction types and the past earthquake performance of structures with given characteristics are known, realistic scenarios on probable damage can be developed.

The planning process for man-made structures to accommodate earthquake ground motion is certainly not new. Robert Mallet, in his landmark book on his observations of the great 1857 earthquake in Naples, Italy noted that some of the damage could have been avoided if the construction recommendations that had been made after previous earthquakes had been followed. These were construction details that had fallen into obscurity with the passage of time. Following the great Japanese earthquake of 1923, city planners envisioned many thoughtful and practical, albeit long-range, goals for reducing damage from future earthquakes. Their plans unfortunately ran headlong into the reality of the immediate necessities of hundreds of thousands of homeless people requiring food, shelter, and work (see Richter, 1958, p. 561).

The planner is faced with the challenge of overcoming public complacency to institute changes, often expensive changes, that will mitigate the effects of future, major earthquakes.

The planner addresses the effects not only on buildings, but also on those features upon which an urban population depends. Broken water mains hindering fire fighting, disrupted avenues of communications that prevent coordination and efficiency in rescue and relief operations, and the destruction or damage to bridges and transportation facilities that block access into or evacuation out of devastated areas are some areas of concern that may debilitate an urban population more than the collapse of buildings.
Numerical values associated with response planning topics, such as damage to hospitals, represent reasonable maximum expected conditions. In other words, these values are credible: they have experience data and/or experienced judgment behind them. The quality of the numbers varies depending upon the extrapolation (if any) from experience data, the reliability of the assumptions supporting the calculations, and the quality of the judgment behind the decisions.

In addition to the possible variations in seismological parameters, the response of buildings and structures to earthquake ground motions is not as well understood as some persons might expect. Surprises and lessons learned and relearned have occurred in every destructive American earthquake. Often the evidence raises new questions without indicating immediate answers; these are a major reason for the many reports arising from such recent earthquakes as 1971 San Fernando, 1979 Imperial Valley, 1983 Coalinga, and 1987 Whittier Narrows. As previously noted, the expected seismic performance of any particular facility can be stated only in a probabilistic sense. As a result, this report generally states its findings by building type and geographic grouping, or on some other compatible basis.

No scenario will prove accurate in detail. The scenario endeavors to facilitate the consideration of lifeline response in emergency response planning for a damaging earthquake. The types and magnitude of problems that will confront emergency response personnel are evaluated. The shaking intensity, liquefaction susceptibility, and landslide susceptibility map is presented to provide the planner with a regional overview of the patterns of potentially damaging geologic effects. One earthquake scenario cannot portray all of the types of damage that are potentially possible in a geologically active area such as San Diego. Many faults in the area may be capable of generating damaging earthquakes, and it is not presently scientifically possible to identify which will be the source of the next seismic event. Any of these faults could pose a greater hazard than the Silver Strand fault, which was chosen for this scenario.
The Planning Area

The planning area for this scenario (as shown in Map 4-S) encompasses all of metropolitan San Diego and Tijuana, from Oceanside on the north, to Rosarito on the south, and east to Alpine and Ramona. All areas likely to experience MMI greater than or equal to VIII and, thus, all areas likely to suffer substantial damage, are included.

The area includes the vast majority of the 2.3 million residents in San Diego County and nearly all of the approximately 1.5 million Tijuana residents. Populations of those incorporated areas north of the Border most significantly affected by the scenario earthquake are listed in Table 1.

The planning area for this scenario is designated "Planning Area 4." Planning areas one through three designate the areas encompassed in previous scenarios for M8.3 earthquakes on the southern and northern San Andreas fault and a M7.5 earthquake on the Hayward fault, respectively (DMG Special Publications 60, 61, and 78).

Choice of the Scenario Earthquake

Unlike other parts of California where the seismic hazard is thought to be well understood, knowledge of the seismic hazard in the San Diego-Tijuana area is incomplete. Throughout most of the area, fault locations are fairly well known (see Plate 2), although exact locations are poorly known in areas of recent alluvium, such as Mission Bay, and in developed areas, such as downtown San Diego. Probable continuity of these faults with active faults in the Los Angeles area and in northern Baja California provides strong circumstantial evidence that San Diego area faults are active and pose a substantial hazard. But only recently has conclusive evidence of Holocene (within last 10,000 years) activity along the Rose Canyon fault been excavated (Lindvall and others, 1990), indicating several
earthquakes in Rose Canyon of M6 to M7 within the past 8,000 years. This new evidence demonstrates that the seismic hazard is not negligible in the San Diego-Tijuana area.

TABLE 1
POPULATION DATA FOR INCORPORATED AREAS
SILVER STRAND FAULT VICINITY

<table>
<thead>
<tr>
<th>City</th>
<th>Population*</th>
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<tbody>
<tr>
<td>Chula Vista</td>
<td>124,300</td>
</tr>
<tr>
<td>Coronado</td>
<td>23,600</td>
</tr>
<tr>
<td>El Cajon</td>
<td>84,600</td>
</tr>
<tr>
<td>Imperial Beach</td>
<td>25,600</td>
</tr>
<tr>
<td>La Mesa</td>
<td>52,300</td>
</tr>
<tr>
<td>Lemon Grove</td>
<td>22,600</td>
</tr>
<tr>
<td>National City</td>
<td>55,300</td>
</tr>
<tr>
<td>San Diego</td>
<td>1,058,700</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1,477,000</strong></td>
</tr>
</tbody>
</table>

* Data from Department of Finance, State of California, for January 1, 1988.

The lack of a severely damaging historical earthquake and the lack of data suggesting such earthquakes in the prehistory in the San Diego area complicate the choice of a "planning" event. The probabilistic seismic hazard analysis of Power and others (1986) indicates that the Rose Canyon fault zone poses the most probable hazard for generating strong ground shaking and liquefaction. This scenario, however, was developed for a specific planning purpose, rather than for the more general, regional, emergency response planning purpose of previous scenarios. Namely, this scenario has been developed to meet
the needs of the bi-national U.S.-Mexico Earthquake Preparedness Project (USMEPP). Planners working on cross border concerns requested a scenario for an earthquake that inflicted significant damage to both the San Diego and Tijuana metropolitan areas. Thus, issues that would require international cooperation could be identified, and plans and procedures can be developed to affect that post-earthquake cooperation.

For an event damaging to both San Diego and Tijuana, the Silver Strand fault (Kennedy and Welday, 1980) was chosen because of its proximity to both downtown areas. Although not the most conspicuous of the offshore faults south of Coronado, it does displace geologically young sediment near the sea floor, indicating fairly "recent" activity. The Silver Strand fault is a component fault of the Rose Canyon fault zone. It is located offshore, south of the Coronado Peninsula and the Silver Strand. Current maps of the fault end at the international border. However, further south, along the coast of Baja California, Minch (1966) inferred the existence of a fault controlling the coastline geomorphology. This inferred fault would be a natural extension of the Silver Strand fault. We extended the scenario fault to include this fault segment. To the north, Kennedy (1975) mapped a short fault segment within San Diego Bay that is along the strike of the Silver Strand fault. Therefore, we also extended the scenario fault to the north, connecting with this short segment and extending into the downtown area in the vicinity of the "Police Administration Building" fault of Testing Engineers and others (1985). This particular fault rupture would have a total length of approximately 24 miles; the earthquake magnitude would be about M6.8.

Power and others (1986), in their liquefaction potential analysis for the San Diego area, identified the Rose Canyon fault zone as the most probable source of strong ground shaking for San Diego. Although the scenario earthquake may not be the most probable, it is a plausible event and provides a ground shaking distribution pattern similar to that which could result from large earthquakes along a variety of near-border faults. The following discussions of faulting and seismicity in the San Diego area place this scenario event within
the more general context of the regional seismic hazard. They give the user of this scenario an overall perspective of the regional hazard in terms of the current state of knowledge regarding the local faults.

**Faulting**

Faulting within and near the San Diego-Tijuana area is part of the complex Pacific-North American plate boundary in southern California that extends from at least the San Andreas fault on the east to well offshore. In Plate 1 (from Treiman, 1984), we show the regional faults of southern California and northern Baja California. The San Andreas-Imperial-Cerro Prieto, San Jacinto, Elsinore-Laguna Salada, Newport-Inglewood-South Coast Offshore Zone of Deformation-Rose Canyon, Vallecitos-San Miguel faults, and other offshore fault zones are the principal component faults. Although earthquakes from many of these faults have been felt and have inflicted minor damage to San Diego in historical time, they do not appear to be major threats to the metropolitan area. For example, the 1956 San Miguel fault (M6.8), the 1968 Borrego Mountain (San Jacinto fault, M6.4) and the 1979 Imperial Valley (Imperial fault, M6.6) earthquakes inflicted little damage on San Diego. The primary seismic hazard appears to be from the Rose Canyon fault and the near offshore faults, such as the Coronado Bank fault.

A more detailed view of the faults near San Diego and Tijuana is shown in Plate 2 and Figure 1. Both are from a report by Treiman (1984) that summarizes the knowledge of the Rose Canyon fault zone. The faulting in the area is extremely complex. The primary fault cutting through the area is the Rose Canyon fault zone. The fault runs parallel to and just offshore of the coast from north of Carlsbad to La Jolla. It comes onshore at La Jolla Shores, bends around Soledad Mountain and runs southward along Mission Bay. At Old Town, it appears to splay into a number of fault segments, none of which appears to be the dominant continuation of the Rose Canyon fault zone. The Silver Strand fault comprises one of these splays. A continuation of the Rose Canyon fault zone to the south through the Tia
Juana River Valley, as suggested by Gastil and others (1979), has not been identified. An alternative continuation is offshore along the coast west of Tijuana.

As seen in Plate 2, the faults of Rose Canyon fault zone are not the only faults mapped within the San Diego metropolitan area. Indeed, the faulting is very complex. Many of these faults, such as the Texas Street, Florida Canyon, and La Nacion faults, are thought to be relatively inactive and not to pose a major threat. Other faults, especially those offshore, are known to be active and any could cause a damaging earthquake.

Knowledge of recency of faulting of the onshore portion of the Rose Canyon fault zone is summarized by Treiman (1984). At the time of his report, no fault in the metropolitan area had demonstrable Holocene (within the last 10,000 years) movement. Subsequent excavation of the site for the new Police Administration and Technical Center (PATC) in downtown San Diego revealed three new faults. One of the three strongly suggested movement within the past 3,000-5,000 years (Testing Engineers and others, 1985). Even in this case, the data are subject to alternate interpretations. Artim and Ninyo (1985) suggested that the data do not demonstrate Holocene faulting. As for the fault used in this scenario, Kennedy and Welday (1980) were unable to identify clear sea-floor offsets along the Silver Strand fault. Faulting does extend into the recent sediments, however, implying relatively recent movement.

More recently, a trench excavated across the Rose Canyon fault contained definite evidence of Holocene activity (Lindvall and others, 1990). Material dated at 7870 and 8300 years before present showed evidence of multiple Holocene earthquake activity. The implications of this new evidence are still being evaluated at the time of this writing. It is clear, however, that San Diego has experienced major earthquakes during the recent geologic past.
Seismicity

In general, historical local earthquakes damaging to San Diego cannot be associated with a particular mapped fault or set of faults. For the earlier earthquakes (pre-1934), locations are not accurate enough to positively identify the causative fault. Instrumentally located events (post-1934) show a complex pattern of activity, concentrated offshore. The pattern does not show alignments along individual faults. Nevertheless, past events testify conclusively to the presence of active faulting in and around the greater San Diego area. For these reasons, this discussion of the San Diego seismicity is presented from a regional point of view, rather than concentrating on the scenario fault--the Silver Strand fault.

The earliest historical record of a damaging earthquake in the San Diego area is for an event on November 22, 1800. This event damaged both the San Diego and San Juan Capistrano missions. Toppozada and others (1981) estimates a magnitude greater than about M6.5 to account for the damage at these widely separated (60 miles) sites. Obviously, for this event and for most nineteenth and early twentieth century earthquakes, the epicenters and the causative faults may never be accurately known. From the damage reports, however, the location and magnitude of many pre-instrumental earthquakes can be approximated. Table 2 lists those earthquakes which have caused some damage to the San Diego metropolitan area and which appear to have occurred along or west of the Elsinore fault. Included in this list are several events from Baja California and from offshore faults. Figure 2 shows the estimated locations of these events. Events which occurred (or probably occurred) along the San Jacinto fault in the Imperial and Mexicali valleys or near Los Angeles are not included.

The $M_L$ (local magnitude) = 4.6 offshore earthquake of June 29, 1983, is the largest event to that date to have been instrumentally located within the San Diego area. The larger event of July 13, 1986 ($M_L = 5.3$) occurred about 30 miles offshore.
Figure 1. Active and potentially active faults of the San Diego region.
Only nine of the events listed in Table 2 appear to have occurred within (or, perhaps, just offshore of) the San Diego metropolitan area and none caused significant damage there. However, the historic earthquake record is very brief compared to the geological history of the area.

Instrumentally located background seismicity (post-1932) can indicate which faults are currently active. We emphasize that the lack of background seismicity does not imply that a fault is not hazardous, merely that it may be currently quiescent. Figure 3a shows the seismicity of an extended San Diego-northern Baja California area from 1932 through 1983 from California Institute of Technology - U.S. Geological Survey (CALTECH-USGS locations). Events identified as quarry blasts by CalTech have been removed, but a number of blasts remain in this catalog. The earthquake locations form a broad, diffuse pattern, but there is a hint of a northwest-southeast offshore trend approaching the coast in the vicinity of Point Loma and Coronado. This "trend" is even more diffuse south of the international border, probably due to the lack of seismograph coverage in the area. Figure 3b shows the seismicity for the same region between 1970 and 1983. The trend is somewhat better defined, but locations are still scattered.

The trend offshore of Figure 3a and Figure 3b is more or less parallel to the onshore regional seismicity trends of the Elsinore, San Jacinto, and Imperial faults and must cross a number of off-shore faults. Whether this seismicity occurs along some continuous thoroughgoing basement fault or along sections of the mapped faults is not known at this time. This persistently active area contains all of the recent local events that have been felt in San Diego. The more recent seismicity--the June 1985 San Diego Bay earthquake swarm and the July 1986 $M_L$ 5.3 offshore earthquake--all occurred within this zone. But, because the causative fault lies primarily offshore, its significance is still uncertain. This may be evidence of a continuous seismic zone passing between the highly seismic region in the
<table>
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<tr>
<th>Date</th>
<th>Intensity In San Diego</th>
<th>Maximum Intensity</th>
<th>M(MMI)*</th>
<th>M_L*</th>
</tr>
</thead>
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<tr>
<td>22 Nov 1800</td>
<td>VII</td>
<td>VII</td>
<td>6.5</td>
<td></td>
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<td>VI</td>
<td>VI-VII</td>
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<tr>
<td>21 Sept 1856</td>
<td>VI</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>27 May 1862</td>
<td>VII</td>
<td>VII</td>
<td>5.9</td>
<td></td>
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<tr>
<td>24 Feb 1892</td>
<td>VI-VIII</td>
<td>VIII-IX</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>23 Oct 1894</td>
<td>V</td>
<td>VI</td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>01 May 1939</td>
<td>V</td>
<td>VI</td>
<td>5.0</td>
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<tr>
<td>04 Nov 1949</td>
<td>V-VI</td>
<td></td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>26 Dec 1951</td>
<td>VI</td>
<td>(offshore)</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>09 Feb 1956</td>
<td>VI</td>
<td>?</td>
<td>6.8</td>
<td></td>
</tr>
<tr>
<td>22 Dec 1964</td>
<td>VI</td>
<td>(offshore)</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
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</tr>
<tr>
<td>13 July 1986</td>
<td>VI(?)</td>
<td>VI(?)</td>
<td>5.3</td>
<td></td>
</tr>
</tbody>
</table>

* M(MMI) is Local magnitude estimated from intensities by Toppozada, et al., (1981).

M_L is instrumental local magnitude.
Figure 2. Damaging earthquakes near San Diego (excluding those from the Elsinore and beyond).
Figure 3a. Seismicity of coastal southern California and northern Baja California.
Figure 3b. Seismicity of coastal southern California and northern Baja California.
Peninsula Ranges of Baja California (the San Miguel fault zone) and the seismicity to the north and west of San Diego. This zone of relatively high activity includes the mapped Silver Strand fault, although no one earthquake can definitely be associated with this fault.

Figure 3C shows more recent epicentral locations (August 1984 to June 1988). The seismicity near San Diego is dominated by the "Oceanside" earthquake sequence that began with a $M_L$ 5.3 on July 13, 1986. The earthquake was widely felt and inflicted minor damage in San Diego and Orange counties. This event has had many more aftershocks than would normally be expected from a M5.3 mainshock. Through July 1987, 91 events over $M_L = 3.0$, many of which were felt in coastal San Diego, have occurred. The seismicity was still high in early 1989.
Figure 3c. Seismicity of coastal southern California and northern Baja California.
Section 2.

GENERAL EFFECTS OF THE SCENARIO EARTHQUAKE
GENERAL EFFECTS OF THE SCENARIO EARTHQUAKE

Surface Fault Rupture

The assumed fault rupture length of 24 miles for this scenario earthquake corresponds to a Richter magnitude of about 6.8. Potentially damaging shaking will continue for 10 to 15 seconds. Maximum right-lateral, horizontal surface displacement will be about two feet. This maximum will most probably occur offshore with smaller surface displacements along the fault across the Silver Strand and in downtown San Diego. Because of the very small portion of faulting onshore and the small expected surface displacement, effects of surface fault displacement in this scenario should be small and are not considered. This does not imply, however, that surface fault rupture could not rupture some gas, water, or sewer lines where they cross the fault along the Silver Strand or in the downtown area. The lack of a fault rupture hazard in this scenario results from the particular earthquake on the Silver Strand fault. More significant surface fault rupture onshore could be associated with a damaging event on another fault such as the Rose Canyon fault. The effects on urban lifelines could be severe and should be considered by emergency response personnel in the total efforts to achieve earthquake preparedness, but these effects are not within the scope of this scenario.

Vertical ground movements will be small and no tsunami is anticipated.

Predicted Seismic Intensity Distribution

To develop an earthquake planning scenario, it is necessary to estimate the regional patterns of ground shaking and permanent ground deformation. This procedure is aided by assuming that the effects of the scenario earthquake can be deduced from previous earthquakes about which there is some knowledge.
Seismic intensity is the felt effect of an earthquake at a particular place. A numerical value conveys the various effects of earthquake shaking at a given place on buildings, furnishings, etc. The determination of seismic intensity is therefore subjective. Many intensity scales have appeared during the last century (Barosh, 1969, p. 6). The Modified Mercalli Intensity scale, used in this scenario, is reproduced and related to the Rossi-Forel scale in Appendix A.

Earthquake magnitude is an instrumental measure of earthquake size, regardless of location or of intensity effects. Earthquakes of similar magnitudes, occurring at different locations, can have different intensities. The M6.3 earthquake of 1933 generated intensity IX in Long Beach. An earthquake of similar magnitude in 1908 had a maximum reported intensity of less than VII, because it occurred in an unpopulated area (Death Valley). The instrumental magnitudes of the 1908 and 1933 earthquakes were similar, even though their felt intensity effects were very different.

Regional Seismic Intensity Investigations

The degree of ground shaking resulting from the scenario earthquake will depend on several factors. Among the most important is the distance from the causative fault. Generally, the amplitude of vibrations associated with earthquakes are complex. Characterizing their anticipated effects at specific locations is further complicated by variations in the geologic materials through which they pass. Consolidated bedrock transmits most seismic frequencies while unconsolidated sand, gravel or mud preferentially transmit low frequencies.

The development of seismic intensity maps also requires consideration of the consequences of ground breakage. In contrast to vibratory shaking, ground breakage is a permanent displacement of earth materials resulting from fault rupture, liquefaction, differential settlement, or slope failure. Lifeline damage due to fault rupture will be confined
to a narrow zone within about 100 meters (330 feet) of the fault (Bonilla, 1967). The potential for liquefaction (Borchardt and Kennedy, 1979) is governed by the presence of susceptible substrate materials such as water-saturated sand. Differential settlement is primarily a site-specific engineering problem occurring where structures are built on materials of varying density and degree of consolidation. Seismically induced landslides occur primarily on slopes greater than 3 in 10 (or 30% grade) in hills containing unstable geologic materials.

Development of the Seismic Intensity Distribution Map

In preparing a regional intensity map for assessing lifeline damage, Reichle and Kahle (1986) developed an algorithm based on the Evernden model (Evernden and others, 1973, 1981; Evernden, 1975; and Evernden and Thomson, 1985). This computer model calculates the ground shaking acceleration on a grid of reference points throughout a region employing equations that account for the influence of distance from the fault source, attenuation, and the surface geology. The intensities are calculated by using an empirical relationship between acceleration and the intensity scale.

Reichle and Kahle’s model is used in this scenario, and differs from that of Evernden and others (1981) in that it assumes that shaking intensity does not depend on depth to water table. Also, it predicts intensities for bedrock sites within 3 miles of the fault and at distances greater than 25 miles on unsaturated alluvium that are approximately one unit higher than Evernden’s. The model was guided by the areal extent of Intensity VII and VIII shaking for earthquakes of about M7 on other California faults, notably the 1868 Hayward and the 1952 Kern County earthquakes.
The calculated seismic shaking intensity distribution for the scenario earthquake on the Silver Strand fault is shown in Map 4-S. Areas of MMI IX (enough to shake unbolted wood-frame houses off their foundations and cause collapse of some unreinforced masonry buildings) include those areas of artificial fill bordering San Diego Bay south and southeast of downtown and the California portion of the Tia Juana River Valley.

Areas of intensity VIII (enough to destroy most unreinforced brick chimneys and to cause some walls to fall) are much more widespread. We have divided intensity VIII into two ranges: high VIII (VIII+), and low VIII (VIII-). The subdivision of individual intensity units is not entirely justified because intensity is defined only in terms of whole integers. However, the broad definitions certainly allow for a range of damage within each unit. Thus, we attempt to distinguish the shaking levels in, for instance, Loma Portal and Mission Valley (VIII+), located on recent alluvium and fill, from the adjacent areas of Pacific Beach, Point Loma and Hillcrest (VIII-), located on older and more competent sedimentary rock. Even though all fall within intensity VIII, the areas indicated "VIII+" will suffer more damage, possibly significantly so, than those of "VIII-." It is not possible to give a more quantitative, rigorous description of the differences.

