

**SEISMIC HAZARD ZONE REPORT FOR THE
LAKE HUGHES 7.5-MINUTE QUADRANGLE,
LOS ANGELES COUNTY, CALIFORNIA**

2003



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California Geological Survey

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SEISMIC HAZARD ZONE REPORT 103

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LOS ANGELES COUNTY, CALIFORNIA**

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CONTENTS

EXECUTIVE SUMMARY	vii
INTRODUCTION	1
SECTION 1 LIQUEFACTION EVALUATION REPORT Liquefaction Zones in the Lake Hughes 7.5-Minute Quadrangle, Los Angeles County, California.....	3
PURPOSE.....	3
BACKGROUND	4
METHODS SUMMARY.....	4
SCOPE AND LIMITATIONS.....	5
PART I.....	5
PHYSIOGRAPHY.....	5
GEOLOGY	6
ENGINEERING GEOLOGY	8
GROUND WATER	10
PART II.....	11
LIQUEFACTION POTENTIAL	11
LIQUEFACTION SUSCEPTIBILITY.....	11
LIQUEFACTION OPPORTUNITY	12
LIQUEFACTION ZONES	13
ACKNOWLEDGMENTS	15
REFERENCES	15

SECTION 2 EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT Earthquake-Induced Landslide Zones in the Lake Hughes 7.5-Minute Quadrangle, Los Angeles County, California	21
PURPOSE.....	21
BACKGROUND	22
METHODS SUMMARY.....	22
SCOPE AND LIMITATIONS.....	23
PART I.....	24
PHYSIOGRAPHY.....	24
GEOLOGY	25
ENGINEERING GEOLOGY.....	29
PART II.....	31
EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL.....	31
EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE.....	34
ACKNOWLEDGMENTS	35
REFERENCES	36
AIR PHOTOS.....	37
APPENDIX A Source of Rock Strength Data.....	38
SECTION 3 GROUND SHAKING EVALUATION REPORT Potential Ground Shaking in the Lake Hughes 7.5-Minute Quadrangle, Los Angeles County, California.....	39
PURPOSE.....	39
EARTHQUAKE HAZARD MODEL	40
APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS	44
USE AND LIMITATIONS.....	47
REFERENCES	48

ILLUSTRATIONS

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Southern California Edison Lucerne Record.....	32
Figure 3.1. Lake Hughes 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10 percent exceedance in 50 years peak ground acceleration (g)—Firm rock conditions.	41
Figure 3.2. Lake Hughes 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10 percent exceedance in 50 years peak ground acceleration (g)—Soft rock conditions.	42
Figure 3.3. Lake Hughes 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10 percent exceedance in 50 years peak ground acceleration (g)—Alluvium conditions.....	43
Figure 3.4. Lake Hughes 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10 percent exceedance in 50 years peak ground acceleration—Predominant earthquake.....	45
Figure 3.5. Lake Hughes 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10 percent exceedance in 50 years magnitude-weighted pseudo-peak acceleration for alluvium - Liquefaction opportunity.....	46
Table 1.1. Map units used in the Lake Hughes Quadrangle.....	8
Table 1.2. Quaternary Map Units used in the Lake Hughes 7.5-Minute Quadrangle and Their Geotechnical Characteristics and Liquefaction Susceptibility	10
Table 2.1. Summary of the Shear Strength Statistics for the Lake Hughes Quadrangle.	30
Table 2.2. Summary of Shear Strength Groups for the Lake Hughes Quadrangle.....	30
Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Lake Hughes Quadrangle.....	34
Plate 1.1. Quaternary geologic map of the Lake Hughes 7.5-Minute Quadrangle, California	50
Plate 1.2. Depth to historically high ground water in alluviated areas and location of boreholes used in this study, Lake Hughes 7.5-Minute Quadrangle, California.....	51
Plate 2.1. Landslide inventory and shear test sample locations, Lake Hughes 7.5-Minute Quadrangle, California.....	52

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Lake Hughes 7.5-Minute Quadrangle, Los Angeles County, California. The map displays the boundaries of zones of required investigation for liquefaction and earthquake-induced landslides over an area of approximately 49 square miles at a scale of 1 inch = 2,000 feet.

The Lake Hughes Quadrangle lies in northern Los Angeles County along the boundary between the San Gabriel Mountains and Antelope Valley. The area is 18 miles west of Lancaster and 46 miles northwest of the Los Angeles Civic Center. Crossing the center of the area is the San Andreas Fault Zone that consists of aligned trough-like valleys, linear hills, and closed depressions that contain Elizabeth Lake, Munz Lakes and Lake Hughes. South of the fault zone, Sawmill Mountain rises to 4,638 feet near the western boundary of the quadrangle and Grass Mountain rises to 4,605 feet. Portal Ridge lies north of the fault zone. Also to the north is the gently sloping terrain of Antelope Valley, which contains scattered hills at Antelope Buttes and Fairmont Butte. Fairmont Reservoir and a segment of the California Aqueduct lie along the northern side of Portal Ridge. The Angeles National Forest covers about 40 percent of the quadrangle. Parcels of private land are scattered within the forest, as are the rural communities of Elizabeth Lake, Lake Hughes, and Green Valley. Land use in the quadrangle includes ranching, rural homes, and recreation (campgrounds, boating, fishing).

The map is prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years.

In the Lake Hughes Quadrangle the liquefaction zone is restricted to the lowlands along the San Andreas Rift Zone and the bottoms of creek canyons where ground water is shallow and sediments are likely to be sandy. The bedrock in this quadrangle is mostly crystalline and typically subject to slope failure only on cliffs or very steep slopes. Sedimentary strata within the San Andreas Rift Zone are also locally subject to landsliding. Approximately two percent of the evaluated area within the quadrangle lies within the earthquake-induced landslide hazard zone.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the California Geological Survey's Internet page: <http://www.conservation.ca.gov/CGS/index.htm>

Paper copies of Official Seismic Hazard Zone Maps, released by CGS, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
945 Bryant Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at CGS offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>

The Act directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. The Act also directed CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Lake Hughes 7.5-Minute Quadrangle.

SECTION 1

LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Lake Hughes 7.5-Minute Quadrangle, Los Angeles County, California

**By
Ralph C. Loyd**

**California Department of Conservation
California Geological Survey**

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC).

The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at:

<http://www.scec.org/>

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Lake Hughes 7.5-Minute Quadrangle. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking), complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page:

<http://www.conservation.ca.gov/CGS/index.htm>

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in, including areas in the Lake Hughes Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill
- Ground-water maps constructed to show the historically highest known ground-water levels
- Geotechnical data analyzed to evaluate liquefaction potential of deposits
- Information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Lake Hughes Quadrangle consist mainly of alluviated valleys. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Lake Hughes Quadrangle covers about 62 square miles in northern Los Angeles County along the boundary between the San Gabriel Mountains and Antelope Valley. The center of the area is 18 miles west of Lancaster and 46 miles northwest of the Los Angeles Civic Center. The northwest-trending San Andreas Rift Zone crosses the center of the quadrangle. The zone consists of a series of aligned trough-like valleys, linear hills, and closed depressions that contain Elizabeth Lake, Munz Lakes and Lake Hughes. South of the rift zone and west of Elizabeth Lake Canyon Sawmill Mountain rises to

4,638 feet near the western boundary of the quadrangle. Between Elizabeth Lake Canyon and San Francisquito Canyon, Grass Mountain rises to 4,605 feet. North of the rift zone is Portal Ridge, which reaches 4,432 feet near the western boundary. North of Portal Ridge the gently sloping terrain of Antelope Valley contains scattered hills at Antelope Buttes and Fairmont Butte. The lowest point in the quadrangle is at 2,621 feet in Myrick Canyon at the eastern boundary. Fairmont Reservoir and a segment of the California Aqueduct lie along the northern side of Portal Ridge.

The boundary of the Angeles National Forest cuts in stair-step fashion across the center of the quadrangle. National forest land covers about 40 percent of the quadrangle. However, numerous parcels of private land are scattered within the forest. All of the private land is unincorporated Los Angeles County land, including the small communities of Elizabeth Lake, Lake Hughes, and Green Valley. Land use in the quadrangle includes ranching, rural homes, and recreation (campgrounds, boating, fishing). Due to the presence of private land within the national forest about 79 percent (49 square miles) of the quadrangle was evaluated for zoning.

Access to the region is via Elizabeth Lake-Pine Canyon Road along the San Andreas Rift Valley and other canyon roads.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that are generally susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. For this evaluation, the Quaternary geologic map of Ponti and others (1981) was used for the Antelope Valley part of the quadrangle. Maps by Barrows and others (1985) and Dibblee (2002) were used for the mountainous areas. The first two maps were digitized by the Southern California Areal Mapping Project [SCAMP] and the Dibblee map was digitized by CGS.

Plate 1.1 shows the generalized Quaternary geology of the Lake Hughes Quadrangle using, for convenience due to the scale, the map of Dibblee (2002). As can be noted on Plate 1.1, only about 20 percent of the quadrangle is covered by alluvial deposits of Quaternary age. These Pleistocene through Holocene surficial deposits are summarized in Table 1.1 and discussed below. The remaining area consists of granitic rocks exposed on Antelope and Fairmont Buttes and sedimentary, granitic, and metamorphic rocks exposed in the San Gabriel Mountains. The bedrock units are discussed in the earthquake-induced landslide portion (Section 2) of this report.

Ponti and others (1981) mapped the Quaternary units based mainly on relative age (Q1-Q7; 1 being oldest) and grain size (f=fine, m=medium, and c=coarse). Barrows and others (1985) divided Quaternary deposits mainly on the basis of age, for example, older alluvium (Qoa) or younger alluvium, (Qal) and/or environment of deposition, for example, stream channel (Qsc), alluvial fan (Qf), and lake deposits (Ql). In the Lake Hughes Quadrangle Dibblee (2002) divides Quaternary deposits on the basis of older and younger deposits (Qoa and Qa) and whether young Quaternary deposits are stream

deposits (Qg) or valley alluvium (Qa). Deposits exposed in the quadrangle are described below.

