SEISMIC HAZARD ZONE REPORT 01

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

1997

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, *STATE GEOLOGIST*

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CONTENTS

ILLUSTRATIONS

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
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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.**

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Topanga 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 45 square miles at a scale of 1 inch = 2,000 feet.

The Topanga Quadrangle intersects the coastline 14 to 21 miles west of downtown Los Angeles. Parts of the cities of Los Angeles, Santa Monica and Malibu, the communities of Pacific Palisades, Fernwood and Topanga and Topanga State Park are within the map. Most of the area is within the Santa Monica Mountains, the crest of which trends east-west just north of the quadrangle. Several south-draining canyons, including Topanga Canyon, extend from the range crest to Santa Monica Bay. On the western half of the quadrangle the mountains extend down to the bay with only a narrow beach. To the east, a broad terrace, ranging in elevation from about 100 to 400 feet above sea level separates the mountains from the bay.

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.

Earthquake-induced landslide zones are widespread in the mountainous terrain of the Topanga Quadrangle where more than 650 landslides were mapped. About 63 percent of the land in the quadrangle lies within the earthquake-induced landslide hazard zone. Liquefaction zones in the Topanga Quadrangle are limited to the beaches and narrow canyon bottomlands where ground water is at shallow depths. The gently sloping terrace in the southeastern corner of the quadrangle is the largest area outside of a hazard zone.

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://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf).

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 Topanga 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

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

By
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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 Topanga 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 has historically 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 sediments within the upper 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 opportunity 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 Topanga 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 consist mainly of alluviated valleys, floodplains, and canyon regions. The evaluation is based on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth data, most of which are gathered from a variety of sources. The quality of the data used varies. Although selection of data used in this evaluation was rigorous, 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 Topanga Quadrangle covers a part of Los Angeles County west of downtown Los Angeles and includes parts of the cities of Los Angeles, Santa Monica and Malibu. Much of the area is within the Santa Monica Mountains. The crest of the mountains trends approximately east-west just north of the quadrangle. Within the quadrangle, several south-draining canyons extend from the range crest to Santa Monica Bay. On the western half of the quadrangle the mountains extend down to the bay with only a narrow beach between them. To the east, a terrace, ranging in elevation from about 100 to 400 feet separates the mountains from the bay.

GEOLOGY

Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. Mapping of late Quaternary geologic units was compiled from published geologic maps of the quadrangle by Yerkes and Campbell (1994), Dibblee (1992), and the detailed geologic map of the Pacific Palisades area by McGill (1989). The published mapping shows three types of latest Quaternary deposits: alluvium in the canyons, beach deposits, and artificial fills. Two types of older alluvial deposits have been mapped: the non-marine, or alluvial, terrace deposits and stream terraces. All referenced map symbols in the following discussions are from the Yerkes and Campbell (1994) geologic map.

Alluvial terrace deposits (Qtc) form the prominent, southward sloping, dissected surface that much of the city of Santa Monica and the Pacific Palisades district Los Angeles are built on. These deposits, confined to the coastal areas of the Topanga Quadrangle, are limited in areal extent to the west, with only small, isolated occurrences west of Topanga Canyon. The terrace, which is capped by Qtc, ranges in elevation from about 100 feet on the south to about 400 feet on the north. Marine terrace deposits (Qtm) are locally interbedded with the non-marine alluvial terrace deposits in the south-central portion of the quadrangle. Yerkes and Campbell (1994) describe them as clean, loose to weakly cemented sand, silty sand, and gravel.

Stream terrace deposits (Qts) are most prominent where Santa Monica and Rustic Canyons cross the Pacific Palisades terrace. The stream terraces are 80 to 100 feet below the level of the Pacific Palisades terrace but 40 to 60 feet above the younger stream alluvium.

Younger alluvium (Qal) is confined to narrow areas extending up most canyons, though parts of some canyons, particularly lower Topanga Canyon are apparently too narrow for any alluvium to be shown at 1:24,000 scale. Beach deposits (Qb) along Santa Monica Bay also are mapped as narrow deposits confined to the strip between the bay and either the mountains or the bluffs of the Pacific Palisades. Areas of artificial fill (af) depicted on published geologic maps include road fills for the Pacific Coast Highway and Topanga Canyon Road and an area at the intersection of Sunset Boulevard and Pacific Coast Highway (mapped by McGill [1989] as hydraulic fill [hf]).

Examination of the published geologic maps indicates that there are differences in the mapping of Quaternary units among the various authors. Generally, Dibblee (1992) shows alluvium in the canyons occupying wider and more continuous areas than Yerkes and Campbell (1994). McGill (1989) mapped terrace deposits in Rustic Canyon, which are also shown by Yerkes and Campbell (1994). However, similar topographic terraces in Rustic Canyon just north of the boundary of McGill's map are not distinguished from the modern stream alluvium by Yerkes and Campbell (1994).

Because of these apparent inconsistencies, aerial photos were obtained and examined. The extent of the youngest alluvial unit was interpreted from aerial photographs of 1:20,000 nominal scale taken by the U.S. Department of Agriculture in 1952. Based on this interpretation, we have adopted the boundaries of alluvial units shown by Yerkes and Campbell (1994) with a few exceptions: slight modifications were made to the boundaries of alluvium in Topanga Canyon; discontinuous bodies of alluvium shown in Santa Ynez and Sullivan canyons were connected; and a stream terrace in lower Rustic Canyon was included in the older stream terrace rather than the younger alluvial unit.

ENGINEERING GEOLOGY

Subsurface data were collected at Caltrans, the Los Angeles County Department of Public Works, the Los Angeles City Departments of Water and Power and Building and Safety, the Los Angeles Regional Water Quality Control Board and the office of Law-Crandall, Inc., a major Los Angeles geotechnical firm. Additional subsurface data were obtained from John Tinsley of the U.S. Geological Survey, who had gathered subsurface data from throughout the Los Angeles region in the early 1980s, and from L.T. Evans, Jr., of Converse Consultants, who provided copies of reports by his father's company, L.T. Evans Foundation Engineers. General features of the Quaternary geologic units, derived from borehole logs, are presented in Table 1.1 and described below. The locations of collected borehole data are shown on Plate 1.1.

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 1 atmosphere (approximately 1 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 $(N_1)_{60}$.

Alluvial (Qtc) and marine (Qtm) terrace deposits

Borehole logs were obtained for sites on the prominent alluvial terrace upon which much of Santa Monica and the Pacific Palisades district in Los Angeles are built. These materials are generally described as dense to very dense sandy silt and sandy clay. No subsurface information was collected for the marine terrace deposits.

Stream terraces (Qts)

Only one borehole log was found for one of the raised terraces in Santa Monica and Rustic Canyons. The material at this location is described as interbedded gravels and clays, with some silt and silty sand.

Younger alluvium (Qal)

Logs of geotechnical boreholes in the alluvium of the major southward-draining canyons describe silty sand to gravelly sand, generally loose to moderately dense.

Geologic Map Unit	Material Type	Consistency	Number of Boreholes	Depth to Water	Liquefaction Susceptibility
Qtc, terrace Deposits	silty sand, silty clay	dense/stiff	17	111' (1 borehole)	low
Qts, stream terraces	gravel, silt, clay		1	>45"	low
Qal, Topanga Canyon	sand & gravel	v. loose-slightly compact	4	6'	high
Qal, Santa Ynez Canyon	sand & gravel	loose-dense	25	10'	high
Qal, Rustic Canyon	sand & gravel	v. loose-med. dense	5	10'	high
Qal, Santa Monica Canyon	sand & gravel	loose-dense	9	5-20'	high
Qal, Mandeville Canyon	sand & gravel	loose-dense	21	10-20'	high
Qb, beach	sand	v. loose-dense	18	10-20'	high
af, artificial fill (roadway fills)	silt & clay	slightly compact-compact	10	7'	low
hf, hydraulic fill	silt & sand	loose-dense	13	5-15'	high

Table 1.1. General Geotechnical Characteristics and Liquefaction Susceptibility of Younger Quaternary Units.

