SEISMIC HAZARD ZONE REPORT 015

SEISMIC HAZARD ZONE REPORT FOR THE SAN FERNANDO 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

1998

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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2001	Text updated
6/14/05	BPS address corrected, web links updated, Figure 3.5 added
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ILLUSTRATIONS

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the San Fernando 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 62 square miles at a scale of 1 inch = 2,000 feet. A thin band in national forest land along the eastern boundary was not included in the evaluation.

The San Fernando Quadrangle is about 18 miles northwest of the Los Angeles Civic Center. The City of Los Angeles communities of Sylmar, Granada Hills, Mission Hills, Pacoima, and Lakeview Terrace and the City of San Fernando are scattered across the northern San Fernando Valley floor south of the San Gabriel Mountains, which cover about one half of the quadrangle. Most of the land in the mountains is in Angeles National Forest. The eastern end of the Santa Susana Mountains extends into the western part of the quadrangle. The northern San Fernando Valley has received sediment from the San Gabriel Mountains primarily via Pacoima and Little Tujunga washes.

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% probability of exceedance in 50 years.

In the San Fernando Quadrangle the liquefaction zone is located in canyon bottoms, around the Hansen Lake area, along the south side of the Mission Hills and in the Van Norman Lake region. Liquefaction has occurred locally during the 1971 and 1994 earthquakes. The steepness of the slopes in the San Gabriel Mountains and the landslide susceptibility of the rock units have produced widespread and abundant landslides. Rockfalls, debris slides, and deep-seated landslides have been triggered by the 1971 and 1994 earthquakes. These conditions contribute to an earthquake-induced landslide zone that covers about 22 percent of the quadrangle.

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 Division of Mines and Geology's Internet page: http://www.conservation.ca.gov/CGS/index.htm

Paper copies of Official Seismic Hazard Zone Maps, released by DMG, 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 DMG 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) 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 established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

The Act also 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. They also directed DMG 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% 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 San Fernando 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the San Fernando 7.5-Minute Quadrangle, Los Angeles County, California

By
Christopher J. Wills

California Department of Conservation
Division of Mines and Geology

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) 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 DMG 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 (DOC, 1997; also available on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf).

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the San Fernando 7.5-minute Quadrangle. This section, along with Section 2 (addressing earthquake-induced landslides), and Section 3 (addressing potential ground shaking), form a report that 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 DMG'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 earthquakes, 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 California, 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 general, as well as in the San Fernando 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

- Construction of shallow ground-water maps showing the historically highest known ground-water levels

- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits

- Information on potential ground shaking intensity based on DMG 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 State Mining and Geology Board (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 San Fernando Quadrangle consist mainly of alluviated valleys, floodplains, and canyon regions. DMG'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 San Fernando Quadrangle covers an area of about 62 square miles in western Los Angeles County about 18 miles northwest of the Los Angeles Civic Center. The communities of Sylmar, Granada Hills, Mission Hills, Pacoima, and Lakeview Terrace, all parts of the City of Los Angeles, and the City of San Fernando are scattered across the northern San Fernando Valley floor in the southern part of the quadrangle. North of the San Fernando Valley, the San Gabriel Mountains cover about half of the San Fernando Quadrangle. Except for a small fringe of unincorporated Los Angles County land along the mountain front most of the land in the mountains lies within the Angeles National Forest. The eastern end of the Santa Susana Mountains extends into the western part of the San Fernando Quadrangle. Canyons within the mountains extend south to the San Fernando Valley. The headwaters of some streams that drain northward into the Santa Clara River Valley are located in the northern part of the San Fernando Quadrangle.

The San Fernando Valley is an east-trending structural trough within the Transverse Ranges of southern California. The San Gabriel Mountains that bound it to the northeast are composed of plutonic and metamorphic rocks that are being thrust over the valley from the north. As the range has been elevated and deformed, the San Fernando Valley has subsided and filled with sediment.

The northern portion of the San Fernando Valley on the San Fernando Quadrangle has received sediment from drainage systems originating in the San Gabriel Mountains. The Pacoima and Little Tujunga Washes are large river systems that have their sources in the steep, rugged San Gabriel Mountains. Each of these drainage systems has a drainage basin of tens of square miles within the mountains and can carry a large volume of sediment. The alluvial fans deposited by these drainage systems have their apexes on the southern San Fernando Quadrangle and cover most of the Van Nuys Quadrangle to the south. North and west of the Pacoima-Tujunga alluvial fan, smaller drainages have deposited alluvial fans that cover most of the San Fernando and Sylmar areas. Composition of these deposits is dependent on the source areas of the drainages. Drainages with source areas in the San Gabriel Mountains primarily have granitic or other plutonic rocks in their drainage basins. The deposits of these streams, consequently, are composed of sandy alluvium.

GEOLOGY

Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. Late Quaternary geologic units in the San Fernando Valley area were completely re-mapped for this study and a concurrent study by engineering geologist Chris Hitchcock of William Lettis and Associates (Hitchcock and Wills, 1998; 2000). Lettis and Associates received a grant from the National Science Foundation (NSF) to study the activity of the Northridge Hills uplift. As part of the research for this study, Hitchcock mapped Quaternary surficial units by interpreting their geomorphic expression on aerial photographs and topographic maps. The primary source for this work was 1938 aerial photographs taken by the U.S. Department of Agriculture (USDA). His interpretations were checked and extended for this study using 1952 U.S.D.A. aerial photos, 1920's topographic maps and subsurface data. The resulting map (Hitchcock and Wills, 2000) represents a cooperative effort to depict the Quaternary geology of the San Fernando Valley combining surficial geomorphic mapping and information about subsurface soils engineering properties. The portions of this map that cover the San Fernando Quadrangle are reproduced as Plate 1.1.

In preparing the Quaternary geologic map for the San Fernando Quadrangle, geologic maps prepared by Barrows and others, (1975), Crook and others (1987), Oakeshott (1958), Tinsley and others (1985), Dibblee (1991) and Yerkes (1996) were referred to. We began with the maps of Yerkes (1996) as digital files in the DMG Geographic Information System (GIS). The Quaternary geology shown on the map of Yerkes (1996) was compiled from Tinsley and others (1985). For the liquefaction portion of this study, we did not review or revise the mapping of bedrock units by Yerkes (1996), except for the contacts between bedrock and Quaternary units. However, changes to the bedrock geology were made for the landslide portion of this study, and the changes are described in the landslide portion (Section 2) of this evaluation report. Within the San Fernando Valley mapping of Quaternary units by Hitchcock (and for this study) was used to refine and substantially revise this mapping. For this map (Plate 1.1), geologic units were defined based on geomorphic expression of Quaternary units (interpreted from aerial photographs and historic topographic maps) and subsurface characteristics of those units (based on borehole data). The nomenclature of the Southern California Areal Mapping Project (SCAMP) (Morton and Kennedy, 1989) was applied to all Quaternary units (Table 1.1).

	Alluvial Fan Deposits	**Alluvial Valley Deposits**	**Age**
Active	Qf- active fan, Qw- active wash	Qa- active depositional basin	Holocene?
Young	Qyf1, Qyf2	Qyt	Holocene?
Old	Qof1, Qof2	Qt	Pleistocene?
Very old	Qvof2	Qvoa1*, Qvoa2	Pleistocene

*may have been alluvial fan, depositional form not preserved

Table 1.1. Units of the Southern California Areal Mapping Project (SCAMP) Nomenclature Used in the San Fernando Valley.

The Quaternary geologic map (Plates 1.1 and 1.2) shows that the oldest alluvial units in the San Fernando Valley are found within an uplift in the San Fernando area and on the south flank of the San Gabriel Mountains. The Saugus and Pacoima formations, both Pleistocene alluvial units, are exposed on the south flank of the San Gabriel Mountains and Saugus Formation is also exposed in the core of the San Fernando uplift and on the south flank of the Santa Susana Mountains.

Overlying Saugus Formation and Pacoima Formation in the San Fernando area are very old alluvial deposits (Qvoa, Qvoa1, Qvof1, and Qvof2). These deposits are uplifted, deformed, have red (mature) soils and are typically dense to very dense. Qvoa consists of intensely deformed older alluvium along the San Fernando segment of the Sierra Madre fault zone. Its age in relation to the other units is not known. Qvof1 exists as remnants of alluvial surfaces on tops of ridges between Pacoima Wash and Big Tujunga Canyon. Qvoa1 shows no trace of its original depositional geomorphology. It is found surrounding the Sylmar sub-basin of the San Fernando Valley, not much elevated above modern alluvial deposits. Qvof2, although similarly uplifted, retains some of the original morphology of alluvial fans that extended from the San Gabriel Mountains into the San Fernando area.

Overlying very old alluvial deposits in the San Fernando and Sylmar areas are remnants of alluvial fans from the San Gabriel Mountains (Qof1). Older alluvial surfaces are also found in the uplifted area between Pacoima and Big Tujunga Canyons. These deposits are composed of sand, silt, and gravel and form recognizable alluvial fans. The fan surfaces are no longer active because continuing deformation has either lifted them out of the area of deposition or because they have been buried by later alluvium. The younger alluvial fans can be subdivided into young (Qyf1 and Qyf2) and active (Qf, Qw) fan deposits on the basis of geomorphology. Young alluvial fans are described below.

Alluvial basin or valley deposits (Qa) in the San Fernando Quadrangle are mainly deposits in man-made flood control basins behind Upper and Lower San Fernando Dams and Hansen Dam.

Younger alluvial fans of Gavin Canyon and Grapevine Canyon

Gavin Canyon and Grapevine Canyon have small (about 1 square mile) drainage basins at the boundary between the Santa Susana and San Gabriel Mountains. Their drainage basins are mostly in sedimentary bedrock of Tertiary and Pleistocene age. Their deposits are in the area of the upper Van Norman Reservoir, the Jensen Filtration Plant, and the I-5 to I-210 interchange, so they have been extensively modified.

Younger alluvial fans of Sombrero and Wilson Canyon fans

Sombrero Canyon and Wilson Canyon are small drainage basins in the San Gabriel Mountains (about 1 and 2 square miles, respectively). Mostly igneous and lesser metamorphic rocks are exposed in their drainage basins. Alluvial fans from these two drainages have their apexes at the mountain front. The fans extend across the Sylmar sub-basin to the San Fernando uplift. The drainage from these canyons has cut an outlet through the San Fernando uplift in the Mission Hills area, but most of the sediment was apparently blocked and deposited in the Sylmar area.

Younger alluvial fans of Pacoima Canyon

Pacoima Canyon Wash has a drainage basin of about 20 square miles in mountainous terrain that includes summits up to 4000 feet in elevation. Pacoima Wash been able to maintain an incised channel through the San Fernando uplift into the main San Fernando basin to the south. Active wash deposits are found in this channel. On the surface, these wash deposits are composed of sand and gravel. South of the uplift the Pacoima Wash deposits merge with the Little Tujunga and Big Tujunga deposits to form the Pacoima-Tujunga fan that fills most of the eastern San Fernando Valley.

Younger alluvial fans of Lopez and Kagel Canyons

Lopez and Kagel Canyons drain an area between Pacoima Wash and Big Tujunga Canyon where Tertiary and Pleistocene rocks have been uplifted on the hanging wall of the San Fernando fault. Both drainages merge with larger streams near the mountain front, so that, except for deposits in the canyons themselves, these streams have not left recognizable deposits. Small drainages between Lopez and Kagel Canyons and similar small drainages to the east between Little Tujunga and Big Tujunga Canyons have deposited a series of alluvial fans that form a sloping surface (Lakeview Terrace) north of the Tujunga Wash.