Areas of high VIII+ include Mission Valley, Mission Bay, Loma Portal, downtown San Diego through San Ysidro, the Tia Juana River Valley south of the border, and the Coronado Peninsula. Those of low VIII- include Soledad (Sorrento) Valley, La Jolla Shores, Pacific Beach, Mission Hills through East San Diego, El Cajon, Santee, the mesas east of National City and Chula Vista, Otay Mesa, and much of metropolitan Tijuana.
Liquefaction

Liquefaction is the temporary transformation of water-saturated, cohesionless, fine-grained material (sedimentary deposits) from a stable, relatively solid condition to a liquefied state as a consequence of increased pore-water pressure. The causes of liquefaction include earthquakes, rapid percolation of water, and explosions. Shallow earthquakes of $M_L$ greater than or equal to 6.0 commonly produce enough shaking to induce liquefaction by increasing the pore-pressure in loosely packed, water-saturated sediments. The degree of liquefaction that may occur at any location is a function of the geologic setting and the intensity of seismic shaking. Liquefaction usually occurs toward the end of or several minutes after the earthquake and may continue for some time.

Liquefaction susceptibility is here defined as the relative likelihood that liquefaction may occur within certain geologic units when they are subjected to intense seismic shaking. Liquefaction by itself poses no particular hazard unless it leads to some form of permanent ground movement or ground failure. Liquefaction-induced ground failure has been the cause of major damage in many large earthquakes, but it is usually confined to specific geologic settings. Ground failure is a common consequence of liquefaction and can be expected to occur in areas susceptible to liquefaction. For our purposes, we will treat liquefaction susceptibility as qualitatively equivalent to that of liquefaction-induced ground failure.

Certain types of sedimentary deposits are more susceptible to liquefaction than others. The age of the deposit, as well as the depth to the water table, is important in predicting the susceptibility. Shallow, Holocene fluvial, deltaic, and aeolian deposits and poorly compacted artificial fill have the highest susceptibility to liquefaction and ground failure. Holocene alluvial-fan, alluvial plain, beach, and terrace deposits are somewhat less susceptible. Pleistocene and pre-Pleistocene sand deposits are even less susceptible. (See Youd, 1973; Youd and Hoose, 1977; and Youd and Perkins, 1978).
The method used for estimating liquefaction susceptibility is based on the type of sedimentary deposit, general distribution of cohesionless sediments in the deposits, and the age of the deposits. Other factors affecting ground failure are depth of burial, slope, and nearness of a free face. The results of Power and others (1982a) and Leighton and Associates (1983) for the San Diego area have been incorporated.

Most of the alluvial deposits of the San Diego area have a very shallow depth to the water table, particularly following wet winters. When the water table depths are greater than about 33 feet, most deposits have a low likelihood of liquefaction. Except for a few inland areas where pumping depresses the water table, the depth to the water table is assumed to be less than 33 feet.

Most of the area within and adjacent to Mission Bay and most of the land adjacent to San Diego Bay has been reclaimed with hydraulically placed fill (Power and others, 1982a,b). Most hydraulic fill is dredged from the bottom of San Diego and Mission bays. It generally consists of medium- to fine-sand and slightly silty, fine sand. Uncompacted fill has a very high liquefaction susceptibility. Thus, the areas of hydraulic fill in the San Diego area have been rated as "very high" because of their method of placement, size of material, very shallow water table, and the presence of adjacent channels that act as a free face. Non-hydraulic fill may be compacted or uncompacted; but since it is commonly located at higher elevations and is isolated from the water table, its susceptibility is usually low.

On the intensity map (Map 4-S) we show only those areas with high and very high liquefaction susceptibility.

Youd and Wieczorek (1982) note that, following the October, 1979, Imperial Valley earthquake (M6.6), most liquefaction effects were confined within 2.5 miles of the Imperial fault. Liquefaction effects were sporadic between 2.5 miles and 10 miles. That event was
slightly smaller than our planning event. It is assumed therefore, that most significant liquefaction effects will be confined to within 4 to 6 miles of the fault and they will be sporadic out to 22 miles (Youd and Perkins, 1978).

It is difficult without specific site studies to predict the damage distribution from liquefaction. For the purposes of this planning scenario, the areas of artificial (hydraulic) fill bordering San Diego Bay, including Loma Portal, are assumed to suffer fairly extensive lateral spreading, enough to close Lindbergh Field and affect built-up road/freeway approaches. Mission Bay is affected to a lesser extent. Portions of Mission Valley and the El Cajon-Santee-Lakeside basin are damaged by localized lateral spreading.

Landslides

Earthquake-induced landslides can produce widespread damage in susceptible terrain. In historical earthquakes, the most abundant landslides have been rockfalls, disrupted soil slides, and rock slides (Keefer, 1984). These landslides are generally shallow, internally disrupted, and detached from steep slopes. In the San Diego area, this type of landslide can occur along undercut coastal bluffs and along steep (greater than about 35 degrees) canyon walls and roadcuts within sedimentary rocks or bedrock. A complete study of those areas susceptible to disrupted slides in the San Diego metropolitan area has not been undertaken, but such areas must certainly include steep slopes (regardless of rock type) other than those discussed here.

Coherent rock slumps, rock block slides, and soil slumps are generally deeper-seated and slower moving with less internal disturbance than rockfalls and disrupted soil slides. They occur in intensely fractured or very weakly cemented rocks and in loose, partly or completely saturated sand, silt, and uncompacted or poorly compacted fill. In this section, we are concerned with coherent slides within steeply sloping terrain. Coherent landsliding and slumping are not uncommon in the San Diego area. Local provinces containing several
large, ancient landslides (primarily Pleistocene in age) have been identified by Hart (1972, 1973, 1977, and 1979); Foster (1973); Kennedy (1975); Kennedy and Peterson (1975); Kennedy and Tan (1977); and Weber (1982). Within these provinces, smaller landslides have occurred since urban development began, mainly during or following very wet winters. Discussions of individual recent slides can be found in the articles cited above and in Hannon and Lough (1973); Lung (1973); Moore (1973); Hannon and Owen (1981); and Artim (1981).

Using this information, data from Leighton and Associates (1983) and suggestions from Michael Kennedy (Division of Mines and Geology, Personal Communication), areas interpreted to have some susceptibility to coherent landsliding and slumping have been included in the shaking intensity map (Map 4-S). Steep slopes not normally associated with landsliding but which might produce incoherent rock/soil falls during an earthquake are not included. No attempt was made to rate the level of susceptibility. That is beyond the current state of knowledge for the San Diego area. The map shows those areas of existing landslides and areas containing susceptible terrain and/or geologic materials.

Areas considered susceptible lie along the slopes of valleys and canyons containing walls of poorly cemented, clay-rich Eocene and Miocene sandstones, within the steeply dipping bedding surface on Soledad Mountain, and along coastal bluffs. In general, the mesa tops, except near the edges, are not involved. Coherent landsliding will tend to be a greater factor if the event occurs during or just following the rainy season than if it occurs toward the end of summer. The coastal cliffs from Ocean Beach to about Ballast Point are probably not as susceptible to coherent slumping as other areas, but may be subject to incoherent rockfalls where undercut by surf action.
Keefer (1984) and Wilson and Keefer (1985) give magnitude-distance relationships for both coherent and disrupted landslides. For a M6.8 earthquake, the historical limits (beyond which one would not expect landsliding to occur) are about 56 miles for coherent slides and 94 miles for disrupted landslides. Within about 20 miles for coherent slides and about 40 miles for disrupted slides, there is a greater than 50 percent probability that ground motion will exceed the level required to trigger the particular type of failure.

Even during the very wet winters of the late 1970's, coherent landslides and slumps were not a serious, widespread problem in San Diego. Most slumps and slides were small and shallow-seated. Therefore, earthquake-induced landslides are not expected to cause an overwhelming response problem within the metropolitan area. Nevertheless, slumps in wet, steep slopes and rockfalls in steep slopes, roadcuts, and canyon walls will occur, and they will occur in the same types of geology and terrain where they have occurred in the past. Thus, prudent planning would consider the possibilities of significant slumping/sliding in such areas as Torrey Pines Mesa, Soledad Mountain, the north slope of Mission Valley and Murphy Canyon, the canyon slopes around Otay Mesa, and (though less probable because of distance from the causative fault) La Mesa.

Ground Motion and Building Damage

The common characteristics of destructive earthquakes in California indicate that the seismic motions near the source generally consist of rapid and irregular oscillations with large amplitudes. Of considerable significance is the fact that earthquake waves change in character when they travel away from the source. Human observations, as well as seismographic records, show that the very rapid and violent ground oscillations (short-period motion) in the epicentral region are quickly damped, leaving principally the gentle, swaying motion (long-period motion) at large distances from the earthquake. 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 and harbors to oscillate with sometimes destructive effects.

Buildings respond differently to different kinds of ground motion which arrive at each building site. Each building has its own specific vibrational characteristics based on its initial stiffness. This initial stiffness is subject to change as damage and destruction to structural and non-structural systems occur. Each building will therefore respond to the particular ground motion at the site in a specific manner, and its response may significantly change during the duration of strong shaking if a degradation of the stiffening elements occurs. One important vibrational characteristic is 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 an earthquake, a case of quasi-resonance will occur, or a condition similar to near-resonance. As a result of this quasi-resonance or "sympathetic vibration," as the vibratory motions of the building may dramatically increase, along with damage. Damage from quasi-resonance is observed in taller buildings during distant large earthquakes.

Based on the changes in ground motions as a function of increasing distance, observed damage patterns tend to reverse with distance. Low, rigid building (short-period) damage predominates over high-rise (long-period) damage in the epicentral regions; the comparative damage patterns reverse at some distance with the degree of reversal being a function of increasing distance (all other factors being equal). In other words, at distances over 100 miles (for example), high-rise building damage may predominate over that of even poorly built one-story structures.
Short-Period Motion Effects

The historical damage patterns worldwide, which cover thousands of years of experience and thousands of earthquakes, are primarily associated with the short-period ground motions (i.e., rapid back-and-forth motions). Obviously, in earlier times the vast majority of structures were in the low, rigid category, which accounts for the long history of this class of structure. These would be expected to respond more to the short-period ground motion. Isoseismal maps for postulated earthquakes, such as those in this report, are generally based on short-period effects.

In general, light-mass structures perform much better than do the heavier-mass structures. Conceptually, this is because 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 force on the structure. Therefore, all other things being equal, a "heavy substantial" building of concrete or masonry which is not designed to be earthquake resistive is more likely to fail than a "flimsy" wood-frame structure. Countless cases of this are found throughout the historic record.

Long-Period Motion Effects

Long-period motion principally affects high-rise buildings. An excellent example of long-period effects is the 1952 Kern County, California, earthquake which resulted in numerous instances of non-structural 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 about 70 and 90 miles from the epicenter, respectively. Generally, the affected buildings were 10 to 12 stories high and had a measured natural period of vibration of one to two seconds, but buildings as low as six
stories were also damaged. (The currently numerous high-rise buildings of over 20 stories did not exist then.) More recently, the 1985 Mexican earthquake, which was centered 200 miles away from Mexico City, dramatically demonstrated this effect.

The 1964 Alaskan earthquake caused extensive damage to multi-story buildings in Anchorage, which was 75 miles from the epicenter and much farther from the center of energy release; low, rigid buildings did not suffer comparable shaking damage in Anchorage.

**Earthquake Resistive Design**

**History of Building Codes**

Prior to 1925 few, if any, buildings in California were designed specifically to resist earthquakes, although many benefitted from design for wind forces which afforded improved resistance to earthquake damage. San Diego was no exception in this regard.

In the years following the 1925 Santa Barbara, California earthquake, a few moderate-sized communities in California adopted building codes which required earthquake bracing. After the 1933 Long Beach earthquake, a number of southern California communities adopted these codes, with their usage spreading generally to northern California by 1950. The City of San Diego has had earthquake resistant requirements in its Building Code since February 21, 1939. Concurrently, improvement in research and design practices also led to substantially improved earthquake resistive construction. Recent earthquakes have clearly shown that earthquake resistive design methods are highly effective, and many case histories exist in the literature showing that most (not all) major structures can and do perform well. California public school buildings constructed after 1933 offer graphic evidence of the performance of well-designed and well-constructed structures. Since the 1933 Long Beach earthquake, public school buildings in California have suffered only approximately 1/30th of the dollar value damage as comparable commercial buildings of the same type and era of
Much of the success of California public school buildings can be attributed to the vigilant surveillance provided by school district inspectors during the construction period. The best of designs are worthless if the buildings are poorly or improperly constructed.

The intent of the earthquake resistive design as required by building codes is to protect life, and it is only partially directed toward damage control. (There are certain exceptions, such as code provisions for new hospitals in California since 1972 which are discussed in the next section.)

The basic philosophy behind the seismic provisions of most American building codes states that the code intends buildings to "Resist major earthquakes of the intensity of severity of the strongest experienced in California, without collapse, but with some structural as well as nonstructural damage." The code further states, "In most structures it is expected that structural damage, even in a major earthquake, could be limited to repairable damage." By using certain types of flexible, but "safe" construction systems in certain occupancies, such as hotels, a structure can suffer 50 percent property loss without serious structural damage. (Design for damage control usually includes life safety, but design for life safety -- i.e., minimum code standards -- does not necessarily include damage control.)

In most cases the earthquake provisions of a building code, plus the design engineer's judgment, determine the seismic damage characteristics of any particular building or structure. Expert advice may have been obtained from engineering geologists, seismologists, soils engineers, and others, but the design engineer must evaluate all reports and synthesize them into a judgment decision in the context of a (hopefully) good architectural design.

The Field Act, adopted within one month following the 1933 Long Beach earthquake, assigned regulatory powers over public school design and construction to a state agency. As previously noted, the resulting high standards, particularly noticeable in substantially improved construction standards, proved to be very successful as evident after the 1952 Kern
County and 1983 Coalinga earthquakes. The original Field Act applied only to new schools. With the passage of time, it became evident the older remaining schools continued to exist as major threats. In 1969, the Garrison Act was passed by the California Legislature to deal with the difficult task of hazard abatement. The legislation was subsequently amended and non-Field Act public schools are now essentially gone.

California’s Hospital Act of 1972, adopted as a result of the 1971 San Fernando earthquake, had significant implications in that damage control became mandatory when the State pre-empted new hospital construction from local control. Listing the technical details of this legislation and its implementation is not necessary other than to mention that the act followed the precepts of the Field Act for public schools plus the following statement which is of major significance:

Section 2. It is the intent of the Legislature that hospitals, which house patients having less than the capacity of normally healthy persons to protect themselves, and which must be completely functional to perform all necessary services to the public after a disaster, shall be designed and constructed to resist, insofar as practicable, the forces generated by earthquakes, gravity, and winds...

The intent of the legislation does not state that the hospital must remain "undamaged," but it must remain "functional" to perform all necessary services.

Immediately following the 1971 San Fernando earthquake, the California Department of Transportation instituted emergency load factor increases to their seismic design provisions. Prior to 1979, the seismic design provisions for highway bridges was minimal. The State also embarked on an ongoing program for seismic upgrading of existing bridges that is still underway.
Considerations for Planners

Most of the larger governmental agencies and private corporations have disaster response plans which include priority arrangements for the use of temporarily leased equipment, such as bulldozers. In each case, the agency or corporation has stated that it expects the contractor will supply required equipment upon demand after an earthquake. This probably is true under "ordinary" emergency conditions. On the other hand, a response planner may wish to examine this carefully to verify that suppliers do not have similar contracts with several agencies/corporations which, in effect, "overbooks" their equipment. There is, of course, alternate planning which involves the Association of General Contractors.

Earthquake bracing will be found lacking in most major computer installations in all occupancies. In far too many cases, the bracing of false floors, air conditioning vital for continued operation, back-up power, and other equipment is deficient. Unless the response planner has specific information to the contrary, the system should be held suspect.
Section 3.

BUILDINGS
HOSPITALS IN THE SAN DIEGO AREA

Emphasis

The principal concerns addressed in this planning scenario relate to the earthquake vulnerability of the major transportation and utility lifelines. However, disaster response planners, when allocating priorities, must give highest attention to saving lives. Hospital buildings are essential in this regard, as are their personnel and other medical resources, including medical supplies and equipment both on-site and in warehouses, blood bank structures and their contents, clinical laboratories, ambulance services, and nursing homes.

A major general acute-care hospital is defined here as a facility having a patient capacity of 99 beds or more. Inventory is limited to the 29 major facilities in the San Diego and Tijuana areas. More complete inventories may be found in "Health Facilities Directory, July 1985" (the latest edition available) by the California Department of Health Services, Licensing and Certification Division, and in "Emergency Medical Service Resource Directory," published by the bi-national Emergency Medical Care Committee of the California/Baja California Health Council. The majority of the San Diego acute-care hospitals are generally distributed along or near three major arterials (I-5 and I-8 and State Highway 163).

The San Diego area contains about 7,000 acute-care hospital beds. Tijuana has about 1,130 hospital and clinic beds, 749 of which are in hospitals with more than 25 beds each. These totals change as obsolete facilities are closed and remodeling or new construction of other hospitals is completed. In San Diego, a large percentage of the new hospitals constructed under the Hospital Act of 1972 utilizes a structural steel framing system, and some are limited to four or five stories in height.
There are a few acute-care facilities that contain less than a 99 bed capacity; they were not part of this review. These facilities will face problems similar to those of the larger facilities described in this section.

Seismic Considerations

The San Fernando earthquake of 1971, in which four major hospital buildings were severely damaged and mostly evacuated, indicates that many hospital facilities constructed prior to the passage of the Hospital Act could be subject to severe damage during a major earthquake. It is not unrealistic to consider that a major hospital may become an added burden rather than an asset in the post-earthquake period.

Another important consideration is access to and egress from hospital sites. Even though the buildings may survive, the facility may be of limited value if access is cut off or restricted because of a landslide, a collapsed freeway structure, or building debris on nearby streets.

Hospitals are also dependent on off-site public utilities for long-term continuous operations. Hospitals do maintain emergency electric generators, but such systems can only meet demands on a limited basis for a limited time. Routinely scheduled maintenance and testing of all emergency equipment is essential to ensure that the equipment will be operational when needed.

Modern hospitals contain a variety of highly complex electronic monitoring and test equipment and laboratory supplies. These items commonly rest on tables or racks and are highly vulnerable to damage by strong shaking. Consequently, even though hospital buildings may escape structural damage, effectiveness of the facility can be greatly reduced by damage to the contents.
In the San Diego area, there are only two acute-care hospitals within one mile of the assumed fault rupture of this scenario event. Both of these facilities were constructed prior to 1972. These two facilities are relatively small, containing a total of only 291 beds. Both contain damage-vulnerable structural features. The fault zone passes close to one site and the northern end of the fault zone terminates near the other site.

Consideration of hospitals within two miles of the assumed fault zone would encompass three more acute-care hospitals, one of which is the new Balboa Naval Hospital. The other two are major base hospitals (one with helicopter access), which also serve as trauma centers. These three additional hospitals are near the northern end of the fault where ground shaking is not expected to be as severe as regions near the middle portion of the zone. Of the 1,303 hospital beds within two miles of the scenario fault, 600 are in the new Balboa Naval Hospital.

Planning Considerations

This scenario postulates that hospital structures near (within one mile) the assumed fault rupture will be evacuated, although ample experience shows that these structures can survive quite well, even when located adjacent to surface fault rupture. For the scenario event in San Diego, the impact on the public welfare would be relatively small since only two hospitals and a low bed count are involved. Appropriate studies and resulting actions such as those taken at the Fairmont Hospital in Alameda County, northern California, could be undertaken for hospitals in the San Diego area (and the results made public). Mitigating the hazards at a particular site should include methods to maintain utility services and also consideration of alternative access routes.
Another effective way of examining the potential loss of facilities is to estimate the loss of hospital beds instead of considering only potential building damage. A slightly damaged building evacuated for psychological or liability reasons results in a critical loss of hospital beds just as effectively as severe structural damage.

Planners should review operational capabilities of hospital facilities from at least these six viewpoints:

1. Loss of life and injuries to personnel and patients.
2. Physical damage to the building.
3. Loss of medical supplies and equipment.
4. Loss of hospital function because of disrupted utility services or access problems.
5. Evacuation of hospitals adjacent to major surface faulting due to public loss of confidence for whatever reasons.
6. Evacuation of hospitals located in other areas at risk (liquefaction, landslide, or in an inundation area downstream from a major dam) due to loss of public confidence.

Planning Scenario

For planning purposes, the two hospitals, with 287 beds, located within one mile of the scenario fault rupture are assumed to be seriously damaged with patients transferred elsewhere.

Facilities near areas of high and very high liquefaction susceptibility will have access problems related to local road failures and massive traffic jams. This will greatly inhibit the capability of rescue vehicles to reach damage sites or return to hospitals, especially in the Mission Bay and Loma Portal areas, and the San Diego Bay margins. (Hospitals in those areas should not be seriously damaged.)
Three major hospitals, two trauma centers located in the Hillcrest area of San Diego, and another in the Telegraph Canyon area of Chula Vista, have steep inaccessible canyon areas around significant portions of the sites. Slides may restrict access to and egress from these major facilities.

Although SDG&E foresees few major electrical problems, hospitals around Mission Bay and Lorna Portal will be without power immediately after the scenario earthquake. For planning purposes, they will have to rely on emergency power for four days.

Almost without exception, hospital facilities need to review their anchorage of liquid oxygen tanks stored on the sites. The contents of these tanks act as a synthesizer and can react explosively with other elements. This will result in evacuation of one facility for 48 hours.
PUBLIC SCHOOLS

General Characteristics

According to the "California Public School Directory 1987," published by the California State Department of Education, there are 48 public school districts in San Diego County including community college districts. The largest has an enrollment of 111,198 pupils and the smallest 32. Enrollment of all schools totals 442,265 students.

Public school buildings are reasonably well distributed throughout populated areas. The distribution in the region south of Miramar Naval Air Station is fairly dense, while north of the station, there is a more widely scattered distribution. Public school buildings will generally be found to be in a safe condition after an earthquake. As a result, these structures can provide a major resource for mass shelter and feeding for those whose homes are destroyed or otherwise rendered uninhabitable.

While this discussion is directed towards public schools, the general remarks and scenario are generally applicable to private schools designed and constructed to Field Act standards. Seismic safety standards for new private schools built since 1933 were, in some cases, the same as those mandated to be used by public schools. This most likely would not be true for older or leased buildings, and probably not true for churches used as schools.

Maps 4-J and 4-U show the locations of intermediate schools, high schools, community colleges, and universities in the San Diego planning area. Elementary schools are too numerous to plot on maps of this scale.
Seismic Considerations

As discussed in a previous section, public schools have been given special legislative attention with respect to earthquake safety since the 1933 Long Beach earthquake. This legislation, commonly known as the Field Act, has been successfully implemented through strictly enforced design and construction practices.

