SEISMIC HAZARD ZONE REPORT 030

SEISMIC HAZARD ZONE REPORT FOR THE MT. WILSON 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 Mt. Wilson 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 40 square miles at a scale of 1 inch = 2,000 feet. The northern one-third is not zoned because it is within the Angeles National Forest.

The southern half of the Mt. Wilson Quadrangle includes a portion of the densely populated San Gabriel Valley where parts of the cities of Pasadena, San Marino, Arcadia, Sierra Madre, and Monrovia and the unincorporated Los Angeles County community of Altadena are located. The northern half covers part of the San Gabriel Mountains, which are in the Angeles National Forest. The primary access routes are the Foothill Freeway (Interstate Highway-210), Foothill Boulevard, Colorado Boulevard, Huntington Drive and San Gabriel, Rosemead, and Santa Anita Boulevards. The mountains rise very abruptly from the valley and reach elevations greater than 6000 feet in the northwest corner of the quadrangle. The largest streams, in Eaton Canyon and Santa Anita Canyon, each drain several square miles of the mountains. Altadena, Sierra Madre, and Arcadia are built on young alluvial fans from the San Gabriel Mountains. Pasadena rests upon an older, no longer active, alluvial surface.

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 Mt. Wilson Quadrangle the liquefaction zone is restricted to the bottoms of canyons and a region north of the Raymond Hill Fault where ground water is shallow. The dominance of steep slopes in the San Gabriel Mountains contributes to an earthquake-induced landslide zone that covers nearly the entire mountainous portion of 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 Mt. Wilson 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Mt. Wilson 7.5-Minute Quadrangle, Los Angeles County, California

By
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California Department of Conservation
Division of Mines and Geology

PURPOSE

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

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Mt. Wilson 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 Mt. Wilson 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 Mt. Wilson Quadrangle consist mainly of alluviated valleys, 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 Mt. Wilson Quadrangle covers an area of about 62 square miles in east-central Los Angeles County. The southern half of the quadrangle includes part of the densely populated San Gabriel Valley and the northern half covers part of the San Gabriel Mountains. Parts of the cities of Pasadena, San Marino, Arcadia, Sierra Madre, and Monrovia and the unincorporated Los Angeles County community of Altadena cover the valley region of the quadrangle. The entire mountainous part of the quadrangle basically lies within the Angeles National Forest. The primary transportation route into and within the quadrangle area is the east-trending Foothill Freeway (I-210), which is supplemented by numerous surface streets such as east-west Foothill Boulevard, Colorado Boulevard, and Huntington Drive as well as the north-south San Gabriel, Rosemead, and Santa Anita Boulevards.

The San Gabriel Mountains rise very abruptly from the valley and reach elevations of more than 6000 feet at San Gabriel Peak in the northwest corner of the quadrangle. These mountains are composed of igneous and metamorphic rocks that range in age from Precambrian through Cretaceous. The San Gabriel Mountains of today rose to their current elevation beginning in Pleistocene time as the ancient rocks were thrust upward and toward the south along range-bounding faults belonging to the Sierra Madre Fault system.

Streams draining from the San Gabriel Mountains have deposited several large, coalescing alluvial fans, creating a broad continuous alluvial slope or bajada, along the mountain front upon which the cities have been built. The two largest streams on the quadrangle, in Eaton Canyon and Santa Anita Canyon, each drain several square miles of the mountains. Slopes in the crystalline bedrock are “exceptionally steep and insecure” (Muir, 1877), which, along with occasional torrential rains, leads to periodic debris flows and floods on the alluvial fans. The Altadena, Sierra Madre, and Arcadia areas are built on young alluvial fans from the San Gabriel Mountains. Pasadena rests largely upon an older alluvial surface that is no longer active because of uplift and erosion.

GEOLOGY

Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. In preparing the Quaternary geologic map for the Mt. Wilson Quadrangle, geologic maps prepared by Saul (1976), Morton (1973), Crook and others (1987), and McCalpin (unpublished) were referred to. We began with the maps of McCalpin (unpublished), Saul (1976) and Morton (1973) as digital files in the DMG Geographic Information System. Morton (1973) mapped the east-central part of the quadrangle and Saul (1976) mapped the northwestern part, each showing the bedrock geology in great detail. McCalpin mapped the Quaternary units, primarily using geomorphic expression and soil surveys to separate and determine the ages of various Quaternary geologic units. He also incorporated the mapping of Crook and others (1987), especially for areas of artificial fill, which McCalpin had not mapped originally (McCalpin, personal communication, 1998). McCalpin’s mapping also used the SCAMP nomenclature for geologic units (Morton and Kennedy, 1989). Saul (1976) and Morton (1973) mapped the bedrock geology of the north half of the quadrangle in detail. The completed map of Quaternary geology primarily uses boundaries between the geologic units as mapped by Saul (1976) and Morton (1973) in the northern half and McCalpin in the southern half, with unit designations modified somewhat from McCalpin based on Crook and others (1987). The Quaternary geologic map of the Mt. Wilson Quadrangle is presented in generalized form as Plate 1.1.

