

**SEISMIC HAZARD ZONE REPORT FOR THE
LA HABRA 7.5-MINUTE QUADRANGLE,
LOS ANGELES AND ORANGE COUNTIES,
CALIFORNIA**

1997



DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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SEISMIC HAZARD ZONE REPORT 09

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the La Habra 7.5-minute Quadrangle, Los Angeles and Orange counties, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 60 square miles at a scale of 1 inch = 2,000 feet.

The La Habra Quadrangle lies in the northeastern part of the Los Angeles Basin and includes the southern portion of the Puente Hills, the West and East Coyote Hills, Brea Canyon and the Yorba Linda-La Habra Valley lowland. The map includes all or parts of the cities of La Habra, La Habra Heights, Brea, Fullerton, Placentia, Buena Park, Industry, Whittier, and La Mirada, as well as unincorporated areas of Hacienda Heights and Rowland Heights within Los Angeles County. Elevations in the quadrangle range from about 100 feet along the Brea Creek floodplain near the southwest corner to 1,428 feet in the Puente Hills near the east-central portion. The Orange Freeway (State Highway 57) runs north and south near the southeastern border of the quadrangle. The east-trending Pomona Freeway (State Highway 60) cuts across the northern part of the quadrangle. Residential and commercial development covers the floor of the valley areas. New residential development over the past twenty years has extended into the lower slopes of the uplands.

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.

South of the Puente Hills the liquefaction zone in the La Habra Quadrangle is primarily within the Coyote Creek and Brea Creek floodplains or restricted to the bottoms of smaller canyons. North of the Puente Hills the zone is in areas of low relief in Rowland Heights, Hacienda Heights and along the Pomona Freeway alignment. The combination of dissected terrain, weak rock units and structural deformation along the Whittier Fault Zone has produced widespread and abundant landslides in the Puente Hills. These conditions contribute to an earthquake-induced landslide zone that covers 12 percent of the quadrangle. A few areas on the Coyote Hills are also within an earthquake-induced landslide zone.

How to view or obtain the map

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

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

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

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

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at <http://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 La Habra 7.5-minute Quadrangle.

SECTION 1

LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the La Habra 7.5-Minute Quadrangle, Los Angeles and Orange Counties, California

By
Ralph C. Loyd

**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 La Habra 7.5-minute Quadrangle. This section, along with Section 2 (addressing earthquake-induced landslides), and Section 3 (addressing potential ground shaking), form a report that is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996).

Additional information on seismic hazards zone mapping in California is on DMG's Internet web page: <http://www.conservation.ca.gov/CGS/index.htm>

BACKGROUND

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

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the La Habra 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. DMG's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

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

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

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The La Habra Quadrangle encompasses about 60 square miles in eastern Los Angeles and northern Orange counties and includes all or parts of the cities of La Habra, La Habra Heights, Brea, Fullerton, Placentia, Buena Park, Industry, Whittier, and La Mirada, as well as unincorporated areas of Hacienda Heights and Rowland Heights within Los Angeles County. More than half of the quadrangle consists of hilly and mountainous terrain. The Puente Hills, which contain several peaks above 1,000 feet in elevation, cover much of the northern half of the quadrangle. The East and West Coyote Hills occupy much of the southern one-third of the quadrangle. The lowlands between the Puente and Coyote hills generally consist of gentle to moderately sloping alluviated surfaces that, for the most part, have been heavily urbanized. Also heavily urbanized are areas north of the Puente Hills in Los Angeles County. The main drainage courses within the quadrangle, which have been channelized for the most part, are La Mirada, Fullerton, Brea, Coyote, and San Jose creeks.

GEOLOGY

Surficial Geology

A compiled geologic map of the La Habra Quadrangle was obtained, in digital form, from the Southern California Areal Mapping Project (1995; Morton and Kennedy, 1989). Additional sources of geologic and engineering geology information used in this evaluation included Yerkes (1972), Morton and others (1973), Sprotte and others (1980), and Tan and others (1984). Geologic maps show that rocks exposed in the Puente Hills are chiefly claystone, siltstone, sandstone, and conglomerate of marine origin that belong to the Pliocene Fernando Formation and the late Miocene Puente Formation, whereas rocks exposed in the Coyote Hills are dominantly marine and/or nonmarine clay, silt, and sand deposits that comprise the Pleistocene La Habra, Coyote Hills, and San Pedro formations. Surficial sediments mapped in the area consist of a series of older Quaternary alluvial fan deposits along the southern margin of the Puente Hills, a series of younger Quaternary alluvial fan deposits along the southern margin of the Coyote Hills, and alluvium deposited upon erosional surfaces on the northern margin of the quadrangle. Young Quaternary alluvium also has been deposited within and adjacent to modern stream courses in canyons and valley areas. The generalized geology of the La Habra Quadrangle is diagrammatically portrayed on Plate 1.1.

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. For this investigation, about 200 borehole logs were collected from the files of the 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 cities of Industry and La Habra; the Fullerton Fire Department; and the geologic consulting firm of Leighton and Associates in Irvine, California. Borehole log selection was limited to boreholes drilled in valleys and canyons underlain by Quaternary sedimentary deposits. Lithologic, soil test, and related data reported in the borehole logs were entered into the DMG geotechnical GIS database. Locations of all exploratory boreholes considered in this investigation are shown on Plate 1.2.

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit and commonly are used as an index of density. Many geotechnical investigations record SPT data, including the number of blows by a 140-pound drop weight required to drive a sampler of specific dimensions one foot into the soil. Recorded blow counts for non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), were converted to SPT-equivalent blow count values and entered into the DMG GIS. The actual and converted SPT blow counts were normalized to a common reference

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

Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are necessarily generalized but give the characteristics of the unit most commonly encountered. Geotechnical characteristics of the Quaternary map units are generalized in Table 1.1.

Younger alluvium

Borehole logs describe soil characteristics of alluvium deposited in the flood plains and alluvial fans of Coyote, Brea, and Carbon creeks. Overall, the sediments deposited in these depositional environments appear to be similar in character because their drainage basins cut across similar bedrock sequences. In general, the alluvium and alluvial fan deposits consist of alternating beds of clay, silt, and fine- to medium-grained sand. Gravel layers are rare. Compactness of sand layers range from loose to dense as indicated by both lithologic descriptions and penetration tests performed during drilling.

The largest of the young Quaternary alluvial fan deposits in the quadrangle lies on the southeast side of the Coyote Hills. This southwest-widening alluvial fan was developed by Carbon Creek, which has since changed its course and abandoned the alluvial fan, probably a result of late Quaternary uplift of the Coyote Hills. Logs of boreholes drilled within the Carbon Creek alluvial fan generally record an abundance of loose to moderately dense clean and silty sand.

Young alluvial sediments deposited on erosional surfaces along the northern margin of the quadrangle (gently sloping to nearly flat surfaces occupied by Hacienda Heights and Rowland Heights) consist of alternating beds of clay, silt, silty fine sand, fine- to medium-grained sand and, locally, scattered gravel. Geomorphology and 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 ranges 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 are generally well compacted and have a high clay content (clay, clayey silt, and clayey sand). However, relatively loose sand layers do occur in some of the borehole logs.

At the northern base of the Puente Hills, the slope sediments described above interfinger with fluvial sediments deposited within the flood plain of San Jose Creek, whose channel is just north of the quadrangle boundary. Borehole logs prepared by both Caltrans and private consultants show that the San Jose Creek flood plain deposits are dominated by clay and silt, but locally include fine- to coarse-grained, loose sand.