Public schools constructed under the Field Act have performed well in all earthquakes. The performance of public schools has been far better than that of 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. Damage of varying degrees occurred to several schools in the 1971 San Fernando earthquake. Structural damage also occurred at the West Hills Community College in Coalinga as a result of the 1983 Coalinga earthquake (Meehan, 1983). In no case was there a major life hazard, and costs of repair were a small fraction of the buildings' value. Experience shows that damage can occur to Field Act schools, and these buildings will not be usable until repairs are completed.

The seismic design provisions of building codes, including those for school buildings, have been considerably improved over the half century since the Field Act became effective. 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. Even so, the overall performance of public schools will continue to be excellent.
Planning Considerations

Schools represent a substantial school age population at risk. Regardless of the state of structural damage to school buildings, nonstructural damage and lack of utilities will cause many to close following the event. Here again, access will be a major problem for school administrators and emergency response personnel in the area along the coast between Pacific Beach and Imperial Beach. Road closures (particularly I-5) will limit parents’ abilities to get to the schools from their work places. Schools should consider alternative plans for care of students for several hours following the scenario earthquake.

A conflicting use of undamaged school buildings is as mass-care centers. Those schools located in the areas of highest damage, with their students unable to leave, are the most logical choices for local evacuation centers, casualty collection points, incident command centers, and so forth. Road closures may prevent immediate use of the unaffected schools more distant from the fault. Emergency response personnel should have plans for examination of sites designated as mass care centers and should develop contingency plans for the students as well as general public in the areas of greatest potential damage.

Planning Scenario

Almost all schools in the metropolitan area south of Pacific Beach and Mission Valley plus those in El Cajon-Santee are within areas of MMI VIII or greater. In the older sections of this area within intensity VIII+ or IX, schools will find considerable damage around them. Schools in downtown San Diego are within one mile of the assumed fault rupture. In South Bay, one elementary and one secondary school are within an area of high liquefaction susceptibility. Between Coronado and Pacific Beach, two elementary schools and one secondary school are within areas of very high liquefaction susceptibility. Even if the schools are relatively undamaged, liquefaction effects to roads and highways may virtually isolate the schools within the local area.
All wood-frame public schools are expected to survive without major structural damage and to be safe for emergency uses. These are usually one-story elementary schools. There may be functional restrictions because of disrupted utilities (water, gas, power, and sewer), broken windows, fallen ceiling tile, jammed doors, overturned bookcases, and similar effects to 10 percent of the classrooms within ten miles of the assumed fault rupture.

Structures that are two or more stories high are often of reinforced concrete or other masonry wall construction. Shortly after the event, these structures should be inspected by professional engineers and architects before occupancy is allowed on any long-term basis, with occupancy delayed if any significant cracking is found. There may be access problems for those located along the coastal strip from Pacific Beach to the international border.
POLICE AND FIRE FACILITIES

General Considerations

Local fire and law enforcement personnel are the primary initial emergency responders. The lifeline needs of emergency response personnel in meeting the demands placed upon responders by a damaging earthquake is one of the primary rationales for the development of earthquake planning scenarios. In this section, the potential impact of the planning earthquake on the fire and law enforcement facilities themselves is reviewed.

In general, police and fire stations have performed very well during recent California earthquakes. Following the February 9, 1971, San Fernando earthquake (M6.4), three (Los Angeles County) fire stations were damaged to the extent that demolition of the structures was necessary (Steinbrugge and others, 1971). One, on the grounds of Olive View Hospital, was constructed in 1926. None of the buildings collapsed or otherwise prevented response. The Sheriff’s station at Newhall lost both electrical power and telephone service, but three stations there received little or no damage (Olson, 1973). Neither the 1979 Imperial Valley (M6.6), the 1983 Coalinga (M6.7), nor the 1984 Morgan Hill (M6.2) earthquakes severely damaged local "essential" facilities.

Even though buildings may not collapse, response can be impeded by structural damage and nonstructural effects. For example, in 1971 "at the Olive View Hospital station, all on-duty firemen were thrown from their beds, were hit by flying articles and falling plaster and sustained cuts, scratches, and minor bruises. It was not until about 6:30 a.m. (1/2 hour after the earthquake), however, before the pumper could be taken out of the building, following removal of obstructing debris (including the hospital’s fire alarm control panel) and freeing of the apparatus floor door" (from Steinbrugge and others, 1971). A number of apparatus
rooms experienced problems, such as binding of rollers with guides, failure of a door retraction spring, and general binding as well as doors damaged by sliding automotive apparatus.

Unlike hospitals, there was no State mandate that police and fire stations remain functional following an earthquake until January 1986. Until the 1976 edition of the Uniform Building Code (UBC), no special considerations were recommended for essential facilities. Even so, the lag time for adoption by many jurisdictions of a specific edition of the UBC may be three or more years. Therefore, realistically, facilities constructed prior to 1979 probably were designed for less stringent criteria. They could be treated as general commercial buildings. Unless a city or county required special seismic design, all comments in the previous section on general buildings apply to police and fire stations.

The 1976 and subsequent versions of the UBC, once adopted by local jurisdictions, require that essential facilities, including police and fire stations, be designed with a 50 percent increase in the prescribed lateral force level over the minimum requirements for non-essential facilities. This increase in force level is primarily aimed at increasing the factor of safety and that the building will remain operational for emergency services when subjected to ground shaking of the level anticipated by the codes. Functioning of the buildings may still be impeded or prevented by structural or nonstructural damage, loss of utilities, or communications. Adherence to UBC guidelines does not guarantee the functioning of an essential facility following a large damaging earthquake, but it will increase the probability that the facility will remain operational. Emergency power, functioning of communications systems, and the abilities to get vehicles from structures are of primary importance.
General Characteristics

Police, sheriff, and fire stations are relatively evenly distributed throughout the metropolitan area. Map 4-LF shows the locations of the 113 fire stations and the 23 police/sheriff stations in the study area. The City of San Diego accounts for 41 of the fire stations. The oldest of the fire stations was constructed in 1913 and the newest in 1982. Nine stations were constructed prior to 1954. Only six of the stations were constructed after 1978 or later. The City of San Diego’s central communications center for both fire and police is located in the City Operations Building (constructed in 1971 to the requirements of the 1967 UBC); the mobile communications van for the Fire Department is housed in this same facility. Seismic intensity at the site from the scenario earthquake is MMI VIII.

Seismic Considerations

As stated above, police and fire stations have generally performed very well during recent, moderately damaging earthquakes in California. Actual structural performance will depend on type and date of construction as well as ground shaking level, liquefaction susceptibility, and local landslide susceptibility. Table 3 lists the number of law enforcement and fire stations which will be subjected to various levels of shaking and liquefaction.
TABLE 3
NUMBERS OF LAW ENFORCEMENT AND FIRE STATIONS
IN AREAS OF HIGH POTENTIAL DAMAGE

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Law</th>
<th>Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquefaction Susceptibility</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Shaking Intensity IX</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Shaking Intensity VIII+</td>
<td>7</td>
<td>32</td>
</tr>
<tr>
<td>Shaking Intensity VIII-</td>
<td>3</td>
<td>8</td>
</tr>
</tbody>
</table>

NOTE: Stations may be included in both an area of liquefaction susceptibility and strong shaking.

Planning Considerations

Three factors to be considered in planning are:

1. Damage can render a law enforcement/fire facility unusable and possibly in need of emergency response itself. The latter is not very likely. However, stations in areas of very high and high liquefaction susceptibility may be significantly damaged.

2. Structural damage may not be significant, but nonstructural damage may render stations nonfunctional. Stations located in areas of very high and high liquefaction susceptibility and/or in areas of shaking intensity VIII or IX may not be able to immediately respond to local emergencies due to lack of communications or due to delays in getting the apparatus from the building. Radios in the units can be used, but base station and telephone communications with the public may be inoperative.
3. The stations themselves may be relatively undamaged (the most likely scenario), but travel throughout the local area may be limited by debris, damaged roadbeds, and so forth.

Planning Scenario

For planning purposes, all law enforcement and fire stations in areas of very high and high liquefaction susceptibility within four miles of the scenario earthquake fault rupture are assumed to be seriously damaged. Other fire stations located in areas of intensity VIII are assumed to have suffered some diminished response capabilities. Damage there will not prevent response, but jammed doors, fallen tiles or bricks, or lack of communication with the public will delay response time from 30 minutes up to two hours. Other fire stations and police/sheriff stations are assumed to be undamaged and able to respond to calls. (See Highways scenario for a discussion of access problems.) Police and sheriff reserves will provide an additional source of manpower.
SAN DIEGO BORDER STATION

General Characteristics

The Border Station at San Ysidro is the main port of entry between Tijuana and the United States. This station operates in conjunction with the Border Station at Otay, which is located five miles to the east.

The San Ysidro Border Station houses Customs, Immigration, Department of Agriculture, U.S. Navy Shore Patrol, Drug Enforcement Agency, and the International Boundary and Water Commission. It is the principal port of entry from Mexico for pedestrian and automobile traffic. The station presently operates at about 70 percent capacity for automobiles (normally 16 to 24 primary inspection lanes are used). Truck traffic is primarily handled at the Otay Border crossing. The building and related facilities are maintained by the General Services Administration.

The San Ysidro Border Station consists of four primary elements. They are as follows:

1. Main building, constructed in 1972.
3. Old Port of Entry Building, constructed in 1932.
4. Outlying buildings to the west of the principal border station facility - recently installed, moveable temporary structures.

The Border Station services vehicular and pedestrian traffic arriving at the border area from the I-5 and the I-805 to the north and through the principal access roads from Tijuana from the south. Ten million vehicles and 35 million people cross the border yearly at this point. Five overpass bridges cross over I-5 and I-805 in the immediate vicinity.
Seismic Considerations

The main building on the California side is a large structure with an irregular plan. The main office section of the building spans the automobile inspection lanes below. A two-story mechanical building section at the east end of the complex houses the SDG&E transformer which was not anchored to the foundation. Natural gas boilers are used for the heating system and hot water; these were not anchored to their foundation. On the roof of the mechanical building are chillers for the air conditioning system and emergency diesel-powered generators for use in case of loss of power from SDG&E. Both the chillers and the emergency power unit had no provisions for preventing the shifting of equipment during strong shaking.

On the northerly side of the main office building is a pedestrian bridge which spans the southbound traffic lanes.

The reinspection sheds are two large open-sided, steel-frame structures, and the outlying office structures are two modular temporary buildings. The Old Port of Entry Building was built in 1932 and continues in use even though most of its functions are supposed to be assumed by the main building constructed in 1972. The old building, recently refurbished, is a two-story structure with a Spanish tile, wood-frame roof, wood floors, steel columns, and exterior walls of unreinforced brick masonry.

For the scenario earthquake, the San Ysidro Border Station is located in an area of shaking intensity VIII. It is in the Tia Juana River Valley and is located in an area susceptible to liquefaction. If serious settlement or distortion of the building takes place due to the liquefaction, the station would be out of use for extensive repairs and/or reconstruction. This closure could be from six months to one year.
In the event of loss of power from SDG&E, the station would be dependent upon its emergency generator, which is inadequately anchored for resistance to strong ground shaking. The potential exists for the building to lack electric power, except for the battery-supplied communication system. For planning purposes, the station will be unable to function for 72 hours, pending restoration of power.

The Old Port of Entry Building, with its unreinforced brick-wall construction, is subject to complete destruction under the design earthquake. It is also subject to damage from liquefaction-induced settlement and distortion.

The reinspection sheds and outlying office structures are both of light construction. These are types which have performed well in past seismic events.

**Planning Scenario**

Access to the Border Station from the California side will be restricted. If one of the five overpasses on I-5 or I-80S is significantly damaged because of severe ground shaking or liquefaction in the immediate area, traffic will be severely limited at the border crossing for up to five days.

Buildings at the Border Station will be severely damaged. Unreinforced masonry walls of the Old Port of Entry Building will suffer major structural damage or collapse and the building will be evacuated. For planning purposes, the pedestrian bridge which spans the traffic lanes will be damaged and out of service for six months. Loss of electric power from SDG&E will occur. Emergency power generators on the site will not function. Limited power supply will not be restored for 72 hours.
Because of severe damage to the complex set of buildings, restricted access, lack of power and utility services, and loss of back-up emergency electric power, for planning purposes the San Ysidro Border Station will be closed for at least three days for all but emergency use. Damage assessment and clean-up at the site will take ten days to complete after which time the Border Station will resume partial function at 50 percent capacity for six months and 80 percent for eight months before normal operations are restored.
Section 4.

TRANSPORTATION LIFELINES
AIRPORTS

General Characteristics

Map 4-HA shows the location of airports in the San Diego area.

The major commercial airports in the planning area are as follows:

San Diego International (Lindbergh Field +*)
Tijuana International (General Rodriguez +*)

Secondary airports include:
Brown Field +
Gillespie Field +
McClelland - Palomar
Montgomery Field
Oceanside Municipal
Ramona

Military airports are as follows:
Naval Air Station, Miramar +*
Naval Air Station, North Island +*
Naval Air Station, Imperial Beach

Those airports with runways capable of supporting C-130 aircraft (requiring at least 5,000 feet of runway and pavement strength to withstand 130,000 pounds wheel weight (dual tandem) are indicated as +. Those capable of supporting C-141 aircraft (at least 5,000 feet of runway and sufficient pavement strength to withstand 250,000 pounds wheel weight, (dual tandem) are indicated as *.
San Diego International Airport

There is only one major commercial airport in the area (north of the Border) namely, the San Diego International Airport (Lindbergh Field). This airport currently handles approximately 11 million passengers per year, averaging 30,000 passengers per day. Fifty airline passenger planes usually are parked overnight at the airport.

San Diego International Airport is located only two miles from the center of the downtown business district. On its north, east, and west sides it is surrounded by densely populated military, commercial, and residential development, and its south side is adjacent to San Diego Bay. It is owned and operated by the San Diego Unified Port District.

The San Diego International Airport is served by two underground SDG&E feeders, one from the north and one from the south. These feeders are interconnected so that one will function in the case of the loss of the other. The alternate power system has been used successfully at least twice during 1988. Gasoline and diesel power emergency generators are maintained for servicing the control tower and navigational aids. These generators are supplemented by two battery-operated emergency systems for the runway, taxiway, and apron lights, which can sustain them at full power for 90 minutes. There is no provision for emergency power to the terminal building, other than for corridor and exit lights. If power is lost, major problems would exist in operating the airport, including handling baggage, operating computers at airline ticket counters and rental car counters, and providing lighting during night operations in the terminal area.

The aircraft fuel usage currently is approximately 380,000 gallons per day. There is less than 24 hours of on-site fuel supply available for normal operations. Part of this supply is in five oil company-owned underground tanks which would require electrical power for pumping into trucks. The remainder of the inventory is carried in the aircraft fueling trucks. There is no aviation fuel pipeline serving the airport. All fuel is brought in by tank truck.
Brown Field Municipal Airport

This airport, owned by the City of San Diego, is presently planned for intensive emergency use if Lindbergh Field is out of commission for an extended period. Brown Field is located 18 miles by freeway south and east of the central San Diego business district. It is approximately 1 1/2 miles north of the Mexican border and is two miles directly north of the Tijuana International Airport. The main runway is approximately 8,000 feet long and can handle commercial aircraft.

The majority of the area surrounding the airport is open country. Clear and approach zones are free of obstructions. Weather is generally good except in the late spring (low cloud cover). However, Brown Field’s proximity to Imperial Beach Naval Air Station on the west and to Mexican airspace and the Tijuana International Airport on the south imposes traffic pattern restrictions. Additionally, the San Ysidro Mountains to the east of Brown Field might restrict straight-in landings. Additional manpower and equipment would have to be provided for Brown Field to be effective in a disaster situation.

Secondary Airports

There are two small general aviation airports in the San Diego area which may play a small, but significant role in the event of the postulated earthquake, but additional manpower and equipment support would need to be brought in so that they could operate effectively. These airports are not capable of handling large commercial aircraft. These airports are described as follows:
Montgomery Field

Montgomery Field is located approximately seven miles north of the City of San Diego’s central business district. The airport is owned and operated by the City of San Diego, and it serves business and recreational flying demands from the central San Diego area. Its two principal runways are 3,400 feet long.

Montgomery Field is served by I-805 and State Highway 163 adjacent to the west side of the field. Interstate 15 lies one mile east of the field. Interstate 8 lies two miles to the south of the airfield. The field is surrounded by four-lane roads that connect with the local street network of San Diego.

Montgomery Field is on a mesa above the city at an elevation of 434 feet. The surrounding terrain is level and does not present any serious obstructions. However, there is a marked power line, several small poles, antennas, and buildings within 2,000 feet of the runways which do affect the approach paths.

The proximity of Miramar Naval Air Station (NAS) is the principal physical restraint to the operations at Montgomery Field. Miramar NAS lies four miles north of the field and has a large number of military aircraft operations. To avoid conflict, Montgomery’s flight patterns are restricted to turning south and away from Miramar.

Gillespie Field

This airport is located approximately 14 miles northeast of San Diego’s central business district. Gillespie Field was originally a World War II airfield, leased by the County in 1947 and acquired in 1953. Its principal runway is 5,340 feet long, and it is asphalt paved.
Gillespie is within two miles of the major east-west freeway, I-8. State Highway 67 borders the east side of the field and connects to I-8. Local access is on improved arterials bordering the east and west sides of the field. A railroad spur terminates at the southeast corner of the field.

Gillespie Field is situated in the El Cajon Valley, with hills to the west and northeast. Although these hills do not directly interfere with the glide slope approach or clear zone, they are marked and lighted for safety reasons.

**Seismic Considerations**

Earthquake problems related to airports can be placed into one of three general categories:

1. Ground access to and egress from the airport.
2. Damage to buildings (including control towers and to non-runway facilities).
3. Damage to runways and access to the airport.

Even if an airport remains completely functional, it would become virtually useless as a resource if it were not accessible. Ground transportation access to and egress from the facility normally involve highway overpasses, underpasses, interchanges, and other bridge-type structures. Damage to or collapse of these types of structures could seriously impair the airport accessibility.
Access and Egress

A. San Diego International Airport

The principal route to the San Diego International Airport terminals is by I-5 with off-ramps that lead to Laurel Street. Laurel Street runs north-south, intersecting Harbor Drive, which is on the southerly border of the airfield. Harbor Drive leads to the terminal. A secondary access to the airport is by a system of streets on Point Loma or the Loma Portal area, which leads to Harbor Drive, thus providing access to the terminal from the west. Several bridges and underpasses are involved on both of these access routes. Emergency access could be provided to the airport through the Marine Corps Recruit Depot at the north end of the airfield, or from several points on the east side of the airfield adjacent to Pacific Highway. Bridge and underpass failures are potential sources of short-term access problems to the San Diego International Airport. Except for most vital services, it is postulated that there will be no access to the airport via I-5 or Harbor Drive for ten days after the earthquake due to bridge damage.

B. Brown Field

Narrow secondary roads could accommodate limited traffic. For planning purposes there will be limited access via single-lane detours from I-805 for ten days after the earthquake.
Non-Runway Damage

The East Terminal Building of San Diego International Airport, built in 1967, is of earthquake-resistant design, but incorporates structural features which are no longer permitted because of poor performance in recent earthquakes. The main portion of the building is founded on spread footings, and the building is potentially subject to extensive damage due to liquefaction of the supporting soils.

The newer West Terminal Building, which went into service in 1978, is also located in a potential liquefaction zone. The baggage claim area and lower concourse of this facility are formed on spread footings. The main terminal structure, however, is founded on a system of piles.

The control tower is a steel-frame structure of good seismic resistant design. The tower is vulnerable to power outage. Also, it faces possible loss of its emergency generator which is not anchored for resistance to ground shaking. Damage is expected to the batteries for starting the generator, which are mounted in unbraced racks.

Emergency power for the airfield is provided in two locations. A battery back-up station for the apron is located in the ground floor of the West Terminal. It has the capacity to maintain service for 90 minutes. Batteries are contained in metal cabinets, which are lightly bolted to the concrete floor. A back-up station for the runway and taxiway lights is located in a small metal building adjacent to the electrical vault on the south side of the field next to the Teledyne Ryan plant. These batteries are contained in cabinets, which are securely anchored for resistance to lateral forces. However, the 480V Primary Transformer in the adjacent vault is spring-mounted and subject to failure of its anchorage to the foundation.
For planning purposes, the airport will be without power from SDG&E ten days. Also the battery-operated emergency power will be inoperative due to overturning or displacement of battery racks and transformers.

**Runway Damage**

Ample experience shows that airports can remain functional (at least to some degree) even if the control tower has collapsed or equipment within it becomes nonfunctional, provided the runways remain intact.

Runway damage can render an airport inoperable for substantial periods of time. Runway damage is a direct function of the strength of the underlying soils and their potential for liquefaction. Federal Aviation Administration (FAA) Regulations require closing of runways if there is a break in the pavement three inches wide. Even this wide a crack would be unacceptable at some places on the runway. Major differential settlements are a distinct possibility for the runways at the San Diego International Airport, since it is located in a zone of very high liquefaction susceptibility. The repairs could require 72 hours, during which the airport would be inoperable.

**Planning Considerations**

Air transport will play a vital role in moving people and material to and from the stricken areas, and in search and rescue, damage assessment, and other immediate response efforts. Integrating delivery systems within the damaged area, however, will be challenging. Selection of air cargo delivery sites will influence the manner in which off-loaded personnel and supplies will be distributed by helicopters, highway, rail, or marine transport. A working agreement with the Navy needs to be made in order that military airfields will be available for emergency use.
Use of helicopters within heavily damaged areas is seen as an extremely important function requiring appropriate planning. Emergency planners should also consider identifying segments of certain strategic surface routes that are free of bridges for the development of emergency access routes to the airport.

**Planning Scenario**

For planning purposes, San Diego International Airport will be closed for all but emergency or vital operations for 48 to 72 hours due to strong shaking and liquefaction affecting runways, accessibility, electric power supply, and damage to the East Terminal Building. If liquefaction-induced damage is severe, however, closure of up to two weeks may be necessary.

For planning purposes, accessibility by way of Harbor Drive and the overpass entrance to the airport will be impaired for 72 hours because of ground failure. Alternate access routes will have to be developed.

Electric power to the airport will be unavailable for ten days because of damage due to ground failure along the feeder line routes. Electric power impairment will affect the pumping of aircraft fuel from the underground storage tanks. For planning purposes, two of the five storage tanks available will be out of service, so it will be necessary to bring in fuel by tank truck to fuel airplanes directly.