In Topanga Canyon, boreholes by Caltrans for bridges over Topanga Creek and Garapito Creek included descriptions of the subsurface soils and Standard Penetration Tests (SPT). At both locations the near surface alluvium is described as gravelly sand, loose to slightly compact. SPT N-values in the alluvium range from 14 to 125, with low values from 14 to about 20. The low values probably represent the consistency of the sandy material, and high values represent impact on pebbles and cobbles within the deposit.

Alluvial deposits in Santa Ynez Canyon have been investigated for various construction and ground-water contamination projects. Results of SPTs were acquired for only one site in the alluvium of Santa Ynez Canyon. At that site, the Self-Realization Fellowship property on Sunset Boulevard, borehole logs describe stiff clayey silty sand and dense silty sand with blow counts (corrected for a hammer drop of 36 inches rather than the standard 30 inches) of 61 and greater. Most other boreholes in the alluvium, however, describe loose silty sand and sand. A layer of well-graded sand in one borehole caved so extensively into a bucket auger hole that the borehole had to be abandoned.

The data acquired for the remaining canyons on the Topanga Quadrangle (Temescal, Rustic, Santa Monica, and Mandeville) are similar to that for Santa Ynez Canyon. No SPT results were obtained for any of these deposits. Grain size distribution test results (sieve analyses) were obtained for alluvium from Rustic and Mandeville canyons. Layers of sand from both canyons had less than 5% passing the #200 sieve. Raveling or caving was reported in several boreholes, only once severe enough to cause the borehole to be abandoned.

The available data suggest that the alluvium in all the southward-draining canyons in the Topanga Quadrangle consists of similar material, predominately sandy gravel. Borehole logs also commonly show loose silty sand or sand, or sand that caved into an open borehole.

Beach deposits (Qb)

Logs of subsurface investigations of the beach deposits in the Topanga Quadrangle were obtained from Caltrans and Law-Crandall, Inc. The beach deposits tend to be relatively thin, commonly about 10 feet thick. Several boreholes describe sand layers as loose or very loose.

Artificial fill (af, hf)

Artificial fill is shown on published geologic maps underlying parts of Pacific Coast Highway and Topanga Canyon Road, filling several graded areas (including landslide repairs) in the Pacific Palisades and near the intersection of Sunset Boulevard and Pacific Coast Highway.

The hydraulic fill mapped by McGill (1989) near the intersection of Sunset Boulevard and Pacific Coast Highway was investigated for two gas stations at that intersection. Subsurface soils were generally reported to be clay, silt and clayey sand, but layers of sand were reported in several boreholes. SPT blow counts of 10 or lower were recorded in layers of silty sand or sand in several boreholes. Because of the heterogeneous nature of artificial fills, it is not known how extensive these relatively loose sand layers are.

Borehole logs through artificial fill along Pacific Coast Highway show that the fill itself is generally clayey or silty sand commonly described by Caltrans as “slightly compact.”

We obtained no subsurface data on the mapped fill underlying Topanga Canyon Road.

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.

Ground-water conditions were investigated in the Topanga 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 presence of ground water was recorded in borehole logs from most surficial geologic units. Depth to ground water is shown on Plate 1.1 for all boreholes where it was measured. Although we could not obtain enough ground-water depth measurements to make a detailed ground-water contour map, the measurements that we did obtain show that ground water is shallow in all Holocene deposits. The ground-water map was digitized and used for the liquefaction analysis.

In older alluvium of the Pacific Palisades area, water was encountered only in one deep borehole. There, ground water was reported to be greater than 100 feet below the surface. At one location in a stream terrace, water was not encountered in a 45-foot deep borehole.

In younger alluvium, ground water is usually shallow. In Topanga Canyon, ground water was encountered at 6 to 7 feet at Garapito Creek but no water was encountered in the Topanga Creek bridge borehole. Shallow ground water was encountered in younger alluvium in the other canyons (though not in all boreholes), generally within 20 feet of the surface.

Water was usually encountered within the beach deposits within 10 feet of the ground surface. In the hydraulic fill at the mouth of Santa Ynez Canyon it was recorded within 15 feet of the surface.

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 the geologic age and environment of deposition of a particular deposit. 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. DMG's qualitative relations between susceptibility, geologic map unit and depth to ground water are summarized in Table 1.1.

Older alluvial (Qtc, Qts) and marine (Qtm) terrace deposits

Based on the lack of shallow ground water noted on the borehole logs we obtained, as well as the qualitative description of the materials as dense silt and stiff clay, the alluvial terrace deposits and the stream terraces in Rustic and Santa Monica canyons are considered to have a low susceptibility to liquefaction. No subsurface information was available to quantitatively evaluate the liquefaction susceptibility of the marine terrace deposits. However, because of the elevated position of these deposits, it is expected that a shallow ground-water table would generally not develop except for brief periods immediately following intense rainstorms. Therefore, the marine terrace deposits are considered to have a low susceptibility to liquefaction.

Younger alluvium (Qal)

Younger alluvium mapped in southward-draining canyons contains layers of sand and silty sand described as loose to moderately dense. The few available grain-size distribution tests show that some of the sand is relatively clean, with some samples having less than 5% grains that pass the #200 sieve. Water is reported in most boreholes within 20 feet of the ground surface. Liquefaction analyses on the few SPT measurements in this material indicate that the shallow sands have factors of safety less than 1.0 for the anticipated earthquake shaking. Although some borehole logs from this unit show there exist relatively dense silty sands and sandy silts that would not liquefy, the limited subsurface information does not allow us to delineate low to moderate susceptibility areas within the mapped Qal. Therefore, Qal deposits are considered to have a high susceptibility to liquefaction throughout the Topanga Quadrangle.

Beach deposits (Qb)

Beach deposits along Santa Monica Bay are relatively thin but contain layers of loose to very loose clean sand and shallow ground water. Liquefaction analyses show that these deposits have factors of safety of less than 1.0 for the anticipated level of earthquake shaking and are, therefore, considered highly susceptible to liquefaction.

Artificial fill (af)

The deposit of hydraulic fill at Sunset Boulevard and Pacific Coast Highway contains layers of loose, saturated sand that have factors of safety of less than 1.0 in the projected earthquake shaking. On this basis, this man-made deposit is considered to have a high susceptibility to liquefaction.

Roadway fills for Pacific Coast Highway and Topanga Canyon Road generally consist of dense silts and clays and are probably not susceptible to liquefaction. Locally, however, they overlie potentially liquefiable beach deposits or alluvium. In those areas, the fill may be affected by liquefaction-induced deformation of the underlying material. Roadway fills underlain by bedrock are considered to have a low susceptibility to liquefaction.

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 Topanga Quadrangle, a peak acceleration of 0.60g resulting from an earthquake of magnitude 6.5 was 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 Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and others, 1985; National Research Council, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (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 factor of safety (FS) relative to liquefaction is: FS=CRR/CSR. 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 related structures. For a regional assessment DMG normally has a range of FS that results from the liquefaction analyses. The DMG liquefaction analysis program calculates an FS at each sample that has blow counts. The lowest FS in each borehole is used for that location. These FS vary in reliability according to the quality of the geotechnical data. These FS as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil are evaluated in order to construct liquefaction potential maps, which then directly translate to zones of required investigation.

