

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

1998



DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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SEISMIC HAZARD ZONE REPORT 037

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LOS ANGELES AND ORANGE COUNTIES,
CALIFORNIA**

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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 Whittier 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 62 square miles at a scale of 1 inch = 2,000 feet.

The Whittier Quadrangle includes all or parts of the cities of Bellflower, Buena Park, Cerritos, Commerce, Downey, La Mirada, Montebello, Norwalk, Pico Rivera, Santa Fe Springs, and Whittier, as well as unincorporated areas of Los Angeles County. More than half the quadrangle is low-relief terrain of the Downey Plain. Northeast of Whittier is a portion of the Puente Hills where hilltops exceed 1000 feet in elevation. The main drainage courses within the quadrangle are the Rio Hondo and San Gabriel River, which flows southward across the entire quadrangle. Nearly the entire quadrangle is intensively urbanized. Major transportation routes traversing the Whittier Quadrangle include the Santa Ana Freeway (I-5), the San Gabriel River Freeway (I-605), the Artesia Freeway (State Highway 91), and the Century Freeway (I-105).

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.

The liquefaction zone covers more than half of the Whittier Quadrangle. It covers the Downey Plain and a strip southwest of Whittier where the slope of the alluvial fans from the Puente Hills flattens. Much of the hilly terrain in the small part of the Puente Hills that extends into the Whittier Quadrangle is in an earthquake-induced landslide zone, although only 3.5 percent of the entire quadrangle is in the 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 Whittier 7.5-minute Quadrangle.

SECTION 1

LIQUEFACTION EVALUATION REPORT

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

By
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California Department of Conservation
Division of Mines and Geology

PURPOSE

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

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Whittier 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, including areas in the Whittier 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 Whittier Quadrangle consist mainly of alluviated floodplains and canyons. 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 Whittier Quadrangle covers an area of about 62 square miles in eastern Los Angeles and northwestern Orange counties. The quadrangle includes all or parts of the cities of Artesia, Bellflower, Buena Park, Cerritos, Commerce, Downey, La Mirada, Montebello, Norwalk, Pico Rivera, Santa Fe Springs, and Whittier, as well as unincorporated areas of Los Angeles County. Major transportation routes traversing the Whittier Quadrangle include the Santa Ana Freeway (I-5), the San Gabriel River Freeway (I-605), the Artesia Freeway (State Highway 91), and the Century Freeway (I-105).

More than half of the quadrangle is covered with Holocene alluvial deposits of the regional coastal basin, also known as the Downey Plain. These deposits overlie an erosional surface of late Pleistocene age.

The main drainage courses within the quadrangle are the Rio Hondo and San Gabriel River. Both rivers flow from the main San Gabriel Valley through the Whittier Narrows. The Rio Hondo flows to the southwest and joins the Los Angeles River to the west of the quadrangle. The San Gabriel River flows southward across the entire quadrangle. Both of these rivers are channelized and have percolation basins associated with them. Additional channelized creeks include Coyote, La Mirada, Leffingwell, La Canada Verde, Savage, Worsham, Turnbull, and Arroyo Pescadero.

GEOLOGY

Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. The generalized geologic map used to evaluate the liquefaction potential of the Whittier Quadrangle is shown in Plate 1.1. This map was modified from a DMG digital compilation (Saucedo, 1996; 1998) that was produced in conjunction with the Southern California Areal Mapping Project (SCAMP). The Quaternary portion of the compilation (Foster, 1996) was derived from early soil surveys (Nelson and others, 1919; Eckmann and others, 1916). DMG staff modified some alluvium and bedrock contacts and reinterpreted some of the Quaternary units. These changes were based on use of 1:20,000-scale topographic maps (Alhambra, 1926; Artesia, 1925), 1:24,000-scale topographic maps (Bell, 1926; Whittier, 1925), and extensive subsurface borehole data. Map unit nomenclature follows the format developed by SCAMP (Morton and Kennedy, 1989).

The map shows that much of the study area is covered by alluvial sediments of Quaternary age. These deposits fall into three basic age groups: older alluvial fan deposits of Pleistocene age associated with the Coyote Hills, Puente Hills and Montebello Hills; younger alluvial fan deposits of Holocene and late Pleistocene age; and modern active wash and channel systems. One significant change made to the original digital map was to reassign a younger age (Holocene to late Pleistocene) to an alluvial fan unit originally mapped as older (Pleistocene). This unit is in the vicinity of eastern Santa Fe Springs, southwestern Whittier and portions of Los Angeles County where Carmenita Avenue and Painter Road intersect. This reinterpretation was based on several cross sections constructed from subsurface borehole data.

The 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 and are discussed in Section 2 of this report.

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, several hundred borehole logs were collected from the files of the California Department of Transportation (Caltrans); the

California Regional Water Quality Control Board - Los Angeles Region; DMG Environmental Review and Hospital Review Projects; and the U. S. Geological Survey (USGS). The USGS supplied copies of paper logs collected from the Los Angeles County Department of Public Works storm drain investigations. These logs were used in earlier liquefaction studies of the Los Angeles area (Tinsley and Fumal, 1985; Tinsley and others, 1985).

Lithologic, soil test, and related data from approximately 290 logs were entered into the DMG (Geographic Information System) database. The remaining logs were reviewed during this investigation to aid with the stratigraphic correlation. Locations of all exploratory boreholes entered into the database are shown on Plate 1.2. Cross sections were constructed from borehole data to correlate soil types and engineering properties, and to extrapolate geotechnical data into outlying areas containing similar soils.

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit and commonly are used as an index of density. Many geotechnical investigations record SPT data, including the number of blows by a 140-pound drop weight required to drive a sampler of specific dimensions one foot into the soil. Recorded blow counts for non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), were converted to SPT-equivalent blow count values and entered into the DMG GIS. The actual and converted SPT blow counts were normalized to a common reference effective overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60% using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

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 unit.

Older alluvium (Qofa, Qofs, Qofc)

The older alluvium in the Whittier Quadrangle is exposed in portions of Montebello, Santa Fe Springs, La Mirada and Whittier. This material consists predominantly of alternating beds of medium-dense to very-dense sand, clay, and silt.

Younger alluvium (Qyfa, Qyfs, Qyfc, Qw)

In general, the younger Quaternary alluvial deposits consist of alternating beds of clay, silt, and very fine- to very coarse-grained sand and gravel. Compactness of sand layers ranges from very loose to dense, as indicated by both lithologic descriptions and penetration tests performed during drilling.

The young Quaternary alluvial fan deposits in the Whittier Quadrangle represent deposition predominantly by the San Gabriel and Rio Hondo rivers. This region has experienced multiple episodes of historic inundation during the past 150 years. Borehole data from within the actual channels are limited; the subsurface deposits consist of mostly very coarse- to very fine-grained sand, gravel, and silt. The fan deposits beyond the river

channels have abundant geotechnical data available. The upper 50 feet of this unit generally consists of loose to moderately dense, fine to coarse sand, silty sand, and silt that appear to interfinger and grade laterally with each other.