Younger alluvial fans of Big Tujunga and Little Tujunga Canyons

Tujunga Wash has a drainage basin of about 90 square miles in rugged mountainous terrain that includes peaks up to 5000 feet in altitude. It is divided into two main branches, Little Tujunga Canyon to the west and Big Tujunga Canyon to the east. These two streams merge in the Tujunga Valley, where they form a broad wash. Deposits in the wash are composed of sandy gravel with boulders. The Tujunga Wash ends at Hansen Dam Flood Control Basin, built where the wash had cut through the northwestern end of the Verdugo Mountains. Hansen Dam marks the apex of the main Tujunga Wash portion of the Pacoima-Tujunga fan, which spreads south from the San Fernando Quadrangle.

ENGINEERING GEOLOGY

The geologic units described above and listed in Table 1.2 were primarily mapped from their surface expression, especially geomorphology, as displayed on aerial photos and old topographic maps. The geomorphic mapping was compared with the subsurface properties described in about 400 borehole logs in the study area. Subsurface data used for this study include the database compiled by John Tinsley for previous studies (Tinsley and Fumal, 1985; Tinsley and others, 1985), a database of shear wave velocity measurements originally compiled by Walter Silva (Wills and Silva, 1998), and additional data collected for this study. Subsurface data were collected for this study at Caltrans, the California Department of Water Resources, DMG files of seismic reports for hospital and school sites, the Regional Water Quality Control Board, the Los Angeles Department of Water and Power and from Law Crandall, Inc., Leighton and Associates, Inc, and Woodward-Clyde Consultants. In general, the data gathered for geotechnical studies appear to be complete and consistent. Data from environmental geology reports filed with the Water Quality Control Board are well distributed areally and provide reliable information on water levels. Geotechnical data, particularly SPT blow counts, from environmental studies are sometimes less reliable however, due to non-standard equipment and incomplete reporting of procedures. Water-well logs from the Department of Water Resources tend to have very sketchy lithologic descriptions and, surprisingly, unreliable reports of water levels. Apparently water-well drillers may note the level of productive water, ignoring shallower perched water or water in less permeable layers.

Geologic Map Unit	Material Type	Consistency	Liquefaction Susceptibility
Qw, stream channels	sand, gravelly sand	Loose-moderately dense	High
Qf, active alluvial fans	silty sand, sand,	Loose-moderately dense	High
Qyf2, younger alluvial fans	silty sand, sand, minor clay	Loose-moderately dense	High
Qyf1, young alluvial fan	silty sand, sand, minor clay	Loose-moderately dense	High
Qof1, older alluvial fan	sand & gravel	Moderately dense	Low
Qvoa, Qvoa1, Qvof1, Qvof2, very old alluvium	clay-silty sand	Dense-very dense	Low

Table 1.2. General Geotechnical Characteristics and Liquefaction Susceptibility of Younger Quaternary Units.

Data from previous databases and additional borehole logs were entered into the DMG GIS database. Locations of all exploratory boreholes considered in this investigation are shown on Plate 1.2. Construction of cross sections from the borehole logs, using the GIS, enabled the correlation of soil types from one borehole to another and outlining of areas of similar soils.

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit and commonly are used as an index of density. Many geotechnical investigations record SPT data, including the number of blows by a 140-pound drop weight required to drive a sampler of specific dimensions one foot into the soil. 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), were converted to SPT-equivalent blow count values and entered into the DMG GIS. The actual and converted SPT blow counts were normalized to a common reference effective overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60% using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

In most cases, the subsurface data allow mapping of different alluvial fans. Different generations of alluvium on the same fan, which are very apparent from the geomorphology, are not distinguishable from the subsurface data.

Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are generalized but give the most commonly encountered characteristics of the unit (see Table 1.2).

Saugus Formation: Qs, Qsu

The Pleistocene Saugus Formation is an alluvial unit that may not always be distinguished from younger overlying alluvium in borehole logs. In the few boreholes where we can be sure Saugus Formation was encountered, it is described as "sandstone." In others, dense or very dense sand may be Saugus Formation but also could be old or very old alluvium.

Very old alluvium: Qvoa1, Qvof1, Qvof2

Very old alluvium, mapped in the San Fernando uplift, is represented in our subsurface data by several boreholes in unit Qvoa1. The material in these boreholes is dense to very dense sand and silty sand. Unit Qvof2 was examined in the field. Exposures of this unit are dense red-brown gravelly sand.

Older alluvium: Qof1

Older alluvium is distinguished from younger alluvium by being uplifted and usually incised by younger drainages and by having relatively even tonal patterns on pre-development aerial photographs. In contrast, younger alluvium typically has a braided stream tonal pattern even where those stream channels have no geomorphic expression. Qof1 consists of remnants of small alluvial fans in the San Fernando and Sylmar areas and uplifted surfaces in the upper Kagel Canyon and adjacent areas.

In the subsurface, Qof1 consists of silt and silty sand with lesser sand, gravel and clay layers. Sand layers are moderately dense to very dense. Individual layers can rarely be traced from borehole to borehole, reflecting the lenticular layering typical of an alluvial fan deposit.

Younger alluvium Qyf1, Qyf2, Qf, Qw

Within an alluvial fan, the different generations of younger alluvium can be distinguished by their geomorphic relationships. In the subsurface, it is not possible to distinguish among the generations on an alluvial fan. There may simply be too little difference in age among these units, which probably range from mid-Holocene to historic, for any differences in density or cementation to have formed.

Gavin Canyon and Grapevine Canyon fans

Alluvium from these drainages in the area around Upper Van Norman Reservoir is silty sand with some silt and sandy clay. SPT blow counts show that this material is medium dense to dense.

Sombrero and Wilson Canyon fans

The alluvial fans of Sombrero and Wilson canyons, in Sylmar, are composed of sand and silty sand. This material is loose to dense, with SPT blow counts as low as 5 in the near surface layers. Below 10 feet the granular deposits are typically moderately dense to dense.

Pacoima Canyon

Deposits in the Pacoima Wash consist of sand and gravel. Surface deposits observed in the field are dominantly loose gravelly sand. We did not collect any borehole logs with SPT blow counts for these materials, but these young deposits are assumed to be loose to moderately dense.

Lopez and Kagel Canyons

Deposits in Lopez and Kagel Canyons consist of young sand and gravelly sand in the active channel. Fan deposits from the small drainages between Lopez Canyon and Kagel Canyon and similar small drainages between Little Tujunga and Big Tujunga canyons are composed of sand and silty sand with sandy clay and gravel. This material is very loose to dense with SPT blow counts as low as 1 in the near surface layers. Most layers between 0 and 20 feet have blow counts between 5 and 10 blows per foot (BPF). Below 20 feet the deposits are generally moderately dense with blow counts between 10 and 25 BPF.

Big Tujunga and Little Tujunga Canyons

The alluvium of Big Tujunga and Little Tujunga canyons is found mainly in channel deposits in the mountains and in the Tujunga Wash. The wash deposits are composed of sand, gravelly sand and silty sand, with some layers of gravel. SPT blow counts show that this material is loose to very dense, although some of the higher blow counts may be due to impact on large clasts in gravelly layers.

Artificial fill (af)

In the San Fernando Quadrangle artificial fills large enough to show at the scale of mapping include the hydraulic fill Upper and Lower San Fernando Dams and engineered fill for other dams, including around the Los Angeles Reservoir, Hansen Dam, the concrete Pacoima Dam, and other small flood control dams. Other engineered fill includes fill underlying the Metropolitan Water District's Jensen Filtration Plant, west of upper Van Norman Reservoir, fill underlying Los Angeles Department of Water and Power facilities east of Upper Van Norman Reservoir, fill at the Olive View hospital complex, and engineered fill for freeways. These units were compiled from the digital map of Yerkes (1996).

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. DMG uses the highest known ground-water levels because water levels during an earthquake cannot be anticipated because of the unpredictable fluctuations caused by natural processes and human activities. A historical-high ground-water map differs from most ground-water maps, which show the actual water table at a particular time. Plate 1.2 depicts a hypothetical ground-water table within alluviated areas.

Ground-water conditions were investigated in the San Fernando Quadrangle to evaluate the depth to saturated materials. Saturated conditions reduce the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on first-encountered water noted in geotechnical borehole logs. The depths to first-encountered unconfined ground water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water. Water depths from boreholes known to penetrate confined aquifers were not utilized.

The San Fernando Valley ground-water basin is a major source of domestic water for the City of Los Angeles and, as a result, has been extensively studied. The legal rights to water in the ground within the San Fernando Valley were the subject of a lawsuit by the City of Los Angeles against the City of San Fernando and other operators of water wells in the basin. The "Report of Referee" (California State Water Rights Board, 1962) contains information on the geology, soils and ground-water levels of the San Fernando Valley.

The Report of Referee shows that ground water reached its highest levels in 1944, before excessive pumping caused drawdowns throughout the basin. Management of the ground-water resources led to stabilizing of ground-water elevations in the 1960's and, in some cases, rise of ground-water elevations in the 1970's and 1980's to levels approaching those of 1944 (Blevins, 1995).

In order to consider the historically highest ground-water level in liquefaction analysis, the 1944 ground-water elevation contours (California State Water Rights Board 1962, Plate 29) were digitized. A three-dimensional model was created from the digitized contours giving a ground-water elevation at any point on a grid. The ground-water elevation values in this grid were then subtracted from the surface elevation values from the USGS Digital Elevation Model (DEM) for the San Fernando Quadrangle. The difference between the surface elevation and the ground-water elevation is the ground-water depth. Subtracting the ground-water depth grid from the DEM results in a grid of ground-water depth values at any point where the grids overlapped.

The resulting grid of ground-water depth values showed several artifacts of the differences between the sources of ground-water elevation data and surface elevation data. The ground-water elevations were interpreted from relatively few measurements in water wells. The USGS DEM is a much more detailed depiction of surface elevation, it also shows man made features such as excavations or fills that have changed the surface elevations. Most of these surface changes occurred after the ground-water levels were measured in 1944. The ground-water depth contours were smoothed and obvious artifacts removed to create a ground-water depth map. Ground-water depth information for the San Fernando Juvenile Hall area from Smith and Fallgren (1975) was added for that area, which was not covered by the Report of Referee ground-water elevation map. Ground-water levels from borehole data collected for this study were compared with the depths on the combined map. Borehole data led to some refinements of the final ground-water depth contours (Plate 1.2).

The ground-water depth map shows areas of shallow ground water north of the Mission Hills and San Fernando faults in the Granada Hills, Sylmar and San Fernando areas.

Ground water is also relatively shallow in all canyons in the Santa Susana and San Gabriel Mountains according to records that we have obtained. In general, it appears that relatively shallow and impermeable bedrock underlying the canyon alluvium helps to maintain a shallow water table.

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. This method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the State Mining and Geology Board (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.

DMG'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. A qualitative susceptible soil inventory is outlined below and summarized in Table 1.2.

Very old alluvium (Qvoa, Qvoa1, Qvof1, Qvof2)

Very old alluvium consists of dense to very dense sand and silty sand deposits in an area of deep ground water. Liquefaction susceptibility of this unit is low.