The Quaternary geologic map (Plate 1.1) shows that the valley areas of the Mt. Wilson Quadrangle are covered by alluvial fans of various ages. The fan deposits include remnants of very old fans along the front of the San Gabriel Mountains, older alluvial surfaces in Pasadena, and smaller fans from the San Gabriel Mountains to the east. The sources of the sediment that makes up the young fans are the small drainages, usually with only a few square miles of watershed, in the San Gabriel Mountains. The largest drainage systems in the area, in Eaton Canyon and Santa Anita Canyon, have deposited young alluvial fans beginning just south of the mountain front. The alluvial fans are composed primarily of sand, silt, and gravel, the compositions of which reflect the crystalline rocks of the San Gabriel Mountains. In the Mt. Wilson Quadrangle, the alluvial units have been subdivided into very old alluvium (Qvoa), three generations of older alluvium (Qoa3- Qoa1), four generations of young alluvium (Qya4- Qya1) and active wash and fan deposits (Table 1.1).

	Alluvial Fan Deposits	Alluvial Valley Deposits	Age
Active	Qf- active fan Qw- active wash	Qa- active depositional basin	
Young	Qyf3 Qyf2 Qyf1	Qya4 Qya3 Qya2 Qya1	Holocene
Old	Qof3 Qof, Qof1	Qoa3 Qoa2 Qoa, Qoa1	Pleistocene
Very old		Qvoa, Qvoa1	Pleistocene

Some unit names include the "characteristic grain size" (e.g. Qyf2a, Qofg)
b: boulder gravel, g: gravel, a: arenaceous (sand), s: silty, c: clayey.

Table 1.1. Units of the Southern California Areal Mapping Project (SCAMP) Nomenclature Used in the Mt. Wilson Quadrangle.

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, 48 borehole logs were collected from the files of the California Department of Transportation (CalTrans), the California Department of Water Resources, the Regional Water Quality Control Board, Los Angeles County Flood Control files by U.S. Geological Survey staff, and DMG files of seismic reports for hospital and school sites. Also used was a database of shear wave velocity measurements originally compiled by Walter Silva (Wills and Silva, 1998). Fewer borehole logs were collected for the Mt. Wilson Quadrangle study than for most other quadrangles in the region because available hydrologic data showed that most of the area covered by the quadrangle throughout historical time has been characterized by deep ground-water levels.

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 $(N_1)_{60}$.

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

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 Mt. Wilson 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 acquired from technical publications, geotechnical boreholes, and water-well logs dating back to the turn-of-the-century, namely 1904 ground-water contour maps (Mendenhall, 1908), 1944 ground-water contour maps (California Department of Water Resources, 1966), and ground-water level measurements reported in compiled 1960-1997 geotechnical borehole logs. The depths to first-encountered unconfined ground water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water. Water depths from boreholes known to penetrate confined aquifers were not utilized.

Two areas within the Mt. Wilson Quadrangle were identified as containing shallow ground water. One area is a 4.5-mile long by 0.3- to 0.75-mile wide strip of land extending southwest from Monrovia toward San Marino (Plate 1.2), where the Raymond Hill Fault acts a ground-water barrier. The other is a horseshoe-shaped area along Eaton

Wash and adjacent washes at the base of the San Gabriel Mountains where saturation of near-surface sediments occurs frequently.

Map Unit	Age	Environment of Deposition	Primary Textures	General Consistency	Susceptible to Liquefaction?*
Qw	latest Holocene	active stream channels	sand, gravel, cobbles	very loose to loose	yes
Qf	latest Holocene	active alluvial fan deposits	sand, silt gravel	very loose to loose	yes
Qa	latest Holocene	active alluvial basin deposits	sand, silt, clay	very loose to loose	yes
Qyf1-4	Holocene to latest Pleistocene	younger alluvial fan deposits	gravel, sand, silt	loose to moderately dense	yes
Qya1-4	Holocene to latest Pleistocene	younger alluvial basin deposits	sand, silt, clay	loose to moderately dense	yes
Qof	late Pleistocene	older alluvial fan deposits	sand, gravel, silt, clay	dense to very dense	not likely
Qoa	late Pleistocene	older alluvial basin deposits	sand, silt, clay	dense to very dense	not likely
Qvoa	Pleistocene	Very old alluvial basin deposits	gravel, sand, silt, clay	dense to very dense	not likely

* When saturated.

Table 1.2. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Sedimentary Deposits in the Mt. Wilson Quadrangle.