Boreholes by Caltrans for a bridge crossing at Tonner Creek and an offramp structure at Fullerton Creek include descriptions of alluvium deposited on canyon floors. These near-surface sediments are described as being composed mainly of clayey silt, silty fine-grained sand, fine- to medium-grained sand, and gravelly sand, generally loose to

moderately dense. The available data and bedrock lithology imply that the alluvium deposited in the other canyons, as well as in the narrow channels incised in older Quaternary alluvium, consists of similar material, i.e., predominately loose to moderately dense silt and fine- to medium-grained sand deposits, along with scattered gravel.

Locations and geotechnical data from borehole logs were entered into DMG's Geographic Information System (GIS). Locations of all exploratory boreholes considered in this investigation are shown on Plate 1.2. Construction of cross sections using data reported on the borehole logs enabled staff to relate soil-engineering properties to various depositional units, to correlate soil types from one borehole to another, and to extrapolate geotechnical data into outlying areas containing similar soils.

Geologic Unit: Area	Sediment Type (Dominant 1st)	Sand Consistency	Historic Depth Ground water	Liquefaction Susceptibility
Qof: South One-Third of Quadrangle	clay, silt, sand	mod. loose to very dense	15-150	Low
Qya: Coyote Creek Flood Plain	clay, silt, clayey sand, sand	loose to dense	8-10 Ft	High
Qyf: Coyote Creek Alluvial Fan	silt, sand, clay	loose to dense	0-10 Ft	High
Qya: Brea Cyn	silt, sand, clay	loose to dense	10 Ft	High
Qya: Brea Creek Flood Plain	clay, silt, sand	loose to dense	10 Ft	High
Qyf: Brea Creek Alluvial Fan	silt, sand, clay	loose to dense	10-40 Ft	High
Qyf: Carbon Creek alluvial Fan	sand, silt, clay	loose to dense	>100 Ft	Low
Qya: Slope Wash-Debris Flow	clay, silt, sand	loose to very dense	25 Ft	High
Qya: San Jose Creek Flood Plain	clay, silt, sand	loose to dense	20 Ft	High
Qya: Incised Channels, Coyote Hills	silt, sand, clay	loose to dense	10 Ft	High

Table 1.1. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Alluvium and Alluvial Fan Units, La Habra Quadrangle.

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. DMG uses the highest known ground-water levels because water levels during an earthquake cannot be anticipated because of the unpredictable fluctuations caused by natural processes and human activities. A historical-high ground-water map differs from

most ground-water maps, which show the actual water table at a particular time. Plate 1.2 depicts a hypothetical ground-water table within alluviated areas.

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

Plate 1.2 shows that historically shallow water conditions (less than 40 feet depth) have existed in several areas of the La Habra Quadrangle, namely, in the south-central La Habra Basin, along Coyote Creek flood plain, in the Buena Park-Fullerton area where Coyote and Brea creeks enter the Downey Plain, in the Hacienda Heights-Industry-Rowland Heights area, and, periodically, in all canyons and incised channels in the quadrangle.

PART II

LIQUEFACTION POTENTIAL

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

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

LIQUEFACTION SUSCEPTIBILITY

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

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

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. DMG's qualitative susceptible soil inventory is outlined below and summarized on Table 1.1.

Older alluvial fans

Based on the generally high blow counts recorded on the borehole logs, as well as the qualitative description of the materials as dense to very dense sands and silts, the older Quaternary alluvial fan deposits present in the La Habra Quadrangle are considered to have low liquefaction susceptibility. However, it must be noted that several logs of boreholes drilled in older alluvium in the south central La Habra area showed anomalously low blow counts in some saturated silt and clayey sand layers. It is suspected that these layers contain a high clay content that resulted in soft material where saturated.

Younger alluvium

Canyons and incised channels (Qya). Canyon and incised channel deposits contain layers of sand and silty sand described as loose to moderately dense. Water is reported in most boreholes within 15 feet of the ground surface. Liquefaction analyses performed on data

from a few boreholes drilled through these sediments indicate that the shallow sands have factors of safety less than 1.0 for the anticipated earthquake shaking. Accordingly, these deposits are assigned a high liquefaction susceptibility rating.

Coyote Creek (Qya). A one-fourth to one-half-mile-wide band mapped as Coyote Creek flood plain and streambed deposits trends west and southwest through the La Habra area. Borehole log information indicates that these deposits contain an abundance of saturated loose sandy soils at depths less than 40 feet. Most of the boreholes whose log data were analyzed using the Seed Simplified Procedure contain sediment layers that theoretically “liquefy” under given earthquake parameters. Similar sediments are described in other boreholes within the Coyote Creek flood plain sediments that do not contain penetration test data. Thus, the liquefaction susceptibility of Coyote Creek channel and flood plain deposits is rated as high.

Slope wash and debris flow deposits (Qya). Borehole data indicate that slope wash and debris flow sediments deposited along the northern margin of the La Habra Quadrangle are dominated by moderately stiff to stiff clays and moderately dense to dense clayey silt and clayey sand beds. However, some of the boreholes penetrated beds composed of poorly to well-sorted loose sands measuring one to three feet in thickness. The occurrence of loose sandy soil in this depositional environment is critical, considering that the natural slope of these deposits is greater than 15 degrees. Consequently, the liquefaction susceptibility of these deposits is rated as high.

San Jose Creek flood plain (Qya). Although the San Jose Creek flood plain sediments are dominated by clay and silt, several of the limited number of boreholes drilled in this geologic environment penetrated one or more beds consisting of fine- to coarse-grained, loose sand. As a result, the San Jose Creek channel and floodplain deposits are rated high for liquefaction susceptibility.

Carbon Creek (Qyf). Although borehole log descriptions and penetration tests indicate that much of the Carbon Creek alluvial fan is composed of loose, sandy material, depth to ground water exceeds 100 feet. Consequently, the liquefaction susceptibility of the deposits is rated low.

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 La Habra Quadrangle, a peak acceleration of 0.45g resulting from an earthquake of magnitude 6.8 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.

Of the 200 geotechnical borehole logs reviewed in this study (Plate 1.2), about 100 include blow-count data from SPT's 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 2 1/2-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 (soil density, moisture content, sieve analysis, etc) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values or using average test values of similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the 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 La Habra Quadrangle is summarized below.

Areas of Past Liquefaction

Historic liquefaction has not been reported in the La Habra Quadrangle, nor is there any known evidence of paleo-seismic liquefaction. Therefore, no areas within the La Habra Quadrangle are zoned for potential liquefaction hazard based on historic liquefaction.

Artificial Fills

Non-engineered artificial fills have not been delineated or mapped in the La Habra Quadrangle. Consequently, no areas within the La Habra Quadrangle are zoned for potential liquefaction hazard based on their presence.

Areas with Sufficient Existing Geotechnical Data

Borehole logs, which generally included limited penetration test data and reasonably sufficient lithologic descriptions, were used to determine the high liquefaction susceptibility ratings assigned fluvial sediments deposited in the Coyote, Brea, and San Jose creek flood plains and related alluvial fans, as well as slope wash and debris flow sediments deposited in the Hacienda Heights-Rowland Heights area. Accordingly, these areas are zoned as potential liquefaction hazard areas based on adequate existing geotechnical data.

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 included in the liquefaction zone 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 La Habra 7.5-Minute Quadrangle, Los Angeles and Orange Counties, California

By

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) 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 La Habra 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 La Habra 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 La Habra 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 La Habra 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 La Habra Quadrangle covers an area of about 60 square miles in eastern Los Angeles and northern Orange County in the northeastern part of the Los Angeles Basin, and includes the southern portion of the Puente Hills, the West and East Coyote Hills, Brea Canyon and the Yorba Linda-La Habra Valley lowland. The map includes all or parts of

the cities of La Habra, La Habra Heights, Brea, Fullerton, Placentia, Buena Park, Industry, Whittier, and La Mirada, as well as unincorporated areas of Hacienda Heights and Rowland Heights within Los Angeles County.

