SEISMIC HAZARD ZONE REPORT 010

SEISMIC HAZARD ZONE REPORT FOR THE YORBA LINDA 7.5-MINUTE QUADRANGLE, LOS ANGELES, ORANGE AND SAN BERNARDINO COUNTIES, CALIFORNIA

2005

DEPARTMENT OF CONSERVATION
California Geological Survey

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CONTENTS

EXECUTIVE SUMMARY vii

INTRODUCTION 1

SECTION 1: LIQUEFACTION EVALUATION REPORT 3

Liquefaction Zones in the Yorba Linda 7.5-Minute Quadrangle, Los Angeles, Orange, and San Bernardino Counties California 3

INTRODUCTION 3

PURPOSE 3
BACKGROUND 4
METHODS SUMMARY 4
SCOPE AND LIMITATIONS 5

PART I 6

PHYSIOGRAPHY 6
GEOLOGY 7
ENGINEERING GEOLOGY 8
GROUND WATER 10

PART II 10

LIQUEFACTION POTENTIAL 10
LIQUEFACTION SUSCEPTIBILITY 11
LIQUEFACTION OPPORTUNITY 11
LIQUEFACTION ZONES 13

ACKNOWLEDGMENTS 15

REFERENCES 16

SECTION 2: EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT . 19

Earthquake-induced landslide Zones in the Yorba Linda 7.5-Minute Quadrangle, Los Angeles, Orange, and San Bernardino Counties California 19

INTRODUCTION 19

PART I 22

PHYSIOGRAPHY 22
GEOLOGY 23
ENGINEERING GEOLOGY 24

PART II 27

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL 27
EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE 30

ACKNOWLEDGMENTS 31

REFERENCES 31

AIR PHOTOS 33

APPENDIX A: Sources of Rock Strength Data 33

SECTION 3: GROUND SHAKING EVALUATION REPORT.................................. 35

Potential Ground Shaking in the Yorba Linda 7.5-Minute Quadrangle,
Los Angeles, Orange, and San Bernardino Counties, California 35

INTRODUCTION 35

EARTHQUAKE HAZARD MODEL 36

APPLICATIONS FOR LIQUEFACTION AND EARTHQUAKE-INDUCED
LANDSLIDE HAZARD ASSESSMENTS..41

USE AND LIMITATIONS..44

ILLUSTRATIONS

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record from the 17 January 1994 Northridge, California Earthquake. 28

Figure 3.1. Yorba Linda 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10 percent exceedance in 50 years peak ground acceleration (g)—Firm rock conditions. 38

Figure 3.2. Yorba Linda 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10 percent exceedance in 50 years peak ground acceleration (g)—Soft rock conditions. 39

Figure 3.3. Yorba Linda 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10 percent exceedance in 50 years peak ground acceleration (g)—Alluvium conditions. 40

Figure 3.4. Yorba Linda 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10 percent exceedance in 50 years peak ground acceleration—Predominant earthquake..........42

Figure 3.5 Yorba Linda 7.6-Minute Quadrangle and portions of adjacent quadrangles, 10 percent exceedance in 50 years magnitude-weighted pseudo-peak acceleration for alluvium- Liquefaction opportunity………………………………………………… …43

Table 1.1 Quaternary map units used in the Yorba Linda Quadrangle 7

Table 1.2 Quaternary map units used in the Yorba Linda 7.5 Minute Quadrangle and their geotechnical characteristics and liquefaction susceptibility. 9

Table 2.1. Summary of the Shear Strength Statistics for the Yorba Linda Quadrangle. 26

Table 2.2. Summary of Shear Strength Groups for the Yorba Linda Quadrangle. 26

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Yorba Linda Quadrangle. Values in the table show the range of slope gradient (expressed as percent slope) corresponding to calculated Newmark displacement ranges from the design earthquake for each material strength group. 29

Plate 1.1. Quaternary geologic map of the Yorba Linda 7.5-minute Quadrangle, California 47

Plate 1.2. Depth to historically highest ground water and locations of boreholes used in this study, Yorba Linda 7.5-minute Quadrangle, California 48

Plate 2.1. Landslide inventory, shear test sample locations, and areas of significant grading, Yorba Linda 7.5-Minute Quadrangle, California …………………………………………49

EXECUTIVE SUMMARY

Note: This report and the accompanying Official Seismic Hazard Zones Map for the Yorba Linda Quadrangle are revisions of the official map released on April 15, 1998 and Seismic Hazard Zone Report 010 revised in 2001. The revisions consist of the addition of a "zone of required investigation" within San Bernardino County, minor zone boundary changes in several canyons and drainages, and modification of Plates 1.1 and 1.2.

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Yorba Linda 7.5-Minute Quadrangle, Los Angeles, Orange and San Bernardino Counties, California. The map, which covers approximately 60 square miles at a scale of 1 inch = 2,000 feet, displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides.

The Yorba Linda Quadrangle encompasses land in eastern Los Angeles, northern Orange and western San Bernardino counties. The Orange County portion of the quadrangle includes parts of the cities of Anaheim, Brea, Fullerton, Placentia and Yorba Linda near the southern edge of the quadrangle that lie on a series of overlapping terraces at the northern margin of the Santa Ana River floodplain. The northern two-thirds of the quadrangle is made up of the Puente and Chino Hills, which are crossed by Brea, Tonner, Carbon and Telegraph canyons. Within Los Angeles County, most of Diamond Bar and a small part of the City of Industry occur in the northern part of the quadrangle. The Orange Freeway (State Highway 57) is near the northwestern corner of the quadrangle. The west-trending Pomona Freeway (State Highway 60) cuts across the northern part and Imperial Highway provides access to cities in the southern part of the quadrangle. Residential and commercial developments cover the floor of the valley south of the Puente Hills. In recent years residential development has taken place mainly along the lower slopes of the Puente Hills and adjacent to the major canyons.

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

Liquefaction zones in the Yorba Linda Quadrangle are restricted to stream channels, their adjacent floodplains, some canyons bottoms, and a small alluviated area in the northwest corner. Earthquake-induced landslide zones, however, encompass more than 35 percent of the map because geologic units forming most of the hilly terrain covering the northern two-thirds of the quadrangle are characterized by relative low rock strength.

How to view or obtain Seismic Hazard Zone maps and associated Evaluation Reports

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports, and additional information on seismic hazard zone mapping in California are available on the California Geological Survey's Internet page: http://www.conservation.ca.gov/CGS/index.htm and are available for reference at CGS offices in Sacramento, San Francisco, and Los Angeles. Seismic Hazard Zone Reports summarize the development of the hazard zone map for each quadrangle and contain background documentation for use by site investigators and local government reviewers.

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

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

Note: BPS Reprographic Services does not sell Seismic Hazard Zone Evaluation Reports. The reports must be downloaded from the CGS's website or viewed at one of the above CGS district offices or on the CGS website.

INTRODUCTION

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Yorba Linda 7.5-Minute Quadrangle. The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. City, county, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997).

The text of this report is on the Internet at
http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

The Act directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria, which were published in 1992 as CGS Special Publication 118, were revised in 2004. They provide detailed standards for mapping regional liquefaction and landslide hazards. The Act also directed CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

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

In April 2004, significant revisions of liquefaction zone mapping criteria relating to application of historically high ground-water level data in desert regions of the state were adopted by the SMGB. These modifications are reflected in the revised CGS Special Publication 118 which is available on the Internet at
http://gmw.consrv.ca.gov/shmp/webdocs/sp118_revised.pdf

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

SECTION 1:
LIQUEFACTION EVALUATION REPORT

LIQUEFACTION ZONES IN THE YORBA LINDA 7.5-MINUTE QUADRANGLE, LOS ANGELES, ORANGE, AND SAN BERNARDINO COUNTIES CALIFORNIA

By
Ralph C. Loyd and Cynthia L. Pridmore

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Note: This report and the accompanying Preliminary Seismic Hazard Zones Map for the Yorba Linda Quadrangle are revisions of the official map released on April 15, 1998 and Seismic Hazard Zone Report 010 revised in 2001. The revisions consist of the addition of a "zone of required investigation" within San Bernardino County, minor zone boundary changes in several canyons and drainages, and modification of Plates 1.1 and 1.2.

INTRODUCTION

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. City, county, and state agencies are directed to use seismic hazard zone maps developed by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the

California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

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

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge 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 50 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, including areas in the Yorba Linda 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

- Historically high, near-surface ground-water maps were constructed
- Geotechnical data were analyzed to evaluate liquefaction potential of deposits
- Information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2004).