Subsurface data for the smaller active washes and stream channels were very sparse. The units from these settings consist of predominately poorly sorted clayey sand, silty sand, silt, and clay. In the vicinity of Whittier, fan sediments from the Puente Hills interfinger with fan deposits of the La Canada Verde Creek and Leffingwell Creek drainage areas. In the subsurface, these units consist of sand, silt, and clay that grade laterally with each other.

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 Whittier 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 relied heavily on turn-of-the-century water-well logs (Mendenhall, 1905; Conkling, 1927), but also included water measurements from wells from the Central Basin Investigation (State Water Resources Board, 1952), Department of Water Resources (circa 1940's), and soil investigations collected for this study. 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. This ground-water map captures the highest shallow ground water in perched, semi-perched, and other water table settings. The map was compared to similar published maps for any major discrepancies (Tinsley and others, 1985; Leighton and Associates, 1990). Plate 1.2 shows that historical shallow water conditions (less than 40 feet depth) occurred throughout much of the Whittier Quadrangle.

In the late 1800's many shallow wells showed near-surface water levels, in addition to the wide spread deeper artesian conditions. The subsequent management and withdrawal of ground water markedly reduced the distribution of both of these conditions. This century's overall declining trend in water levels was reversed during the middle 1930's to middle 1940's due to increased precipitation rates. Hydrographs from this region show that water levels can vary seasonally as much as 35 feet. It is important to note that shallow water was encountered in geotechnical investigations (post-1960) throughout the Whittier Quadrangle.

Although the potential for recharge is beyond the scope of this report, the review of 100's of boreholes, as well as conclusions from the California Department of Water Resources (1961) and Tinsley and others (1985), all suggest that water could move upward into semi-perched zones if pressure levels in the underlying units become sufficiently high, due to the discontinuous character and high sand content of the confining units. Similarly, both Rio Hondo and the San Gabriel River have the potential to recharge ground water due to the percolation and flood control basins associated with them.

PART II

LIQUEFACTION POTENTIAL

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

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

LIQUEFACTION SUSCEPTIBILITY

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

processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

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

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

Older alluvium (Qofa, Qofs, Qofc)

The older Quaternary sedimentary deposits of the Whittier Quadrangle are described in borehole logs as being dense to very dense sand, silt, and clay. In general, these deposits are considered to have low liquefaction susceptibility

Younger alluvium (Qyfa, Qyfs, Qyfc, Qw)

Younger alluvial fan deposits within the Whittier Quadrangle consist largely of sand, along with lesser amounts of silty sand, silt, gravel and clay. Most borehole descriptions and test data from these units report the presence of loose to moderately dense sand. Some deposits consist of very loose sand. Where historical ground-water levels are within 40 feet of the surface, these deposits are assigned a high liquefaction susceptibility rating.

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 Whittier Quadrangle, peak accelerations of 0.40 g to 0.58 g, resulting from earthquakes ranging in magnitude from 6.7 to 6.8, 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.

Approximately 90 percent of the borehole logs collected for alluviated areas in the Whittier Quadrangle (Plate 1.2) 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 Whittier Quadrangle is summarized below.

Areas of Past Liquefaction

Historic liquefaction has not been reported in the Whittier Quadrangle. Evidence of paleoseismic liquefaction was not found. Therefore, no areas within the Whittier 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 Whittier Quadrangle. Consequently, no areas are zoned for potential liquefaction relative to artificial fill.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that included penetration test data and reasonably sufficient lithologic descriptions were used to determine the liquefaction potential. Accordingly, these areas are zoned or not zoned according to the liquefaction potential based on adequate existing geotechnical data. In the younger alluvium, most of the boreholes whose log data were analyzed using the Seed Simplified Procedure contain sediment layers that liquefy under the given earthquake parameters. These areas containing potentially liquefiable material are zoned.

Areas with Insufficient Existing Geotechnical Data

Younger alluvium deposited in stream channel and active wash 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 stream channel and active wash 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 Whittier 7.5-Minute Quadrangle, Los Angeles and Orange Counties, 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 Whittier 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 Whittier 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 Whittier 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 Whittier 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 Whittier Quadrangle covers an area of about 62 square miles in eastern Los Angeles and northwestern Orange counties. The quadrangle includes all or parts of the cities of Bellflower, Buena Park, Cerritos, Commerce, Downey, La Mirada, Montebello, Norwalk, Pico Rivera, Santa Fe Springs, and Whittier, as well as unincorporated areas of Los Angeles County. Major transportation routes traversing the Whittier Quadrangle include

the Santa Ana Freeway (I-5), the San Gabriel River Freeway (I-605), the Artesia Freeway (State Highway 91), and the Century Freeway (I-105).

More than half the quadrangle is covered with Holocene alluvial deposits of the regional coastal basin, also known as the Downey Plain. These deposits overlie an erosional surface of late Pleistocene age. The northwestern end of the Coyote Hills, which are composed of gently uplifted and dissected Pleistocene sediments, extends into the quadrangle from the east. In the northeastern corner of the quadrangle lies a portion of the Puente Hills with ridges and peaks over 1000 feet above sea level.

The main drainage courses within the quadrangle are the Rio Hondo and San Gabriel River. Both rivers flow from the main San Gabriel basin through the Whittier Narrows. The Rio Hondo flows to the southwest and joins the Los Angeles River to the west of the quadrangle. The San Gabriel River flows southward across the entire quadrangle. Both of these rivers are channelized and have percolation basins associated with them. Additional channelized creeks include Coyote, La Mirada, Leffingwell, La Canada Verde, Savage, Worsham, Turnbull, and Arroyo Pescadero.

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 Whittier 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 topographic base map, areas that have undergone large-scale grading as a part of residential development in the hilly portions of the Whittier Quadrangle were identified (see Plate 2.1). Using 1:40,000-scale NAPP photography taken in May and June, 1994, photogrammetric DEMs covering the graded areas were prepared by the U.S. Bureau of Reclamation with ground control obtained by DMG (USGS, 1994a, 1994b). The photogrammetric DEMs were then merged into the USGS DEM, replacing the areas of out-dated elevation data.