Old alluvium (Qof1)

Old alluvium on the San Fernando Quadrangle consists of moderately dense sand and silty sand. This deposit has low liquefaction susceptibility over most of its area due to deep ground water.

Young alluvium (Qyf1, Qyf2, Qf, Qw, Qa)

Younger alluvium on the San Fernando Quadrangle consists of sand with sand, silt and clay. Most boreholes in these units contain loose to moderately dense sand or silty sand.

Where ground water is within 40 feet of the surface, liquefaction susceptibility of these units is high.

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% probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in DMG's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the San Fernando Quadrangle, peak accelerations of 0.62 g to 1.22 g, resulting from an earthquake of magnitude 6.6 to 6.85 were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% 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

DMG 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). 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, DMG'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. DMG 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 DMG liquefaction analysis program calculates an FS for each geotechnical sample for which blow counts were collected. Typically, multiple samples are collected for each borehole. The lowest FS in each borehole is used for that location. FS values vary in reliability according to the quality of the geotechnical data used in their calculation. 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.

Of the about 400 borehole logs compiled for this study, fewer than 150 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, were translated to SPT-equivalent values if reasonable factors could 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.

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.

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 California State Mining and Geology Board (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% 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% 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% 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 San Fernando Quadrangle is summarized below.

Areas of Past Liquefaction

Evidence of liquefaction was recorded in the San Fernando Quadrangle in the 1971 San Fernando earthquake and the 1994 Northridge earthquake. In 1971 liquefaction of the hydraulic fill caused spectacular, and nearly catastrophic, failure of Lower San Fernando Dam (Seed and Lee, 1973; Cortright, 1975) (locality 1, Plate 1.2). The hydraulic fill of upper San Fernando Dam also liquefied during the earthquake, but damage to the dam was not as severe. Liquefaction and lateral spreading in natural alluvial deposits occurred both east and west of Upper Van Norman Reservoir (Qw and Qyf2). East of the reservoir a major lateral spread damaged the Los Angeles County Juvenile Hall (Fallgren and Smith, 1973; Smith and Fallgren, 1975; Youd, 1973) (locality 2, Plate 1.2). Similar, but apparently less severe, ground cracking was mapped in the area around Van Gogh Street Elementary School (locality 3, Plate 1.2 and to the west on the Oat Mountain Quadrangle; Saul, 1974). Arcuate cracks on the school grounds showed down to the east and vertical offset. Although no sand boils or other clear indications of liquefaction were noted. Saul (1974) described subsidence and extensional and compressional ground cracks as being similar to slides to the east (the Juvenile Hall lateral spread). Meehan (1974) states that "it is believed the ground displacement was due to liquefaction." Liquefaction of alluvium underlying 35 to 50 feet of artificial fill at the Jensen Filtration plant of the Metropolitan Water District of Southern California northwest of the Upper Van Norman Reservoir also caused lateral spreading of the fill and extensive damage to structures (Marachi, 1973; O'Rourke and others, 1989) (locality 4, Plate 1.2).

Liquefaction may have occurred in 1971 in the sediment deposited behind Lopez Dam in Pacoima Wash (locality 5, Plate 1.2). That sediment, deposited after the dam was built in

1954, was about 20 feet thick and saturated at the time of the earthquake. The earthquake caused cracking along the edge of the sediments and settlement of the sediments (Committee on Water and Sewerage Systems, 1973). The photograph published illustrating these cracks (Figure 46 ibid.) shows that they follow the crests of low, unvegetated mounds. Although the report does not mention liquefaction or refer to these features, they strongly resemble sand boils.

Similarly, liquefaction occurred in the 1994 Northridge earthquake in the sediments behind Hansen Dam (locality 6, plate 1.2). Sand boils, fissures, and minor lateral spreading features occurred in an area about 300 by 1000 feet (Moehle, 1994). The exact location of this liquefaction is not shown in the volume by Moehle (1994), this liquefaction could have been on the San Fernando, the Sunland Quadrangle, or both. Settlements of up to one foot and lateral spreading of up to three feet were reported. It is not reported if the liquefaction occurred in the recent deposits behind the dam, in the underlying Holocene wash deposits, or both.

In the 1994 Northridge earthquakes, liquefaction occurred again in the hydraulic fills of both Upper and Lower San Fernando Dams (Bardet and Davis, 1996). Ground cracks and associated permanent ground movements in the areas of the 1971 Juvenile Hall and Van Gogh Street School lateral spreads indicate liquefaction and reactivation of those features (Davis and Bardet, 1995). Liquefaction was most severe around the San Fernando Power Plant and the Power Plant Tailrace, a small reservoir that serves as the afterbay of the power plant (Davis and Bardet, 1996). This liquefaction occurred in the alluvium underlying the fill for the power plant and tailrace and led to failure of the tailrace dike. Liquefaction and lateral spreading extended from the western side of the tailrace westward onto the Jensen Filtration Plant property.

The most extensive damage due to liquefaction in 1994 occurred near Balboa Blvd. and Rinaldi Streets in the Granada Hills area (locality 5, Plate 1.2). In that area, liquefaction within early Holocene alluvium (Qyf2) led to lateral spreading and both extensional and compressional ground cracking. Post-earthquake investigations showed that the Mission Hills fault, mapped just south of the area of liquefaction, may form a ground-water barrier (Hecker and others, 1995a, 1995b). Because of this barrier, ground water is within 20 feet of the ground surface north of the fault. There was no recorded liquefaction south of the fault, apparently because ground water is too deep.

Artificial Fills

In the San Fernando quadrangle artificial fills large enough to show at the scale of mapping include the hydraulic fill Upper and Lower San Fernando Dams and engineered fill for other dams, including around the Los Angeles Reservoir, the concrete Pacoima Dam, and other small flood control dams. Other engineered fill includes fill underlying the Metropolitan Water District's Jensen Filtration Plant, west of upper Van Norman Reservoir, fill underlying Los Angeles Department of Water and Power facilities east of Upper Van Norman Reservoir, fill at the Olive View hospital complex, and engineered fill for freeways.

Hydraulic fills of Upper and Lower San Fernando Dams liquefied in the 1971 and 1994 earthquakes (Cortright, 1975; Bardet and Davis, 1996). Areas underlain by artificial fill on both sides of Upper Van Norman reservoir were damaged by liquefaction in 1971 and 1994, but this liquefaction occurred in the young alluvium underlying the fill (Smith and Fallgren, 1975; Dixon and Burke, 1973; Davis and Bardet, 1996). The engineered fills for freeways are generally too thin to have an impact on liquefaction hazard and so were not investigated.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data were evaluated for zoning based on the liquefaction potential determined by the Seed-Idriss Simplified Procedure.

The dense consistency and deep ground water encountered in boreholes into the very old alluvium exposed in the hills surrounding the San Fernando-Sylmar area and in the San Fernando uplift indicates a low susceptibility to liquefaction. This geologic unit has not been included in a liquefaction zone in this area.

Older alluvial fans from the San Gabriel Mountains found as remnants around the edge of the San Fernando Valley and uplifted in the Kagel Canyon and Lopez Canyon areas are generally moderately dense and are located in areas of deep ground water. These areas are not included in a liquefaction zone.

Younger alluvial deposits (Qyf1, Qyf2, Qf, Qw) of the alluvial fans are composed of sand and silty sand. Most wells have layers of loose to moderately dense sand or silty sand. Those sand layers generally have a factor of safety against liquefaction of less than one in the anticipated earthquake shaking. All younger alluvial fan deposits and stream channel deposits where ground water has been less than 40 feet from the surface have been included in the liquefaction zones.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the San Fernando 7.5-Minute Quadrangle, Los Angeles County, California

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Division of Mines and Geology

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) 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 DMG 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; also available on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf).

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the San Fernando 7.5-minute Quadrangle. This section, along with Section 1 (addressing liquefaction), and Section 3 (addressing earthquake shaking), form a report that 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 DMG's Internet web 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 San Fernando 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 DMG 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 DMG pilot study (McCrink and Real, 1996) 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 San Fernando 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 San Fernando 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 San Fernando Quadrangle covers an area of about 62 square miles in western Los Angeles County about 18 miles northwest of the Los Angeles Civic Center. The communities of Sylmar, Granada Hills, Mission Hills, Pacoima, and Lakeview Terrace, all parts of the City of Los Angeles, and the City of San Fernando are scattered across the northern San Fernando Valley floor in the southern part of the quadrangle. North of the

San Fernando Valley, the San Gabriel Mountains cover about half of the San Fernando Quadrangle. Except for a small fringe of unincorporated Los Angles County land along the mountain front most of the land in the mountains lies within the Angeles National Forest. The eastern end of the Santa Susana Mountains extends into the western part of the quadrangle. Canyons within the mountains extend south to the San Fernando Valley. The headwaters of some streams that drain northward into the Santa Clara River Valley are located in the northern part of the quadrangle.

The San Fernando Valley is an east-trending structural trough within the Transverse Ranges of southern California. The San Gabriel Mountains that bound it to the northeast are composed of plutonic and metamorphic rocks that are being thrust over the valley from the north. As the range has been elevated and deformed, the San Fernando Valley has subsided and filled with sediment.

The northern portion of the San Fernando Valley on the San Fernando Quadrangle has received sediment from drainage systems originating in the San Gabriel Mountains. The Pacoima and Little Tujunga Washes are large river systems that have their sources in the steep, rugged San Gabriel Mountains. Each of these drainage systems has a drainage basin of tens of square miles within the mountains and can carry a large volume of sediment. The alluvial fans deposited by these drainage systems have their apexes on the southern San Fernando Quadrangle and cover most of the Van Nuys Quadrangle to the south. North and west of the Pacoima-Tujunga alluvial fan, smaller drainages have deposited alluvial fans that cover most of the San Fernando and Sylmar areas. Composition of these deposits is dependent on the source areas of the drainages. Drainages with source areas in the San Gabriel Mountains primarily have granitic or other plutonic rocks in their drainage basins. The deposits of these streams, consequently are composed of sandy alluvium.

The Seismic Hazard Zone Map for the San Fernando Quadrangle has been trimmed back so that it is slightly smaller than the entire 7.5-minute San Fernando Quadrangle. A sliver of land approximately 3.5 miles long and 500 to 800 feet wide along the northern half of the eastern border of the quadrangle was not included on the Seismic Hazard Zone map. This land is all within the Angeles National Forest, and includes the portions of Sections 8, 17, and 20 of T3N, R14 W, which extend into the San Fernando Quadrangle from the east.

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. Within the San Fernando Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours that are based on 1964 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

To update the topographic base map, areas that have undergone large-scale grading as a part of residential development in the hilly portions of the San Fernando Quadrangle, along the base of the San Gabriel Mountains and around Van Norman Reservoir were identified on aerial photography flown in the spring of 1994. Terrain data for these areas were obtained from an airborne interferometric radar (TOPSAR) DEM flown and processed in August 1994 by NASA's Jet Propulsion Laboratory (JPL), and reprocessed by Calgis, Inc. (GeoSAR Consortium, 1995 and 1996). These terrain data were also smoothed prior to analysis.