PART II

LIQUEFACTION POTENTIAL

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

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

LIQUEFACTION SUSCEPTIBILITY

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

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

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

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% 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 Mt. Wilson Quadrangle, PGAs of 0.56 g to 0.79 g, resulting from earthquakes ranging in magnitude from 6.9 to 7.0, 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 48 geotechnical borehole logs reviewed in this study (Plate 1.2), 21 include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed primarily for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

LIQUEFACTION ZONES

Criteria for Zoning

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

Areas of Past Liquefaction

In the Mt. Wilson Quadrangle, no areas of documented historic liquefaction are known. Evidence of paleoseismic liquefaction was documented in an excavation across a trace of the Raymond Hill fault logged by Robert Hill, Division of Mines and Geology, at San Marino High School (Bryant, 1978, p. 140).

Artificial Fills

In the Mt. Wilson Quadrangle, artificial fill areas large enough to show at the scale of mapping are engineered fill for freeways. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata.

Areas with Sufficient Existing Geotechnical Data

Sufficient geologic and geotechnical data exist for DMG to adequately evaluate liquefaction potential of alluvial sediments throughout the Mt. Wilson Quadrangle. DMG's liquefaction susceptible soil inventory and quantitative analyses of geotechnical data in the Mt. Wilson Quadrangle indicate that all Holocene and modern soils saturated within 40 feet of the ground surface are potentially liquefiable. These conditions are present within a 4.5-mile long by 0.3- to 0.75-mile wide strip of land extending southwest from Monrovia toward San Marino. Accordingly, DMG delineates this area as a zone of required investigation.

Areas with Insufficient Existing Geotechnical Data

Some stream drainage and alluviated low land areas within the San Gabriel Mountains are zoned on the basis of SMGB criteria for areas where geotechnical data are lacking or insufficient. Most of these areas were placed within Zones of Required Investigations because such soils generally reflect conditions named in criteria item 4a. The largest of these is a horseshoe-shaped area along Eaton Wash and adjacent washes at the base of the San Gabriel Mountains where saturation of near-surface loose, sandy sediments occurs frequently.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Mt. Wilson 7.5-Minute Quadrangle, Los Angeles County, California

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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 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 Mt. Wilson 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 Mt. Wilson 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 Mt. Wilson 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 Mt. Wilson 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 Mt. Wilson Quadrangle covers an area of about 62 square miles in central Los Angeles County. The southern half of the quadrangle includes part of the densely populated San Gabriel Valley and the northern half covers part of the San Gabriel Mountains. Parts of the cities of Pasadena, San Marino, Arcadia, Sierra Madre, and Monrovia and the unincorporated Los Angeles County community of Altadena cover the valley part of the quadrangle. Essentially, the entire mountainous part of the quadrangle lies within the Angeles National Forest. Primary transportation routes into and within the quadrangle area trend east-west, primarily the Foothill Freeway (I-210), in the San Gabriel Valley, supplemented by north-south feeder routes. These include major thoroughfares such as Foothill Boulevard, Colorado Boulevard, and Huntington Drive.

The San Gabriel Mountains rise very abruptly from the valley and reach elevations of more than 6000 feet at San Gabriel Peak in the northwest corner of the quadrangle. These mountains are composed of igneous and metamorphic rocks that range in age from Precambrian through Cretaceous. The San Gabriel Mountains of today rose to their current elevation beginning in Pleistocene time as the ancient rocks were thrust upward and toward the south along range-bounding faults belonging to the Sierra Madre Fault system.

Streams draining from the San Gabriel Mountains have deposited several large, coalescing alluvial fans, creating a broad continuous alluvial slope or bajada, along the mountain front upon which the cities have been built. The two largest streams on the quadrangle, in Eaton Canyon and Santa Anita Canyon, each drain several square miles of the mountains. Slopes in the crystalline bedrock are "exceptionally steep and insecure" (Muir, 1877), which, along with occasional torrential rains, leads to periodic debris flows and floods on the alluvial fans. The Altadena, Sierra Madre, and Arcadia areas are built on young alluvial fans from the San Gabriel Mountains. Pasadena rests largely upon an older alluvial surface that is no longer active because of uplift and erosion. For details of the properties of the Quaternary geologic units see Section 1 (Liquefaction).

Residential and commercial development is concentrated in the gently sloping valley areas. Along the mountain front, hillside residential development began before World War II with small developments of single homes or cabins along streams at the base of the San Gabriel Mountains. Hillside development has continued with small residential developments sited along the parts of the mountain front outside of the national forest.

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 Mt. Wilson 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 1964 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 Mt. Wilson Quadrangle were identified (see Plate 2.1). Using 1:40,000-scale NAPP photography taken in May and June, 1994, and October 1995, photogrammetric DEMs covering the graded areas were prepared by the U.S. Bureau of Reclamation with ground control obtained by DMG. 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 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

Recently compiled geologic maps were obtained in digital form from the Southern California Areal Mapping Project (Morton and Kennedy, 1989). These maps included the Quaternary geologic map of McCalpin (unpublished) for the Mt. Wilson Quadrangle and the geologic maps of Saul (1976) and Morton (1973). This map was compared with the geologic map of the area by Crook and others (1987). The mapping was briefly field checked. Observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted.