A slope map was made from the combined DEMs 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 Whittier Quadrangle, a geologic map was compiled and digitized by CDMG-Southern California Mapping Project (SCAMP: Morton and Kennedy, 1989; Saucedo,

1996; 1998) from original mapping by Yerkes (1972), and Foster (1996). The digital geologic map was modified during the project to reflect field observations and the most recent mapping in the area. In the field, observations were made of exposures of the bedrock units, 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 oldest rock unit mapped in the Whittier Quadrangle is the middle-upper Miocene Puente Formation consisting of a very thick sequence of marine sandstone, siltstone, shale, and pebble conglomerate. It is exposed only in the northeast corner of the quadrangle. The Puente Formation is subdivided into four members. The lowest member, the La Vida Member (Tpl), consists of laminated to platy siltstone with interbedded pebbly sandstone (Tplc) and local limestone and tuff beds. The La Vida Member grades upwards into the Soquel Member (Tpsq), which consists of massive to locally thick-bedded sandstone with interbedded clayey siltstone and pebble-cobble conglomerate (Tpsqc). The Yorba Member (Tpy) has a gradational contact with the Soquel Member and is made up of interbedded sandy and diatomaceous siltstone containing thin beds of limestone and thin-bedded to massive sandstone. The uppermost member, the Sycamore Canyon Member (Tpsc), consists of interlayered micaceous siltstone and coarse-grained sandstone with interbedded conglomerate (Tpssc). The La Vida Member occupies the central portion of the Puente Hills while the Soquel, Yorba, and Sycamore Canyon members form elongated bands along its northwest and southeast fringes.

Overlying the Puente Formation is the Pliocene Fernando Formation (Tf) that consists of repetitiously interbedded fine to coarse clastic marine strata that is divided into lower (Tfl) and upper (Tfu) members on the basis of an extensive erosional unconformity and lithologic variations (Yerkes and others, 1965). The Fernando Formation is exposed only on the southwest-facing slopes of the Puente Hills south of the Whittier Fault zone. The lower member consists of alternating massive silty sandstone and pebble conglomerate (Tflc). The upper member is characterized by massive and friable silty and pebbly sandstone with interbedded siltstone and pebble conglomerate (Tfuc).

Quaternary deposits cover most parts of the quadrangle comprising the flood plains of the San Gabriel River and Rio Hondo. They are composed of active channel wash (Qwa), younger alluvial fan deposits (Qyfc, Qyfa, Qyfs, Qyfsa), older alluvial fan deposits (Qofc, Qofs), and some erosional outliers of the La Habra Formation (Qlh). Landslides (Qls, Qls?) occur in the Puente Hills in the northeastern portion of the quadrangle. A more detailed discussion of the Quaternary deposits in the Whittier Quadrangle can be found in Section 1.

Structural Geology

The most prominent structural feature in the Whittier Quadrangle is the north-northwest trending Whittier Fault zone that transects the southern slope of the Puente Hills. Recent deformation along this fault zone is indicated by the presence of steeply tilted and locally overturned strata of late Pleistocene and Pliocene age (Yerkes and others, 1965). Another prominent feature is the Workman Hill Fault, which branches off toward the

northwest from the Whittier Fault. This fault forms the north boundary of an uplifted wedge of folded strata that underlies the Whittier oil field area.

A band of east-trending anticlines and synclines is evident along the trace of the Whittier Fault zone and is confined to the wedge-shaped area between the Whittier and Workman Hill faults. Most of the folds are inclined so that their axial surfaces are subparallel to the Whittier Fault and their north limbs are overturned (Yerkes, 1972).

The orientation of bedding layers within the formations and the differences in rock strength between fine and coarse-grained lithologies do not appear to have a very significant influence on slope stability in the area so no attempt was made to identify adverse bedding conditions in the Whittier Quadrangle.

Landslide Inventory

The evaluation of earthquake-induced landsliding requires an up-to-date and complete analysis of previously mapped landslides. DMG geologists compiled the existing landslides in the Whittier Quadrangle from the published geologic map by Yerkes (1972), the CDMG-SCAMP digital map compiled by Saucedo (1996), and the published landslide hazard maps by Tan (1988). Then by combining analysis of aerial photos and interpretation of landforms with field observations, all landslides compiled on the map were verified, re-mapped, or deleted during the preparation of the landslide inventory map. 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.

The most landslide-prone bedrock units in the quadrangle are the La Vida Member of the Puente Formation and the upper member of the Fernando Formation. The most stable is the Soquel Member of the Puente Formation. Most of the landslides inventoried are debris slides, block slides, or slumps.

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 Whittier Quadrangle geologic map were obtained from the files of the local government permitting departments, from the Corporate Library of Leighton and Associates, Inc., the City of Whittier, and the Los

Angeles County Department of Public Works (see Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1.

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

| WHITTIER QUADRANGLE | | | | | | | |
|--|-----------------------|------------------------|-----------------------|--|------------------------------------|--|--|
| Shear Strength Group Statistics | | | | | | | |
| | Formation Name | Number of Tests | Mean Phi Value | Group Phi Mean/Median (degrees) | Group Phi Mean/Median (psf) | No Data Similar Lithology | Phi Values used in Stability Analysis |
| GROUP 1 | Tpsc/Tpscc | 12 | 35.9 | 35.9/32.7 | 293/290 | Tps/Tpscg | 36 |
| GROUP 2 | Tfl/Tfls Tflc | 4 | 33.0 | 33.0/35.0 | 487/400 | Tpy | 33 |
| GROUP 3 | Tfu Qof Qyf | 6 28 27 | 31.5 29.5 29.2 | 29.6/30.5 | 380/280 | Tpl, Tpls Qyfa, Qyfc, Qyfs Qyfsa, Qofa, Qofc Qofs, Qwa, Qlh | 30 |
| GROUP 4 | Qls | | | | | | 14 |

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

| WHITTIER QUADRANGLE | | | |
|------------------------------|----------------------|--|----------------|
| Shear Strength Groups | | | |
| Group 1 | Group 2 | Group 3 | Group 4 |
| Tpsc/Tpscc Tps/Tpscg | Tfl/Tfls/Tflc Tpy | Tfi Tpl/Tpls Qyfa, Qyfc, Qyfs Qyfsa, Qofa, Qofc Qofs, Qwa, Qlh | Qls |

Table 2.2. Summary of the Shear Strength Groups for the Whittier 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 Whittier 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 6.8 |
| Modal Distance: | 2.5 to 2.6 km |
| PGA: | 0.41 to 0.48 g |

The strong-motion record selected for the slope stability analysis in the Whittier Quadrangle was the Channel 3 (N35°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 (PGA) 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 Whittier Quadrangle.