The oldest Quaternary unit mapped by Ponti and others (1981) consists of weakly consolidated, uplifted, and moderately to severely dissected Pleistocene alluvial fan deposits (Q1, Q2, Q3). These deposits occur in small, isolated patches generally along the base of Portal Ridge as well as around Fairmont Butte and Antelope Buttes. Soils on these deposits are distinctly reddish-brown and are moderately to well developed with well formed B horizons and clay accumulations. B profile ranges from 2 m in the oldest (Q1) to 50 cm in the youngest deposits (Q3). The units are mapped largely on the basis of the distribution of three units, which progresses from close relationship to present day topography and clast sources (Q3) to no apparent relationship (Q1). Some older exposures are undifferentiated (for example, Q1-3). Generally, Q1, Q2, and Q3 of Ponti and others (1981) correlate with the late Pleistocene units mapped by Barrows and others (1985) as Sandberg Formation, Nadeau Gravel, and Shoemaker Gravel. Q1-Q3 also corresponds to parts of the undifferentiated older Quaternary surficial deposits (Qoa) of Dibblee (2002).

Late Pleistocene deposits (Q4) cover about two-thirds of the Antelope Valley region of the Lake Hughes Quadrangle. Ponti and others (1981) describe this unit along with small patches of Q5 as unconsolidated, uplifted, and slightly dissected alluvial fan deposits. The two units are grouped because of similarities in topographic expression and soil development. The exposed materials are generally coarse and have moderately developed soils and clay accumulations in B profiles that are less than 50 cm with sound, but weathered, granitic clasts. Color ranges from medium to dark brown with occasional reddish-brown mottling in the older unit (Q4). Q4 and Q5 correlate with a variety of units mapped by Barrows and others (1985) as older alluvium and related surficial deposits. They also correspond to part of the deposits mapped as older Quaternary surficial deposits (Qoa) by Dibblee (2002).

Latest Pleistocene to Holocene alluvial fan and wash sediments (Q6) exposed in the northeast part of the quadrangle are unconsolidated, mainly sandy and silty sediments. Soils on these alluvial fan and colluvial materials are weakly developed. These sediments correlate closely in age with the sediments mapped as various younger alluvial and related surficial deposits by Barrows and others (1985) and Qa by Dibblee (2002).

Map Unit			Environment of Deposition	Age
Ponti and others (1981)	Barrows and others (1985)	Dibblee (2002)		
Q6	Qf, Ql, Qpa, Qsw, Qsc, Qt	Qa	alluvial fan, wash, ponds, terrace colluvial aprons	latest Pleistocene and Holocene
Q4, Q5	Qoa, Qof, Qopo	Qoa	alluvial fan, wash, colluvial aprons	late Pleistocene
Q1, Q2, Q3	Qsb, Qn, Qs	Qoa	alluvial fan, wash, colluvial aprons	late Pleistocene

Table 1.1. Map units used in the Lake Hughes Quadrangle

Structural Geology

The Antelope Valley covers about 25 percent of the Lake Hughes Quadrangle. It is a wedge-shaped high desert region of low local relief except for scattered buttes bounded on the northwest by the Garlock Fault and the Tehachapi Mountains and on the south by the San Andreas Fault and the Transverse Ranges. The remainder of the quadrangle lies within mountainous terrain. An 8-mile segment of the northwest-trending San Andreas Rift cuts across the central part of the quadrangle. This segment includes fault traces that ruptured during the great 1857 Fort Tejon earthquake, and faults within the rift have been included in the Official Earthquake Fault Zone prepared by CDMG (1974). The San Andreas Fault is a major potential seismic source. See section 3 of this report.

ENGINEERING GEOLOGY

As stated above, soils that are generally susceptible to liquefaction are mainly late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. Deposits that contain saturated loose sandy and silty soils are most susceptible to liquefaction. Lithologic descriptions and soil test results reported in geotechnical borehole logs provide valuable information regarding subsurface geology, ground-water levels, and the engineering characteristics of sedimentary deposits.

Of particular value in liquefaction evaluations are logs that report the results of downhole standard penetration tests. Standard Penetration Tests (SPTs) provide a uniform measure of the penetration resistance of geologic deposits and are commonly used as an index of soil density. This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil at the bottom of a borehole at chosen intervals while drilling. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 1999). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts

are normalized to a common-reference, effective-overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60 percent using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed primarily for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

During the initial stages of this investigation, CGS obtained logs of geotechnical boreholes that had been drilled in various localities within Antelope Valley. Staff collected the logs from the files of the cities of Lancaster and Palmdale, California Department of Transportation, Los Angeles County Public Works Department, and Earth Systems, Inc. Nearly 50 of the logs collected are from boreholes drilled within the Lake Hughes Quadrangle. The drill sites were digitally located and associated log data entered into the CGS geotechnical GIS database to enable computer-assisted analysis and evaluation.

Examination of borehole logs indicate that much of Leona Valley and wash areas of Antelope Valley contain sedimentary deposits composed of loose to moderately dense sandy and silty sediments. The lithologic descriptions provided in geotechnical borehole logs were augmented by examination of lithologic descriptions included in the logs of water wells drilled in the study area.

Geologic Map Unit*	Material Type	Consistency	Age	Liquefaction Susceptibility**
stream channel, wash (Qsc; Qg)	medium to coarse sand and gravel	very loose	latest Holocene	high
sand dune (Qsd)	sand	very loose	Holocene & late Pleistocene	high
wash (Q7; Qsc; Qa)	sand, gravel, & silt	loose	Holocene & late Pleistocene	high
alluvium, alluvial fan, wash (Q6; Qa: Qf, Ql, Qpa, Qt)	sand, gravel, & silt	loose to moderately dense	Holocene & late Pleistocene	high to moderate
alluvium, alluvial fan (Q4, Q5; Qoa, Qof, Qopo)	gravel, sand, silt, clay	dense	Pleistocene	low
alluvium, alluvial fan (Q1, Q2, Q3; Qsb, Qn, Qs:Qoa)	gravel, sand, silt, clay	dense	Pleistocene	low

* see Table 1.1 for correlation of map units among Ponti and others (1981), Barrows and others (1985), and Dibblee (2002).

**when saturated

Table 1.2. Quaternary Map Units Used in the Lake Hughes 7.5-Minute Quadrangle and Their Geotechnical Characteristics and Liquefaction Susceptibility

GROUND WATER

An essential element in evaluating liquefaction susceptibility is the determination of the depths at which soils are saturated by ground water. Saturated conditions reduce the effective normal stress acting on loose, near-surface sandy deposits, thereby increasing the likelihood of liquefaction (Youd, 1973). For zoning purposes, "near surface deposits" include those sediment layers between 0 and 40 feet deep, the interval being derived from item 4a of the SMGB criteria for delineating seismic hazard zones in California (DOC, 2000; see Criteria for Zoning section of this report). Liquefaction evaluations, therefore, concentrate on areas where investigations indicate that young Quaternary sediments might be saturated within 40 feet of the ground surface. Unfortunately, unpredictable and dramatic fluctuations in ground water caused by natural processes and human activities make it impossible to anticipate water levels that might exist at the time of future earthquakes. For that reason, CGS uses historically high ground-water levels for evaluating and zoning liquefaction potential. This approach assumes that even in areas where levels are presently significantly lower, ground water could return to historically high levels in the future. This, in fact, has occurred in basins where water-importing urbanized areas have replaced vast farm and orchard lands that were characterized by substantial ground-water withdrawal (for example, Simi Valley, Ventura County) as well as in basins where large-scale ground-water recharge programs are employed.

Plate 1.2 depicts historically shallowest depths to ground water of the Antelope Valley and Leona Valley areas within the Lake Hughes Quadrangle. As shown, historically high ground-water levels throughout most of the quadrangle are generally deeper than 40 feet. Exceptions are (1) active washes that extend out onto the Antelope Valley floor from the mountains where ground water is assumed to historically have been within 40 feet of the surface; (2) alluviated areas of Leona Valley where ground-water levels have been measured at shallower than 10 feet; and (3) restricted canyons where ground water is assumed to be less than 10 feet deep during wet periods.

Sources of ground-water data used in this report include: Galloway and others (1998); U.S. Geological Survey (2003); Johnson (1911); Thompson (1929); California Department of Water Resources (1965); Bloyd (1967); Durbin (1978); Duell (1987); Leighton and Associates (1990); Templin and others (1995); Carlson and others (1998); Carlson and Phillips (1998); Sneed and Galloway (2000); and California Department of Water Resources (2003).

PART II

LIQUEFACTION POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the SMGB (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's

geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

CGS's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10 percent probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in CGS's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Lake Hughes Quadrangle, PGAs ranging from 0.55 to 0.82g, resulting from a predominant earthquake of magnitude 7.8, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10 percent in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion portion (Section 3) of this report for further details.

Quantitative Liquefaction Analysis

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd

and Idriss, 1997; Youd and others, 2001). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, CGS's analysis uses the Idriss magnitude-scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: $FS = (CRR / CSR) * MSF$. FS, therefore, is a quantitative measure of liquefaction potential. CGS uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures.

The CGS liquefaction analysis program calculates an FS for each geotechnical sample where blow counts were collected. Typically, multiple samples are collected for each borehole. The program then independently calculates an FS for each non-clay layer that includes at least one penetration test using the minimum $(N_1)_{60}$ value for that layer. The minimum FS value of the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

About one half of the 50 geotechnical borehole logs reviewed in this study (Plate 1.2) include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, are generally translated to SPT-equivalent values if reasonable factors can be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes
2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated
3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable
4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

- a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or
- b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or
- c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the Lake Hughes Quadrangle is summarized below.

