SEISMIC HAZARD ZONE REPORT 028

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

1998

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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ILLUSTRATIONS

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Long Beach 7.5-minute Quadrangle, Los Angeles County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 58 square miles at a scale of 1 inch = 2,000 feet.

The onshore portion of the oversize Long Beach Quadrangle includes portions of the cities of Long Beach (including the communities of Belmont Shore, Naples, Los Altos, Bixby Knolls, and North Long Beach), Bellflower, Lakewood, Carson, Compton, Signal Hill, and the City of Los Angeles (including the communities of Wilmington, and East San Pedro). The remainder of the quadrangle consists of unincorporated Los Angeles County land, such as Rancho Dominguez, or U.S. Government facilities. The quadrangle consists predominantly of the low, gently sloping to nearly level coastal plain of the southern Los Angeles Basin. The Los Angeles River, which empties into San Pedro Bay just east of the Port of Long Beach, and the Dominguez Channel, which joins the Cerritos Channel in the Los Angeles Harbor are the major drainage courses. The only upland areas are the Dominguez Hills and Signal Hill, which are surface manifestations of the Newport-Inglewood Fault Zone. Elevations range from sea level to about 350 feet near the crest of Signal Hill. The Long Beach Freeway (Interstate Highway 710), San Diego Freeway (Interstate Highway 405), Artesia Freeway (State Highway 91) and the Pacific Coast Highway (State Highway 1), all provide access to the quadrangle.

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

In the Long Beach Quadrangle the liquefaction zone is widespread due to shallow ground water and abundant young alluvium. The zone covers the lowland terrain adjacent to the hills along the Newport-Inglewood uplift, the beaches and areas of artificial fill associated with the harbor. The lack of steep terrain, except for a few slopes on Signal Hill and Reservoir Hill, results in only about 0.1% of the land (62 acres) in the Long Beach Quadrangle lying within the earthquake-induced landslide zone for the quadrangle.

How to view or obtain the map

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

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

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

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

INTRODUCTION

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

SECTION 1
LIQUEFACTION EVALUATION REPORT

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

By
Richard B. Greenwood

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 Long Beach 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, including the densely populated area encompassed by the Long Beach 7.5-minute Quadrangle.

METHODS SUMMARY

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

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill
- Construction of shallow ground-water maps showing the historically highest known ground-water levels
- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits
- Information on potential ground shaking intensity based on DMG probabilistic shaking maps

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

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Long Beach Quadrangle consist mainly of alluviated valleys and floodplains. 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 onshore portion of the oversize Long Beach Quadrangle covers an area of about 58 square miles in southwestern Los Angeles County. The map area includes portions of the cities of Long Beach (including the communities of Belmont Shore, Naples, Los Altos, Bixby Knolls, and North Long Beach), Bellflower, Lakewood, Carson, Compton, Signal Hill, and the City of Los Angeles (including the communities of Wilmington, and East San Pedro). The remainder of the quadrangle consists of unincorporated Los Angeles County land, such as Rancho Dominguez, or U.S. Government facilities.

The overview of the Los Angeles Basin in Greenwood (1995 a; 1995 b) describes the Los Angeles coastal plain as being bound on the north by the eastern Santa Monica Mountains, the Elysian Hills and Montebello Hills, and parts of the Puente Hills—which have been collectively described as overlying the Elysian Park Fold and Thrust Belt

(Hauksson, 1990). The basin is bound on the south by the Newport-Inglewood Fault Zone, which is manifested as a belt of primarily anticlinal hills that includes the Dominguez Hills, Signal Hill, and Alamitos Heights. The Orange County portion of the coastal plain is bound on the north by the inferred trace of the Norwalk Fault Zone and the late Pleistocene fan deposits associated with the adjacent anticlinal hills of the Coyote Hills Uplift (Greenwood and Morton, 1990). The southern portion of this coastal plain is underlain by the broad, northwest-plunging synclinal Los Angeles Basin, which includes up to 4200 feet of relatively unconsolidated Quaternary marine and non-marine sediments (Greenwood, 1980 b) and up to 170 feet of unconsolidated non-marine sediments (Fuller, 1980 a).

The Long Beach Quadrangle includes the broad southern margin of the Los Angeles Basin, which culminates abruptly with coastal hills and mesas associated with the Newport-Inglewood Fault Zone. In the Long Beach Quadrangle the uplift is locally represented by Dominguez Hill, Signal Hill, and Alamitos Heights. To the southeast, in the Newport Beach Quadrangle, coastal mesas expose marine terrace deposits, which are underlain by late Miocene to early Pleistocene marine sediments. Alamitos Gap and Dominguez Gap separate the coastal mesas in the Long Beach Quadrangle. These drainage gaps are deeply incised antecedent drainages of the latest Pleistocene to earliest Holocene ancestral Los Angeles River and San Gabriel River.

Access to various parts of the quadrangle is by means of Interstate Highway 710 (Long Beach Freeway), State Route 91 (Artesia Freeway), and Interstate Highway 405 (San Diego Freeway). The Pacific Coast Highway (State Highway 1) cuts across the southern portion of the map. The quadrangle is also transected by many major streets.

GEOLOGY

Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. A geologic map of late Quaternary alluvial deposits, digitally compiled by the Southern California Areal Mapping Project (SCAMP, 1995), was used to evaluate the distribution and character of young, unconsolidated sediments exposed in the Long Beach Quadrangle. This geologic map relied extensively on early soil surveys (Nelson and others, 1919), to which geologic nomenclature was applied. Additional detail was added from the Long Beach 1:100,000-scale digital geologic map, prepared by the California Division of Mines and Geology (Bezore and others, unpublished).

Quaternary geologic contacts received minor modifications in accordance with early edition 1:62,500-scale topographic maps (Downey, 1902), 1:24,000-scale topographic maps (Clearwater, 1925; Wilmington, 1925), 1:20,000-scale topographic maps (Compton, 1942; Long Beach, 1942), and old regional soils maps (Nelson and others, 1919). Stratigraphic nomenclature was revised to follow the format developed by

SCAMP (Morton and Kennedy, 1989). The revised geologic map that was used in this study of liquefaction susceptibility is included as Plate 1.1.

The mapped units fall into five basic sediment types: 1) late Pleistocene marine terrace deposits and overlying veneer of older alluvium (Qoa), dense silty sands that cover the Dominguez Hills, Signal Hill, and Alamitos Heights; 2) Holocene soft silt, sandy silt, and sand within and a minor drainage along the northeastern edge of the Dominguez Hills (Qya1); 3) Holocene alluvial soft clay, silt, silty sand, and sand of distal fan deposits (Qya2), associated with the active Los Angeles River, Rio Hondo, and San Gabriel River alluvial systems and local, discontinuous drainages associated with the Bouton Lakes and Hamilton Bowl; and 4) large areas of artificial fill (af), which cover extensive modern beach sands and lagoonal deposits.

Prior to the development of Alamitos Bay, and the greater Long Beach and Los Angeles Harbor complexes, extensive estuarine deposits were present at the mouths of the present Los Angeles River and San Gabriel River. The organic tidal muds therein were extensively dredged and covered in many places with artificial fill (af).

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of flatland deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. For this investigation, more than 220 borehole logs were studied. Subsurface data used for this study include the database compiled for previous liquefaction studies in Los Angeles County (Tinsley and Fumal, 1985; Tinsley and others, 1985) and in the Long Beach area by Martin and Andrews (1995). Additional data were collected for this study from the files of the Southern California District of the California Department of Water Resources, Caltrans, California Water Quality Control Board, and the California State Architect's Office. Data from previous databases and additional borehole logs were entered into the DMG GIS database. Locations of all exploratory boreholes considered in this investigation are shown on Plate 1.2. Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are necessarily generalized, but give the most commonly encountered characteristics of the units (see Table 1.1).