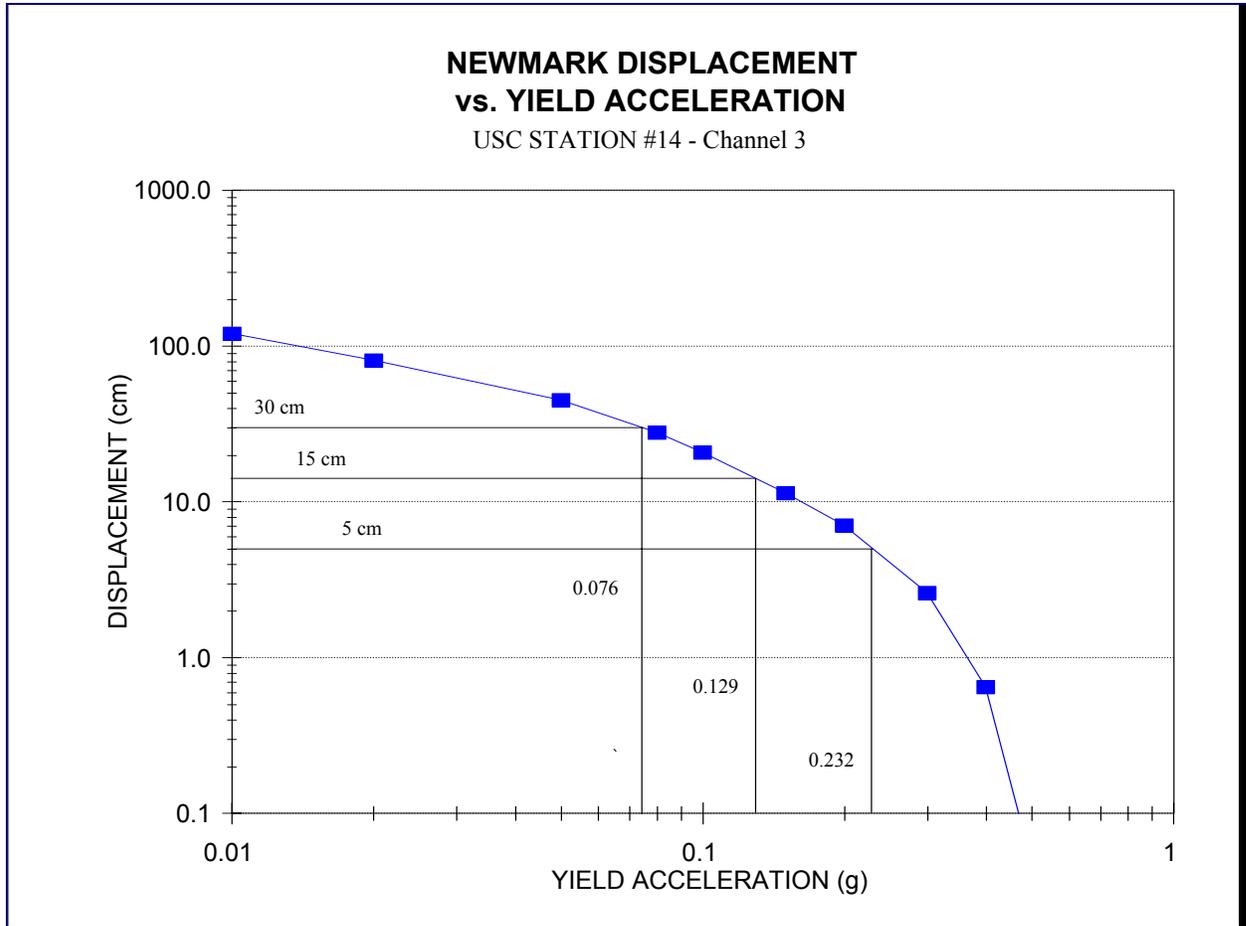


Figure 2.1. Yield acceleration vs. Newmark displacement for the USC Station # 14 strong-motion record From the 17 January 1994 Northridge, California Earthquake.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.076g, 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.

| WHITTIER QUADRANGLE Hazard Potential Matrix | | | | | | | |
|--|----------------|-----------------|------------------|-----------------|----------------|-----------------|-------------|
| Geologic Material Group | Slope Category | | | | | | |
| | I 0 to 11% | II 12 to 33% | III 34 to 39% | IV 40 to 48% | V 49 to 56% | VI 57 to 64% | VII >65% |
| | 0 to 6° | 7 to 18° | 19 to 22° | 23 to 26° | 27 to 29° | 30 to 33° | >34° |
| Group 1 | VL | VL | VL | VL | L | M | H |
| Group 2 | VL | VL | VL | L | M | H | H |
| Group 3 | VL | VL | L | M | H | H | H |
| Group 4 | L | H | H | H | H | H | H |

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Whittier 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 4 is included for all slope gradient categories. (Note: Geologic Strength Group 4 includes all mappable landslides with a definite or probable confidence rating).
2. Geologic Strength Group 3 is included for all slopes steeper than 33 percent.
3. Geologic Strength Group 2 is included for all slopes steeper than 39 percent.
4. Geologic Strength Group 1 is included for all slopes steeper than 48 percent.

This results in approximately 3.5 percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the Whittier Quadrangle. The small area within the zone is a result of the predominantly low relief in most of the quadrangle.

ACKNOWLEDGMENTS

The authors thank Kathryn Davanaugh of Leighton and Associates, Inc. Corporate Library, Robert Larson and Mario Ramirez of the Los Angeles County Department of Public Works Material Engineering Division, and Howard Miller of the City of Wittier for their assistance in obtaining geologic material strength data used in the preparation of this report. Patricia V. Kennedy assisted in the collection of geotechnical data. Digital terrain data were provided by Randy Jibson of the U.S. Geological Survey, and Monte Lorenz and George Knight of the U.S. Bureau of Reclamation. 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 Scott Shepherd, Teri McGuire, and Bob Moskovitz for their Geographic Information System operations support, Barbara Wanish for designing and plotting the graphic displays associated with the Hazard Zone Map and this report, Lisa Chisholm for preparing the landslide attribute tables, and Jacob Summerhayes for the data entry of geotechnical data into the Paradox database.

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AIR PHOTOS

- Whittier-Fairchild Collection 1927 Aerial Photographs, flight 113, frames 594-596, and 603-608, black & white, vertical, approximate scale 1:18,000.
- USGS (U.S. Geological Survey), 1994a, NAPP Aerial Photography, Flight 6858, May 31, 1994, Frames 104 to 108, black and white, vertical; scale 1:40,000.
- USGS (U.S. Geological Survey), 1994b, NAPP Aerial Photography, Flight 6862, June 1, 1994, Frames 151 to 155, black and white, vertical; scale 1:40,000.

**APPENDIX A
SOURCE OF ROCK STRENGTH DATA**

| SOURCE | NUMBER OF TESTS SELECTED |
|--|---------------------------------|
| Leighton and Associates, Inc., Corporate Library | 42 |
| City of Whittier | 75 |
| Los Angeles County Department of Public Works Material Engineering Division files | 2 |
| Total Number of Shear Tests | 119 |

SECTION 3

GROUND SHAKING EVALUATION REPORT

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

By

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Charles R. Real, and Michael S. Reichle**