Areas of Past Liquefaction

Documentation of historical liquefaction or paleoseismic liquefaction in the Lake Hughes Quadrangle was not found during this study.

Artificial Fills

Artificial fill large enough to show at the scale of mapping is limited to the levies along the California Aqueduct and the earthen dam at Fairmont Reservoir. Since the California Aqueduct levies are considered to be properly engineered, zoning for liquefaction along its course in such areas depends on soil conditions in underlying strata. On the other hand, the engineering strength of the Fairmont Reservoir Dam is not known and, therefore, it is zoned as potentially liquefiable.

Areas with Sufficient Existing Geotechnical Data

Geologic mapping, geotechnical borehole and water well data, and liquefaction analysis using the Seed-Idriss Simplified Procedure provided a marginal basis for evaluating liquefaction potential in the Lake Hughes Quadrangle. The log descriptions and

liquefaction analysis in the Lake Hughes and adjacent quadrangles indicate that near surface young Quaternary sedimentary layers (Q6 and Q7 of Ponti and others (1980)) in Antelope and Leona Valleys are dominated by loose, sandy material that could liquefy where saturated under historically shallowest ground-water conditions presented on Plate 1.2. These areas are designated zones of required investigation on the Seismic Hazard Zone Map of the Lake Hughes Quadrangle.

Areas with Insufficient Existing Geotechnical Data

Staff depended significantly on SMGB Criterion Item 4 (see above) for zoning for liquefaction in the Lake Hughes Quadrangle because available geotechnical data, other than in the eastern Elizabeth Lake and Munz Lake areas, were marginally adequate for evaluating liquefaction potential. In addition, major washes extending from the highlands out into Antelope Valley were zoned as potentially liquefiable because surface and shallow sediments within them are periodically saturated by stream flow during wet seasons. The wash and flood-control basin behind Fairmont Reservoir Dam is included in such areas.

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SECTION 2

EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Lake Hughes 7.5-Minute Quadrangle, Los Angeles County, California

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing landslide hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee in 1998 under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of landslide analysis, evaluation, and mitigation techniques (SCEC, 2002). This text is also on the Internet at: <http://www.scec.org/>

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Lake Hughes 7.5-Minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking) complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: <http://www.conservation.ca.gov/CGS/index.htm>

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Lake Hughes Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope

gradient and slope aspect in the study area.

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared.
- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area.
- Seismological data in the form of CGS probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area.

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink and Real, 1996; McCrink, 2001) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Lake Hughes Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Lake Hughes Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Lake Hughes Quadrangle covers about 62 square miles in northern Los Angeles County along the boundary between the San Gabriel Mountains and Antelope Valley. The center of the area is 18 miles west of Lancaster and 46 miles northwest of the Los Angeles Civic Center. The northwest-trending San Andreas Rift Zone crosses the center of the quadrangle. The rift zone consists of a series of aligned trough-like valleys, linear hills, and closed depressions that contain Elizabeth Lake, Munz Lakes and Lake Hughes. South of the rift zone and west of Elizabeth Lake Canyon, Sawmill Mountain rises to 4,638 feet near the western boundary of the quadrangle. Between Elizabeth Lake Canyon and San Francisquito Canyon, Grass Mountain rises to 4,605 feet. North of the rift zone is Portal Ridge, which reaches 4,432 feet near the western boundary. North of Portal Ridge the gently sloping terrain of Antelope Valley contains scattered hills at Antelope Buttes and Fairmont Butte. The lowest point in the quadrangle is at 2,621 feet in Myrick Canyon at the eastern boundary. Fairmont Reservoir and a segment of the California Aqueduct lie along the northern side of Portal Ridge.

The boundary of the Angeles National Forest cuts in stair-step fashion across the center of the quadrangle. National forest land covers about 40 percent of the quadrangle, however numerous parcels of private land are scattered within the forest. All of the private land is unincorporated Los Angeles County land, including the small communities of Elizabeth Lake, Lake Hughes, and Green Valley. Land use in the quadrangle includes ranching, rural homes, and recreation (campgrounds, boating, fishing). Due to the presence of private land within the national forest about 79 percent (49 square miles) of the quadrangle was evaluated for zoning.

Access to the region is via Elizabeth Lake-Pine Canyon Road along the San Andreas Rift Valley, and via Lake Hughes, San Francisquito Canyon and Munz Ranch roads that traverse across the mountains along canyon roads.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface in the form of a digital topographic map.

Within the Lake Hughes Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, prepared from the 7.5-minute quadrangle topographic contours based on 1956 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

A slope map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The DEM was also used to make a slope aspect map. The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The geologic map used as background geology for the Lake Hughes Quadrangle was prepared from three sources. Ponti and others (1981) mapped the Quaternary geology of central Antelope Valley and vicinity, including the Lake Hughes Quadrangle. The pre-Quaternary sedimentary, volcanic, and crystalline rocks are generalized on the Ponti and others (1981) map. Detailed geologic maps of the San Andreas Fault Zone, including the segment that traverses the Lake Hughes Quadrangle, were prepared by Barrows and others (1985, Plates 1B and 1C). Geologic maps from both of these sources were digitized by the Southern California Areal Mapping Project [SCAMP]. Additionally, the third background geologic map source used was Dibblee (2002), which was digitized by CGS, and utilized for the southern map area, south of the detailed map by Barrows and others (1985). Bedrock units are described in detail in this section. Surficial geologic units are briefly described here and are discussed in more detail in Section 1, Liquefaction Evaluation Report.

CGS geologists modified the digital geologic map in the following ways. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the newly created landslide inventory would exist on separate layers for the hazard analysis. Contacts between bedrock and surficial units were revised to better conform to the topographic contours of the U.S. Geological Survey 7.5-minute quadrangle. Air-photo interpretation, digital orthophoto quarter quadrangle photo review, and field reconnaissance was performed to assist in adjusting contacts between bedrock and surficial geologic units, between map sources, and to review geologic unit lithology and geologic structure. The digital geologic map was modified to include interpretations of observations made during the aerial photograph review for the landslide inventory and field reconnaissance. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. The relation of the various geologic units to the development and abundance of landslides was noted.

Rock assemblages are distinct for areas that are north of and within, and south of the San Andreas Fault Zone, which crosses the entire quadrangle.

North of and within the San Andreas Fault Zone

The oldest rock unit north of the main trace of the San Andreas Fault is the pre-Cenozoic age Portal Schist (map symbol pos), which is exposed north of the Elizabeth Lake – Pine Canyon Road near the junction with Johnson Road south of the Hitchbrook Fault. Portal Schist predominantly consists of quartzo-feldspathic and dark biotite schist, with common marble and quartzite layers and abundant vein quartz (Barrows and others, 1985). North of the Hitchbrook Fault, a body of granodiorite and gneissic granodiorite (gd) extends across the entire quadrangle and beyond, along the northern side of the San Andreas Fault. The granodiorite unit is white to grayish white, fine to medium grained, massive to gneissic rock that ranges in composition from quartz monzonite to quartz diorite and is locally intruded by aplite and pegmatite dikes. A few small inclusions of marble (m, [Dibble (2002) map symbol ml]) within the granodiorite are exposed in south-facing slopes above Pine Canyon about two miles west of Lake Hughes. Rocks similar to the granodiorite and gneissic granodiorite units are exposed at Antelope Buttes where they were designated quartz monzonite to granodiorite (qm) by Dibblee (2002). Within the San Andreas Fault zone, slivers of deeply weathered, poorly exposed, greenish-gray to dark gray, highly sheared and shattered brecciated granodiorite and quartz monzonite (grbx) with abundant clay seams are scattered directly along the main trace of the San Andreas Fault. These rocks occur for two miles on the south side of the center-trough ridge southeast of Elizabeth Lake. Ponti and others (1981) mapped all of the pre-Tertiary rocks as gr-m.

At the northern boundary of the quadrangle Dibblee (2002) mapped volcanic rocks of the Gem Hill Formation (Tgh) of late Oligocene to early Miocene age. The Gem Hill Formation consists of whitish tuff and tuff breccia and is exposed on the eastern side of Fairmont Butte. Ponti and others (1981) mapped these rocks as Tertiary volcanics (Tv). Resting upon the Gem Hill Formation at Fairmont Butte is the poorly sorted volcanic-clast conglomerate member (Tfgv) of the Fiss Fanglomerate (Dibblee, 2002). Ponti and others (1981) mapped these rocks as Tertiary sedimentary rocks (Ts). Nearby to the south is an exposure of the unsorted fanglomerate of granitic debris member (Tfgg) of the Fiss Fanglomerate (Dibblee, 2002).

Exposed among interlacing fault strands within the center-trough ridge along San Andreas Fault Zone south of Elizabeth Lake are several members of the non-marine Pliocene Anaverde Formation. These include the red arkose, buff arkose, and clay shale members (Barrows and others, 1985). The red arkose member (Tar) is a pink to red, medium-to thick-bedded, locally massive, coarse pebbly arkose. The buff arkose (Tab) is a buff to gray, medium-bedded to massive, medium- to very coarse-grained pebbly arkose with thin silty interbeds near the top. The clay shale member (Tac) is a gray to brown, thin-bedded, sandy, silty, locally very gypsiferous clay shale with interbedded siltstone and sandstone layers. The center-trough ridge ends near the western end of Elizabeth Lake where the Hitchbrook Fault is inferred to intersect the San Andreas Fault Zone (Barrows and others, 1985, Plate 1C). No Anaverde Formation rocks are found to the west of this junction.