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 Yorba Linda Quadrangle consist mainly of alluviated valleys, floodplains and canyons. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

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

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

PART I

PHYSIOGRAPHY

The Yorba Linda Quadrangle encompasses about 60 square miles in eastern Los Angeles, northern Orange and western San Bernardino counties in the eastern part of the Los Angeles Basin. Portions of the cities of Anaheim, Brea, Fullerton, Placentia and Yorba Linda lie near the southern edge of the quadrangle on a series of overlapping terraces at the northern margin of the Santa Ana River floodplain. The northern two-thirds of the quadrangle is made up of the Puente and Chino Hills, which are crossed by Brea, Tonner, Carbon and Telegraph canyons. These major canyons and many smaller intervening ones dissect the upland area and provide drainage toward the southwest. The City of Industry is in the extreme northwestern corner of the quadrangle and lies in the floodplain of San Jose Creek. Diamond Bar, the community of Rowland Heights and scattered unincorporated developments occur along the canyons, slopes and ridge tops. The City of Chino Hills and Chino Hills State Park and Carbon Canyon Regional Park occupy the rolling hills in the central and eastern portions of the quadrangle. Carbon Canyon Dam, an earth-filled embankment, was completed in 1961 and is operated by the U.S. Army Corps of Engineers, Los Angeles District.

The study area lies within the northwestern most part of the Santa Ana Mountains in the Peninsular Ranges geomorphic province of southern California. The Whittier Fault transects the quadrangle near the southwestern base of the Puente Hills. The Puente and Chino Hills comprise the upland area north of the fault, where elevations range from 500 feet along the fault to 1,685 feet at Gillman Peak near the east central portion of the quadrangle.

The Orange Freeway (State Highway 57) follows Brea Canyon near the northwest corner of the quadrangle. The west-trending Pomona Freeway (State Highway 60) cuts across the northern part of the quadrangle following the San Jose Creek drainage. Imperial Highway (State Highway 90) provides access to cities in the southern portion of the quadrangle, and Carbon Canyon Road (State Highway 142) provides access though the Chino Hills.

Residential and commercial development covers the lower lying areas. Newer residential development over the past twenty-five years has taken place along the slopes of the Puente Hills and adjacent to major canyons, along Brea Canyon, along the terraces in the southeast corner of the quadrangle, and within the Chino Hills. Many of these developments involved substantial hill-slope grading and individual lot-drainage preparation prior to construction.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. To evaluate the areal and vertical distribution of shallow Quaternary deposits in the Yorba Linda Quadrangle, CGS compiled and digitized the geology of Yerkes (1972; northern half of quadrangle) and Tan and others (1984; southern half of quadrangle). Digital geology of the Yorba Linda Quadrangle was also obtained from the Southern California Areal Mapping Project (SCAMP), a provisional digital geologic-map database generated during compilation of the Santa Ana 30' x 60' quadrangle (Morton and Kennedy, 1989; Morton, 1998; Morton and others, 1999). Additional sources of geologic and engineering geology information used in this evaluation included Morton and others (1973) and Sprotte and others (1980). Limited field reconnaissance was conducted to confirm the location of geologic contacts, map recently modified ground surfaces, observe properties of near-surface deposits and characterize the surface expression of individual geologic units.

Quaternary alluvial deposits cover approximately 35 percent of the quadrangle. Plate 1.1 shows the distribution of these deposits, with minor modifications along bedrock/Quaternary contacts. The distribution of these deposits was used in combination with other data to evaluate liquefaction susceptibility and develop the Seismic Hazard Zone Map. These deposits are summarized in Table 1.1 and discussed below.

Surficial sediments mapped in the quadrangle consist of a series of older Quaternary alluvial fan deposits (Qvof, Qlh) along the southern margin of the Puente Hills and younger Quaternary alluvial fan materials (Qyf) associated with the creek and canyon areas, including slope wash and debris flow deposits in the Rowland Heights area. Modern wash deposits (Qyw) also occur within the smaller creek and canyon areas. The remainder of the quadrangle consists of pre-Quaternary claystone, siltstone, sandstone and conglomerate that belong to the Pliocene Fernando Formation and the late Miocene Puente Formation. These are discussed in the earthquake-induced landslide portion (Section 2) of this report.

Map Unit	Environment of Deposition	Age
Qyw	Alluvial wash	Holocene to Late Pleistocene
Qyf	Alluvial fan	Holocene to Late Pleistocene
Qvof	Alluvial fan	Mid to Early Pleistocene
Qlh **(La Habra Formation)**	Alluvial fan	Early Pleistocene

Table 1.1 Quaternary map units used in the Yorba Linda Quadrangle

Structural Geology

Within this portion of Southern California, the active San Andreas Fault system distributes shearing across a complex system of primarily northwest-trending faults. Among these, the Whittier Fault cuts diagonally across the Yorba Linda Quadrangle along the base of the southwestern slopes of the Puente and Chino Hills.

ENGINEERING GEOLOGY

As stated above, soils that are generally susceptible to liquefaction are mainly late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. Deposits that contain saturated loose sandy and silty soils are most susceptible to liquefaction. Lithologic descriptions and soil test results reported in geotechnical borehole logs provide valuable information regarding subsurface geology, ground-water levels, and the engineering characteristics of sedimentary deposits. For this investigation, about 124 borehole logs were collected from the files of the California Department of Transportation (Caltrans); the Department of Water Resources; the Orange County Department of Health, Environmental Management Agency, Water District, and Flood Control; the Los Angeles County Department of Public Works; the California Regional Water Quality Control Board - Los Angeles Region; the Fullerton Fire Department; and the geologic consulting firm of Leighton and Associates in Irvine, California. Data from 124 borehole logs were entered into a CGS geotechnical GIS database (Table 1.2). This investigation also included a review of geotechnical reports submitted by lead agencies to the State Geologist as required by the Seismic Hazards Mapping Act of 1990 [Public Resources Code, Chapter 7.8, Division 2, section 2697(a)].

Of particular value in liquefaction evaluations are logs that report the results of downhole standard penetration tests. Standard Penetration Tests (SPTs) provide a standardized measure of the penetration resistance of geologic deposits and are commonly used as an index of soil density. This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil at the bottom of a borehole at chosen intervals while drilling. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 2004). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differs from that specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts are normalized to a common-reference, effective-overburden pressure of 1 atmosphere (approximately 1 ton per square foot) and a hammer efficiency of 60 percent using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

Younger Alluvium (Qyf, Qyw)

Young Quaternary alluvial fan deposits (Qyf) occur in the area around Placentia. The southwest-draining fan was produced by Carbon Creek, which changed its course in prehistoric time and has since abandoned the fan, probably a result of late Quaternary uplift of the Coyote Hills just west of the quadrangle boundary. Logs of boreholes drilled within the fan generally record an abundance of loose to moderately dense clean and silty sands.

Geologic Map Unit	Sediment Type	Consistency	Age	Liquefaction Susceptibility*
Qyw	silty sand, sand, gravelly sand	loose	Holocene to Late Pleistocene	yes
Qyf	clay, silt, silty sand, sand, gravelly sand	very loose to dense	Holocene to Late Pleistocene	yes
Qvof	clay, silt, sand	mod. loose to very dense	Mid to Early Pleistocene	not likely
Qlh	mudstone, sandstone, conglomerate	dense	Pleistocene	not likely

(*when saturated)

Table 1.2 Quaternary map units used in the Yorba Linda 7.5 Minute Quadrangle and their geotechnical characteristics and liquefaction susceptibility.

Young alluvial sediments deposited on gently sloping erosional surfaces in the Rowland Heights area (Qyf), consist of alternating beds of clay, silt, silty fine sand, fine- to medium-grained sand and, locally, scattered gravel. Geomorphology and borehole log lithologic descriptions indicate that the material, in large part, was deposited as slope wash and debris flows originating from the surrounding mountains. Water-well logs indicate that total thickness of these deposits range from a few feet to about 80 feet. Although geotechnical borehole data for these areas are limited, lithologic descriptions and penetration tests indicate most of the sediment layers contain a high clay content (clay, clayey silt, and clayey sand) that is generally well compacted. However, relatively loose sand layers do appear in some of the borehole logs.

The slope sediments of the Rowland Heights area interfinger with fluvial sediments deposited within the flood plain of San Jose Creek, whose channel is just north of the quadrangle boundary. Borehole logs collected from both Caltrans and private consultants show that in the Yorba Linda Quadrangle, the San Jose Creek flood plain deposits are composed of alternating beds of clay, silt and fine- to coarse-grained, loose sand.