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit and commonly are used as an index of density. Many geotechnical investigations record SPT data, including the number of blows by a 140-pound drop weight required to drive a sampler of specific dimensions one foot into the soil. Recorded blow counts for non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), were converted to SPT-equivalent blow count values and entered into the DMG GIS. The actual and converted SPT blow counts were normalized to a common reference effective overburden pressure of 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 $(N_1)_{60}$.

Older alluvium (Qoa) covering marine terrace deposits

Older alluvium overlies, but is not differentiated from, late Pleistocene terrace deposits on the Dominguez Hills, Signal Hill, and Alamitos Heights. Ground water is deep throughout these areas, so no extensive effort was made to collect subsurface data. They are generally described as dense to very dense sand and silty sand deposits.

Young alluvial deposits (Qya1)

Holocene soft silt, sandy silt, and sand within a minor drainage along the northeastern edge of Dominguez Hills.

Younger alluvial deposits (Qya2)

Younger alluvial deposits associated with the lowlands of the Los Angeles River, Rio Hondo, and San Gabriel River were not subdivided into "alluvium" and "floodplain" deposits. These deposits consist of Holocene alluvial soft clay, silt, silty sand, and sand. The unit also includes deposits in discontinuous drainages associated with the Bouton Lakes and Hamilton Bowl.

Artificial fill (af)

Artificial fill in the Long Beach Quadrangle consists of undifferentiated young and old fills associated with development of the greater Long Beach and Los Angeles Harbor complexes and margins of Alamitos Bay.

Geologic Map Unit	Material Type	Consistency	Liquefaction Susceptibility
af, artificial fill	sand, silty sand	soft to dense	high
Qya2, younger alluvium	clay, silt, silty sand, and sand	soft	high
Qya1, young alluvial deposits	silt, sandy silt, and sand	soft	high
Qoa, old alluvium	silty sand, minor gravel	dense-very dense	low

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

Subsurface Stratigraphic Analysis

An analysis of the local subsurface geology reveals a dynamic interaction between the Los Angeles River, Rio Hondo, and San Gabriel River fans and the coastal mesas, whose elevation is related to deformation along the Newport-Inglewood Fault Zone. The reference time-frame of the depositional regime is controlled by the last "low stand" of sea level -- approximately 20,000 years ago (McNeilan and others, 1996). During that time, local drainages became incised because of lower base levels (for example, sea level was 100's of feet below the modern level).

Although the immediate scope of the present study focuses on geologic conditions within 50 feet of the ground surface, an appreciation of the underlying aquifers assists in establishing a temporally constrained (Holocene) stratgraphic framework for determining the nature and distribution of overlying, potentially liquefiable sediments.

Latest Pleistocene to earliest Holocene (?) aquifers

The stratigraphic base of the Holocene is related to the most recent Pleistocene rise in sea level, which raised stream-base levels, that led to the deposition of fan sediments. This latest Pleistocene to earliest Holocene (?) fluvial backfilling of incised drainages controlled the initial distribution of coarse-grained sediments, locally named the Gaspur aquifer in Los Angeles County (Reagan, 1917). These depositional processes have been well documented in California State Department of Public Works (1952 a, 1952 b), Poland and others (1956), Poland (1959), and California Department of Water Resources (1961). The depth to base, thickness, and lateral distribution of the Gaspur aquifer were mapped by Poland (1956) and the staff of the California Department of Water Resources (1961), who showed the top of the Gaspur aquifer to be from less than 50 feet to approximately 90 feet deep.

Earliest Holocene to modern sediments

The distribution of Holocene sediments, as recorded in early editions of regional soil survey maps (Nelson and others, 1919), suggests that the Los Angeles River, Rio Hondo, and San Gabriel River have, during the recent past, moved back and forth across the Los Angeles County coastal plain from Los Angeles Harbor to Alamitos Bay. Historical accounts further support the conclusion that widespread sheet flooding has been the dominant depositional process associated with the Los Angeles River, Rio Hondo, and San Gabriel River until the construction of Whittier Narrows Dam (California Department of Water Resources, 1959).

Regional cross sections were constructed using Caltrans and underground tank borehole data, which allowed the definition of at least four and as many as six regional, repetitive, upward-fining sequences of fluvial sediments, with recognizable lateral continuity in the Orange County Coastal Plain (Greenwood, 1998). The cross-sectional models became better defined as local cases of crosscutting relationships and longitudinal facies changes also became apparent. Stratigraphic units were first identified via correlations of lithology and standard penetration tests (SPT) of deep CalTrans geotechnical boreholes (generally 60 to 80 feet. These detailed geotechnical borehole logs were placed in cross sections having a horizontal scale of 1 inch = 1000 feet and a vertical scale of 1 inch = 10 feet.

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 Long Beach 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 obtained from compiled geotechnical boreholes, environmental monitoring wells, and water-well logs. The depths to first-encountered unconfined ground water were plotted onto a map (Plate 1.2) 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.

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 discussed below and summarized on Table 1.1.

Older alluvium (Qoa) covering marine terrace deposits

Older alluvium overlies, but is not differentiated from, late Pleistocene terrace deposits on the Dominguez Hills, Signal Hill, and Alamitos Heights. Ground water is deep throughout these areas, so no extensive effort was made to collect subsurface data. They are generally described as dense to very dense sand and silty sand deposits with low liquefaction susceptibility.

Young alluvial deposits (Qya1)

Holocene soft silt, sandy silt, and sand within and a minor drainage along the northeastern edge of the Dominguez Hills. Where this unit is saturated, liquefaction susceptibility is high.

Younger alluvial deposits (Qya2)

Younger alluvial deposits associated with the lowlands of the Los Angeles River, Rio Hondo, and San Gabriel River were not subdivided into "alluvium" and "floodplain" deposits. These deposits consist of Holocene alluvial soft clay, silt, silty sand, and sand. This unit also includes discontinuous drainages associated with the Bouton Lakes and Hamilton Bowl. Where this unit is saturated, liquefaction susceptibility is high.

Artificial fill (af)

Artificial fill in the Long Beach Quadrangle consists of undifferentiated young and old fills associated with development of the greater Long Beach and Los Angeles Harbor complexes and environs of Alamitos Bay. These artificial fills commonly overlie young alluvial or estuarine deposits. Because the artificial fills are usually too thin to affect the liquefaction hazard, and the underlying estuarine and alluvial deposits have a high liquefaction susceptibility, they are assumed to have a high susceptibility to liquefaction.

LIQUEFACTION OPPORTUNITY

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

For the Long Beach Quadrangle, peak accelerations of 0.45 g to 0.59 g, resulting from earthquakes ranging in magnitude from 6.8 to 7.1, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion section (3) of this report for further details.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, DMG's analysis uses the Idriss magnitude scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: $FS = (CRR / CSR) * MSF$. FS, therefore, is a quantitative measure of liquefaction potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures. The DMG liquefaction analysis program calculates an FS for each geotechnical sample for which blow counts were collected. Typically, multiple samples are collected for each borehole. The lowest FS in each borehole is used for that location. FS values vary in reliability according to the quality of the geotechnical data used in their calculation. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

Of the 220 geotechnical borehole logs reviewed in this study (Plate 1.2), 145 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.

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 Long Beach Quadrangle is summarized below.

Areas of Past Liquefaction

In the Long Beach Quadrangle, numerous effects attributed to liquefaction were noted following the 1933 Long Beach earthquake including numerous leaks in gas lines, water mains broken, roads cracked, and displaced pavement (Barrows, 1974).

Part of the Port of Los Angeles is situated in the southwesternmost corner of the Long Beach Quadrangle. During the 1994 Northridge earthquake significant damage occurred to facilities near Berths 121 to 126 and at Pier 300 (Stewart and others, 1994, p. 135). Features that developed at these localities, such as lateral spreading, settlement, and sand boils, manifested liquefaction (see Plate 1.2).