The study area lies within the northwesternmost part of the Santa Ana Mountains in the Peninsular Ranges geomorphic province of southern California. In the southern portion of the quadrangle, the East and West Coyote Hills contain active oil fields, which produce oil and gas from structural traps created by faulting and an east-west anticline that coincides with the crest of the topographic trend of the hills. In the north, the Puente Hills reach higher elevations, ranging from 400 feet to several peaks above 1,000 feet, and have more irregular topography than the Coyote Hills. The intervening lowland areas are part of the Los Angeles Basin plain and are drained to the northeast and south by streams such as San Jose, La Mirada and Brea creeks. Elevations throughout the quadrangle range from about 100 feet along the Brea Creek floodplain near the southwest corner of the quadrangle to 1,428 feet in the Puente Hills near the east-central portion of the quadrangle.

The Orange Freeway (State Highway 57) runs north and south near the southeast border of the quadrangle. The east-west trending Pomona Freeway (State Highway 60) cuts across the northern part of the quadrangle and follows the San Jose Creek drainage.

Residential and commercial development covers the floor of the valley. New residential development over the past twenty years has taken place mainly along the lower slopes of the uplands. Although minor lot grading has been performed for most of the modern residential development, substantial hillslope grading and drainage modification has been required prior to construction some of the larger projects in the quadrangle. Some of the nearly level areas and older road bases, such as those in Brea Canyon, have been only lightly compacted under undocumented fill conditions.

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 La Habra 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 1963 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

To update the terrain data, areas that have recently undergone large-scale grading in the hilly portions of the La Habra Quadrangle were identified on 1:40,000-scale aerial photography flown in 1994 and 1995 (NAAP, 1994). Terrain data for this area were produced by scanning and rectifying diapositives made from the photography. Using this stereo-rectified image, DMG manually digitized the terrain to produce accurate and up-to-date topography for the mass graded area. This corrected terrain data was digitally merged with the USGS DEM.} Plate 2.1 shows the area where topography is updated to 1994 grading conditions.

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

GEOLOGY

Bedrock and Surficial Geology

The geologic map for the La Habra Quadrangle was digitized by DMG from 1:24,000 scale mapping (Tan, 1988) in the north half, and 1:12,000 scale mapping (Tan and others, 1984) in the south half of the quadrangle. Geologic mapping in the lowland areas and Quaternary unit designations were compiled by the Southern California Areal Mapping Project (1995). This mapping was modified during this project to reflect field observations and the most recent mapping in the area. 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 mainly from the U.S. Geological Survey (Yerkes, 1972) and DMG (Tan and others, 1984) mapping done in this area.

The oldest rock units exposed in the La Habra Quadrangle belong to the late Miocene Puente Formation, which underlies the Puente Hills. The Puente Formation is comprised of four members; they include the Sycamore Canyon (Tp_{sc}), Yorba (Tp_y), Soquel (Tp_s) and La Vida (Tp_{lv}) members and their coarse-grained sub-members (Tp_{sc}(c), Tp_y(c), Tp_s(c) and Tp_{lv}(c)). The La Vida and Yorba members have similar lithology 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 upper member of the Fernando Formation (T_{fu}) is composed of thick-bedded to massive marine sandstone, conglomerate and, locally, thin-bedded mudstone and siltstone. The lower Fernando Formation (T_{fl}) is interbedded siltstone and sandstone with lenticular conglomerate layers. Both of these formations have coarse-grained sub-members. There is a small area of tabular, sill-like diabase (T_d) mapped north of the Whittier fault zone.

The bedrock underlying the Coyote Hills consists of the upper Pleistocene La Habra Formation (Q_{lh}), Pleistocene Coyote Hills Formation (Q_{ch}), and lower Pleistocene San Pedro Formation (Q_{sp}) rocks. The Coyote Hills Formation consists of non-marine massive sandstone, siltstone, conglomerate and pebbly sandstone. The La Habra Formation is exposed in the Coyote Hills and south of the Whittier Fault in the Puente Hills. It consists of floodplain deposits of siltstone, thick-bedded sandstone, conglomerate and pebbly sandstone. The San Pedro Formation is marine silty sandstone with conglomerate and pebbly sandstone in the upper portions of the formation.

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, floodplain, stream terrace deposits, and Holocene to modern alluvium Qyf, Qya and landslides (Qls). These materials are poorly sorted and crudely layered. Minor amounts of alluvium occur along the bottom of all the canyons in the Puente and Coyote Hills. There are minor areas of unmapped artificial fill (af) in the developed areas of the quadrangle. A more detailed discussion of the Quaternary deposits in the La Habra Quadrangle can be found in Section 1.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the La Habra Quadrangle was prepared from published regional landslide maps (Tan, 1988). Then, by combining field observations, analysis of aerial photos, and interpretation of landforms on current and older topographic maps all landslides on the compiled landslide map were either verified, re-mapped, or deleted during preparation of the landslide inventory map. The aerial photos used for landslide interpretation are listed under Air Photos in the References. Also consulted during the mapping process were previous maps and reports that contain geologic and landslide data. Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the slope stability analysis. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed hand-drawn landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the La Habra Quadrangle geologic map were obtained mainly from the consulting firm of Leighton and Associates (see Appendix A). Shear strength data were also obtained from consultant reports on file with the Los Angeles County Department of Public Works, Materials Engineering Division. 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 ϕ) and lithologic character. Average (mean and median) ϕ 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.

Because of the homogeneous character of bedrock units in the La Habra Quadrangle, it was determined that the underlying geologic structure does not have a significant impact on slope stability of these rock units. Although the layered sedimentary rocks have relatively shallow bedding dips that may contribute to slope instability, there is a greater difference in material strength between formations than internally within formations. It was, therefore, determined that adverse bedding dips are not a significant factor in the material strength and no attempt was made to identify adverse bedding conditions in the La Habra Quadrangle.

LA HABRA QUADRANGLE SHEAR STRENGTH GROUPINGS							
	Formation Name	Number Tests	Mean phi value	Group Mean/Median Phi(deg)	Group Mean/Median Cohesion (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1	Qch	9	32.8	34.2/32	578/400	Tpsc(c)	33
	Tpsc	12	35.3				
	Tplv	14	33				
GROUP 2	af	15	31.5	31.1/30	415/350	Qsp, Qyf, Qof Td, Tf(c), Tfu, Tfu(c), Tps(c), Tpy(c)	30
	Qya	3	30.5				
	Qvo	4	30.6				
	Qlh	11	31.5				
	Tps	13	31.1				
	Tpy	6	28.5				
	Tvs	3	30.8				
Tfl	8	29.9					
GROUP 3	Qls	14	12.6	12.6/11	318/300		12

Table 2.1. Summary of the Shear Strength Statistics for the La Habra Quadrangle.

SHEAR STRENGTH GROUPS FOR LA HABRA QUADRANGLE		
GROUP 1	GROUP 2	GROUP 3
Qch Tpsc Tpsc(c) Tplv	af, Qof Qya, Qvo Qyf Qlh Qsp Td Tfl, Tfl (c) Tfu, tfu (c) Tps, Tps (c) Tpy, Tpy (c)	Qls

Table 2.2. Summary of the Shear Strength Groups for the La Habra 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 of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used.

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 La Habra Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.7 to 6.9
Modal Distance:	2.5 to 9 km
PGA:	0.40 to 0.49 g

The strong-motion record selected for the slope stability analysis in the La Habra 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 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 0.076, 0.129 and 0.232 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 La Habra Quadrangle.