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

For the San Fernando Quadrangle, a recently compiled geologic map was obtained from the U.S. Geological Survey (USGS) in digital form (Yerkes, 1996b). Other geologic maps reviewed for this project include: Oakeshott (1958), Barrows and others (1975), Weber (1982), and Dibblee (1991). The digital geologic map was modified to reflect the most recent mapping in the area and to include interpretations of observations made during the aerial photograph-based landslide inventory and field reconnaissance. Modifications to the geologic map included refining most of the contacts between the bedrock and Quaternary units. Additionally, the sedimentary units north of the San Gabriel Fault, along the northern quadrangle boundary, were revised to better correlate with those along the southern boundary of the Mint Canyon Quadrangle as mapped by Saul and Wootton (1983) and compiled by Yerkes (1996a). In the field, observations were also made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of slope failures were noted.

The uplands of the San Fernando Quadrangle consist of the western end of the San Gabriel Mountains, which are comprised of a basement complex of Precambrian to Cretaceous igneous and metamorphic rocks. Along the mountain front and in the lower-elevation terrain near the western boundary of the quadrangle Eocene to Pleistocene sedimentary and volcanic rocks rest upon or have been faulted against the basement rocks. The San Gabriel Fault crosses the northeastern corner of the quadrangle and trends southeasterly from about the middle of the northern boundary to the eastern boundary. This fault separates the Precambrian metamorphic basement rocks exposed northeast of it from the younger igneous and metamorphic rocks exposed southwest of it. The fault also separates two distinct groups of sedimentary and volcanic rocks. Those units that accumulated in the Ventura Basin are exposed southwest of the fault, and those that accumulated in the Soledad Basin are exposed northeast of the fault.

The oldest rocks in the San Fernando Quadrangle are the Precambrian Mendenhall gneiss (pCm) and gabbroic rocks (gb) exposed north of the San Gabriel Fault. On the south side of the fault assorted pre-Cenozoic rocks consisting of serpentinite (sp), schist and feldspathic gneiss of the Placerita Formation (pm), limestone (pl), diorite gneiss (dgn), gneiss (gn), and granodiorite (gd) are exposed. The igneous and metasedimentary rocks of the basement complex are exposed over much of the northern half of the San Fernando Quadrangle.

North of the San Gabriel Fault, sedimentary rocks rest upon the basement complex near the middle of the northern boundary of the quadrangle. The oldest rocks of this sequence of sedimentary rocks belong to the Oligocene Vasquez Formation (Tvz) that consists chiefly of lacustrine-fluvial "redbed" sequences of gritty siltstone, locally derived breccia-conglomerate with gneissic and plutonic rock clasts, sandy and silty claystone, mudstone, and limestone. The next youngest units are two facies of the middle to upper Miocene Mint Canyon Formation. The marginal facies (Tmc1) consists of arkosic sandstone and conglomeratic sandstone, with minor siltstone and silty clay shale, and the bottomset facies (Tmc2) consists of interbedded claystone, siltstone, silty sandstone, sandstone, and minor coarse conglomerate and limestone. The Castaic Formation (Tcs) consisting of upper Miocene marine silty or pebbly sandstone, clay shale, tuffaceous and diatomaceous shale, and sparse limestone concretions generally unconformably overlies and is in fault contact with the Mint Canyon Formation. The youngest unit is the upper Miocene to lower Pliocene Towsley Formation (Tw) that consists of sandstone and conglomerate with local beds of breccia, some siltstone and shale, and conglomerate that commonly contains clasts of anorthosite. The contact between the Towsley Formation and underlying Castaic Formation is generally conformable and gradational.

Incorporated within the San Gabriel Fault zone, near the eastern edge of the quadrangle are slivers of Paleocene-aged Martinez Formation (Tmz on Yerkes, 1996b after Oakeshott, 1958). Although rocks mapped as Martinez Formation to the north of the San Fernando Quadrangle were renamed the San Francisquito Formation by Dibblee (1967, p. 44), the rocks in the San Fernando Quadrangle were mapped as Eocene Santa Susana (?) Formation by Dibblee (1991). The Martinez Formation in the San Fernando Quadrangle, as used here, consists of shattered and sheared coarse-grained marine sandstone, thin interbeds of black shale, and lenticular beds of pebble conglomerate.

South of the San Gabriel Fault, sedimentary rocks that rest upon the basement complex occur near the western quadrangle boundary and in a band across the middle of the quadrangle. The oldest rocks are the Domengine Formation (Td), which consists of calcareous sandstone of middle Eocene age that crops out in the northwestern quarter of the quadrangle. The Topanga Formation (Tt?) of middle Miocene age is exposed in the southeastern quarter of the quadrangle. It consists of nonmarine arkose, mudstone, and conglomerate, as well as vesicular basaltic flows and minor volcanic breccia (Tb).

The next youngest unit, the Modelo Formation (Tm), consists of upper Miocene shale, siltstone, sandstone and conglomerate. It is exposed along the mountain front above Lakeview Terrace and in the Mission Hills. Pico Formation (QTp) is mapped in the western half of the quadrangle and consists of Pliocene marine sandstone and pebble conglomerate that grades downward into undifferentiated Towsley and/or Pico Formation (Twp). This latter terminology was used in the 1:18,000-scale mapping of Barrows and others (1975). This mixed unit ranges in age from late Miocene to early Pliocene and consists of sandstone and pebble conglomerate.

The Plio-Pleistocene nonmarine Saugus Formation is more widespread in the quadrangle than any of the other pre-alluvial sedimentary units. The Saugus Formation rests unconformably upon the Pico Formation and Towsley Formation, and unconformably overlies or is in fault contact with the igneous and metamorphic rocks. The oldest or lower unit of the Saugus Formation, the Sunshine Ranch Member (Tsr) of Pliocene age, is comprised of brackish-water to nonmarine gravel, sandstone, sandy mudstone, mudstone, and conglomerate, which is exposed in the northwest corner of the quadrangle and in the Mission Hills. The Pleistocene Saugus Formation (Qs) is well exposed in a large synclinal fold, labeled the Merrick Syncline by Barrows and others (1975) and Dibblee (1991), near the eastern boundary of the quadrangle. In this area it consists of nonmarine pebble conglomerate and coarse-grained arkosic sandstone. In the Mission Hills, an upper, unnamed, member of the Saugus Formation (Qsu) consists of pebble conglomerate and coarse-grained sandstone. It is lithologically similar to the Qs, mapped on the eastern side of the quadrangle but grades downward into the Sunshine Ranch Member (Tsr).

The Pleistocene Pacoima Formation (Qpa) is distributed along the mountain front on either side of Pacoima Canyon. Pacoima Formation rests unconformably upon Saugus Formation rocks and consists of nonmarine pebble-boulder fanglomerate of locally derived basement rock clasts in a matrix of dark brown-reddish mudstone-soil.

The late Quaternary geologic units exposed on geomorphic terraces in the uplands and exposed on the uplifted and undeformed portions of the flatlands in the San Fernando Valley area of the quadrangle were completely re-mapped for this study. The geomorphic terraces and the uplifted flatlands in the San Fernando Valley area are generally mapped as older and very old alluvium (Qt, Qao, Qfo, Qfp, Qof1, Qof2, Qvoa, Qvoa1, Qvof1, and Qvof2), which consists of moderately dense to very dense sand, clayey and silty sand, gravel and clay layers. The undeformed portions of the flatlands in the San Fernando Valley area are underlain by younger alluvium (Qa, Qal, Qay1, Qay2, Qyf1, Qyf2, Qf, Qfy1, Qfy2, Qyt and Qw) that consists of loose to moderately dense sand, silty sand, gravelly sand, and minor clay. A more detailed description of the late Quaternary geologic units is presented in Section 1 of this report.

Landslide deposits (Qls) are particularly abundant in the northwestern and north-central portions of the quadrangle where they occur primarily associated with the sedimentary rocks of the uplands. In the northeastern portion of the quadrangle landslides occur on igneous and metamorphic rocks. Areas of man-made fill (af) are mapped at dams, large water-storage or water-treatment facilities and along freeway embankments. A more detailed description of the man-made fill is presented in Section 1 of this report.

Structural Geology

The northwest-striking San Gabriel Fault, which crosses the northeastern corner of the San Fernando Quadrangle, is one of the most dominant structural features in the area. It separates contrasting suites of rocks. Another dominant structural feature in the San Fernando Quadrangle is the family of north-dipping thrust faults, which comprise the San Fernando Fault Zone, that manifested their presence by rupturing the surface across the quadrangle during the February 9, 1971 San Fernando earthquake. Detailed maps of these fault ruptures were prepared by Barrows and others (1975).

Segments of other, older faults are identified in the uplands. Fault names used in the following discussion are taken from Dibblee (1991) and Barrows and others (1975). The Sombrero Fault in the western, the Hospital Fault in the central and the Lopez Fault in the eastern portions of the northern half of the quadrangle trend nearly west-east or northeast-southwest where the basement complex rocks have been thrust over Tertiary and Quaternary sedimentary units. Near the northwestern corner of the quadrangle, the Whitney Fault trends about north-south in the sedimentary rocks. The Mission Hills Fault and the Mission Wells Fault on the west, the Sylmar Fault Zone in the central and the Tujunga Fault on the east trend about west-east across the southern half of the quadrangle. These faults form the contact between the consolidated sedimentary rocks, or older alluvium along the Sylmar Fault Zone, on the northern side of the fault and younger alluvium on the southern side of the fault. The Buck Canyon Fault and Lone Tree Fault cut the igneous and metamorphic rocks in the north and the Kagel Fault cuts the sedimentary rocks in the south along the eastern margins of the quadrangle. These faults trend about northeast-southwest. The buried Verdugo Fault trends about northwest-southeast across the younger alluvium in the central and eastern portions of the southern half of the quadrangle.

In the igneous and metasedimentary basement rocks the foliation strikes approximately northwest-southeast, generally parallel with the trend of the San Gabriel Fault. Dips of the foliation are generally greater than 70 degrees to the northeast in the granodiorite (gd), but, locally, are as low as 45 degrees. Foliation in the other basement rocks is less well defined, although it generally strikes in a northwest-southeast direction, and dips typically toward the north, with some exceptions. Dips are typically between 25 and 75 degrees regardless of strike.

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Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the San Fernando Quadrangle was prepared using interpretation of stereo-paired aerial photographs (see Air-Photos in the References) of the study area and limited field reconnaissance (Treiman, unpublished). All areas containing landslides identified in the previous work (Oakeshott ,1958; Morton, 1975; Weber, 1982; and Dibblee,1991) where reevaluated during the aerial photograph interpretation conducted for this investigation. Some of the landslides identified in the previous work were not included in the landslide inventory because, in our reevaluation, it was concluded the feature was not a landslide. Additionally, all landslides shown on the digital geologic map (Yerkes, 1996b) were verified, re-mapped or removed during preparation of the inventory maps. Landslides were mapped and digitized 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 slope stability analysis. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed hand-drawn 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.

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 rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the San Fernando Quadrangle geologic map were obtained from the City of Los Angeles, Department of Public Works, and the Los Angeles County Department of Public Works, Material Engineering Division (see Appendix A). Due to the nature of the topography and land-ownership patterns within the quadrangle, residential and commercial development has taken place primarily on the gently sloping alluvial areas of the San Fernando Valley. Consequently, shear strength information was scarce or entirely lacking for many rock units in the hilly portions of the quadrangle. Where appropriate, strength data from rock units in adjacent quadrangles were used to characterize the shear strength of rock units within the San Fernando Quadrangle. Shear strength data from the eastern half of the Oat Mountain Quadrangle, the southeastern quarter of the Mint Canyon Quadrangle, and the Sunland Quadrangle were used to supplement data from the San Fernando Quadrangle. The locations of rock and soil samples taken for shear testing by consultants are shown on Plate 2.1.

