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EARTHQUAKE PLANNING SCENARIO
FOR A MAGNITUDE 8.3 EARTHQUAKE ON THE
SAN ANDREAS FAULT IN SOUTHERN CALIFORNIA

by

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EARTHQUAKE PLANNING SCENARIO
FOR A MAGNITUDE 8.3 EARTHQUAKE ON THE
SAN ANDREAS FAULT IN SOUTHERN CALIFORNIA

PURPOSE, APPROACH, AND DESIGN
OF THIS EARTHQUAKE PLANNING SCENARIO

Perspective: In 1857, just seven years after California obtained statehood, southern California experienced a great earthquake upon the south-central portion of the San Andreas fault. As this region has developed, it has been subjected to a number of smaller events that have done considerable damage. The 1971 San Fernando and 1933 Long Beach earthquakes have demonstrated the need for improved construction and institutional practices. New state legislation, changes in local policies, and revisions of the Uniform Building Code have since provided for the improvement of these practices.

The prospect of another large earthquake on the south-central San Andreas fault has been a latent source of concern in public policy over the years. During the mid-1960's earth scientists began to appreciate the dynamic motion of the earth's crust and to understand the role of the San Andreas and other tectonic plate boundary faults in such movement. This confirmed the inevitability of future large earthquakes on the San Andreas. In the mid-1970's the Palmdale bulge, or southern California uplift, drew attention to the state of deformation of the earth's crust in the vicinity of the San Andreas fault. Subsequent analysis of the geodetic data relating to the uplift and deformation since that time have demonstrated the complexity of such phenomena, but do not modify the prospect of a great earthquake.

During the late 1970's, K. Sieh explored the history of displacements created by large earthquakes on the south-central San Andreas by studying offsets in stratified materials that were exposed in trenches. The results of

this work have materially advanced the understanding of the frequency of great earthquakes on the segment of the San Andreas fault. A sequence of twelve large events have occurred on this portion of the fault over the last 2,000 years at various intervals ranging between 100 to 200 years, averaging about one large event every 140 years. During this decade we will mark the 130th anniversary of the 1857 event.

Challenge: Following the eruption of Mount St. Helens, the President requested the National Security Council to consider the implications of the occurrence of a large damaging earthquake in the State of California. The results of this analysis were presented in a report published by the Federal Emergency Management Agency (FEMA) in January 1981. Several conclusions were highlighted.

- o A large earthquake (M 8.3) on the south-central San Andreas fault is likely before the end of the twentieth century and is estimated to have a current annual probability of occurrence between two and five per cent.

- o First instance property losses for the M 8.3 event on the south-central San Andreas fault are estimated to be close to \$20 billion.

- o Depending upon the time of day or night, this M 8.3 event will kill between 3,000 and 14,000 people and cause between 12,000 and 55,000 people to require hospitalization.

- o A survey of local, State, and Federal government emergency plans indicated that although there is a general capacity to respond to small- and intermediate-sized earthquakes, it is unlikely that any of these units of

government can cope with a large earthquake such as a magnitude 8.3 event on the south-central San Andreas.

Workers in California generally agree with these conclusions. To California citizens the message is that we must anticipate the occurrence of large earthquakes which will overwhelm our present capabilities to respond adequately and in an organized manner both as a society and as individuals. Such sobering events satisfy the definition of the term "catastrophic" as it is used in this report.

Response: The conclusions of the National Security Council were communicated to the Governor of California by the President. In response, the Governor's Taskforce on Earthquake Preparedness was established in February 1981. The taskforce chairman, Dr. William Whitson, has established a group of committees designated to deal with improvement of functions such as communications, management of waste and water, search and rescue, fire fighting. In addition, the Threat Assessment Committee was created to characterize the outcomes of large earthquakes as a basis for improved emergency-response planning. The committee has been co-chaired by James F. Davis, the California State Geologist, and Karl V. Steinbrugge, structural engineer. Members of the committee include Rachel Gulliver, Mary Woods, Jan Hutton, Roger Sherburne, and Dennis Miletic.

Scenarios: The January 1981 FEMA report has underscored that the occurrence of a large earthquake on the south-central San Andreas is a matter which should engender immediate public concern. The Threat Assessment Committee, in conjunction with the chairman of the Taskforce, elected to use scenarios to serve as a basis for emergency planning. Selected for scenarios

were the M 8.3 event on the northern segment of the San Andreas which produced the 1906 San Francisco earthquake and the M 8.3 event on the portion of this fault which was the source of the 1857 earthquake in southern California.

The general plan of the committee is to forecast the physical effects of the northern and southern California scenario earthquakes. An analysis of the ground shaking and ground failure associated with the magnitude 8.3 event on the south-central San Andreas fault is presented in this scenario. This information, together with an assessment of the anticipated general damage patterns, constitutes the Earthquake Planning Scenario map series included in this report.

Earthquake planning scenarios are intended to portray the consequences of catastrophic earthquakes. By this means we communicate the message that it is possible to cope with the natural threats by personal, corporate, and government efforts in planning preparedness. Hopefully, this report will be constructive to such an end. We also intend that it will motivate a commitment to participation since it provides an understanding that planning and action will make a real difference in reducing the dimensions of the disaster.

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

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

- o Elected officials who must be able to visualize the threat in order to commit themselves to the leadership roles needed to cope with the earthquake.
- o Private-sector leaders and planners who must know about and understand the hazard in order to prepare for it.
- o Educators, journalists, and other public opinion makers who must appreciate the threat and communicate its character in order to motivate citizen commitment to preparedness.
- o The citizens of southern California who must support public mitigation efforts and develop personal strategies for themselves and their families in order to minimize the effects of the earthquake on their lives.

It is reassuring that many of these users are participating in the activities of the Governor's Taskforce on Earthquake Preparedness, which during 1981 and 1982 has numbered between 300 and 400 individuals.

EXECUTIVE SUMMARY

This scenario portrays anticipated damage to the highway, airport, railway, marine, communication, water, waste disposal, electrical power, natural gas, and petroleum lifelines that service the metropolitan areas in the Los Angeles Basin and environs when they are subjected to the large (magnitude 8.3) earthquake expected to take place during the lifetime of many of the current residents of southern California. Most of the lifelines will experience significant adverse effects. Coping with each of these results, taken alone, would require a major emergency-response effort. The combined impacts of all the lifelines being simultaneously impaired by the scenario earthquake will greatly escalate the problem. The added strain of dealing with the expected 3,000 to 14,000 dead and with the 12,000 and 55,000 casualties requiring hospitalization resulting from this earthquake will put an unprecedented demand upon government institutions, utilities, businesses, individuals, and society in general. The circumstances will be catastrophic, i.e., they will overwhelm our institutional and personal capacities to cope, unless public awareness and emergency preparedness can provide an adequate means of responding. The information presented in this report is intended to be a basis for such planning and preparedness.

The principal challenge in responding to the consequences of this event will be local transport of people and materiel within the planning area rather than access to the stricken region from the outside. Emergency preparations should be based upon the assumption that electrical power, communications, water supplies, and sewage treatment facilities will be significantly affected.

In developing this earthquake planning scenario, the California Division of Mines and Geology (CDMG) assumed the occurrence of a magnitude 8.3 earthquake on the San Andreas fault modeled on the great Fort Tejon earthquake of January 9, 1857. Besides information on the known effects of that earthquake, CDMG used a mathematical model for predicting the ground-shaking effects of great earthquakes (U.S. Geological Survey, 1981), supplemented by a designation for areas having potential for ground failure, to prepare a SEISMIC INTENSITY DISTRIBUTION map. This map was used as an aid in predicting the damage to lifelines and critical structures that would probably result from the scenario earthquake.

Because of the need to encompass all the affected major population centers, the SEISMIC INTENSITY DISTRIBUTION map (and the derivative lifeline damage assessment maps), were compiled on two sheets with some overlap of coverage between the two. The southern sheet (Map No.'s 2S-) encompasses most of the Los Angeles Basin and adjacent areas to the east, including the San Bernardino-Riverside area. The northern sheet (Map No.'s 2N-) encompasses the western part of the Los Angeles Basin and the Oxnard-Ventura area.

Intensity zones roughly paralleling the San Andreas fault are shown on the map as isoseismal areas--that is, as areas within which the anticipated seismic intensities, or local earthquake effects, are considered comparable. Each intensity zone is assigned an intensity rating based on the Rossi-Forel (R-F) scale (see Appendix).

A broad area to the north of the San Andreas fault in the Antelope Valley is shown on the map as an intensity 9 (R-F) zone because it is underlain principally by alluvial fan materials eroded from the San Gabriel Mountains.

A broad area to the south of the fault is shown as intensity 7 (R-F), or less than 7, because the substrate is mountain bedrock that has greater coherency than alluvial material.

The San Bernardino-Riverside area is shown as intensity 8 or higher because of its alluvial substrate. An area in San Bernardino and along the Santa Ana River is shown as intensity 9 (R-F) because of the presence of a high groundwater table and granular materials--a combination that also makes ground failure (by liquefaction) a strong possibility during a great earthquake. If fault rupture extended further southeast along the San Andreas fault than assumed for this scenario earthquake (based on the Fort Tejon earthquake), the San Bernardino area could experience intensity 9 (R-F).

The isoseismal values diminish to intensity 7 (R-F) southward and westward across the Los Angeles basin toward the coast at progressively greater distances from the fault. In the Long Beach and Huntington Beach areas, the Santa Clara Valley, and Ventura-Oxnard areas further west, the groundwater saturated substrates are considered to be intensity 8 (R-F) with ground failure potential. The San Fernando Valley is shown mostly as intensity 8 (R-F) because of the distance from the fault and the nature of the underlying unconsolidated materials.

These regional patterns of seismic intensity distribution associated with the scenario event were used in drawing the following scenarios for specific lifelines that service the greater Los Angeles region and adjacent communities.

Highways

Maps 2N-HA and 2S-HA display the regional effects of the scenario earthquake upon the highway system. In the southern portion of the metropolitan area, the highway system will be only locally impaired by the event, principally by damage in areas of intensity 8 (R-F) where ground failure occurs. Transportation routes through the mountains to the north will be significantly impaired and access from the high desert areas near Palmdale and Victorville will be difficult, if even possible, during the initial post-earthquake period. Interstate 5 from the north and Interstate 15 from the northeast will be closed, leaving U.S. 101 along the coast as the only major route open from the north. Highway connections with San Diego will remain open providing important routes for access into the area. Many highways within the Los Angeles Basin and environs will have significant delays because of damage.

Emergency planners should identify major emergency routes likely to be open immediately following the scenario earthquake. To prepare for the closure of some segments of the freeway system alternate emergency routes should be selected which are at grade, wide, and neither flanked by buildings likely to be damaged nor likely to be affected by overhead powerlines or other potential obstructions. This search for alternative routes is especially important in populous areas such as San Bernardino, portions of the San Fernando Valley, Newhall-Saugus area, and others where significant highway damage is probable. Several corridors should be established so that necessary flexibility is achieved.

Planning insights: Highway emergency response plans should be integrated with air, rail, and marine transport scenarios in order to provide a plan for integrated transportation capability. Access to the area with supplies and emergency assistance personnel from San Diego will be feasible. Distribution of people and materiel within the damaged areas will be more difficult than achieving access from outside the area.

Recommended further work: Assessment of highway performance and identification of alternative emergency routes is especially important in San Bernardino and other populated areas where major damage is apt to occur.

Airports

Most major air facilities within the region (see Maps 2N-HA and 2S-HA) are expected to have intact runways capable of landing military C-130 and C-141 cargo planes following the scenario earthquake. It is less certain how the control towers, fuel facilities, and electric power will fare. Air transport will play a vital role in moving people and materiel into the stricken area from the outside as well as search and rescue, damage assessment, and other critical air operations. Integrating the delivery system within the area however, will be challenging.

Planning insights: Plans for air cargo delivery should determine the extent that off-loaded people and supplies will be distributed by helicopters and highway, rail or marine transport. Preferred airports should be identified by the planning process discussed above and should be checked for auxiliary electrical power supply, integrity of buildings, and vulnerability of stored fuels in order to finalize transportation plans.

Recommended further work: The survival of the runways at Norton A.F.B. near San Bernardino and Los Alamitos Armed Forces Reserve Center in Orange County should be reappraised using data derived from recent subsurface investigations conducted especially for this purpose. The CDMG analysis indicates that runways at these two facilities could be damaged by ground failure (liquefaction) although the available information is not sufficiently complete to warrant a definitive conclusion.

Railroads

Maps 2N-RM and 2S-RM depict the earthquake planning scenario for railroads. Rail service from the north and east via the Palmdale and Cajon Pass corridors will be seriously affected by ground rupture and ground shaking. Rail transportation into the area from the north may also be impaired in the Ventura area. Some rail damage will be experienced in the vicinity of the marine terminals in the Long Beach harbor areas. Rail service within much of the Los Angeles Basin may still be feasible. Access to the Basin from San Diego should be possible. Rail facilities in the San Bernardino area, including yards and shops, will probably be significantly damaged. The major railroad companies have heavy equipment for the repair of their facilities which can be brought to the damaged area and set up in a relatively short time. Surviving rail service into the metropolitan areas from the outside will probably be limited to service from San Diego.

Planning insights: planning might involve importation of heavy equipment and emergency supplies from military installations in that area.

Integrated planning should be undertaken for air, highway, rail, and marine transport.

Recommended further work: The performance of railroad facilities in the Ventura and San Bernardino areas should be further investigated in order to evaluate their availability immediately following the earthquake, if response plans are established which depend upon these links.

Marine Facilities

The marine facilities (see Maps 2N-RM and 2S-RM) are anticipated to survive the scenario earthquake with only minor impact. Adjacent rail lines and other support facilities may, however, be impaired by damage due to liquefaction.

Planning insights: The importance of marine shipping into the area to satisfy the needs of the initial 72 hours after the earthquake needs to be evaluated. This should be a part of the correlation and integration of regional transportation. Nearby sources of supplies could be Oakland and San Diego.

Recommended further work: If marine transport is considered to be important to emergency planning, the performance of the marine terminals should be reappraised using more detailed information.

Communications

Telephone communications (see Maps 2N-C and 2S-C) will be adversely affected by overloading following the scenario earthquake. Calls within the area and from the outside will saturate telephone systems and significantly reduce their usefulness, especially since not all of the systems in the greater Los Angeles region are set up to process emergency calls automatically on a previously established priority basis. This situation will be further complicated by physical damage to some of the equipment due to ground shaking and perhaps some loss of service due to electrical power failure and possible subsequent failure of auxiliary sources of power.

This post-earthquake communications scenario is an estimate of how much the effectiveness of telecommunications systems will be reduced by the scenario earthquake. "Effectiveness" is defined as the ability of a system to perform to its design limits and provide the intended service. The effectiveness scale has then been applied to a three-day time frame. Four patterns of effectiveness over time were distinguished and used as the basis for zoning the study area (Zones A, B, C, and D). Zone D areas will have the greatest loss of effectiveness-over-time, Zone A the least. Much of the San Fernando Valley, where there is recent earthquake experience, is rated Zone D. The same is true for the Newhall area, which has additional access problems. The San Bernardino-Riverside area is rated Zone D not only because of the high shaking intensities that are predicted, but also because of anticipated inhibition of repairs by transportation difficulties; further, most of this area does not have line access control.