Few borehole logs collected for Quaternary geologic units in the Topanga Quadrangle contained sufficient information to conduct liquefaction analyses using the Seed Simplified Procedure. Although ground-water levels are recorded in most boreholes, few borehole logs included records of SPTs, and none included all of the required information (SPTs, density, water content, percentage of silt and clay size grains). For those boreholes where SPTs were recorded, the liquefaction analysis was conducted using data extrapolated from other boreholes nearby or in similar materials. In areas where no SPTs were recorded, qualitative descriptions of loose or very loose sandy soils or of extensive caving into open boreholes were considered indicators of liquefaction susceptible sediments. For each borehole where ground water was recorded and SPTs conducted, information was entered in spreadsheet format along with density, moisture content, and grain size information (where available). These data were then processed through a program developed by DMG staff for liquefaction analysis by the Seed Simplified Procedure.

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 Topanga Quadrangle is summarized below.

Areas of Past Liquefaction

In the Topanga Quadrangle, no areas of documented historic liquefaction are known. Areas showing evidence of paleoseismic liquefaction have not been reported.

Artificial Fills

The hydraulic fill deposit at Sunset Boulevard and Pacific Coast Highway contains layers of loose to very loose clean sand that have a high susceptibility to liquefaction. This deposit has been included in the Liquefaction Zone. Roadway fills for Pacific Coast Highway and Topanga Canyon Road have a low liquefaction susceptibility and are not included in a liquefaction hazard zone except where the fill is underlain by highly susceptible beach and alluvium deposits.

Areas with Sufficient Existing Geotechnical Data

The dense consistency and deep ground water encountered in boreholes into the alluvial terrace deposits of the Pacific Palisades (Qtc) indicates a low susceptibility to liquefaction and this geologic unit has not been included in a liquefaction zone in this area.

Younger alluvial deposits (Qal) mapped in southward-draining canyons contain areas of high and moderate liquefaction susceptibility. Because the amount of subsurface data does not allow us to subdivide this geologic unit, all Qal has been included in the liquefaction zones.

Beach deposits (Qb), though relatively thin, are typically loose, saturated and highly susceptible to liquefaction and are included in the liquefaction zones.

Areas with Insufficient Existing Geotechnical Data

Alluvial terrace deposits (Qtc) west of the Pacific Palisades area are not represented with borehole information. In the central and western portions of the Topanga Quadrangle, these deposits directly overlie bedrock units, and are elevated above areas subjected to active coastal and stream processes. Ground water is not expected to remain for long periods in these deposits. Also, it is assumed that, in the subsurface, materials are similar to those described to the east -- that is, dense silts and stiff clays. For these reasons, the Qtc deposits in the central and western part of the quadrangle were not included in the liquefaction zones.

No subsurface information was available for the marine terrace deposits (Qtm). The geologic map (Yerkes and Campbell, 1994) describes them as clean, loose to weakly cemented sand, silty sand, and gravel. However, based on the elevated position of these deposits it was concluded that shallow ground water would be unlikely in these deposits, and they have not been included in the liquefaction zones.

Stream terrace deposits (Qts) in Rustic and Santa Monica canyons have only one geotechnical borehole to represent the subsurface conditions. The borehole log from this borehole indicates that ground water is deep (>45 feet) and the materials consist of interbedded gravels and clays. On the basis of this information, the susceptibility of Qts to liquefaction was rated as low, and it was excluded from the liquefaction zones.

Younger alluvium (Qal) in several canyons (Old Topanga, the lower portions of Topanga, Temescal, the upper reaches of Rustic and Sullivan canyons) has no geotechnical borehole information. It was assumed in these cases that the material characteristics and ground water conditions are similar to Qal deposits where subsurface information is available, and these deposits are included in the liquefaction zones.

ACKNOWLEDGMENTS

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

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

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) 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 Topanga 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 Topanga 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 Topanga 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 Topanga 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 Topanga Quadrangle covers approximately 45 square miles of Los Angeles County, primarily within the Santa Monica Mountains, 14 to 21 miles west of the Los Angeles Civic Center. The map includes parts of Los Angeles, Santa Monica, and Malibu. Topanga State Park covers a sizable eastern and central portion of the map area. The crest of the west-trending Santa Monica Mountain range lies just north of the quadrangle. Within the map area several large south-trending canyons extend from the range crest to

Santa Monica Bay. In the western half of the quadrangle, only a narrow beach separates the mountains from the ocean. On the east, within Santa Monica and Pacific Palisades, however, an alluviated terrace, ranging from 100 to 400 feet above sea level, slopes gently toward the sea and separates it from the steep mountain front.

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 Topanga 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 1947 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

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

GEOLOGY

Bedrock and Surficial Geology

For the Topanga Quadrangle, a recently compiled geologic map was obtained from the U.S. Geological Survey (USGS) in digital form (Yerkes and Campbell, 1994). In the field, observations were 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 landslides was noted.

The oldest geologic unit mapped in the Topanga Quadrangle is the Jurassic Santa Monica Slate (Yerkes and Campbell map symbols Jsm and Jsms), which underlies the northeast quarter of the quadrangle. Overlying the Jurassic slate is a sequence of Upper Cretaceous marine clastic rocks of the Tuna Canyon and Trabuco formations (conglomerate and sandstone with minor interbedded shale; Kt, Ktb, Ktc, Ktd, Kte, and Ktr).

Tertiary bedrock formations include the Paleocene and lower-middle Eocene Coal Canyon Formation (marine sandstone, siltstone, conglomerate, and algal limestone; Tcc, and Tls), the upper Eocene, Oligocene, and lower Miocene Sespe Formation (nonmarine sandstone, mudstone and conglomerate; Ts), the lower Miocene Vaqueros Formation (marine sandstone and interbedded nonmarine mudstone; Tv), middle Miocene formations and members of the Topanga Group (siltstone, sandstone, volcanics and tuff-bearing conglomerate; Tt, Ttc, Tcob, Tttc, Ttcc, Ttf, and Ttsp), upper Miocene Modelo Formation (interbedded marine sandstone and shaly mudstone; Tmo or Tm), and lower and upper Pliocene sedimentary rocks (marine siltstone, sandstone and shale; Tp, and QTs). Diabasic and basaltic volcanic rocks (Ti) intrude middle Miocene and older strata.

Quaternary deposits are in the canyon bottoms and along the southern and southeastern portions of the quadrangle. They are composed of upper Pleistocene marine and non-marine coastal terrace deposits, and upper Pleistocene and Holocene alluvium, colluvium, and beach deposits (Qtm, Qt/Qtc, Qdt, Qfp, Qb, Qc, and Qal). Landslides (Qls) are widespread in the Topanga Quadrangle. Also mapped in some areas are modern, artificial (man-made) fills (hf, ag, af).