In the northern map area, north of Portal Ridge (map segment from Ponti and others, 1981), the upper Quaternary alluvial and colluvial units are designated by numbers (Q1 through Q7; higher numbers signify more recent deposits) and letters that signify coarseness of the materials (c being coarse- and m being medium-grained). Also in the northern map area, in the highlands along Portal Ridge, are several weathered erosional surface features, which were designated as Ql by Ponti and others (1981). These exposures were mapped by CGS geologists, after field reconnaissance and air photo review, and were designated as decomposed weathered granitic bedrock surfaces (map unit Qdg for our study). Ponti and others (1981) also mapped deposits designated as QTcs that they interpreted as Plio-Pleistocene continental sediments near Fairmont Reservoir. Dibblee (2002) did not separate these units from Qoa on his map. In places, older and/or younger alluvial deposits cover the pre-Quaternary rocks of Portal Ridge and the San Andreas Fault Zone (Barrows and others, 1985). Older alluvium (Qoa) is unconsolidated to moderately consolidated, poorly sorted to massive, moderately dissected fluvial gravel, sand, and silt deposits that was mapped by Barrows and others (1985, Plate 1C) almost exclusively on hilltops within the center-trough ridge on the south side of Elizabeth Lake. Older fan deposits (Qof), which are variable in texture, occur above modern erosional surfaces north of the fault zone only near the eastern edge of the quadrangle. Younger alluvial units include fan deposits (Qf), slope wash (Qsw), lake deposits (Ql), landslide deposits (Qls), alluvium (Qal), and stream channel deposits (Qsc).

South of the San Andreas Fault

The bedrock south of the fault consists predominantly of pre-Tertiary gneissic diorite and granodiorite exposed in the mountainous terrain of Grass Mountain and Sawmill Mountain. These rocks were mapped as a gneiss complex (dgn) of dark gray to black and white igneous, meta-igneous and metasedimentary rocks, migmatite, gneissic diorite, quartz diorite and granodiorite (Barrows and others, 1985). Map unit dgn is typically deeply weathered, commonly sheared and shattered, and rarely yields debris coarser than small pebbles. White, medium to coarsely crystalline, slightly graphitic elongate lenses of marble (m) up to 50 feet thick occur within the dgn on Sawmill Mountain. West of Munz Canyon in the center of the quadrangle a body of white, massive, coarsely crystalline quartz monzonite (qm) with included aplite dikes has intruded the dgn. Similar rocks are widespread west of Forsythe Canyon near the western boundary and within adjacent Burnt Peak Quadrangle (Barrows and others, 1985, Plate 1C and 1B). In the southern portion of the quadrangle compiled from the geologic map by Dibblee (2002) rocks of the gneissic diorite complex were mapped as quartz diorite (qd) with local inclusions of marble (ml). Dibblee (2002) mapped small intrusive bodies of granite-quartz monzonite (gr) on Grass Mountain. In the southern quarter of the quadrangle Dibblee (2002) mapped large areas of gray quartzo-feldspathic and biotitic gneiss (gn).

The mountainous, deeply dissected terrain south of the San Andreas Fault Zone is mostly exposed bedrock with only scattered alluvial deposits. Barrows and others (1985) mapped older fan deposits (Qof) and older alluvium (Qoa) on some of the lower slopes near the fault zone. Dibblee (2002) mapped similar deposits as older surficial sediments

composed of sand and gravel (Qoa). Younger units include fan deposits (Qf), alluvium (Qal; Qa of Dibblee, 2002), and stream channel deposits (Qsc) in Pine Canyon.

Structural Geology

The dominant structural feature is the San Andreas Fault Zone that crosses the central part of the entire quadrangle and separates geologic terranes with dissimilar rock assemblages. Topographically, the San Andreas Fault lies within a linear, trough-like valley called the San Andreas Rift Zone. The Hitchbrook Fault diverges from the San Andreas Fault Zone just west of Elizabeth Lake. East of the fault junction there is a center-trough ridge within the rift zone that is bound by parallel strands that define the zone. West of Munz Lakes the San Andreas Fault is much simpler in expression and consists essentially of a single trace (Barrows and others, 1985). The basement rocks of Portal Ridge border the zone on the north. South of the fault zone Grass Mountain and Sawmill Mountain consist of large bodies of dioritic gneiss intruded by quartz monzonite. Several faults, which lie about one mile south of the San Andreas Fault, occur within these mountains including the Grass Mountain Fault and the Sawmill Mountain Fault. The San Andreas Fault is the southwestern boundary of the Mojave block geomorphic province of California. The San Andreas Fault is considered to be an active seismic source (DOC, 1997), and in the Lake Hughes Quadrangle, this fault is mapped with an Official Earthquake Fault Zone designation along the fault zone trace (DOC, 1974).

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Lake Hughes Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping. Landslides were mapped at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the landslide zoning as described later in this report. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

Landslides were mapped mainly within the San Andreas Fault Zone and close proximity. The landslides identified in the study area are present within the steeply dipping Anaverde Formation and the crystalline bedrock units. Landslides generally range from surficial failures resulting from soil and rock creep, to moderate-size rotational rock slides and debris slides.

Because it is not within the scope of the Act to review and monitor grading practices to ensure past slope failures have been properly mitigated, all documented slope failures, whether or not surface expression currently exists, are included in the landslide inventory.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the Lake Hughes Quadrangle geologic map was obtained from County of Los Angeles- Department of Public Works (see Appendix A). The locations of rock and soil samples taken for shear testing within the Lake Hughes Quadrangle are shown on Plate 2.1.

Shear strength data gathered from the above source were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean or median) phi values for each geologic map unit and corresponding strength group, are summarized in Table 2.1. For each geologic strength group (Table 2.2) in the map area, the average shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Table 2.1 and Table 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

Existing Landslides

As discussed later in this report, the criteria for landslide zone mapping state that all existing landslides that are mapped as definite or probable are automatically included in the landslide zone of required investigation. Therefore, an evaluation of shear strength parameters for existing landslides is not necessary for the preparation of the zone map. However, in the interest of completeness for the material strength map, to provide relevant material strength information to project plan reviewers, and to allow for future revisions of our zone mapping procedures, we have collected and compiled shear strength data considered representative of existing landslides within the quadrangle.

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily "residual" strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used. For the Lake Hughes Quadrangle, no shear tests of landslide slip surface materials were available. A phi value of 16 degrees was derived from shear tests collected in nearby quadrangles and was judged to be representative of the relatively few landslides in the study area.

LAKE HUGHES QUADRANGLE SHEAR STRENGTH GROUPS							
	Formation Name	Number Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1	qd ¹ qm ²	6 28	44/43 41/42	41/42	181/180	Tfgv, Tgh, Ts, Tv	42
GROUP 2						psp, pos, gr	34
GROUP 3	Tab ³ Qa ⁴	26 37	28/28 33/34	28/29	228/190	af	28
GROUP 4						Qls	16

Formation abbreviations from Dibblee (2002); Barrows and others (1985), and Ponti and others (1981) equivalents shown below:

qd¹ = gn, dgn, ml
 qm² = gd, gr-m, Qdg
 Tab³ = Qopo, Tac, Tas, Tar, grbx, m
 Qa⁴ = Q1, Q1-2c, Q1-3c, Q2, Q2-3c, Q2c, Q3c, Q4c, Q4m, Q5c, Q6c, Q6m, Q7c, Q7f, Q7m, QTcs, Qal, Qf, Qg, Ql, Qoa, Qof, Qpa, Qsc, Qsw
 Note: "ml" and "m" outcrops are considered minor enough to be incorporated within their host-rock formations. Qdg designates veneer of weathered bedrock, incorporated into bedrock strength group.

Table 2.1. Summary of the Shear Strength Statistics for the Lake Hughes Quadrangle.

SHEAR STRENGTH GROUPS FOR THE LAKE HUGHES 7.5-MINUTE QUADRANGLE			
GROUP 1	GROUP 2	GROUP 3	GROUP 4
Qd ¹ , qm ² , Tfgv, Tgh, Ts, Tv	psp, pos, gr	Tab ³ , Qa ⁴ , af	Qls

Table 2.2. Summary of Shear Strength Groups for the Lake Hughes Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the “ground shaking opportunity.” For the Lake Hughes Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by CGS for a 10 percent probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	7.8
Modal Distance:	2.6 to 10.3 km
PGA:	0.56 to 0.97 g

The strong-motion record selected for the slope stability analysis in the Lake Hughes Quadrangle was the Southern California Edison Lucerne record from the 1992 magnitude 7.3 Landers, California, earthquake was used because it was the closest fit to the above criteria. This record had a source to recording site distance of 1.1 km and a peak ground acceleration (PGA) of 0.80g. Although the distance and PGA from the Lucerne record do not fall within the range of the probabilistic parameters, this record was considered to be sufficiently conservative to be used in the stability analyses. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and

estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.24, 0.18 and 0.14 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Lake Hughes Quadrangle.