Boreholes drilled in the Diamond Bar area penetrate alluvium (Qyf) deposited on floor of Brea Canyon. These near-surface sediments are described as being composed mainly of clayey silt, silty fine-grained sand, fine- to medium-grained sand, and gravely sand, generally loose to moderately dense. The available borehole log data and similar bedrock lithology suggest that the alluvium deposited in nearby canyons (Qyf, Qyw), as well as in the narrow channels (Qyf) along the south margin of the quadrangle, consists of similar material, predominately loose to moderately dense silt and fine- to medium-grained sand deposits, along with scattered gravel.

GROUND WATER

Ground-water conditions were investigated in the Yorba Linda Quadrangle to evaluate the depth to saturated materials. Saturation reduces the effective normal stress of near-surface sediment, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). CGS compiles and interprets ground-water data to identify areas characterized by, or anticipated to have in the future, near-surface saturated soils.

Natural hydrologic processes and human activities can cause ground-water levels to fluctuate over time. Therefore, it is impossible to predict depths to saturated soils during future earthquakes. One method of addressing time-variable depth to saturated soils is to establish an anticipated high ground-water level based on historical ground-water data. In areas where ground water is either currently near-surface or could return to near-surface levels within a land-use planning interval of 50 years, CGS constructs regional contour maps that depict these levels. Plate 1.2 depicts areas characterized by present or anticipated shallow ground water within the Yorba Linda Quadrangle.

For purposes of seismic hazard zonation, "near-surface" means at a depth less than 40 feet. The evaluation is based on first-encountered unconfined ground water noted in geotechnical borehole and water-well logs. Water depths from boreholes known to penetrate confined aquifers were not utilized.

Plate 1.2 shows that historical shallow water conditions (less than 40 feet depth) have existed in several areas of the Yorba Linda Quadrangle, namely, in the Industry-Rowland Heights area within and adjacent to the San Jose Creek flood plain, upper portions of the Carbon Creek fan, and within the various canyons and incised channels where near-surface water conditions exist during wet periods.

PART II

LIQUEFACTION POTENTIAL

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

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the SMGB (DOC, 2004).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

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

CGS's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. CGS's qualitative relations between susceptibility and geologic map unit are summarized in Table 1.2.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10 percent probability of exceedance over a 50-year period (DOC, 2004). The earthquake magnitude used in

CGS's analysis is the magnitude that contributes most to the calculated PGA for an area.

Across the Yorba Linda Quadrangle, PGAs for alluvium conditions range from 0.43 to 0.50 g resulting from earthquakes of magnitude 6.8 to 7.0 (Figures 3.3 and 3.4). The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10 percent in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). These values represent a slightly wider range from those used in the previously released report for Yorba Linda (2001) but did not result in modifications to preexisting liquefaction zones. See the ground motion section (3) of this report for discussion of liquefaction opportunity.

Quantitative Liquefaction Analysis

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997; Youd and others, 2001). Using the Seed-Idriss Simplified Procedure, one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, CGS's analysis uses the Idriss magnitude-scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. CGS uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site-specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures.

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

Of the 121 geotechnical borehole logs reviewed and entered into the GIS data base (Plate 1.2), 64 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 SMGB (DOC, 2004). 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 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 subsurface data are not sufficient for quantitative evaluation of liquefaction hazard. Within such areas, zones may be delineated by geologic criteria as follows:
    a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.10 g and the anticipated depth to saturated soil is less than 40 feet; or
    b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the

M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.20 g and the anticipated depth to saturated soil is less than 30 feet; or

c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 g and the anticipated depth to saturated soil is less than 20 feet.

Application of these criteria allows compilation of liquefaction zones of required investigation, which are useful for preliminary evaluations, general land-use planning and delineation of special studies zones (Youd, 1991).

Areas of Past Liquefaction

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

Artificial Fills

In the Yorba Linda Quadrangle, artificial fill (af) large enough to show at the scale of mapping (Plate 1.1) consist of engineered fill for the Carbon Canyon Dam. Other engineered fills within the study area include flood control levees, elevated highways, and mass grading for cut and fill projects. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depend on soil conditions in underlying strata. Non-engineered fills are commonly loose and uncompacted, and the material varies in size and type.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to quantitatively analyze liquefaction potential using the Seed-Idriss Simplified Procedure. In the Yorba Linda Quadrangle borehole logs from Holocene alluvial deposits contain sediment layers that may liquefy under the expected earthquake loading where saturated within 40 feet of the surface (Plate 1.2). These areas are delineated as zones of required investigation for liquefaction hazard and include portions of San Jose Creek floodplain, Rowland Heights, Brea Canyon, Carbon Creek fan, Carbon Canyon and smaller tributaries.

Areas with Insufficient Existing Geotechnical Data

Younger alluvium deposited in canyon and incised channel areas generally lack adequate geotechnical borehole information. The soil characteristics and ground-water conditions in these cases are assumed to be similar to deposits where subsurface information is available. The canyon and incised stream channel deposits, therefore, are delineated as zones of required investigation for reasons presented in criteria item 4a above.

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SECTION 2: EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

EARTHQUAKE-INDUCED LANDSLIDE ZONES IN THE YORBA LINDA 7.5-MINUTE QUADRANGLE, LOS ANGELES, ORANGE, AND SAN BERNARDINO COUNTIES CALIFORNIA

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Note: This report and the accompanying Preliminary Seismic Hazard Zones Map for the Yorba Linda Quadrangle are revisions of the official map released on April 15, 1998 and Seismic Hazard Zone Report 010 revised in 2001. Among the revisions are rezoning of the Los Angeles and Orange county areas, the inclusion of San Bernardino County, and modification of Plates 1.1 and 1.2.

INTRODUCTION

Purpose

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

California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

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

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

Background

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

Methods Summary

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

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area

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

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink and Real, 1996; McCrink, 2001) and adopted by the State Mining and Geology Board (DOC, 2004).

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 Yorba Linda 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 Yorba Linda 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

The Yorba Linda Quadrangle encompasses about 60 square miles in eastern Los Angeles, northern Orange and western San Bernardino counties in the eastern part of the Los Angeles Basin. Portions of the cities of Anaheim, Brea, Fullerton, Placentia and Yorba Linda lie near the southern edge of the quadrangle on a series of overlapping terraces at the northern margin of the Santa Ana River floodplain. The northern two-thirds of the quadrangle is made up of the Puente and Chino Hills, which are crossed by Brea, Tonner, Carbon and Telegraph canyons. These major canyons and many smaller intervening ones dissect the upland area and provide drainage toward the southwest. The City of Industry is in the extreme northwestern corner of the quadrangle. Diamond Bar, the community of Rowland Heights and scattered unincorporated developments occur along the canyons, slopes and ridge tops. The City of Chino Hills and Chino Hills State Park and Carbon Canyon Regional Park occupy the rolling hills in the central and eastern portions of the quadrangle.

The study area lies within the northwestern part of the Santa Ana Mountains in the Peninsular Ranges geomorphic province of southern California. The Whittier Fault transects it near the southwestern base of the foothills. The Puente and Chino hills make up the upland area north of the fault, where elevations range from 500 feet along the fault to 1,685 feet at Gillman Peak near the east central portion of the quadrangle.

The Orange Freeway (State Highway 57) follows Brea Canyon near the northwest corner of the quadrangle. The west-trending Pomona Freeway (State Highway 60) cuts across the northern part of the quadrangle following the San Jose Creek drainage and the Imperial Highway provides access to cities in the southern portion of the quadrangle.

Residential and commercial development covers the floor of the valley south of the Whittier Fault. New residential development over the past twenty years has taken place mainly along the lower slopes of the Puente Hills and adjacent to the major canyons. Most of residential developments in the Diamond Bar area along Brea Canyon and along the terraces in the southeast corner of the quadrangle were built as large-scale developments using substantial hill-slope grading and individual lot drainage preparation prior to construction.

Digital Terrain Data

A digital representation of the topography in the Yorba Linda Quadrangle was used in the preparation of the earthquake-induced landslide zones of required investigation. The digital topographic, or terrain, data was used to calculate slope gradient, which is an essential part of the evaluation of slope stability under earthquake conditions.