Structural Geology

Accompanying the digital geologic map (Yerkes and Campbell, 1994) were digital files of associated geologic structural data, including bedding and foliation attitudes (strike and dip) and fold axes. We used the structural geologic information provided with the digital geologic map (Yerkes and Campbell, 1994) and from Dibblee (1992) to categorize areas of common stratigraphic dip direction and magnitude, similar to the method presented by Brabb (1983). The dip direction category was compared to the slope aspect (direction) category and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, and the bedding dip was greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area. This information was then used to subdivide mapped geologic units into areas where fine-grained and coarse-grained strengths would be used.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Topanga Quadrangle was prepared by field reconnaissance and analysis of stereo-paired aerial photographs. Also consulted during the mapping process were previous maps and reports that contain geologic and landslide data (McGill, 1989; Weber and Wills, 1983; and Weber and Frasse, 1984). Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map various 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 database was attributed. 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 Topanga Quadrangle geologic map were obtained from geotechnical and engineering geologic reports contained in Environmental Impact Reports and Hospital Review Project files at DMG. Other sources include reports published in professional journals, and summaries of "state of the practice" values for some widespread formations in the region provided by practicing professionals and local government geologists. The locations of rock and soil samples taken for shear testing 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.

TOPANGA QUADRANGLE
SHEAR STRENGTH GROUPINGS

	Formation Name	Number Tests	Mean/Median Phi	Mean/Median (Group phi) (deg)	Group Mean/Median C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Kt	5	39.5 / 40.8	39.0 / 38.4	263 / 270	Ktc, Kte, Ktr	38
	Ktb	2	38 / 38			Tls	
GROUP 2	Ti/Tcob	12	33.6 / 35	34.9 / 35.4	427 / 300	Tcos	35
	Ts	21	36.1 / 36.9			Ktd	
GROUP 3	Qal	5	34 / 32			Qdt, Qfp	
	af,	10	29 / 31.0			ag, hf	
	Qt, Qtm	19	29.6 / 30.0			Qts, Qb	
	Tm (fbc)	13	30.8 / 30				
	Tp	6	28.5 / 29.0			Ttsp, Tv	
	Ttf	12	31.9 / 33.5	31.8 / 32	448 / 400	Tttc	32
	Ttc (fbc)	14	31.5 / 34.0				
	Ttcc	5	33 / 32				
	Ttu	5	32.2 / 30				
	Tt	5	32.4 / 32				
GROUP 4	Qc	3	25.3 / 26				
	Qtm	2	24.8 / 24.8			QTs	
	Tcc	9	25.5 / 26	26.1 / 26	370 / 358	Tml	26
	Ttc (abc)	17	28.1 / 27.7				
	Jsm	8	27.4 / 27.8			Jsms	
	Tt (abc)	3	21 / 24				
GROUP 5	Qls, Qls?	6	14.5 / 14.0	16.7 / 15	725 / 500	Qly,Qlo	15
	Tm (abc)	11	18.0 / 17.5				

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength

Table 2.1. Summary of the Shear Strength Statistics for the Topanga Quadrangle.

SHEAR STRENGTH GROUPS FOR THE TOPANGA QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Kt	Ts	Qal	af, ag, hf	Qls
Ktb	Ti/Tcob	Qdt, Qfp	Qt/Qtc	Qls?
Ktc	Tcos	Tp	QTs	Qlo
Kte	Ktd	Ttf	Qc, Qtc	Qly
Ktr		Ttu	Qtm	Tm(abc)
Tls		Ttcc	Qfp	
		Tv	Qts	
		Ttsp	Tcc	
		Tm (fbc)	Tml	
		Tttc	Tt,Ttc (abc)	
			Jsm/Jsms	

Table 2.2. Summary of the Shear Strength Groups for the Topanga Quadrangle.

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 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.

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 Topanga 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; Cramer and Petersen, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.5 to 6.75
Modal Distance:	0 to 5.0 km
PGA:	0.4 to 0.5 g

The strong-motion record selected 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 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 0.21 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Topanga Quadrangle.

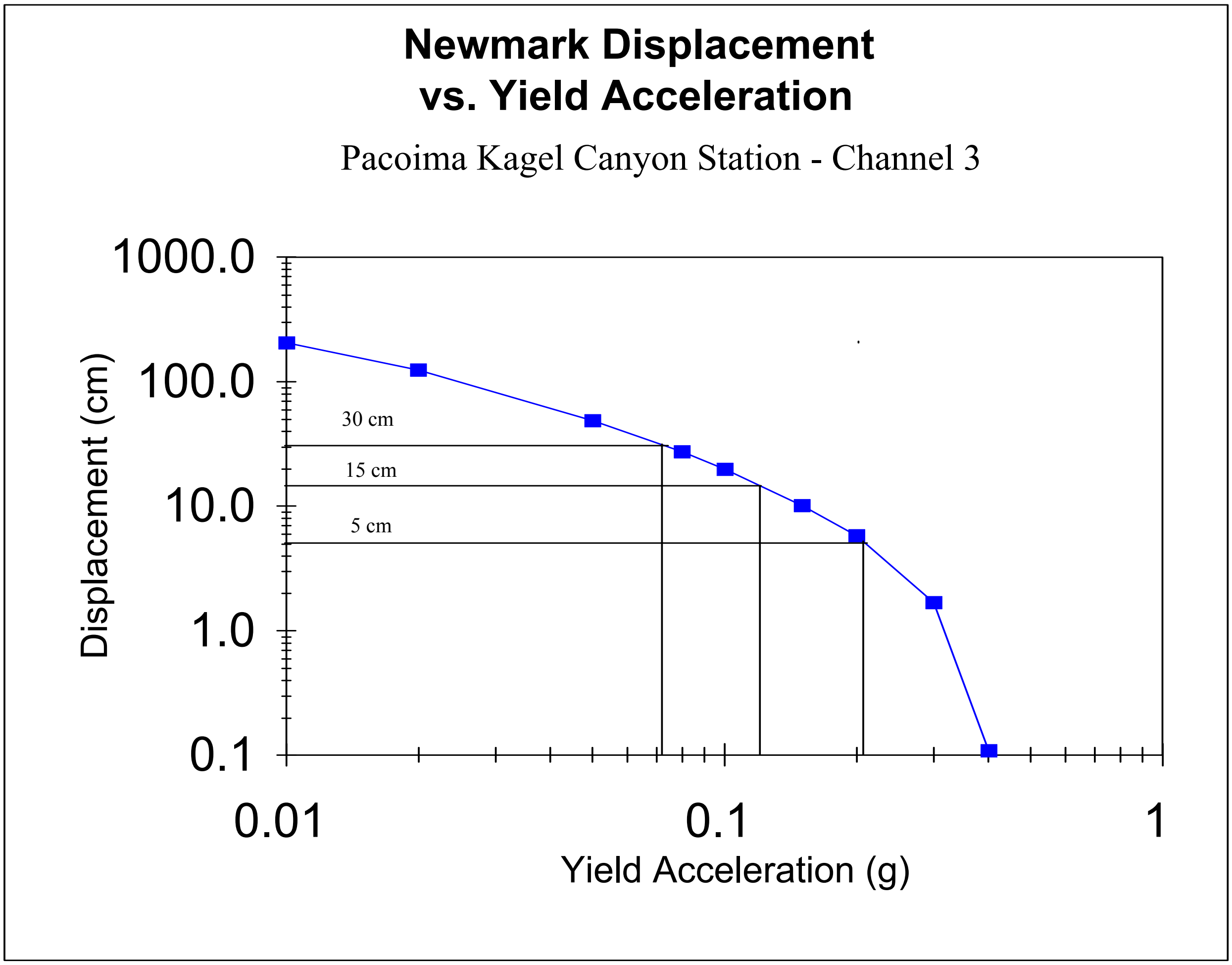

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Pacoima-Kagel Canyon Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake. Record from California Strong Motion Instrumentation Program (CSMIP) Station 24088.

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.