The San Gabriel Mountains in the northern part of the quadrangle are comprised of blocks of plutonic igneous and metamorphic rocks that have been thrust over the San Gabriel Valley from the north. Bedrock geology in the crystalline bedrock of the San Gabriel Mountains shown by McCalpin (unpublished) is simplified to just one unit, herein called Mx (Mesozoic crystalline rocks). Morton (1973) mapped the east-central part of the Mt. Wilson Quadrangle and Saul (1976) mapped the northwestern part. Both of these authors mapped the bedrock geology in great detail and also depicted the locations of contacts between crystalline rocks and Quaternary sediments with more detail than McCalpin. In order to show as much detail in the bedrock as feasible and show contacts as accurately as possible, the completed geologic map for this evaluation principally used the geologic boundaries as mapped by Morton (1973) and Saul (1976) in the northern half, and those mapped by McCalpin in the southern half. Unit designations are from Morton (1973) and Saul (1976) for the bedrock units. No attempt has been made here to harmonize the nomenclature used by Morton (1973) and Saul (1976). This leads to several instances where a single rock type has two different designations, depending on who mapped it.

Major crystalline bedrock units mapped by Morton (1973) in the Mt. Wilson Quadrangle include gneissic-granitic rocks mapped as hornblende orthogneiss (m4), biotite gneiss and gneissic granitic rock (m3), and undifferentiated biotite and hornblende gneiss, calc-silicate marble and amphibolite (m2). Saul (1976) designates the gneissic rock metamorphic-granitic complex (mg), and interlayered gneiss and schist (mgf) and schist (mm). These have been intruded by dioritic igneous rocks mapped as quartz diorite (qd) by Morton, and quartz diorite (qd), quartz monzonite (qm, qm1), granite (g), and diorite (mh) by Saul. Dikes of basaltic rocks are called Td1 by Morton and Tb by Saul. Leucocratic or dacitic dikes are called Td2 by Morton and Tid by Saul.

Other surficial units in the mountainous areas colluvium (Qc), talus (Qta), and active stream channel deposits (Qw). Elevated terraces of young alluvium (Qyf), older alluvium (Qoa) or very old alluvium (Qvoa) are present locally along the canyon edges above the modern channel level.

The valley areas of the Mt. Wilson Quadrangle are covered by alluvial deposits derived from the San Gabriel Mountains. These deposits include remnants of very old fans (Qvoa), older alluvial surfaces (Qoa, Qof), and coalescing younger fans (Qyf). A more detailed discussion of the Quaternary deposits in the Mt. Wilson Quadrangle can be found in Section 1.

Structural Geology

Accompanying the digital geologic map (Morton, 1973; Saul, 1976) were digital files of associated geologic structural data, including bedding and foliation attitudes (strike and dip) and fold axes. Because of the massive to weakly foliated nature of the bedrock in the Mt. Wilson Quadrangle, it was determined that the underlying geologic structure does not have a significant impact on slope stability of the rock units. It was concluded, therefore, that adverse bedding or foliation dips do not significantly affect the geologic material strength, and no attempt was made to identify these conditions in the Mt. Wilson Quadrangle.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Mt. Wilson Quadrangle was prepared (Treiman, unpublished) by combining field observations, analysis of aerial photos, and interpretation of landforms on current and older topographic maps. Aerial photos taken by the U.S. Department of Agriculture (1952 and 1953) were the primary source for landslide interpretation (see Air Photos in References). Also consulted during the mapping process were previous maps and reports that contain geologic and landslide data (Morton and Streitz, 1969; Morton, 1973; Saul, 1976; and Crook and others, 1987). The completed hand-drawn landslide map was scanned and digitized by the Southern California Areal Mapping Project (SCAMP) at U.C. Riverside. 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. All landslides on the digital geologic map (from Morton, 1973, and Saul, 1976) were verified or re-mapped during preparation of the inventory map. To keep the landslide inventory of consistent quality, all landslides originally depicted on the digitized geologic map were deleted, and only those included in the DMG inventory were incorporated into the hazard-evaluation process. A version of this landslide inventory is included with Plate 2.1.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the Mt. Wilson Quadrangle geologic map were obtained from the Los Angeles County Public Works Department (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.

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.

The results of the grouping of geologic materials in the Mt. Wilson Quadrangle are in Tables 2.1 and 2.2.

MT. WILSON QUADRANGLE SHEAR STRENGTH GROUPS							
	Formation Name* (rock types)	**Number of Tests**	**Mean/Median Phi (deg)**	**Mean/Median Group Phi (deg)**	**Mean/Median Group C (psf)**	**No Data but Similar Lithology**	**Phi Values Used in Stability Analyses**
GROUP 1	grantic dioritic granodirotic	15 3 2	41/41 37/37 39/38	40/40	630/595	m2, mfg mm,Td1 Td2,Tb	40
GROUP 2	Qoa, Qof Qw, Qyf af	4 27 7	32/32 33/32 30/30	32/32	341/435	Qc Qca Qvoa	32
GROUP 3						f**	26
GROUP 4						Qls***	15

* Generic rock types idenified in this column are linked to more specific rock types discussed in Surface and Bedrock Geology section above.