Artificial Fills

Artificial fill in the Long Beach Quadrangle consists of undifferentiated new and old fills associated with development of the greater Long Beach and Los Angeles Harbor complexes and environs of Alamitos Bay. Residential-related engineered fills are generally too thin to have an impact on liquefaction, but fills which overlie beach sands and estuarine deposits are more likely to be susceptible to liquefaction. Extensive low-lying areas of artificial fill have been included in liquefaction hazard zones.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data were evaluated for zoning based on the liquefaction potential determined by the Seed-Idriss Simplified Procedure. The marine terrace deposits and/or older alluvial covering exposed in the Long Beach Quadrangle (Qoa) generally have a dense consistency, high fines content, or deep ground water and accordingly have not been included in liquefaction hazard zones. Young alluvial deposits (Qya1) commonly have layers of soft silt, sandy silt, and sand. Where these deposits are saturated, they are included in a liquefaction hazard zone. Younger alluvial deposits (Qya2) commonly have layers of soft clay, silt, silty sand and sand. Where these deposits are saturated, they are included in a liquefaction hazard zone. Artificial fills, which overlie beach sands and estuarine deposits, are likely to be susceptible to liquefaction. These extensive low-lying areas of artificial fill have been included in liquefaction hazard zones.

Young alluvial deposits (Qya1)

Holocene soft silt, sandy silt, and sand within and a minor drainage along the northeastern edge of the Dominguez Hills. Where this unit is saturated, liquefaction susceptibility is high and accordingly, these occurrences have been included in liquefaction hazard zones.

Younger Alluvial Deposits (Qya2)

Younger alluvium associated with the lowlands of the Los Angeles River, Rio Hondo, and San Gabriel River were not subdivided into “alluvium” and “floodplain” deposits. These deposits consist of Holocene alluvial soft clay, silt, silty sand, and sand. This unit also includes discontinuous drainages associated with the Bouton Lakes and Hamilton Bowl. Where this unit is saturated, liquefaction susceptibility is high and accordingly, these occurrences have been included in liquefaction hazard zones.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

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

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PURPOSE

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

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Long Beach 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 Long Beach 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 Long Beach 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 Long Beach 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 onshore portion of the oversize Long Beach Quadrangle covers an area of about 58 square miles in southwestern Los Angeles County. The map area includes portions of the cities of Long Beach (including the communities of Belmont Shore, Naples, Los Altos, Bixby Knolls, and North Long Beach), Bellflower, Lakewood, Carson, Compton, Signal Hill, and the City of Los Angeles (including the communities of Wilmington, and East San Pedro). The remainder of the quadrangle consists of unincorporated Los Angeles County land, such as Rancho Dominguez, or U.S. Government facilities.

Topographically, the Long Beach Quadrangle consists predominantly of the low, gently sloping to nearly level coastal plain of the southern Los Angeles Basin. The Los Angeles River, which empties into San Pedro Bay just east of the Port of Long Beach, and the Dominguez Channel, which joins the Cerritos Channel in the Los Angeles Harbor are the major drainage courses in the quadrangle. The only upland areas in the quadrangle are the Dominguez Hills and Signal Hill, which are surface manifestations of the Newport-Inglewood Fault Zone. Elevations range from sea level to about 350 feet near the crest of Signal Hill.

The Long Beach Freeway (Interstate Highway 710), San Diego Freeway (Interstate Highway 405), Artesia Freeway (State Highway 91) and the Pacific Coast Highway (State Highway 1), all provide access to the quadrangle.

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 Long Beach 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.

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

GEOLOGY

Bedrock and Surficial Geology

For the Long Beach Quadrangle, a geologic map at an approximate scale of 1:295,000 was published by Tinsley and others (1985). This map was enlarged to a scale of 1:24,000 and supplied to DMG by the U.S. Geological Survey. These maps were scanned into the DMG GIS system and digitized, and formed the basis of the geologic map used in this investigation. Additional geologic maps covering the Long Beach Quadrangle include: Poland and Piper (1956) at a scale of 1:31,680; Randell and others (1983) at a scale of 1:145,500; and Bezore and others, (unpublished) at a scale of 100,000. The digital geologic map was modified to reflect the most recent mapping in the area and to include interpretations of observations made during the aerial photograph landslide inventory and field reconnaissance. 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 Long Beach Quadrangle is underlain entirely by Quaternary sedimentary deposits. These deposits can be divided into two broad types; the lower to upper Pleistocene consolidated sediments of the hills, mesas and older plains, and Holocene unconsolidated sediments of the gaps and younger plains.

The oldest deposits exposed in the study area are lower to upper Pleistocene undifferentiated older alluvial deposits (Qoa). The lower Pleistocene deposits consist of the San Pedro Formation, not differentiated on the geologic map, that forms small exposures on Signal Hill and is comprised of sand, gravel, silt and clay. The upper Pleistocene deposits underlie three parts of the study area: 1) the Dominguez Hills and most of Signal Hill; 2) the Torrance Plain, which is the raised and dissected, generally gently eastward- to southeastward-sloping mesa along the western margin of the quadrangle, north of Wilmington, south of the San Diego Freeway, and west of the Dominguez Channel; and 3) the Long Beach Plain, which is the raised and dissected, generally north-, east- and/or west-sloping mesa. The Long Beach Plain extends south of Signal Hill to the sea cliff and toward the west to the stream cut bluffs that delineate the edge of the mesa, generally along Long Beach Boulevard or the Los Angeles River, and north and east of Signal Hill to where the slope of the land changes from eastward, on the mesa, to southward on the adjacent younger alluvial plain.

The upper Pleistocene deposits consist of three units that are not differentiated on the geologic map. The oldest deposits are unnamed deposits of silt, sand and gravel that are inferred to crop out only locally at the edges of the mesas. The next youngest unit is the Palos Verdes Sand, which consists of marine sand and some pebble gravel that crops out locally at the edges of the mesas. The youngest unit is the terrace cover deposits that consist of mostly nonmarine reddish-brown sand.

Holocene unconsolidated alluvial sediments (Qya2) deposited by the modern rivers, such as the Los Angeles River and lesser creeks, underlie the balance of the quadrangle, exclusive of artificial-fill areas. These deposits underlie the flatlands in four parts of the quadrangle: 1) the relatively planar, downstream, gently southward-sloping flatlands adjacent to the Los Angeles River and between the flanking mesas, in the area called Dominguez Gap; 2) the relatively planar, gently southeastward-sloping flatlands that are tributary to the Dominguez Gap along the western quadrangle boundary, south of the Dominguez Hills and north of the Dominguez Channel; 3) the relatively planar, gently southward-sloping alluvial apron to the north and east of the mesa containing the Long Beach Plain, called the Downey Plain; and 4) in an undrained depression on the Long Beach Plain just south of Signal Hill.

Modern artificial fill (af) is mapped extensively throughout the Los Angeles Harbor facilities. A more detailed description of the artificial fill is presented in the Liquefaction portion (Section 1) of this report.

Structural Geology

The Newport-Inglewood Fault Zone dominates the geologic structure of the Long Beach Quadrangle. The northwest-trending Newport-Inglewood Fault Zone is marked at the surface by low eroded scarps along en-echelon faults and by a northwest-trending chain of elongated low hills and mesas that extend from Newport Bay to Beverly Hills, (Yerkes and others, 1965; Barrows, 1974). The major fault strands within the zone in the Long Beach Quadrangle include: the Cherry Hill Fault; Pickler Fault; Northeast Flank Fault; Reservoir Hill Fault; and the Seal Beach Fault. The orientation of structural elements of the zone is generally attributed to right-lateral, strike-slip faulting at depth.

In the Long Beach Quadrangle, the Dominguez Hills and Signal Hill are uplifts along the Newport-Inglewood Fault Zone. The Dominguez Hills are dome-shaped, whereas Signal Hill is an elongated, asymmetric, faulted anticline that trends about N 55 W.