TOPANGA QUADRANGLE
HAZARD POTENTIAL MATRIX

Geologic Material Group	MEAN PHI	SLOPE CATEGORY I 0-13	II 14-19	III 20-25	IV 26-31	V 32-38	VI 39-45	VII 46-52	VIII 53-57	IX 58-63	X 64-68	XI >68 %
1	38	VL	VL	VL	VL	VL	VL	VL	L	L	M	H
2	35	VL	VL	VL	VL	VL	VL	L	L	M	H	H
3	32	VL	VL	VL	VL	VL	L	M	H	H	H	H
4	26	VL	VL	VL	VL	L	M	H	H	H	H	H
5	15	L	M	H	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Topanga 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, as follows:

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.

No earthquake-triggered landslides had been identified in the Topanga Quadrangle prior to the Northridge earthquake. The Northridge earthquake caused a number of relatively small, shallow slope failures in the Topanga Quadrangle (Harp and Jibson, 1995). Landslides attributed to the Northridge earthquake covered approximately 72 acres of land in the quadrangle, which is less than 1/2 of 1 percent of the total area covered by the map. Of the area covered by these Northridge earthquake landslides, 88% 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). Areas with a Very Low hazard potential 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 32 percent.

3. Geologic Strength Group 3 is included for all slopes steeper than 39 percent.

4. Geologic Strength Group 2 is included for all slopes steeper than 46 percent.

5. Geologic Strength Group 1 is included for all slopes greater than 53 percent.

This results in roughly 63 percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the Topanga 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 Larson and Charles Nestle, and at the City of Los Angeles with the assistance of Joseph Cobarrubias and Nicki Girmay. Additional shear test data for the Santa Monica Slate were provided by Joseph Cota of GeoSoils, Inc. Digital terrain data were provided by Randy Jibson of the U.S. Geological Survey. 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, Scott Shepherd and Oris Miller for their Geographic Information System operations support, and to Joy Arthur 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
Los Angeles County Department of Public Works, Material Engineering Division files.	180
Division of Mines and Geology, Environmental Impact Report files	10
Consultant Report on Pacific Palisades May 1958 landslide (Moran, Proctor, Mueser, and Rutledge)	25
Los Angeles City Geologist (J. Cobarrubias) file measured and assumed (state of the practice) values	35
Total number of tests used to characterize the units in the Topanga Quadrangle.	250

SECTION 3
GROUND SHAKING EVALUATION REPORT

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

By

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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.

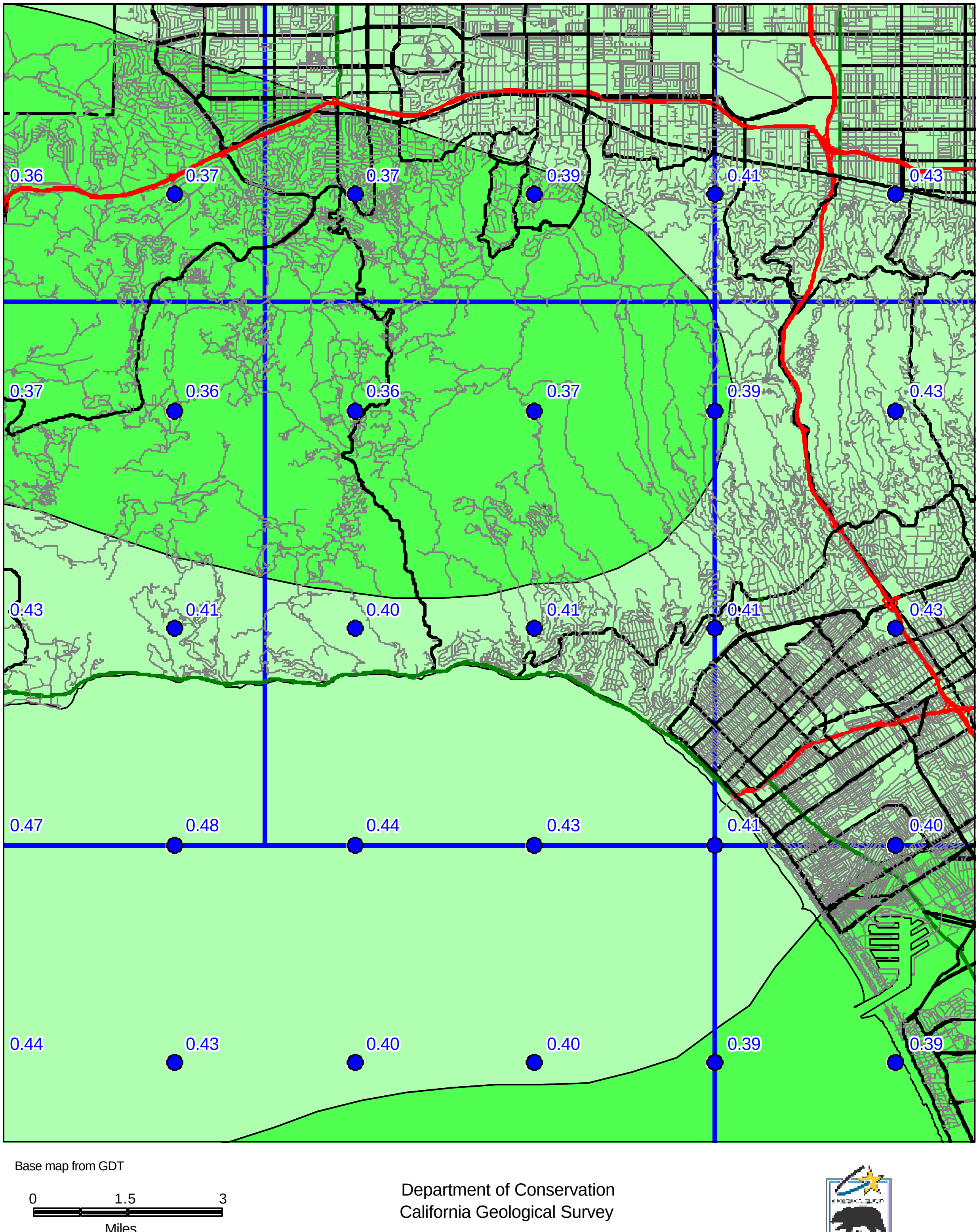
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

TOPANGA 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Department of Conservation
California Geological Survey