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

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

PURPOSE

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

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

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

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

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

EARTHQUAKE HAZARD MODEL

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

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

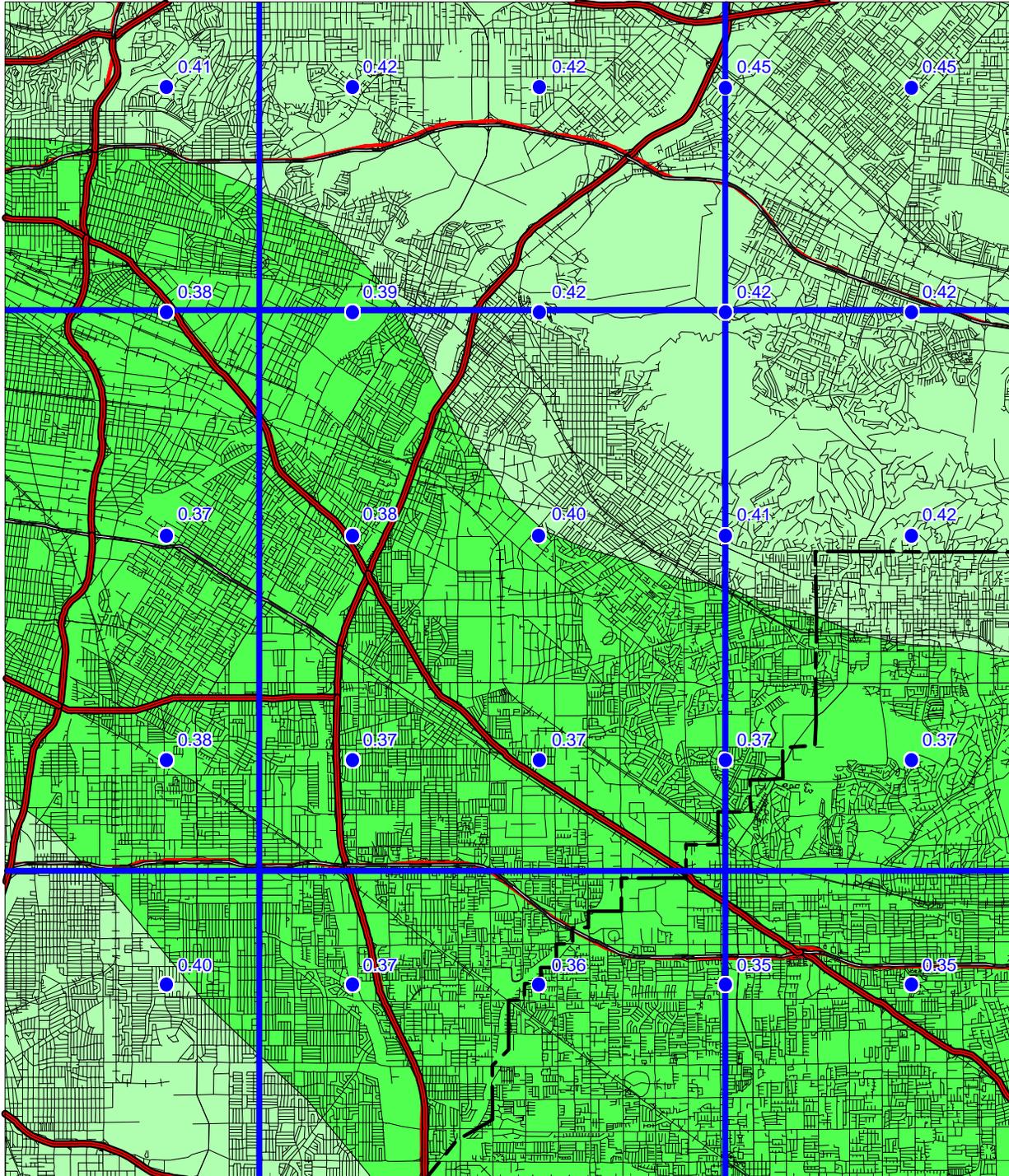
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

SEISMIC HAZARD EVALUATION OF THE WHITTIER QUADRANGLE WHITTIER 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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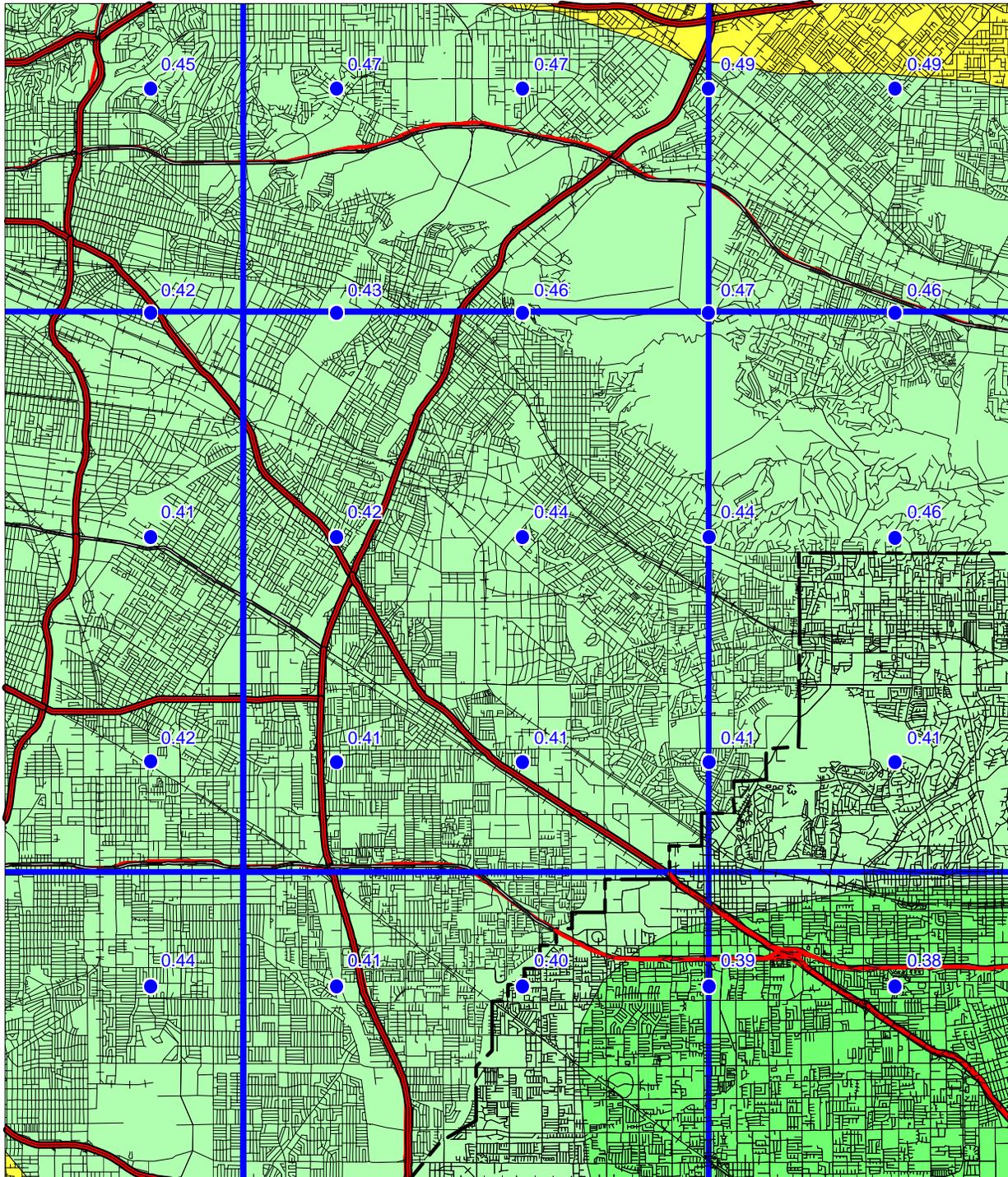
Figure 3.1