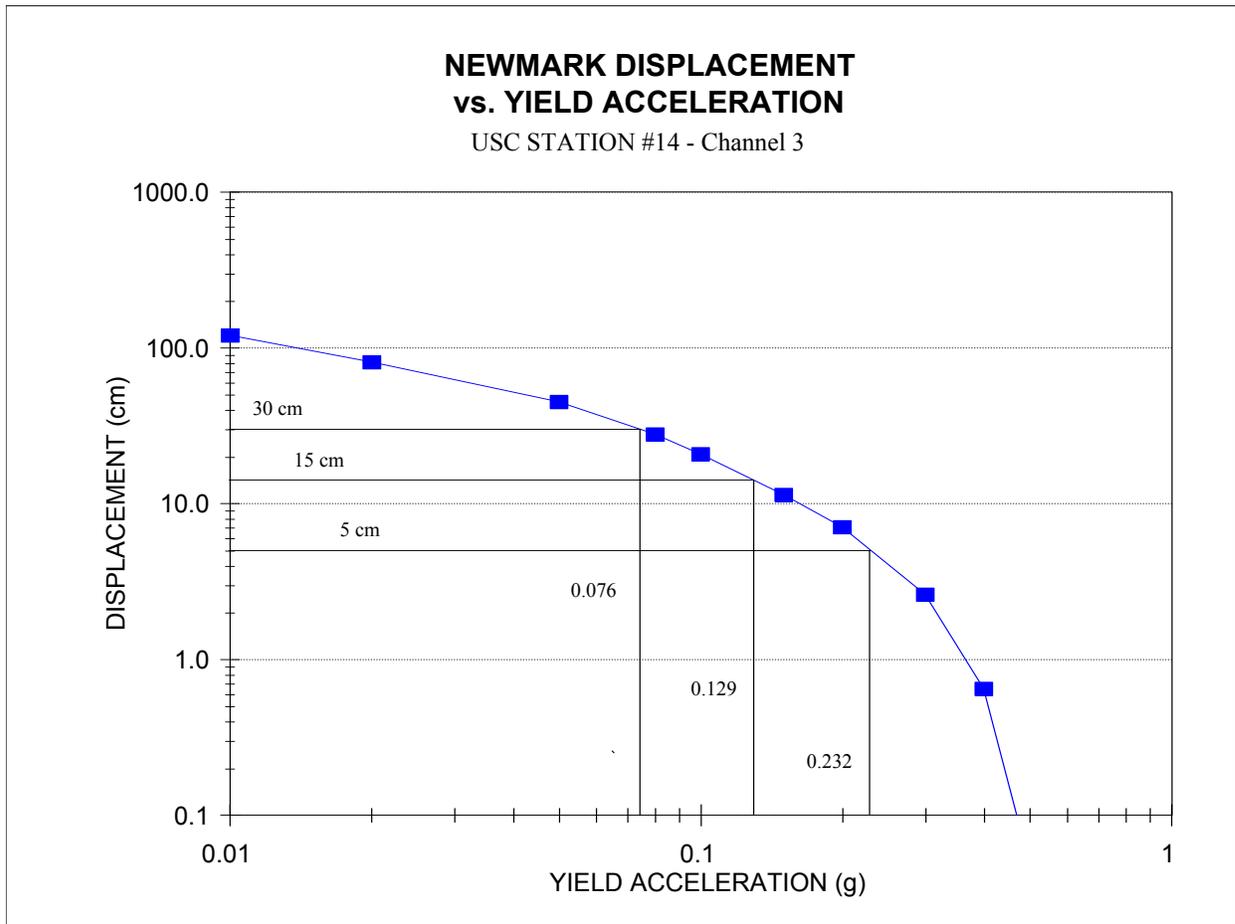


Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record from the 17 January 1994 Northridge Earthquake.

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 0.076g, 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 0.076g and 0.129g, 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 0.129g and 0.232g, 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 0.232g, 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.

LA HABRA QUADRANGLE HAZARD POTENTIAL MATRIX									
Geologic Material Strength Group	Mean Phi	SLOPE CATEGORY							percent
		I 0-13	II 14-33	III 34-39	IV 40-43	V 44-50	VI 51-56	VII >56	
1	33	VL	VL	VL	L	L	M	H	
2	30	VL	VL	L	L	M	H	H	
3	12	L-M	H	H	H	H	H	H	

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

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

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

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

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

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies

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

Geologic and Geotechnical Analysis

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

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

1. Geologic Strength Group 3 is included for all slope gradient categories. (Note: Geologic Strength Group 3 includes all mappable landslides with a definite or probable confidence rating).
2. Geologic Strength Group 2 is included for all slopes steeper than 33 percent.
3. Geologic Strength Group 1 is included for all slopes steeper than 39 percent.

This results in approximately 12 percent (5,200 acres) of the quadrangle lying within the earthquake-induced landslide hazard zone for the La Habra Quadrangle.

ACKNOWLEDGMENTS

The authors thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Library 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. 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. Mushtaq Hussain and Riad Munjy of the Geomatics Engineering Program in the School of Engineering and Computer Science at California State University, Fresno, assisted in the soft-copy photogrammetry production. At DMG, Siang Tan provided valuable

information, gained from years of field study, about the stability characteristics of the geologic units in the area. Special thanks to Bob Moskovitz, Teri McGuire, Scott Shepherd and Barbara Wanish for their Geographic Information System operations support, to Joy Arthur for designing and plotting the graphic displays associated with the earthquake-induced landslide zone map, and Lisa Chisholm for preparing the landslide attribute tables for input into this report.

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APPENDIX A SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Leighton and Associates	99
County of Los Angeles, Department of Public Works, Materials Engineering Division	20
Total Number of Shear Tests	119

SECTION 3

GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the La Habra 7.5-Minute Quadrangle, Los Angeles and Orange Counties, California

By

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

**California Department of Conservation
Division of Mines and Geology**

***Formerly with DMG, now with U.S. Geological Survey**

PURPOSE

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

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

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

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage:

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

EARTHQUAKE HAZARD MODEL

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

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

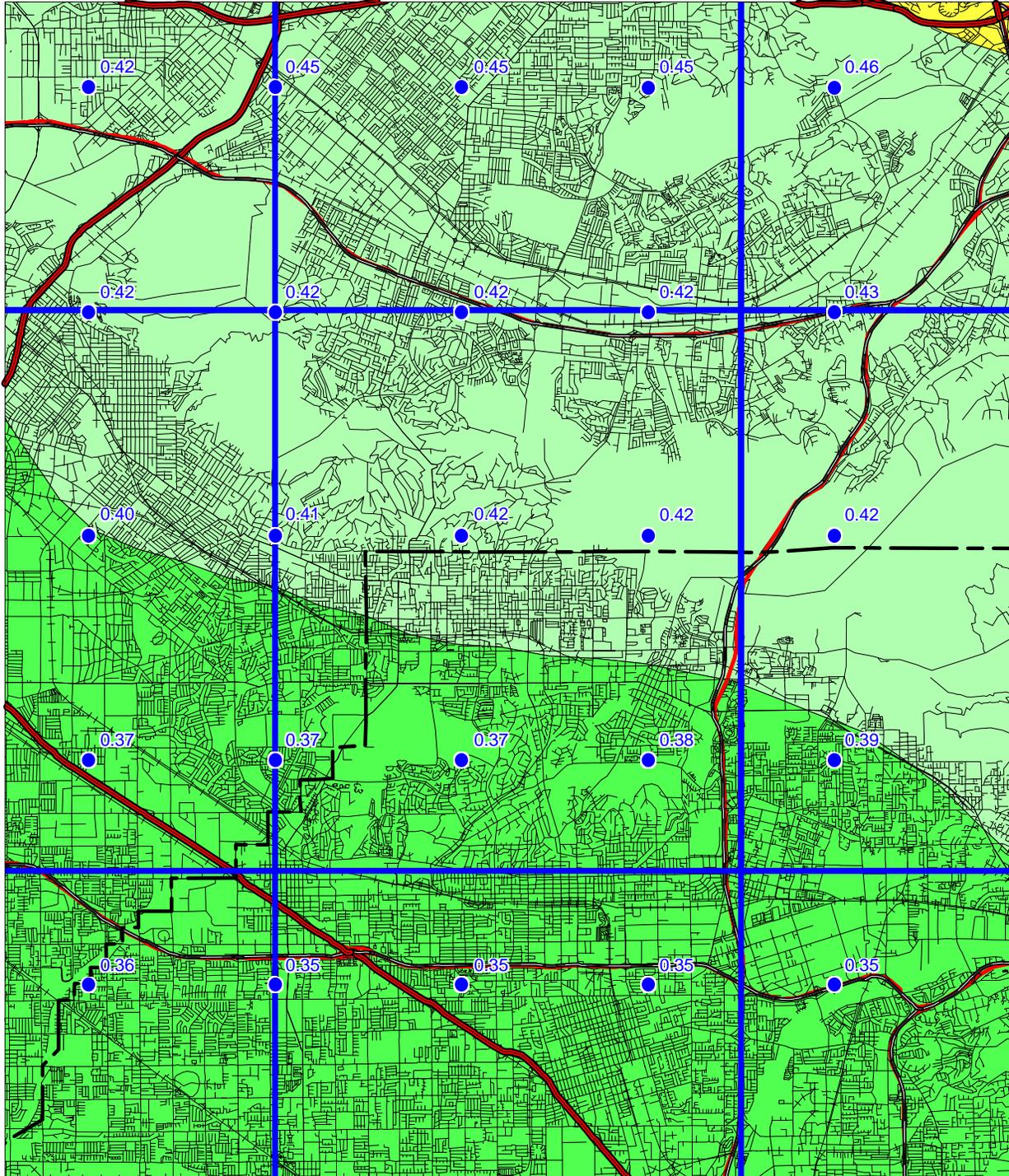
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