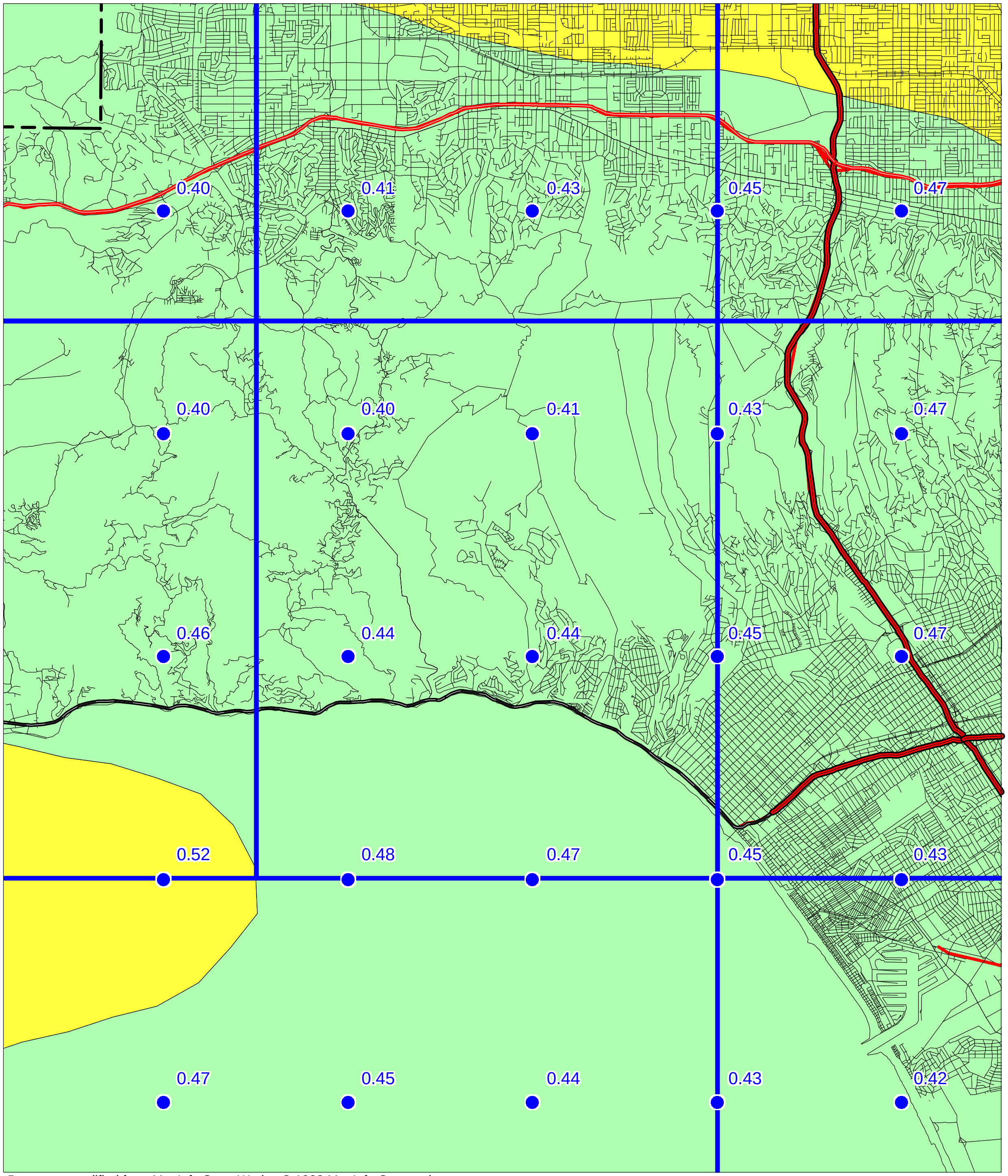
Figure 3.1

TOPANGA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

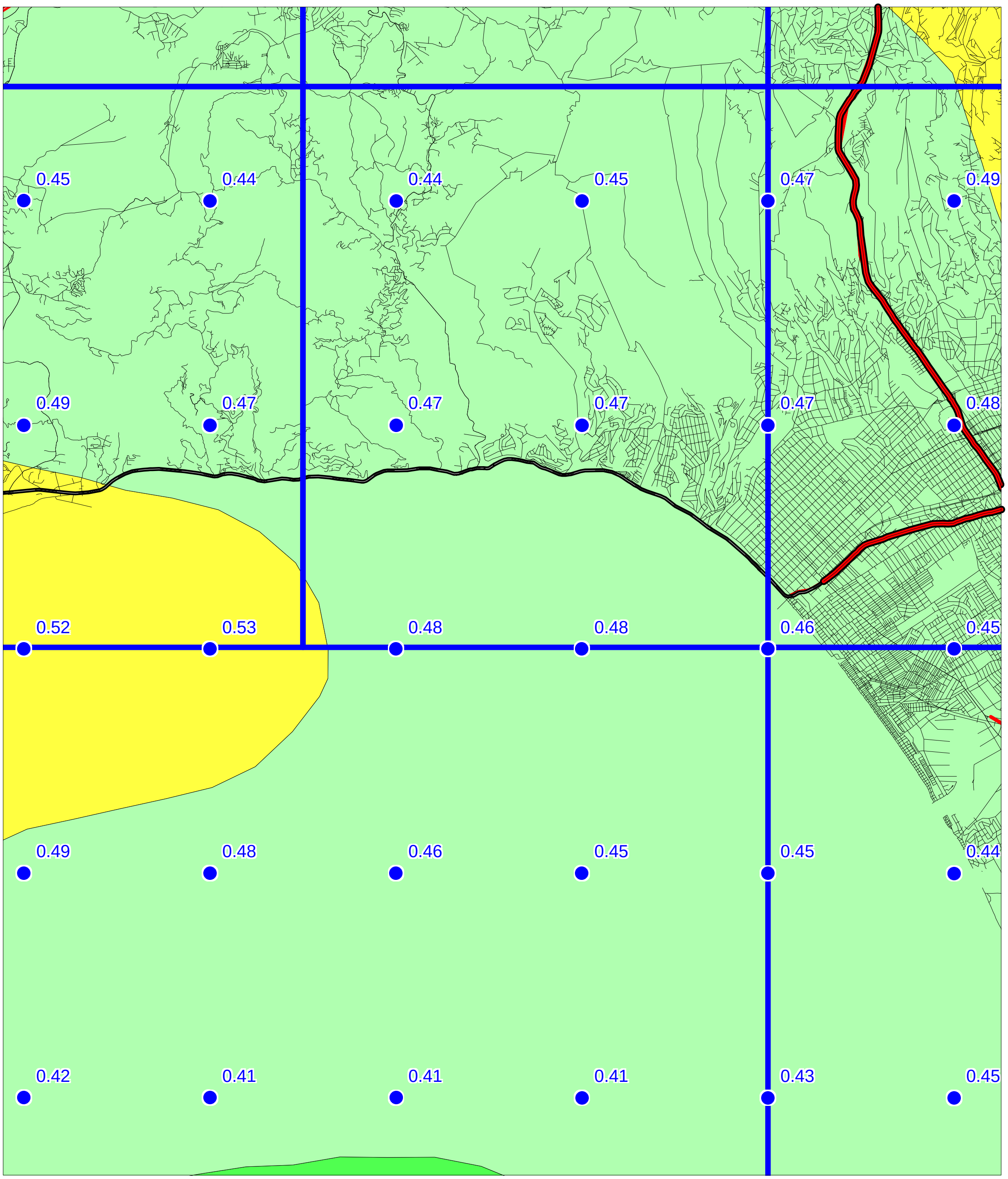
Figure 3.2

TOPANGA 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

0 2.5 5

Kilometers

Department of Conservation
Division of Mines and Geology

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.