Four major airports in the planning area are capable of providing the 5,000 feet of undamaged runway necessary for the landing of C-130 and C-141 aircraft. Two of the four, namely San Diego International Airport and the Naval Air Station at North Island, are in zones of heavy damage and potential liquefaction. The two other major airports (Brown Field and Miramar Naval Air Station) are located in areas not subject to liquefaction where predicted shaking will produce minimal damage. In general, then, only these latter two
major airports will be capable of handling emergency response operations. Performance of the lifeline systems necessary for airport operations will be critical. The success of air operations will be more dependent upon electrical power, fuel handling, and survival of critical buildings than upon the direct effects of the earthquake.

Damage Assessments

Damage assessments have been postulated for certain airport facilities. The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map 4-HA.
# MAP NOTATIONS

<table>
<thead>
<tr>
<th>MAP NO.</th>
<th>AIRPORT</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td>SAN DIEGO INTERNATIONAL AIRPORT (Lindbergh Field)</td>
<td>Closed. Large portions of the runway and taxiways are located on hydraulic fill and on old marine deposits of depths to 100 feet. Liquefaction is a distinct possibility.</td>
</tr>
<tr>
<td>A-2</td>
<td>NORTH ISLAND NAVAL AIR STATION</td>
<td>Limited Operation, but access extremely limited.</td>
</tr>
<tr>
<td>A-3</td>
<td>MONTGOMERY FIELD</td>
<td>Limited Use</td>
</tr>
<tr>
<td>A-4</td>
<td>GILLESPE FIELD</td>
<td>Limited Use</td>
</tr>
<tr>
<td>A-5</td>
<td>BROWN FIELD MUNICIPAL AIRPORT</td>
<td>Open</td>
</tr>
<tr>
<td>A-6</td>
<td>IMPERIAL BEACH NAVAL AIR STATION</td>
<td>Limited Use</td>
</tr>
<tr>
<td>A-7</td>
<td>TIJUANA INTERNATIONAL AIRPORT</td>
<td>Open</td>
</tr>
<tr>
<td>A-8</td>
<td>MIRAMAR NAVAL AIR STATION</td>
<td>Open</td>
</tr>
</tbody>
</table>
HIGHPWAYS

General Characteristics

The major corridors of highway traffic in the San Diego area are as follows:

- Two major east-west routes: I-8 and State Highway 94.

Interstate 5 and I-15 lead into the area from the north. Interstate 5 leads to the Mexican border on the south and passes by both Mission Bay and San Diego Bay. Interstate 8 is the primary access to points to the east. Interstate 805 provides an alternative north-south corridor east of I-5. There are several alternative surface streets which can be used to bypass portions of the freeways, but primary access to the portion of the city west of I-5 in the Mission and San Diego Bay areas is limited to a few critical corridors. Some city maintained bridges occur along these corridors.

Seismic Considerations

Over 115 miles of State highways and over 500 State bridges in the southern San Diego area will be shaken with MMI of VIII or greater from the scenario event. A recent Federal highway study (Vulnerability of Transportation Systems to Earthquakes -- U.S., FHWA/RD-81/128, October, 1982) considers MM intensity VIII to IX to be the threshold of critical damage to highways.

As a result of the 1971 San Fernando earthquake, approximately six of the 60 damaged bridges either collapsed or were so badly damaged that repair was not feasible. Subsequently CalTrans implemented design criteria and details for bridges which resulted in significantly higher seismic resistance. The changes included very significant changes in force level (prior
to 1971, the lateral force coefficients used by the Bridge Department varied from a low of two percent to a high of 13 percent; during this same period, the Japanese Code lateral force coefficients varied from a low of 15 percent to a high of 35 percent. Additional detailing requirements, especially relative to confinement requirements for reinforced concrete columns and additional restraint at hinge seats, provided needed toughness and increased factors of safety. Also, increased emphasis was placed on non-redundant systems such as single column bents. This dramatic change in design means that bridges built after 1971 have considerably greater seismic resistance than bridges built earlier, and most of the damage due to shaking will be in these older bridges. Prior to 1971, the seismic requirements of the Bridge Department were less stringent than current requirements, nevertheless, bridges tend to be fairly seismic resistant (compared to buildings).

Twenty-three City of San Diego maintained bridges along "lifeline" routes have been identified as requiring seismic upgrading. Thirteen of these bridges were selected for upgrading (where parallel conditions occurred). Eleven of the 13 bridges are already in the design process to retrofit them to current standards and the other two are expected to be put out for design in the very near future. The County of San Diego also has a program of partially upgrading some of its bridges. Six bridges are involved in the county program, but the anticipated level of retrofit will be less than that used by the city. It must be emphasized that a retrofit bridge which is heavily damaged, but not collapsed, may still be unusable for many days after an earthquake. Levels of acceptable risk could obviously be raised during periods of emergency to permit use of such facilities.

The magnitude of movements and settlements due to liquefaction and soil failures is difficult to predict, but based on experience with previous events, much of the anticipated damage is expected to be in the form of settlement of high fills and soils near streams and water. Many lengthy sections of freeway routes through the Mission Bay area and near the Mission Bay and San Diego Bay margins are subject to damage from ground failure.
Planning Considerations

Emergency planners need to identify major emergency corridors that can be most readily opened immediately following the earthquake. In contrast to some segments of the freeway system which are above or below grade with many structures subject to damage, alternative emergency routes should be selected which are at grade, wide, not likely to be significantly affected by fallen power lines or other obstructions, and not flanked by larger buildings that are likely to be damaged. Wherever possible, alternate corridors should be established so that flexibility is maximized.

The utilities and local government agencies should identify all installations and facilities that they will need to rapidly inspect, repair, operate, or otherwise access during the emergency. Emergency planners then need to examine available routes to these and other critical facilities, assess the potential for damage, and identify the most probable access routes. Critical facilities include communication centers, hospitals, airports, heliports, staging areas, fuel storage sites, and other locations essential to emergency response operations.

Emergency response plans for highways should be coordinated with those developed for air, rail, and marine transport to optimize plans for integrated transportation capability. Access to and travel within the stricken area will be difficult and will be limited to the highest emergency priorities.

Planning Scenario

In the southern San Diego area, along I-5 from Palm Avenue north across I-8 to Balboa Avenue, liquefaction has caused considerable settlements and distortions to pavements. The route is also blocked by a few damaged bridges and pavement breakage. Hundreds of vehicles are trapped and abandoned along I-5, especially in the Mission Bay and San Diego
Bay area. Gigantic traffic jams are present on all routes leading into the Mission Bay and San Diego Bay area. The San Diego-Coronado Bridge is undamaged but large fill settlements at the approaches prohibit access. Limited one-lane access to Coronado is available via the Silver Strand Highway. A few surface streets in the region along Mission Bay and San Diego Bay are blocked by fires and rubble. All nonessential, in-bound traffic to the region bordering Mission and San Diego bays is being held at checkpoints and is being redirected around the area. Outbound traffic moves with delays and detours on limited open arteries.

**Damage Assessments**

Damage assessments have been postulated for certain major highway facilities. The statements regarding the performance of facilities are hypothetical, intended for planning purposes only, and are generally pessimistic in overall effect. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map 4-HA. Routes not discussed may be assumed to be open with delays due to heavy traffic and obstructions.

**Interstate 5**

Interstate 5 is closed from Balboa Avenue south to Palm Avenue due to damage to several bridges and considerable approach pavement damage including several sections which have settled more than two feet. Limited emergency traffic with some detours may be restored in about 24 to 36 hours. Limited airport access through the area at Washington and Laurel streets can be obtained in about eight hours via surface streets. Many bridges along I-5 are heavily damaged but still standing. Some of the damaged bridges can carry light traffic (no trucks), but a few select bridges could be strengthened (or by-passed) to permit limited truck traffic to move in about 36 to 48 hours.
North from Balboa Avenue to I-805, I-5 traffic is generally open with a small one-lane detour around damaged bridges at the I-5/I-805 interchange. This detour cannot be improved in less than 72 hours.

North of the I-5/I-805 interchange to Oceanside, settlements of fill at stream crossings has temporarily blocked several bridges. Bridges at the San Diequito River, Batiquitos Lagoon (San Marcos Creek), Agua Hedionda Lagoon, and Buena Vista Lagoon have severe fill settlements although the bridges are undamaged. Local detours are not available as other stream crossings in the area have similar problems. This route cannot be opened within 72 hours; however, an all-out effort could possibly open the bridges to single-lane traffic in about 36 hours.

**Interstate 8**

Damage to I-8 is limited to the section west of and including the interchange with I-5. Severe damage at the I-8/I-5 interchange combined with heavy liquefaction damage will not permit any traffic to move through this portion of the route for at least 72 hours.

Interstate 8 to the east of I-5 is open with a small detour around some minor bridge damage at the I-8/State Highway 163 interchange. Traffic through this section is limited to one lane. It is not expected to be able to improve this situation in less than 72 hours.

**Interstate 15**

Damage to I-15 is limited to the area near the interchange with I-5. Moderate damage at the I-15/I-5 interchange combined with heavy liquefaction damage will not permit any traffic to move on this portion of the route for at least 48 hours. Interstate 15 is open to the north of the I-15/I-5 interchange.
**State Highway 75**

The San Diego-Coronado Bridge is undamaged but large settlements of the approach fills prohibit access. The Coronado Bridge probably cannot be opened before 72 hours; however, an all-out effort could possibly open the bridge to limited traffic in about 36 hours.

Limited one-lane access to Coronado is available via the Silver Strand Highway. Several settlements and pavement breakages exist along this route. Improved traffic capacity along the Silver Strand Highway can be established in about 24 hours.

**State Highway 163**

State Highway 163 to the north of I-5 is generally open with a short detour around some minor bridge damage at the I-8/State Highway 163 interchange. Traffic through this one section is limited to one lane. This situation probably cannot be improved in less than 72 hours.

**State Highway 209**

State Highway 209 to the south of I-5 is open except for major damage to the bridges and liquefaction in the State Highway 209/I-5 interchange. This connection cannot be opened within 72 hours.

**Interstate 805**

Interstate 805 traffic is open except for a short, single-lane detour around damaged bridges at the northern I-5/I-805 interchange and damage inspection of other bridges. This detour cannot be improved in less than 72 hours.
Other Roads

Damage to city and county streets generally parallels that to the State highway system. North to Encinitas, old Highway 101 is closed at each of the lagoons because of liquefaction of fills. Access to the north coastal communities is via State Highway 78 and Rancho Santa Fe. Highway 101 cannot be repaired within 72 hours. With considerable effort, Ardath Road could be opened to limited traffic in about 36 hours.

Sea World Drive, Mission Bay Drive, and Ingraham Street are closed due to liquefaction around Mission Bay. These will not be reopened within 72 hours.

Harbor Drive along the airport and Embarcadero is closed from liquefaction-induced slumping of fill.

The entrance to North Island across the "Spanish Bight" fill is initially closed but can be reopened within several hours by the Navy.

Route 117

Route 117 is generally open from I-5 to the Otay Border Crossing.

Roads in Mexico

An evaluation of the type conducted by CalTrans for State highways has not been undertaken for roads in Mexico. Based on knowledge of the geology and on past experiences in California, the following partial scenario can be assumed for response planning purposes only.
Roads within the Tia Juana River Valley are closed as a result of liquefaction and the collapse of a few overpasses. The most common failures will be from abutment movements and from settlement of approach fills at stream crossings. Border traffic can be routed across the Tia Juana River Channel at only a few places.

The Tijuana-Ensenada toll road (Route 1) is closed in several places. A large landslide blocks the road within the steep road cuts east of Playas de Tijuana. A number of slides and slumps have closed the road between Playas and Rosarito.

The Tijuana-Rosarito free road is generally open after small slides and roadbed slumps are repaired. There are major delays as all north-south traffic is routed to this road.
Figure 4. Marine terminals, San Diego Bay.
MARINE FACILITIES (PORTS)

General Characteristics

San Diego Bay is a landlocked crescent shaped bay about 14 miles long, and is considered to be one of the world’s great natural harbors. However, extensive port facilities, such as those in San Francisco and Long Beach, do not currently exist in San Diego. The port area under the jurisdiction of the San Diego Unified Port District includes corporate areas of the cities of San Diego, Chula Vista, Coronado, National City, and Imperial Beach. San Diego Bay is crossed by the San Diego-Coronado Bridge just south of the Tenth Avenue Marine Terminal. Approximately 2 1/3 miles of non-military berthing is available at the port facilities. They are located at three primary sites: B Street and Broadway Piers, Tenth Avenue Marine Terminal, and National City Marine Terminal.

The latter two terminal sites are served by the Atchison, Topeka and Santa Fe (ATSF) and the San Diego and Imperial Valley (SDIV) railroads. The SDIV was formerly the San Diego and Arizona Eastern (SD&AE) Railroad. The ATSF railroad facilities are more extensive, with a large switching yard located at the Tenth Avenue Terminal. The U.S.-Mexico border is located 16 km (10 miles) south of the National City Marine Terminal.

Virtually the entire port of San Diego is built on artificial fill. Extensive liquefaction-induced lateral spreading is possible all along the bay front. This will affect both structures built behind quaywalls and approaches (road and rail) to the dock area. The B Street Pier, which is a dredged-earth mole pier, was constructed in the early 1920’s in several phases. The Transit Shed Number 2 on the B Street Pier has been renovated to serve as a cruise ship terminal.
There is only one container rail-mounted crane in the entire San Diego harbor area. It is located at the National City Marine Terminal, and currently it is not in heavy use.

Tsunami waves within the harbor are not anticipated to be generated by the scenario event. Harbor surging, to date, has never been recorded to exceed the maximum tidal fluctuations. Nevertheless, oscillations (seiche) within the harbor, caused by the strong shaking, may damage boats moored to piers and quaywalls.

Seismic Considerations

The scenario fault crosses San Diego Bay along a zone extending from downtown San Diego through the southeast side of Coronado. The Tenth Avenue Marine Terminal is just east of the fault zone, and the B Street Broadway Piers are within one-half mile of the fault zone.

In addition, all three terminals are located in zones subject to major liquefaction and severe ground shaking intensity IX. Major portions of access/egress roads to the terminals, including I-5, and railroad lines and yards are located in similar high probable damage areas.

Experience from the 1906 San Francisco earthquake provides a basis for estimating the probable damage to port facilities. Damage patterns to equipment, such as rail-mounted cranes, can be judged from the 1964 Alaskan earthquake experience.

In 1906, the earthquake performance of the pile-supported docks along San Francisco's waterfront was excellent, although the soil in some of the nearby fills settled several feet. Pile-supported structures have generally performed well in earthquakes, with the major exceptions being due to submarine landslides such as at Seward, Alaska, in 1964. However, major submarine landslides are not expected in San Diego Bay. Damage to the B Street Pier can be expected since the piles for the apron wharf are too shallow to make it safe from...
settlement under conditions of liquefaction. In 1956, (M6.8, epicenter 50 miles east of Ensenada, Baja California) earthquake damage did occur to Transit Shed Number 2 on the B Street Pier. The damage, however, did not affect the structural integrity of the facility, and the concrete cracks were quickly repaired.

Quaywall structures have often failed in the past. Quaywalls are docks which generally consist of concrete bulkhead walls with earthen fills behind them. These earthen fills provide dock space. Most of the previous quaywall failures can be attributed to liquefaction. Also, there has been a significant amount of soil transport from behind some of the older quaywalls along San Diego Bay. This can further contribute to the potential for damage to quaywalls.

Overall, marine facilities are not expected to be greatly affected insofar as the pile-supported docks are concerned. Pipelines from storage tanks to docks will be ruptured where they cross areas of structurally poor ground in the vicinity of the docks. Ship bunker fuel tanks at the Tenth Avenue Marine Terminal are anticipated to suffer damage because of liquefaction, but this will not have any significant effect on marine operations.

Disruption of electric power to the port facilities will cause a severe problem for pierside marine operations. Restricted access to docks because of damage to freeways and nearby surface streets will be more common than significant damage to the pile-supported docks. In general, docks and crane operating areas are pile-supported, while storage and access areas are located on more vulnerable filled land.

Pile-supported docks and piers with the exception of the B Street Pier should fare well, but access problems may preclude their use during the initial post-earthquake period. For response planning purposes, it is assumed that the port facilities are completely unusable for three days (a conservative assumption). Under San Diego’s current level of utilization of non-military port facilities, the loss of port facilities will have only minimal impact on the public welfare.
Rail-mounted cranes, such as those used for containers, are often dislodged from their rails during an earthquake, but they do not turn over unless the supporting dock fails. These derailed cranes can be remounted on their rails by the use of jacks and other means, but skilled labor and time are involved. As indicated previously, there is only one rail-mounted crane in the entire harbor area.

Planning Considerations

The use of privately owned vessels in any near-coast evacuation effort is appropriate. Practical education, planning, and training programs to implement this participation should be considered by response planners.

The various roles that marine transport can assume in the emergency response efforts and the extent of marine transport resources should be determined. Locations with suitable land access (emergency routes) and loading capabilities that are most likely to be available for post-earthquake access to marine transport should be selected.

Use of port facilities outside the heavily damaged areas should be coordinated with ground transport to identify the most efficient means of transportation. The Harbor Police would coordinate emergency response measures for the Port District. Emergency mobile communications facilities (both land and sea) are available.

Planning Scenario

All port facilities are similarly affected. For planning purposes, they should not be relied on to receive supplies for several days following the scenario earthquake. Since the current utilization of non-military San Diego port facilities is rather limited, the impact will be small. After the initial emergency response period, lighter ramps and temporary roads to undamaged pile-supported piers to receive supplies could be considered by response planners.
For purposes of the planning scenario, widespread and serious damage should be anticipated. Approximately 50 percent of the access routes and facilities should be considered unusable for 14 days. Less accessible alternate surface routes will be required. The crane at the National City Marine Terminal will be off its rails, but can be remounted within 3 to 5 days.

Pile-supported docks will not suffer serious damage, but access will be limited due to settlement of fills, road damage, and impairments to railroad lines and yards. Rail access to areas of the terminals will be restored on a limited basis in two weeks. As a consequence, it is improbable that marine terminal facilities will remain functional.

For planning purposes, the port facilities should be considered 100 percent out of service for three days, 80 percent for seven days, and 40 percent for an indefinite period.

Electric power is supplied to terminals by San Diego Gas and Electric Company; the two southern marine terminals, Tenth Avenue Terminal and National City Terminal, currently do not have any back-up power. For planning purposes, it should be assumed that no electric power for operations will be available for seven days. During this period, bulk loaders, fuel pumps, onshore cranes for loading and unloading of ships, and power for heating fuel oil to keep it liquid, will be out of service. Onboard, mobile or floating barge cranes can be used as access is restored.

**Damage Assessments**

Damage assessments have been postulated for certain port facilities. The statements regarding the performance of facilities are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map 4-RM.
<table>
<thead>
<tr>
<th>MAP NO.</th>
<th>FACILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td><strong>North Island</strong> (Naval Air Station)</td>
</tr>
<tr>
<td></td>
<td>Liquefaction induced slumping and lateral spreading within the artificial fill and failure of the quaywall will prevent direct off loading of supplies. If needed, a temporary ramp could be constructed during the first day and supplies for North Island and Coronado barged from the mainland (The San Diego-Coronado Bridge will not be accessible for 72 hours due to settlement of approaches).</td>
</tr>
<tr>
<td>M2</td>
<td><strong>Embarcadero Area</strong> (B Street Pier, Broadway Pier, Navy Pier, and G Street Mole)</td>
</tr>
<tr>
<td></td>
<td>Liquefaction induced slumping along Harbor Drive and Pacific Highway will prevent access to the relatively undamaged pile-supported piers. The quaywall north of the B Street Pier will fail as will the B Street Pier. Railroad access will be restored on a limited basis in two weeks. Facilities will be 100 percent out of service for three days, 80 percent for seven days, and 40 percent for an indefinite period of time.</td>
</tr>
<tr>
<td>M3</td>
<td><strong>Tenth Avenue Marine Terminal</strong></td>
</tr>
<tr>
<td></td>
<td>As above, liquefaction-induced settling and lateral spreading and failure of quaywalls will preclude use of these facilities for delivery of supplies. Electric power supply will be unavailable for seven days. Railroad access will be restored on a limited basis in two weeks. Emergency temporary repairs to roads and equipment may be expected to restore 80 percent of the functional capability within a week. However, major problems will arise from external sources, such as the restoration of electric power, repair of</td>
</tr>
</tbody>
</table>
access routes, and railroad lines. Accordingly, facilities at this terminal should be considered 100 percent out of service for three days, 80 percent for seven days, and 40 percent for an indefinite period of time.

M4 National City Marine Terminal and 32nd Street Naval Station

A similar level of impairment as noted above for Tenth Avenue Marine Terminal will occur because of liquefaction-induced settling and lateral spreading, and the failure of quaywalls will preclude use of these facilities for the delivery of supplies. Electric power supply will be unavailable for seven days. Railroad access will be restored on a limited basis in two weeks.
RAILROADS

General Characteristics

Only ATSF (Atchison & Topeka-Sante Fe) Railroad provides freight service to San Diego at present. Amtrak operates eight passenger trains daily between San Diego and Los Angeles, using the ATSF right-of-way.

The SDIV (San Diego and Imperial Valley) Railroad extends from downtown San Diego through Tijuana and the northern border area of Mexico to Tecate where it reenters the United States and continues to El Centro in the Imperial Valley. The line has been out of service from Tecate eastward for many years. A branch line of this railroad extends from downtown San Diego to El Cajon. The roadbeds and systems are maintained on the main line to Tecate and the branch line to El Cajon for the minimal freight traffic which presently uses it. The San Diego Trolley light-rail system is mostly located on the right-of-way for SDIV, providing passenger service only from downtown San Diego south to San Ysidro and east to El Cajon.

Seismic Considerations

From experiences of large U.S. earthquakes, it is known that railroads have fared extremely well; damages that have occurred have been repaired quickly by an industry organized to handle emergencies. Except for highway overpass collapses on tracks and moveable bridge damage, problems have usually occurred because of structurally poor ground. Experience gained in the 1964 Alaska earthquake is excellent in regard to damage in areas of poor ground.
The poor ground areas of San Diego of concern to railroads occur mainly in the filled sections to the east of San Diego Bay and in the slide-prone coastal bluffs through which the trains must pass. Ground conditions become more critical during the wet seasons. Experience indicates that fills placed over poor ground or ground affected by faulting will experience unequal settlement and cracking at bridge approaches and elsewhere. This requires the repair of the subgrade and the realignment of track after an earthquake. In the coastal bluffs to the north, steep cuts exist. Experience indicates that these may become unstable due to earthquake shaking. Resulting slides may cause extensive blockage of tracks. The removal of slide debris becomes difficult due to the rough terrain.