Following the scenario earthquake, radio systems will have an effectiveness ranging from about 40-75%. Microwave systems are an exception: most will be 30% effective or less.

Planning insights: A general communication plan should be developed for use to insure that key agencies and personnel have access to needed communications after the scenario earthquake. This plan should anticipate the needs of the most vital parties and of those who presently possess their own communications systems.

Reliance on the telephone system for communications should be kept at a minimum. A strategy should be developed for communication to the general public which relies upon the capabilities of surviving commercial radio and television stations.

Recommended further work: An inventory of commercial and amateur broadcasting capabilities should be undertaken and the resulting information employed in developing the regional emergency communications plan.

Water Supply and Waste Disposal

Maps 2N-W and 2S-W depict the earthquake planning scenario for water supply and waste disposal systems. Two of the three major aqueduct systems which cross the San Andreas fault will be ruptured and supplies will not be restored for a three- to six-month period. Water users in the Los Angeles region will have to rely primarily upon existing reservoir storage and the

Colorado River Aqueduct. Impairments to reservoir intake and outlet structures and distribution lines will locally affect water pressure and availability. For purposes of planning, one important reservoir is assumed to sustain damage necessitating emergency procedures to lower water levels and evacuate the downstream population. A number of water treatment facilities will be damaged and some will probably be without electrical power. Waste water treatment will be impaired by loss of power and damage to some sewage treatment plants. Collection lines will also be impaired causing significant contamination problems to the water supply in some areas.

Planning insights: Water supply agencies should develop public education procedures to acquaint water consumers with the possibility of contamination and loss of water supply. Plans for fire fighting should be coordinated with water supply agencies, and alternative sources of water for fire fighting should be planned for in areas where the danger of fire is greatest.

Recommended further work: Feasibility of emergency distribution of water using ground transportation should be considered in areas identified as likely to have impaired water availability.

Electrical Power

Maps 2N-E and 2S-E depict the earthquake planning scenario for electrical power. Approximately one-third of the power consumed in the greater Los Angeles region is imported via routes that will be subjected to intense shaking by this scenario earthquake. Immediately following the earthquake,

transmission of a significant portion of this power will be impaired. The power generated at the five hydroelectric plants north of Castaic and Devil's Canyon plant will be shut down. These losses, coupled with impaired generation capacity at Etiwanda and the major plants along the coast could cause a loss of about 25% of the capacity generated within the Basin. Most of the imported power will be lost, reducing power availability to about 50% of the normal level. Some substations near the fault may also be impaired.

Planning insights: Managing power with a short term loss of about 50% availability is important.

Recommended further work: Confirm the tentative conclusion that about 50% of available power could be lost during the immediate post-earthquake period. Assess capabilities to respond to an event of this magnitude.

Natural Gas

Maps 2N-G and 2S-G depict the earthquake planning scenario for natural gas. For planning purposes, pipelines importing natural gas into the greater Los Angeles area will be breached near Tejon Pass, south of Palmdale and Cajon Pass. These lines will be shut off automatically as a result. Damage to pumping stations may also reduce gas transmission.

Planning insights: In general, these effects will only be moderate to minor. Underground storage facilities will be available to provide gas for users in many parts of the Basin during the post-earthquake period.

Recommended further work: Locations where gas availability would be most severely impacted should be identified. Emergency users of natural gas should be identified so that provisions can be made to insure its availability to them.

Petroleum Fuels

Maps 2N-P and 2S-P depict the earthquake planning scenario for petroleum fuels. Imported crude oil from the San Joaquin Valley will be disrupted in lines crossing the San Andreas fault near Tejon Pass. Petroleum product pipelines exporting from the Los Angeles Basin may also be damaged in the Cajon Pass area. Resulting possibilities of fire exist in both of these areas.

Planning insights: Plans for fire control should be made for areas where pipelines cross the San Andreas fault. Plans should also be made for distribution of fuel supplies at airports selected for emergency activities and at other locations where emergency supplies will be needed.

Recommended further work: The effects on pipelines located in areas where ground failure is plausible should be evaluated. The existence and adequacy of shutoff valves to stop pipeline flow in the event of a rupture should be confirmed at all crossings of the San Andreas fault and in any other areas where ground failure is plausible.

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INTRODUCTION

One and a quarter centuries ago, one of the largest earthquakes to strike California was felt over much of central and all of southern California. Severe shaking, strong enough to cause damage, was felt from as far north as the San Benito River in central California to Cajon Pass near San Bernardino in southern California. Although California was sparsely settled in 1857, there are enough contemporary reports to document this Fort Tejon earthquake and its effects (Wood, 1955; Agnew and Sieh, 1978).

During the remainder of this century or early in the next, the southern half of the state will in all probability again be affected by a great earthquake along the south-central segment of the San Andreas fault. An earthquake similar to the 1857 event will have a magnitude of approximately 8 on the Richter scale, but unlike the earlier event, it will affect a population of several million people. Some older critical facilities could be seriously damaged or destroyed since they were not built to withstand intense shaking and may have been built upon ground that could fail.

This report and accompanying Earthquake Planning Scenario maps extend the work begun by Algermissen and others (1973). In addition to predicting the extent of damage likely to occur to lifeline facilities, this scenario endeavors to specify where damages will occur. Because this scenario is based upon the occurrence of a specific earthquake on the San Andreas fault, it is not valid for the assessment of possible damage produced by an earthquake on any other fault or by a different earthquake on the San Andreas fault.

The EARTHQUAKE PLANNING SCENARIO maps included in this report reflect the fact that earthquake damage will not be uniform. Damage will be related to the design of specific structures, the geologic ground conditions upon which they are built, and their distance from the fault. Many structures are designed to resist earthquake shaking, while others are not.

Structures on competent bedrock are subjected predominantly to the effects of relatively high-frequency, low-amplitude vibrations for relatively short durations. The ground surface in such settings is not likely to suffer permanent deformation (ground failure). On the other hand, structures on compressible deposits, particularly where the water table is high, are subjected not only to the effects of relatively low frequency, high amplitude vibrations, but also may be subjected to disruption caused by differential settlement, lateral displacement, or liquefaction.

In general, earthquake effects diminish with distance from the causative fault. These considerations are reflected in the damage assessments described in this report.

HOW TO USE THE EARTHQUAKE PLANNING SCENARIO MAPS

For emergency planning purposes, it is important to have an assessment of the effects of the scenario earthquake upon principal lifelines. The present investigation provides a regional characterization of anticipated damage patterns. CDMG's approach in formulating this assessment was, first, to interpret the regional pattern of ground shaking and ground failure and, second, to evaluate the resulting performance of lifeline segments throughout

the area. In this way, CDMG reached conclusions which constitute the regional post-earthquake conditions of each of the lifelines. It is important to have a variety of emergency-response contingency plans to deal with these circumstances. It was not feasible to rigorously determine the effects of the scenario earthquake on each bridge, overpass, or other types of lifeline structures. To accomplish such exhaustive analyses would require borehole sampling of soil and rock conditions at each site in order to further assess ground shaking and ground failure. Moreover, an engineering analysis of the manner in which specific structures would respond to the ground-shaking characteristics determined in this way would be necessary to draw more definitive conclusions. It is, therefore, improper to use the earthquake scenario conclusions to forecast the effects of the scenario earthquake for any other purpose than emergency planning. For example, decisions on whether or not to replace or retrofit lifeline components, etc., should definitely be based upon more intensive and rigorous investigations than were practicable for this project.

In general, people in well-designed structures built upon firm bedrock some distance from the fault will be able to aid people in poorly-designed structures built upon soft alluvium near the fault. While no scenario will prove accurate in detail, a general effort such as this provides a regional pattern of the magnitude and types of problems that will confront emergency-response planners. As more detailed engineering and geologic data become available, these maps will be periodically updated. Other scenarios, similar in scope, could be developed for earthquakes on other faults, or different earthquakes on the San Andreas fault. Once these scenarios are developed a more complete understanding of the earthquake hazard within the planning area will be possible.

LIMITATIONS OF EARTHQUAKE PLANNING SCENARIO MAPS

In this text, a description of the regional impacts of the scenario earthquake is presented for each lifeline, together with a discussion of the planning insights which are implied by the damage patterns. Where appropriate, further work is recommended. Next, an annotated list of damage localities for each lifeline precedes the planning scenario maps which graphically portray the geographic pattern of earthquake effects.

1. The maps in this report illustrate only a regional pattern of damage, specifically, one that it is plausible to expect from the great earthquake (magnitude 8.3) on the south-central San Andreas fault. The maps do not present assessments of the damage produced by shaking from earthquakes which may take place on other faults or on other segments of the San Andreas fault.
2. The seismic intensity forecasts upon which the damage distribution is dependent are interpretative. There are various judgments among workers regarding which is the most appropriate model for forecasting intensity.
3. The quality of information upon which the ground-failure forecasts have been made varies area to area within the study region. Only general geologic information is available concerning ground conditions associated with most lifeline elements. Furthermore, modeling of ground shaking on a regional basis using this generalized geologic information can produce plausible damage conclusions which are appropriate for emergency planning. Other types of conclusions regarding specific structures, such as the desirability of upgrading seismic resistance, etc., require more detailed geologic information and more extensive engineering analysis than is practical for this study.

EARTHQUAKE INTENSITY DISTRIBUTION

FOR AN M 8.3 EARTHQUAKE ON THE SAN ANDREAS FAULT

(Maps 2N-S and 2S-S)

To develop an earthquake planning scenario, it is necessary first to estimate the regional patterns of ground shaking and ground failure. This procedure is aided by assuming that the effects of the scenario earthquake will be interpretable from previous earthquakes about which there is some knowledge. In this instance the scenario earthquake has been assumed to be similar to the great Fort Tejon earthquake of January 9, 1857. There is some scattered information on the effects of that earthquake (Wood, 1955; Agnew and Sieh, 1978), but additional information is required. The available information must be augmented through the development of a regional seismic intensity map which provides the basis for assessing the performances of modern lifelines in the Los Angeles region.

"Seismic intensity" is the local effect of an earthquake at a particular point of reference (Barosh, 1969, p.6). Unfortunately, forecasting of seismic intensity has inherent problems. This is primarily because intensity scaling is based upon generalizations. With a single numerical value, scaling attempts to convey all of the effects of earthquake shaking upon humans and their cultural paraphernalia. The measurement, therefore, is unavoidably a somewhat subjective description. Over 44 different intensity scales have appeared during the last century (Barosh, 1969, p.6).

REGIONAL SEISMIC INTENSITY INVESTIGATIONS, IN GENERAL

Forecasting seismic intensity patterns resulting from a specific earthquake is complicated by other considerations in addition to uncertainties in describing and scaling earthquake effects. Assessing the intensity distributions of an anticipated scenario earthquake requires the investigator to determine approximate ground shaking and ground failure conditions at reference points throughout the area. To scale the intensity of these physical parameters, it is necessary to interpret their consequences upon a variety of types of construction at the reference points.

The degree of ground shaking at a specified location resulting from the scenario earthquake is dependent upon a number of circumstances. Among the most influential considerations are the distance from the fault source of the event and the nature of earth materials through which the vibrations pass. Generally, the amplitude of vibratory motion diminishes away from the source of excitation through the process of attenuation. The vibrations associated with earthquakes are complex. Characterizing their anticipated effects on ground shaking at specific reference points is further complicated by the different geologic materials through which they pass. Well-consolidated bedrock, for example, transmits most frequencies while unconsolidated sand and gravel or water-saturated mud preferentially transmit low frequencies.

Development of seismic intensity maps also requires consideration of the consequences of ground failure. In contrast to vibratory shaking, ground failure is a permanent displacement of earth materials resulting from such secondary earthquake-induced processes as liquefaction, differential settlement, and slope failure. The potential for ground failure is governed

by the presence of susceptible substrate materials such as water-saturated mud or granular materials. Ground failure has been observed at considerable distances (150 km) from the earthquake source.

DEVELOPMENT OF THE SEISMIC INTENSITY MAP FOR THIS SCENARIO

In preparing a regional intensity map to be employed in the assessment of lifeline damages, CDMG selected the Evernden model (Evernden and others, 1973, 1981). This computer model calculates the ground shaking parameters of particle acceleration at grid of reference points throughout a region employing equations which include the influence of distance from fault source, attenuation, and the geology of the substrate. The intensities are calculated using an empirical relationship between acceleration and the Rossi-Forel (R-F) intensity scale. The Rossi-Forel scale was selected by Evernden because he interprets a rather straight-forward mathematical relationship to exist between acceleration and this measure of intensity. The Modified Mercalli (MM) scale, which was developed in 1931 about half a century after the R-F scale, is extensively used today because it provides a classification of earthquake effects related to types of construction. The R-F scale does not distinguish classes of buildings. In order to make the Seismic Intensity Distribution maps developed for this earthquake planning scenario as useful as possible, CDMG will publish a Modified Mercalli scale intensity map of the same area in the near future. Both scales are described and compared in the Appendix of this report.

Evernden and others (1981) have published a series of intensity maps for specific earthquakes, including the M 8.3 event on the southern San Andreas

that is addressed in this scenario. The geologic substrate information used in the Evernden analysis was based upon 1:250,000 scale maps from the CDMG "Geologic Atlas of California." CDMG has modified this intensity map based on more detailed, additional geological information that was not included in Evernden's analysis.

The methodology of the Evernden model does not characterize the consequences of ground failure. In order to add this dimension to the CDMG intensity maps, information on local geology and ground water conditions were evaluated in order to identify areas of potential ground failure. Such locations are indicated on CDMG's Seismic Intensity Distribution maps with a separate map unit. Thus the CDMG intensity map possesses intensity based upon the synthesis of both shaking and ground-failure effects.

Areas of high water table (within 10 meters of the surface) were delineated wherever possible and the prediction for intensity was increased by one R-F intensity unit in these areas as suggested by the U.S. Geological Survey (1981). Areas already at intensity 9 (R-F) were not increased because we regard intensity 10 (R-F) principally as an indicator of ground failure rather than shaking. As mentioned, the potential for ground failure has to be assessed independently of the algorithm used to predict shaking intensity.

The principal sources of groundwater information used in the CDMG analysis are:

Orange County: The areas of high liquefaction potential are units IV and V of Cole (in press), based on both subsurface data and reports of numerous sand

boils during the 1933 Long Beach earthquake, as evidence for liquefaction. The 10 meter water table isobath was taken from Greenwood (1980) and represents the historical high water.

Los Angeles County: The high water table area was taken from Gulliver and Sonnenfeld (1980). Irvine and others (1974, p. 98) suggested that high water areas in the County be considered potential liquefaction zones. This was done for the Los Angeles Basin, but for the San Fernando Valley, units M and H from the liquefaction study of Youd and others were used (1978, p. 272).

San Bernardino County: Liquefaction features, such as sand boils, are present in the sediments of the Colton-San Bernardino area (Fife and others, 1976, p. 23). The high water table area for the City of San Bernardino is from the San Bernardino Municipal Water Department (1981, Plate 2), updated slightly (as of January 1982, Shervington, 1982). The water table fluctuates greatly, and since it has been rising during recent years, the area affected by liquefaction during a future earthquake may be even more extensive than shown on the map. For the remainder of the County, the areas of high water table shown in Gulliver and Sonnenfeld (1980) was used. Lacking detailed liquefaction studies, all these areas were considered to be of high liquefaction potential in view of the evidence elsewhere in the Santa Ana drainage system.