WHITTIER 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



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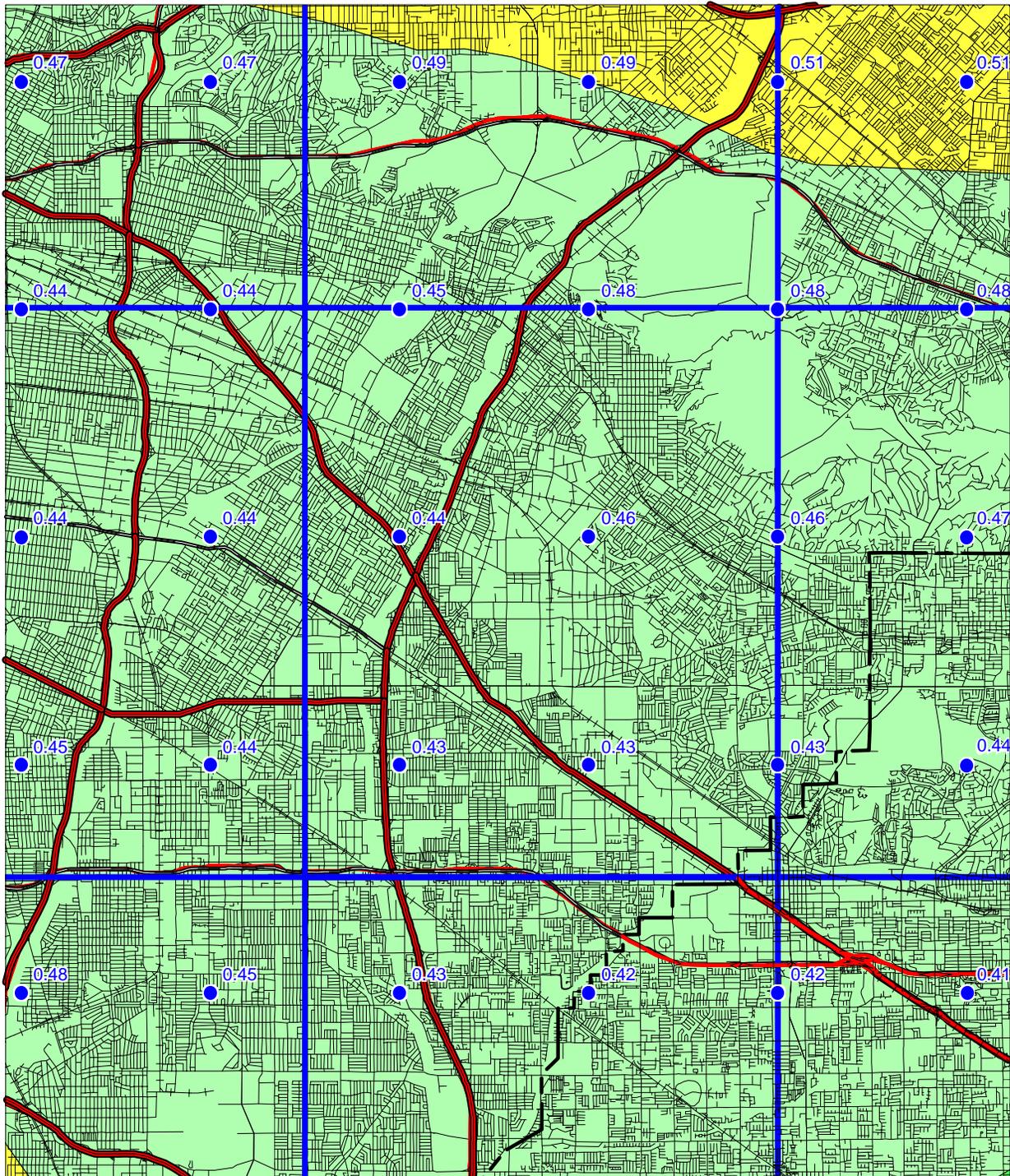


Figure 3.2

SEISMIC HAZARD EVALUATION OF THE WHITTIER. QUADRANGLE
WHITTIER 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

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

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works ©1998 MapInfo Corporation



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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.

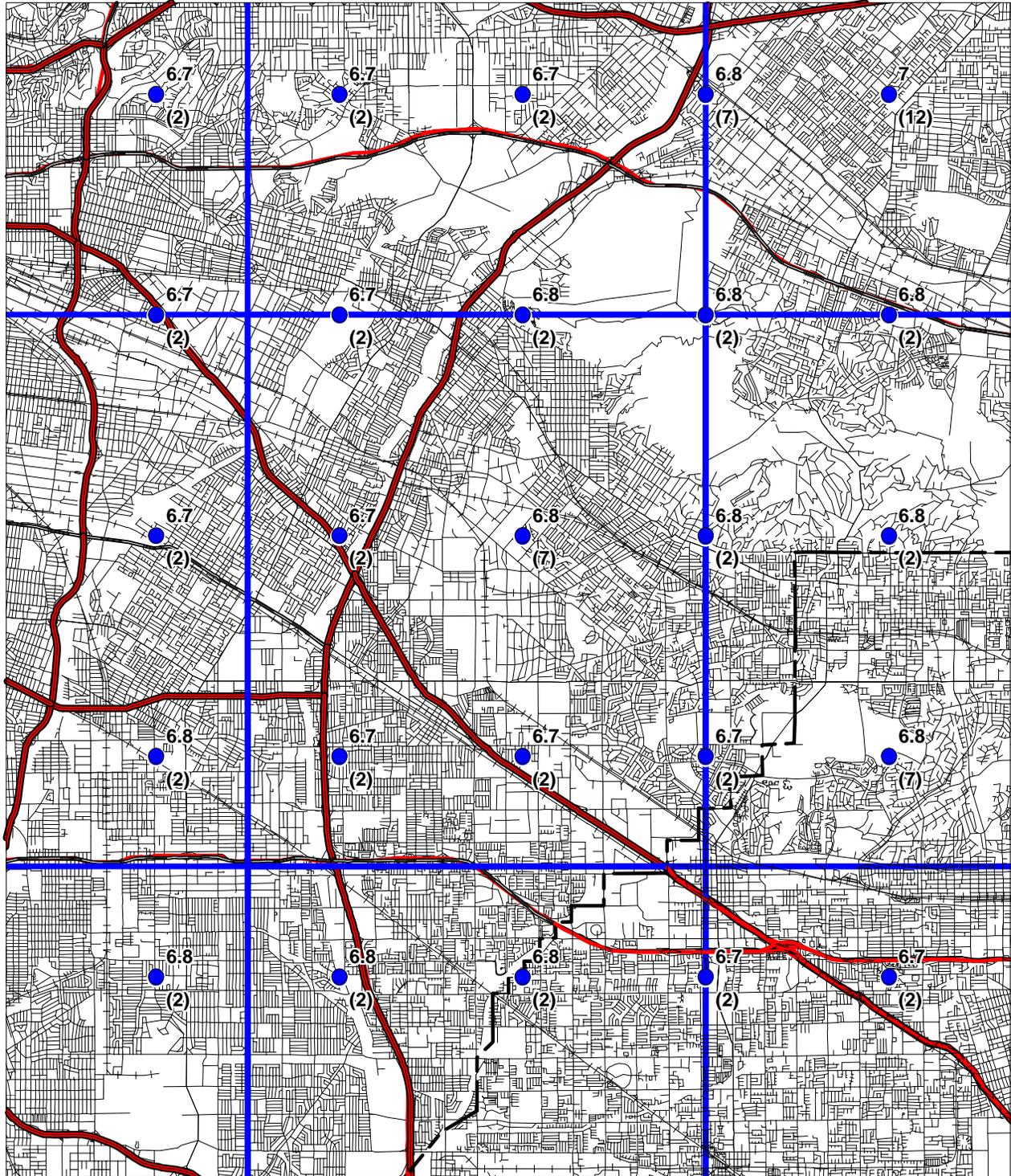
A preferred method of using the probabilistic seismic hazard model and the “simplified Seed-Idriss method” of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a “magnitude-weighted” ground motion (liquefaction 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 WHITTIER QUADRANGLE
WHITTIER 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