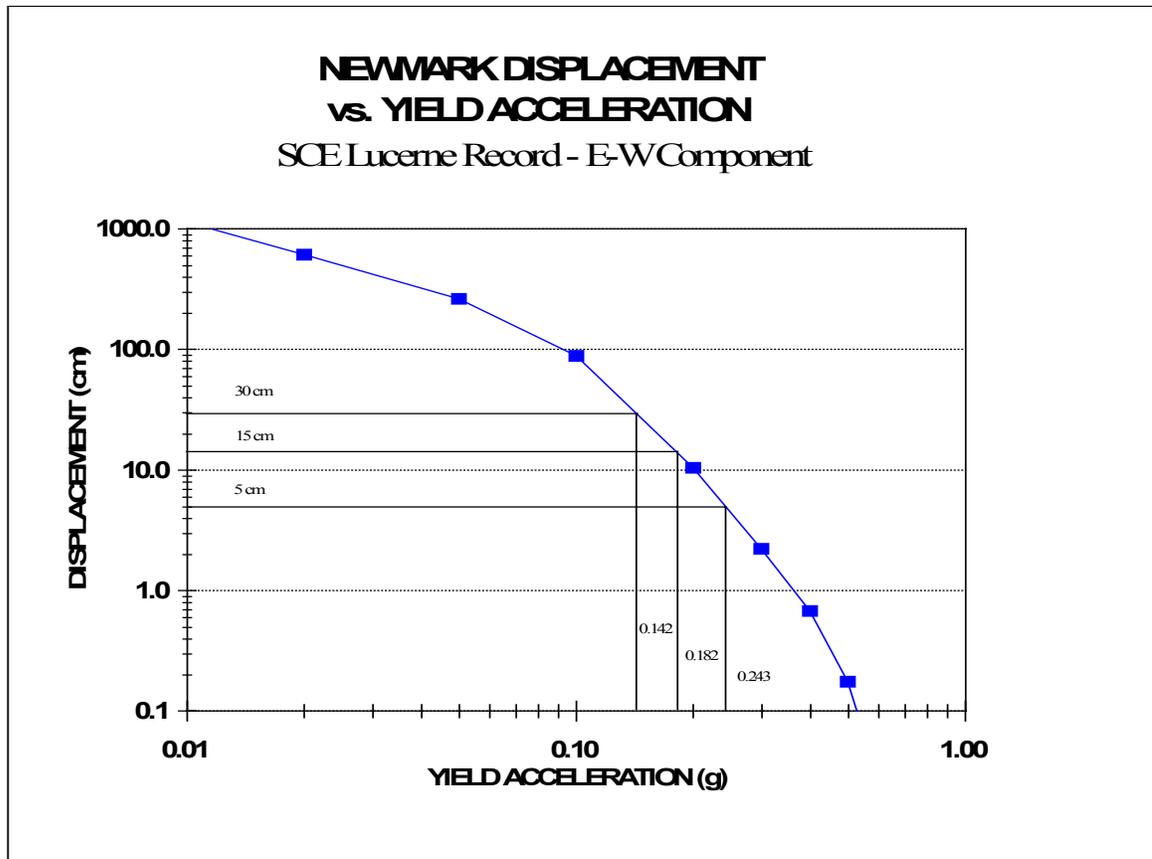


Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Southern California Edison Lucerne Record.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where **FS** is the Factor of Safety, **g** is the acceleration due to gravity, and **α** is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure **α** is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.14g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned.
2. If the calculated yield acceleration fell between 0.18g and 0.14g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned.
3. If the calculated yield acceleration fell between 0.24g and 0.18g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned.
4. If the calculated yield acceleration was greater than 0.24g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

LAKE HUGHES QUADRANGLE HAZARD POTENTIAL MATRIX				
Geologic Material Strength Group (Average Phi)	HAZARD POTENTIAL (Percent Slope)			
	Very Low	Low	Moderate	High
1 (42)	0 to 61 %	61 to 69 %	69 to 71 %	> 71 %
2 (34)	0 to 41 %	41 to 47 %	47 to 52 %	> 52 %
3 (28)	0 to 28 %	28 to 33 %	33 to 37 %	> 37 %
4 (16)	0 to 4 %	4 to 10 %	10 to 14 %	> 14 %

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Lake Hughes Quadrangle. Values in the table show the range of slope gradient (expressed as percent slope) corresponding to calculated Newmark displacement ranges from the design earthquake for each material strength group.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.
2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of

deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; McCrink, 2001), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 4 is included for all slopes steeper than 4 percent. (Note: The only geologic unit included in Geologic Strength Group 4 is Qls (existing landslides). Qls have been included or excluded from the landslide zones on the basis of the criteria described in the previous section)
2. Geologic Strength Group 3 is included for all slopes steeper than 28 percent.
3. Geologic Strength Group 2 is included for all slopes steeper than 41 percent.
4. Geologic Strength Group 1 is included for all slopes steeper than 61 percent.

This results in approximately two percent of the area mapped within the quadrangle lying within the earthquake-induced landslide hazard zone for the Lake Hughes Quadrangle. As previously discussed, approximately 79 percent of the entire map area was evaluated for zoning.

ACKNOWLEDGMENTS

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AIR PHOTOS

Department of County Engineers, Soil Survey Los Angeles County, photo numbers 1-1 through 1-9 and 1-80 through 1-84, dated 3-25-68 and 3-42 through 3-46, dated 3-28-68 and 5-136 through 5-141 dated 4-4-68, scale 1:24,000.

Fairchild Surveys, Inc., flight # C-300, photo numbers 1030, 1215 through 1218, and 1224 through 1228, scale 1:20,000.

I.K. Curtis Services, Inc., Burbank, CA, photo numbers; 8208 through 8212, dated 6/24/1971, scale 1:12,000.

- I.K. Curtis Services, Inc., Burbank, CA, color, photo numbers; 1 through 11, dated October, 1976, scale 1:12,000.
- I.K. Curtis Services, Inc., Burbank, CA, photo numbers; 6869 through 6873, dated October, 1976, scale 1:12,000.
- U.S. Forest Service color, flight # EUX frame 1-6 through 1-8, and 7-19 through 7-21 and 1-51 through 1-52, 7/15/69, scale 1:15,840.
- Digital Orthophoto Quarter Quadrangle Photos, dated 6/1/94, entire quadrangle area, Lake Hughes Quadrangle. (DOQQ and information concerning them can be obtained at <http://www-wmc.wr.usgs.gov/doq/>)

**APPENDIX A
SOURCE OF ROCK STRENGTH DATA**

SOURCE	NUMBER OF TESTS SELECTED
Los Angeles County Department of Public Works	100
Total Number of Shear Tests	100

SECTION 3

GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Lake Hughes 7.5-Minute Quadrangle, Los Angeles County, California

By

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided

herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions *for the analysis of ground failure* according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (DOC, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: <http://www.conservation.ca.gov/CGS/index.htm>

EARTHQUAKE HAZARD MODEL

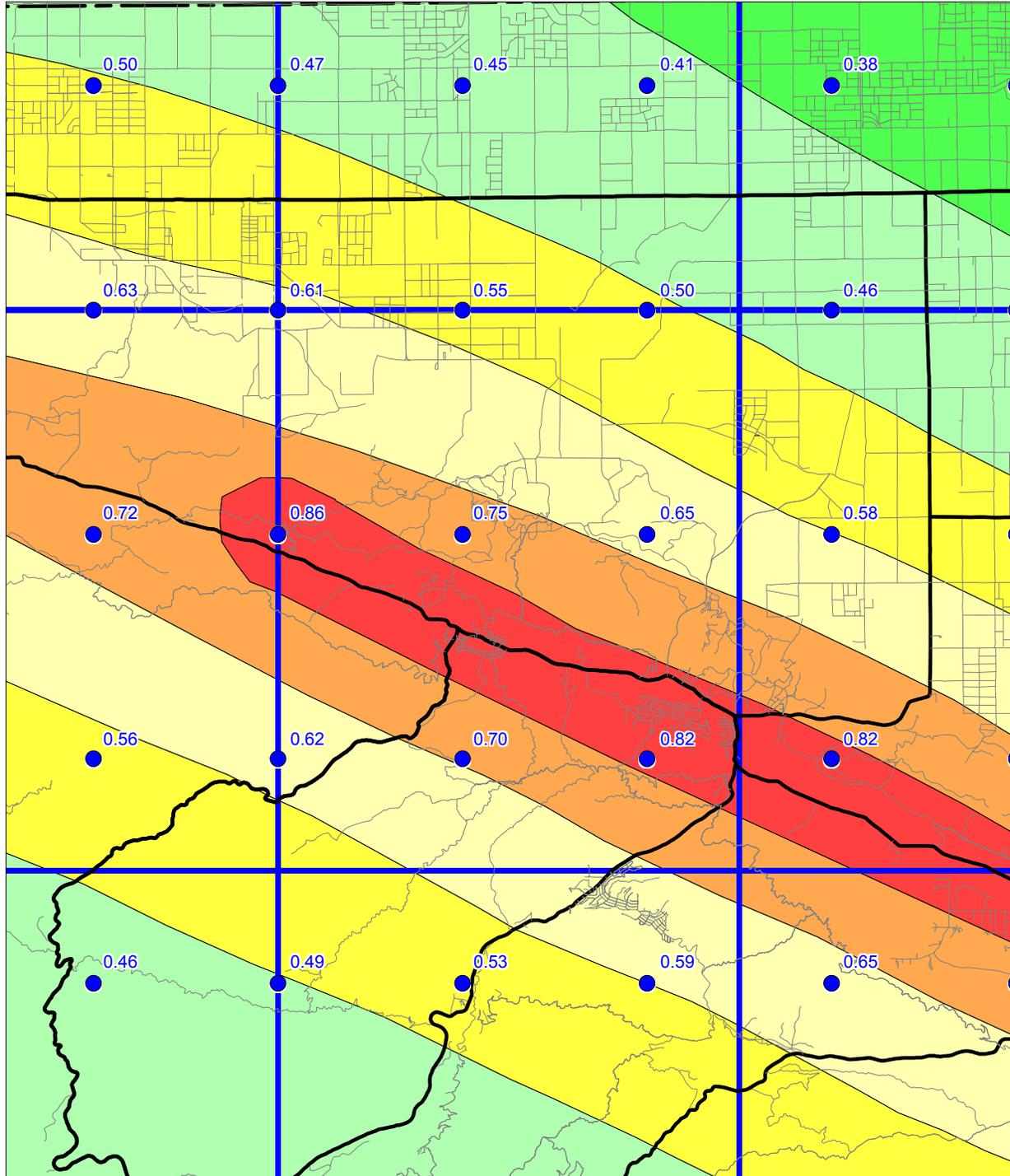
The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology [California Geological Survey], and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10 percent probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)
1998