Ventura County: The areas of potential ground failure are the areas of high water table transferred from Gulliver and Sonnenfeld (1980). According to Husbands and others (1974, Plate V), the high water areas in the County also have high and moderate liquefaction potential.

The Evernden model is one of several that can be used in forecasting intensity. This model is satisfactory for the purposes of this scenario development, because it includes a relatively low attenuation rate which makes it an appropriate, moderately conservative assessment tool. Since intensity models in general do not address the spectral characteristics of the vibratory motions, users should keep this limitation in mind when they interpret CDMG's Intensity maps. The spectral character of ground motions in coherent bedrock such as granite as contrasted with unconsolidated surficial materials such as sand and gravel is likely to be quite different even in areas having the same R-F intensity levels. These spectral differences can account for notable divergences in their effects on certain classes of buildings even though the forecast Rossi-Forel values are similar.

GENERAL FEATURES OF THE SEISMIC INTENSITY DISTRIBUTION MAP

To include all the major population centers in the planning area, this compilation has been developed in two map sheets with a common area of overlap. The southernmost (2S-S) of the two map sheets comprehends the Los Angeles Basin and adjacent areas to the east, including the San Bernardino-Riverside area. The northern map sheet (2N-S) includes the northwestern portion of the Los Angeles urban area extending west to Ventura-Oxnard. Although the convention is to use Roman numerals for intensity, in this report we have employed arabic characters on the map and thus have also adopted them in the text.

The isoseismal areas displayed on the map encompass locales within which the anticipated intensities levels are considered to be comparable. The general characteristics of the different levels of the Rossi-Forel intensity scale are presented in the Appendix. These zones parallel the San Andreas fault in an approximate fashion.

To the north of the fault, a broad area of intensity 9 (R-F) is underlain principally by alluvial fan materials eroded from the San Gabriel Mountains to the south. By contrast, to the south of the fault, the bedrock area comprising the mountains will experience only intensity 7 (R-F) or less, due to greater coherency of the substrate.

Much of the San Bernardino and Riverside areas are subjected to intensity 8 shaking because of the alluvial substrate. In the event that fault rupture extends further to the southeast than assumed in this scenario, the San Bernardino area can be expected to experience shaking of intensity 9 (R-F).

Even in this scenario, which anticipates a rupture similar to that of 1857, the presence of high groundwater and granular materials in the vicinity of San Bernardino and along the Santa Ana River will be subjected to intensity 9 (R-F) shaking, as shown on the map. The plausibility of fault rupture extending further to the southeast is also considered in the lifeline analyses. Ground failure is also plausible in these areas and others, as designated by the stippled areas on the map.

The San Fernando Valley is generally intensity 8 (R-F), based upon distance from the fault and the nature of the underlying unconsolidated materials.

Regionally, the isoseismal values diminish to intensity 7 or less (R-F) southward and westward across the Los Angeles basin toward the coast at successively greater distances from the fault. In the Long Beach and Huntington Beach areas, the Santa Clara Valley, and Ventura-Oxnard areas further west, the groundwater-saturated substrates are considered to be intensity 8 (R-F) with ground failure potential.

These regional patterns associated with the scenario event are of sufficient plausibility to form a credible basis for evaluation of general affects upon lifelines that service the greater Los Angeles area and adjacent communities. The discussions which follow highlight the anticipated regional consequences on these lifelines which are identified in the accompanying maps.

EARTHQUAKE PLANNING SCENARIOS

FOR LIFELINES

IN THE GREATER LOS ANGELES AREA

The capacity for structures to withstand the effects of earthquake shaking, liquefaction, and related ground failure depends upon the soundness of each structure in relation to its geologic environment. Generally, structures within areas of less than intensity 8 (R-F) that are unaffected by ground failure are considered unlikely to sustain significant damage. "Significant damage" is defined here as damage that would render a structure unusable for 3 to 72 hours after the earthquake--the period most important for emergency response operations.

The following earthquake planning scenarios for lifelines in the greater Los Angeles area are based upon an evaluation of the earthquake-engineering literature, comments by numerous engineers and other public agency officials, and judgments by the authors. These damage scenarios will hopefully stimulate those concerned with particular lifelines to offer additional insights that will serve to enhance earthquake preparedness efforts in the area. For example, critical corridors in transportation routes and other lifelines became apparent when such routes and lifelines were considered in light of the geologic input. At such critical locations, more extensive evaluations of the geologic hazards and potential damage to lifelines are in order.

EARTHQUAKE PLANNING SCENARIO: HIGHWAYS

Maps 2N-HA and 2S-HA

General Pattern

The accompanying maps display the regional effects of the scenario earthquake upon the highway network. In the southern portion of the planning area, the highway system will not be significantly impaired by the scenario event except locally in areas of intensity 8 (R-F) or higher and areas of ground failure. The north-south routes through the mountains will be significantly impaired and access to and from the high desert areas of Palmdale and Victorville will be difficult, at best. Interstate 5 from the San Joaquin Valley and Interstate 15 through Cajon Pass will be closed, leaving U.S. 101 along the coast as the only major viable route open from the north. Highway connections with San Diego will remain open. Many highways within the Basin and environs will have significant damage and obstructions with consequent detours and delays.

Description

The greatest impact of the earthquake on the various transportation systems will be the effect on the highway network. In urban areas within Los Angeles, Orange, Riverside, and Ventura counties, damage to the extensive freeway system will be moderate to locally extensive. In the San Bernardino area there will be considerable impact on the highway system.

Though relatively few major structural failures will occur, some are inevitable, particularly where structures are located in areas of poor ground. Consequently, some segments of the freeway network will be closed for extended periods. Urban segments of Interstate 5, 10, 15, and 210, for example, will be closed, necessitating routing of traffic onto major surface streets and resulting in congestion and lengthy delays. Lesser damage that can be more rapidly repaired will result from the failure of minor structural or facilities within or crossing the roadway, minor settlement of bridge approaches and other fills, slides on cut slopes, rockfalls, etc.

Away from the mountain front, the severity of damage will diminish southerly across the urban area, with most routes open, subject only to occasional detours.

The major damage to both the freeway and local highway network will occur along those routes leading north from the Los Angeles-San Bernardino urban areas to the high desert and San Joaquin Valley. Interstate 5 will be closed to all traffic between Tejon Pass and Newhall for at least 72 hours. There will be major damage to the roadway and freeway overpasses near the San Andreas fault between Lebec and the Route 138 turnoff southeast of Gorman. Other freeway structures to the south along Interstate 5 will be seriously damaged and numerous slides and settlement of large highway fills will occur. Sections of this route will be isolated and many travelers will be stranded regardless of the time of day. Slides and rockfalls onto Interstate 5 in Grapevine Canyon will impede rescue efforts directed toward residents of the Lebec-Frazier Park area, but this route north of Tejon Pass should be cleared for emergency vehicles within a few hours.

To the east, Route 14 will be closed by failure of one or more overpasses, rockfalls, and fault rupture south of Palmdale.

In San Bernardino County, Interstate 15 will be closed by settlement of major fills and rockfalls in Cajon Canyon. Other freeway damage along Interstate 15E to the south, including major damage to the Interstate 15E/10 interchange will result in closure of this route south to Riverside and Interstate 10 to the east.

All of the secondary mountain roads between the urban areas and the high desert will be closed until cleared of rockfalls and slides.

The community of Wrightwood will be affected by both fault rupture and intense shaking. Once cleared of rocks on the roadway, State Highways 18 and 138 between San Bernardino and the Hesperia-Cajon Summit area will enable emergency vehicles to circumvent the damaged segment of Interstate 15 in Cajon Canyon.

To the west, coastal route U.S. 101 will be open to the north subject to delays and detours caused by damaged freeway structures in the Ventura area. Route 33 between Ventura and Bakersfield will be closed temporarily by rockfalls north of Ventura and disrupted pavement at the fault crossing near Maricopa, but will be open to traffic within a few hours.

The occurrence of this earthquake during a wet winter season would probably result in a significant increase in the number of landslides, particularly if the ground is highly saturated. These ground failures could

have a significant impact on residential streets in the many extensive hillside developments throughout the region, and create even more serious problems on the major trans-mountain roads.

The primary contribution regarding the integrity of the major highways was provided by the California Department of Transportation (CDOT, 1981) with the caveat that "this scenario is presented for planning purposes only and may be overly pessimistic in its overall impact." Thus, where numerous bridges, highways, and other facilities are located in areas where failures could occur, CALTRANS has noted the route as closed, even though it is unlikely that the entire route would be impassable for the time periods specified. The alternative is to ignore some possibilities in an arbitrary way. It is important in emergency planning for this earthquake to have contingency plans to deal with all plausible possibilities which may significantly impair ground transportation during the important 72-hour period following this catastrophic event. We think the CALTRANS approach to emergency planning is wise. CDMG worked with the CALTRANS staff to relate the geologic conditions and seismic intensity to highway effects.

Planning Insights

Emergency planners need to identify major emergency routes 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 flanked by buildings which are likely to be

damaged, and not likely to be obstructed by fallen powerlines or other obstructions. Selection of emergency routes is especially important in the urban areas of San Bernardino-Riverside where significant damage is a distinct possibility. Several corridors should be established so that flexibility to the few major routes available is achieved. Secondary routes generally paralleling Route 14 between the Newhall area and Palmdale should also be examined for their possible utilization as alternatives to all or segments of Route 14.

Highway emergency response plans should be integrated with air, rail, and marine transport scenarios in order to optimize plans for interrelated transportation capability. Access to the area with supplies and personnel from San Diego should be feasible. Distribution of people and material within the basin itself may be more difficult than access from the outside.

Recommended Further Work: Assessment of highway performance and identification of alternative emergency routes is especially important in all areas where major damage is a reasonable expectation.

HIGHWAYS SCENARIO

MAP NOTATIONS

<u>NO.</u>	<u>ROUTE</u>	<u>COUNTY</u>
H1	Route 2 - Glendale to Montrose	Los Angeles
	<u>Closed for over 72 hours.</u>	
	Closed between Interstate 210 and Route 134 by damage to Route 2/Route 134 and/or Route 2/Interstate 210 interchanges. Alternate route available via Verdugo Road - Canada Blvd.	
H2	Interstate 5 - Tejon Pass Area	Los Angeles and Kern
	<u>Closed for over 72 hours.</u>	
	Closed from Grapevine to 5 miles south of Hungry Valley Road (includes Pyramid Lake area). Major roadway damage due to surface fault rupture at the crossing of the San Andreas fault zone in the Gorman - Tejon Pass area. The segment between Grapevine and the Frazier Park Rd. should be open for emergency vehicles within a few hours.	
H3	Interstate 5 - Route 126 Junction	Los Angeles
	<u>Closed for over 72 hours.</u>	
	Closed from 1 mile north to 2 miles south of the junction with Route 126 due to bridge and road damage in this area of high ground water and intense shaking.	
H4	Interstate 5 - Sylmar Area	Los Angeles
	<u>Closed for over 72 hours.</u>	
	Closed between Interstate 210 and 405 (includes Interstate 5/210 and Interstate 5/405 interchanges) as a result of damage to freeway structures. Alternate routes available.	
H5	Interstate 10/15E Interchange	San Bernardino
	<u>Closed for over 72 hours.</u>	
	Closed from Cedar Avenue to at least 2 miles east of Interstate 15E. Major damage to the interchange resulting from ground failure and intense shaking along the Santa Ana River channel.	

- H6 Interstate 15 - Cajon Canyon San Bernardino
Closed for over 72 hours.
Closed from 1 mile north of Route 66 to the junction with U.S. 395 by settlement of major fills, rockfalls, and other obstructions. Alternate route for emergency vehicles available via Routes 138 and 18 (See note H64).
- H7 Interstate 15E San Bernardino
Closed for over 72 hours
Closed from junction of Interstate 15 and 15E to Route 60 by damage to overpasses in San Bernardino and damage to Interstate 15E/10 interchange.
- H8 Route 14 Los Angeles
Closed for over 72 hours.
Closed from Lancaster to Sierra Highway by damage to several overpass structures, rockfalls, and fault rupture near Ave. S south of Palmdale. Alternate routes available within the Antelope Valley.
- H9 Sierra Highway & Pearblossom Hwy. Los Angeles
Closed for over 72 hours.
Sierra Highway closed between Pearblossom Highway and Avenue S and Pearblossom Highway closed between Sierra Highway and Route 138 due to major damage resulting from fault rupture.
- H10 Mt. Emma Road Los Angeles
Closed for less than 36 hours.
Mt. Emma Road closed temporarily between Route 138 and Angeles Forest Highway (Route N3), by minor slides and fill settlement.
- H11 (not used)
- H12 Route 71 - South of Chino San Bernardino
Closed for over 72 hours.
Closed from junction with Route 142 to 2 miles south of Route 142 by damage to the roadway in this area of high ground water and intense shaking. Alternate routes available.

- H13 Route 126 - West of Castaic Jct. Los Angeles and Ventura
Closed for over 72 hours.
Closed from Interstate 5 to 3 miles east of Route 23 by localized failures of the roadway along the Santa Clara River.
- H14 Route 138 Los Angeles
Closed for over 72 hours.
Closed from Interstate 5 to the East Branch of the California Aqueduct by major damage to the roadway at the crossing of the San Andreas fault.
- H15 Route 138 - Antelope Valley Los Angeles
Closed for over 72 hours.
Closed from 1 mile east of Littlerock to the Los Angeles/San Bernardino County line by damage to the roadway and obstructions. Alternate routes available.
- H16 Interstate 210 - Big Tujunga Wash Los Angeles
Closed for over 72 hours.
Closed from Osborne Street to 0.5 miles south of Wheatland Avenue as a result of damage to the roadway. Alternate routes available.
- H17 Interstate 210/Route 30 Interchange Los Angeles
Closed for over 72 hours.
Closed in the Interstate 210/Route 30 interchange area as a result of structural damage. Alternate routes available.
- H18 Route 2 - Wrightwood San Bernardino
Closed for less than 36 hours.
Route 2 closed temporarily from junction with Route 138 to Wrightwood by roadway damage and minor slides resulting from intense shaking.
- H19 County Route N3 - Angeles Forest Highway Los Angeles
Closed for less than 36 hours.
Temporarily closed from Mt. Gleason Road to Route 14 by minor slides and rocks on the roadway.

- H20 Route 138 San Bernardino
Closed for over 72 hours.
 Closed from Los Angeles/San Bernardino County line to Interstate 15.
 Access to Wrightwood area from U.S. 395 (Victorville-Barstow) via Phelan.
- H21 Interstate 5 Los Angeles
Closed for over 72 hours.
 Closed at Branford Street southbound Interstate 5 on-ramp overcrossing
 [southbound Route 170 (Hollywood Freeway) transition from Interstate 5
 closed] by bridge damage.
- H22 Interstate 10 - El Monte Los Angeles
Closed for over 72 hours.
 Closed at Santa Anita Blvd. undercrossing due to structural damage.
- H23 Route 14 - Santa Clara River Bridge Los Angeles
Closed for over 72 hours.
 Closed at Santa Clara River due to damage to bridge/approaches.
- H24 Route 72 - San Gabriel River Bridge Los Angeles
Closed for over 72 hours.
 Closed at San Gabriel River bridge due to structural damage.
- H25 U.S. 101 - San Fernando Valley Los Angeles
Closed for less than 36 hours.
 Spot closures from Los Virgenes to Route 101/134 (Ventura/Hollywood
 Freeways) interchange due to structural damage. Repairs or detours
 available within 36 hours. Alternate routes available.
- H26-40 (Not used)
- H41 Interstate 5 - Vicinity of Castaic Los Angeles
Closed for over 72 hours.
 Southbound lanes closed from 1 mile to 3.5 miles north of junction with
 Lake Hughes Road due to fill failure. Southbound traffic may be routed
 onto northbound lanes.