In the San Pedro Bay and harbor areas of Los Angeles and Long Beach the Wilmington Structural Complex consists of a complexly faulted broad anticline. Major faults in the complex strike nearly north-south and dip east or west between 45 and 60 degrees. Typically, they show normal dip-slip displacement of a few hundred feet (Randell and others, 1983).

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Long Beach Quadrangle was prepared by combining field observations, analysis of aerial photos, and interpretation of landforms on current and older topographic maps. However, no landslides that meet the mapping criteria established by DMG were identified in the Long Beach Quadrangle.

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 Long Beach Quadrangle geologic map were obtained from the files of Leighton and Associates and DMG files of Environmental Impact Reports (see Appendix A). The locations of rock and soil samples taken for shear testing by consultants are shown on Plate 2.1.

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

LONG BEACH QUADRANGLE
SHEAR STRENGTH GROUPINGS

	Formation Name	Number Tests	Mean phi value	Group phi Mean/Median (deg.)	Group C Mean/Median (psf)	Phi Values Used in Stability Analyses	Similar Lithology: no data
GROUP 1	af	5	33				Qvom/c
	Qvom/a	8	34.9	**34.4/35**	**103/100**	**34**	Qvom/s
GROUP 2	Qyf/a	27	30.2	**30.2/30**	**186/135**	**30**	Qyf/c, Qyf/s

Table 2.1. Summary of the Shear Strength Statistics for the Long Beach Quadrangle.

SHEAR STRENGTH GROUPS FOR THE LONG BEACH QUADRANGLE

GROUP 1	GROUP 2
af	Qyf/a
Qvom/a	Qyf/s
Qvom/s	Qyf/c
Qvom/c	

Table 2.2. Summary of the Shear Strength Groups for the Long Beach 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 Long Beach 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:	6.8 to 7.1
Modal Distance:	2.5 to 3.4 km
PGA:	0.43 to 0.55 g

The strong-motion record selected for the slope stability analysis in the Long Beach Quadrangle was the Channel 3 (N 35° E 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 of 0.59 g. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

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

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a 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 Long Beach Quadrangle.

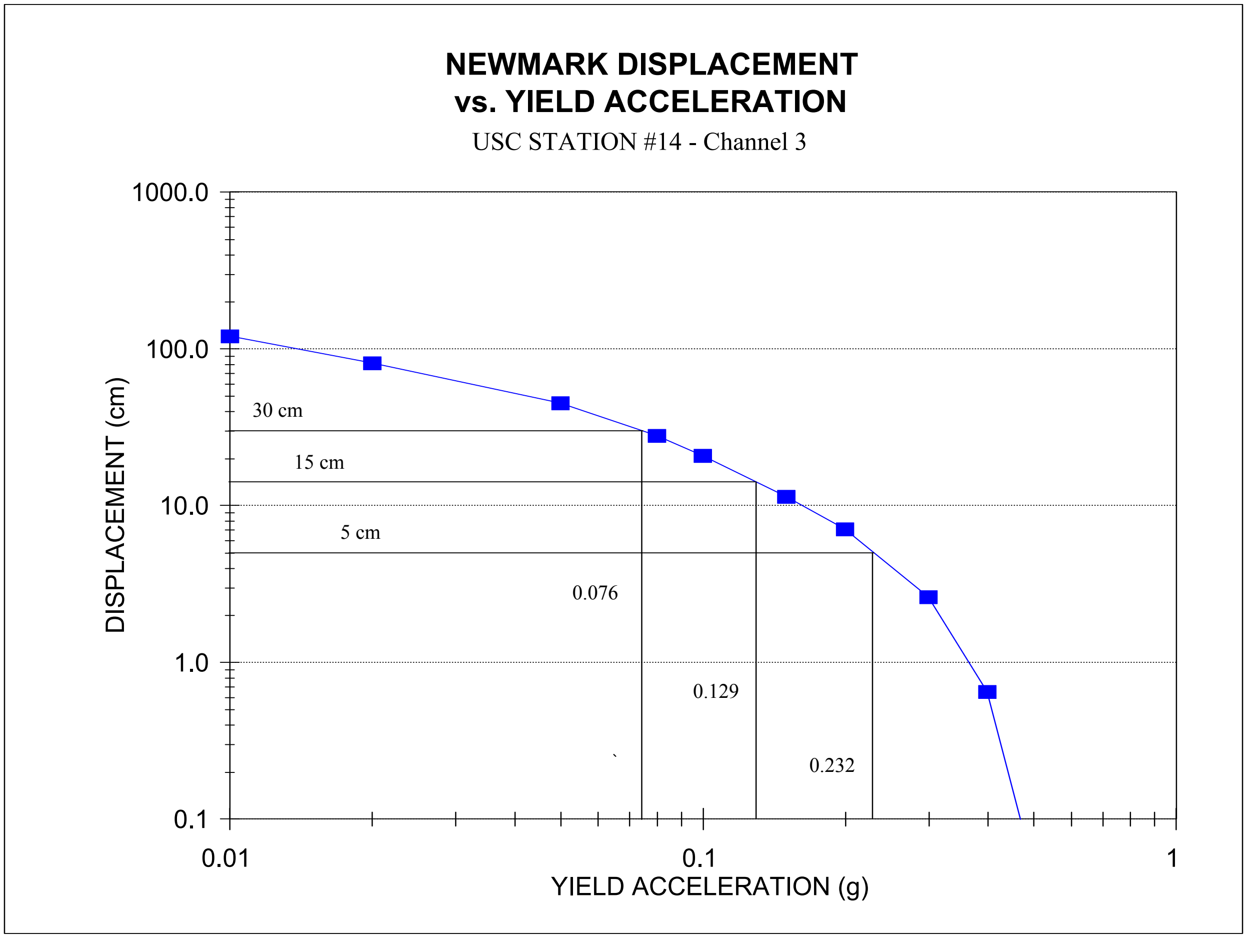

Figure 2.1. Yield Acceleration vs. Newmark Displacement for th USC Station # 14 Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake.

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 0.076g, 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.

LONG BEACH QUADRANGLE
SUSCEPTIBILITY MATRIX

		SLOPE CATEGORY (percent)					
		I	II	III	IV	V	VI
Geologic Material Strength Group	Mean Phi	0-28	29-39	40-44	45-55	56-61	>61
1	34	VL	VL	VL	L	M	H
2	30	VL	L	M	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Long Beach 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 2 is included for all slopes steeper than 28 percent.

2. Geologic Strength Group 1 is included for all slopes steeper than 44 percent.

This results in roughly 0.1% of the land (62 acres) in the Long Beach Quadrangle lying within the earthquake-induced landslide zone for the quadrangle. The zone is restricted to a few steep slopes on Signal Hill and Reservoir Hill.

ACKNOWLEDGMENTS

The authors thank staff from the City of Signal Hill and County of Los Angeles, Department of Public Works, Material Engineering Division for their assistance in obtaining geotechnical information used in the preparation of this report. Technical review of the methodology was provided by Bruce Clark, Randy Jibson, Robert Larson, Scott Lindvall, and J. David Rogers, who are members of the State Mining and Geology Board's Seismic Hazards Mapping Act Advisory Committee Landslides Working Group. At DMG, special thanks to Bob Moskovitz, Teri McGuire, Scott Shepherd and Barbara Wanish for their Geographic Information System operations support. Thanks also to Tim McCrink and Rick Wilson for help with geotechnical analysis and to Joy Arthur for designing and plotting the graphic displays associated with the earthquake-induced landslide zone map.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Division of Mines and Geology, Environmental Impact Reports File	**27**
Leighton and Associates	**13**
Total Number of Shear Tests	**40**

SECTION 3
GROUND SHAKING EVALUATION REPORT

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

By

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California Department of Conservation
Division of Mines and Geology
***Formerly with DMG, now with U.S. Geological Survey**