TOPANGA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

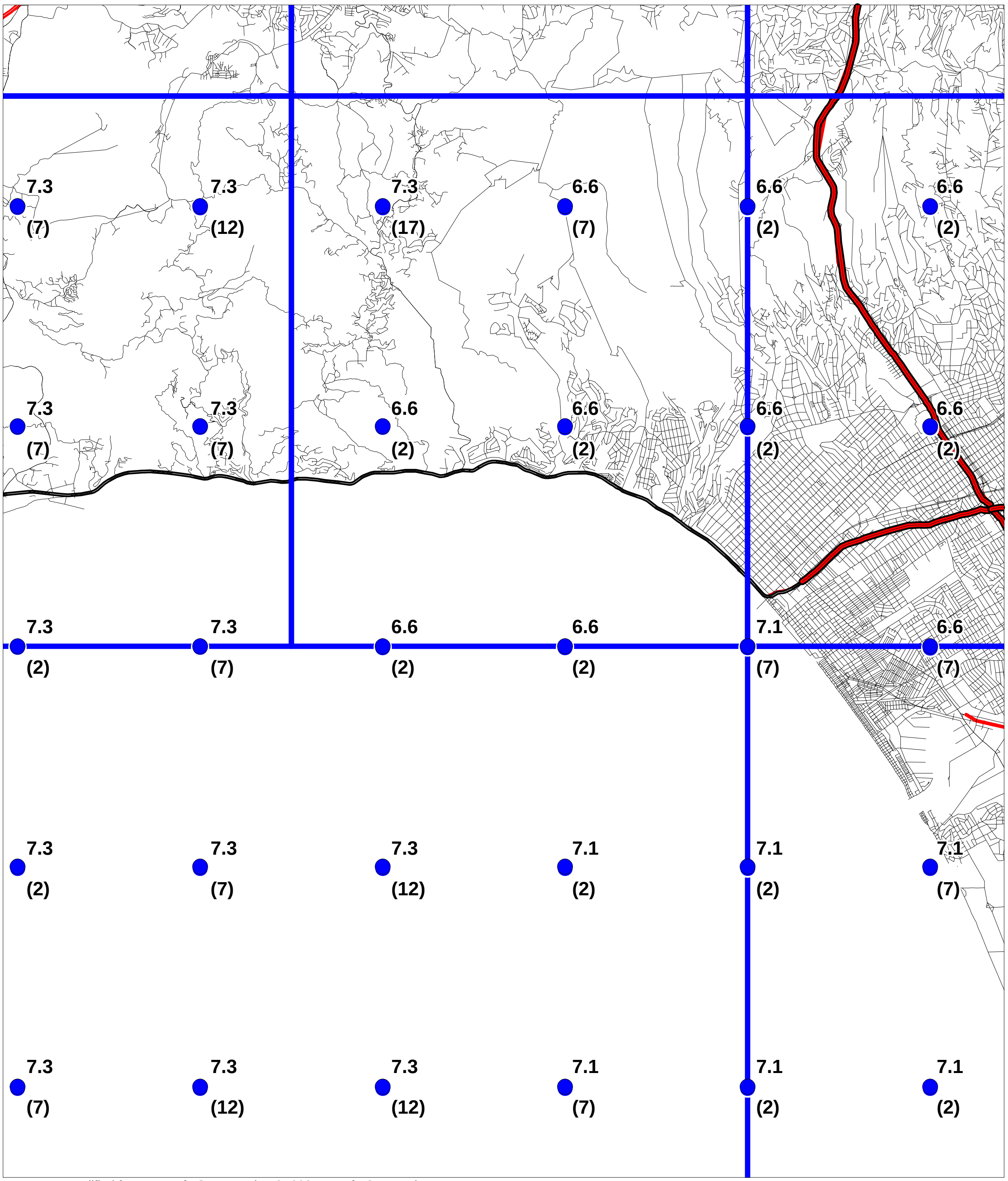
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)

(Distance (km))