H42 Lake Hughes Road (Elizabeth Lake Canyon) Los Angeles

Closed for over 72 hours.

Blocked by rockfalls, slides, and fill failure from junction with Elizabeth Lake Forest Station Road to junction with County Route N2. At least 15 feet of fault offset will occur in frequently saturated alluvium just south of the junction with County Route N2.

H43 County Route N2 - Pine Canyon-Elizabeth Lake Road Los Angeles

Closed for over 72 hours.

Road closed from junction with Route 138 (near Quail Lake) to 1.5 miles west of Three Points by fault rupture (average 15 feet offset) (Kahle, 1979).

H44 County Route N2 - Pine Canyon-Elizabeth Lake Road Los Angeles

Closed for over 72 hours.

Closed by fault rupture (about 15 feet of offset) and rockfalls from 2.0 miles east of Three Points to about 2 miles west of junction of Lake Hughes Road and County Route N2. (Kahle and Barrows, 1980; Beeby, 1979).

H45 County Route N2 - Elizabeth Lake-Leona Valley Road Los Angeles

Closed for less than 12 hours.

Road offset about 15 feet by fault rupture where San Andreas fault crosses County Route N2 between the junction with Johnson Summit Road and junction with San Francisquito Canyon Road. (Beeby, 1979; Kahle, Smith and Beeby, 1975).

H46 Frazier Mountain Park Road Kern

Closed for over 72 hours.

Closed by bridge damage and rockfalls from Interstate 5 to Lake of the Woods. Access to Frazier Park from Interstate 5 from the north available in less than 36 hours. Lake of the Woods is accessible via Lockwood Valley.

H47 San Francisquito Canyon Road Los Angeles

Closed for over 72 hours.

Closed by rockfalls and bridge damage. Access to Los Angeles Aqueduct facilities could be delayed from 2 miles south of Green Valley Road junction to 0.5 miles south of San Francisquito Power Plant #2.

- H48 County Route N2 - Leona Valley Road Los Angeles
Closed for over 72 hours.
Closed from 0.5 miles west of junction with Bouquet Canyon Road to 3.5 miles east of junction by both fault rupture and erosion from ruptured major waterline. Fault crosses road at three locations in this area and crosses waterline (which parallels road) at one location. (Kahle, Smith, and Beeby, 1975).
- H49 Route 2 - Angeles Crest Highway Los Angeles
Closed for over 72 hours.
Rockfalls and minor slides close this route.
- H50 Route 39 - Crystal Lake Road Los Angeles
Closed for over 72 hours.
Closed from Sierra Madre Avenue to Route 2 by rockfalls and landslides.
- H51 County Route N3 - Vicinity of Sunland Los Angeles
Closed for over 72 hours.
Closed from Los Angeles city-county line to 2 miles north by rockfalls and fill failure.
- H52 County Route N3 - Big Tujunga Canyon Road Los Angeles
Closed for less than 36 hours.
Temporarily closed between Mt. Gleason Road (described in note H51) by rockfalls and landslides, but cleared for one-lane traffic within 36 hours.
- H53 Route 2 Los Angeles and San Bernardino
Closed for over 72 hours.
Closed along the San Andreas fault zone between Big Pines and Wrightwood by major disruption to the roadway.

- H54 County Route N4 Los Angeles
Closed for over 72 hours.
 Damaged by fault rupture in at least eleven locations (Ross, 1969).
 Offset averages 10-12 feet and rockfalls and fill failures are common.
- H55 Shoemaker Canyon Road Los Angeles
Closed for over 72 hours.
 Closed by fault rupture at five locations (Ross, 1969) and by rockfalls
 and fill failures.
- H57 Bouquet Canyon Road Los Angeles
Open in less than 12 hours (East of Bouquet Canyon Dam)
 Some minor rockfalls and road damage. The area downstream from Bouquet
 Reservoir will be evacuated and the road closed as a result of damage to
 Bouquet Canyon Dam (see note on Map No. 2N-W).
- H58 Route 138 - West of Route 14 Los Angeles
Closed for less than 36 hours.
 Closed from crossing of the East Branch of the California Aqueduct to
 Route 14 by severe roadbed damage and power lines on the roadway.
 Alternative routes available.
- H59 Route 138 - East of Route 14 Los Angeles
Closed for less than 36 hours.
 Closed from Route 14 to about 1 mile east of Littlerock by pavement
 damage and obstructions on the roadway. Alternative routes available.
- H60 U.S. 101 - Santa Clara River Bridge Ventura
Closed for over 72 hours.
 Bridge and approaches damaged due to ground failure (Wood, 1955).
- H61 Cuddy Valley Road Kern
Closed for over 72 hours.
 Closed by fault rupture and lurch cracks along Pine Valley Road from Lake
 of the Woods to about 7 miles west of Lake of the Woods.

H62 Route 1 - Malibu Coast Los Angeles

Closed for less than 36 hours.

Temporarily closed for cleanup of slides between Pacific Palisades and Malibu.

H63 Route 60 Riverside

Closed for over 72 hours.

Closed at Santa Ana River crossing by damage to the roadway.

H64 Routes 18 and 138 - Crestline San Bernardino

Closed for less than 12 hours.

Routes 18 and 138 closed temporarily for removal of minor slides and rockfalls. Routes provide an alternative to damaged and obstructed Interstate 15 between San Bernardino and the high desert.

H65 Route 330 San Bernardino

Closed for less than 12 hours.

Route 330 closed temporarily (less than 12 hours) between Highland Avenue (Route 30) and Running Springs (Route 18) for removal of minor slides and rockfalls.

H66 Route 138 - Cajon Junction San Bernardino

Closed for over 72 hours.

Route 138 closed between Interstate 15 (Cajon Junction) and Summit Valley by minor slides and obstructions on Interstate 15 at Cajon Junction.

EARTHQUAKE PLANNING SCENARIO: AIRPORTS

Maps 2N-HA and 2S-HA

General Pattern

Essentially all major air facilities within the planning area are expected to have runways sufficiently intact to be capable of landing military C-130 and C-141 cargo aircraft. It is less certain that all of these airports will have operational towers with communications, fuel-handling facilities, and electrical power.

Description

Numerous 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 providing massive logistics to the response effort. Norton Air Force Base near San Bernardino could experience some shaking of an intensity high enough to damage runways through the secondary effects of ground failure. Some damage could also occur to runways at Los Alamitos Armed Forces Reserve Center, but this may not be great enough to disrupt emergency operations. The other major airports are located in areas where predicted shaking will produce minimal damage to runways. In general, then, virtually all of the numerous major airports are 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.

Planning Insights

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. Preferred airports need to be identified.

Recommended Further Work

Available airports for major logistics need to be evaluated in terms of auxiliary electrical power supply, integrity of airport buildings, and vulnerability of access routes in order to finalize transportation plans. The vulnerability of runways at Norton A.F.B. near San Bernardino and Los Alamitos in Orange County should be reappraised using recently developed subsurface data. The scenario analysis indicates that runways at these two airports could be damaged by ground failure (liquefaction), although the available information is not sufficiently complete to warrant a definitive conclusion at this time.

MAP NOTATIONS
(see Maps 2N-HA and 2S-HA)

<u>NO.</u> <u>AIRPORT</u>	<u>COUNTY</u>
A1 Los Angeles International Airport <u>Open</u> No known liquefaction potential. Predicted Shaking Intensity, 7 (R-F).	Los Angeles
A2 Hollywood-Burbank Airport <u>Open</u> No known liquefaction potential. Predicted Shaking Intensity, 8 (R-F).	Los Angeles
A3 Van Nuys Airport <u>Open</u> No known liquefaction potential. Predicted Shaking Intensity, 8 (R-F).	Los Angeles
A4 Ontario International Airport <u>Open</u> No known liquefaction potential. Predicted Shaking Intensity, 8 (R-F).	San Bernardino
A5 March AFB <u>Open</u> No known liquefaction potential. Predicted Shaking Intensity, 7 (R-F).	Riverside
A6 George AFB <u>Open</u> No known liquefaction potential. Predicted Shaking Intensity, 8 (R-F).	San Bernardino

A7 Los Alamitos Armed Forces Reserve Center

Orange

Open

Predicted Shaking Intensity, 8 (R-F).

Possible high water table and liquefaction hazard present (Gulliver, and Sonnenfeld, 1980). Ground failure is not considered a significant hazard here because "materials to a depth of +50 feet are mostly clay, which is not subject to liquefaction. The historically shallowest ground water in the area is about 20 feet below the ground surface" (Gray, 1980). Gray (1980) recommended that "for the San Andreas type event, the Los Alamitos location may be satisfactory" for an Emergency Operations Center.

A8 El Toro Air Station (U.S.M.C.)

Orange

Open

No known liquefaction potential.

Predicted Shaking Intensity, 7 (R-F).

A9 Norton AFB

San Bernardino

Open for limited use.

Predicted Shaking Intensity, 8-9 (R-F).

No known liquefaction potential. However, this facility's proximity to the Santa Ana River and an extensive area of high ground water suggests that the runways at this facility could be subject to major damage. Consequently, in the absence of site-specific data to the contrary, this base may be unavailable for major emergency response purposes.

A10 U.S.A.F. Plant 42

Los Angeles

Open

No known liquefaction potential.

Predicted Shaking Intensity, 9 (R-F).

Though major damage to airport buildings can be expected in this area of high intensity shaking (9 R-F), the runways capable of handling the largest aircraft are assumed to remain operational.

All Airports - - Ventura County

Ventura

There are three airports in Ventura County, i.e., Oxnard, Camarillo, and Point Mugu Naval Air Station. These facilities were not evaluated for this scenario. However, Point Mugu is constructed in a swampy area, and

recent excavations for a county arterial highway project (Victoria Avenue) near the runway of the Ventura County Airport in Oxnard disclosed large areas of saturated, unstable soil which required special lime treatment for highway construction. These facts suggest that these facilities may be subject to ground failure during a major earthquake and should not be relied upon for emergency response purposes.

EARTHQUAKE PLANNING SCENARIO: RAILROADS

Maps 2N-RM and 2S-RM

General Pattern

Rail service into the southern California metropolitan area from the north via the Palmdale and Cajon Pass rail corridors will be seriously affected by fault rupture and ground shaking. Rail transportation into the area from the north may also be impaired in the Ventura area. Some damage to rail facilities will be experienced in the vicinity of the marine terminals in the Long Beach harbor areas. Rail service within much of the Los Angeles Basin should still be feasible and access to the area from San Diego should be unimpaired. Significant damage to rail facilities in the San Bernardino area, including yards and shops, should be anticipated.

Description

The most extensive damage to railroads in the planning area will occur at those locations directly affected by surface fault rupture along the San Andreas fault, landslides and rockfalls in mountainous terrain, and in areas of poor ground where the roadbed can be seriously disrupted by ground movement. In addition, failure of other structures, notably, highway overcrossings and many other secondary spans, can seriously impair the railroad's ability to function.

According to Algermissen and others (1973), railway bridges generally do not suffer serious damage except in areas subject to ground failure or by surface fault rupture. Significant settlement of approach fills require repair before bridge structures can be used. Railroad tunnels experience severe damage in areas affected by permanent ground movements due to landslides or surface fault rupture, but rarely suffer internal damage from ground shaking.

For planning purposes, four mainline railroad corridors serving the southern California metropolitan areas will be seriously damaged with rail service interrupted for periods in excess of 72 hours. These are (a) the coastal route from the north via Ventura, closed for at least 5 days by an overpass collapse and landslides, (b) the San Joaquin Valley route from the north, closed by fault rupture and overpass collapse near Palmdale, (c) the Cajon Canyon corridor from the east, closed by landslides, rockfalls and structure failure, and (d) through San Geronio Pass from the east, closed near Colton by an overpass collapse and damage to the roadbed.

In addition, numerous other rail facilities within the planning areas will be damaged by localized ground failures and/or intense shaking. Areas particularly vulnerable include (a) the Los Angeles-Long Beach harbor area where a concentration of rail facilities service these two major ports in an area of poor ground conditions, (b) routes leading to and across the Oxnard Plain, (c) in the Antelope Valley, and (d) in the Colton-San Bernardino area.

Planning Insights

Surviving rail service into the damaged area from the outside is assumed to be limited to service from San Diego. It is conceivable that emergency supplies could be transported by rail from military installations in that area.

Integrated planning needs to be undertaken for air, highway, rail and marine transport.

Recommended Further Work

The vulnerability of railroad facilities in the Ventura and San Bernardino areas should be investigated in order to evaluate their probable utility immediately following a major earthquake.

MAP NOTATIONS

<u>NO.</u>	<u>RAIL LINE LOCATIONS</u>	<u>COUNTY</u>
R1	San Andreas Fault Crossing near Palmdale <u>Closed for over 72 hours.</u> Southern Pacific main line (San Joaquin Valley route) between Los Angeles and San Francisco will suffer major disruption of the roadbed at the crossing of the San Andreas fault 2 miles south of Palmdale. Leakage from adjacent Palmdale Reservoir may create a condition prolonging the time required for repairs.	Los Angeles
R2	Santa Clara River <u>Closed for over 72 hours.</u> Southern Pacific tracks along the Santa Clara River between Saugus and Ventura will be disrupted due to local ground failures resulting from liquefaction.	Los Angeles and Ventura

R3 Simi Valley

Ventura

Closed for less than 72 hours.

Southern Pacific main line tracks will be disrupted in the Simi Valley-Moorpark area due to intense shaking in an area of high ground water.

R4 Cajon Pass

San Bernardino

Closed for over 72 hours.

All major railroads traversing Cajon Canyon-Cajon Summit will be out of service. Landslides, fill settlement, and structural failures, coupled with relatively difficult access, will result in this route being closed for an extended period. Algermissen and others (1973) concluded that, for planning purposes, the rail lines through Cajon Pass should be considered out of service for one month.

R5 Colton-San Bernardino

San Bernardino

Closed for over 72 hours.

Rail facilities including yards and shops of each of the three major railroads located in the Colton-San Bernardino area will sustain significant damage and disruption of tracks caused by intense shaking (R-F 8-9) and local ground failures. Major damage to the Interstate 15E/10 interchange, immediately east of the Southern Pacific yards, will force closure of the Southern Pacific route east through San Geronio Pass.

R6 Oxnard Plain

Ventura

Closed for over 72 hours.

Southern Pacific's main line (Coastal Route) north to San Francisco will be disrupted in the Oxnard Plain by localized ground failures due to liquefaction. Algermissen and others (1973) suggest that "a 5 day blockage of the Ventura line due to highway overpass failure and landslides is reasonable, especially during the rainy season."

R7 Western San Fernando Valley

Los Angeles

Closed for less than 72 hours.

Southern Pacific tracks in the southern and western San Fernando Valley will be disrupted locally by roadbed failure caused by severe shaking in an area of high ground water.