For the Yorba Linda Quadrangle, a digital elevation model (DEM) was obtained from the National Oceanic and Atmospheric Administration (NOAA). This DEM was derived from an airborne interferometric synthetic aperture radar (IfSAR) DEM flown and processed in the winter of 2002/2003 by EarthData International under contract with NOAA (NOAA, 2003). The DEM has a 3-meter horizontal resolution and a 1.08-meter vertical accuracy. An interferometric radar DEM is prone to creating false topography where tall buildings, metal structures, or trees are present. To minimize the effects of the cultural and vegetation "noise" in the DEM, it was sub-sampled to a coarser 10-meter resolution and processed through a smoothing algorithm. A slope map was made from the resampled DEM using a third order, finite difference, center-weighted algorithm (Horn, 1981). The manner in which the slope map was used to prepare the zone map will be described in subsequent sections of this report. When the zone map was completed an additional inspection step was performed in which the zones were displayed on orthophotography and shaded relief images to identify and remove areas where zones were created on the basis of false topography.

GEOLOGY

Bedrock and Surficial Geology

The geologic map for the Yorba Linda Quadrangle was extracted from the updated digital geologic map of the 1:100,000 scale Santa Ana sheet (Morton, 2004). 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 slope failures was noted. The geologic unit descriptions below are taken from Morton (2004).

The oldest rock units exposed in the Yorba Linda Quadrangle belong to the late Miocene Puente Formation, which underlies the Puente and Chino hills. The Puente Formation is comprised of four members: the Sycamore Canyon (Tpsc), Yorba (Tpy), Soquel (Tpsq) and La Vida (Tplv) members. The Sycamore Canyon member includes a coarse-grained sub-member, Tpscc. The La Vida and Yorba members are composed of similar rock types consisting of limy siltstone, and interbedded sandstone. The Soquel Member is thick-bedded, medium- to coarse-grained sandstone with interbedded siltstone. The Sycamore Canyon Member is characterized by pebble conglomerate interbedded with thin sandstone beds and massive siltstone. The coarse grained sub-member is predominantly conglomerate.

The bedrock underlying the terraces south of the Whittier Fault consists of the Tertiary Fernando Formation (Tfu), a coarse-grained sub-member (Tfuc), and lower sub-members (Tfl, Tflc); and the Pleistocene La Habra Formation (Qlh). The undifferentiated Fernando formation is composed of thick-bedded to massive marine sandstone, conglomerate and locally thin-bedded mudstone and siltstone. The lower Fernando Formation is interbedded siltstone and sandstone with lenticular conglomerate layers. The coarse grained sub-members of both units are composed of conglomerate. The La Habra Formation is primarily nonmarine mudstone, fluvial sandstone, and conglomerate.

Quaternary deposits are located in the canyon bottoms and the low valley areas in the upper middle portion of the quadrangle. They are comprised of Holocene and late

Pleistocene alluvium and colluvium (Qvofa), floodplain, stream terrace deposits, and Holocene to modern alluvium (Qya, Qyf), artificial fill (Qaf), and landslides (Qls, Qyls). These materials are poorly sorted and crudely layered. Minor amounts of alluvium occur along the bottom of all the canyons in the Puente and Chino hills. A more detailed discussion of the Quaternary deposits in the Yorba Linda Quadrangle can be found in Section 1.

Structural Geology

The most prominent structural feature of the Yorba Linda Quadrangle is the Whittier Fault zone. The zone is comprised of two or more major faults separating younger Puente and Fernando formation strata on the south side from older Puente on the north (Durham and Yerkes, 1964). Durham and Yerkes also mapped minor east-trending faults in the hills north of the Whittier Fault. Major anticlines in the quadrangle include the Soquel Canyon Anticline, Diamond Bar Anticline, and the Yorba Anticline. Rapid uplift and associated folding along the Whittier fault zone has created over-steepened unstable slopes exacerbating landslide formation in the weak rocks of the Puente Formation.

Landslide Inventory

The evaluation of earthquake-induced landsliding requires an up-to-date and complete picture of the previous occurrence of landsliding. CGS geologists compiled the existing landslides in the Yorba Linda Quadrangle from published regional landslide maps (Tan, 1988) and prepared a landslide inventory by combining field observations, analysis of aerial photos (see Air Photos in References) and interpretation of landforms on current and older topographic 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.

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

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear strength data used in both the present and previous evaluations were originally obtained from consultant reports on file with the Los Angeles County Department of Public Works, Materials Engineering Division, and geotechnical sections of Environmental Impact Reports on file at the CGS Sacramento office (Appendix A). Additional shear-strength data have been collected from the City of Chino Hills and used in preparing the present report. The locations of rock and soil samples taken for shear testing within the Yorba Linda Quadrangle are shown on Plate 2.1. Shear tests from the adjoining Prado Dam, Ontario and San Dimas quadrangles were used to augment data for Tertiary geologic formations Tpsc, Tps and Tpy. Data for Quaternary units within the Yorba Linda Quadrangle were augmented with data from the Orange Quadrangle.

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 or median) phi values for each geologic map unit and corresponding strength groups are summarized in Table 2.1. For each geologic strength group (Table 2.2) in the map area, the average shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Table 2.1 and Table 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

Existing Landslides

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

The strength characteristics of existing landslides (Qls, Qyls) 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. We collect and compile 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 included in our compilation. Six shear tests of landslide slip surface materials from within the Yorba Linda Quadrangle and five shear tests from within the Prado Dam Quadrangle constitute the eleven tests shown in Table 2.1.

YORBA LINDA QUADRANGLE SHEAR STRENGTH GROUPS							
	Formation Name	**Number Tests**	**Mean/Median Phi (deg)**	**Mean/Median Group Phi (deg)**	**Mean/Median Group C (psf)**	**No Data: Similar Lithology**	**Phi Values Used in Stability Analyses**
GROUP 1	Qaf Tpsc	20 58	32/33 31/32	31/32	539/403	Tpscc	32
GROUP 2	Qya Qyfa Tfl Tpsq	8 19 2 72	30/31 30/31 30 30	30	370/275	Qlh, Qyf Qyf3a, Qyfsa Tflc, Tfu Tfuc	30
GROUP 3	Qvofa Tpy	25 65	28/29 28	28/29	343/223	Qvofsa Tplv	28
GROUP 4	Qls	11	13/14	13/14	291/210	Qyls	14

Formation name abbreviations from Morton (2004)

Table 2.1. Summary of the Shear Strength Statistics for the Yorba Linda Quadrangle.

SHEAR STRENGTH GROUPS FOR THE YORBA LINDA 7.5-MINUTE QUADRANGLE			
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**
af	Qlh	Qvofa	Qls
Tpsc	Qoa	Qvofsa	Qyls
Tpscc	Qyf	Tplv	
	Qyf3a	Tpy	
	Qyfa		
	Qyfsa		
	Qywa		
	Tfl		
	Tflc		
	Tfu		
	Tfuc		
	Tpsq		

Table 2.2. Summary of Shear Strength Groups for the Yorba Linda Quadrangle

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

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

Modal Magnitude:	6.8 to 7.0
Modal Distance:	3.0 to 17 km
PGA:	0.41 to 0.51 g

The strong-motion record selected selected for the slope stability analysis in the Yorba Linda Quadrangle was the Channel 3 (north 35 degrees east horizontal component) University of Southern California Station #14 recording from the magnitude 6.7 Northridge earthquake (Trifunac and others, 1994). This record had a source to recording site distance of 8.5 km and a peak ground acceleration (PGA) of 0.59 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 CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.08, 0.13 and 0.23g. 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 Yorba Linda Quadrangle.