Shear strength data gathered from the above sources 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 and median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1. For most of the geologic strength groups in the map area, a single 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 Tables 2.1 and 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

SAN FERNANDO QUADRANGLE
SHEAR STRENGTH STATISTICS

	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 Analyses
GROUP 1	Kgr*	0	38	38	300	Kgr*	38
GROUP 2	Tm-fbc	20	35.9/35	34.6/34	362/300	Td, Tcs-fbc	35
	Qs-fbc**	33	34.5/34			Tmc1-fbc,Tvz-fbc	
	Tt-fbc	21	34.3/33			Tb	
	QTp/Tw/Twp-fbc	9	33/34				
GROUP 3	Tsr-fbc	20	31.1/30.5	29.6/30	348/255	Tmc2-fbc	30
	Qa*	48	30.5/31				
	Qtp/Tw/Twp-abc	11	29.4/28				
	Tm-abc	18	28/29.5				
	Qs-abc**	19	27.2/28				
GROUP 4	Tsr-abc	12	24.7/26	24.7/26	757/490	Tcs-abc,Tmc1-abc	26
	Tt-abc	7	24.7/25			Tmc2-abc,Tmz	
						Tvz-abc	
GROUP 5	Qls	0	14	14	400		14**

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength
* subunits of these formations have been combined
** lowest calculated phi value was accepted as representative phi value for landslides

Table 2.1. Summary of the Shear Strength Statistics for the San Fernando Quadrangle.

SHEAR STRENGTH GROUPS
FOR THE SAN FERNANDO QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Dgn gb gd gd/gn pCm pl pm sp	Qs-fbc Qsu-fbc Qtp-fbc Tw-fbc Twp-fbc Tm-fbc Tt-fbc Tcs-fbc Tmc1-fbc Tvz-fbc Td Tb	Qs-abc Qsu-abc QTp-abc Tw-abc Twp-abc Tm-abc Tsr-fbc Tmc2-fbc Qa Qal Qao Qay Qc Qco Qf af	Tsr-abc Tt-abc Tcs-abc Tmc1-abc Tmc2-abc Tvz-abc Tmz	Qls

Table 2.2. Summary of the Shear Strength Groups for the San Fernando Quadrangle.

The crystalline rocks of the San Gabriel Mountains, as a group, have engineering characteristics different from other rock units in the quadrangle, yet very few shear test results were available for them from the quadrangle, or from adjacent quadrangles. Thus some assumptions had to be made about the choice of phi value for the rock group, based on field observations and comparisons with other rock units. The ancient crystalline bedrock in the western San Gabriel Mountains is pervasively fractured. This pervasive fracturing is the dominant physical characteristic of all the crystalline rocks, and it appears to dominate the engineering behavior of the rocks, regardless of their mineralogy, age, or metamorphic history. Although they are pervasively fractured, the rocks support some of the steepest slopes in the quadrangle, and are, therefore, likely to be some of the strongest rocks in the quadrangle. For the purpose of slope stability analysis, all the crystalline rocks of the San Gabriel Mountains were consolidated into one group (Kgr), and this group was designated as the highest strength group. A phi value of 38 degrees was chosen to represent the group, based on phi values published in rock mechanics and engineering geology text books (Franklin and Dusseault, 1989; Hoek and Bray, 1981; Jumikis, 1983) and comparison with shear test results for the group. The value of 38 degrees was in the middle of the range of the few shear test results that were collected from the quadrangle and the surrounding area.

Towsley Formation (Tw), Pico Formation (QTp), and undifferentiated Pico and Towsley formations combined (Twp) are similar lithologically, and were combined into one rock unit for shear strength purposes.

Adverse Bedding Conditions

Adverse bedding conditions are an important consideration in slope stability analyses. Adverse bedding conditions occur where the dip direction of bedded sedimentary rocks is roughly the same as the slope aspect, and where the dip magnitude is less than the slope gradient. Under these conditions, landslides can slip along bedding surfaces due to a lack of lateral support.

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, derived from the geologic map database, was used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude was less than or equal to the slope gradient category but greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area.

Formations that contain interbedded sandstone and shale were subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material (higher strength) dominates where bedding dips into a slope (favorable bedding) while fine-grained (lower strength) material dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. The favorable and adverse bedding shear strength parameters for the formations are included in Table 2.1.

Existing Landslides

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. Existing landslides (Qls) were assigned a phi of 14 for stability analysis calculations for this quadrangle. None of the geotechnical reports reviewed for the quadrangle contained any direct shear tests run on actual slide plane material, but there were a few such test results for nearby quadrangles. The phi values for slide plane material actually tested had a wide range, and 14 was near the low end of this range. In those geotechnical reports that provided slope stability calculations, conservative assumed phi values were generally chosen, and 14 was again on the low end of the range of values used.

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 San Fernando 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 DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.6 to 6.7
Modal Distance:	2.5 to 11.4 km
PGA:	0.63 to 1.15 g

The strong-motion record selected for the slope stability analysis in the San Fernando Quadrangle was the Channel 3 (north horizontal component) Pacoima-Kagel Canyon Fire Station recording from the magnitude 6.7 Northridge earthquake (Shakal and others, 1994). This record had a source to recording site distance of 2.6 km and a peak ground acceleration (PGA) of 0.44 g. The selected strong-motion record was not scaled or otherwise modified prior to 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 DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.074, 0.13 and 0.21g. 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 San Fernando Quadrangle.

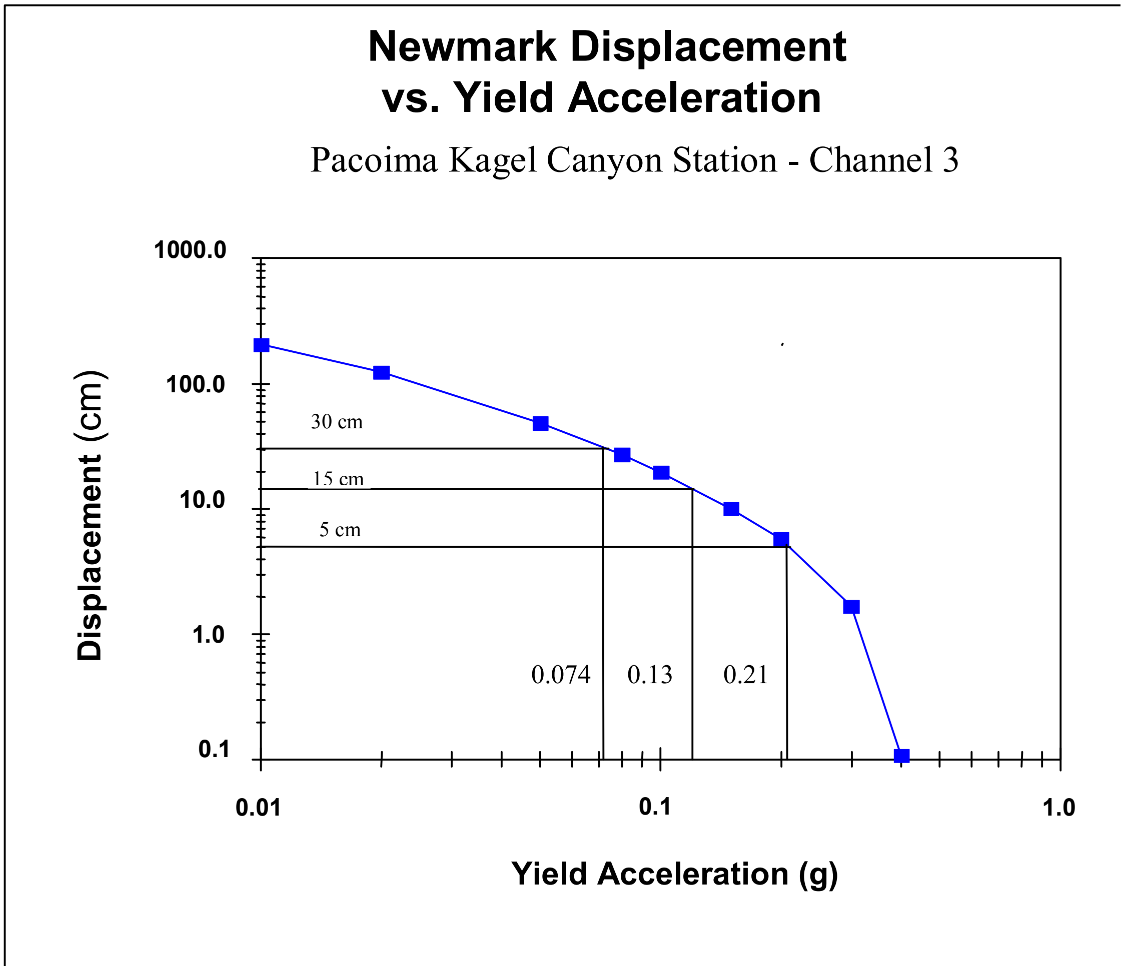

Figure 2.1. Yield acceleration vs. Newmark displacement for the Pacoima-Kagel Canyon strong-motion record from the 17 January 1994 Northridge, California Earthquake. Record from California Strong Motion Instrumentation Program (CSMIP) station 24088.

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 0.074g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)
2. If the calculated yield acceleration fell between 0.074g and 0.13g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)
3. If the calculated yield acceleration fell between 0.13g and 0.21g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)
4. If the calculated yield acceleration was greater than 0.21g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

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.

SAN FERNANDO QUADRANGLE
HAZARD POTENTIAL MATRIX

		SLOPE CATEGORY										
Geologic Material Group	**Mean Phi**	**I 0-11**	**II 11-18**	**III 18-28**	**IV 28-35**	**V 35-42**	**VI 42-47**	**VII 47-50**	**VIII 50-59**	**IX 59-62**	**X 62-74**	**XI >74**
1	38	VL	VL	VL	VL	VL	VL	VL	VL	L	M	H
2	35	VL	VL	VL	VL	VL	VL	L	M	M	H	H
3	30	VL	VL	VL	VL	L	M	M	H	H	H	H
4	26	VL	VL	VL	L	M	H	H	H	H	H	H
5	14	L	M	H	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the San Fernando Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone. H = High, M = Moderate, L = Low, VL = Very Low.

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.

The February 9, 1971 San Fernando earthquake triggered widespread rockfalls, soil falls, debris slides, avalanches, and slumps in the foothills of the San Gabriel Mountains that rise above the Tujunga segment of the San Fernando Fault (Morton, 1975). Most of the failures were shallow debris or soil falls, although several larger landslides were triggered such as in Bartholomaus Canyon. In addition, rockfalls were especially abundant in the igneous and metamorphic basement rocks on the ridges on both sides of Pacoima Canyon (Morton, 1975, plate 3). Fewer and smaller landslides were also triggered along the mountain front between Pacoima Canyon and Santa Susana Pass. The most significant “landslide” to be triggered by the San Fernando earthquake was associated with the liquefaction-related near-collapse of Lower Van Norman Dam.