- R8 Soledad Pass Area Los Angeles
Closed for over 72 hours.
 Southern Pacific main line tracks will be disrupted by intense ground shaking (9 R-F) between Acton and Lancaster.
- R9 South Coast-Harbor Areas Los Angeles and Orange
 The rail system in the Wilmington-Long Beach-Seal Beach harbor areas will sustain considerable damage due to localized occurrences of ground failure, particularly in areas of filled ground near the port facilities. Algermissen and others (1973) note that the railroad bridge from the mainland to Terminal Island has been closed frequently due to subsidence induced ground movements and concludes that this structure would be unusable after a major earthquake.
- R10 Santa Ana Canyon Orange
Closed for less than 72 hours.
 The A.T. & S.F. railroad from Placentia to the Riverside County line, following the Santa Ana River through Santa Ana Canyon, will be subjected to localized ground failures causing temporary disruption of rail traffic via this route.
- R11 Santa Ana River Crossing Riverside
Closed for less than 72 hours.
 Union Pacific tracks will be disrupted by high intensity shaking at the crossing of the Santa Ana River west of Riverside.
- R12 Antelope Valley Los Angeles and San Bernardino
Closed for over 72 hours.
 Southern Pacific line between Palmdale and Interstate 15 will be closed due to track disruption and settlement of bridge-approach fills.
- R13 Ventura River Ventura
Closed for more than 72 hours.
 Southern Pacific spur between Ventura and Ojai will be closed due to local ground failures along the Ventura River.

Closed for less than 72 hours.

Union Pacific and Southern Pacific lines along San Jose Creek south and west from Diamond Bar to the West Whittier area will be subjected to localized track outages due to intense shaking in areas of high ground water.

EARTHQUAKE PLANNING SCENARIO: MARINE TRANSPORT

Maps 2N-RM and 2S-RM

General Pattern

Marine facilities will survive the scenario earthquake with only minor impact. Connecting rail facilities serving the major ports in the Long Beach area may, however, sustain damage that will curtail port operations.

Description

The principal marine facilities within the planning area are concentrated in the Los Angeles - Long Beach harbor areas. Other marine facilities include a deep water port at Port Hueneme in Ventura County and several harbors for pleasure craft scattered along the coast.

For both the Los Angeles - Long Beach and Port Hueneme areas, a shaking intensity of 8 (R-F) is forecast. Both areas have high ground-water levels and are therefore susceptible to ground failure due to liquefaction and differential settlements. According to Algermissen and others (1973), most of the piers in the Los Angeles - Long Beach area are pile supported, although many of the main bulkhead walls from which the piers project are quay walls and rock fills. Most of the pile supported docks in the area will probably not be greatly affected. Quay walls probably will suffer serious damage due to liquefaction of retained soils. In addition, shaking and resulting differential ground movements will cause damage to various structures throughout the harbor area.

In some parts of the harbor area access to facilities may pose the greatest problem. Rail traffic, in particular, is likely to be disrupted by local ground failures, becoming more common near the port facilities. Some damage to roadways within the harbor area is also probable, but there will be no major closures and repairs should be accomplished within a relatively short period of time.

Another potential problem in the harbor areas is the contamination of waters by ruptured sewer lines and, of potentially greater importance, ruptured petroleum product and natural gas pipelines, which pose the threat of fire.

Planning Insights

The importance of marine shipping into the area to satisfy the needs of the first 72 hours after the scenario earthquake needs to be evaluated. This should be a part of the correlation and integration of regional transportation systems.

Recommended Further Work

If marine transport is considered important in emergency planning, a detailed engineering and geologic evaluation of the marine terminals should be undertaken in order to confirm that they will survive.

MAP NOTATION

(see Maps 2N-RM and 2S-RM)

NO. HARBOR

COUNTY

M-1 Los Angeles - Long Beach Harbor

Los Angeles County

The Los Angeles - Long Beach harbor area will sustain light to moderate damage, a result of localized failures due to liquefaction and differential settlements. Algermissen and others (1973) conclude that "For planning purposes, approximately 20% of the access routes and facilities should be considered unusable for 14 days."

EARTHQUAKE PLANNING SCENARIO: COMMUNICATIONS

Maps 2N-C and 2S-C

The following discussion of communication systems was prepared by the Communications Advisory Committee of the Governor's Emergency Task Force on Earthquake Preparedness. James Cotter is principally responsible for development of this analysis.

General Pattern

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

Not all of the systems in the greater Los Angeles 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. CDMG has treated the post-earthquake communications scenario 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 by resourceful operators. 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%, most systems operate at approximately 85% because of ongoing maintenance. The effects of the scenario earthquake event 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.

Description

The 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 - Map No. 2N-C and 2S-C

Telephone systems are mutually dependent because of a vast, complex interconnected network, yet they are also self-supporting on a local basis.

One service provided by the telephone companies is intraexchange traffic, i.e., calls between telephones within the area served by a single central office or "exchange." Another is interexchange service where calls are switched between two central offices within a region. There is third service, similar to interexchange, where 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. Nonetheless, there has not been a disaster in modern times of the magnitude here addressed. It is therefore quite difficult to forecast the detailed effects of a major earthquake on the telephone systems. There are, however, a number of outcomes that can be anticipated: hardware damage such as underground cable failure in areas of liquefaction, damage to surface cable carriers, system-call saturation during post-earthquake recovery, and repair-access problems.

Our evaluation of system performance takes into account the likelihood of any or all of these events occurring and subjectively applies this evaluation to an effectiveness scale, as shown on Maps 2N-C and 2S-C. The effectiveness scale essentially is an attempt to quantify the ability of public safety agencies to conduct recovery efforts by using the telephone system. It is not directly applicable to the general performances of the system nor to the public's ability to use the system.

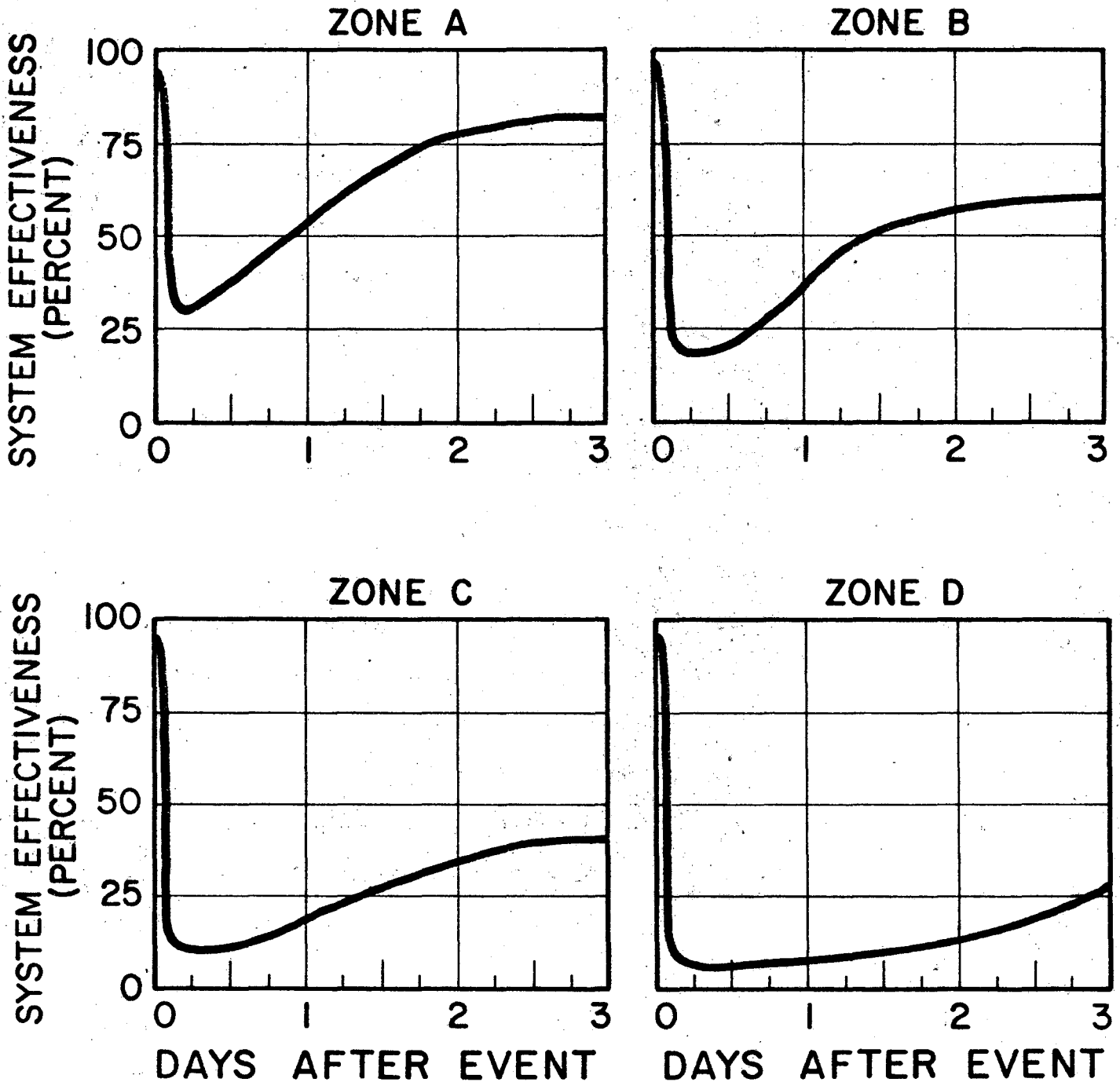
The effectiveness scale has then been applied to a three-day time frame. From patterns of effectiveness-over-time were distinguished and used as the basis for zoning the study area (Zones A, B, C, and D on Maps 2N-C and 2S-C).

Zone A will fair best and Zone D the worst. The definitions of these zones are based upon a number of factors: past telephone performance in disaster situations, casualty projections, population density and demography, post-earthquake transportation evaluations, the probable performance of commercial power facilities, and any known site-specific technical considerations. No attempt has been made to separately evaluate each of several hundred telephone facilities.

Some basic assumptions have been made: (1) the shaking intensities used in this scenario were projected by the CDMG; (2) areas suffering a shaking intensity of Rossi-Forel 8 or better will have 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 backup power provisions will be functional; (6) the long distance network, although difficult to access, will remain generically stable; (7) interexchange facilities will be difficult to access, but would remain essentially intact; (8) shortly after the event, numerous relatively simple failures will occur that, coupled with intense call saturation, will effectively disable the telephone networks for approximately 6 hours; and (9) for planning purposes, the event will be considered to occur after normal business hours.

COMMUNICATIONS

TELEPHONE SYSTEM EFFECTIVENESS



These graphs represent assessments of relative telephone systems performance in various parts of the planning area during the initial 72 hours following the earthquake (See Map No.'s 2N-C and 2S-C). The assessments are based on a matrix of anticipated events with a margin for contingencies. "System effectiveness" is a subjective rating of the ability of emergency response agencies to use the telephone systems.

Specific Vulnerabilities

The most vulnerable aspects of telephone systems are the computers used to switch message traffic. All are environmentally sensitive 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 control failure. Call saturation, resulting in local station and all-trunks busy, is the most obvious system access problem that can be predicted. Most telephone systems presently are working at or near capacity for normal traffic; the systems will be saturated easily by the sudden activity following an earthquake. Most exchanges, however, have the capability through the switching computers to control system load by limiting access to only predesignated circuits. Another potential problem is emergency power. While the telephone systems work mostly on battery power, with propane or gasoline backup generators to provide charging, the generators depend upon batteries for starting and fuel lines and tanks for continued operation. If emergency power does fail, system performance on batteries will degrade at a significant rate.

Assuming the earthquake will occur 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 assessment of 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 of the 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, will probably be immobilized by facility failure. In systems that must revert to operator intercept, where all dialed calls go to an operator, fatigue would curtail effectiveness. The same fatigue will apply to central office personnel. Further, the telephone companies will probably be without upper-echelon management and supervisory personnel during the first hours following an earthquake; the transportation situation may be magnified because these persons often live further from their office than journeymen. 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 be dynamic and dependent upon a multitude of events rather than upon any single factor. The overall evaluation, thus, is highly subjective and must be considered only as a public safety planning document.

Post Earthquake Telephone Systems Effectiveness

A number of telephone exchanges in the greater Los Angeles area currently work at capacity and do not have line access control. Unlike San Francisco, the area is replete with switching options. Primary long distance facilities should be relatively undamaged by low or moderate shaking intensities. The repair staff is well distributed, and most of the area should have fair transportation facilities.

After an earthquake, this heavily populated region can be expected to saturate telephone systems. For the most part, special public safety circuits would remain intact. In the San Fernando Valley, however, there is recent earthquake experience, and the area is rated Zone D (lowest post-earthquake effectiveness of the four zones). The same is true for the Newhall area, which has additional access problems. The San Bernardino- Riverside area is rated Zone D not only because of the high shaking intensities that are predicted, but also because of anticipated transportation difficulties; further, most of this region does not have line access control.

Radio Systems

Radio systems will generally operate at 40% effectiveness for the first 12 hours after a major earthquake, increase to 50% for the second 12 hours, then begin a slow decline to approximately 40% within 36 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 irresponsible communications from mobile units; it is clear, however, that radio traffic densities would increase, particularly when remote base station and repeater failures would tend to limit the number of redundant channels available. Nonetheless, after 12 hours, at which time the number of operable units will have declined (with exhaustion of emergency power fuel) and recovery efforts will have restored some order, the radio traffic density problem will ease.

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 discussions:

Radio Control Consoles

Radio control 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 doesn't rely on remote equipment), it is often not supplied with emergency backup power. System designs using control stations normally have such backup power provisions. Control consoles rely either upon telephone or microwave circuits to access remote equipment. We do not anticipate continued microwave operation and cannot recommend telephone lines as an alternative, though 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 upon telephone and microwave circuits and have an added problem of repair complexity. If a key component of a large console fails, many radio subsystems would be fragmented, placing the burden of communications on outlying stations more vulnerable to earthquake damage. Further, software-based consoles would probably face additional complications within 12 hours. We estimate that self-contained tabletop base stations would be 40%

effective, tabletop control consoles 55% effective, and large consoles 50% 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 was 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 that effectiveness will be 70% for local base station installations and 55% for remote stations, declining after 12 hours as emergency-power fuel supplies become exhausted.

Repeaters (mobile relays)

Repeaters are not dependent upon control circuits and are normally provided with backup emergency power. Located atop mountains, they are vulnerable to structural, electric, and other internal damage from heat buildup. Depending upon the proximity of the fault source, they are more

likely to experience technical problems than base stations. We estimate that repeaters will be 60% effective, declining as emergency power supplies are exhausted and technical problems develop, becoming 40% effective after 24 hours.

Antennas

We do not believe that antennas will fail on a large scale. Antennas and related structures should remain 70% 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. We do not consider this kind of portable equipment to be of any significant benefit to the overall recovery effort after 12 hours per battery that is available to each unit; that is, a unit equipped with one fully-charged backup battery would be operational for 24 hours total.