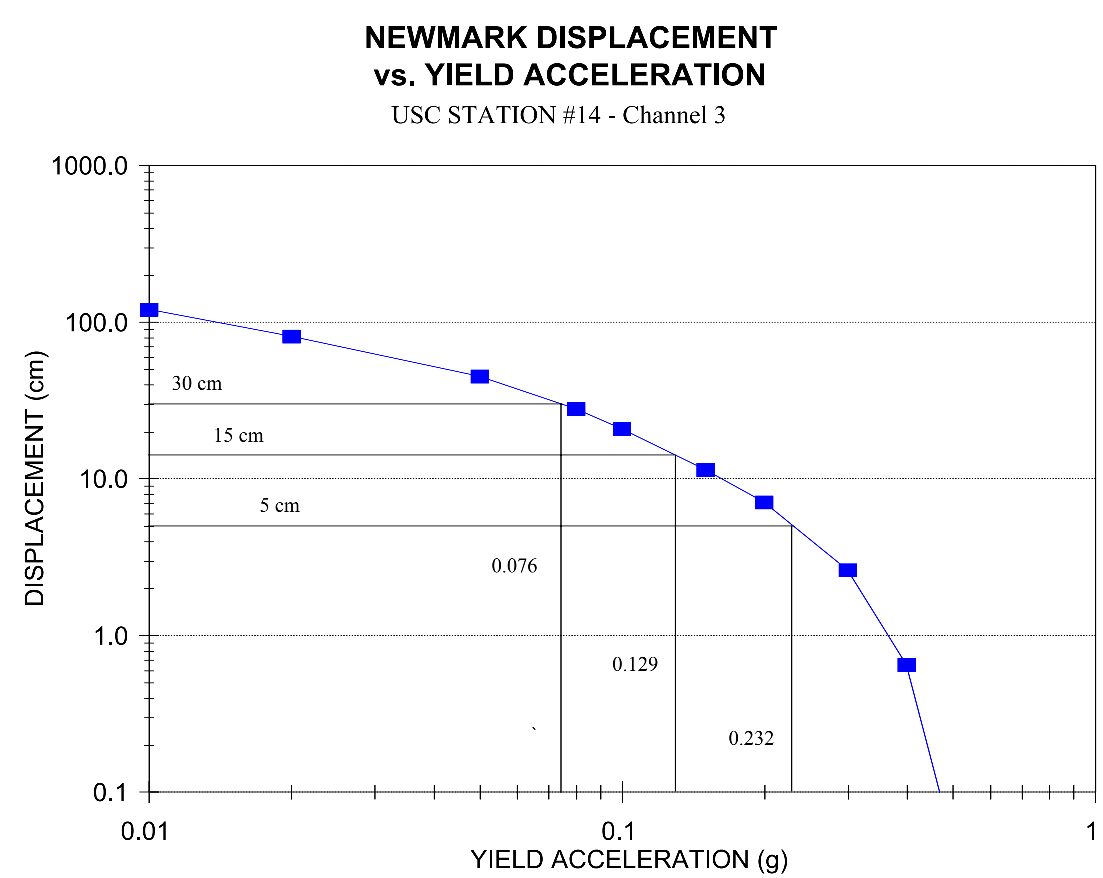

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record from the 17 January 1994 Northridge, California Earthquake.

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 0.08g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned.
2. If the calculated yield acceleration fell between 0.08g and 0.13g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned.
3. If the calculated yield acceleration fell between 0.13g and 0.23g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned.
4. If the calculated yield acceleration was greater than 0.23g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned.

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

YORBA LINDA QUADRANGLE HAZARD POTENTIAL MATRIX				
Geologic Material Strength Group (Average Phi)	HAZARD POTENTIAL (Percent Slope)			
	Very Low	Low	Moderate	High
1 (32)	0 to 38%	38 to 48%	48 to 55%	>55%
2 (30)	0 to 34%	34 to 44%	44 to 50%	>50%
3 (28)	0 to 28%	28 to 40%	40 to 46%	>46%
4 (14)	NA	0 to 12%	12 to 18%	>18%

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

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2004). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

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

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

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

Geologic and Geotechnical Analysis

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

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

1. Geologic Strength Group 4 is included in the zone for all slope gradients. (Note: The only geologic units included in Geologic Strength Group 4 are Qls and Qyls, existing landslides.)
2. Geologic Strength Group 3 is included for all slopes steeper than 28 percent.
3. Geologic Strength Group 2 is included for all slopes steeper than 34 percent.
4. Geologic Strength Group 1 is included for all slopes steeper than 38 percent.

This results in 32 percent of the quadrangle area lying within the earthquake-induced landslide hazard zone for the Yorba Linda Quadrangle.

ACKNOWLEDGMENTS

The authors thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Assistance and geotechnical review were provided by Iraj Poormand and Kathy Black from Leighton and Associates. Geotechnical material strength data were also collected from the County of Los Angeles, Department of Public Works, Division of Materials Engineering. Geotechnical data for the update was collected in the City of Chino Hills with the assistance of Susie Keen, Records Coordinator for the city. Special thanks to California Geological Survey employees Barbara Wanish for Geographic Information System operations support, and for designing and plotting the graphic displays associated with the zone map and the evaluation report, Lisa Chisholm for preparing the landslide attribute tables for the landslide inventory, and Tim McCrink for DEM processing and analysis.

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APPENDIX A

SOURCES OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Chino Hills (new data)	166
Yorba Linda Quadrangle (previous study)	50
Leighton and Associates	
City of Los Angeles	10
Adjacent Quadrangles (various sources)	54
Total Number of Shear Tests	**280**

SECTION 3:
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Yorba Linda 7.5-Minute Quadrangle, Los Angeles, Orange, and San Bernardino Counties, California

By

Mark D. Petersen*, Chris H. Cramer*, Geoffrey A. Faneros, Charles R. Real, and Michael S. Reichle

California Department of Conservation
California Geological Survey

***U.S. Geological Survey**

INTRODUCTION

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

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (DOC, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