SEISMIC HAZARD EVALUATION OF THE LA HABRA QUADRANGLE
LA HABRA 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation



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Division of Mines and Geology



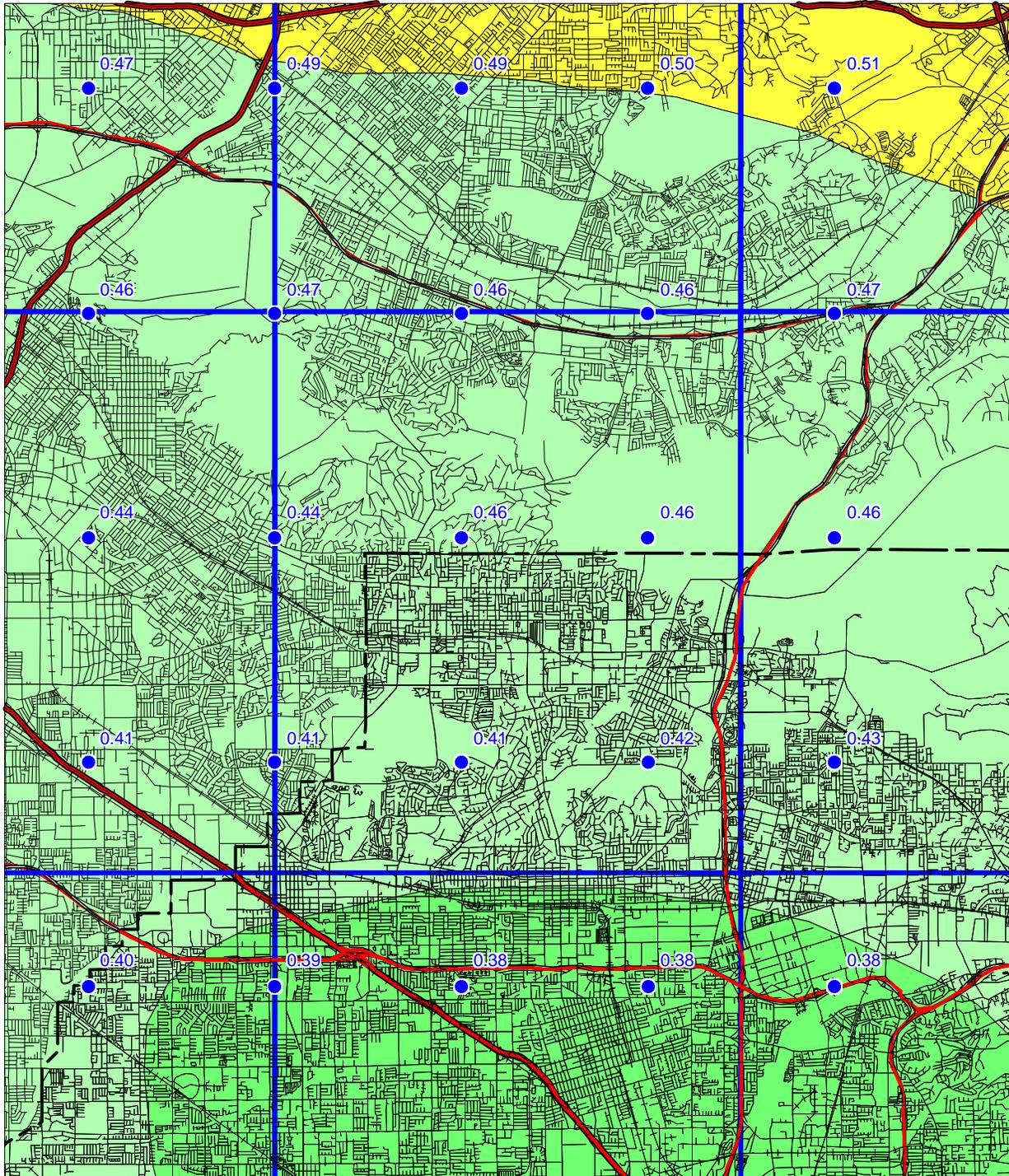
Figure 3.1

LA HABRA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

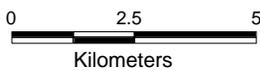
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