Mobile (Vehicular) Radios

Assuming that gasoline supplies will be scarce and that transportation systems would be disrupted, the value of mobile radios would coincide with

their distribution at the time of the disaster. We estimate that, functionally, higher-powered mobile radios would be 75% effective for the first 12 hours, declining thereafter because of fuel and battery problems. At the same time, the mobile radio system as a whole would doubtlessly be compromised because of the distribution of the units. It is more realistic to consider mobile radios approximately 60% effective initially, declining thereafter. This estimate is for public agencies; should an earthquake occur after working hours, the effect on commercial systems will be more severe.

HAM and Other Amateur Radio

Amateur radio stations are subject to the hazards outlined earlier. A particularly vulnerable point is emergency power; most home base stations do not have backup 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, in some cases, radio amateurs may be the only means of reaching the outside world. The amateur radio service should remain more than 50% effective because of pre-organization and the long distance capabilities of the equipment.

Citizens' Band Radio

We do not believe that CB radios will have an appreciable effectiveness in the public agency recovery effort, although there would be 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 for the general public, Citizens' Band would 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

Either radio service will be at least 80% effective provided that airfields are nominally accessible and there are no severe conditions that would significantly disrupt moored maritime resources. While there are many potentials 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 would increase as recovery efforts commence.

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 (directionability) 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 30% effective or less.

Satellite Communications

Remote satellite terminals relying upon telephone or microwave circuits will be 40% to 50% effective, similar to radio base stations. Station-proximate terminals will have a greater likelihood of survival approximating 70%. 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% effective. When facilities are not physically damaged, air conditioning and environmental control systems failures may gradually reduce effectiveness.

Commercial Broadcasters

Some commercial stations generally will be able to provide emergency public information to the stricken area.

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; a large number of casualties could cause saturation of the channels and make them virtually useless. Further, the hospital-to-hospital systems are expected to fail. We do not anticipate the continued function of medical radio services to an appreciable level of effectiveness.

General Comments on the Communications Scenario

Emergency power has been the primary cause of communications failure in past disasters. Poor installation practices and inadequate preventative maintenance of backup power equipment contribute to a high failure rate. The presumed scarcity of propane and gasoline after a major earthquake will strictly limit the viability of surviving communications sites.

The availability of repair parts and ability to transport them are other factors when considering both short- and long-range implications. We believe

that 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. 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 the scenario earthquake occurs, the number of technical staff available for repair services could range between 20% and 50% of the total for the first 24 hours. If it occurs between 1600 and 0600 hours, approximately 20% may be available in the first 24 hours, 40% in 48 hours, and 70% in 72 hours. If the disaster occurs between 0600 hours and 1600 hours, a portion of personnel would be disabled, isolated, or occupied with verifying the status of their families: 50% will be available for the first 24 hours, 60% in 48 hours, and 70% in 72 hours. The effectiveness of technical personnel is severely affected by the availability of transportation. In many cases, for example, helicopters would 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 approximately one week, 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 adequate interface between systems. This applies equally to local systems and systems drawn from outside the disaster area.

Planning Insights

A general communication plan should be developed for use by appropriate agencies and personnel following the scenario earthquake. This should anticipate the needs of the most vital parties.

Reliance on emergency telephone communications should be kept at a minimum. A strategy should be developed for communication to the general public which relies upon the capabilities of surviving commercial radio and television stations.

Recommended Additional Work

An inventory of commercial and amateur broadcasting capabilities should be undertaken and the resulting information employed in developing the regional emergency communications plan.

A survey of existing critical communications facilities should be undertaken by structural engineers leading to development of improved equipment installation standards.

There is need for a technical examination of alternative means of communication.

EARTHQUAKE PLANNING SCENARIO: WATER SUPPLY AND WASTE DISPOSAL

Maps 2N-W and 2S-W

General Pattern

Two of the three major aqueduct systems that import water to southern California will be ruptured by displacement on the San Andreas fault , and supply will not be restored for a three- to six-month period. Water consumers in the Los Angeles Basin will need to rely to a great extent upon existing reservoir storage and supplies from the Colorado River Aqueduct. Impairments to reservoir intake and outlet structures and to various distribution facilities will locally affect water pressure and availability. For purposes of planning, it has been assumed that one important reservoir will sustain serious damage necessitating emergency evacuation procedures. Water treatment facilities will be damaged and many will be without electrical power. Waste water treatment will be impaired by loss of power and damage to some treatment plants. Collection lines will also be impaired causing significant contamination problems to the water supply in some areas.

Description

Most of southern California's water supply is imported via three major aqueduct systems: the Los Angeles Aqueduct from the eastern Sierra Nevada (City of Los Angeles, Department of Water and Power), the California Aqueduct from northern California (California Department of Water Resources), and the

Colorado River Aqueduct (Metropolitan Water District of Southern California). The earthquake will cause major damage to both the Los Angeles and California Aqueducts, eliminating these two primary sources of supply for a period of 3 to 6 months. The Los Angeles Aqueduct crosses the San Andreas fault (Map 2S-W) in a tunnel some 250 feet below the surface and repairs will be both difficult and extremely hazardous with a continuing threat of major aftershocks. The California Aqueduct, East Branch, is highly vulnerable to widespread damage because it closely parallels the San Andreas fault for over 100 kilometers and crosses the fault at two locations near Palmdale (Map 2N-W). The West Branch will also sustain significant damage to its facilities including major damage at the fault crossing near Quail Lake. The Colorado River Aqueduct also crosses the San Andreas fault, but well beyond the southern limit of surface fault rupture considered in this scenario. Only very minor damage will occur to the Colorado River Aqueduct east of the terminal reservoir at Lake Mathews. For an estimated minimum period of three months, then, the metropolitan areas will be dependent upon the Colorado River Aqueduct, available storage in reservoirs generally south of the surface rupture, and local supplies.

The major reservoirs storing imported water include Bouquet Canyon, Castaic, Pyramid, Perris, Lake Silverwood, and Lake Mathews. Four of these reservoirs (Bouquet Canyon, Castaic, Pyramid, and Lake Silverwood) are located such that delivery of water into the regional water distribution systems could be impaired for a considerable period of time by damage to downstream transmission facilities or to appurtenant works such as the reservoir intake and outlet structures and related control facilities. Water deliveries from Perris Reservoir and Lake Mathews will not be seriously impacted by the earthquake. Storage in Lake Silverwood will be available to San Bernardino,

providing there is no unexpected major damage to the San Bernardino Tunnel or Devil Canyon facilities.

Local storage capacity in the Los Angeles-Orange Counties area south of the San Andreas fault is about 1,000,000 acre-feet. In a worst possible situation available storage of 235,000 acre-feet would result from a combination of drought conditions and three of the major reservoirs being inoperative. Average daily use for the study area is about 5,000 acre-feet. In response to a major public information campaign following a major event, it is expected that the urban population would implement extraordinary conservation measures, and daily usage would be reduced by approximately 50 percent. As noted above, however, much of this water could be unavailable due to damage to distribution systems. In heavily damaged areas, supplies can be transported using tank trucks until normal distribution lines can be repaired. Additionally, water will be needed for fire fighting which can frustrate attempts to conserve water unless alternative sources for fire control are considered in planning.

Catastrophic failure of a major dam as a result of the scenario earthquake is considered unlikely. Current design and construction practices and on-going programs of review, modification, and reconstruction of some existing dams are intended to ensure that all dams are capable of withstanding the maximum credible earthquake (MCE) for the site.

For purposes of emergency planning, however, we have assumed that one major dam in the planning area will sustain damage affecting its integrity. For this scenario, Bouquet Canyon Dam has arbitrarily been assumed to develop

significant leakage necessitating rapid reservoir drawdown and evacuation of the downstream population. As a consequence, water storage in Bouquet Reservoir (36,505 acre-feet) would not be available.

Beyond the major terminal reservoirs, major transmission pipelines convey water to treatment facilities, distribution reservoirs, and the local distribution systems. Widespread major damage to these primary transmission lines is not anticipated, although some pipe failures will occur, particularly where these lines cross areas of poor ground and stream channels where differential movements are likely to occur.

The Waste and Water Committee of the Governor's Taskforce has considered the impact of the scenario event on distribution (Finlayson, 1982). The discussion which follows is based upon the work of this committee. Moderate damage to distribution reservoirs is expected. Underground excavated type reservoirs, with column-support roofs, could suffer extensive roof collapse; for tank-type reservoirs of concrete construction, pipeline connections and surface damage to the shell are expected; distribution reservoirs of welded or bolted steel construction will suffer little damage, but pipe connections will in some cases be severed. The damage to distribution storage, especially tanks without flexible couplings, will be significant, primarily at connections, and will likely lead to early loss of storage.

Water distribution pipelines vary from 2 inches to 54 inches or more in diameter. Pipe materials vary from cast iron to welded steel and asbestos cement to a variety of plastic materials. The damage to distribution pipelines is expected to vary with pipe material, soil type, slide condition,

degree of corrosion, design and installation practices, and joint type. It is anticipated that for the scenario earthquake, all water systems within the region will suffer some damage. In local distribution lines of under twelve inches in diameter, there will be hundreds of breaks and thousands of leaks. Breaks in house service connections will be common.

Pumping plants are generally more compact structures and, with the exception of related electrical equipment and transformers, will probably not suffer as great damage as distribution reservoirs. Large pumping plants will suffer damage closely related to horizontal acceleration and to the soils in which they were constructed. Damage is anticipated to be primarily related to pipeline rupture and transformer damage.

Water and Waste Treatment Facilities - Treatment plant facilities are expected to suffer damage, primarily where large pipelines connect with concrete structures and where pre-1960 concrete construction does not involve adequate concrete column ties to the floor and roof. The damage sustained is expected to depend upon the periodicity of the earthquake and differences in oscillations caused in concrete structures compared to pipeline and valve structures and result in difficult-to-repair situations.

For planning purposes, treatment plants were categorically assumed to be damaged and shutdown if located in an area of intensity 8 (R-F) or greater, as indicated on the Seismic Intensity Distribution maps. The assumption was made that plants subjected to this degree of shaking would experience sufficient damage to necessitate shutdown for any one or a combination of reasons. These include physical damage to the various components of the plant, rupture of

auxiliary pipelines, loss of power, or other damage that would interrupt the continuity of operations for a minimum of 72 hours.

Finlayson (1982) states that treatment plants close to the fault or those built in liquefiable soils, will experience differential settlement and treatment unit dislocation which will require shutdown of the plants, probable civil engineering damage assessment, and significant repair. Rupture of chlorine tanks due to collapsing buildings and improperly anchored containers will pose a health hazard to the surrounding area.

In waste water treatment plants, there is a limited volume of storage available. If the treatment train cannot be restored before storage is exceeded, the waste water will require discharge with emergency chlorination to reduce health hazards. Disruption of the sewerage system will result in sewerage flowing in some streets and channels where human contact can result.

Overflow of sewerage through manholes and from ponds can be expected due to breaks in mains and loss of power. As a result, there will be danger of excessive collection of explosive gas in sewer mains and flow of untreated sewerage in some street gutters. Many house connection sewers will break and plug causing them to become inoperative.

The spillage of raw sewage can be expected to pollute most waterways, rivers, harbors, and beaches. The public health hazard created by this pollution will be large.

Although extensive damage will be caused to the sewage collection system affected, the damage will not be sufficient in most areas to significantly

impair the system's ability to convey wastewater. This is because most of the system is by gravity. There are several small important systems that must pump. In addition, some old mains and mains in poor soils will break and leak.

Spillage from the sewage collection systems in the study area is not anticipated to exceed 25-35% as a result of structural failures of underground conduits and structures.

Aftershocks which will occur during the 72-hour period may cause significant damage to weakened buildings and facilities. Loss of dependable power supplies, damage to transportation facilities, and temporary supply problems are expected to seriously affect recovery of water and waste disposal systems during the 72-hour period (Finlayson, 1982).

Planning Insights

Water supply agencies should develop public education programs to acquaint water users with the possibility of contamination and loss of water supply. Plans for fire fighting should be coordinated with water supply agencies, and alternative sources of water for fire fighting planned for in areas where this is deemed critical. Arrangements should be made to cope with lack of function of domestic waste-removal capabilities. Plans to cope with sewer gases should be considered.

Recommended Further Work

Coordinate local estimates of water supply impairment with fire fighting water requirements. Water supply agencies should review their distribution systems and identify areas which are likely to be most severely affected by distribution line breakage.

Feasibility of emergency distribution of water using ground transportation needs to be evaluated in areas which are identified as having significant possibility of impaired water availability.

Feasibility of providing additional interconnections between various transmission and distribution systems should be considered in order to provide alternative supply routes.

WATER SUPPLY AND WASTE DISPOSAL FACILITIES

Maps 2N-W and 2S-W

MAP NOTATIONS

<u>NO.</u>	<u>FACILITY</u>	<u>COUNTY</u>
W1	California Aqueduct	Kern-Los Angeles

Most of the facilities of the California Aqueduct within the planning area and four major pumping plants and appurtenant works located along the southern margin of the San Joaquin Valley will be subjected to high intensity shaking and ground failures. Though all of the Aqueduct facilities are designed to resist the effects of a great earthquake comparable to the scenario event, widespread damage to these facilities will inevitably occur. For planning purposes, a minimum of three months will be required to accomplish those repairs necessary to restore water deliveries to southern California (Finlayson, 1982).

W2	California Aqueduct-West Branch	Los Angeles
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The West Branch of the California Aqueduct will be subjected to intensity 9 (R-F) shaking throughout most of its length with resulting damage to various aqueduct facilities.

W3	San Andreas Fault Crossing-Quail Lake	Los Angeles
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The West Branch Aqueduct will be heavily damaged by fault rupture and intense shaking where it crosses the San Andreas fault near Quail Lake.

W4	Los Angeles Aqueduct	Kern-Los Angeles
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The Los Angeles Aqueduct will be subjected to intense shaking (9 R-F) and some damage where it crosses the western Antelope Valley. The controlling element in the resumption of water deliveries to Los Angeles from the Owens Valley, however, will be repair of the Elizabeth Tunnel which crosses the San Andreas fault some 250 feet below the surface. Repairs will require more than 90 days (Algermissen and others, 1973) a difficult and hazardous task under a continuing threat of major aftershocks.

W5	California Aqueduct-East Branch	Los Angeles
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The East Branch of the California Aqueduct, closely paralleling the San Andreas fault for 100 kilometers from the South Portal of the Tehachapi

Tunnels to beyond the Los Angeles - San Bernardino County line, will be subjected to intense shaking (9 R-F). The canal and various appurtenant structures along this extended reach of aqueduct will be damaged due to shaking and local ground failures.

W6 San Andreas Fault Crossing-Anaverde Valley Los Angeles

The Leona Siphon, near the crossing of the San Andreas fault, will be damaged by shaking and the canal just south of the siphon severely damaged by fault rupture with some consequent water loss into Amargosa Creek.

W7 Palmdale Reservoir Los Angeles

The embankment of Palmdale Reservoir will be heavily damaged by fault rupture and very intense shaking. This very shallow reservoir poses no great threat, but leakage may impede efforts to accomplish timely repairs to both the adjacent main line of the Southern Pacific Railroad and Sierra Highway.

W8 San Andreas Fault Crossing-Barrel Springs Los Angeles

The East Branch Aqueduct will be severely damaged by fault rupture with resulting water discharge at the crossing of the San Andreas fault near Barrel Springs.