PURPOSE

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

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

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

EARTHQUAKE HAZARD MODEL

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

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

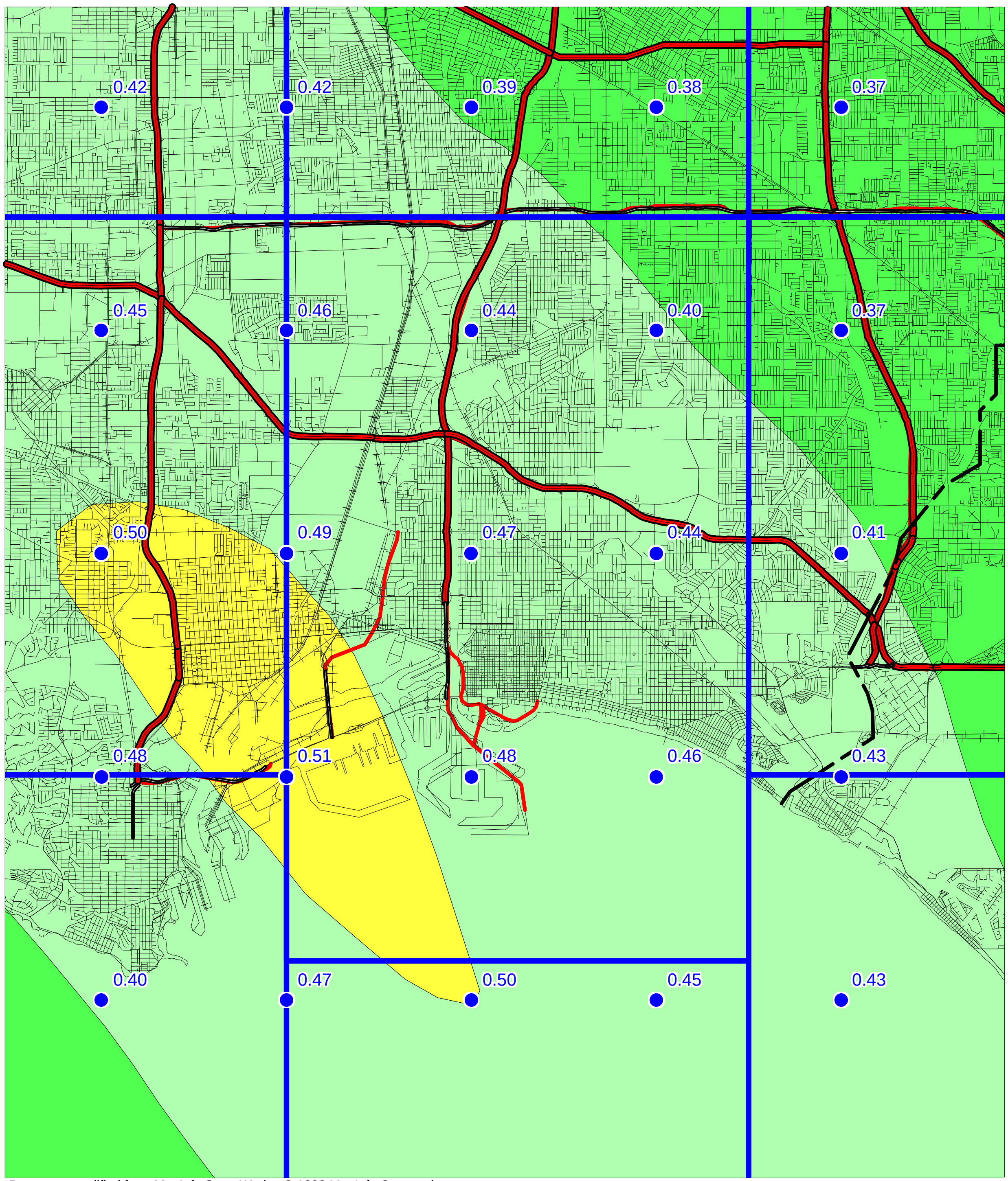
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