Railway bridges generally do not suffer serious damage except in areas subject to ground failure or surface fault rupture. There are no tunnels in this system. There are numerous bridges on the line serving San Diego from the north. Most of these are ballast deck-pile trestles of wood construction. Most are on friction piles which do not extend to bedrock. Accordingly, those bridges in zones of potential liquefaction are vulnerable to settlement and distortion if liquefaction occurs. Bridge damage, when it does occur, generally involves a lengthy repair time, so up to 14 days has been used as the estimated time for making a major bridge repair. Significant settlement of approach fills also requires repair before bridge structures can be used again.

Rail facilities are also highly vulnerable to closure by collapse or major damage to the many freeway over crossings and other grade-separation structures. Many of these have been constructed during recent years in the San Diego area along I-5, I-8, I-15, and State Highways 52 and 75.
Planning Considerations

Railroad companies possess substantial internal repair capabilities. Additionally, they have extensive experience with outside contractors from all parts of the nation. The Santa Fe Railroad is no exception. The San Diego Metropolitan Transit System and the SDIV railroad have much less in the way of such capabilities, but are also prepared to make repairs by their own crews or through prearranged contracts with others. Major washouts, landslides, and derailments are common. It is reasonable to assume that the railroads will be able to solve most of their reconstruction problems without undue attention from those concerned with disaster response. However, complete restoration of rail service throughout the area will take time. This in turn will impact many others dependent on rail service. Failures that involve both the railroad and other transportation facilities and/or utilities may result in problems of work priorities.

Planning Scenario

Both rail lines to San Diego cross areas of high to very high liquefaction susceptibility. Service along the ATSF line from Los Angeles will be disrupted along Mission Bay and south of Oceanside where tracks are subject to landslide liquefaction-induced damage. For planning purposes, assume service will not be restored for three weeks after the earthquake. Supplies can be off-loaded at Oceanside or Escondido and trucked south, although travel will be disrupted on major freeways due to damaged bridges blocking through traffic.

The San Diego and Imperial Valley Railroad and the San Diego Trolley cross areas of high liquefaction susceptibility along San Diego Bay and in the Tia Juana River Valley. Roadbed damage will prevent use of the lines from downtown San Diego to the International Border for a planning period of three weeks.
Other damages are postulated for various sites as indicated. Statements regarding the performance of facilities are intended for planning purposes and are not to be construed as site-specific engineering evaluations. In addition to the liquefaction-induced failures indicated, landslides along coastal bluffs or in the steeply cut roadbed between Oceanside and Mission Bay may inhibit rail traffic for 72 hours or, at worst, take out the tracks. For planning purposes, assume that the line will be out of use for seven days due to landslides damage. The following locations are shown on Map 4-RM.

R1. **ATSF - Soledad (Sorrento) Valley - Carmel Valley**

Closed for four days. Localized liquefaction-induced ground failure will cause settlement of the built-up track bed. Approaches to the bridge over Soledad Creek will similarly settle. Track-bed repairs will render portions of the line out of use for up to four days after the earthquake.

R2. **ATSF - Mission Bay to Santa Fe Station**

Closed for three weeks. Tracks cross areas of high liquefaction susceptibility all along the easterly margins of Mission Bay and San Diego Bay. For emergency response purposes, extensive track disruption is postulated, especially where the tracks cross the San Diego River Valley. Bridge repairs requiring 14 days are anticipated at this location.

R3. **ATSF and SDIV - San Diego Bay**

Closed for three weeks. Tracks cross areas of high liquefaction susceptibility all along the margins of the southerly reaches of San Diego Bay. For emergency response purposes, extensive track disruptions are assumed, especially where the tracks cross Switzer and Chollas creeks and the Sweetwater River and Otay River valleys. Bridge
Switzer and Chollas creeks and the Sweetwater River and Otay River valleys. Bridge repairs requiring 14 days at both of these locations are anticipated. This damage will affect freight service, but not Amtrak.

**R4. SDIV RR - Tia Juana River Valley**

Closed for four days. Tracks enter an area of liquefaction susceptibility south of the international border, within the Tia Juana River Valley, north of the international border. Localized roadbed disruptions can be repaired by the fourth day following the earthquake.

**R5. Terminal Facilities**

The effects of the scenario earthquakes on terminal facilities in downtown San Diego will be serious. They are located in areas which will experience severe ground shaking. The depot and terminal were built between 1910 and 1920. The buildings are fundamentally braced by unreinforced clay-brick masonry walls and can be expected to suffer serious structural damage, if not complete collapse. Other terminal facilities located on artificial fill bordering San Diego Bay may be significantly damaged, further lengthening the time before they can become operational and hampering off-loading and turn-around. The time to restore the depot and terminal function for temporary service is postulated to be two weeks. Passenger service to the north will be able to continue even without the terminal once the tracks open.
Section 5.

UTILITY LIFELINES
COMMUNICATIONS

The discussion of telephone communication systems was prepared in conjunction with the California Department of General Services, Office of Telecommunications.

General Characteristics and Seismic Considerations

Telephone communications will be adversely affected because of well-known overloading resulting from post-earthquake calls within the area and from the outside. This situation will be further complicated by physical damage to equipment because of ground shaking, loss of service because of loss of electrical power, and subsequent failure of some auxiliary power sources.

Not all of the systems in the region are set up to process emergency calls automatically on previously established priority bases. Thus, overloading of equipment still in service could be very significant.

Telecommunications systems are composed of many subsystems, each interconnected and interdependent. A radio network, for example, may use a combination of telephone lines, microwave circuits, satellite interfaces, underground and overhead cables, and secondary radio paths. The failure of one link in this electronic "chain" can effectively disable a large portion of the system. The post-earthquake communications scenario has been treated as a matrix of events that would reduce the effectiveness of systems rather than completely destroy them. It is also assumed that portions of many systems could be repaired to a limited extent. Criteria, such as geographical coverage, the number of system elements, and functional integration, were considered in estimating the post-earthquake effectiveness of a particular system. With the maximum capacity of any system represented as 100 percent, most systems operate at approximately 85 percent because of ongoing maintenance. The
effects of the scenario earthquake must be applied to this ratio to determine the degree to which the overall effectiveness is reduced. "Effectiveness" is defined as the ability of a system to perform to its design limits and provide the intended service.

This communications scenario is described in subsections, each of which treats one of the following generic systems: telephone, radio, microwave, satellite, data, and commercial broadcast.

Telephone Systems

Telephone systems comprising a vast, complex, interconnected network are mutually interdependent; yet they are also self-supporting on a local basis. One service provided by the telephone companies is intra-exchange traffic, that is, calls between telephones within the area served by a single central office or "exchange." Another is inter-exchange service whereby calls are switched between two central offices within a region. There is a third service, similar to inter-exchange, whereby calls are routed to a long-distance facility. Each of these services can be provided by a variety of system configurations.

The telephone companies have installation standards that minimize earthquake damage. They also have emergency mobilization plans and have exercised these plans effectively. Nevertheless, there has not been a disaster of the magnitude addressed here in San Diego in modern times. It is therefore difficult to forecast the detailed effects of a major earthquake on telephone systems. A number of outcomes can be anticipated however: hardware damage such as underground cable failure in areas of liquefaction, damage to surface cable carriers, system-call saturation during post-earthquake recovery, and access problems for repairs.

Some basic assumptions have been made: (1) the shaking intensities used in this scenario are shown on Map 4-S; (2) areas experiencing intensity VIII or greater will have some significant hardware damage although such damage would be fairly localized and not on a
large regional scale; (3) some underground cables will be damaged by ground failure, but not in sufficient number to preclude switching alternatives; (4) most predesignated public safety circuits will receive priority restoration; (5) most telephone company back-up power provisions will be functional; (6) the long distance network, although difficult to access, will remain generically stable; (7) interchange facilities will be difficult to access, but will remain essentially intact; (8) shortly after the event, numerous relatively simple failures will occur, for example, "off-hook" condition produced by intense shaking. Coupled with intense call saturation, these will effectively disable the telephone networks for approximately six hours.

**Effectiveness of Essential Services Lines**

Emergency response agencies have a portion of their telephone lines, sometimes as little as 10 percent, predesignated as essential services lines. For planning purposes, we postulate that after the scenario earthquake, these essential services telephone lines will be 25 percent usable in the first day, 50 percent usable in the second day, and 75 percent usable at the end of the third day. This assessment is for most of the area within 40 km (25 miles) of the fault. The availability of telephone communications for the general public will be significantly lower than for emergency response agencies.

**Specific Vulnerabilities**

The most vulnerable aspects of telephone systems are the computers used to switch message traffic. All are sensitive to changes in cooling and may be mounted on false floors. The performance of these computers is not easily associated with a time-frame because of the long-term effect of environmental (temperature) control failure. Call saturation, resulting in local station and all-trunks busy, is the most obvious system access problem that can be predicted. Most exchanges, however, have the capability through the switching computers to
control system load by limiting access to only predesignated circuits. The telephone systems work primarily on battery power, with back-up generators. If emergency power fails, system performance on batteries will degrade at a significant rate.

Assuming the earthquake occurs outside normal business hours, a number of staffing dimensions must be considered when evaluating telephone system performance in the scenario. The first concern of telephone company employees will be to assess their own immediate condition. Second, they will be concerned about their families and friends. A small percentage of staff will leave their jobs to ameliorate the effects of the disaster in their personal lives. Some employees will suffer casualties and will be confronted with mobility problems on streets and highways. The repair vehicle fleets will probably be generally inaccessible to staff for several hours and, in some cases, may be immobilized by facility failure. Fatigue will apply to all restoration personnel. Another portion of staff will be unavailable because of normal vacation and illness. It is likely that telephone company mobilization plans will be difficult to implement because of the exercise of other priorities by local and State government as well as limited transportation. The thousands of repair parts and materials needed for recovery may also be difficult to obtain. In summary, the effects of a major earthquake on telephone systems will depend upon a multitude of events rather than upon any single factor.
Main Telephone Exchange Building

Pacific Telephone Company

General Information

The Ninth Avenue facility of Pacific Telephone Company houses the telephone exchange for the San Diego downtown area. The building handles local calls and long distance calls being transferred to the Pacific Telephone Company or AT&T facilities approximately two miles north in the Hillcrest area. The building was originally constructed in the 1930's. Several additions were later added. The various additions represent various stages in building code requirements for seismic resistant design. The latest addition, built in 1976, employs reinforced clay-brick masonry walls whereas the original construction of the 1930's employed unreinforced masonry for the walls. The roofs and floors are made of reinforced concrete. The frame is structural steel enclosed in reinforced-concrete fireproofing.

The main use of the building is housing switching equipment, which is contained in high racks extending from floor to ceiling in most cases. Some of the main distribution frames, installed in the 1930's, are still in use. These are being replaced by the modern equipment which is much lighter and smaller. The new digital switches are 1/8 as large as the switches which were used in the 1930's. They are installed in racks so that the switches are now located within six or seven feet of the floor level. Computerized fiberoptics equipment is also housed there.

A program is under way in this building, as in other Pacific Telephone Company exchanges in the San Diego area, to improve the seismic bracing of equipment within the building. Lateral bracing is being installed on some of the older main-distribution frames, particularly that which is necessary to brace them in the longitudinal direction. They are presently braced to the ceiling in the lateral direction.
Electric power is furnished by the San Diego Gas and Electric Company by means of an underground transformer vault beneath the sidewalk on Ninth Avenue. Power is converted by rectifiers which in turn charge batteries that furnish the direct current to the system. Emergency power is available by means of a turbine generator that operates on diesel fuel. This is a 750-kilowatt unit which is tested for two hours each month.

**Seismic Considerations**

The Ninth Avenue Exchange Building is located in an area of shaking intensity VIII. It is expected that newer portions of this building will experience little structural damage. However, some of the unreinforced masonry walls in the 1930 building unit would experience cracking and disintegration even though the concrete-encased, steel frame will continue to support the building. Disintegration and partial collapse of some of the unreinforced masonry walls and partitions and other nonstructural elements will damage parts of the operating equipment, including computer components.

The batteries that furnish the direct current to the system are good for three hours in case of loss of both commercial and emergency power, after which time operations will be impaired.

**Planning Scenario**

For planning purposes, because of the complexity of operations, sensitivity of equipment, critical power requirements of a telephone exchange facility, and the age of the building located in ground shaking intensity zone VIII, postulated outages and impairments are applied to a three day recovery time frame with telephone networks disabled for the initial six hour period after the earthquake.
Commercial Radio Stations and Emergency Communication Centers

Introduction

The 1971 San Fernando earthquake caused failures of communications which limited contact between certain critical locations and agencies responsible for emergency relief. This resulted in delays in assignment and use of available volunteers and materials and in the transmittal of adequate emergency information to the public.

Emphasis in this section is given to the communication types, such as Emergency Broadcasting System stations (EBS) and inter-governmental communication centers that are vital to emergency services and to minimal maintenance of community life in the days immediately after the disaster.

It is obvious that post office facilities will be severely damaged when located in older non-earthquake resistive structures that are in high-intensity zones or areas of liquefaction. Additionally, it is obvious that post office facilities located in the congested portions of the study area, for example, may be inoperative should access be restricted.

Newspapers are important in that they give the public much of the detail that cannot be carried by radio or television. Electric power outages, misalignment of sophisticated printing equipment or direct damage to it, and commuting problems for employees will cause delays in the publishing process. For planning purposes it may be assumed that newspapers will have to rely on presses located outside the urban areas of the study area for at least one week.
A. Radio Stations

There are 17 principal commercial AM radio stations in the San Diego area which were reviewed. Of these, two are Emergency Broadcasting System (EBS) stations. Table 4 below indicates their geographic distribution by city and community.

TABLE 4
AM RADIO STATIONS
SAN DIEGO REGION

<table>
<thead>
<tr>
<th>City/Community</th>
<th>Total Number</th>
<th>Number of EBS Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carlsbad</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Chula Vista</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>El Cajon</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>La Mesa</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Oceanside</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>San Diego</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Santee</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>17</strong></td>
<td><strong>2</strong></td>
</tr>
</tbody>
</table>

B. Local Inter-governmental Communications Center

Both the City and County of San Diego operate communication facilities for use as emergency operation centers.
**County of San Diego**

The San Diego County Communications Center is located at the Overland Avenue County Operations Center in Kearny Mesa. The facility is housed in a modified warehouse building of tilt-up concrete wall and steel-frame, metal-deck roof construction. The center is operated by the San Diego County Sheriff's Department. The County Office of Disaster Preparedness has its primary communications center within this same facility.

The Kearny Mesa communications center normally operates on utility power. A standby emergency generator with 250 kilowatt capacity is in place. A smaller 150 kilowatt emergency generator is planned as a back-up. A battery system for "uninterrupted" power supply for the microwave system and for the computers is located in one room of the center; the battery racks are anchored to resist strong ground shaking forces.

Messages would be sent from these disaster operations centers to the Emergency Broadcast System stations (KKLQ or KCBQ), which in turn would relay the messages to all cooperating radio and television stations in the San Diego area.

**City of San Diego**

The City Operations Building in downtown San Diego contains the fire, police dispatch, and emergency operations center in the basement. A new fire communications/dispatch center and training/maintenance facility near Montgomery Field is under construction. A new Police Department Building with communications capability is located on a site in downtown San Diego.
Seismic Considerations

Damage to radio and TV facilities may be divided into that which occurs (a) to the studio building and its equipment, (b) to the lines from the studio to the tower, and (c) to the tower, appurtenant structures, and related facilities.

Commercial Radio Stations

Of the 17 radio stations listed in Table 4, two are located near the scenario fault zone and consequently in an area of heavy ground shaking (intensity VIII), one is an area of high liquefaction susceptibility and severe ground shaking (intensity IX), and four are in areas of heavy ground shaking (intensity VIII). In total, seven out of the 17 stations listed are in areas of a high risk potential. Past studies indicate damage to radio and television stations can significantly impair normal operations.

Radio Station KKLQ is located near Montgomery Field in Kearny Mesa in an area of ground shaking intensity VII. KCBQ is a secondary (back-up) Emergency Broadcast Station. In the event of use failure of KKLQ to respond during a disaster situation, KCBQ would automatically assume this function. KKLQ and KCBQ have a two-way VHF link to the County Communications Center at Overland Avenue in Kearny Mesa.

Radio Station KCBQ, together with its transmitting towers, is located 15 miles northeast of San Diego in Santee, in an area with an expected ground shaking intensity VIII. The building is of wood-frame construction built according to 1960's standards. According to past experiences, this type of building would be expected to survive with little structural damage. Emergency power, if needed, is questionable because of the non-anchorage of the 50 KVA emergency generator. Shifting of this unit on its foundation would break the connecting circuits. It is anticipated that the generator could be placed back in use within a 12 hour period depending on availability of personnel and equipment.
Emergency Communication Centers

Fire, police, hospital, school, bus, public utility, and other special service center communication requirements were not specifically field inspected, except in situations where inspection of the buildings was necessary for other purposes, and where the facility functions as an emergency operations center.

The problems described for the public radio and TV facilities also apply in a general way to these governmental facilities. Even though emergency service communications may be redundant to varying degrees because of multiple frequencies and alternate base stations, experience has proved that, at best, a considerable number of unanticipated problems will emerge. Those services relying upon a single radio frequency must expect to experience overloading to a nearly impossible degree. However, in view of the large amount of mobile transmitting and receiving equipment, makeshift facilities are possible. Therefore, reliance must be placed on the management ability of those in charge of each special communication facility to make best use of mobile equipment if the base station becomes inoperative.

The San Diego County Communications System for departments other than the Sheriffs Department (roads, utilities, and so forth) operates out of "Station X" at the County Operations Center on Kearny Mesa. This is in a portion of the facility with a raised computer floor. Although it is located in an area of seismic intensity VII, the consoles rest on the floor and on desks with no anchorage against lateral forces. The Office of Disaster Preparedness communication system operates as part of "Station X," including the VHF two-way system to the Emergency Broadcasting Systems stations KKLQ and KCBQ. This broadcast equipment for the EBS is similarly desk-mounted with no anchorage for lateral forces.
It may be assumed that the microwave system will be out of use because of the effects of ground shaking on the alignment of the antennas. For purposes of the scenario, the microwave system should be assumed to be more than 20 percent effective, and it would not be capable of being fully effective for three days following the earthquake.

The City of San Diego Operations Building in downtown San Diego, which contains the Emergency Operations Center in the basement, is located close to the scenario fault zone. The Police Department building is within a mile of the fault zone. Both, accordingly, are located in an area of high ground shaking, intensity VIII. While damage to the buildings may not be severe enough to cause collapse, severe non-structural damage sufficient to cause functional impairment is to be expected.

Planning Scenario

A. Commercial Radio and TV Stations

For planning purposes, 60 percent of the commercial radio stations will be inoperable immediately after the postulated earthquake because of damage to buildings, equipment, antennas, or towers. Radio systems will generally operate at 40 percent effectiveness for the first 12 hours after the earthquake.

It is expected that 25 percent of the impairments will be restored in 12 hours and the remainder in up to 15 days. In addition, three stations, one in an area of severe liquefaction, and two at the edge of the fault zone, will incur additional non-structural and equipment damage severe enough to cause functional impairment for 45 days before full operation is restored.
B. Emergency Communication Centers

Similar to the damage patterns postulated for planning purposes for the commercial radio stations, 50 percent of the total emergency communications capability available to the County and City of San Diego will be impaired. It is expected that 25 percent of the impairments will be restored in 24 hours and the remainder in up to 30 days. For planning purposes, the two city facilities located in the downtown area are expected to incur additional damage to non-structural building elements and equipment components to delay full operation for up to 45 days.

C. Radio Systems

Radio systems will generally operate at 50 percent effectiveness for the first 12 hours after the earthquake and increase to 75 percent effectiveness for the second 12 hours. The long-term implications are that individual systems gradually will become less useful to the overall recovery effort when supplanted by systems relocated from outside the disaster area. It is unlikely that public safety radio systems would become saturated with non-critical communications from mobile units. It is clear, however, that radio traffic densities on redundant (non-emergency designated) channels would increase, particularly when remote base station and repeater failures may limit the number of redundant channels available.

For each of the various components of a radio system, we anticipate specific effects under the scenario. These effects are described in the following component discussion:
Radio Control Consoles

Radio consoles generally fall into three categories: self-contained tabletop base stations, tabletop control consoles for remote base stations, and full-size consoles using electronic circuitry (often very sophisticated) to control remote base stations. Both tabletop models are vulnerable to earthquake damage because they are rarely secured. While the self-contained station is more likely to remain functional than other types (since it does not rely on remote equipment), it is often not supplied with emergency back-up power. System designs using control stations normally have back-up power provisions. Control consoles rely either on telephone or microwave circuits to access remote equipment. Continued microwave operation is not anticipated; and telephone lines cannot be recommended as a alternative, although such dedicated control circuits are more likely to remain functional than conventional telephone service. Sophisticated consoles are better protected against physical damage and normally have emergency power available, but they rely on telephone and microwave circuits and have an added problem of repair complexity. If a key component of a large console fails, many radio sub-systems would be fragmented, placing the burden of communications on outlying stations that are also vulnerable to earthquake damage. Further, software-based consoles would probably face additional complications within 12 hours. It is estimated that self-contained tabletop base stations would be 50 percent effective, tabletop control consoles 65 percent effective, and large consoles 60 percent effective.

Base Stations

Radio base stations are often located on the roof of the same building housing the control console. In such cases, the condition of the building would determine post-earthquake performance. Even if cabling between the two units were to fail, base stations can be operated on-site via a microphone provided within the equipment cabinet. Dispatchers, however, are not normally aware of this and even more rarely have the key needed to gain access to the microphone. Remote base stations, located in a different building or in a
mountain top radio vault, are subject to potential structural damage. Stations atop buildings are probably less vulnerable to wiring and component malfunctions than other installations but share the threat of telephone circuit interruption. We estimate the effectiveness will be 70 percent for local base station installations and 55 percent for remote stations.

Repeater (Mobile Relays)

Repeater (Mobile Relays) are not dependent on control circuits and are normally provided with back-up emergency power. Generally located atop mountains, they are vulnerable to structural, electrical, and other internal damage. Depending on the proximity of the fault source, they are more likely to experience technical problems than base stations. It is estimated that repeaters will be 60 percent effective.

Antennas

It is not believed that antennas will fail on a large scale. Antennas and related structures should remain 70 percent effective.