W9 California Aqueduct-Devil Canyon San Bernardino

No major damage to aqueduct facilities between Lake Silverwood and the power plant and penstocks at Devil Canyon is expected. The pipeline crossing the San Andreas fault will also be intact provided that surface fault rupture does, indeed, terminate some 25 km to the northwest (as assumed in this scenario).

W10 California Aqueduct-Santa Ana Crossing San Bernardino

This large-diameter pipeline between Devil Canyon and Perris Reservoir will be subject to intense shaking and possible ground failures in areas of high ground water near Colton and at the crossing of the Santa Ana River. The pipeline at this location is under high pressure and rupture could result in discharge of a significant volume of water until control facilities at Devil Canyon are activated. Though no sympathetic movement on other faults is considered in this planning scenario, this pipeline is particularly vulnerable to movement along the major San Jacinto fault which it crosses in this same area.

W11 Colorado River Aqueduct Riverside

There will be no significant damage to facilities of the Colorado River Aqueduct. The aqueduct crosses the San Andreas fault far beyond the

southern limit of fault rupture and the highest predicted intensity east of the terminal reservoir at Lake Matthews is 7 (R-F).

W12 MWD Upper Feeder

Riverside

Water deliveries through the MWD Upper Feeder will be temporarily interrupted by pipe rupture where this major transmission line crosses the Santa Ana River.

W13 West of Diamond Bar-Sewage pipe line

Los Angeles

This major trunk sewer line will be damaged at several locations by differential movements resulting from high intensity shaking between Diamond Bar and La Puente.

W14 Whittier Narrows Area-Sewage facilities

Los Angeles

Two sewage treatment facilities and segments of adjacent major trunk sewer lines will sustain major damage due to high intensity shaking in this area of high ground water.

EARTHQUAKE PLANNING SCENARIO: ELECTRICAL POWER

Map Nos. 2N-E and 2S-E

General Pattern

Approximately one-third of the power consumed in the greater Los Angeles region is imported via transmission facilities that will be subjected to intense shaking by the scenario earthquake. Immediately following the earthquake it is very probable that transmission of a significant portion of this power will be interrupted. Additionally, power generated at the five hydroelectric power plants north of Castaic and the Devil Canyon power plant near San Bernardino will be lost as a result of interrupted water supplies from the California and Los Angeles Aqueducts. These losses, coupled with some impairment of power generation capacity at Etiwanda and other major plants in the South Coastal and Oxnard areas could cause an additional temporary loss of about 25% of the generating capacity within the Basin. With the loss of most imported power supplies a temporary reduction in total power availability of 50% is conceivable. Major substations near the fault may also sustain significant damage.

Description

The major providers of electrical power within the planning area are the Southern California Edison Company and the City of Los Angeles, Department of

Water and Power. The latter serves the City of Los Angeles, and Edison Co. to the remainder of the area, except for the cities of Glendale, Burbank, and Pasadena, which have their own generating capability.

A major portion of the electrical power needs of the planning area are met by power generated within the area. These power plants, most of which are located in the southern coastal area (Map 2S-E), are not expected to sustain major damage that would seriously impair their generating capability. Most of the damage to electrical power systems will be in the areas of high intensity shaking nearer the zone of surface rupture (Maps 2S-E and 2N-E) and will have the greatest effect upon the imported power supplies entering the planning area from the north and northeast. Damage to major substations and transmission lines in this area will result in reliance upon the locally generated power sources until repairs to these import facilities can be accomplished.

Duke (1981) points out that "Since about 1933, most California electrical utilities have used earthquake design criteria for their critical facilities which are in excess of those required by local building codes. Some changes in criteria for new electrical equipment have been made since 1971 and considerable research is presently underway. Some existing equipment has been upgraded. Present design criteria for critical equipment are generally based on spectra representing a 50 percent of gravity horizontal ground acceleration combined with a vertical acceleration. System redundancy is recognized as effective in minimizing earthquake effects."

Relative to power generation in the planning area, Algermissen and others (1973) have stated that all but one or two of the thermal electrical

generating plants in Los Angeles and Orange counties have been designed for lateral forces approximately twice that required by local building codes for ordinary buildings. These increased design loads are applied to the buildings, piping, boilers, generators, and equipment. The behavior of the Valley Steam Plant (LADWP) in the February 9, 1971 San Fernando earthquake was excellent and damage was negligible although the estimated ground motion at this plant was Intensity VIII Modified Mercalli (MM). Experience indicates that well-designed electrical generating plants should suffer minimum (less than 5%) damage in Intensity VIII (MM) zones and only slight (less than 10%) damage in Intensity IX (MM) zones. Ordinarily, the plants will not shut down automatically when subjected to earthquake motions unless some malfunction of the control equipment occurs or the surveillance system detects a condition outside of acceptable limits.

For magnitude 8.3 scenario earthquake on the San Andreas fault, Algermissen and others (1973) estimated that generating stations within the Los Angeles-Orange County study area would have a functional impairment on the order of only 5 percent. Impairment of the Etiwanda Plant in western San Bernardino County was estimated to be 10 percent. Plants in Ventura County were not considered.

Davis (1980) noted that "Further consideration must also be given to generating plants located in areas of high ground water and/or poor soil conditions which make these plants susceptible to liquefaction." Several of the major plants in the Long Beach-Huntington Beach and Ventura coastal areas are located in areas of potential ground failure but site-specific studies are required to ascertain the actual potential at the plant sites. For the three

Edison Company plants in the Long Beach-Huntington Beach area, Davis (1980) estimated that "damage for the combined plants could be in the order of 25 percent...Based on the assumption that damage to generating stations would be in the order of 10% - 25%, it is very probable that a majority of the reduction in capacity would be restored within four to five days."

The several hydroelectric-power plants located on the California and Los Angeles Aqueducts in northwestern Los Angeles County and the Devil Canyon Power Plant near San Bernardino will be out of service for an extended period of time due to major damage to both of these aqueduct systems. The combined capacity of these several hydroelectric plants, however, is only the equivalent of one of the smaller fossil fuel plants located in the Los Angeles Basin.

For planning purposes, we have indicated extensive damage at several major substations. These particular facilities were designated on the basis of their location relative to areas of predicted intensity 9 (R-F) shaking, as shown on the Seismic Intensity Distribution maps for this planning area (Map 2N-S and 2S-S). Thus, extensive damage is indicated at all of the major substations located within a few kilometers of the surface rupture. Several other stations located within or in proximity to areas having high ground water conditions with potential for ground failure and intensity 9 (R-F) shaking are also indicated as sustaining extensive damage. These were categorical selections for planning purposes with no site-specific analysis of particular facilities.

Relative to substations, Davis (1980) noted that "the Vincent substation received some damage during the San Fernando earthquake at an estimated shaking intensity of 7 (R-F). The seismic resistance of equipment at this station has since been improved and modified designs applied to other facilities." Davis also points out that "Substation facilities have extreme flexibility with regard to routing power flow through the bus structure and, therefore, temporary rearrangements should be available. However, large breakers used in the 500KV system are not readily available and, therefore, repair of facilities to their original condition may take extended periods of time."

The CDMG analysis concurs with Algermissen and others (1973), who in commenting on power transmission facilities, indicated that "Transmission towers are designed for heavy lateral forces due to wind and broken conductor conditions so that they are inherently very earthquake resistant. However, they are susceptible to damage due to landslides and movements of supporting soils. Most of the transmission lines entering the Los Angeles Basin traverse mountainous terrain which is subject to extensive earthquake induced landsliding, particularly during the wet season. Additionally, transmission lines can be put out of service for very short periods of time (seconds) due to conductors swinging together and shorting or for longer periods of time by lines being broken due to tension caused by surface fault movements."

Major transmission routes into the metropolitan area cross the surface rupture and areas of intense shaking (9 R-F) at three general locations: near Tejon Pass, Portal Ridge west of Palmdale, and near Littlerock. Numerous damaged or collapsed towers are a reasonable expectation at each of these

locations. A fourth transmission corridor is through Cajon Pass, just beyond the assumed southern limit of surface rupture, but still vulnerable to damage by intense shaking and ground failures in steep, mountainous terrain. With regard to repairs, Davis (1980) indicates that "temporary structures can be installed in 1 to 2 days in order to restore the capability to import power. However, the amount of earth movement and the number of structures damaged could affect this restoration time. It is very probable that within 5 to 7 days at least one major transmission line could be restored to service for a case of severe and widespread damage to transmission facilities."

Davis (1980) considered three plausible outcomes affecting the Edison system following the scenario earthquake:

1. That all transmission lines that terminate at Vincent Substation and the joint SCE-LADWP 500 VK DC line are inoperative due to towers down, broken conductors, or switchyard damage.
2. That all transmission lines that terminate at Lugo Substation are also inoperative for the same reasons.
3. There is a 10% reduction in generating capacity from Etiwanda and San Bernardino generating stations and, further, that there is a 25% reduction in generating capacity at Long Beach, Alamitos, and Huntington Beach generating stations.

Davis concludes that if all these cases occurred simultaneously, a severe deficiency of electrical energy would exist. "For this situation, emergency

operating procedures and contingency plans would be put into effect. In general, these procedures and plans would require the curtailment of load on a rotating basis, for one hour periods, throughout the Edison service area." The predicted intensities developed in this scenario suggest that it is prudent, for planning purposes, to consider that these three cases do, indeed, occur simultaneously.

Damage to the distribution system will be widespread and will require a major repair effort. Underground distribution systems will be damaged by various ground failures. Surface distribution lines and poles will be broken by fire and by failures of adjacent structures. Many transformers will fall. Wires in contact will cause short circuits and fires. Davis (1980) indicates that "Although the distribution systems can be expected to receive widespread damage, it is anticipated that a majority of the affected area will be ready to have service restored within 1 to 2 days. For those situations requiring new temporary service, it is expected that a 2 to 3 day time period will be required. It can also be expected that areas of underground distribution will require a longer time to restore service, probably on the order of 5 to 7 days for a majority of the underground distribution systems."

Algermissen and others (1973) also notes that "Damage to oil storage tanks and connecting piping has been common in Intensity VIII and IX zones (MM); this damage could seriously affect the operations of generating plants which depend on oil for fuel due to curtailment of natural gas."

Planning Insights

Possible temporary loss of electrical power amounting to as much as 50 percent. Planning should work with this assumption. Local lack of power should be considered in all emergency planning.

Recommended Further Work

Further analysis should be undertaken to confirm the tentative conclusion that up to 50 percent of the total power supply could be lost by this or a similar scenario earthquake and evaluate utility capabilities necessary to accomplish timely repairs to various damaged facilities.

ELECTRICAL POWER

Maps 2N-E and 2S-E

MAP NOTATIONS

- | <u>NO.</u> | <u>FACILITY</u> | <u>COUNTY</u> |
|------------|--|---------------|
| E1 | Substation-Gorman | Los Angeles |
| | This substation, located very near the San Andreas fault, will be subjected to intense shaking with resulting major damage. | |
| E2 | Substation-Saugus and Sylmar | Los Angeles |
| | These two substations, located in proximity to areas of high ground water subject to intense shaking, will sustain major damage. | |
| E3 | Power Plants-Burbank/Glendale Area | Los Angeles |
| | Predicted shaking in the vicinity of the Valley Steam Plant and the other plants in the area operated by the cities of Burbank, Glendale, and Pasadena is intensity 8 (R-F) (See Map No. 2S-S) for this scenario. Expected damage to these plants is minimal, in concurrence with Algermissen and others' (1973) estimate of a functional impairment of 5% for these facilities. Algermissen and others (1973) point out that "The behavior of the Valley Steam Plant (LADWP) in the February 9, 1971, San Fernando earthquake was excellent and damage was negligible although the estimated ground motion at this plant was Intensity VIII (MM). Experience indicates that well designed electrical generating plants should suffer minimum (less than 5%) damage in Intensity VIII (MM) zones." (Intensity VIII-IX [MM] corresponds roughly to Intensity 8.75 - 9.5 [R-F]). | |
| E4 | Power Plants-Oxnard Plain | Ventura |
| | For reasons outlined in note E-3 above, only minor damage will occur to these two generating plants as a result of shaking. These plants are located in areas of potential ground failure, however, that could result in loss of some appurtenant facilities and/or generating capacity. For planning purposes, it is assumed that the combined plant output is diminished by 15 per cent. | |
| E5 | Substation-Vincent | Los Angeles |
| | This substation, located 7 km from the rupture zone, will sustain major damage as a result of very intense shaking. Many transmission lines routed to this station will be out of service due to damaged and collapsed towers. | |

E6 Transmission Lines-Littlerock Area Los Angeles

Multiple high-voltage transmission tower lines crossing the San Andreas fault near Littlerock Creek will be out of service due to numerous towers damaged or collapsed by intense shaking and failures on steep slopes east of Vincent substation.

E7 Transmission Lines-Tejon Pass Area Kern-Ventura-
Los Angeles

Major power transmission lines routed through the Tejon Pass corridor are out of service due to damaged and collapsed towers resulting from intense shaking (9 R-F) and ground failures in an area of steep mountainous terrain.

E8 Transmission Lines-Portal Ridge Area Los Angeles

Major power transmission lines crossing the San Andreas fault near Portal Ridge, including the joint SCE-LADWP high voltage DC transmission line, will be out of service due to numerous damaged towers both north and south of the rupture zone.

E9 Hydroelectric Power Plants-North of Castaic Los Angeles

Power generation at the five hydroelectric plants in this area will be essentially terminated for a minimum of three months until aqueduct repairs (both the California and Los Angeles Aqueducts) are completed and water deliveries resumed.

E10 Transmission Lines-Cajon Pass Area San Bernardino

Numerous high voltage transmission towers located on steep slopes in the Cajon Canyon corridor will be damaged or collapse as a result of shaking and failures of steep slopes. Restoration of damaged lines in this area will be difficult due to the steep mountainous terrain and limited access.

E11 Lugo Substation San Bernardino

Adhering strictly to the predicted intensities shown on Map No. 2S-S, Lugo substation will receive only intensity 8 (R-F) shaking and consequent minor damage. However, if surface rupture extended only slightly further to the southeast than assumed in this scenario, the predicted intensity at this facility would be intensity 9 (R-F). For planning purposes, therefore, it has been assumed that the Lugo substation will incur major damage.

E12 Substation-San Bernardino

San Bernardino

This substation is located in the immediate vicinity of the historically active San Jacinto fault. Though no sympathetic movement along this or other faults is considered in this scenario, that eventuality could inflict major damage to this facility. Ground water levels east of the fault, though currently rising, appear to be deeper than 10m at this location (Shervington, 1982). Site-specific studies will be required to adequately assess conditions at this site. For planning purposes, this facility is assumed to be seriously damaged and non-operational.

E13 Substations-La Puente Area

Los Angeles

Two major substations located along the San Jose Creek drainage will sustain moderate damage resulting from Intensity 9 (R-F) shaking.

E14 Power Plants-Long Beach/Huntington Beach Area

Los Angeles

Five major power plants located in the Long Beach-Huntington Beach area will sustain some damage. Algermissen and others (1973) conclude, for reasons stated in note E-3, that functional impairment of any one of these stations will be on the order of only 5%. Noting that generating plants located in areas of high ground water and/or poor soil conditions may be subject to ground failure due to liquefaction, Davis (1981), in discussing the three Edison plants located in this area, concludes that "damage for the combined plants could be in the order of 25%."