** Fault zone composed of clay gouge; shear strength value designated based on Hoek and Bray (1981).

*** Existing mapped landslides; shear strenth value designated based on information from adjacent Pasadena Quadrangle.

Table 2.1. Summary of the Shear Strength Statistics for the Mt. Wilson Quadrangle.

SHEAR STRENGTH GROUPS FOR THE MT. WILSON QUADRANGLE			
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**
g	Qvoa	f	Qls
hbd	Qoa		
m2	Qyf		
m3	Qc		
m4a	Qta		
m4b	Qw		
mg			
mgf			
mh			
mm			
qd			
qd+m3			
qd+m4a			
qd2			
qm			
qm1			
xqd			
Tb			
Td1			
Td2			
Tld			

Table 2.2. Summary of the Shear Strength Groups for the Mt. Wilson Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the "ground shaking opportunity." For the Mt. Wilson 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:	7.0
Modal Distance:	2.5 to 6.1 km
PGA:	0.64 to 0.86g

The strong-motion record selected for the slope stability analysis in the Mt. Wilson Quadrangle was the Channel 3 (north 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 0.69 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, 0.13 and 0.23 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 Mt. Wilson Quadrangle.

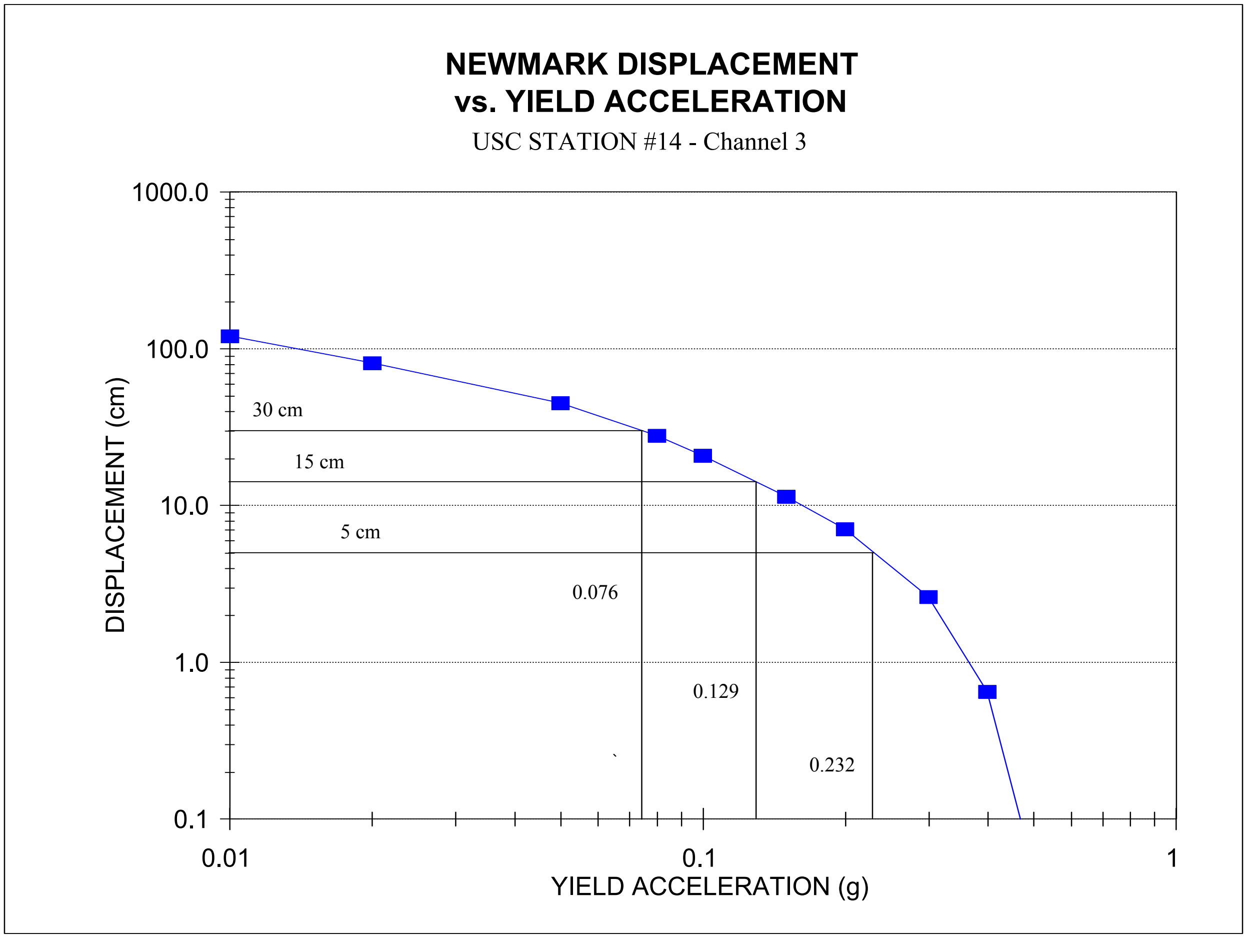

Figure 2.1. Yield acceleration vs. Newmark displacement for the USC Station # 14 strong-motion record from the 17 January 1994 Northridge, California earthquake.