0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

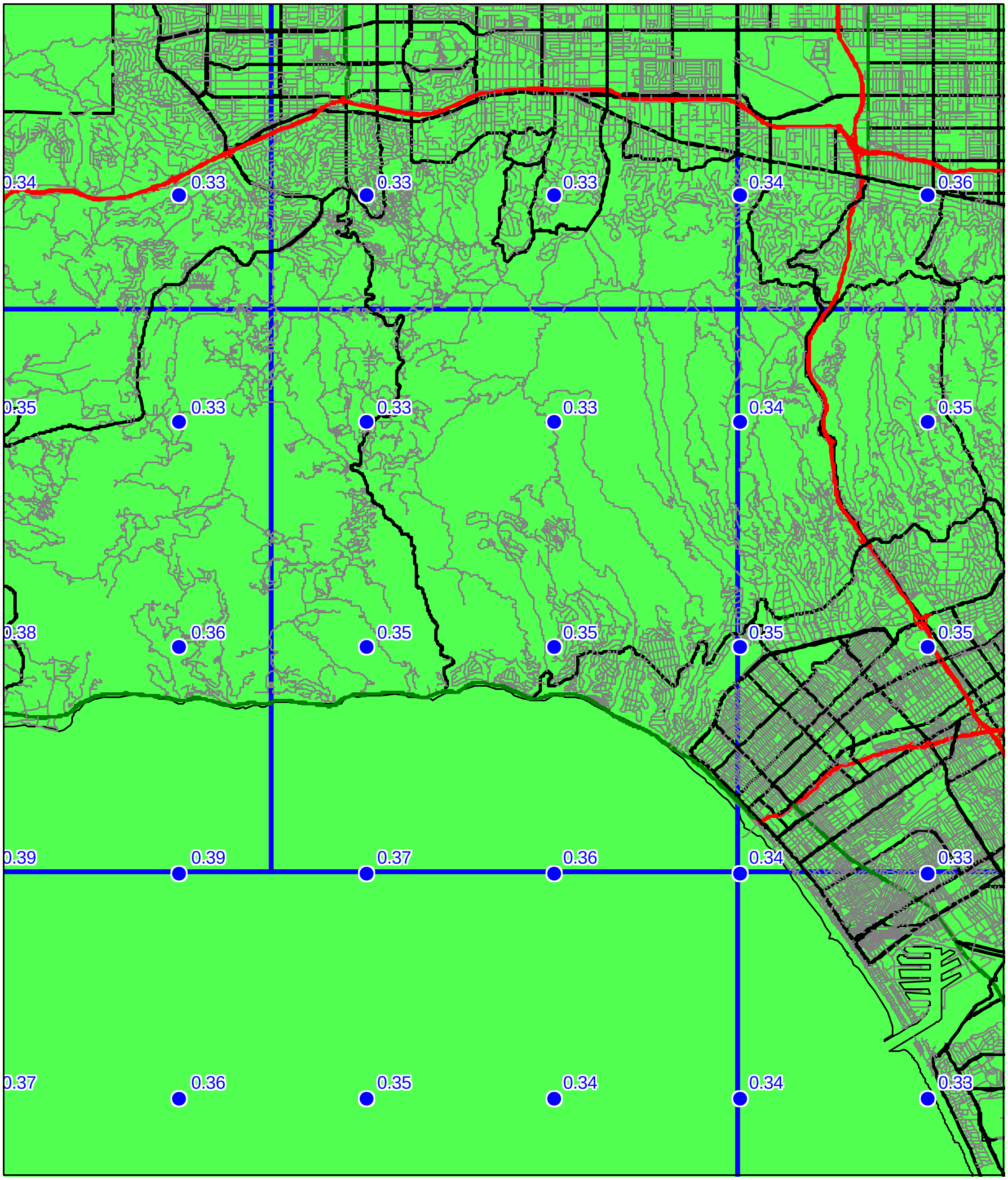
Figure 3.4

TOPANGA 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

0 1.5 3
Miles

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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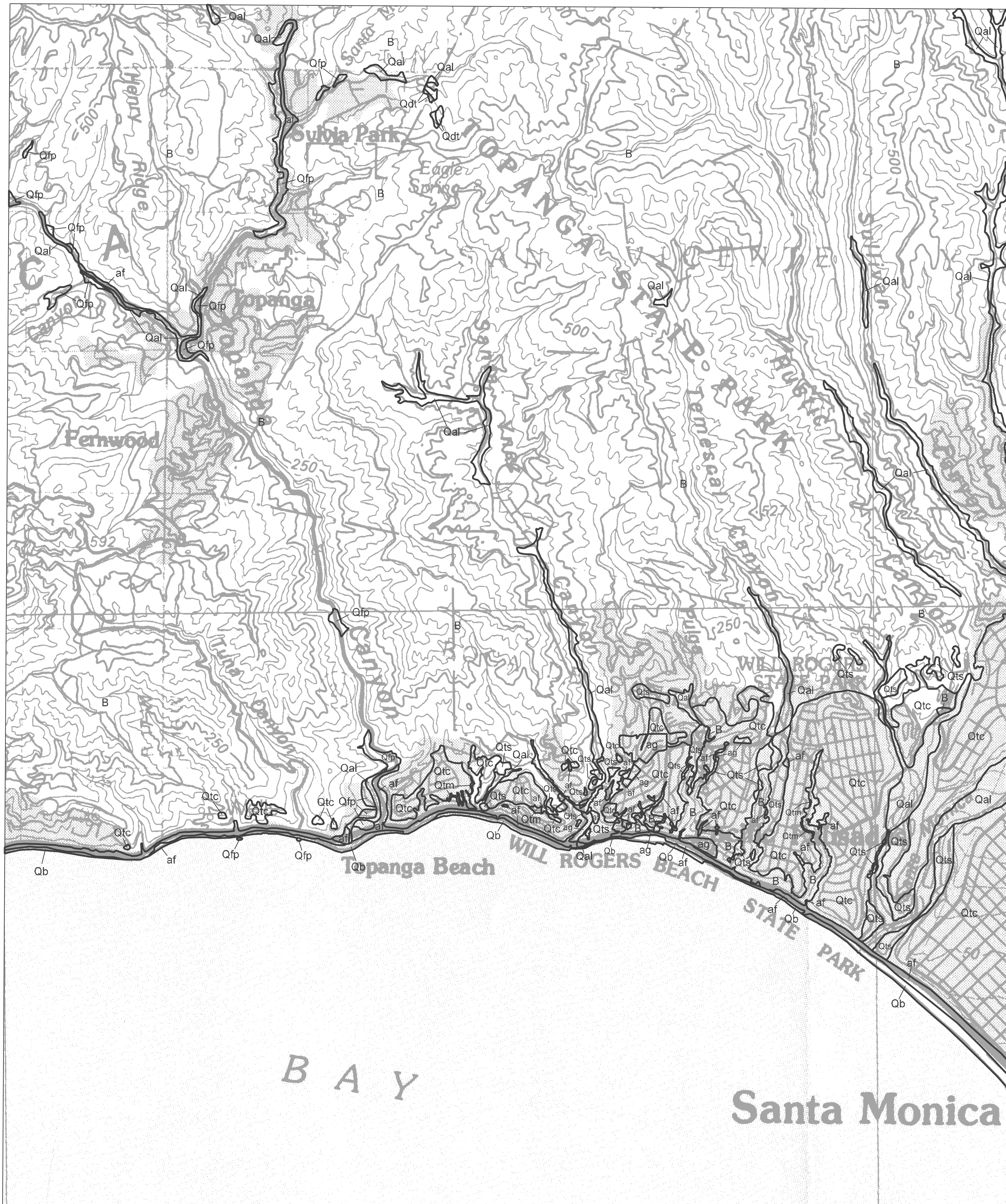
118°37'30"

37°07'30"



34°00'

118°30'

Plate 1.1 Quaternary Geologic Map of the Topanga 7.5–minute Quadrangle, California.

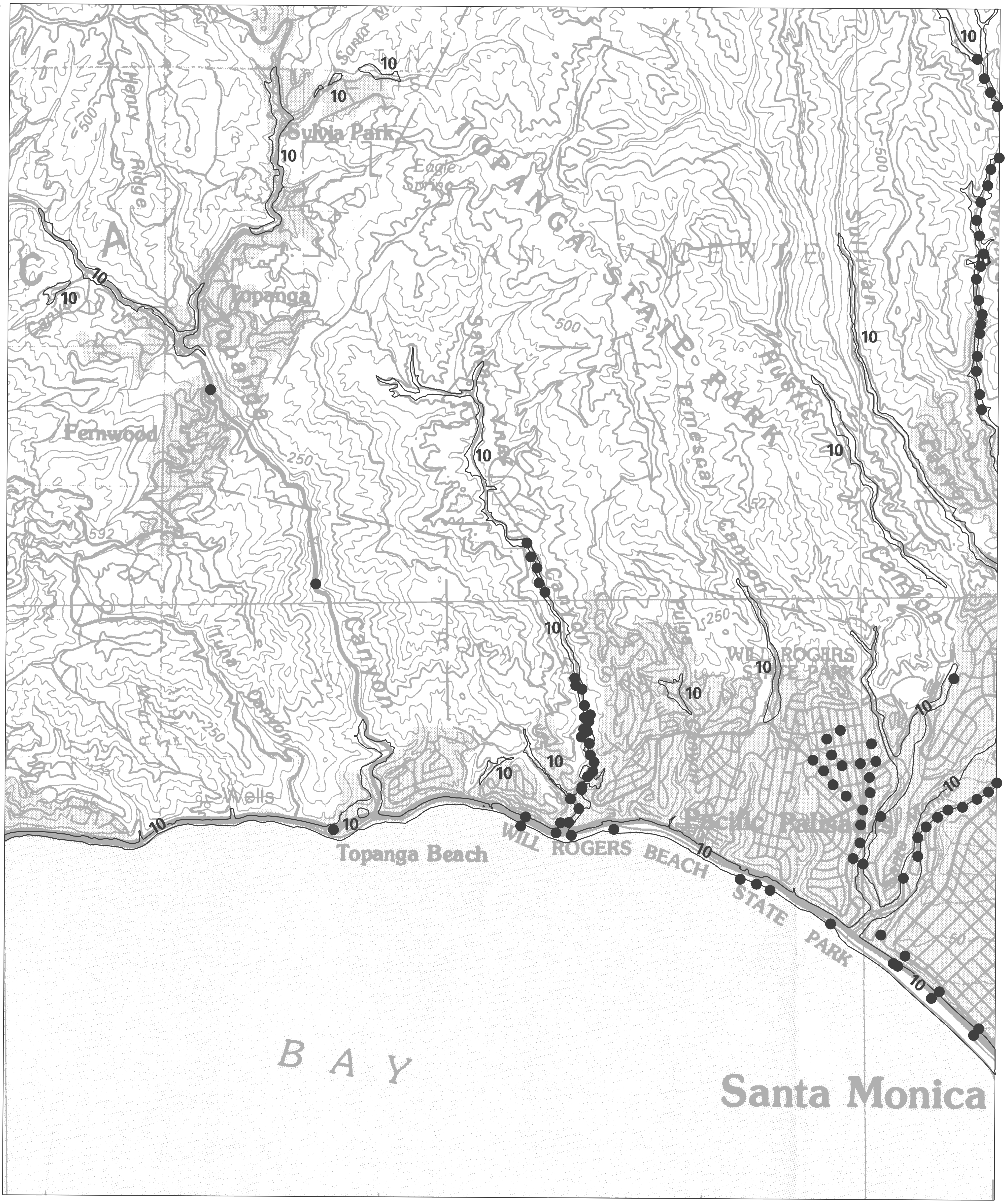
See Geologic Conditions section in report for descriptions of the units.
B = Pre–Quaternary bedrock.

ONE MILE

SCALE

118° 37'30"

34° 07'30"



34° 00'

118° 30'

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

Plate 1.2 Historically highest ground water contours and borehole locations, Topanga 7.5–minute Quadrangle.

● Borehole Site

30 — Depth to ground water in feet

ONE MILE

SCALE