The 1994 Northridge earthquake caused a number of relatively small, shallow slope failures in the San Fernando Quadrangle. Some of these soil falls occurred in the same places as those triggered by the 1971 earthquake, such as the foothills north of the Tujunga fault segment (Barrows and others (1995, p. 69). Harp and Jibson (1995) prepared an inventory of Northridge earthquake-triggered landslides. Their map depicts abundant rockfalls in the vicinity of Pacoima Canyon in the same places that developed slides during the 1971 earthquake. Landslides attributed to the Northridge earthquake covered approximately 264 acres in the mountainous northern half of the quadrangle, which is approximately 0.6 percent of the total area covered by the map. Of the area covered by these Northridge earthquake landslides, 89% falls within the area of the hazard zone based on a computer comparison of the zone map and the Harp and Jibson (1995) inventory.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by DMG (McCrink and Real, 1996), 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 5 is included for all slope gradient categories. (Note: Geologic Strength Group 5 includes all mappable landslides with a definite or probable confidence rating).
2. Geologic Strength Group 4 is included for all slopes steeper than 28 percent.
3. Geologic Strength Group 3 is included for all slopes steeper than 35 percent.
4. Geologic Strength Group 2 is included for all slopes steeper than 47 percent.
5. Geologic Strength Group 1 is included for all slopes greater than 59 percent.

This results in 22 percent of the land within the quadrangle, including National Forest Service land, lying within the earthquake-induced landslide hazard zone for the San Fernando Quadrangle.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Geologic material strength data were collected at the Los Angeles County Department of Public Works with the assistance of Robert Larsen, Michael Montgomery, Charles Nestle, and Dave Poplar and the City of Los Angeles with the assistance of Nicki Girmay. Digital terrain data were provided by Randy Jibson of the U.S. Geological Survey (USGS DEM), and Scott Hensley of JPL and Gerald Dildine and Chris Bohain of Calgis, Inc. (Radar DEM).

Technical review of the methodology was provided by Bruce Clark, Randy Jibson, Robert Larson, Scott Lindvall, and J. David Rogers, who are members of the State Mining and Geology Board's Seismic Hazards Mapping Act Advisory Committee Landslides Working Group. At DMG, special thanks to Bob Moskovitz, Teri McGuire, Barbara Wanish, and Scott Shepherd for their GIS operations support, and to Barbara Wanish for designing and plotting the graphic displays associated with the hazard zone map and this report.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Los Angeles, Department of Building and Safety:	**181 (127)***
Los Angeles County Department of Public Works:	**30 (19)**
Total Number of Shear Tests	**221 (146)**

* The numbers in parentheses are those tests taken from adjacent quadrangles.

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the San Fernando 7.5-Minute Quadrangle, Los Angeles County, California

By

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Charles R. Real, and Michael S. Reichle

California Department of Conservation
Division of Mines and Geology
***Formerly with DMG, now with U.S. 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) 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; also available 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 (California Department of Conservation, 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 DMG's Internet homepage: 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, 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% 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.

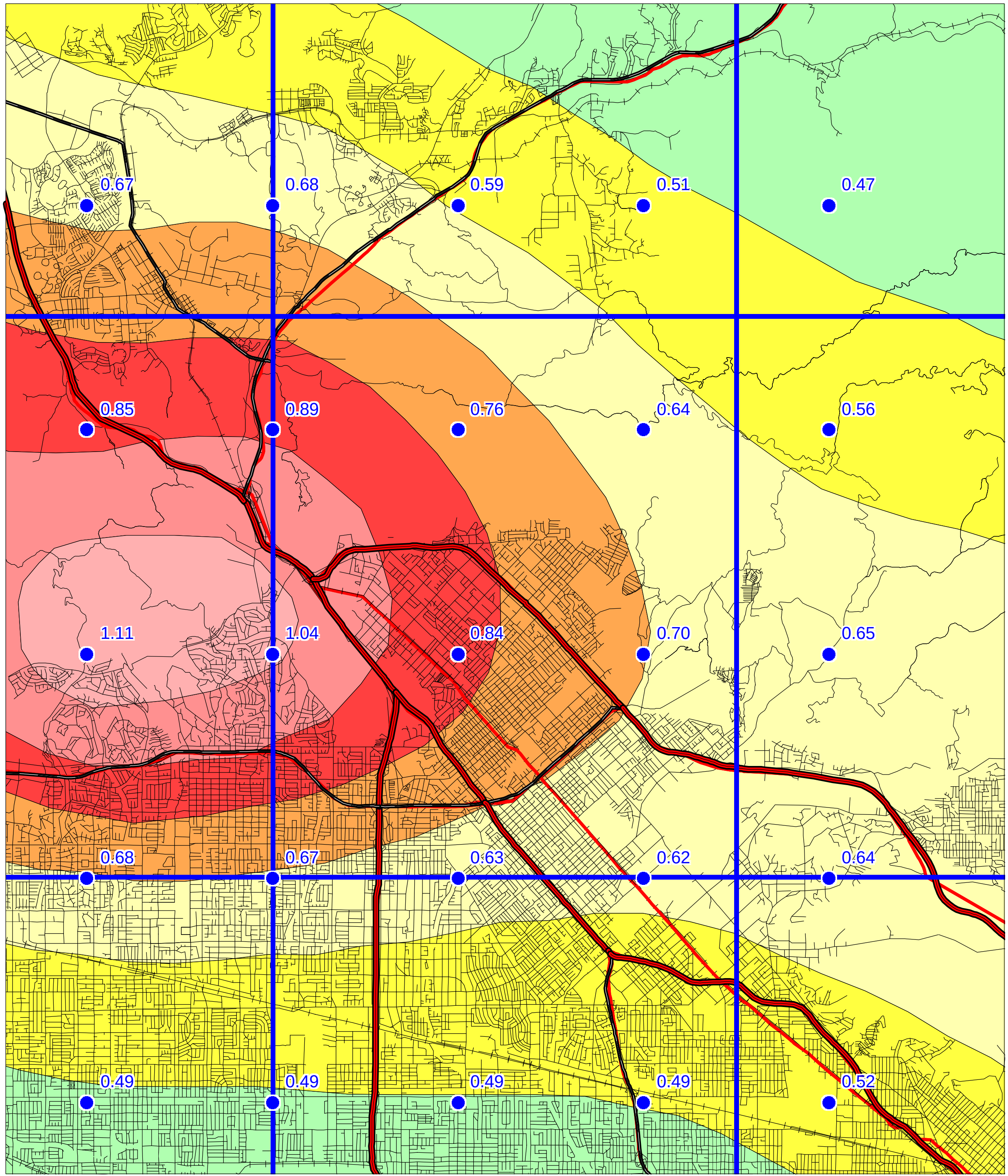
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. 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 adjacent

SAN FERNANDO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

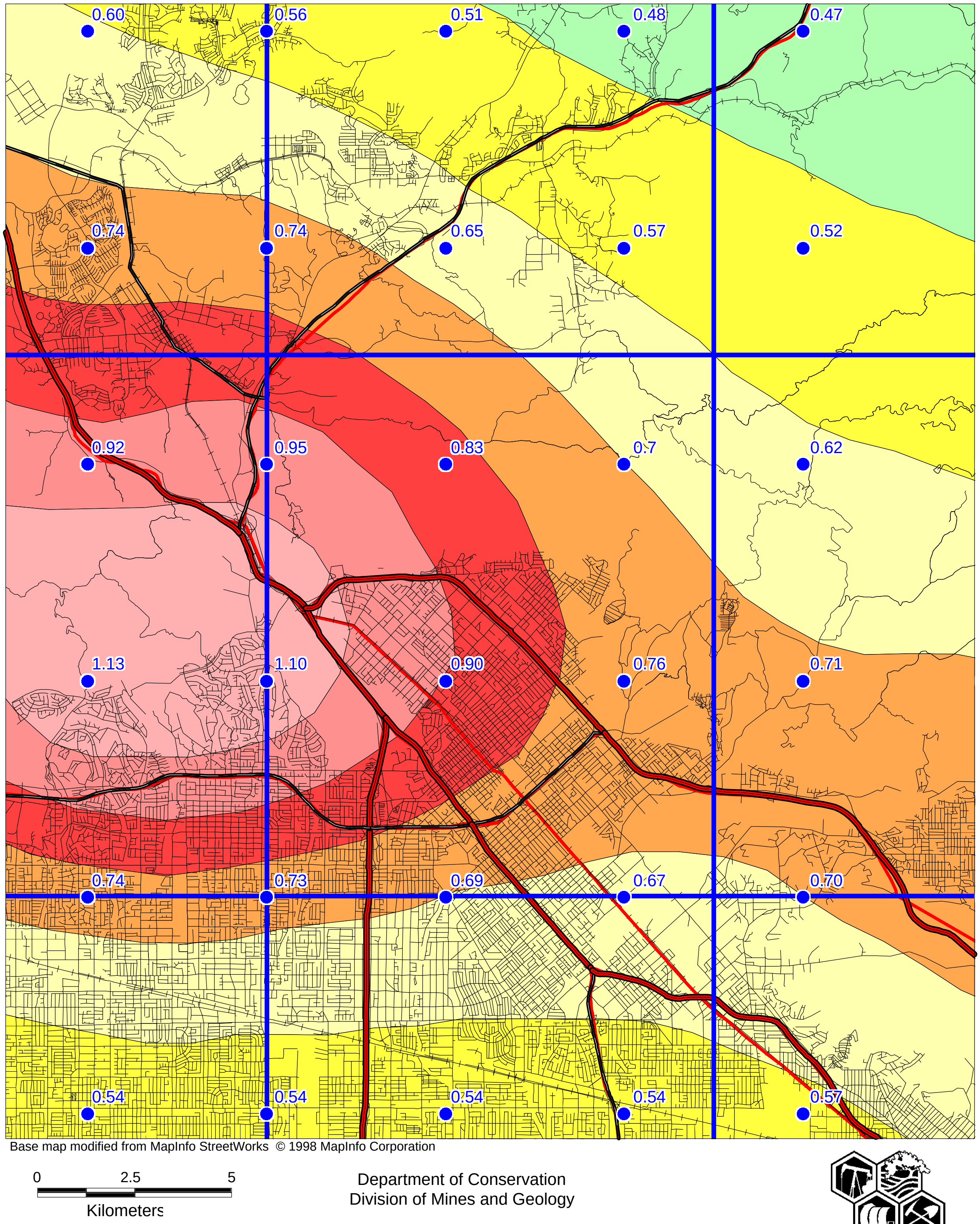
Figure 3.1

SAN FERNANDO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



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Department of Conservation
Division of Mines and Geology