FIRM ROCK CONDITIONS



Base map from GDT



Department of Conservation
California Geological Survey



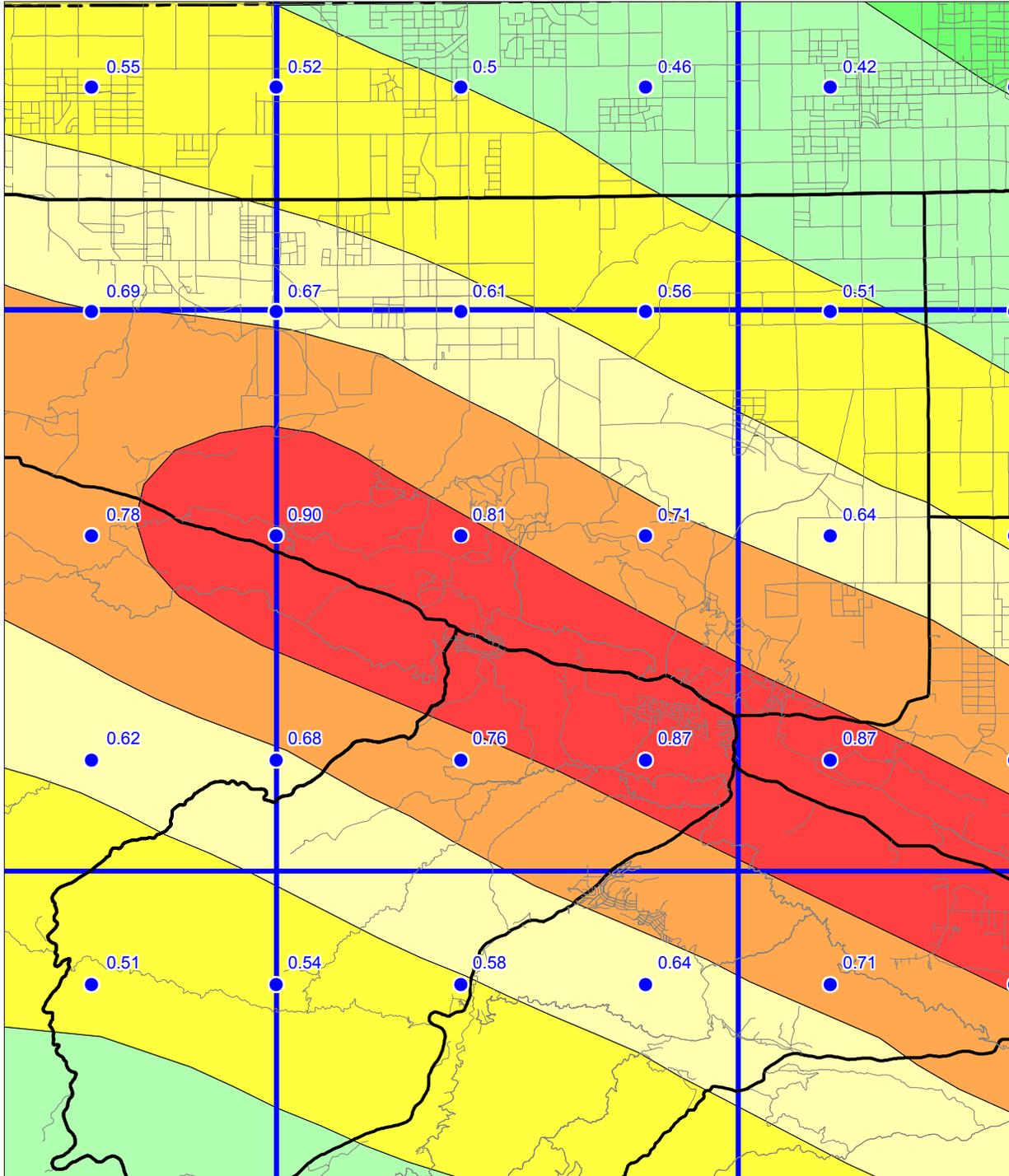
Figure 3.1

LAKE HUGHES 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map from GDT



Department of Conservation
California Geological Survey

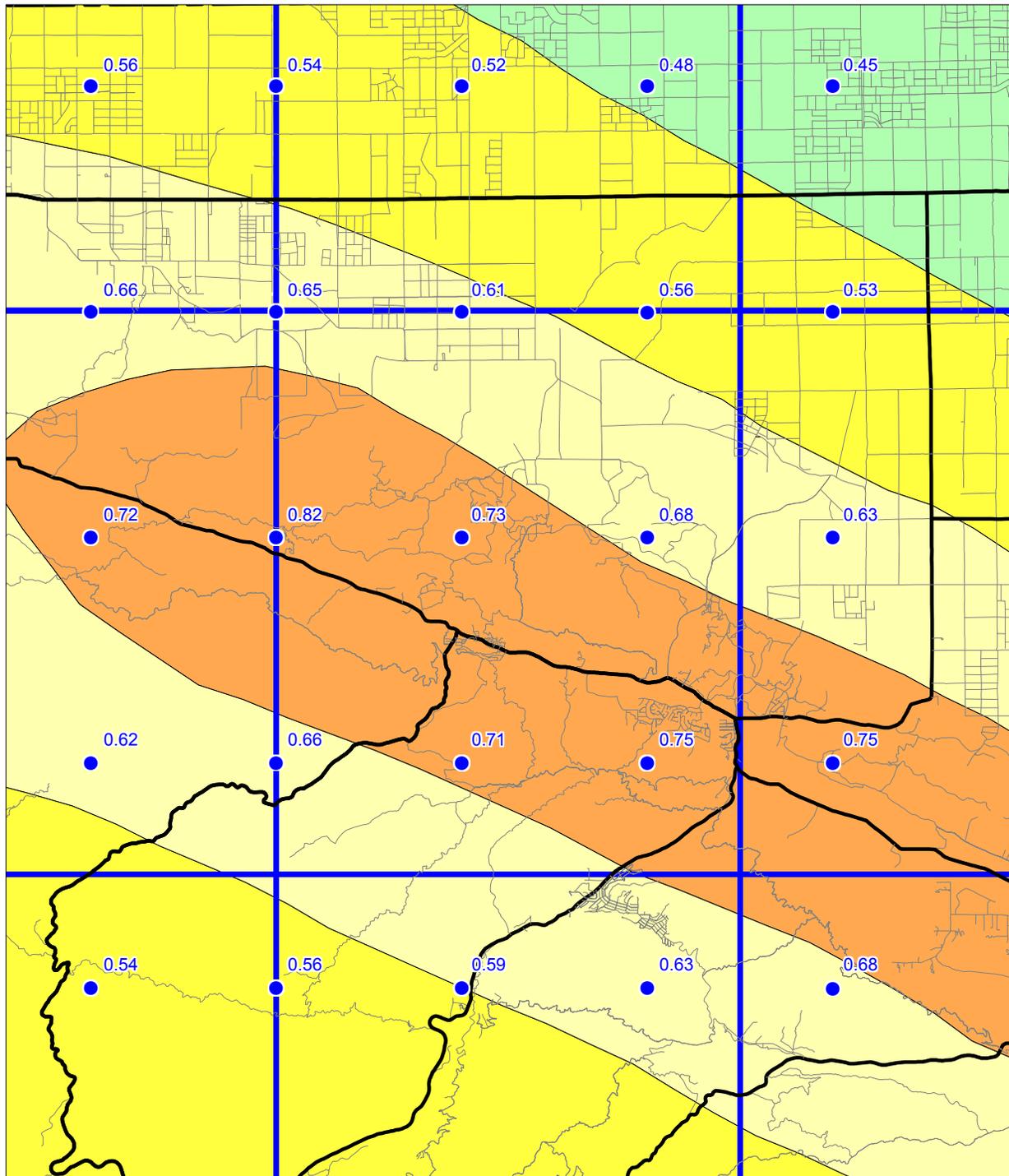


Figure 3.2

LAKE HUGHES 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)
1998

ALLUVIUM CONDITIONS



Base map from GDT



Department of Conservation
California Geological Survey



Figure 3.3

adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10 percent probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the “simplified Seed-Idriss method” of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a “magnitude-weighted” ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