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

EARTHQUAKE HAZARD MODEL

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

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

The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

YORBA LINDA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS

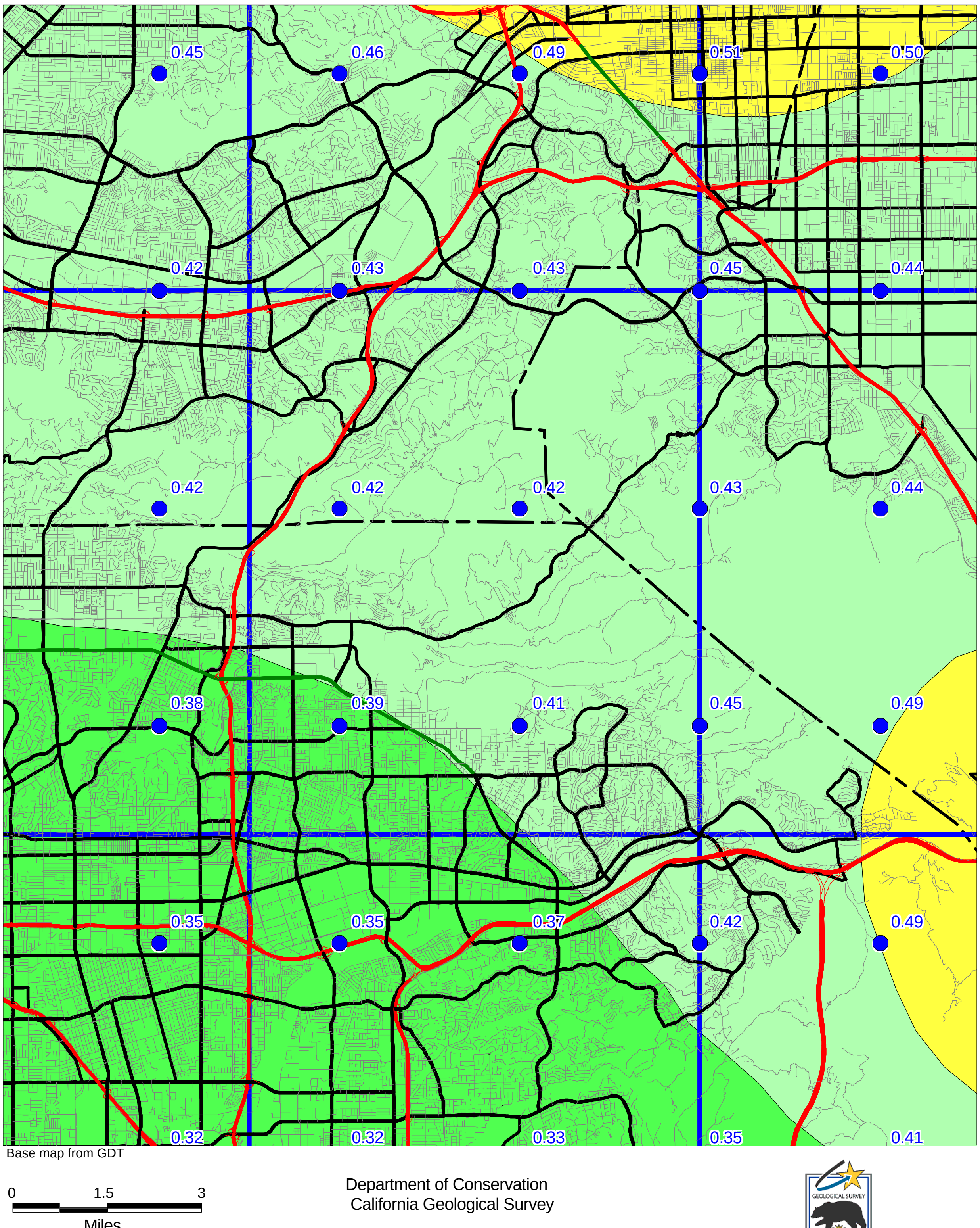

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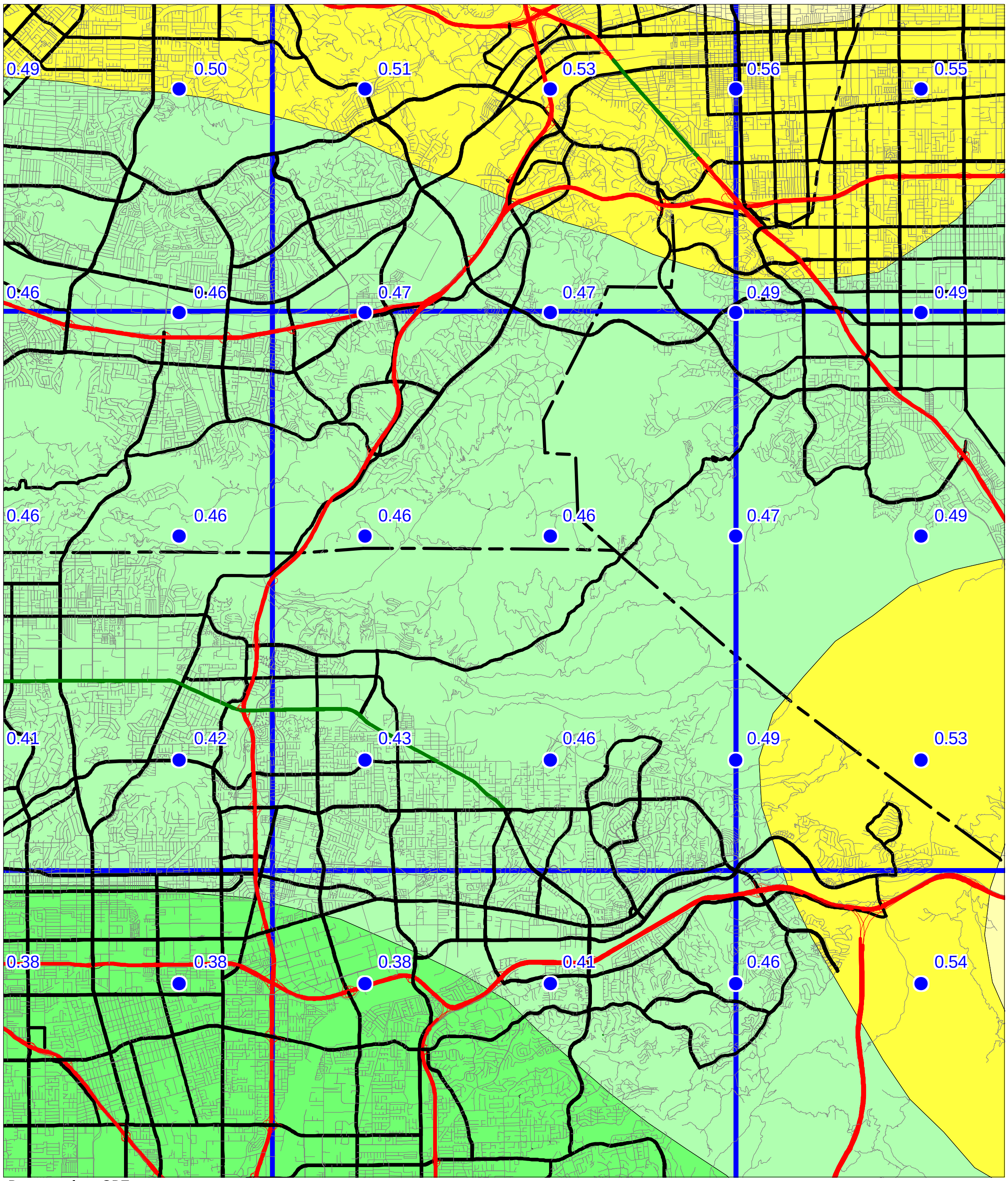
Figure 3.1

YORBA LINDA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map from GDT

0 1.5 3

Miles

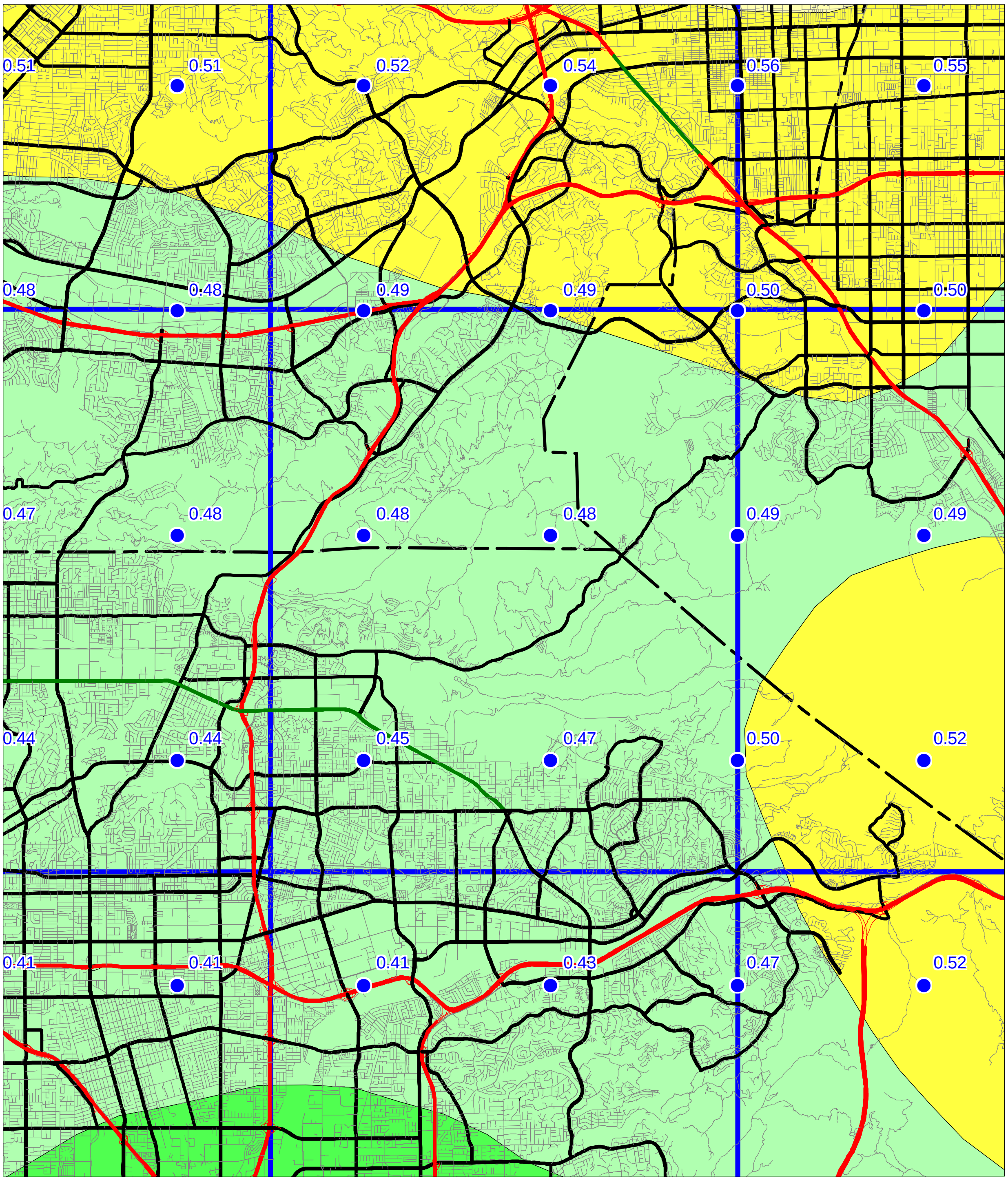
Department of Conservation
California Geological Survey

Figure 3.2

YORBA LINDA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

ALLUVIUM CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
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Figure 3.3