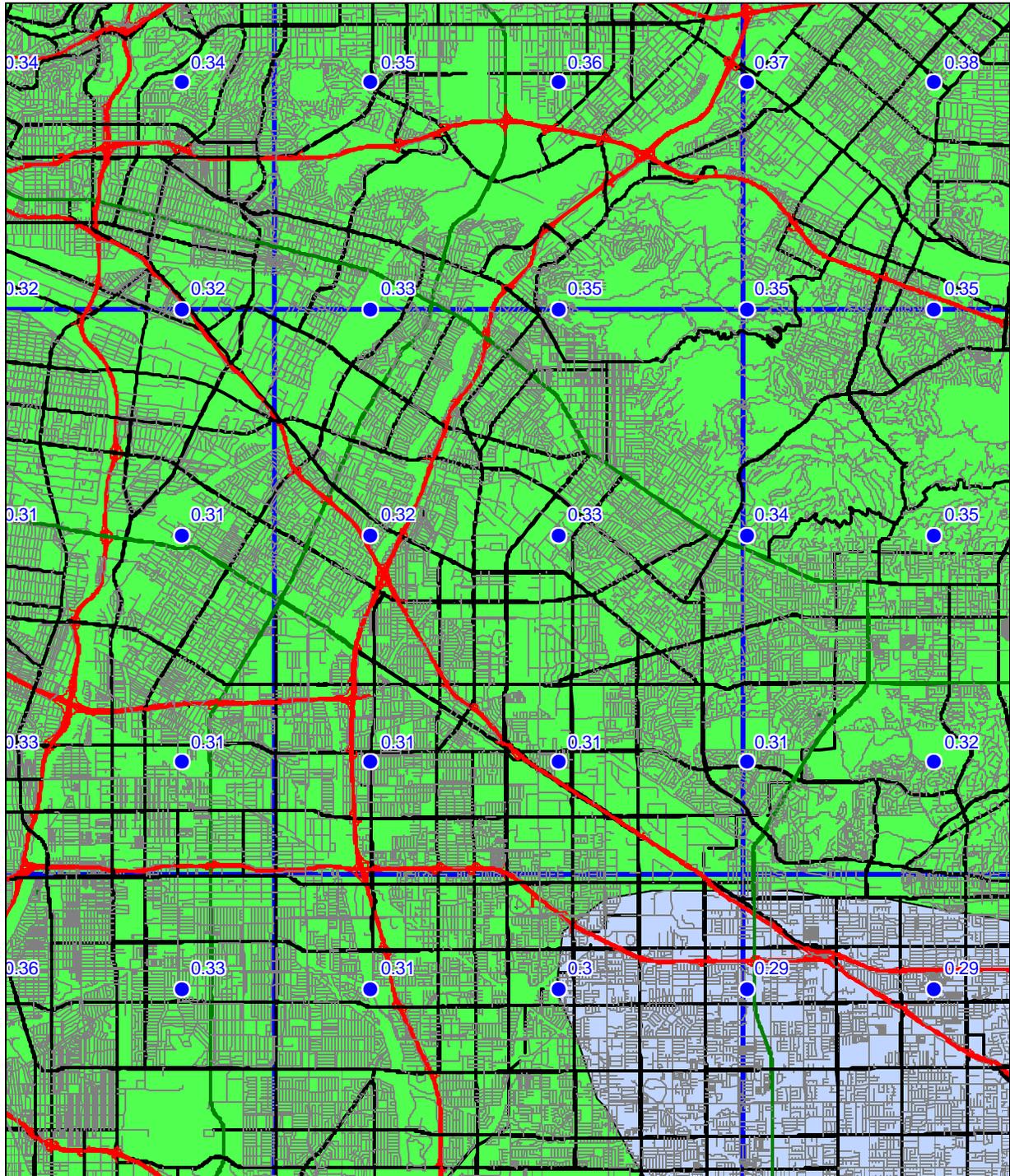


SEISMIC HAZARD EVALUATION OF THE WHITTIER QUADRANGLE
WHITTIER 7.5-MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

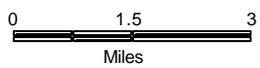
10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g)
FOR ALLUVIUM