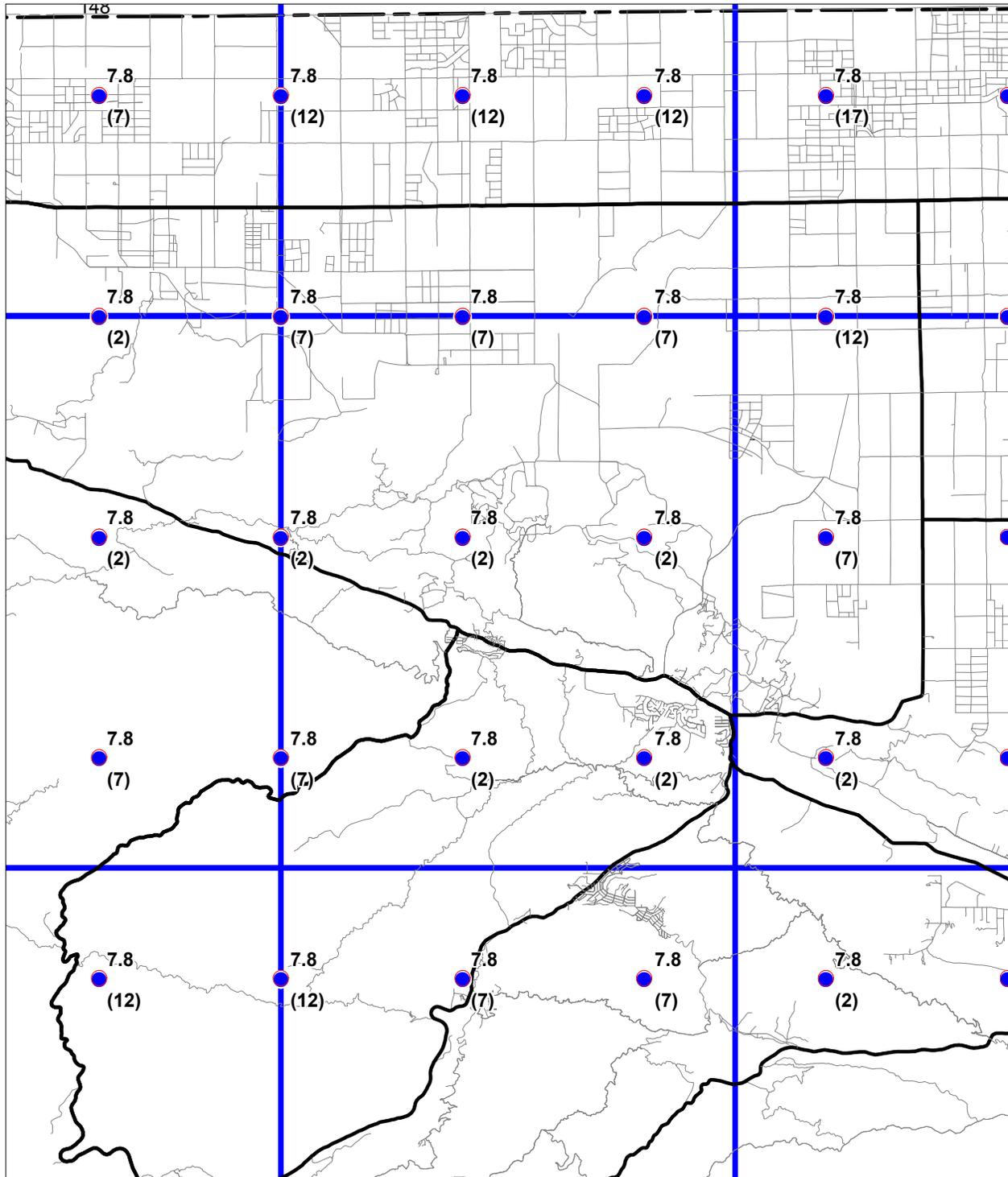
SEISMIC HAZARD EVALUATION OF THE LAKE HUGHES QUADRANGLE LAKE HUGHES 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)
(Distance (km))



Base map from GDT



Department of Conservation
California Geological Survey

Figure 3.4

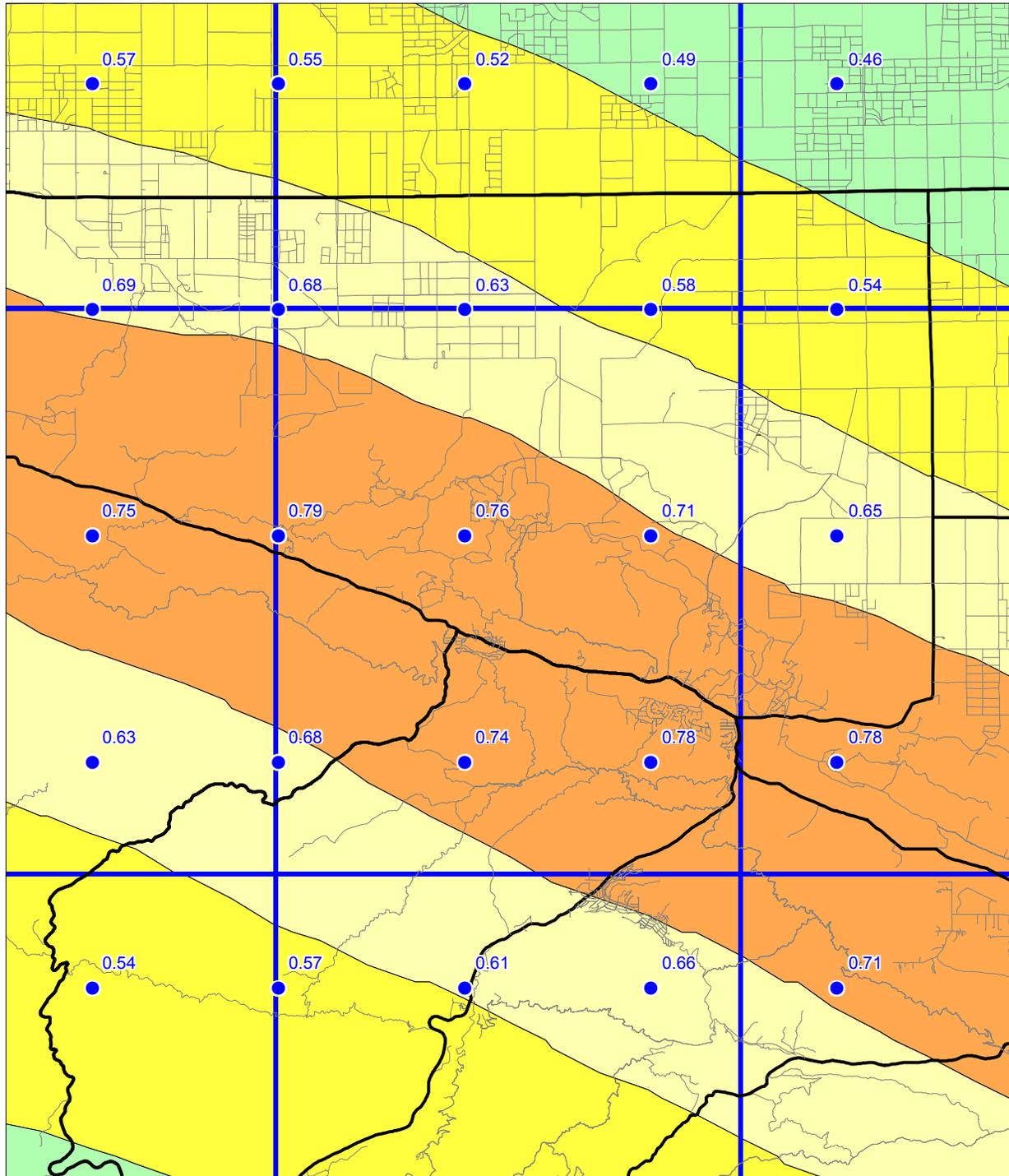


SEISMIC HAZARD EVALUATION OF THE LAKE HUGHES QUADRANGLE LAKE HUGHES 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g)
FOR ALLUVIUM

1998

LIQUEFACTION OPPORTUNITY



Base map from GDT



Department of Conservation
California Geological Survey



Figure 3.5

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is *not appropriate for site specific structural design applications*. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.
2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours.*
3. Uncertainties in the hazard values have been estimated to be about +/- 50 percent of the ground motion value at two standard deviations (Cramer and others, 1996).
4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.
5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

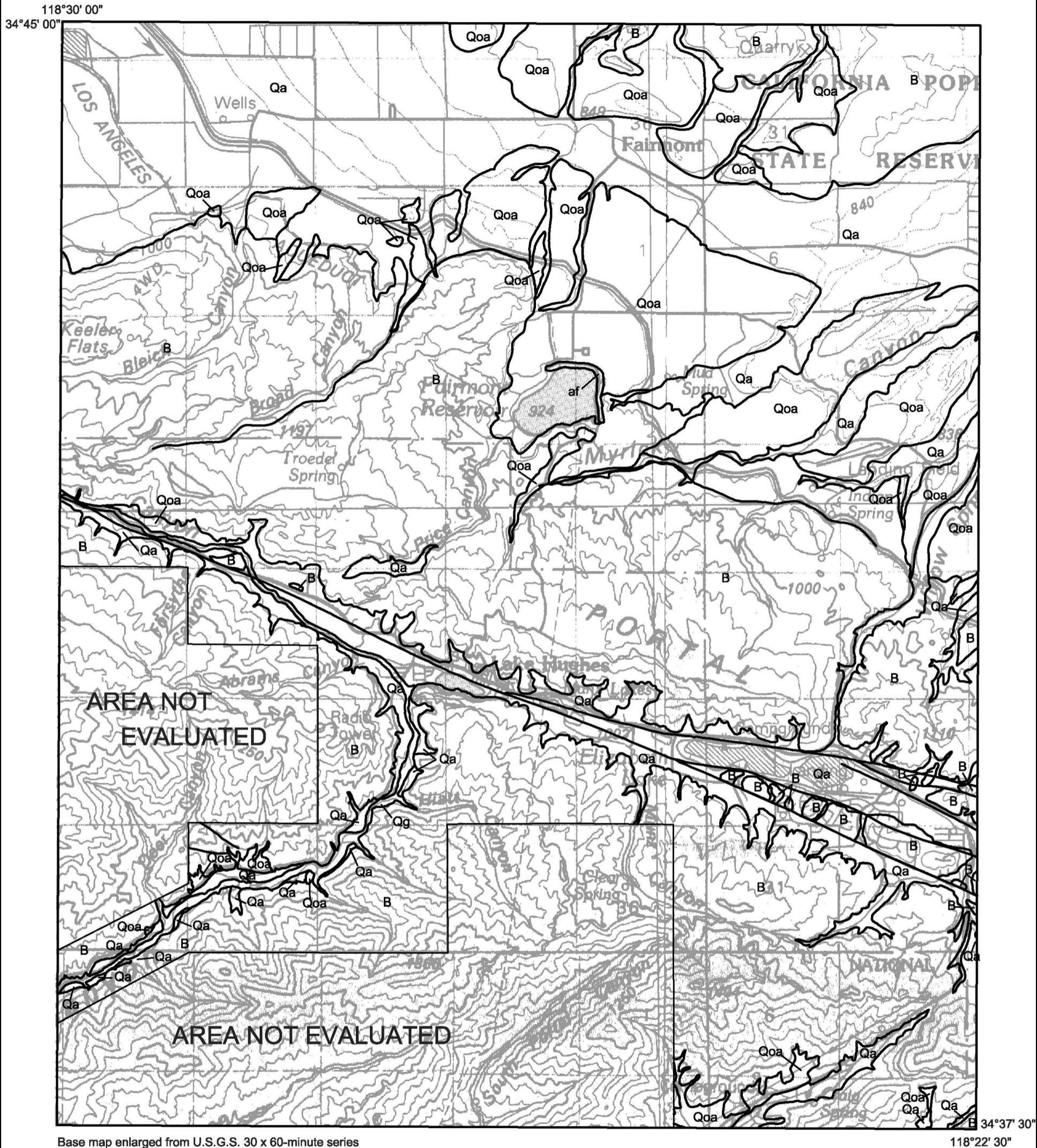
Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV