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Department of Conservation
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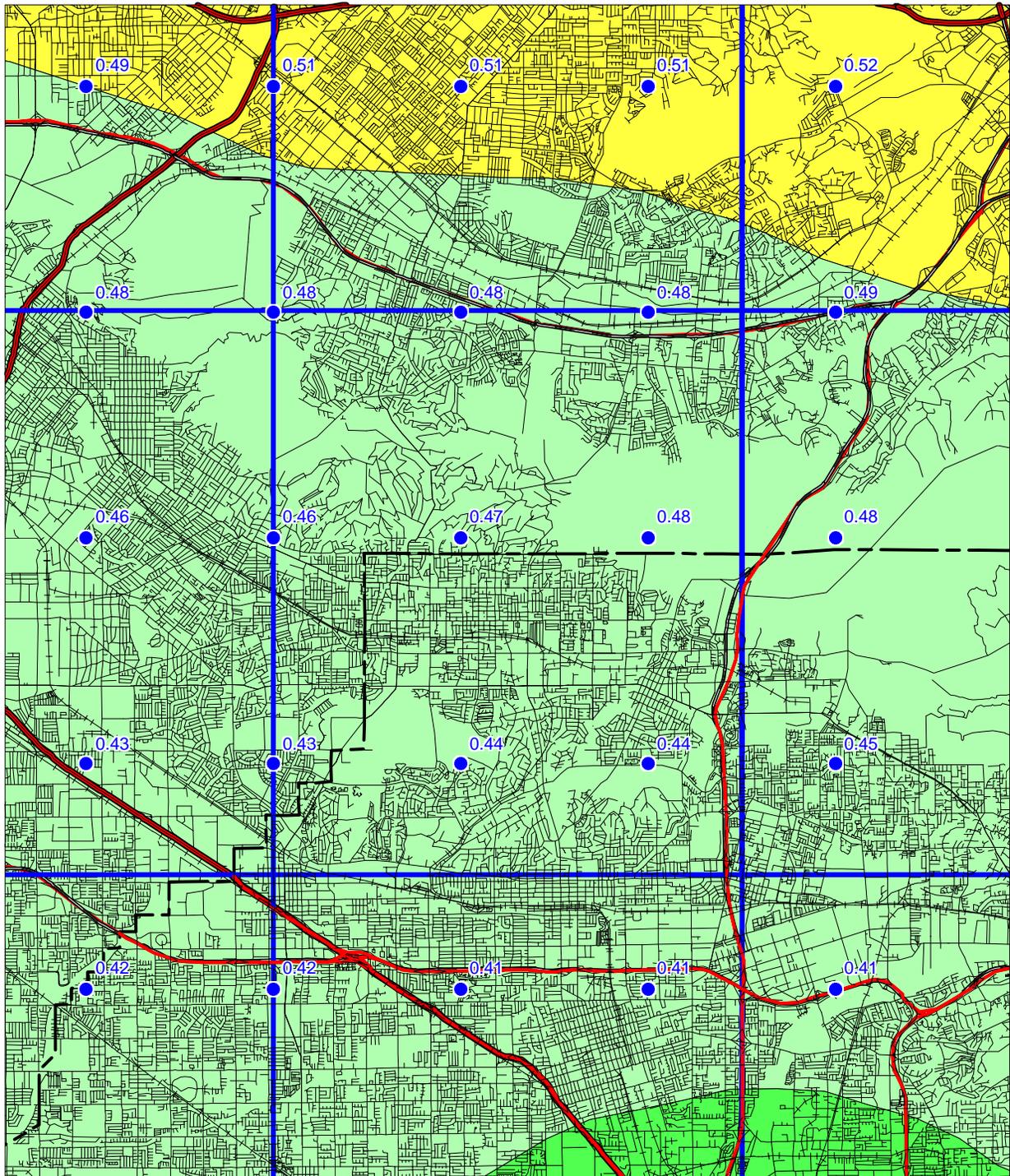
Figure 3.2

LA HABRA 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



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.

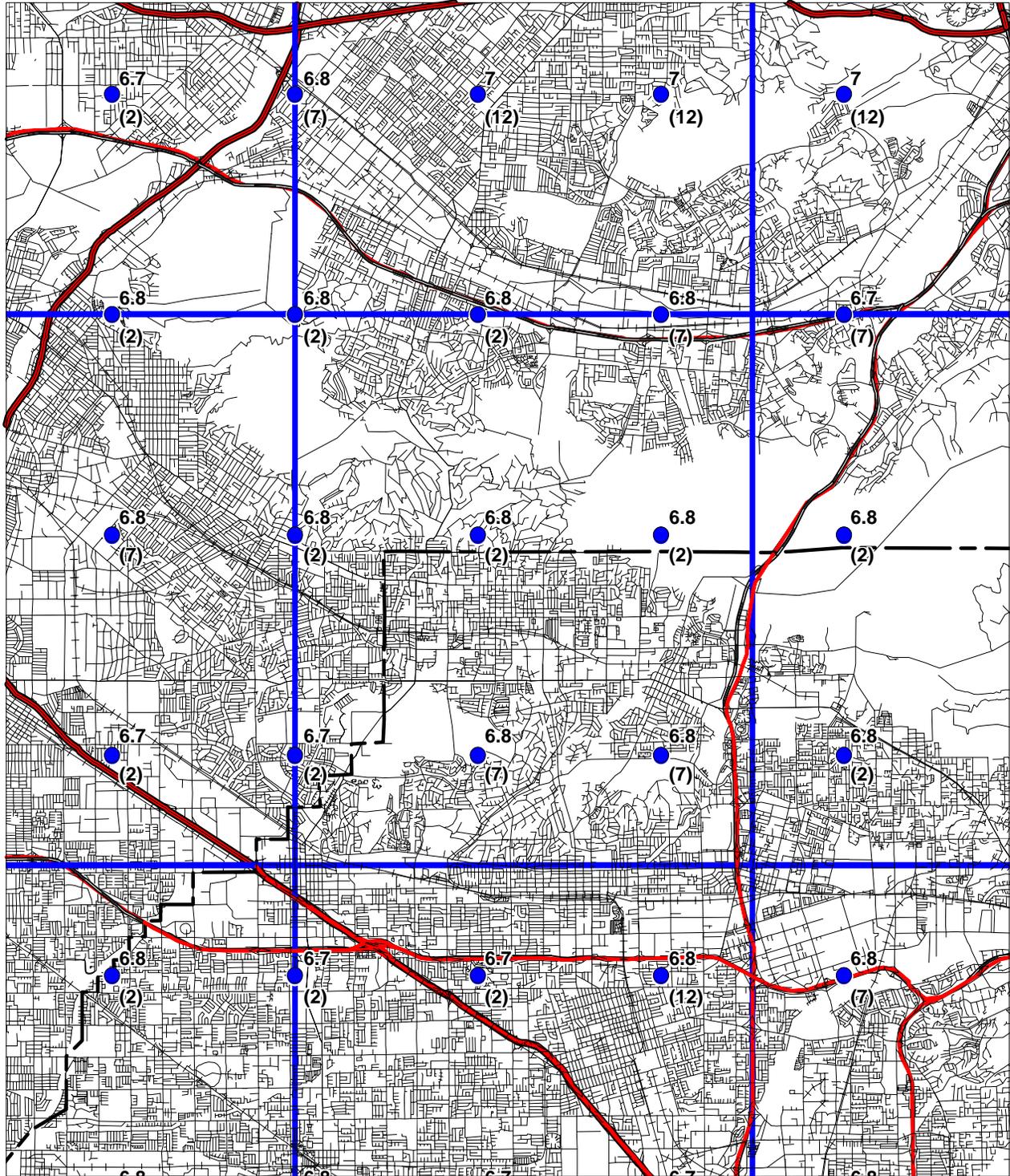
SEISMIC HAZARD EVALUATION OF THE LA HABRA QUADRANGLE
LA HABRA 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation