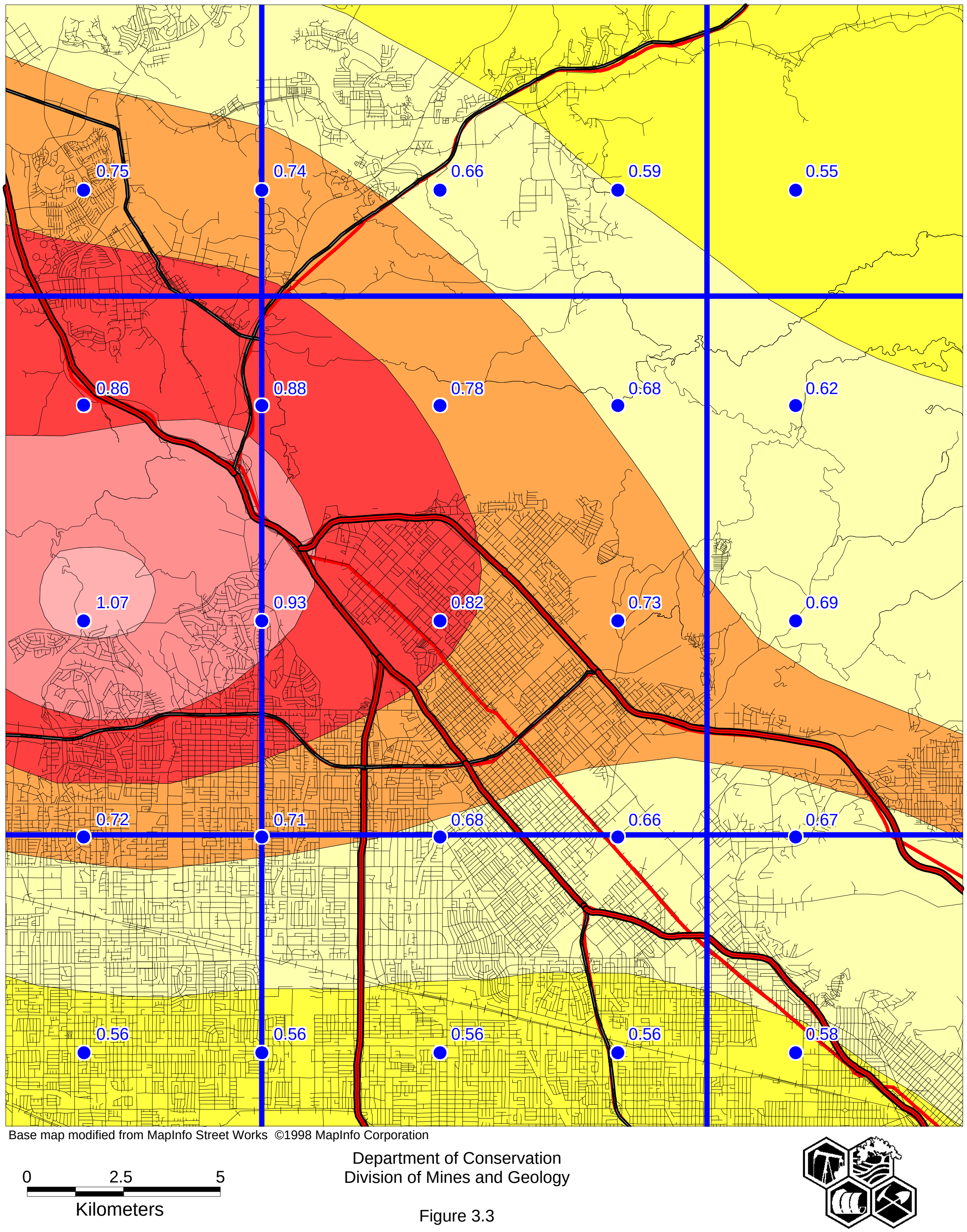
Figure 3.2

SAN FERNANDO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works ©1998 MapInfo Corporation

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Figure 3.3

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% 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.

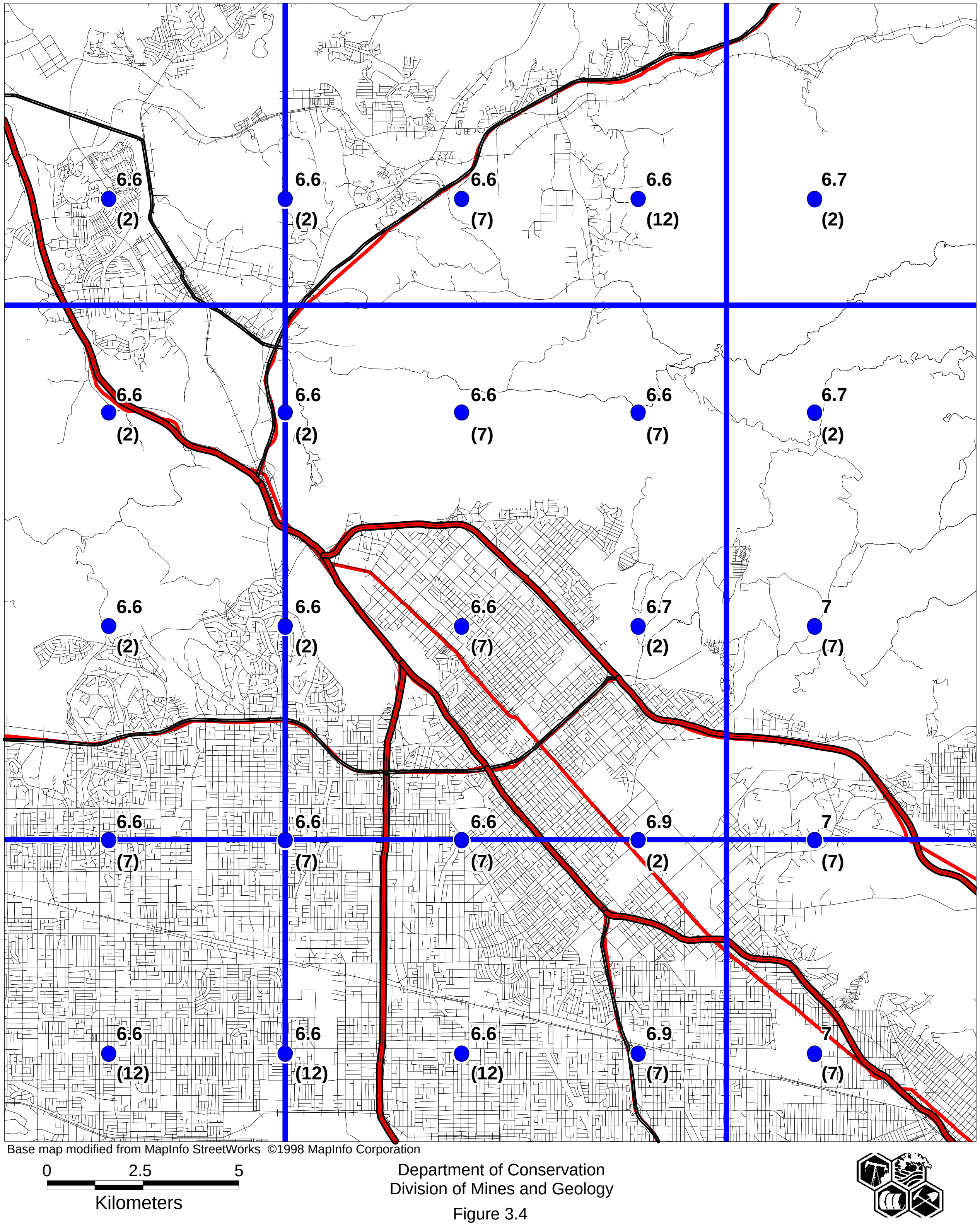
SAN FERNANDO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

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Division of Mines and Geology