APPLICATIONS FOR LIQUEFACTION AND EARTHQUAKE-INDUCED LANDSLIDE HAZARD ASSESSMENTS

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

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

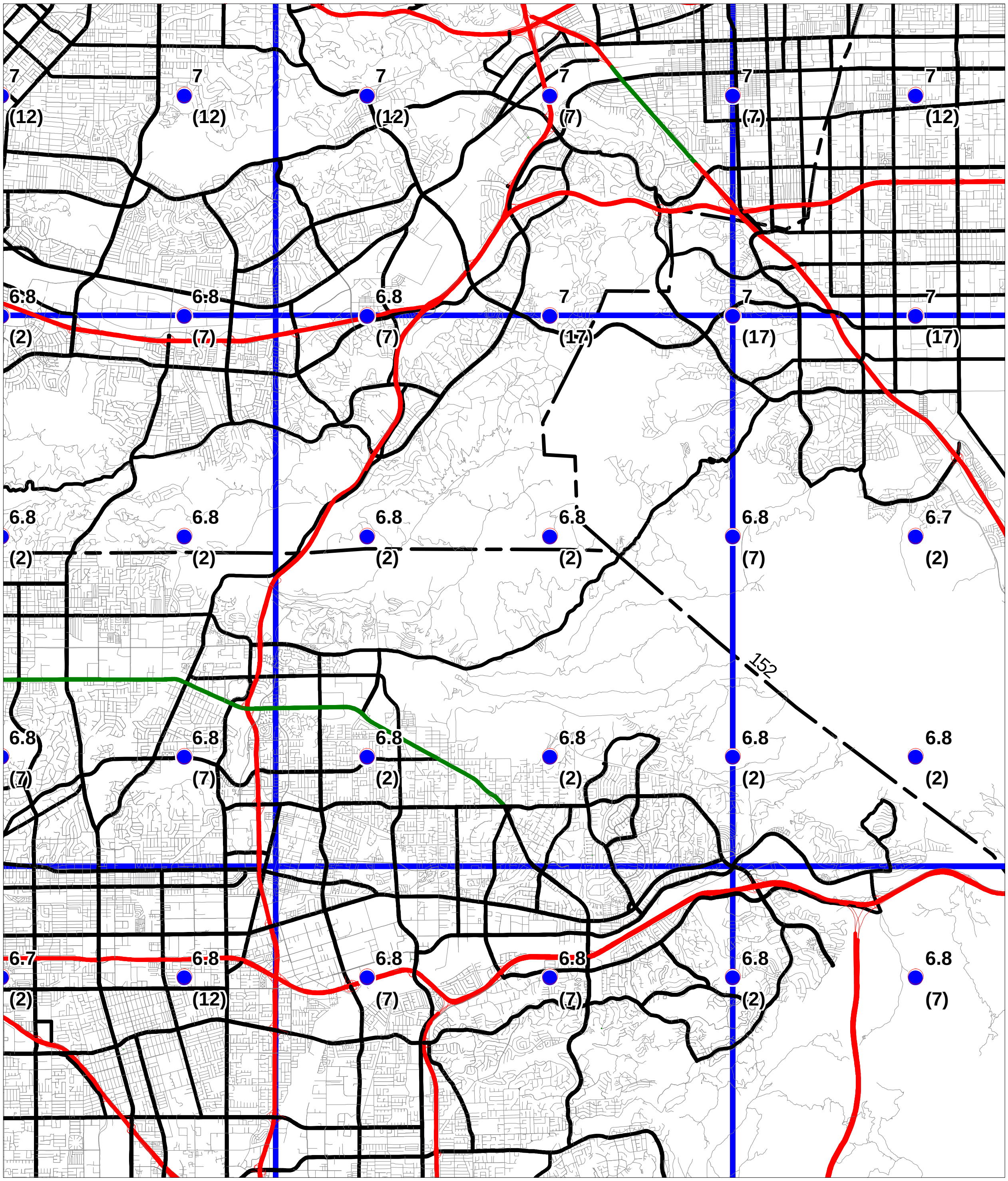
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss' weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

YORBA LINDA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

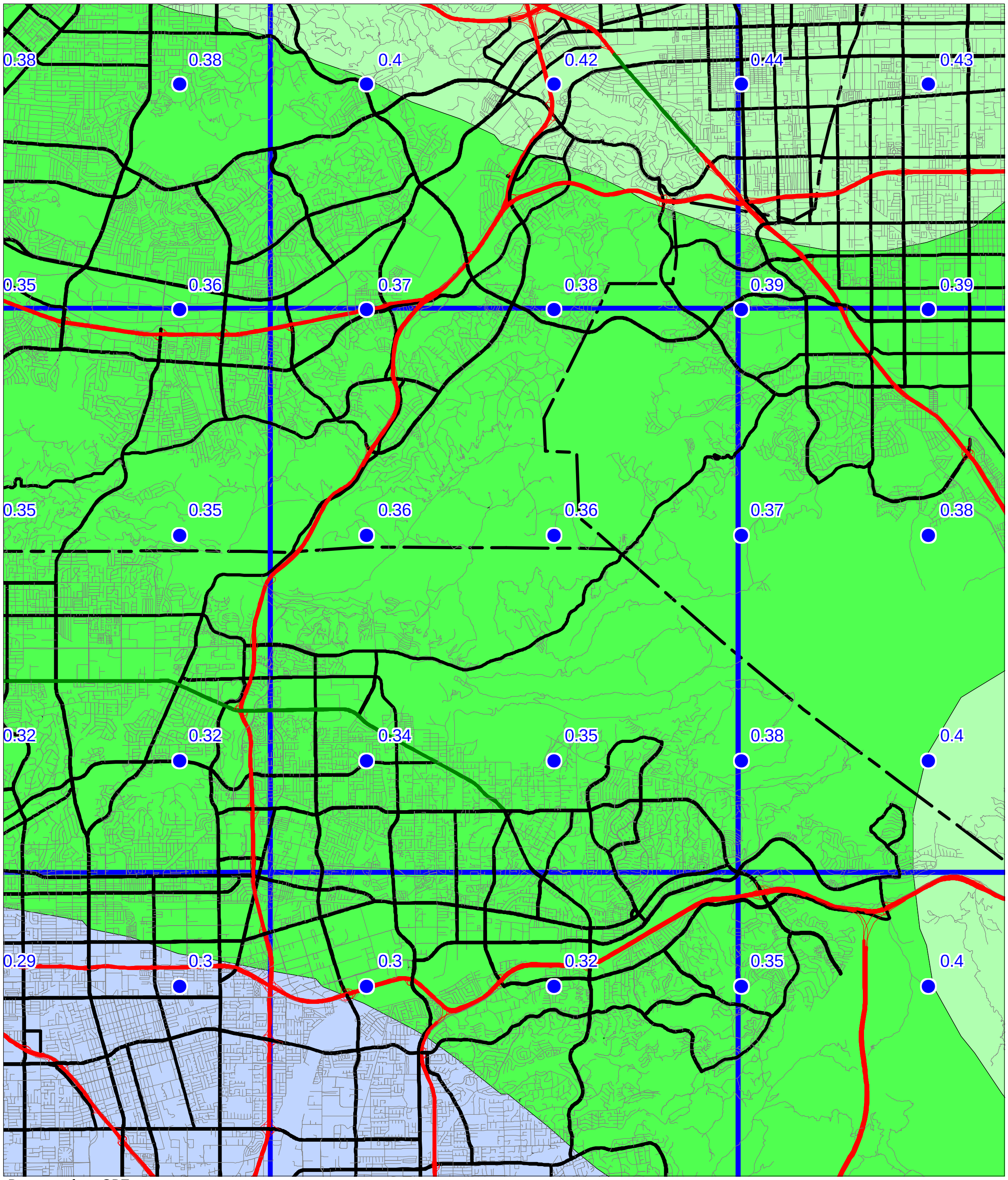
Figure 3.4

YORBA LINDA 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 percent of the ground motion value at two standard deviations (Cramer and others, 1996).
4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.
5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