Department of Conservation
Division of Mines and Geology

Figure 3.4

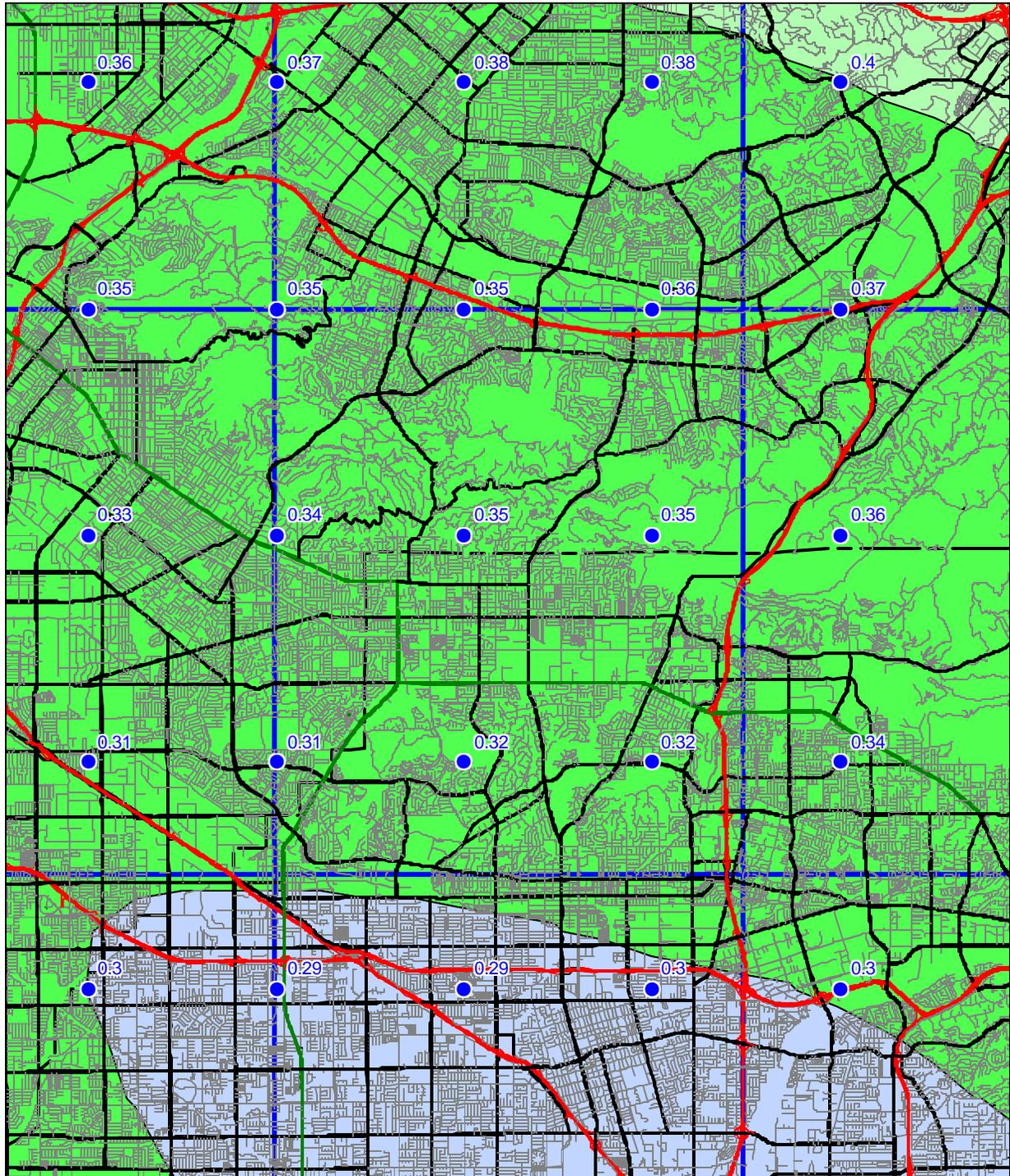


**SEISMIC HAZARD EVALUATION OF THE LA HABRA QUADRANGLE
LA HABRA 7.5-MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES**

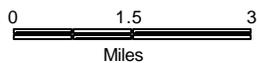
*10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g)
FOR ALLUVIUM*

1998

LIQUEFACTION OPPORTUNITY



Base map from GDT



Department of Conservation
California Geological Survey



Figure 3.5

USE AND LIMITATIONS

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

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

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the

recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

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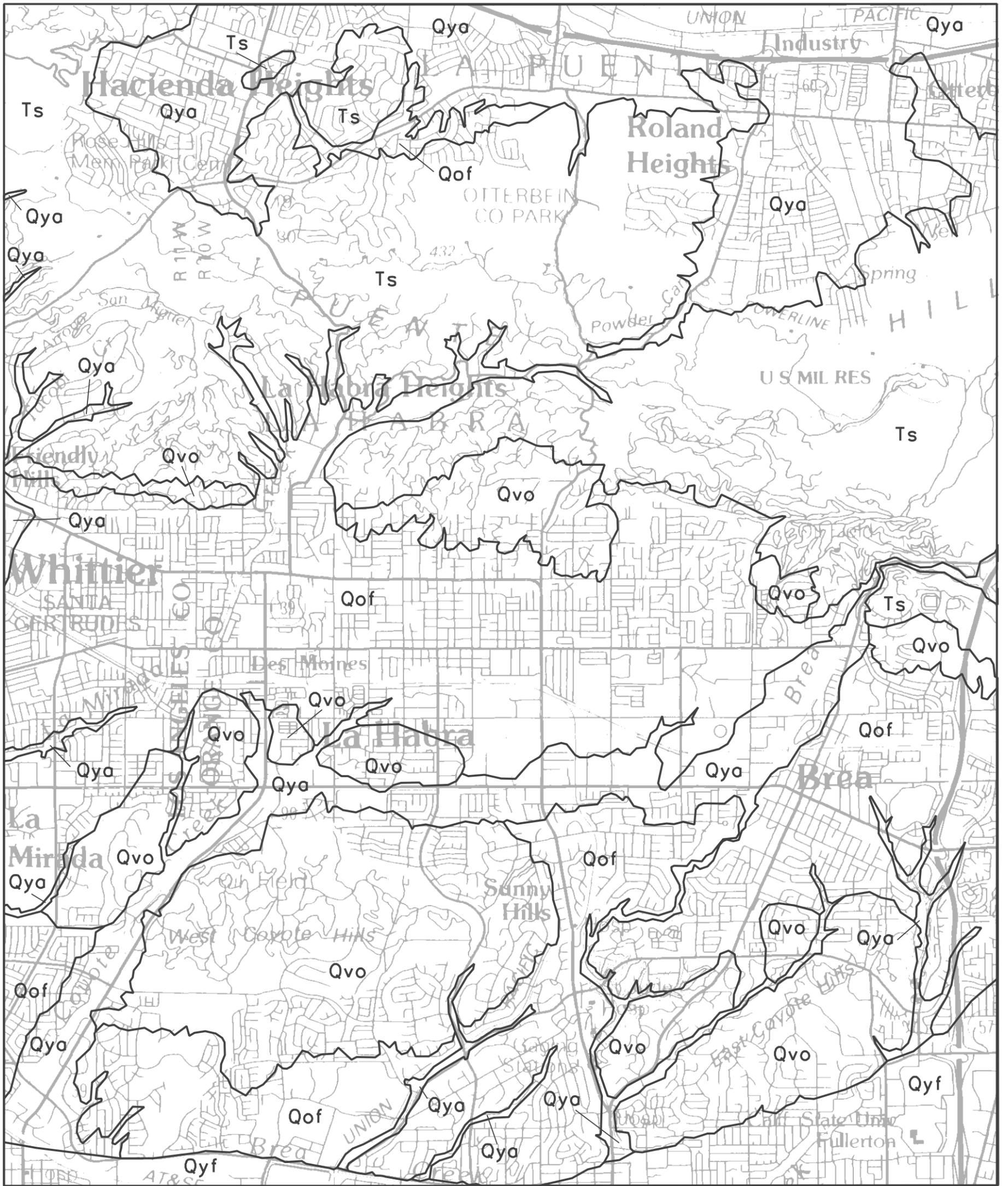


Plate 1.1. Quaternary geology of La Habra 7.5-minute quadrangle.

Scale



1 Mile

EXPLANATION

- Qya: Younger Quaternary alluvium
- Qyf: Younger Quaternary alluvial fan
- Qof: Older Quaternary alluvial fan
- Qvo: Very old Quaternary sediments
- Ts: Tertiary sedimentary rocks