LONG BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

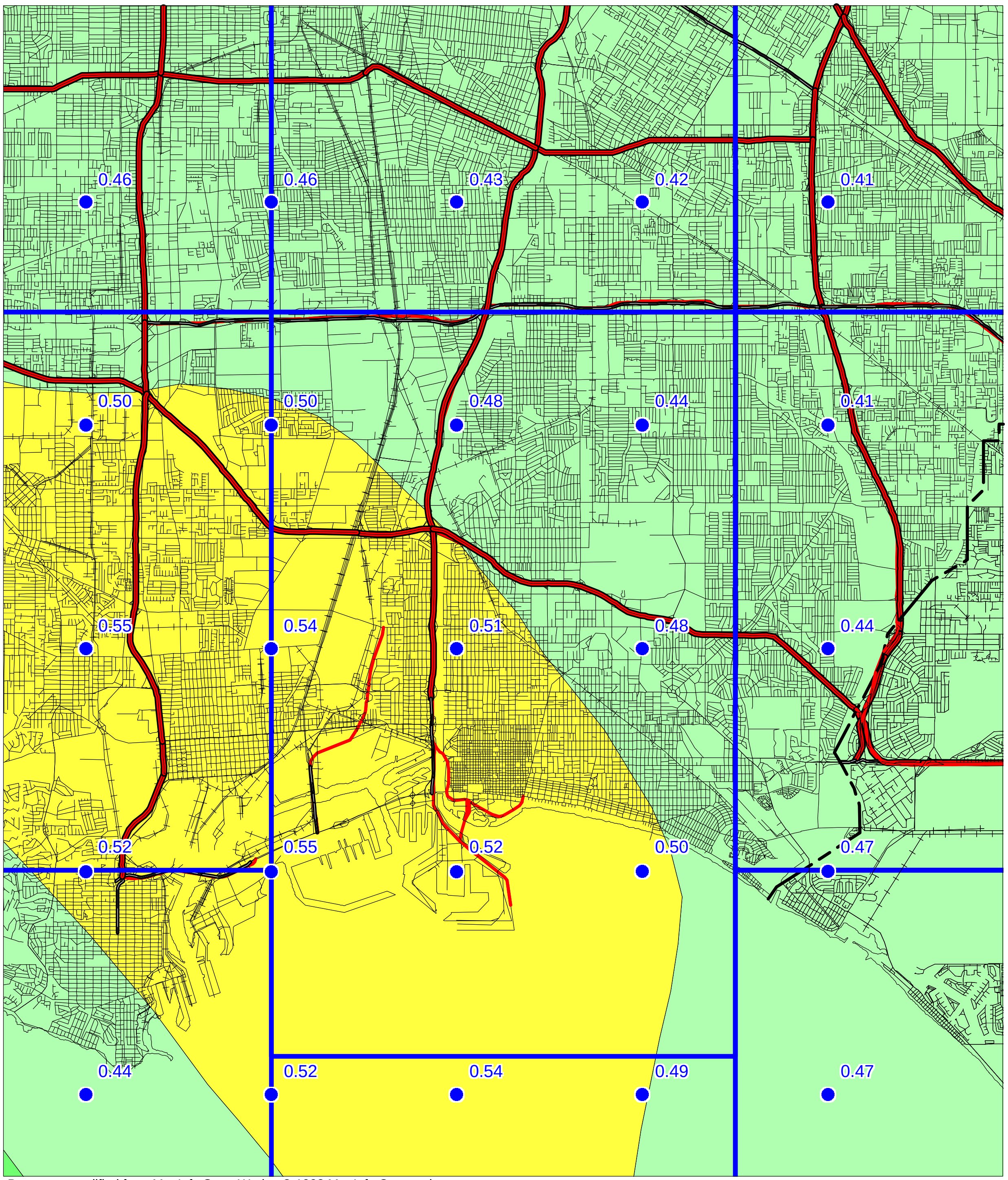
Figure 3.1

LONG BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

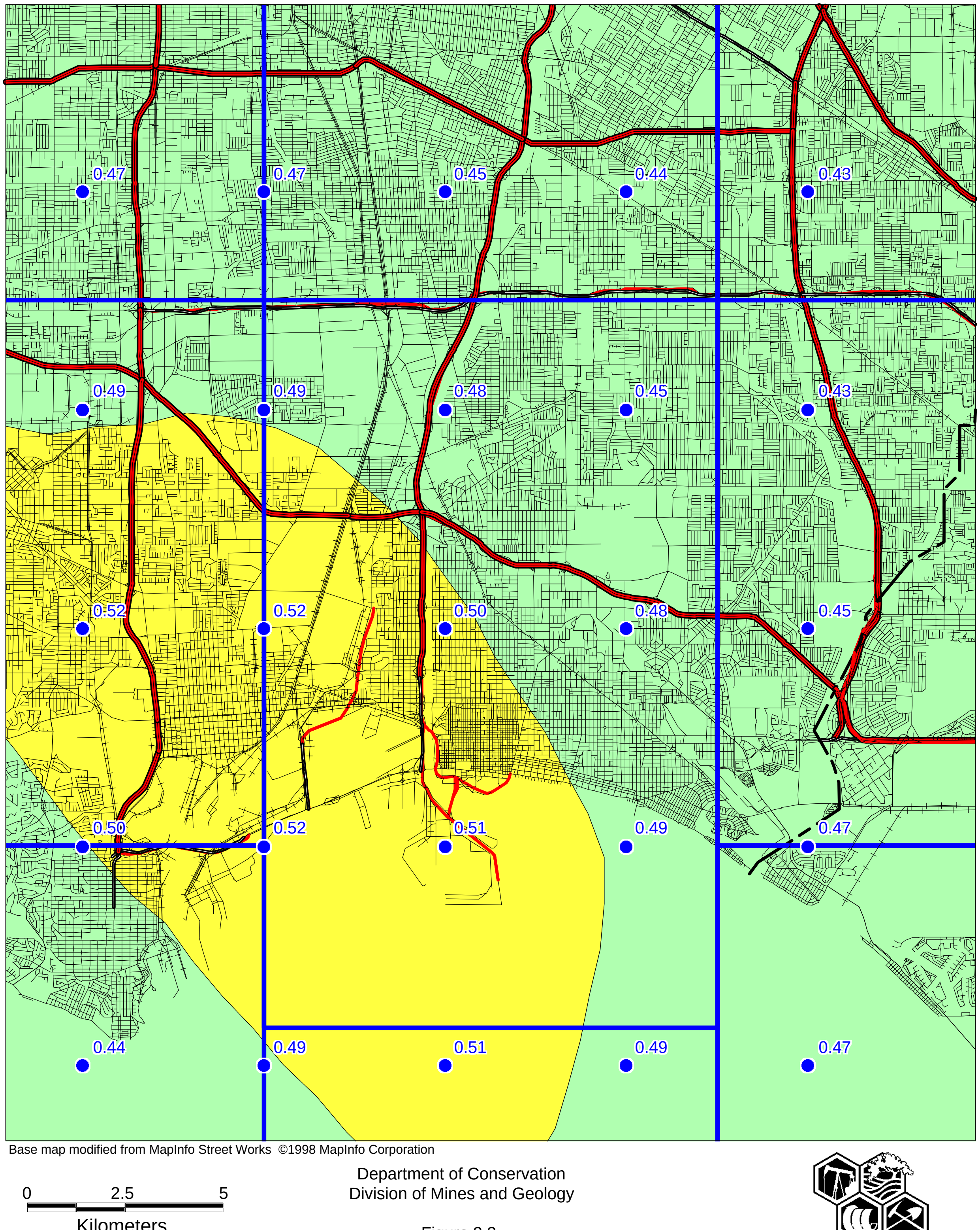
Figure 3.2

LONG BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



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.

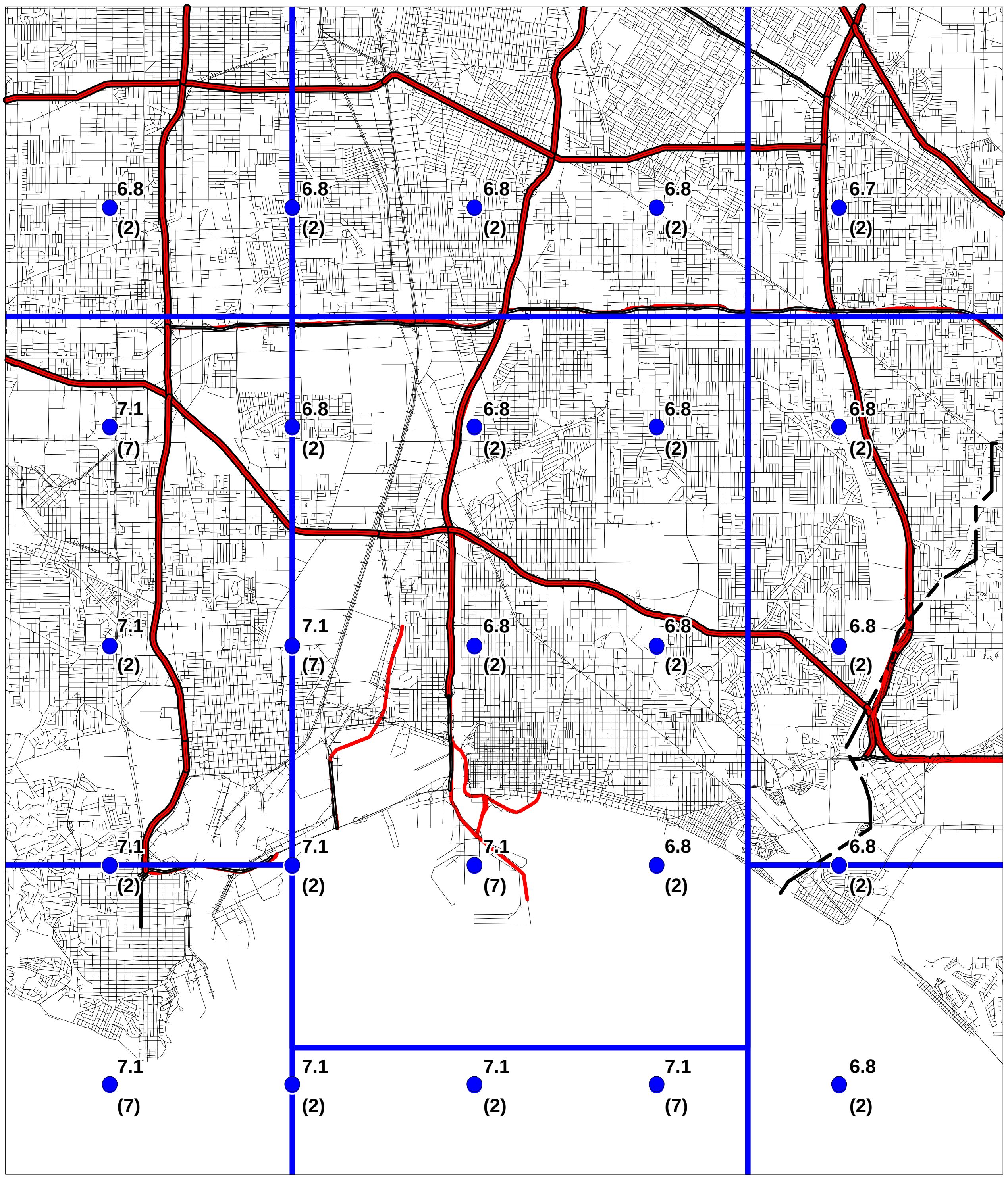
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss' weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