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 0.13g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)

3. If the calculated yield acceleration fell between 0.13g and 0.23g, 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 0.23g, 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.

MT. WILSON QUADRANGLE
HAZARD POTENTIAL MATRIX

SLOPE

Geologic Material Group	Mean Phi	I 0-13%	II 14-19%	III 20-24%	IV 25-37%	V 38-41%	VI 42-48%	VII 49-56%	VIII 57-69%	IX 70-74%	X >75%
1	40	VL	VL	VL	VL	VL	VL	L	L	M	H
2	32	VL	VL	VL	VL	L	L	M	H	H	H
3	26	VL	VL	VL	L	M	H	H	H	H	H
4	15	L	M	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Mt. Wilson 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.

Earthquake-triggered landslides, primarily rockfalls, were observed in numerous places within the Mt. Wilson Quadrangle resulting from the 5.8 ML Sierra Madre earthquake of June 28, 1991 (Barrows and Irvine, 1991). For example, in Arcadia Wilderness Park at the mouth of Santa Anita Canyon rockfalls buried a well-known exposure of the Sierra Madre Fault. Rockfalls were also common from roadcuts along the Mt. Wilson-Red Box Road. On the day of the earthquake, helicopter-borne observers reported observations of rockfalls from mountain roadcuts and dustclouds rising from the canyons in the portion of the Mt.Wilson Quadrangle that lies between Mt. Wilson and the cities along the mountain front.

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 24 percent.

3. Geologic Strength Group 2 is included for all slopes steeper than 37 percent.

4. Geologic Strength Group 1is included for all slopes steeper than 56 percent.

This results in nearly all of the mountainous terrain in the zoned part of the Mt. Wilson Quadrangle lying within the earthquake-induced landslide hazard zone for the quadrangle.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Geologic material strength data were collected at the Los Angeles County Department of Public Works with the assistance of Robert Larsen, James Shuttleworth, Charles Nestle, and Dave Poplar. 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 Barbara Wanish, Bob Moskovitz, Teri McGuire, and Scott Shepherd for their GIS operations support, and to Barbara Wanish for preparing the graphic displays associated with the hazard zone map and this report.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Los Angeles County Public Works Department	**58**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Mt. Wilson 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.

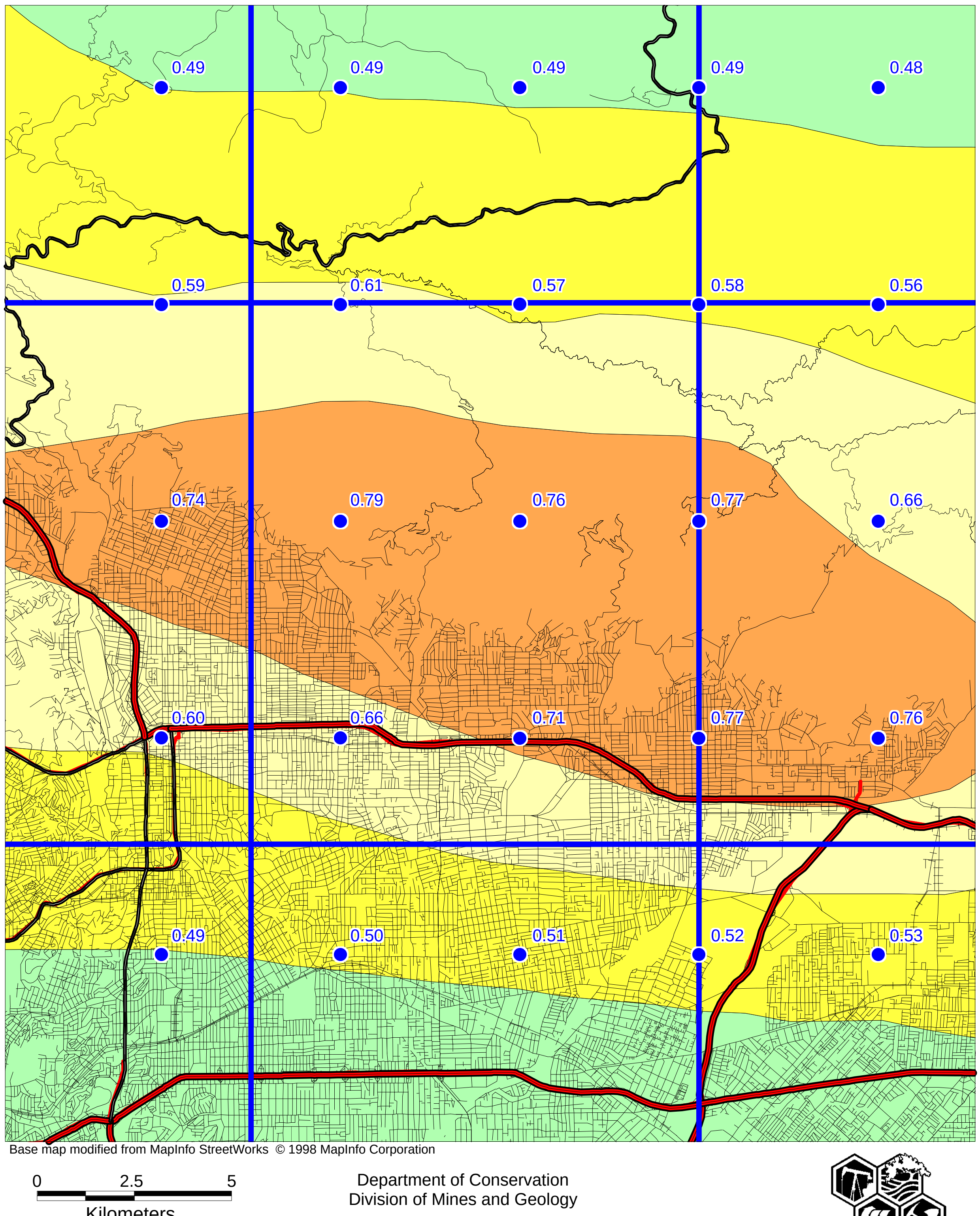
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