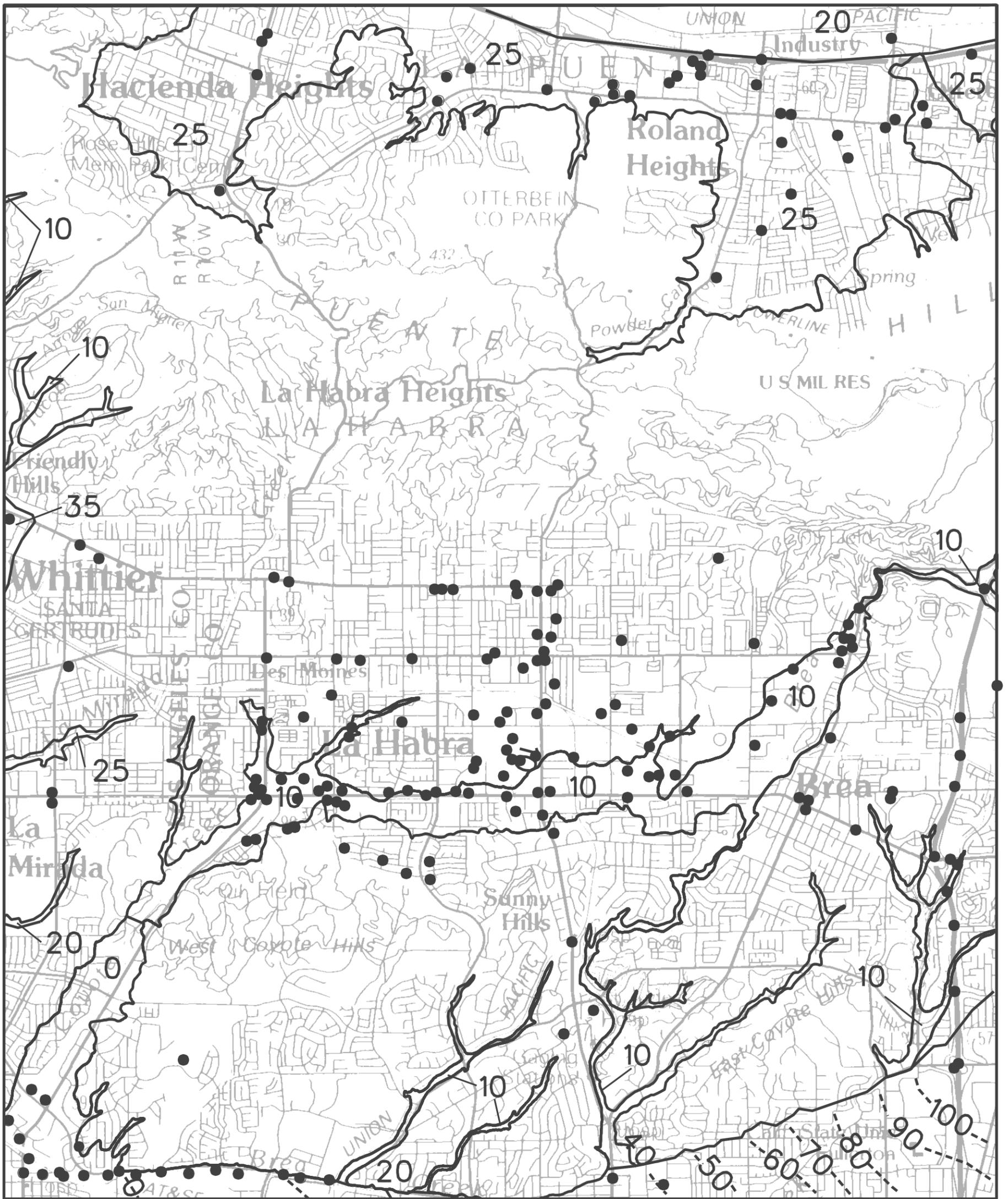
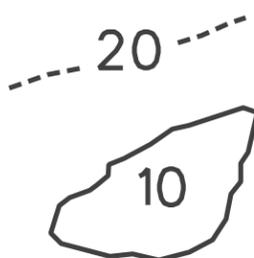


Plate 1.2 Map showing borehole locations and depths (in feet) to historically shallowest groundwater in areas underlain by younger Quaternary sediments in the La Habra quadrangle.

Scale

One Mile

EXPLANATION



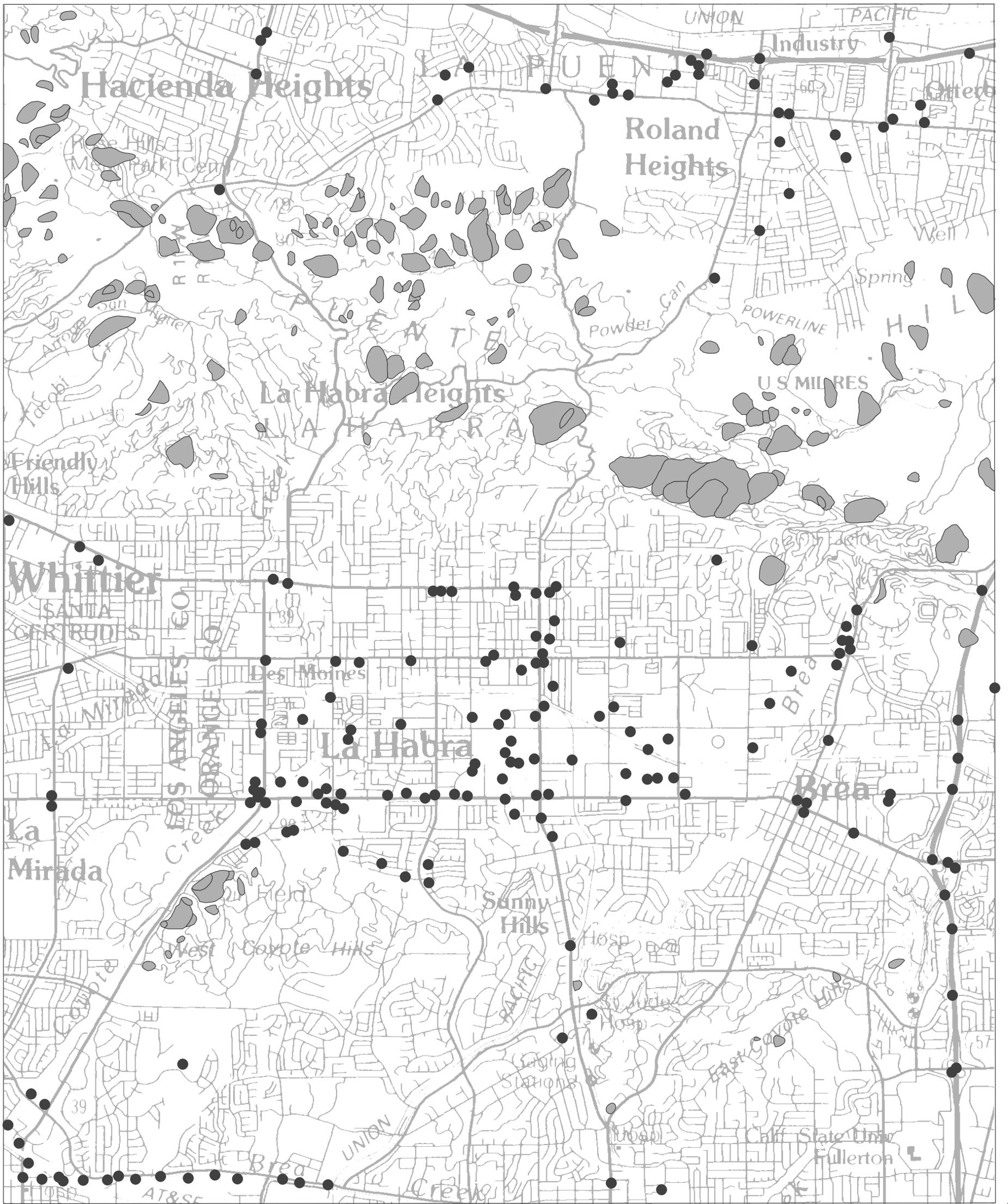
Contour interval depth (in feet) to historic high groundwater.

Depth (in feet) to historic high groundwater within defined area.

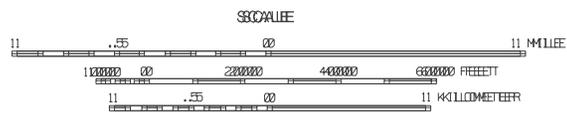
● Borehole Location



118° 00'
34° 00'



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



- Shear test sample location
- Landslide

Plate 2.1 Landslide inventory, shear test sample locations, and areas of significant grading, La Habra 7.5-minute quadrangle.