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

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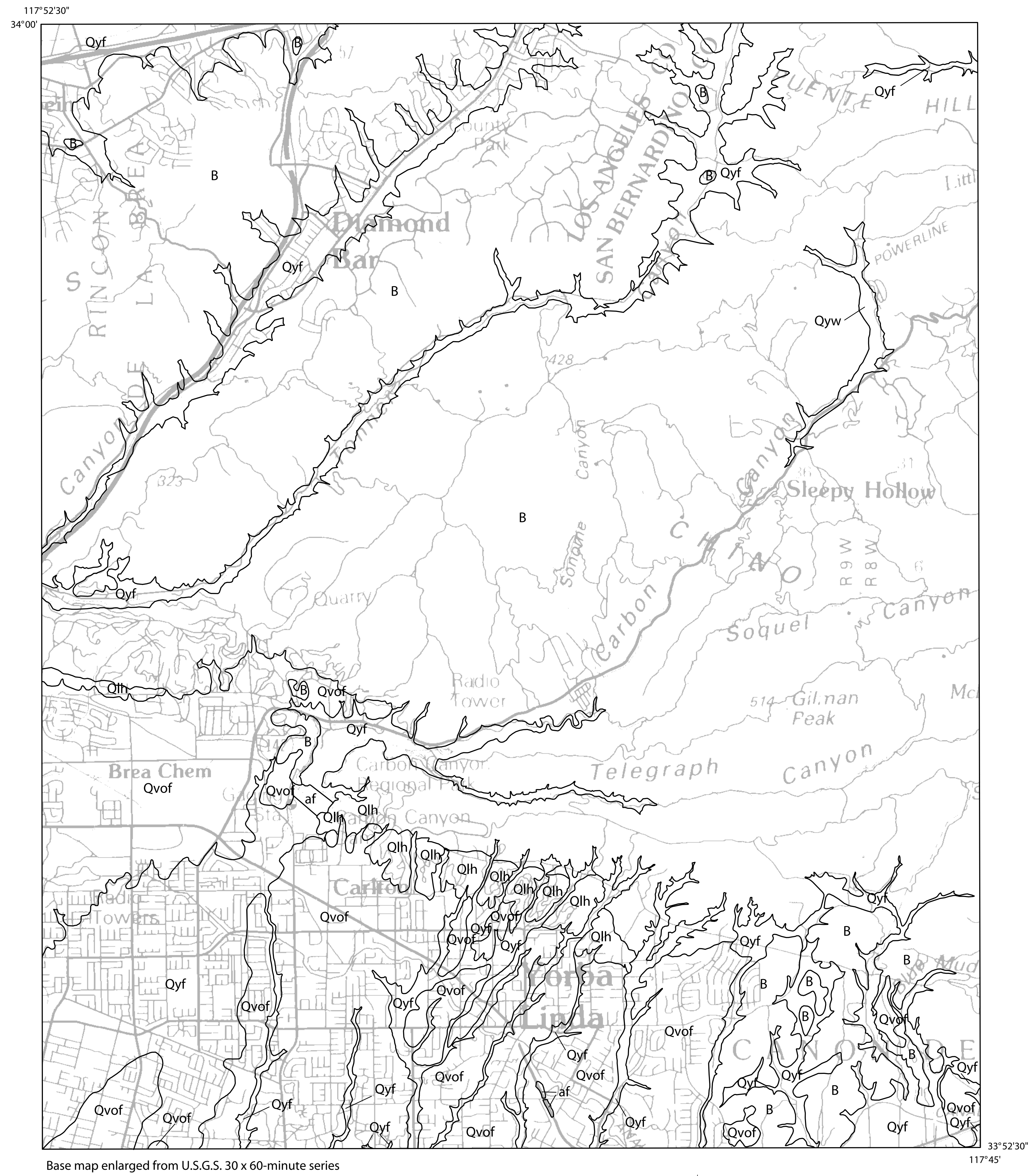


YORBA LINDA QUADRANGLE

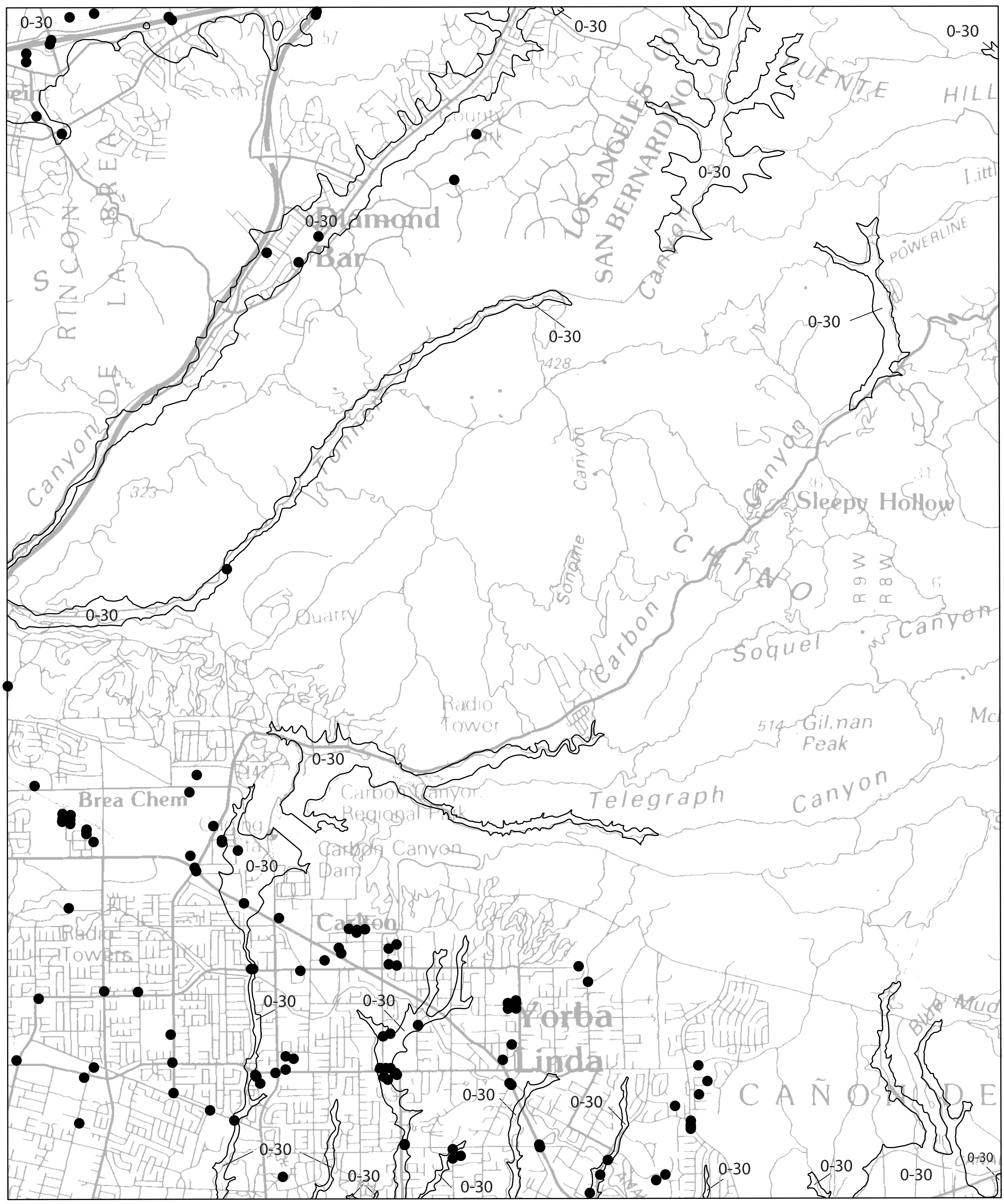
N

SCALE

B = Pre-Quaternary bedrock.
See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

Plate 1.1 Quaternary Geologic Map of the Yorba Linda 7.5-Minute Quadrangle, California. Modified from Yerkes (1972; north half) and Tan and others (1984; south half).

117°52'30"
34°00'



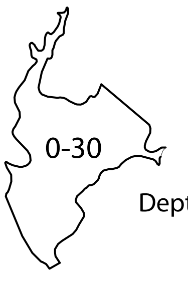
33°52'30"
117°45'

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

YORBA LINDA QUADRANGLE

N

SCALE



Depth to anticipated ground water, in feet

● Geotechnical borings used in liquefaction evaluation

Plate 1.2 Depth to historically high ground water, and locations of boreholes used in this study, Yorba Linda 7.5-Minute Quadrangle, California

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

YORBA LINDA QUADRANGLE

SCALE

0 .5 0 1 MILE

1000 0 2000 4000 6000 FEET

1 .5 0 1 KILOMETER

N

● Shear test sample location

Landslide

Tract report with multiple shear tests

Plate 2.1 Landslide inventory, shear test sample locations, and areas of significant grading, Yorba Linda 7.5-Minute Quadrangle, California.