Hand-held and Portable Two-way Radios

It is probable that hand-held radios will be valuable to field units during the first 12 hours after a major earthquake, particularly in a system that does not use repeaters. In any case, there are problems with charging and distributing batteries which have a life of about 12 hours. A unit equipped with one fully charged back-up battery would be operational for no more than 24 hours. Without a large supply of back-up batteries, these units are of limited benefit to the overall recovery effort.
HAM and Other Amateur Radio

Amateur radio stations are subject to the same hazards discussed above. A particularly vulnerable point is emergency power; most home-based stations do not have back-up facilities. Nonetheless, there is an extensive vehicular radio and repeater system in the amateur radio service. Much of the first post-disaster intelligence would come from this private sector resource; and, as demonstrated in the 1985 Mexico earthquake, radio amateurs may be the only means of reaching the outside world. The amateur radio service should remain more than 50 percent effective because of pre-organization and the long distance capabilities of the equipment.

Citizens' Band (CB) Radio

It is not believed that CB radios will have an appreciable effectiveness in the public agency recovery effort, although they would have some post-disaster intelligence value. The units are too-low-powered and are susceptible to frequency saturation. It is possible that CB "zones," each zone using a predesignated channel, could be established within neighborhoods for the self-help effort. Being the most accessible two-way communications resource available for the general public, Citizens' Band could be a significant element in the smaller recovery "cells" if users receive prior education and orientation.

Radio Common Carrier (RCC)

Radio common carriers will be subject to the events noted earlier for public agencies.
Aircraft and Marine Radio Communication

These radio services will be at least 80 percent effective provided that airfields are nominally accessible, and there are no severe conditions that would significantly disrupt moored maritime resources. While there is much potential within either service for providing good quality emergency communications, existing land-based systems are completely incompatible. The overall effectiveness of marine radio must be equated to prior frequency coordination for marine transport systems. The relative importance of these radio services will increase as recovery efforts get underway.

Microwave Systems

Microwave systems have all the vulnerability of other radio systems plus additional problems related to narrow frequency tolerances, software controlled switching systems, and sensitive gain (direction-ability) tolerances. Additionally, many systems are not point-to-point but are linked through several points. The likelihood of failure in any one link is fairly great. Therefore, we feel that microwave systems, with the possible exception of telephone microwave systems, will not extend beyond the affected disaster regions. Some circuits may remain operable on a point-to-point basis. It is estimated that most microwave systems would be 50 percent effective or less.

Satellite Communications

Remote satellite terminals relying on telephone or microwave circuits will be 50 percent to 60 percent effective, similar to radio-based stations. Station proximate terminals will have a greater likelihood of survival, approximating 80 percent. Because the satellites themselves are impervious to earthquake damage, they are one of the most significant resources for supplanted communications systems.
**Data Communications**

Communications systems used to support computers will be 40 percent effective. When facilities are not physically damaged, failures in air conditioning and environmental control systems may gradually reduce effectiveness.

**Medical Services Radio Systems**

The VHF medical services radio frequencies are crowded and poorly coordinated. UHF repeater systems, while less saturated, are more vulnerable to damage and failure. There are insufficient channels dedicated to telemetry; these would be saturated and, therefore, virtually useless in any earthquake in which there is a large number of casualties. The hospital-to-hospital systems are also expected to fail. It is not anticipated that medical radio services will function at an appreciable level of effectiveness.

**General Comments on the Communications Scenario**

The lack of emergency power has been the primary cause of communications failure in past disasters. For this scenario, however, power to most areas will not be disrupted for an extensive length of time. Poor installation practices and inadequate preventive maintenance of back-up power equipment contribute to a high failure rate.

The availability of repair parts and the ability to transport them are other factors when considering both short- and long-range implications. Supplanted communications systems will be needed as local systems suffer earthquake-caused and normal equipment malfunctions for which there are no repair parts.
The current state of technology is such that communications technicians have specialized areas of expertise. Tools, test equipment, and repair parts are often suited only for the particular type of equipment a particular specialist uses. As a result, a specialist would have difficulty repairing equipment outside his area of specialization. Most radio technicians, for example, are unable to repair microwave equipment; military staff are unable to repair some types of public radio equipment; and microwave specialists are unable to assist telephone staff. This problem is further compounded by the unique characteristics of many systems otherwise generically related. Depending on the time of day the earthquake occurs, the number of technical staff available for repair services could range between 20 percent and 80 percent of the total for the first 24 hours. The effectiveness of technical personnel is severely affected by the availability of transportation. In many cases, for example, helicopters may be needed for access to remote sites. Technical staff would only be able to support the continued operation of systems at a level of post-disaster effectiveness. After several days, system performance would begin improving.

The regulation of communications has necessarily separated users to avoid mutual interference. One result of this separation is mutual exclusion. Except in rare circumstances, two adjacent communications systems are physically or functionally incompatible. The greatest danger to a post-earthquake recovery effort is the absence of an adequate interface between systems. This applies equally to local systems and systems drawn from outside the disaster area.
ELECTRICAL POWER

General Characteristics

The San Diego Gas and Electric Company (SDG&E) distributes practically all of the electrical power throughout San Diego County. The actual service territory, which includes southwestern Orange County, covers 4,100 square miles (double the size of the state of Delaware) and includes over 940,000 customers.

In 1988, SDG&E distributed 12.7 billion kilowatt-hours of electricity. Of this total, oil and gas generation at their own power plants accounted for 30 percent, nuclear generation from the San Onofre Nuclear Generating Station accounted for 22 percent and the remaining 48 percent was purchased from other sources. Purchased power is primarily provided via the Southwest Power Link (SWPL).

The San Onofre Nuclear Generating Station, in which SDG&E has a 20 percent interest, is outside the planning area for the scenario earthquake. Accordingly, it is not part of this report.

Two operating power plants (Encina and South Bay) are included in the planning area. One power plant (Silvergate) is in long-term storage and is neither manned nor in use at the time of writing this report. A summary of major facilities operated and maintained by SDG&E is presented in Table 5.
TABLE 5
SAN DIEGO GAS AND ELECTRIC COMPANY MAJOR FACILITIES

<table>
<thead>
<tr>
<th>Major Power Facilities</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encina Power</td>
<td>917 megawatts</td>
</tr>
<tr>
<td>South Bay</td>
<td>706 megawatts</td>
</tr>
<tr>
<td>San Onofre Nuclear Plant</td>
<td>517 megawatts</td>
</tr>
<tr>
<td>Combustion Turbines (20 total)</td>
<td>333 megawatts</td>
</tr>
<tr>
<td>Southwest Power Link</td>
<td>500 kilovolts</td>
</tr>
<tr>
<td>(Silvergate - in storage, older unit)</td>
<td>(230 megawatts)</td>
</tr>
</tbody>
</table>

Other Facilities

| Number of Substations                      | 247               |
| Overhead Lines                             | 8,605 miles       |
| Underground Lines                          | 7,313 miles       |

Map 4-E delineates the two major power plants and selected portions of the extensive substation network and their interconnecting transmission lines.

Relative to seismic design considerations for its power plants, SDG&E has recognized the vulnerability of electric power facilities to earthquake damage and instituted measures to mitigate possible damage. SDG&E's earthquake planning goes back to 1933 in response to the reports of extensive damage to electric power facilities resulting from the Long Beach earthquake of that year. The initial earthquake planning manual is dated May 10, 1933, exactly two months after the earthquake. At the time, SDG&E engaged a San Francisco consulting engineer, W.L. Huber, to survey all the company's plants. The company's efforts at strengthening existing facilities were featured in an article of the "Engineering News-
Some argued that there is no known active fault line extending through the city and that there is no record of an earthquake of destructive violence at that place. There is little logic in such arguments. They are not supported by earthquake history. Wiser counsel finally prevailed and Walter L. Huber, consulting civil engineer, San Francisco, was engaged to survey the various plans of the company, report on the hazard and recommend means of minimizing the danger of serious interruption to service. As a result the strengthening of 4 buildings was undertaken.

The same ENR article described the extensive structure retrofit work that was completed at the Station B Power Plant located at the foot of Broadway. This power plant has been decommissioned.

Seismic Considerations

Power Plants

According to a 1973 report by the National Oceanic and Atmospheric Administration (NOAA) (p. 274), "Experience indicates that well-designed electrical generating plants should suffer minimum (less than 5 percent) damage in intensity VIII (MM) zones and only slight (less than 10 percent) damage in intensity IX (MM) zones." The report noted that damage at the Valley Steam Plant during the 1971 San Fernando earthquake (M6.4) was negligible though the estimated intensity at this plant was VIII (MM). For comparative purposes, SDG&E’s two power plants were designed to 0.2g (static) lateral force levels, exactly the same as Imperial Irrigation District’s power plant in El Centro, which contains equipment similar to the SDG&E plants (soil conditions are, however, not similar). Units 3 and 4 were operating at the time of the October 15, 1979 earthquake. While some structural damage did occur, Unit 3 was restored to service approximately five minutes after the main shock, and Unit 4 was back in service five hours later (Unit 4’s problem was due to a malfunction of a
A strong motion accelerograph at Station Number 9 in El Centro, which is only 1 km (0.62 mile) from the power plant, recorded the following peak accelerations:

- 0.40g N - S
- 0.27g E - W
- 0.38g Vertical

The boiler at Unit 3, which utilized diagonal braces in lieu of seismic restrainers (stops), was not damaged whereas the seismic stops at boilers for Units 2 and 4 were damaged and required repair.

South of the International Border, power is supplied by the Comision Federal de Electricidad (CFE, Federal Power Commission). Power sources include a local power plant in Rosarito (19 km south of the border), the Cerro Prieto geothermal plant south of Mexicali (approximately 120 miles to the east), and SDG&E power which crosses the border in two places. There also exists an agreement between Mexico and the United States for mutual exchange of power.

The capacity of the major power generating facilities located within the U.S. portion of the area affected by this scenario earthquake aggregate about 1956 megawatts (not including San Onofre or other outside sources), and is principally derived from the two plants within the metropolitan area. Given the assumptions set forth in the damage assessments that follow, it is probable that most of this locally generated capacity will be available to the majority of the study area following the scenario earthquake.

Because SDG&E has access to sources of power from outside the affected area, it will be possible to reroute power to most consumers. Consumption of power will be less than normal while both power generation and consumer facilities are being gradually restored.
For planning purposes, all emergency operations and support systems necessary for responding to the scenario earthquake should be reviewed for alternate power sources.

The South Bay Power Plant is located within a region of MMI IX and within a high liquefaction potential zone. The plant is 5.5 km (3.4 miles) from the Silver Strand fault. During construction of this facility, which took place between 1960 and 1971, extensive measures were undertaken to mitigate the susceptibility for liquefaction. All the bay deposits were excavated from the site and replaced by a densely compacted sand fill. The depth of excavation extended to the underlying, highly cohesive, sandy clay subsoils (30 percent clay content) that would not be subject to liquefaction. The sand fill, which was compacted to 98 percent of maximum dry-vibrated density, varies in thickness from about 13 feet at the western limits of the site to approximately six feet at the eastern boundary.

The South Bay Plant consists of four power producing units, constructed in 1960, 1962, 1964, and 1971, respectively. Units 2 and 4 are of the cyclic type, that is, they can operate on an intermittent basis, and Unit 4 is currently not being used. Each boiler structure is a structural steel-braced frame with the boiler suspended from girders at the top. The main structure for each unit (turbine building and boiler) is supported on reinforced concrete footings. Riveted connections in conjunction with standard bolting were used for Units 1 and 2; standard bolted connections were used in Unit 3; and high-strength bolts in Unit 4. A variety of schemes were utilized for seismic bracing (primarily seismic restrainers) of the boilers with the restrainers concentrated in a few locations. Damage to the restrainers and to the boiler units can be expected from the scenario earthquake. Each of the units has an unlined steel stack supported on a reinforced concrete foundation. Very little supplementary bracing of piping was apparent at the facility. The network of piping of all types (water, gas, steam, and electric) is so complex and interwoven that some mutual bracing and damping will obviously occur.
Natural gas piping into the facility is from two separate sources for added redundancy. Also, gas piping penetrations into the structures have been retrofitted to provide isolation from the structure. A large jet engine type generator provides emergency power for the facility. This generator can be actuated within about ten minutes. A program of periodic start-ups of the generator is in effect.

The South Bay facility utilizes sea water for cooling and fresh water for steam condensate generation. Current average usage of fresh water is approximately 9,346,000 gallons per month (28.7 acre-feet). Loss of water supply to the power plant would be critical. Water lines traverse areas of highest intensity ground shaking that are also zones of liquefaction susceptibility.

The available water storage at the site (for condensate usage) would only provide for two to a maximum of five days of usage, depending on the amount of power distributed. Trucking the quantity of water needed, considering damage to the highways and massive traffic jams during the emergency period, does not appear to be a viable alternative. The circulating water pumps located outside the buildings are at an elevation of roughly 20 to 25 feet above the normal salt water level. Salt water, if it did reach the pump motors, would cause a major problem; however, the probability of the simultaneous occurrence of high tides and tsunami effects appear rather remote.

The Encina Power Plant consists of five units, constructed in 1954, 1956, 1958, 1973, and 1978, respectively. The Encina facility is in a location subject to liquefaction, but the intensity of ground shaking from the scenario event at this location in only MMI VII. The Encina Power Plant has added supplementary bracing to some of their piping. As with the South Bay facility, loss of fresh water to this facility would seriously curtail operations.
Overall, SDG&E currently has a good, workable emergency response plan with a separate response plan for each facility. Adequate radio and telephone communications with separate emergency power sources are available, and an emergency crew operates the facilities 24 hours a day. Computers in the control rooms could be reviewed for anchorage, but their loss would not be critical to operation of the power plants.

Substations

SDG&E operates 247 substations dispersed throughout the study area. Some of the substations require upgrading of their anchorage of equipment and some restoration of bracing, which has been altered by equipment changes.

Transmission substations are essential to the routing of locally generated power and of power available from outside the region affected by the earthquake. These major substations, which contain banks of switches, circuit breakers, and massive transformers, are particularly vulnerable to damage by earthquake ground shaking. In addition to the major transmission substations through which high voltage (greater than 230 kilovolts (KV)) is routed, many small, local substations provide vital links in the electrical power distribution network.

The conclusions of this investigation regarding the substations are similar to those presented in the NOAA report on earthquake losses in the San Francisco Bay area. "Despite their good anchorages to power poles, to rails, and the like, many hundreds of (pole mounted distribution) transformers will be knocked out, and some will burn as they have in other earthquakes. Switch gear damage will result in serious power outages. Failure of porcelain insulators will additionally result in significant number of power failures." The NOAA report deals with projected losses from a "great" earthquake. The damage from the moderate sized event discussed here will be less pervasive but similar in areas of high ground shaking intensity or ground failure. It is important to note the distinction between transmission and...
distribution transformers. Replacement of a large transmission transformer can take several days, with resulting implications on the extent and duration of power outage. The availability of replacement high-voltage equipment is another vital consideration.

Transmission Lines

Transmission towers and lines are principally subject to damage through secondary effects such as landslides and other ground failures. Conductor lines (usually distribution lines) swinging together could cause many "burn downs." Where line tensions are high, internal damping will be reduced, and the potential for swaying will be increased.

Within the planning area major transmission lines, for the most part, do not cross areas of intense shaking. The South Bay area is an exception to this. The 500 KV Southwest Power Link terminates near the eastern edge of the metropolitan area. The 230 KV transmission grid skirts the areas of MMI high VIII and IX and of high or very high liquefaction susceptibility. Even under the worst scenario, one would not expect severe damage to the 230 KV transmission system from the scenario earthquake. One hundred thirty-eight (138) KV lines occur in the South Bay region, which is the area of highest intensity and contains areas subject to liquefaction.

Planning Considerations

The occurrence of the scenario earthquake will significantly impact on local power-generating capabilities. In particular, damage or disruption of the water supply to the power stations will have a critical effect on the power generation capabilities. For planning purposes, the South Bay Power Plant should be considered out of operation for three days and at a significantly reduced capacity for 1 1/2 weeks following the scenario earthquake. Regional power facilities and the high-voltage transmission grid will remain relatively undamaged outside of the downtown, San Diego Bay, and coastal Mexico area. The
distribution system, on the other hand, may be severely affected in those areas subject to intense shaking and ground failure. Immediate concerns will focus on repairs necessary to restore power within the damaged areas of greatest need. Major restoration problems include repairs necessary to route power through the major substations, reactivation of equipment at local substations, and replacement of fallen poles, burned transformers, shattered ceramic isolators, and so forth.

On Map 4-E, numerous substations are located within areas of predicted seismic intensity high VIII and IX and in areas having potential for ground failure. Based on this intensity pattern, it is a reasonable expectation that each of these stations will sustain some damage. In the absence of site specific engineering and geologic evaluations, it is wise for emergency planning purposes to conclude that sufficient damage is likely to occur at some substations to seriously impair or curtail their performance. It should be noted that the utility has considerable flexibility with regard to routing power flow and, therefore, temporary reassignments may be possible.

Although the electricity transmission system remains generally intact following the scenario earthquake, local distribution lines and substations will suffer moderate to severe damage, especially between Mission Bay and Rosarito along the coast. Recovery time for these outages will depend on access and logistic support. The Lindbergh Field - Loma Portal - Mission Bay area, for example, will have extremely limited access for the first 72 hours following the scenario earthquake. Downtown San Diego will be generally accessible, with long delays. SDG&E has identified "sensitive" substations and circuits which service critical facilities in the area and which would receive priority. Given access problems, it may be several days before power can be restored even to high-priority locations in the severely damaged areas.
The critical power corridors and facilities should be examined in light of the best geologic data available to assess the vulnerability of specific elements in the electrical power network. Capability to respond and accomplish timely repairs to even a relatively small affected area as described in this scenario requires further evaluation. Other lifelines discussed in the report, especially water supply, waste treatment, and communications, will be affected by interruptions in electrical power. Strategies for repair of facilities must take into account the post-earthquake condition of transportation means and facilities. Strategies for rerouting power into the area to augment decreased capacity within the region should also be emphasized. Public education should be undertaken to prepare people to contend with the power outages.

Planning Scenario

It is reasonable that during some portion of the first 72 hour period following the earthquake virtually all portions of the planning area will have experienced some loss of power, at least temporarily. Portions of the regions of Mission Bay, Loma Portal, Mission Valley, and the coastal regions from Pacific Beach south to the Mexican border will experience a longer duration of outages of up to two weeks. For planning purposes, it is reasonable to consider 25 percent of the service connections in the study area to be without power for 24 hours. In the previously mentioned, more vulnerable sections of Mission Bay, Loma Portal, and so forth, the power outage should be considered at 100 percent for 48 hours, and thereafter at 75 percent for an additional 24 hours. (This means that 75 percent of the customers have no power, not that all customers are limited to 25 percent of demand.)

Electrical power facilities in the South Bay are more vulnerable to both damage from the scenario earthquake and to the curtailment of production capacity due to damage to the water supply. Under the best of conditions it will take up to 14 days to restore full power. 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.
Realistically, power is unlikely to be restored to many areas for extended periods of time, possibly up to two weeks. Emergency planning for power-dependent systems such as communications, water supply, fire fighting, and waste treatment should be very aware of this possibility.

**Damage Assessments**

Damage assessments have been postulated, for certain electrical power facilities. The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map 4-E.

<table>
<thead>
<tr>
<th>MAP NO.</th>
<th>FACILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td><strong>South Bay Power Plant</strong></td>
</tr>
</tbody>
</table>

The South Bay Power Plant is located on an engineered, hydraulically-placed fill, within the area of intensity IX. Some localized ground failure and loss of water supply will require shutdown for more than 72 hours. Time required to restore full power could be prolonged for up to 14 days.

| E2      | **Rosarito Power Plant (Mexico)** |

Rosarito Power Plant, located on Pleistocene marine sediments (not highly liquefiable), will be subject to high VIII intensity shaking and will be shut down for more than 72 hours.
E3 **Encina Power Plant**

The Encina Power Plant will not be significantly damaged by the scenario earthquake. Damage to non-structural elements and equipment will occur, but will not cause shut-down.

E4 **Southwest Power Link**

The Southwest Power Link will not be significantly damaged by the scenario earthquake.

E5 **"Old Town" Substation**

The "Old Town" substation will be heavily shaken and out of operation for one to four days.

E6 **Substations in Downtown Area**

Substations in the Downtown area will be heavily shaken. Those located on artificial fill (near the margins of San Diego Bay) will be inoperative for more than 72 hours and up to two weeks.
NATURAL GAS FACILITIES

General Characteristics

Natural gas is supplied to the San Diego area at two points by the Southern California Gas Company. The SDG&E then supplies the San Diego area through its own transmission and distribution pipeline system as shown on Map 4-GP.

Seismic Considerations

The primary impact on natural gas facilities in the San Diego area will be from liquefaction-induced ground failures resulting from high-intensity shaking. This will result in many breaks in the distribution system in the proximity of the fault zone especially in areas of artificial fill and recent alluvium. Fires can be expected in streets due to broken gas mains. Structural fires will occur as a result of broken mains and service connections.

Planning Scenario

As a result of damage to the distribution system, natural gas will be unavailable to most of the coastal area from Pacific Beach on the north to the International Border on the south. Repairs to distribution mains can be accomplished rapidly, however, and restoration of gas service to the area can then begin. Restoration within the distribution system is a gradual process, however, 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 be 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 (UNG Task Force, 1980).

Thus, while gas supplies to most areas of the coastal area will be restored rapidly, some areas could be without gas for as long as several weeks.

The transmission system will suffer relatively little damage. The Southern California Gas Company pipeline along the coast may suffer some damage resulting from liquefaction where it crosses the coastal lagoons, especially Soledad Valley. The rest of the transmission system, being inland, will be undamaged.

**Damage Assessments**

Damage assessments have been postulated for certain natural gas facilities. The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map 4-GP.
### MAP NO. LOCATION

<table>
<thead>
<tr>
<th>MAP NO.</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td><strong>Pacific Beach main</strong></td>
</tr>
<tr>
<td></td>
<td>Pipeline damage because of ground failure. Repair completed in 72 hours. Complete restoration (including relight) completed in one to two weeks.</td>
</tr>
<tr>
<td>G2</td>
<td><strong>Point Loma main</strong></td>
</tr>
<tr>
<td></td>
<td>See Comment G1.</td>
</tr>
<tr>
<td>G3</td>
<td><strong>Downtown main</strong></td>
</tr>
<tr>
<td></td>
<td>See Comment G1.</td>
</tr>
<tr>
<td>G4</td>
<td><strong>Coronado distribution mains</strong></td>
</tr>
<tr>
<td></td>
<td>Pipelines damaged because of ground failure beneath and along margins of Bay. Coronado could be out of service two to four months until a new pipeline is installed.</td>
</tr>
<tr>
<td>G5</td>
<td><strong>Southern California Gas Company pipeline at Soledad Valley</strong></td>
</tr>
<tr>
<td></td>
<td>Pipeline damaged because of liquefaction in Soledad Valley and landslides on Torrey Pines Grade. This pipeline could be shutdown for five days.</td>
</tr>
</tbody>
</table>
PETROLEUM PRODUCTS

General Characteristics

Petroleum products are transported to San Diego via a pipeline from the north, shown on Map 4-GP. The storage tank farm near San Diego Stadium is in an area of high liquefaction susceptibility and subject to damage from landslides along the walls of Murphy Canyon. A subsidiary pipeline carries fuel to the Navy's Point Loma fuel facility. This pipeline crosses the relatively poor ground of the Mission Bay-Loma Portal area.