1998

LIQUEFACTION OPPORTUNITY



Base map from GDT



Department of Conservation
California Geological Survey



Figure 3.5

USE AND LIMITATIONS

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

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

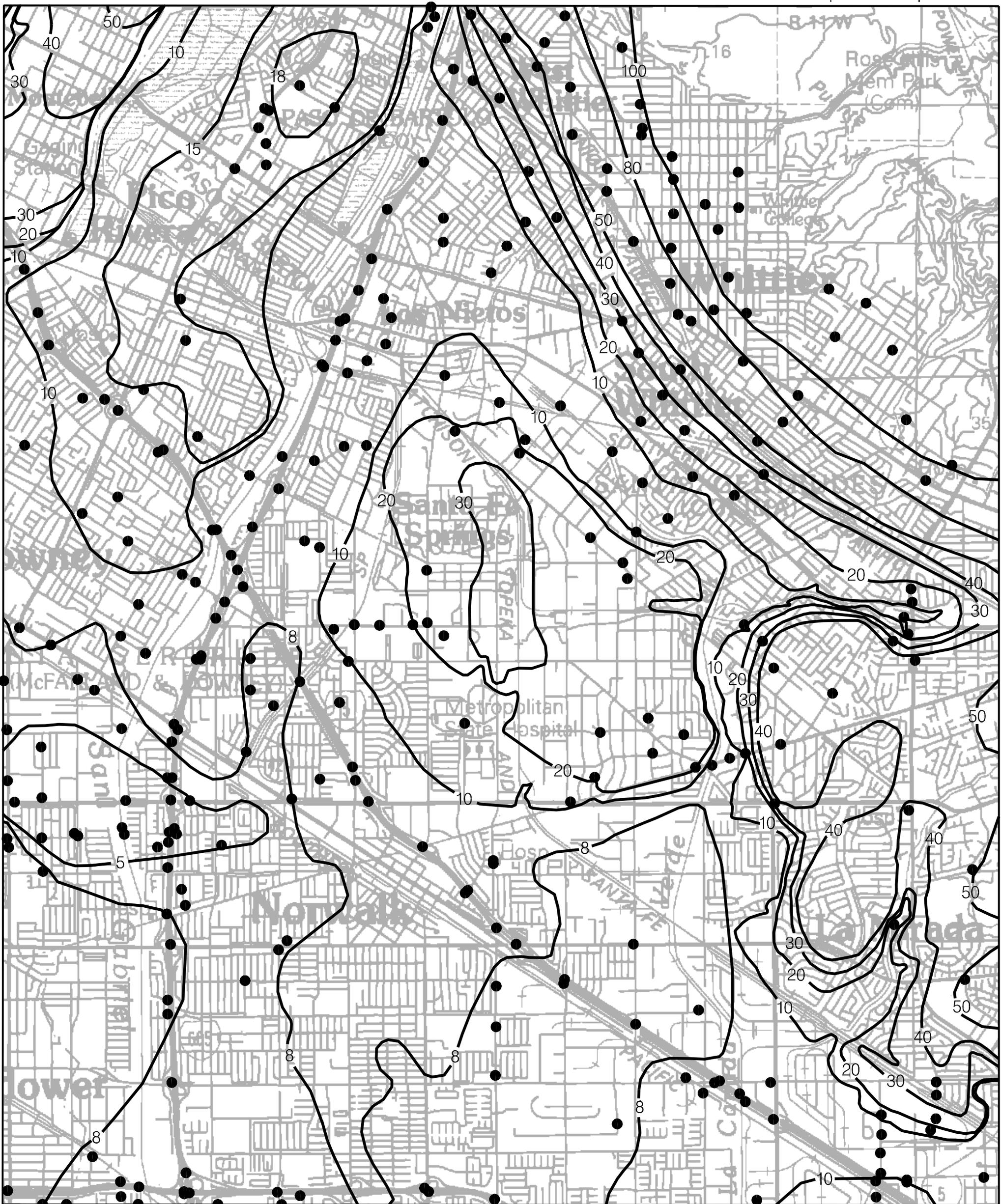
Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific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

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

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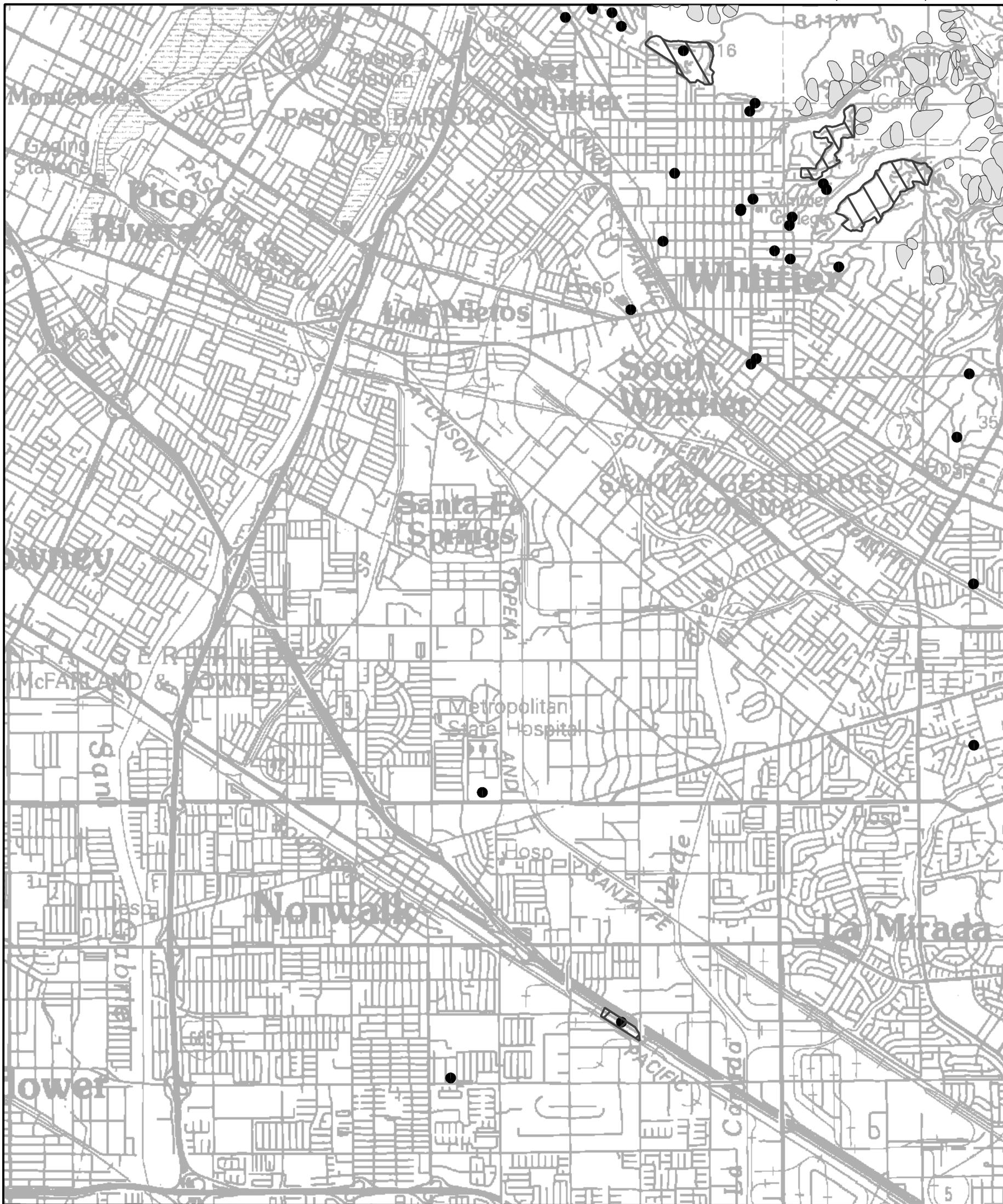


Base map enlarged from U.S.G.S. 30 x 60-minute series

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

● Borehole Site — 30 — Depth to ground water in feet

ONE MILE
SCALE



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

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

- shear test sample location
- landslide
- areas of significant grading
- tract report with multiple borings

ONE MILE
 SCALE