LONG BEACH 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

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

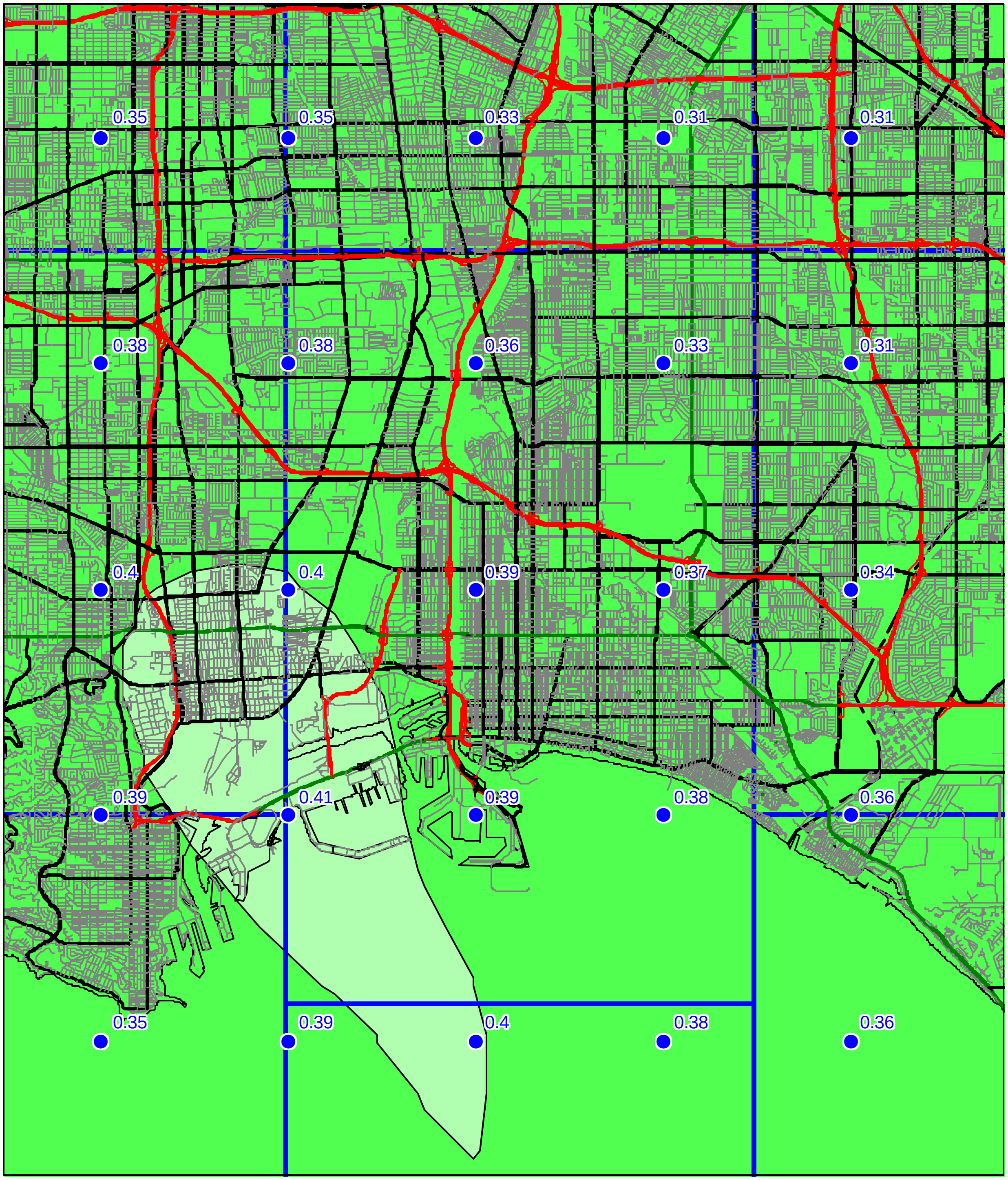
Figure 3.4

LONG BEACH 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

LIQUEFACTION OPPORTUNITY



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

Figure 3.5

USE AND LIMITATIONS

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

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

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

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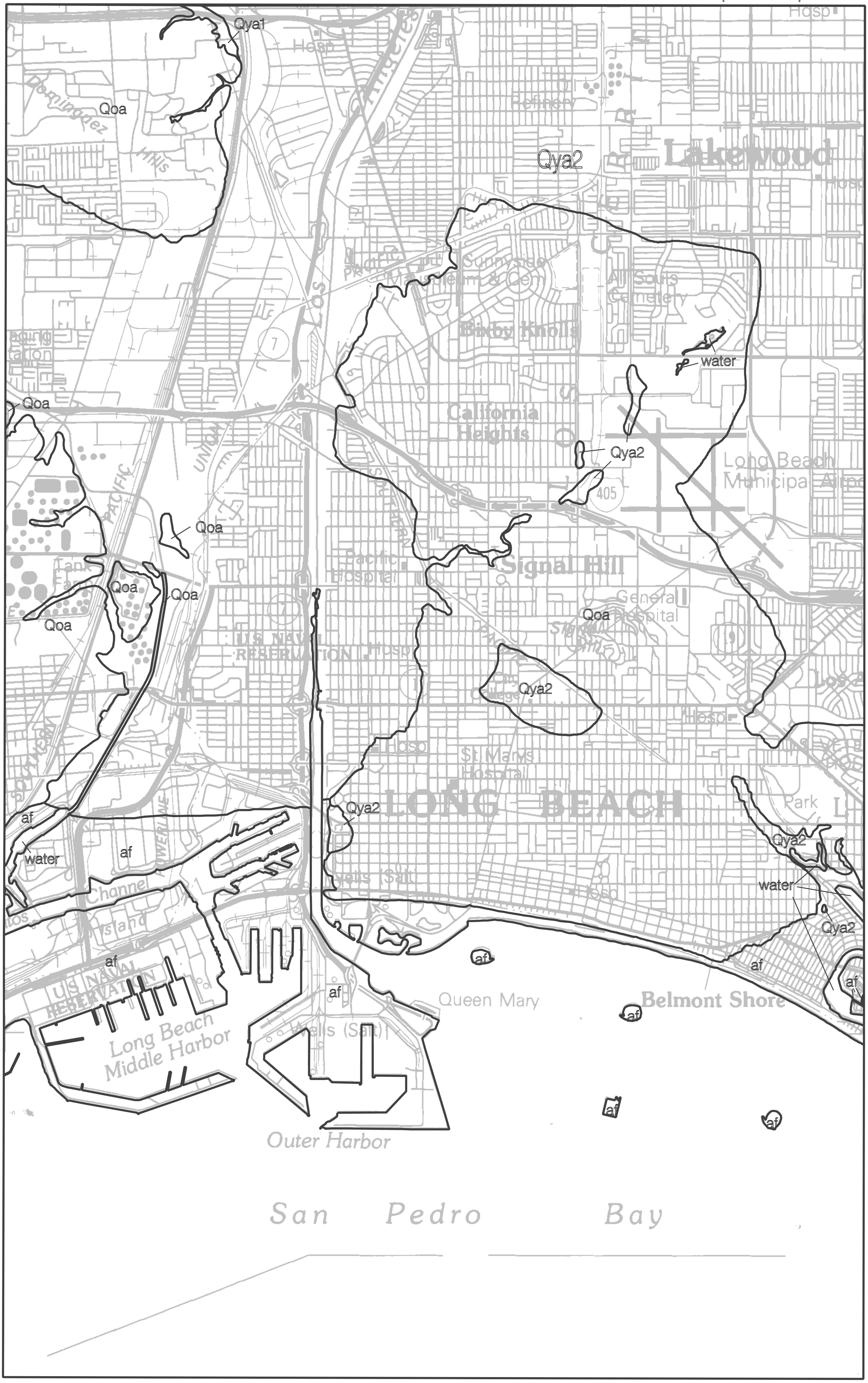