From the tank farm, a pipeline carries fuel to an Arco Oil Company facility near the Tenth Avenue Pier. This facility is located on artificial fill and will be subjected to severe shaking and liquefaction.

Seismic Considerations

Pipelines designed to carry products under high pressure are inherently strong. The result has been generally good performance by these types of pipelines in earthquakes. For example, a large diameter interstate natural gas line was not damaged where it crossed the White Wolf fault during the 1952 Kern County earthquake. Fuel lines were undamaged during the 1979 Imperial Valley (M6.6), California, earthquake. Natural gas transmission lines crossing Turnagain Arm of Cook Inlet at Anchorage experienced no damage in the 1964 Alaska earthquake despite the poor ground. A major water line (Hetch Hetchy) to San Francisco performed without damage in the 1906 earthquake, even though founded on Bay mud. On the other hand, major natural gas distribution lines in San Fernando failed during the 1971 earthquake. Experience shows that damage occurs in geologically unstable areas but not necessarily to every line.
If pipe rupture occurs during the dry season, fire could be a serious problem. This threat is also present during the rainy season if the fluids are ignited as storm waters wash them into sewers.

Shut-off valves installed on many of these pipelines will automatically function when the line pressure drops below a particular threshold, such as would occur in the case of a pipe rupture. Some of these valves are dependent on electrical power; in the event of a major earthquake causing large-scale power loss, these valves would not perform.

The low earthen embankments used as retention dikes around fuel and oil storage tanks, evaporation ponds, and waste containments are subject to failure resulting from earthquake shaking. The location of these types of structures, their vulnerability, and the consequences of failure need to be examined as part of any emergency planning program.

Damage to storage tanks is common because of the sloshing of liquids, which damages or destroys the fixed or floating tops. Tank piping often breaks when it does not possess sufficient flexibility. While the spillage of oil may be spectacular, it has not been serious when oil is contained within its dikes and kept free of ignition sources.

Planning Considerations

The indirect effects of damage to a major entity such as a public utility may have significant impact on other vital entities. For example, the loss of electric power and water to the tank farm would impact fuel availability.

Emergency planning should provide for distribution of fuel to those locations designated for emergency response operations, including airports. Adequate emergency power and pumping capability should be available at fuel storage locations for refueling of helicopters and other emergency vehicles.
All of the petroleum product pipelines that serve the metropolitan area should be examined in detail relative to their vulnerability to ground failure. The adequacy and locations of automatic shut-off valves should be examined on all product lines and remedial measures undertaken, as appropriate. 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. Predetermination of fuel storage facilities throughout the area would facilitate planning of other emergency response efforts that will be dependent on these sources of fuel.

**Planning Scenario**

The primary pipeline to the tank farm is expected to survive with minor or no damage along most of its length. The pipeline may be damaged by landslides along the edge of Murphy Canyon or by differential settling/lateral spreading as it approaches the tanks. Liquefaction-induced spreading and internal sloshing will cause some damage to the tanks. For planning purposes, a fire may be assumed to follow the earthquake. Depending on the extent of liquefaction-induced tank damage, the fire may or may not be controlled by pipeline company personnel.

The fuel facility on San Diego Bay will be severely damaged. A spill and possible fire can be expected to follow the earthquake.

The Navy pipeline will be damaged where it crosses the Mission Bay-Loma Portal area. It is assumed that the pipeline will not pose a hazard to the area (i.e., no fire ensues), but that it will be nonoperative for several days to weeks following the earthquake.
Damage Assessments

Damage assessments have been postulated for certain petroleum-related facilities. The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map 4-P.

<table>
<thead>
<tr>
<th>MAP NO.</th>
<th>FACILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Murphy Canyon terminal facilities</td>
</tr>
<tr>
<td></td>
<td>Localized landslides and liquefaction-induced differential settling will cause moderate damage at the juncture of the pipelines and terminal facilities. Slight damage to storage tanks will result from the settling and from sloshing liquids.</td>
</tr>
<tr>
<td>P2</td>
<td>Tenth Avenue Pier Terminal</td>
</tr>
<tr>
<td></td>
<td>Lateral spreading, induced by liquefaction of the artificial fill, will result in severe damage to terminal facilities.</td>
</tr>
<tr>
<td>P3</td>
<td>Navy fuel pipeline</td>
</tr>
<tr>
<td></td>
<td>Pipeline will break in several places where crossing poor ground in the Mission Bay and Loma Portal areas.</td>
</tr>
</tbody>
</table>
Figure 5. Existing metropolitan sewer system, San Diego.
WASTE WATER SYSTEM

General Characteristics

The Metropolitan Sewerage System serves virtually all of the populated metropolitan area of San Diego and adjacent communities south of Del Mar, extending south to the Mexican border and east as far as Spring Valley and Alpine. The system collects, transports, pumps, treats, and disposes of the liquid waste from the cities of Chula Vista, Coronado, Del Mar, El Cajon, Imperial Beach, La Mesa, Lakeside, Alpine, Winter Gardens, National City, and San Diego; and from the Lemon Grove, Poway, Rolando, and Spring Valley sanitation districts, and the Padre Dam Municipal Water District. The city also has an "emergency" connection to Tijuana which is in use about 80 percent of the time. Under some circumstances, 10 to 12 million gallons of waste water from Tijuana can be processed through the San Diego system each day. The total flow of waste water, all of which is treated at the plant on Point Loma, is currently about 180 million gallons per day.

A number of pumping installations and major collecting mains bring this waste water into the Metropolitan Sewerage System, connecting into the mains which generally skirt the easterly edge of San Diego Bay. Included in the Metropolitan Sewerage System are about 22.5 miles of main interceptors, two pumping stations on East and North Harbor Drives, the Point Loma Treatment Plant, and an ocean outfall over 14,000 feet in length which discharges the treated effluent into the Pacific Ocean at a depth of over 200 feet (see Figure 5). The southerly terminus of the system is in Imperial Beach. An interceptor extends northward to Pumping Station Number 1, which is located close to the boundary between San Diego and National City. Pump Station Number 1 handles about one-third of total flow from the system (60 million gallons per day). This flow is pumped to a point at the intersection of 26th Street and Newton Avenue, where it enters a tunnel. From this point the sewage flows by gravity through the tunnel beneath downtown San Diego, continuing through an interceptor to Pumping Station Number 2, which is located immediately west of Lindbergh
Field on the north side of Harbor Drive. At this point, the southerly metropolitan sewer line converges with major interceptor lines from the north and east so that the total flow of 180 million gallons per day is pumped through Station Number 2. The discharge from Station Number 2 is split into two force mains, one of which goes under water through the northerly side of San Diego Bay, and the other of which follows along the southerly shore of Point Loma to the portal of another gravity flow underground tunnel crossing Point Loma. The flow continues by gravity to the Metropolitan Treatment Plant on the southerly tip of the west side of Point Loma.

Pipelines throughout the system, which vary in diameter from 72 inches to 114 inches, are of bell and spigot, reinforced concrete with a typical section length of 16 feet. A large percentage of the length of the system is located in zones of high potential liquefaction and severe ground shaking.

**Pumping Stations**

Pumping Stations Numbers 1 and 2 are of similar design. Both pumping stations are of reinforced concrete design with raft foundations designed to "float" in the bay mud deposits, which extend to depths of 60 to 100 feet. Pumping Station Number 2 is approximately 40 feet deep from ground level to its foundation. Pumping Station Number 1 is approximately 35 feet deep. Both stations depend upon electric power from San Diego Gas & Electric Company for their operation. Each has a dual source of power from the north and the south so that a switch-over can take place in the event one system or the other is out of use.

The pumping stations have the capability of being shut down for not more than 1 1/2 hours maximum during daytime hours without overflow of the system. During nighttime hours this period is from five to six hours. Overflow, if it occurs, would be delivered into
San Diego Bay or the San Diego River at designated spill points. The gravity flow lines into each pumping station are approximately 36 feet below ground level with 30 feet cover. The discharge force mains are at a shallower location with five feet of cover.

San Diego Gas & Electric substations serving the pumping stations are immediately adjacent. The operation of the pumping plants depends on fresh water. At Station Number 2, two 16 inch water mains serve the facility, one on either side of Harbor Drive.

**Point Loma Disposal Plant**

The plant provides advanced primary treatment for the waste water. It consists of eight large sedimentation basins and six sludge digestors. These elements are of reinforced concrete construction and are designed to seismic-resistant standards. Bypass gates are available which can divert sewage directly to the outfall in case of failure of the plant in its operation. Sludge is pumped through an eight mile long pipeline to a disposal field on Fiesta Island in Mission Bay.

The plant is dependent upon electric power for its operation and is served by the San Diego Gas & Electric Company. An alternate source of power is available, consisting of a Digester Gas Utilization Plant, which produces more than twice the amount of power that the plant needs. Additional power is soon to be produced by a hydroelectric system involving the conversion of the effluent waste water into electrical energy as it drops 90 feet between the plant and the ocean outfall. The plant is dependent on water for its operation, and it has a one day supply in tank storage located above the plant.
Seismic Considerations

Sewage collection systems are susceptible to earthquake damage as a result of broken underground collectors and interceptor pipelines. These lines are relatively brittle clay or reinforced concrete and can tolerate little movement without fracture. The magnitude of the damage is dependent on the size of the urban area affected by strong ground motion; damage is greater where permanent ground movements occur due to fault rupture, landslide, or poor ground conditions. The distribution of damage will be similar to that suffered by other buried conduits, such as those carrying water, natural gas, and petroleum products.

The time necessary to determine the overall damage and to make repairs to a damaged collection system depends on the area involved and the availability of manpower, equipment, and materials. For example, in the relatively small area affected by the 1971 San Fernando earthquake, 145 km (90 miles) of sewer lines were surveyed by pulling television cameras through them. From a practical standpoint, the sewer-collection lines will not be used significantly until the adjacent water distribution systems are restored.

Treatment plant buildings, tanks, piping, smokestacks, machinery, and equipment are all subject to earthquake damage. If the treatment plants are inoperable, untreated sewage must bypass the plant and be dumped onto spreading beds and into rivers or the ocean.

A. Pipelines and Tunnels

The pipelines for the Metropolitan Sewerage System, most of which extend along the easterly shore of San Diego Bay, are predominantly located in zones of potential liquefaction and severe ground shaking. They are generally below the water table in sandy, silty soils. Rupture of these lines, which is most likely in areas of liquefaction, would involve massive excavation, pumping, and shoring operations to gain access to the point of rupture. The availability of spare pipe sections to complete the repairs is
questionable, and other means of restoring the conduit would have to be considered in many cases. Repairs at the deeper locations (30 feet cover) are estimated to require a minimum of ten days to finish under emergency conditions with repair crews working 24 hours per day. For planning purposes, allowing for non-availability of the required pipe, three weeks is postulated to be necessary to make a repair and resume service.

The sewer tunnel under downtown San Diego (which carries 33 percent of the total flow of the system) crosses the northerly trace of the Silver Strand fault. Repair of a rupture of this tunnel, which is located as much as 90 feet below the streets of downtown San Diego, is not practical on an emergency basis. For planning purposes, repair of the tunnel will require four months under conditions when other more urgent reconstruction is in progress. During this period, the sewage would be spilled into San Diego Bay.

The tunnel crossing Point Loma, which is 108 inches in diameter, is not susceptible to the liquefaction problem but at its westerly terminus enters a zone of potential landslides. Thus, for planning purposes it is assumed that this conduit will rupture at or near its point of entry into the treatment plant. Untreated sewage will be diverted into the ocean.

B. Pumping Plants

Both Pumping Plants Numbers 1 and 2 are subject to differential settlement due to liquefaction. Pumping Plant Number 1 is located in a zone of high-potential ground shaking damage. It is expected that the electric substation serving this station would not be usable and that the waste water mains entering and/or leaving the station would be ruptured at their point of connection. In this station, as well as in Pump Station Number 2, the electric switch gear within the station is inadequately anchored and braced. For planning purposes it is expected to topple over and be out of service for
seven days. Sewage will be discharged into San Diego Bay. Pump Station Number 2 is probably the most vital spot in the entire system, and in this scenario it is the place where serious long-term damage will occur. This pump station handles the entire sewage flow of the metropolitan area. In case of its outage, sewage would be discharged into the San Diego River on the north side of Point Loma or alternately into San Diego Bay, or possibly both. This could take place for a considerable period of time, if the Pumping Plant Number 2 were to settle differentially under liquefaction conditions or suffer structural damage. For planning purposes, it is assumed that the pumping station will shift or settle under liquefaction and be functionally impaired for 45 days.

Interceptor mains on the intake side of the Pumping Station Number 2, which are located approximately 36 feet below grade, might be expected to shear at their connection to the building and require repair under the adverse conditions of deep excavation, shoring and pumping. For planning purposes, 45 days will be required to make this repair.

Discharge manifolds carry the flow from Pumping Station Number 2 on the discharge side to the dual force mains for transport to the tunnel on the south side of Point Loma. These manifolds are located above ground and are susceptible to ground shaking damage. It is expected that they would be out of service for less than three days since they could be readily repaired by welding steel plates and taking other emergency remedies. The dual lines from Pumping Station Number 2 to the Point Loma tunnel provide redundancy in the system since either line can carry the entire flow under emergency conditions.
C. **Point Loma Treatment Plant**

The Point Loma Treatment Plant is not expected to suffer serious damage. It is of good construction and is located on stable ground. However, the road leading to the plant is assumed to be out of service for two days due to earthquake-induced landslides restricting access to the site. Landslide conditions will also rupture the line bringing the flow directly to the plant. Four weeks is the postulated time for repair of such a break during which the sewage flow would be diverted to the ocean. In the event of loss of water supply for more than one day, the treatment plant will cease to operate since the capacity of its water storage tank provides for only one day of use.

**Planning Scenario**

For planning purposes, the flow capacity of the collection system carrying waste water to the Metropolitan Sewerage System will be reduced by 50 percent, and for 50 percent of the area served, the system will be nonfunctional. The main interceptor will be out of service for six weeks. Rupture of the tunnel below the streets of downtown San Diego means that it will be out of service for four months during which period raw sewerage will be discharged into San Diego Bay.

Pumping Station Number 2, the most vital spot of the entire system, will be functionally impaired for 45 days. Lines to the Point Loma Treatment Plant will be ruptured due to landslide conditions with four weeks required for repairs. During this period raw sewerage will be discharged into the ocean or the San Diego River. Surface access to the Point Loma Treatment Plant will be disrupted for two days due to landslides in the area.

As a result of the anticipated damage to the San Diego Metropolitan Sewerage System described above, for planning purposes the waste water connector line from Tijuana will be interrupted for 60 days before normal service is restored.
Figure 6. San Diego County Water Authority and its member agencies.
WATER SUPPLY

General Characteristics

San Diego County is a semiarid region and depends almost entirely on water imported from other areas. An adequate supply of water is critical during emergencies, not only for drinking purposes and fire fighting, but also for the operation of other utilities, such as waste water treatment. Lack of cooling water for air conditioning units can affect many computer operations.

The San Diego County Water Authority (Figure 6), which encompasses a 1412.5 square mile area, serves a population of approximately 2,106,000. It receives its supply of water from the Metropolitan Water District of Southern California (MWD) at a location within San Diego County approximately six miles south of the Riverside/San Diego County line. The MWD is the sole source of the normal and supplemental water for San Diego County, accounting for 90 percent of the total water supply to the county. In turn, the County Water Authority supplies 97 percent of San Diego County’s population. The current water demand, for the area under the San Diego County Water Authority, is approximately 525,000 acre-feet per year.

San Diego County Water Authority

The San Diego County Water Authority picks up its supply of water from the MWD via two aqueduct systems (Map 4-W). Aqueduct Number 1 was constructed from 1946 to 1954. It consists of two 48 inch diameter steel pipelines. The two pipelines of this aqueduct system are operated as single unit within San Diego County. Aqueduct Number 1 goes through seven separate tunnels before it reaches the San Vicente Reservoir. Aqueduct Number 2 was constructed from 1960 to 1982 and consists of three pipelines, varying in size from 97 inch diameter to 66 inch diameter. There are no tunnels along this aqueduct. All three pipelines,
which are of varying lengths, are operated separately. The pipe sections are made of steel in some locations and prestressed concrete cylinders in other locations. Most pipeline joints are of the bell and spigot type. Corrosion problems in some portions of the prestressed concrete lines south of La Mesa have resulted in the rehabilitation of 10,500 feet of the 66 inch diameter line. Rehabilitation was effected by inserting a steel liner inside the prestressed pipe. A cross-over connection between the two aqueduct systems north of Escondido provides operational flexibility.

The facilities and equipment maintained by the authority include: the Operations Center buildings, shops and yard; about 222 miles of major pipelines; 69 buildings housing meters and control equipment; a large volume chlorine station; a pump station containing three pumps with motors from 400 to 1,000 horsepower, capable of pumping about 180 cubic feet per second; and over 900 underground valve vaults.

The central control center for the San Diego County Water Authority’s aqueduct system and the hydroelectric plants is located in Escondido. A back-up emergency generator is located at the center; however, this generator must be manually started. A staff of 37 provides all operational and maintenance repair on the aqueduct system, as well as construction and modification of metering and control buildings. The longest reported emergency downtime for service to a user agency since 1955 was a 72 hour period in 1980 due to a pipe break in Spring Valley.

Aqueduct Number 2 is located approximately nine miles from the northern portion of the Silver Strand Fault Zone, whereas Aqueduct Number 1 is approximately 18 miles away. Aqueduct Number 2 passes through a region of identified coherent landslides just north of the Lake Murray Reservoir and through a region susceptible to seismically induced landslides immediately west of Lower Otay Reservoir.
The San Diego County Water Authority delivers water to 24 member agencies in the County of San Diego, one of which is a military reservation. Table 6 lists the 24 member agencies, and Figure 6 indicates their locations.

### TABLE 6
MEMBER AGENCIES
SAN DIEGO COUNTY WATER AUTHORITY

| Bueno Colorado Municipal Water District, Vista | Pendleton Military Reservation, Camp Pendleton |
| Costa Real Municipal Water District, Carlsbad | City of Poway, Poway |
| City of Del Mar District, Del Mar | Rainbow Municipal Water District, Fallbrook |
| De Luz Heights Municipal Water District, Fallbrook | Ramona Municipal Water District, Ramona |
| City of Escondido, Escondido | Rincon del Diablo Municipal Water District, Escondido |
| Fallbrook Public Utility District, Fallbrook | City of San Diego Water Utilities Department, San Diego |
| Helix Water District La Mesa | San Dieguito Water District, Encinitas |
| City of National City District, National City | San Marcos County Water District, San Marcos |
| City of Oceanside District, Oceanside | Santa Fe Irrigation District, Rancho Santa Fe |
| Olivenhain Municipal Water District, Encinitas | South Bay Irrigation District, Chula Vista |
| Otay Water District, Spring Valley | Valley Center Municipal Water District, Valley Center |
| Padre Dam Municipal Water District, Santee | Yuima Municipal Water District, Pauma |
Twelve major dams are located within the San Diego study area of this scenario and one major dam is located in the Tijuana area. Dams are owned and maintained by the individual water districts. The water districts work together with the California Department of Water Resources, Division of Safety of Dams. The closest to the Silver Strand fault is the Lake Murray Dam, approximately eight miles from the northern extension of the fault zone. The Lake Murray Dam is a multiple arch concrete dam, constructed in 1917. This dam suffered a minor leak as a result of the July 13, 1986 earthquake (M5.3) (epicenter approximately 25 miles west of Solana Beach). Further information on the assessment of dams is presented below.

The amount of water storage available in San Diego County varies significantly among the different districts. The supply varies anywhere from three days to several years. For example, currently Lake Murray, San Vicente Reservoir, and El Capitan Reservoir (Alvarado Filter Plant) have an approximate six to seven month supply; and Miramar Reservoir (Miramar Filter Plant) has a 15 to 25 day supply. The supply at Miramar Reservoir could be supplemented by Lake Skinner in Riverside County. On the other hand, the group of reservoirs consisting of the Morena, Barrett, Upper Otay, and Lower Otay reservoirs has an estimated 6.2 year storage. San Vicente Reservoir, with a usable storage capacity of 89,800 acre-feet, is the main storage reservoir for the City of San Diego.

There are ten water treatment plants in San Diego County. The City of San Diego has three filtration plants: Alvarado Plant located at the Lake Murray Reservoir, Miramar Plant at Miramar Reservoir, and Otay Plant at Lower Otay Reservoir.

The City of San Diego has an ongoing program of pipe replacement for its water distribution system. Some of the older cast iron pipes have been in service for 50 to 60 years. The current City of San Diego distribution system has asbestos cement pipe accounting for 76 percent of the system, cast iron 15.6 percent, and the remainder is a mixture of PVC, wrought iron, ductile iron, steel, and copper.
**Potable Water**

Potable water for the San Diego region is taken directly from the aqueduct systems and from local storage after being imported via aqueduct systems. Map 4-W shows the locations of the two aqueduct systems, major storage reservoirs, and primary distribution mains in the planning area. Since most of the water system flows from the hills in the east toward the coast, major disruption of the system is not anticipated. Disruptions, if they should occur, will most likely be in high-pressure areas (that is low points in the aqueduct system). The prestressed concrete portions of the aqueduct system will be more vulnerable to failure than the steel sections. Water distribution lines will be seriously impacted in areas of severe shaking (high VIII to IX), or where there is liquefaction-induced settling and lateral spreading.