EARTHQUAKE PLANNING SCENARIO: NATURAL GAS

Map Nos. 2N-G and 2S-G

General Pattern

Major pipelines importing natural gas into the greater Los Angeles region will be ruptured near Tejon Pass, south of Palmdale, and Cajon Pass. These lines will be shut off automatically. Damage to pumping stations may also affect gas transmission. In general, these effects will be moderate to minor. Underground storage facilities within the planning area will provide gas for users in many parts of the Basin during the post-earthquake period.

Description

Natural Gas is supplied to the region through facilities of the Southern California Gas Company (S.C.G.) and its affiliated utility, Pacific Lighting Service (P.L.S.). Analysis of the natural gas supply system can be considered in two phases, the bulk supply lines from out of state and the San Joaquin Valley and the local distribution network, including underground storage and pumping stations.

For planning purposes, we conclude that fault rupture will sever the imported supplies from the San Joaquin Valley that cross the fault near Tejon Pass (Map 2N-G), and the 30-inch diameter import line that crosses the fault south of Palmdale. In addition, we have assumed that the two major lines routed through the Cajon Canyon corridor (Map 2S-G) will be ruptured by

seismically-triggered landslides or conceivably by fault rupture if displacement along the San Andreas extends further east than during the 1857 earthquake. The two imported supply lines routed through San Geronio Pass cross the San Andreas fault well beyond the southeastern limit of surface rupture. One of these two lines is assumed, however, to be ruptured as a result of ground failure west of Riverside.

The CDMG concurs with Algermissen and others (1973) that the line breaks can be isolated with the automatic pressure-actuated shut-off valves and repairs should be relatively easy. Damage to these transmission lines will necessitate temporary dependence upon underground storage. No significant damage to the underground storage facilities is foreseen, though the adjacent compressor station could experience damage necessitating temporary shutdown.

For a similar scenario, Algermissen and others (1973) estimated a total of 1510 breaks in gas mains and service connections in Los Angeles and Orange Counties, affecting some 68,000 customers. The implications of this conditions include local fire vulnerability and losses of gas pressure.

Planning Insights

Utilities should collaborate in a continuing public education campaign which explains the most likely types of utility impairments. Plans should be developed to ensure gas availability for those users who have priority emergency responsibilities.

Recommended Further Work

Locations where gas availability would be most severely impacted should be identified. Emergency users of natural gas should be identified.

Exploration of the likelihood of fire vulnerability due to breaks in local gas mains should also be explored.

MAP NOTATIONS

<u>NO.</u>	<u>FACILITY</u>	<u>COUNTY</u>
G1	San Andreas Fault Crossing-Quail Lake P.L.S. 34-inch diameter pipeline from the San Joaquin Valley will be severed by fault rupture where it crosses the San Andreas fault near Quail Lake.	Los Angeles
G2	San Andreas Fault Crossing-Palmdale P.L.S. 30-inch diameter pipeline will be severed by fault rupture where it crosses the San Andreas fault south of Palmdale.	Los Angeles
G3	San Andreas Fault Crossing-Tejon Pass P.L.S. 26-inch diameter pipeline will be severed by fault rupture where it crosses the San Andreas fault at Tejon Pass.	Los Angeles
G4	San Andreas Fault Crossing-Tejon Pass S.C.G. 22-inch diameter pipeline will be severed by fault rupture where it crosses the San Andreas fault at Tejon Pass.	Los Angeles
G5	Cajon Canyon Two major gas supply lines (S.C.G.) will be ruptured by seismically triggered landslides or rockfalls in the Cajon Pass corridor and possibly by fault rupture.	San Bernardino

G-6 Riverside-Rosemead

Riverside

Several lengthy sections of 30-inch diameter pipeline S.C.G. between Riverside and Rosemead are exposed to Intensity 9 (R-F) shaking in areas with high probability of ground failure. Although these larger diameter transmission pipelines (30-inch diameter and larger) are capable of withstanding significant deformation, we assume, for planning purposes, that this line will be ruptured as a result of ground failures at one or more unspecified locations along this route.

G7 Castaic Creek-Santa Clara River

Los Angeles

The 22-inch diameter (S.C.G.) and 26-inch diameter (P.L.S.) pipelines, severed by fault rupture near Tejon Pass, will be further damaged by ground failures and intense shaking where they cross Castaic Creek and the Santa Clara River.

EARTHQUAKE PLANNING SCENARIO: PETROLEUM FUELS

Maps 2N-P and 2S-P

General Pattern

Imports of crude oil from the San Joaquin Valley will be disrupted in lines routed through Tejon Pass. Petroleum product pipelines exporting from refineries in the Los Angeles Basin may also be damaged. No major widespread damage to oil handling and refinery facilities is foreseen except, possibly, in the Long Beach and adjacent harbor areas where many older petroleum pipelines are located in areas of poor ground. Resulting possibilities of fire exist in all of these areas. In general, effects on petroleum pipelines regionally will not be extensive, except in the immediate vicinity of the fault and local areas of ground failure.

Description

The planning area includes a major concentration of petroleum related facilities, including many producing oil fields, major refineries, and extensive related oil handling facilities. Most are located in the central and southern Los Angeles basin, becoming particularly dense within and adjacent to the Los Angeles-Long Beach harbor area (Map 2S-P). The various oil fields and related facilities are interconnected by a dense network of petroleum pipelines.

Other petroleum producing areas within the planning area include the Orange County coastline, the greater Whittier area of southeast Los Angeles and Orange Counties, and the area paralleling the Santa Clara River between

Newhall-Saugus and Ventura-Oxnard. In addition to these production facilities within the area, several major pipelines import crude oil to the local refineries and export of petroleum products to Nevada, Arizona, and San Diego.

Most of the refineries and related storage facilities are located in areas with predicted shaking of intensity 7 and 8 (R-F). Facilities near the harbor and coastal areas are subject to ground failures. While some damage to these facilities will occur, total impact on the industry should be relatively minor.

The newer pipelines are equipped with pressure-sensitive automatic shut-off valves. Algermissen and others (1973) indicate that perhaps 50% of the lines in the Los Angeles and Harbor areas have such valves; automatic valves are also used on most lines going out of Los Angeles and to the east through Cajon Pass.

Major damage to petroleum pipelines as envisioned in this scenario include: (a) rupture of pipelines (crude) from the San Joaquin Valley near Tejon Pass (Map 2N-P), (b) damage to major export product line in Cajon Canyon, and (c) numerous breaks of older lines in the Los Angeles-Long Beach harbor areas.

Algermissen and others (1973) pointed out that such breaks will constitute a fire threat, particularly in the hot, dry season. Should the petroleum ignite during the rainy season, water will transport the fire. The same threat exists in the harbor area where leaking product lines could be ignited and petroleum on water can burn as it did in the 1964 Alaskan earthquake.

Planning Insights

Plans for fire control should be developed for areas where these pipelines cross the San Andreas fault. Plans should also exist to ensure distribution of fuel supplies to airports selected for emergency activity and to other locations where fuel supplies for emergency response activities will be needed.

Recommended Further Work

The effects on pipelines at specific locations where ground failure is plausible should be evaluated. The locations and adequacy of shutoff valves should be confirmed at all crossings of the San Andreas fault and in other areas where ground failure is plausible.

PETROLEUM FUELS

Maps 2N-P and 2S-P

MAP NOTATIONS

NO. FACILITY

COUNTY

P1 Pumping Stations-Tejon Pass Area

Kern

Petroleum pumping stations in the vicinity of Fort Tejon, pumping crude oil from the San Joaquin Valley to Los Angeles area refineries, will suffer major damage. Agnew and Sieh (1978) estimate Intensity VIII - IX (MM) in this area during the 1857 earthquake, corresponding to Rossi-Forel intensity 9. "At Ft. Tejon, 7 km. from the fault, none of the buildings were totally destroyed; of seven that had been completed, two were so badly damaged as to be unsafe, and half of the six under construction were seriously damaged...These buildings had timber framed roofs and adobe bearing walls. The reports indicate Intensity VIII (MM) for this location."

P2 Pipelines-Tejon Pass Area

Los Angeles

Three major petroleum pipelines transporting crude oil south will be severed by fault rupture in the Tejon Pass - Gorman area.

P3 Pumping Station-Oak Flats Los Angeles

Petroleum pumping station near Oak Flats will suffer major damage due to intense shaking (9 R-F).

P4 Petroleum facilities near Castaic Junction Los Angeles

Ground failure resulting from liquefaction of sediments in Castaic Creek and/or the Santa Clara River is assumed to cause further damage to one or more of the three crude oil pipelines from the San Joaquin Valley. (These same lines are severed by fault rupture near Tejon Pass--see Note P2). In the Newhall-Saugus area, pumping stations and other petroleum production and handling facilities, including pipelines, will sustain light to moderate damage.

P5 Southern Los Angeles Basin-Harbor Area Los Angeles

Many petroleum pipelines in the southern Los Angeles Basin will be ruptured, particularly near the harbor areas where poor ground conditions are more prevalent. Older lines will experience the most damage and in the absence of automatic shut-off valves on many of these lines some parts of the harbors may be contaminated by leaking petroleum products. Damage to refineries and related oil handling and storage facilities will be relatively light, though facilities located on poor ground near the harbors will experience localized damage due to ground failures.

P6 Petroleum Pipelines-Diamond Bar Los Angeles

This important 20-inch diameter export petroleum product pipeline, exposed to high intensity shaking for several miles along the San Jose Creek drainage, will rupture by ground failure near Diamond Bar.

P7 Petroleum Pipelines-Cajon Canyon San Bernardino

CAL NEV pipeline, exporting petroleum products to Nevada, crosses the San Andreas fault southeast of the southern limit of the San Andreas fault rupture (Lone Pine Canyon) assumed in this scenario. Even so, this important lifeline will be severed in Cajon Canyon by a major seismically-triggered landslide or possible extension of fault rupture along the San Andreas beyond the limits of the 1857 earthquake.

GLOSSARY

(Definitions adapted from Glossary of Geology, American Geological Institute, 1981, and American Heritage Dictionary, 1981).

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

MAGNITUDE See Earthquake Magnitude.

MODIFIED MERCALLI SCALE See Appendix.

REINFORCED MASONRY Masonry construction with steel reinforcement.

RICHTER SCALE See Appendix.

ROSSI-FOREL SCALE See Appendix.

SEISMIC HAZARD A condition of risk or potential damage due to an earthquake.

THRUST FAULT A fault with a dip of 45° or less over much of its extent, on which the hanging wall appears to have moved upward relative to the footwall. Horizontal compression rather than vertical displacement is its characteristic feature.

WATER TABLE The upper surface of ground water saturation of pores and fractures in rock or surficial earth materials.

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APPENDIX

Rossi-Forel Scale,
Modified Mercalli Scale,
and Richter Scale

EARTHQUAKE-MEASURING SCALES

ROSSI-FOREL INTENSITY SCALE

The first scale to reflect earthquake intensities was developed in the 1880s by de Rossi of Italy and Forel of Switzerland. This scale, with values from 1 to 10, was used for about two decades. The most commonly used form of the Rossi-Forel (R-F) scale reads as follows:

- 1* Microseismic shock. Recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds: the shock felt by an experienced observer.
- 2 Extremely feeble shock. Recorded by several seismographs of different kinds; felt by a small number of persons at rest.
- 3 Very feeble shock. Felt by several persons at rest; strong enough for the direction or duration to be appreciable.
- 4 Feeble shock. Felt by persons in motion; disturbance of movable objects, doors, windows, cracking of ceilings.
- 5 Shock of moderate intensity. Felt generally by everyone; disturbance of furniture, beds, etc., ringing of some bells.
- 6 Fairly strong shock. General awakening of those asleep; general ringing of bells; oscillation of chandeliers; stopping of clocks; visible agitation of trees and shrubs; some startled persons leaving their dwellings.
- 7 Strong shock. Overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.
- 8 Very strong shock. Fall of chimneys; cracks in the walls of buildings.
- 9 Extremely strong shock. Partial or total destruction of some buildings.
- 10 Shock of extreme intensity. Great disaster; ruins; disturbance of the strata, fissures in the ground, rock falls from mountains.

* Although the convention is to use Roman numerals for intensity, in this report we have employed arabic characters on the map and thus have adopted them in the text.

MODIFIED MERCALLI INTENSITY SCALE

A need for a more refined scale increased with the advancement of the science of seismology, and in 1902 the Italian seismologist, Mercalli, devised a new scale on a I to XII range. The Mercalli scale was modified in 1931 by American seismologists Harry O. Wood and Frank Neumann to take into account modern structural features. The Modified Mercalli (MM) scale reads as follows:

- I Not felt except by a very few under especially favorable circumstances.
- II Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
- III Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
- IV During the day felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
- V Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
- VI Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
- VII Everybody runs outdoors. Damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
- VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
- IX Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

- X Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
- XI Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
- XII Damage total. Practically all works of construction are damaged greatly or destroyed. Waves seen on ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air.

The Modified Mercalli intensity scale measures the intensity of an earthquake's effects in a given locality, and is perhaps much more meaningful to the layman because it is based on actual observations of earthquake effects at specific places. It should be noted that because the data used for assigning intensities can be obtained only from direct firsthand reports, considerable time--weeks or months--is sometimes needed before an intensity map can be assembled for a particular earthquake. On the Modified Mercalli intensity scale, values range from I to XII. The most commonly used adaptation covers the range of intensity from the conditions of "I--not felt except by very few, favorably situated," to "XII--damage total, lines of sight disturbed, objects thrown into the air." While an earthquake has only one magnitude, it can have many intensities, which decrease with distance from the epicenter.

CORRELATION OF MODIFIED MERCALLI AND ROSSI-FOREL
SEISMIC INTENSITY SCALES

To convert from R-F to MM, the following table may be useful:

R-F	1	3	5	7.75	8.75	9.5	10
MM	I	III	IV-V	VII	VIII	IX	X-XII

RICHTER MAGNITUDE SCALE

The Richter magnitude scale, named after Dr. Charles F. Richter, Professor Emeritus of the California Institute of Technology, is the scale most commonly used, but often misunderstood. On this scale, the earthquake's magnitude is expressed in whole numbers and decimals. However, Richter magnitudes can be confusing and misleading unless the mathematical basis for the scale is understood. It is important to recognize that magnitude varies logarithmically with the wave amplitude of the quake recorded by the seismograph. Each whole number step of magnitude on the scale represents an increase of 10 times in the measured wave amplitude of an earthquake. Thus, the amplitude of an 8.3 magnitude earthquake is not twice as large as a shock of magnitude 4.3, but 10,000 times as large.

Richter magnitude can also provide an estimate of the amount of energy released during the quake. For every unit increase in magnitude, there is a 31-fold increase in energy. For the previous example, a magnitude 8.3 earthquake releases almost one million times more energy than one of magnitude 4.3.

A quake of magnitude 2 on the Richter scale is the smallest quake normally felt by humans. Earthquakes with a Richter magnitude of 7 or more are commonly considered to be major. The Richter magnitude scale has no fixed maximum or minimum; observations have placed the largest recorded earthquakes in the world at about 8.9, and the smallest at -3. Earthquakes with magnitudes smaller than 2 are called "micro-earthquakes." Richter magnitudes are not used to estimate damage. An earthquake in a densely populated area, which results in many deaths and considerable damage, may have the same magnitude as an earthquake that occurs in a barren, remote area, that may do nothing more than frighten the wildlife.