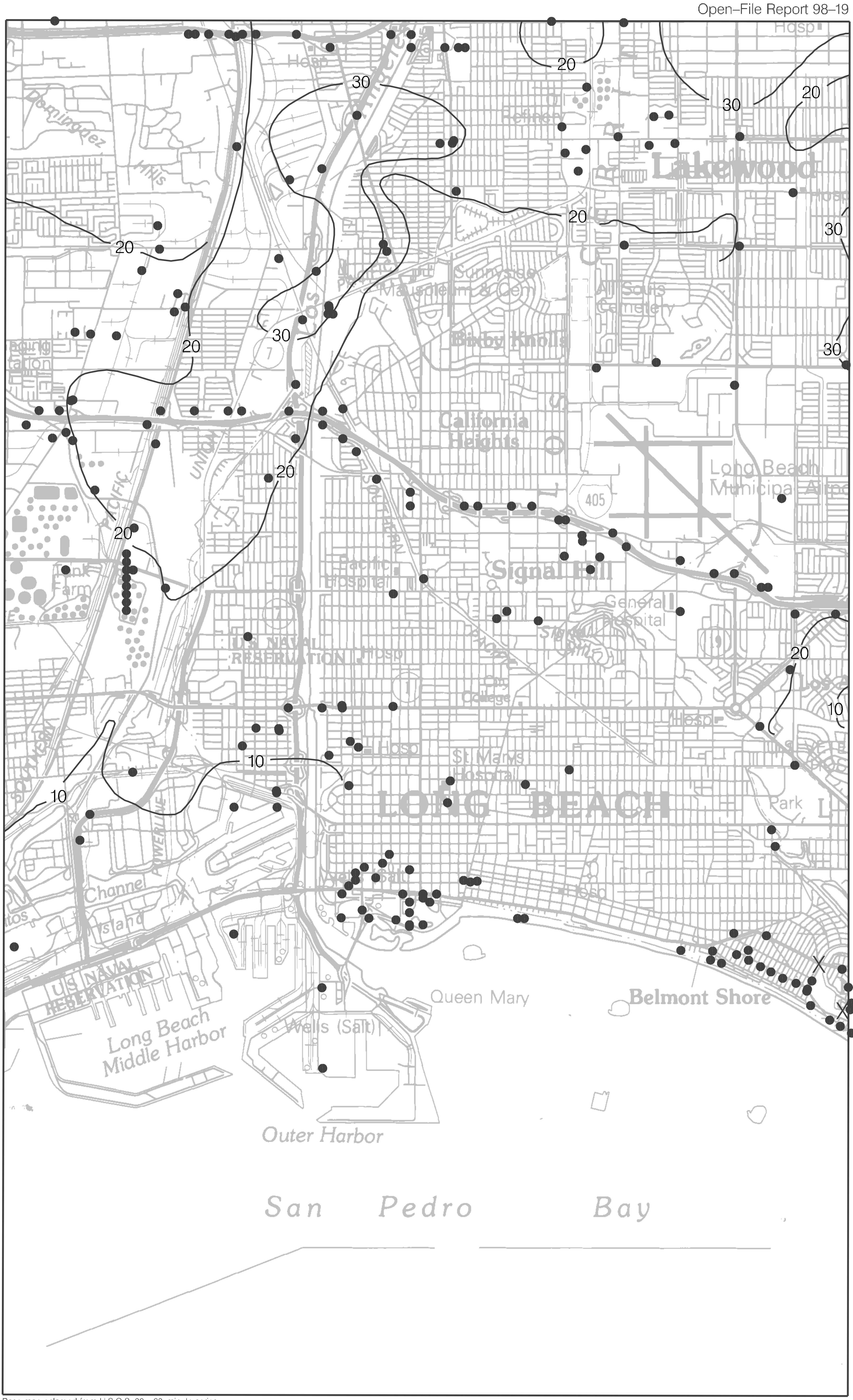
Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 1.1 Quaternary Geologic Map of the Long Beach Quadrangle.

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

ONE MILE

SCALE



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

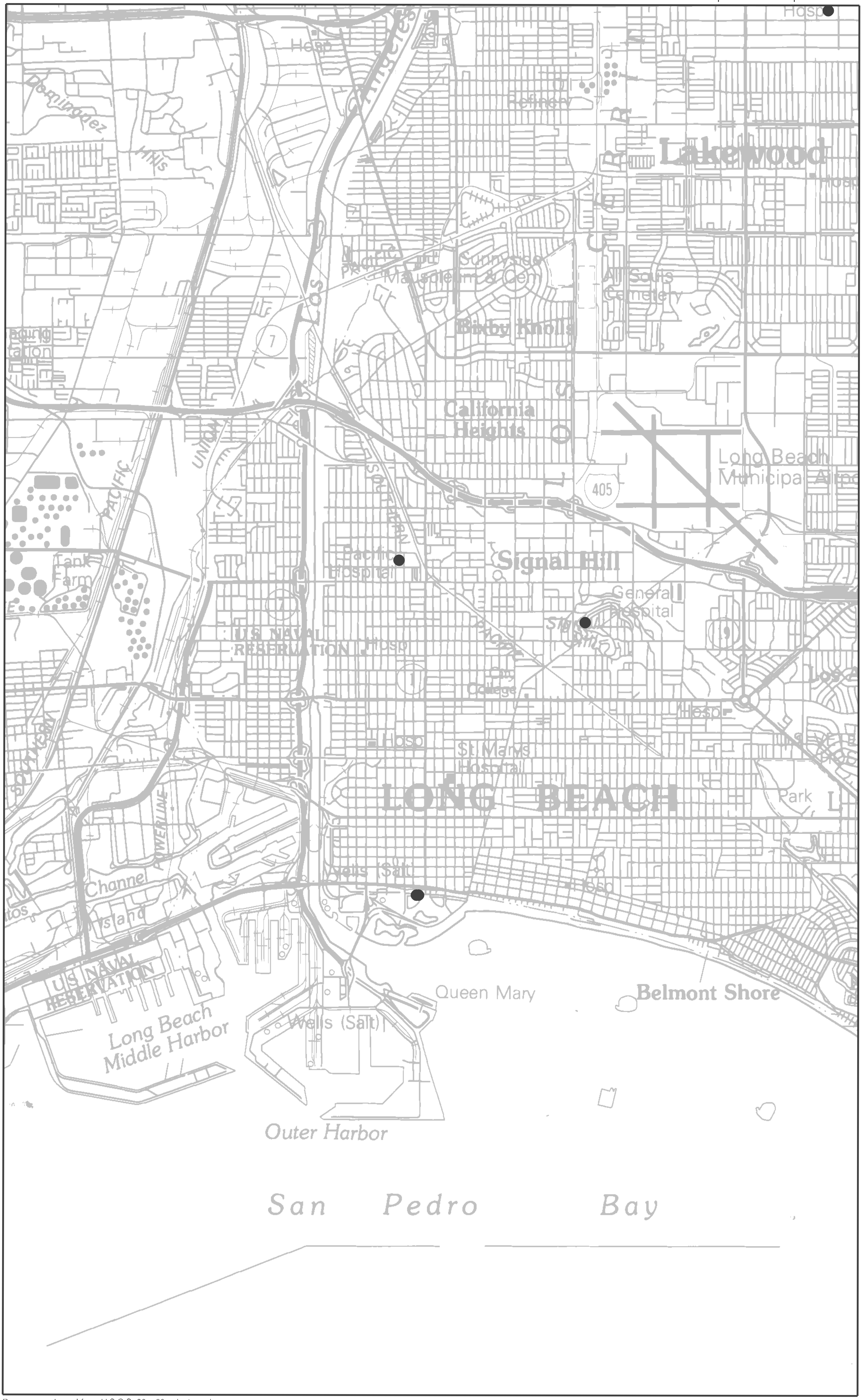
Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Long Beach Quadrangle.

● Borehole Site

30 Depth to ground water in feet

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

ONE MILE



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

Plate 2.1 Shear Test Sample Locations, Long Beach Quadrangle.

● Shear test sample location

ONE MILE

SCALE