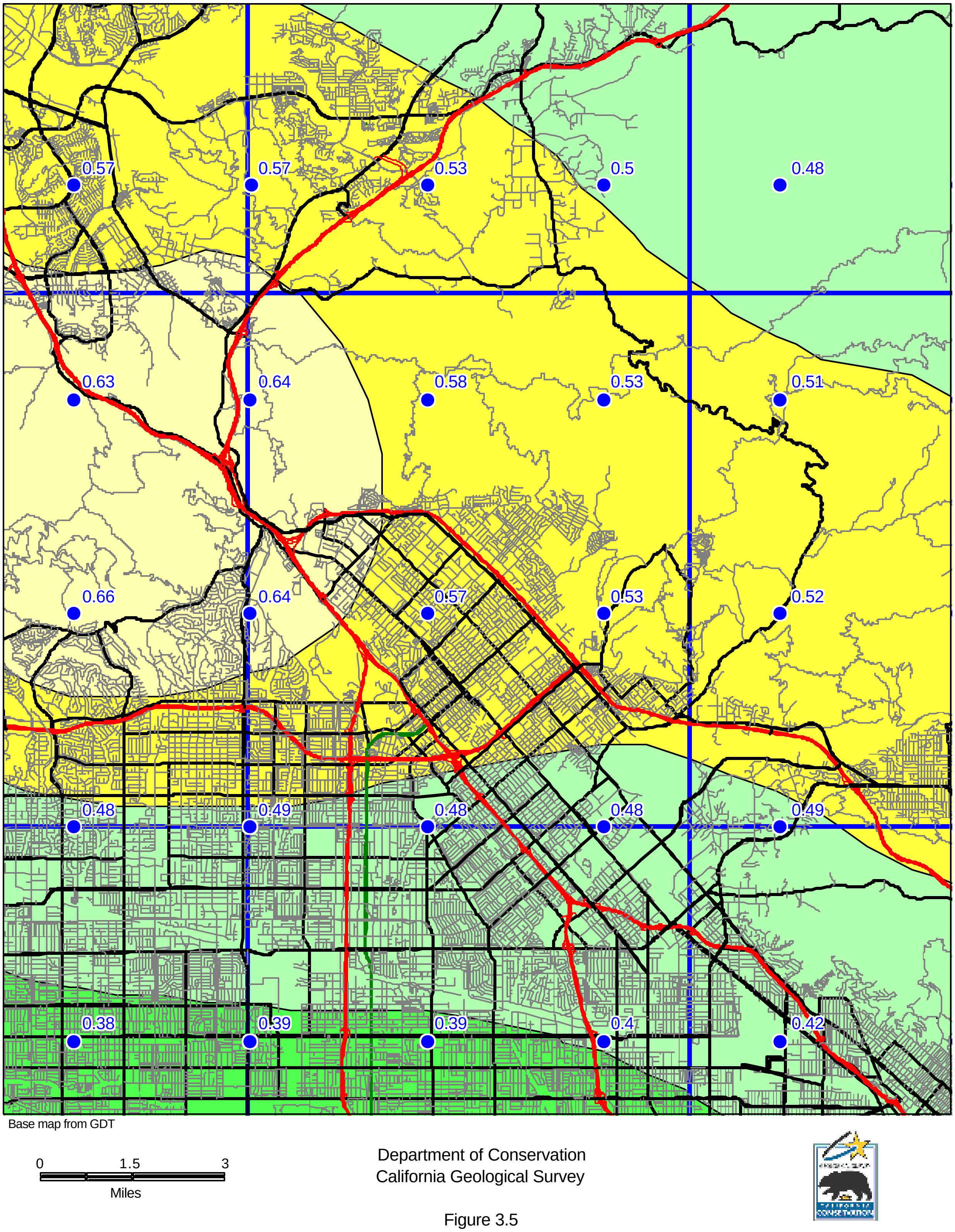
Figure 3.4

SAN FERNANDO 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% 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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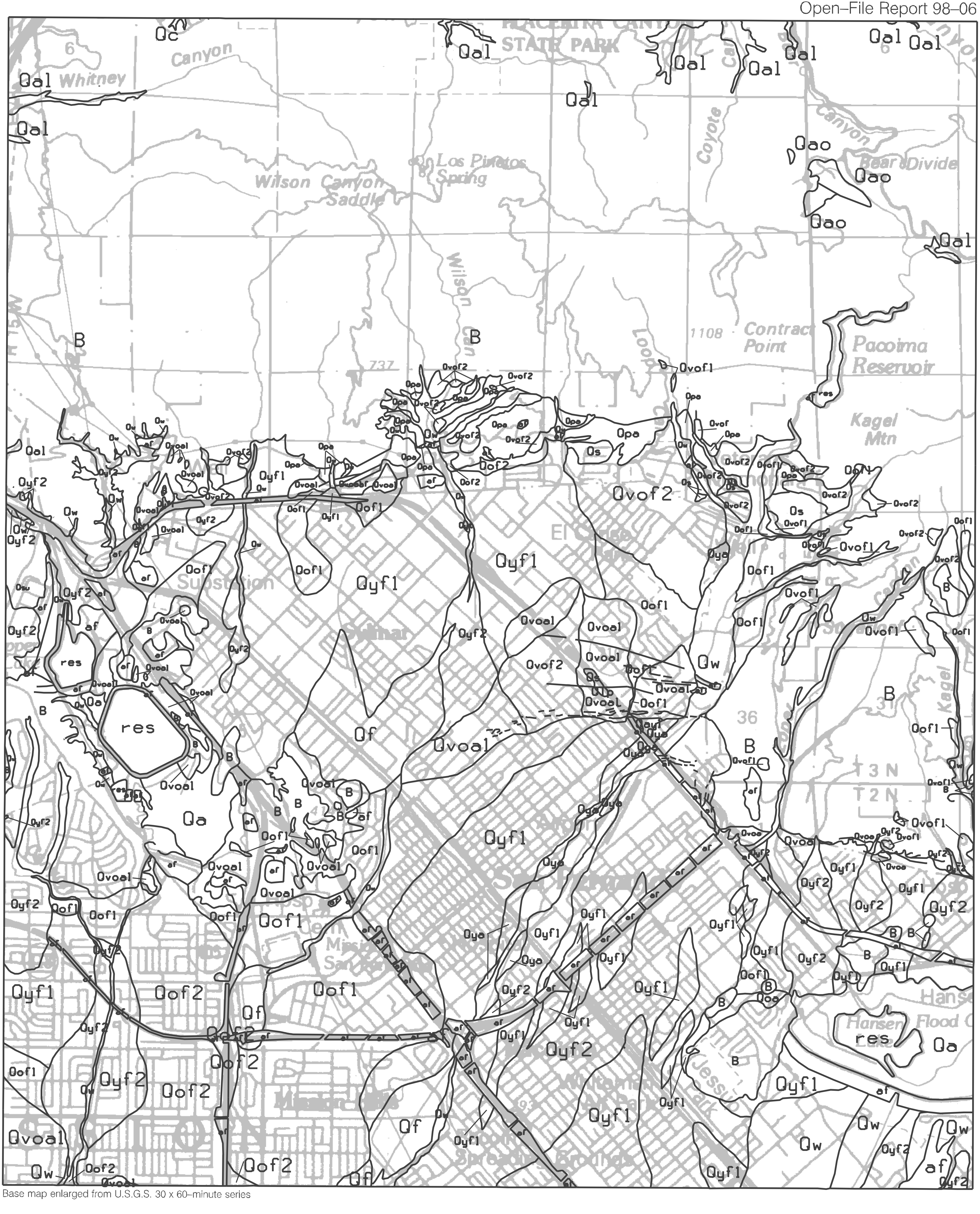


Base map enlarged from U.S.G.S. 30 x 60–minute series

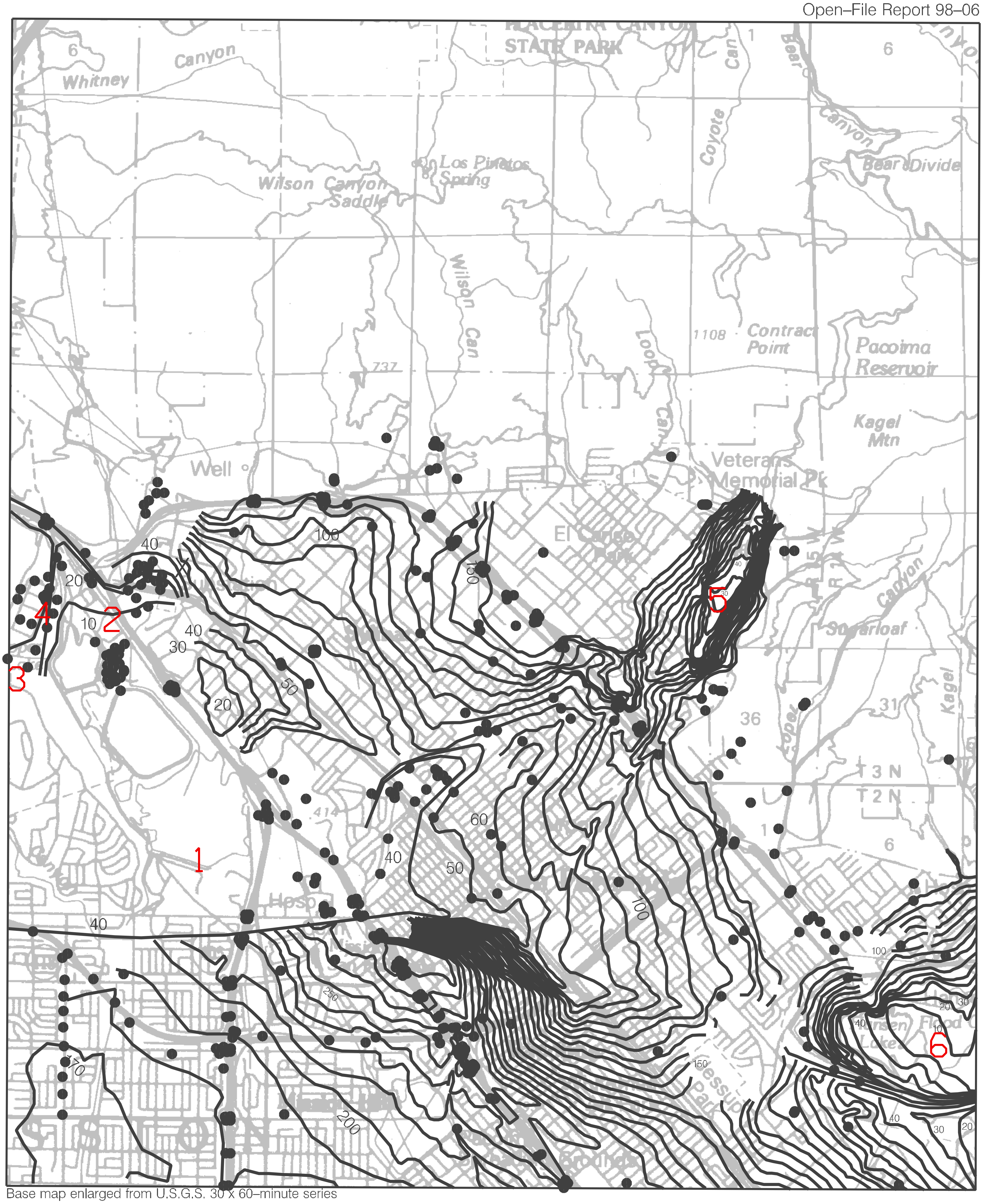
Plate 1.1 Quaternary Geologic Map of the San Fernando Quadrangle.

See Geologic Conditions section in report for descriptions of the units.

B = Areas of pre–Quaternary bedrock. Res = reservoir.

ONE MILE

SCALE



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

Plate 1.2 Historically Highest Ground–Water Contours and Borehole Log Data Locations, San Fernando Quadrangle.

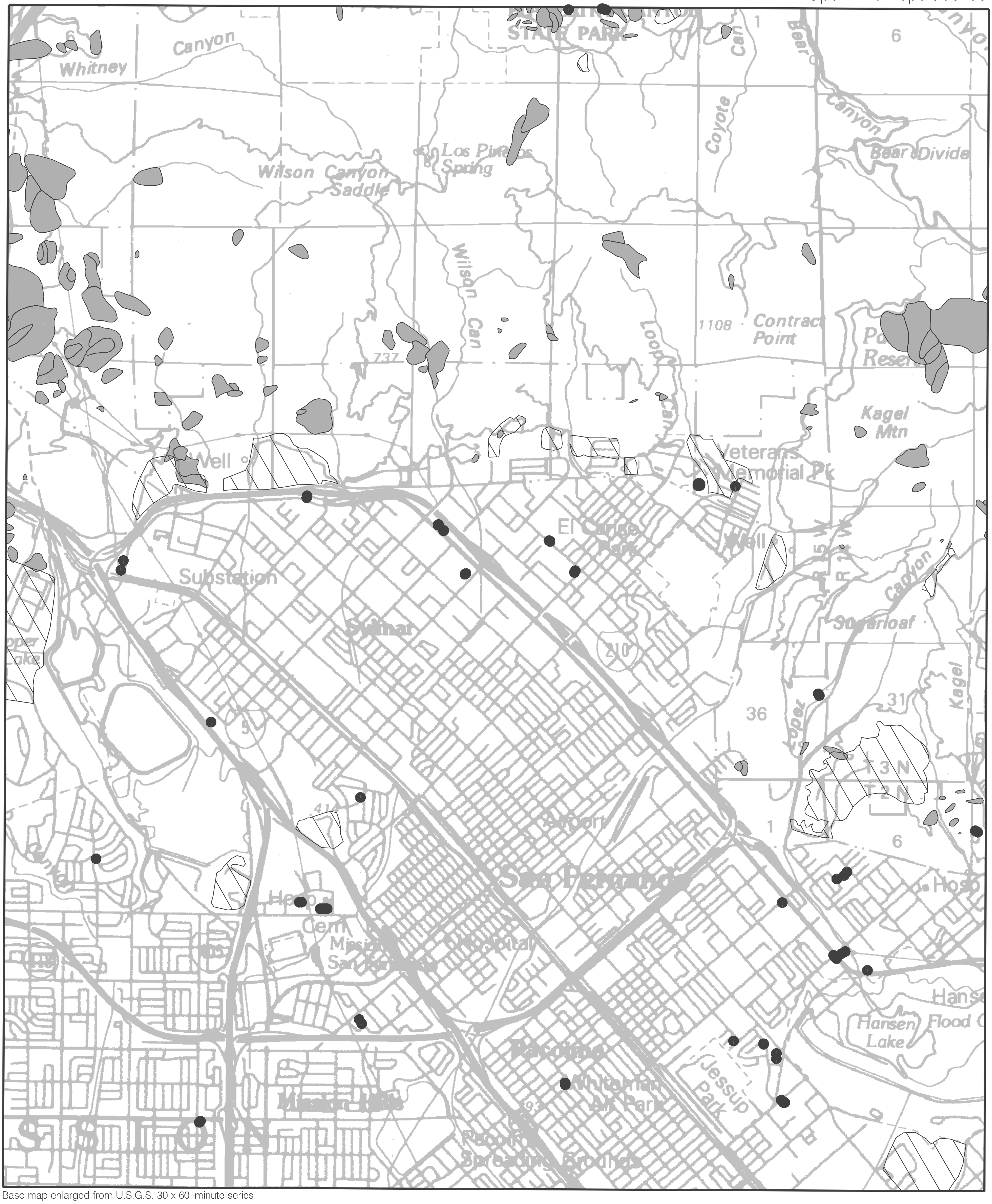
● Borehole Site

~30~ Depth to ground water in feet

6 Site of historical earthquake–generated liquefaction. See "Areas of Past Liquefaction" discussion in text.

ONE MILE

SCALE



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

Plate 2.1 Landslide inventory, Shear Test Sample Locations, and Areas of Significant Grading, San Fernando Quadrangle.

● shear test sample location

▨ landslide

▧ areas of significant grading

ONE MILE

SCALE