**Seismic Considerations**

It is anticipated that all water systems within the region will suffer some damage. In areas of intense shaking and/or ground failure, two to four main breaks in every residential block will be common where cast iron or asbestos cement pipe is used. There were some reports of broken pipes following the October 28, 1986 earthquake in southeast San Diego (M4.1). The earthquake vulnerability of underground pipe in areas of ground failure will generally be greatest for the asbestos cement pipes followed closely in level of vulnerability by cast iron; also, steel pipe with caulked joints or gas welded joints will perform poorly. Steel pipe with arc welded joints will show superior performance (Eguchi, 1983). PVC piping, especially where it has had exposure to sunlight (such as piping to roof-mounted equipment), will also suffer considerable damage in regions of strong ground shaking. In regions of acidic soils where significant corrosion has occurred, both cast iron and steel piping will obviously suffer a greater relative failure rate. Where such general
damage to the water distribution system occurs, restoration of water mains begins at the lowest topographic point, progressing uphill so that broken sewers in the same areas do not contaminate still broken water lines.

The difficulty in determining the extent of damage to the distribution system is that leaks may not be located until water pressure is restored. For this reason, it will take weeks to totally repair damage in the densely populated, heavily damaged areas. Fresh water for domestic purposes will have to be supplied by tanker trucks to seriously affected neighborhoods.

Fire fighting efforts will be seriously hampered in some areas during the first 72 hours. This condition is not only because of a lack of water, but also because of blocked streets, insufficient manpower, and possibly structurally damaged fire stations.

Water supply to Point Loma Waste Water Treatment Plant and to the main waste water pumping stations will be disrupted, as will the water supply to SDG&E’s South Bay Power Plant. A shut off of fresh water to the South Bay Power Plant would be critical. For planning purposes, shut down of the power units would result. Available water storage capacity at the power plant is adequate for two to five days. The water pumping plants that are dependent upon SDG&E will be required to curtail their operations, which will in turn affect fire fighting operations.

Distribution system damage and water outages will occur in the structurally poor ground areas within coastal San Diego south of La Jolla, in the Mission Valley and Loma Portal areas and in poorly consolidated fill areas. Elsewhere, the water distribution system is expected to remain mostly intact, and significant outages will be few and controllable, commensurate with availability of spare pipe, fittings, degree of repair crew efforts and accessibility. For scenario purposes, 90 percent of the water outages in the structural poor
ground areas should be restored within two weeks by above-ground piping similar to that which was used in San Fernando. There are stockpiles of large pipe sections that will permit relatively rapid repair (within three days) of damage to the aqueduct system.

Chlorine facility anchorage and chlorine spill control programs will determine the degree to which chlorine spills threaten population near both water and waste water treatment plants. In San Diego, the probability of chlorine spills posing any significant threat to the population appears remote. However, for planning purposes a chlorine spill is postulated to occur at one of the water treatment plants in the San Diego Water Utilities Department system. It will take 24 hours to completely clear it up.

Planning Considerations

The major water supply (90 percent) to the San Diego area is provided by a single source (the MWD) via two primary aqueduct systems. The major storage reservoir is at San Vicente. The vulnerability of each of these systems within the study area must be appraised as well as the debilitating consequences of failure to the source resulting from rupture of the San Andreas fault to the north of Los Angeles.

The individual components of each system—the water source, aqueducts, local storage reservoirs (including dams), pumping stations, transmission pipelines, and distribution lines—must be viewed in the context of the entire system and its performance. Impairment of any one major element could seriously compromise the performance of the entire system. Effects on other systems, such as electrical power and waste water treatment, must also be kept in mind. For emergency planning purposes, it is important to recognize that the total effects make each system’s overall performance more vulnerable than casual examination of individual components might suggest.
It is essential that all water agencies examine their transmission and distribution system in detail to identify areas and facilities most likely to be impaired. Existing programs should be reviewed and new programs should be established and maintained to progressively upgrade facilities of questionable seismic resistance in areas of high vulnerability.

Capabilities to provide emergency distribution of potable water by means of ground transportation need to be planned in areas identified as having a significant possibility of water system damage.

**Water Supply Connection to Mexico**

Under the auspices of the joint U.S./Mexico Bi-National Water Commission, an emergency water supply connection to Tijuana was established in the late 1960's through the Otay Municipal Water District. In the late 1970's, after the emergency drought period subsided, Mexico abandoned use of the connection as it was no longer needed, and the metering devices were removed. The physical connection is still in place with all necessary mechanical equipment intact except for the metering devices. The San Diego County Water Authority indicates that metering devices could be reinstalled within 48 hours. Periodic testing of this connection would be prudent to insure its dependability for emergency usage.

**Planning Scenario**

For the scenario earthquake, the areas of the water distribution system most vulnerable to damage are those bordering Mission Bay and San Diego Bay, coastal areas, western Mission Valley, and the Otay (Tia Juana River) Valley. Mains (both primary and secondary) passing through these areas of recent alluvium and artificial fill will suffer several breaks per mile of pipe. Landslides in the Soledad Mountain area, coastal regions of La Jolla, the north wall of Mission Valley, and the edges of Otay Mesa may also damage facilities and distribution mains. As a result, several of the areas will be without water for up to four weeks following
the scenario event. For planning purposes, it is assumed that parts of La Jolla, Pacific Beach, Ocean Beach, and Mission Beach will be without water for up to four weeks following the scenario earthquake.

For the purpose of emergency response planning, two dams, Rodriguez on the Mexican side (approximately 11 1/2 miles from the Silver Strand fault) and Savage (lower Otay) on the U.S. side (approximately 13 miles from the Silver Strand fault), are assumed to be damaged and possibly near failure. For planning purposes, downstream population in the inundation areas will be evacuated. If failure does not occur, residents will be allowed to return home after three days. This assumption is not based on a specific assessment of the safety of either dam but is included as an example of a near-failure to facilitate emergency planning.

Failure of Rodriguez Dam would severely restrict access to and egress from the international border and adjacent communities. Failure or near-failure of Savage Dam would only involve planning on the U.S. side. One need not assume that both dams have failed or will fail, but the differences in planning approaches necessitated by the existence of the international border must be understood and various contingencies thought out.

The San Diego County Water Authority made a tour of Rodriguez Dam and the Tijuana Aqueduct system in November 1985 to explore prospects with Mexican and Imperial Irrigation District officials of a potential source of supplementary water for San Diego County. The dam, which was not visited as part of this study, is situated upstream of the developing Tia Juana River Valley and the San Ysidro-Tijuana border crossing, the busiest international border crossing in the world. Of the two dams, Rodriguez Dam is the closest to the scenario earthquake fault zone.
For planning purposes, it is projected that one of the San Diego County Water Authority aqueducts in the north will fail with an estimated service outage of 1 1/2 months. Total water supply to member agencies will be reduced to 80 percent for three months. Those with a water storage supply of less than six months, such as those dependent on the Miramar Reservoir which has a 15 to 25 day supply, would be severely restricted, and they would be forced to rely on other means of emergency water supply during this period. One member agency, which has a limited three day supply of water, would be quickly dependent on outside sources of potable water.

Facilities whose operation is dependent on water supply, such as the Point Loma Waste Water Treatment Plant (one day supply of water storage) and the SDG&E South Bay Power Plant (two to five day supply of water storage capacity), will be functionally impaired due to the lack of water indicated in their respective sections of the report.

Because of failures in local water distribution systems, segments of the population will be asked for a period of time (one day minimum, four day maximum) to use emergency supplies, boil their water, or take other measures against contamination.

For planning purposes, it must be emphasized that the water supply is the single most critical element in the study area. The significance of the problem increases exponentially if the scenario earthquake occurs after a dry year, such as 1978. Water supply systems are expected to be moderately to severely crippled in this scenario earthquake. Restoration of full service could take months.

Due to the public's crucial need for water and the critical nature of the system, it is assumed that highest priorities will be given to the restoration of electric power supplying water facilities. It is, therefore, expected that emergency electric power will be provided by some means to all major pumping and treatment facilities.
**Damage Assessments**

Damage assessments have been postulated for certain potable water and waste water facilities. The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map 4-W.

<table>
<thead>
<tr>
<th>MAP NO.</th>
<th>FACILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>Storage Facilities, Mt. Soledad</td>
</tr>
<tr>
<td></td>
<td>Local landslides and strong shaking damage older storage facilities and distribution pipelines located near the crest of Mt. Soledad. Storage facilities will be out of service for several weeks.</td>
</tr>
<tr>
<td>W2</td>
<td>Lower Otay Reservoir</td>
</tr>
<tr>
<td></td>
<td>For planning purposes, Savage Dam is assumed to be damaged and possibly near failure. Downstream populations are evacuated for three days.</td>
</tr>
<tr>
<td>W3</td>
<td>Waste Water Tunnel beneath Downtown San Diego</td>
</tr>
<tr>
<td></td>
<td>The waste water tunnel beneath the streets of downtown San Diego is damaged and suffers partial collapse. It will be out of service for four months.</td>
</tr>
</tbody>
</table>
W4  **Metro Number 1 Pump Station**

Local liquefaction and strong shaking damage the Metro Number 1 Pumping Station. The electrical substation serving the station is damaged. Waste water mains entering and leaving the station are ruptured at their points of connection. The station will be out of service for seven days.

W5  **Metro Number 2 Pump Station**

Damage is similar to, but more severe than, that at the Metro Number 1 Pump Station. The station will be out of service for up to 45 days.

W6  **Metro Waste Treatment Plant, Point Loma**

The Point Loma waste treatment plant is not severely damaged.

W7  **Tijuana Coastal Aqueduct**

The coastal potable water aqueduct servicing Tijuana is ruptured at several points by local landslides. Service will not be restored for up to 60 days.

W8  **Rodriguez Dam and Reservoir**

For planning purposes, Rodriguez Dam is assumed to be damaged and possibly near failure. Downstream populations are evacuated for three days.
DAMS

Introduction

There has been increased interest in the seismic safety of dams in recent years, and protection of the public from the consequences of dam failure has increased in importance as urban growth has concentrated populations in vulnerable areas downstream from existing dams. This increased interest is because of:

- The occurrence of several disastrous incidents involving uncontrolled releases of impounded waters (for example, Vaiont in Italy, Malpasset in France, and Machha II in India, and in the United States such dams as Buffalo Creek, Bear Wallow, Baldwin Hills, Teton, Toccoa Falls, and Laurel Run).

- Several near failures (severe damage) because of earthquakes, for example, the Koyna Dam in India in 1967 and the Upper and Lower Van Norman (San Fernando) dams in California in 1971.

- The results of the U.S. National Dam Inspection Program conducted by the U.S. Army Corps of Engineers, in which one-third of the approximately 9,000 dams inspected (all in high-hazard situations) were tentatively classified as unsafe.

- The realization that improvement of dams in the United States to meet current safety standards would have very high costs, and that finding funds to improve many dams would be difficult.

- The recent activity in many states to regulate privately owned dams in the interest of public safety.
On the average, about ten significant dam failures have occurred somewhere in the world each decade, and many more near-failures have occurred. Some of these events resulted from incorrect decisions made during the design and construction process; whereas others were the consequence of inadequate maintenance or operations mismanagement. Many resulted from unanticipated large floods, and others resulted from intense earthquake shaking.

The water retained in a large reservoir has enormous potential energy. When released uncontrollably, it can cause extensive loss of life and damage to property downstream. In fact, few activities of man pose greater potential for destruction. Accordingly, engineers tend to take very conservative approaches in designing dams; however, the more conservative the design, the greater the cost of the dam. Relatively few dams will experience the extreme events for which they are designed; but such events are difficult to quantify; and, therefore, conservative designs generally are provided for most dams to avoid catastrophic failures of a few.

San Diego experienced such a catastrophe one day in 1916. On January 27, a flood overtopped the Lower Otay Dam, resulting in the collapse of the dam. The Lower Otay Dam was built in 1897; it was a dumped-rock fill structure, 130 feet high and 565 feet long. The flood overtopping eroded the downstream fill within a few minutes, causing the upstream embankment to open like a pair of giant gates. The reservoir emptied in about 2 1/2 hours, and a flood wave estimated to be 20 feet high swept ten miles down the Otay Valley, destroying everything in its path and killing 30 people. The loss of life was minimized somewhat because dam owners sounded alarms and sent men downstream to warn and evacuate residents.

In California, we now have a reasonably good understanding of earthquakes, their effects, and the measures that can be provided in dam design to resist earthquake forces. The State of California has established the Department of Water Resources, Division of Safety of Dams (DSOD) to regulate dam safety and to judge whether reasonable care and
prudence have been exercised in the design of new dams and in the reevaluation of existing
dams. Dams in the San Diego area are listed in Table 7. All have been or are presently in
the process of being carefully evaluated by the DSOD for their safety during earthquakes.

**Dam Failure Scenarios**

Catastrophic failure of a major dam as a result of the scenario earthquake is regarded as
unlikely. Current design and construction practices, and ongoing programs of review,
modification or total reconstruction of existing dams are intended to ensure that all dams are
capable of withstanding the maximum earthquake for a site. In the previous section, the two
dams closest to the scenario earthquake are, for emergency response planning purposes,
considered to be damaged sufficiently to cause downstream evacuation while drawdown
occurs. However, for all dams in the zone of high shaking, minor damage from shaking,
landslides or seiches can cause concern for public safety. Therefore, in this section we
consider failure scenarios for dams north of the border within the area of strong shaking.

For emergency response planning purposes, it is recommended that emergency plans be
considered for the Savage Dam, which impounds the Lower Otay Reservoir; the Sweetwater
Dam, which impounds the Sweetwater Reservoir; El Capitan Dam, which impounds El
Capitan Reservoir; the Murray Dam, which impounds Lake Murray, and the Rodriguez Dam
in Mexico. These dams are likely to be exposed to intense and significantly long-duration
shaking during the scenario earthquake.

For the purposes of emergency response planning, following are failure scenarios for
each of the above-mentioned dams. The preparedness plans should include evacuation of pre­
selected areas that represent the relative highest hazard given the scenario earthquake.
### TABLE 7
### DAMS IN THE SAN DIEGO AREA

<table>
<thead>
<tr>
<th>Dam</th>
<th>Storage (Acre feet)</th>
<th>Crest Height (feet)</th>
<th>Length (feet)</th>
<th>Type</th>
<th>Year Completed</th>
<th>Distance To Fault (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrett</td>
<td>44,755</td>
<td>161</td>
<td>750</td>
<td>Concrete Gravity</td>
<td>1922</td>
<td>28</td>
</tr>
<tr>
<td>Morena</td>
<td>50,206</td>
<td>181</td>
<td>550</td>
<td>Rock Fill</td>
<td>1912</td>
<td>36</td>
</tr>
<tr>
<td>Otay, Upper and Lower</td>
<td>59,151</td>
<td>50</td>
<td>350</td>
<td>Concrete Radius Arch</td>
<td>1928</td>
<td>12</td>
</tr>
<tr>
<td>(Savage)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweetwater</td>
<td>27,700</td>
<td>112</td>
<td>700</td>
<td>Concrete Gravity with Rock Fill</td>
<td>1888</td>
<td>22</td>
</tr>
<tr>
<td>Loveland</td>
<td>25,400</td>
<td>203</td>
<td>614</td>
<td>Variable-Radius</td>
<td>1945</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Concrete Arch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>El Capitan</td>
<td>112,800</td>
<td>237</td>
<td>1,170</td>
<td>Hydraulic Fill</td>
<td>1934</td>
<td>23</td>
</tr>
<tr>
<td>Cuyamaca</td>
<td>11,740</td>
<td>40</td>
<td>665</td>
<td>Earth Fill</td>
<td>1887</td>
<td>39</td>
</tr>
<tr>
<td>San Vicente</td>
<td>90,230</td>
<td>203</td>
<td>940</td>
<td>Concrete Gravity</td>
<td>1943</td>
<td>19</td>
</tr>
<tr>
<td>Hodges</td>
<td>37,700</td>
<td>131</td>
<td>729</td>
<td>Multiple Concrete Arch</td>
<td>1918</td>
<td>11*</td>
</tr>
<tr>
<td>Wohlford</td>
<td>6,900</td>
<td>100</td>
<td>422</td>
<td>Hydraulic Fill</td>
<td>1924</td>
<td>21*</td>
</tr>
<tr>
<td>Sutherland</td>
<td>29,000</td>
<td>161</td>
<td>1,102</td>
<td>Multiple Concrete Arch</td>
<td>1954</td>
<td>31*</td>
</tr>
<tr>
<td>Murray</td>
<td>6,085</td>
<td>110</td>
<td>870</td>
<td>Multiple Concrete Arch</td>
<td>1918</td>
<td>8</td>
</tr>
</tbody>
</table>

* Distance to the Rose Canyon fault (northern extension of the Silver Strand fault).

Savage Dam

The failure of this dam would result in flooding of the Otay Valley from the reservoir to San Diego Bay. This flooding would be similar to and with greater consequences than the tragic flood in 1916. Jurisdictions that would be affected include the City of San Diego, San Diego County, the City of Chula Vista, the City of Coronado, and the City of Imperial Beach. The area that would be inundated includes agricultural land, commercial and industrial properties, and some limited residential areas. The following highways and thoroughfares would be affected: State Highway 125, I-805, and I-5; in Chula Vista, Montgomery Freeway and Broadway; in San Diego, Industrial Boulevard, 19th Street, Sweetwater Road, Edgemere Avenue, and Fourth Avenue.

Sweetwater Dam

The area downstream of this dam, Sweetwater Valley, is occupied by two major golf courses (Chula Vista Municipal and Bonita), limited residential development, and some industrial development along the shores of San Diego Bay, including the Naval Station and the San Diego and Imperial Valley Railroad. The following highways and major roads would be affected: I-5, National Avenue, Highland Avenue, Edgemere Avenue, and Sweetwater Road.

El Capitan Dam

The failure of this dam would have the most serious consequences, causing widespread damage along El Monte Road and the San Diego River Valley, through the northern portion of El Monte Park, into the Moreno Valley, as far north as the intersection of Vigilante Road and Moreno Avenue, throughout northern Lakeside, northern Santee, and down the San Diego Valley to Mission Bay and the Pacific Ocean. Threatened areas in the inundated zone are highly populated and include the following public facilities: Lindo Lake School, Our
Lady of Perpetual Help School, El Capitan High School, Lakeside Farms School, Lakeside Middle School, Woodside Manor Convalescent Hospital, Home of Guiding Hands, Willow Brook Mobile Home Park, Willow Brook Country Club, Santana High School, Rio Seco School, Santee School, Las Colinas Correctional Facility, Edgemoor Geriatric Hospital, San Diego Stadium, Old Town San Diego, Sea World, and the development around Mission Bay. The following highways and thoroughfares would be affected: State Highway 67, El Monte Road, Wildcat Canyon Road, Mission Gorge Road, Magnolia Avenue, Friars Road, I-8, I-805, State Highway 163, I-5, and Midway Drive.

**Murray Dam**

This dam impounds a small reservoir that would inundate a portion of Mission Valley that has already been covered by the failure scenario for El Capitan Dam. The Alvarado Medical Center lies directly downstream.
GENERAL EMERGENCY PLANNING CONSIDERATIONS
GENERAL EMERGENCY PLANNING CONSIDERATIONS

A major earthquake will severely disrupt water, power, sanitation, and telephone service in the area. Virtually all homes and businesses will be without at least one of these essential services for various lengths of time. Several areas will experience a loss of all of essential services immediately following the earthquake. Some services in the most heavily damaged areas will require a few weeks to restore. The most extensive damage is expected in the areas bordering Mission Bay and San Diego Bay, western Mission Valley, Loma Portal, and in coastal areas. There will be a heavy demand for emergency repairs, assistance to the affected population, and public information. There will be a need among all emergency services to coordinate restoring essential services according to agreed upon priorities. Activities will be hampered by communications outages and transportation problems.

Although it was not part of this study to make estimates of casualties, it should be assumed that there will be numerous persons with injuries requiring medical treatment. Sufficient medical facilities should be functioning to care for the injured, but damage to the road network will hinder movement of the injured to those facilities.

Governmental and private sector resources in San Diego County will be fully involved in emergency response and recovery operations. In addition, assistance from outside the area will be needed. Any assistance requested for the Municipality of Tijuana will also have to come from outside the affected area. The nearest major source of support will be from the Los Angeles metropolitan area.

Vehicular access from the north may be feasible via I-15, but delays may be encountered at single-lane detours around some damaged interchanges. Air transport will be the quickest means of providing support from outside the area. Plans and agreements should be developed for use of Miramar Naval Air Station and Brown Field as Disaster Support Areas.
Movement of emergency responders and other resources within the area will be impaired by damage to roads, bridges, and overpasses and by debris, traffic congestion, and abandoned vehicles. Many persons who are within heavily damaged areas, but are not residents of the area, will be attempting to leave at a time when traffic signals are not working and major routes are blocked. The use of helicopters for movement of emergency personnel and resources should be planned.

Damage to the San Ysidro border crossing facilities, which are used by nearly 100,000 persons a day, will create serious problems. Many people will be at the border crossing at the time of the earthquake, and some will be injured depending on the time of day. Access to and egress from the border crossing will be impaired by highway detours. Thousands of people in both Tijuana and San Diego will want to return to their homes on the other side of the border. It will be necessary to rely on the Otay Mesa border crossing, or some other alternate crossing for an extended period. Access from Otay Mesa into San Diego may be impaired by damage to I-805 interchanges and by the close of I-5. Cross-border communications, which currently depend on telephones, will be severely disrupted.
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Appendix A

Modified Mercalli and Rossi–Forel
Intensity Scales
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.
   [I R.F.] shock is felt:
   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 noticeable:
   [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 heavy, or heavily 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.
Appendix A (continued)

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.

VI Felt by all, indoors and outdoors.
Frightened many, excitement general, some alarm, many ran outdoors.
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.
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.
Dilodge 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.
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.
Appendix A (continued)

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 chimney’s, columns, monuments, also factory stacks, towers.
Moved conspicuously, overturned, very heavy furniture.

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 with ran parallel to canal and stream banks.

[X R.F.] Landslides considerable from river banks and steep 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.
Appendix A (continued)

XII  Damage total—practically all works of construction damaged greatly or 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 cases).
     Distorted lines of sight and level.
     Threw objects upward into the air.
Appendix B

Earthquake Planning Scenario Maps
## INDEX TO APPENDIX B

**EARTHAQUAKE PLANNING SCENARIO**

**PLANNING AREA 4 - METROPOLITAN SAN DIEGO AND TIJUANA**

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<tbody>
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<td>Seismic Intensity Distribution</td>
</tr>
<tr>
<td>4-H</td>
<td>Acute Care Hospitals</td>
</tr>
<tr>
<td>4-U</td>
<td>High Schools, Colleges and Universities</td>
</tr>
<tr>
<td>4-J</td>
<td>Intermediate Schools</td>
</tr>
<tr>
<td>4-LF</td>
<td>Fire and Law Enforcement Stations</td>
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<td>4-W</td>
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