method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

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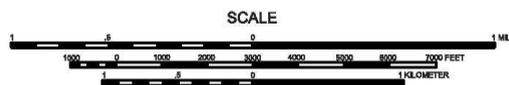
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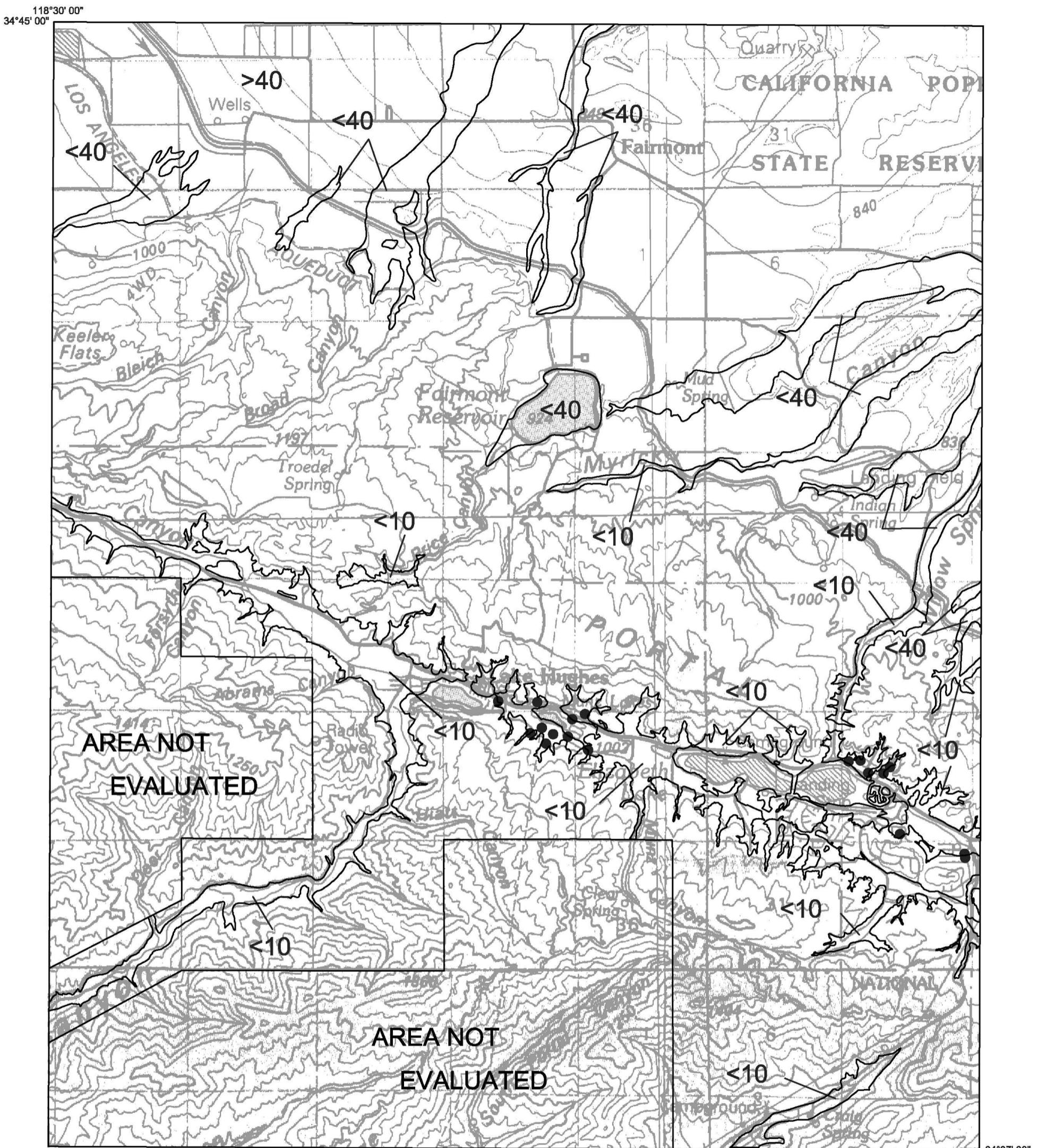
Base map enlarged from U.S.G.S. 30 x 60-minute series

LAKE HUGHES QUADRANGLE



See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

B = Pre-Quaternary bedrock.

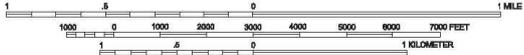


Base map enlarged from U.S.G.S. 30 x 60-minute series

34°37' 30"
 118°22' 30"

LAKE HUGHES QUADRANGLE

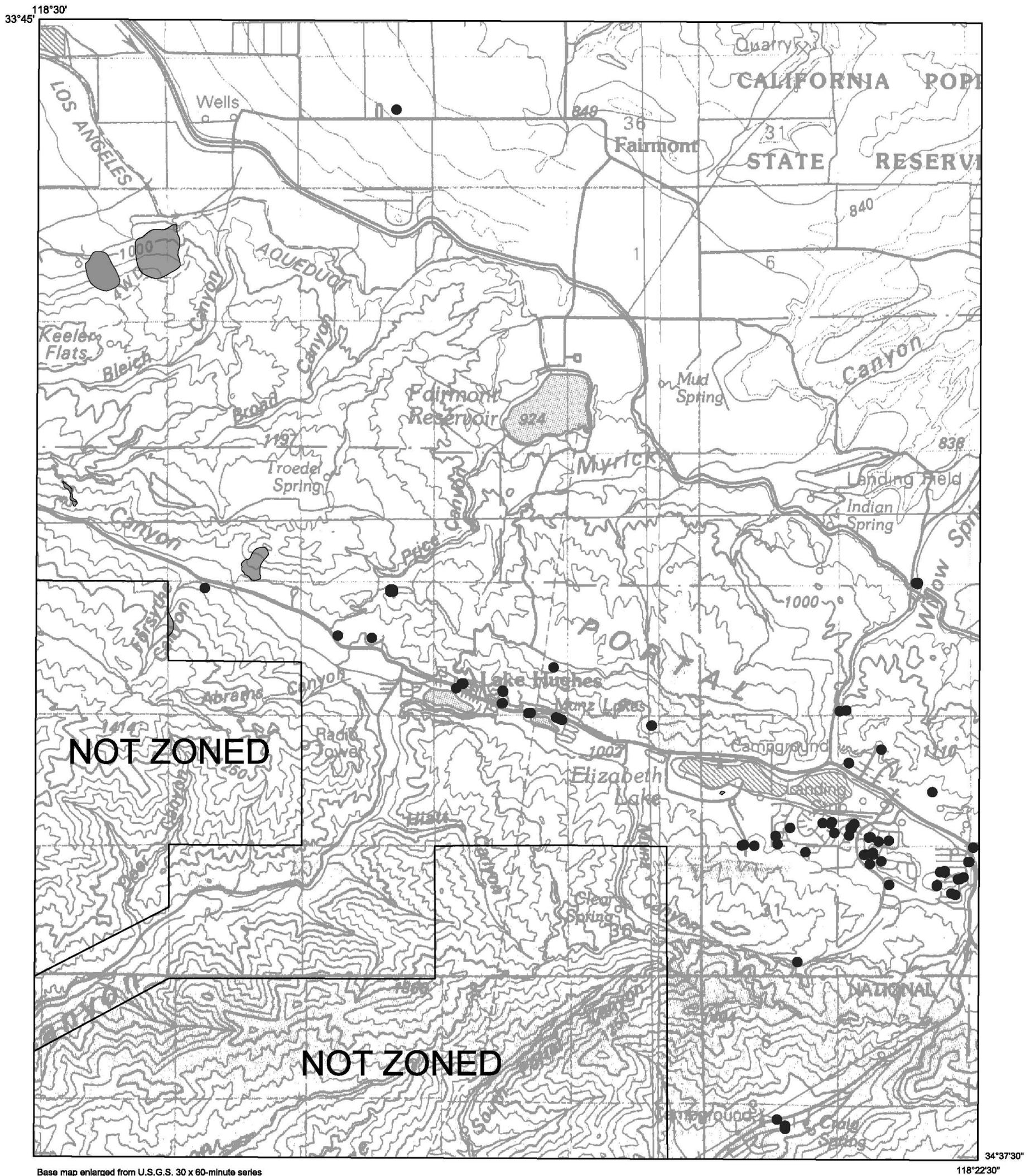
SCALE



10 — Depth to ground water, in feet

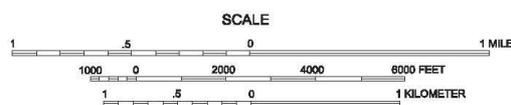
● Geotechnical borings used in liquefaction evaluation

Plate 1.2 Depth to historically high ground water in alluviated areas and locations of boreholes used in this study, Lake Hughes 7.5-Minute Quadrangle, California



Base map enlarged from U.S.G.S. 30 x 60-minute series

LAKE HUGHES QUADRANGLE



● Shear test sample location

○ Landslide

Plate 2.1 Landslide inventory and shear test sample locations, Lake Hughes 7.5-Minute Quadrangle, California.