MT. WILSON 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Department of Conservation
Division of Mines and Geology

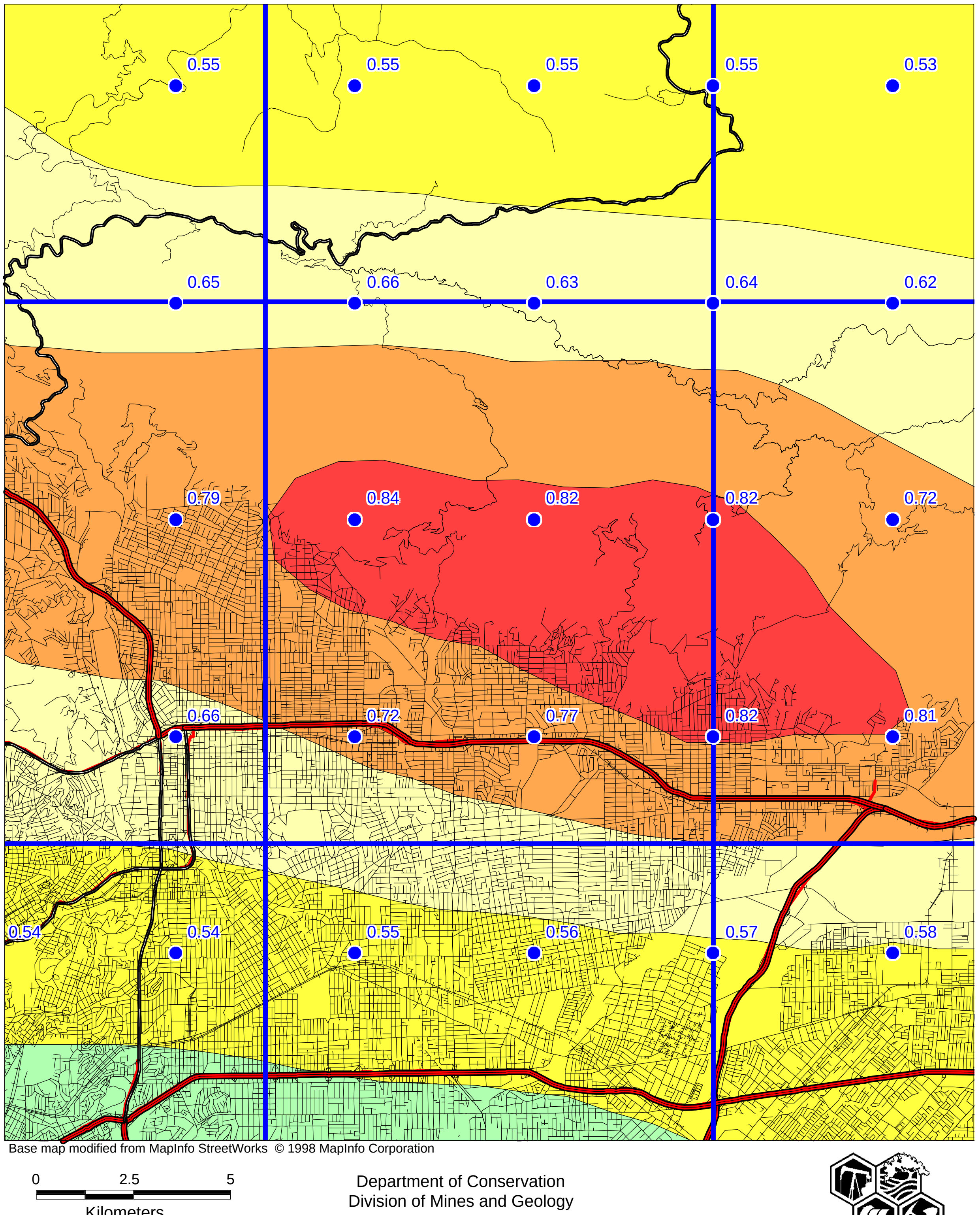
Figure 3.1

MT. WILSON 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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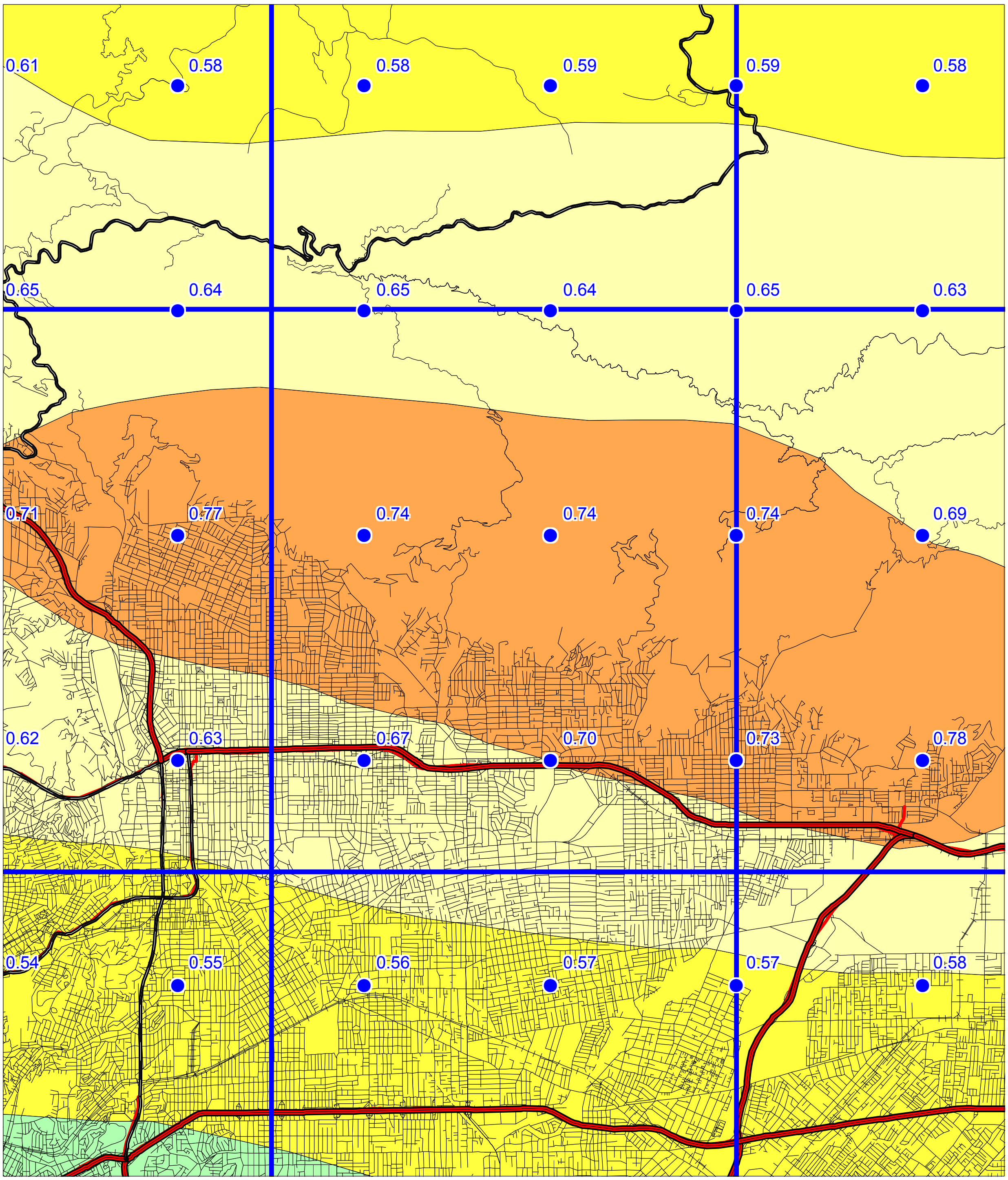
Figure 3.2

MT. WILSON 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

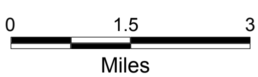
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works © 1998 MapInfo Corporation



Department of Conservation
Division of Mines and Geology

Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

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

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

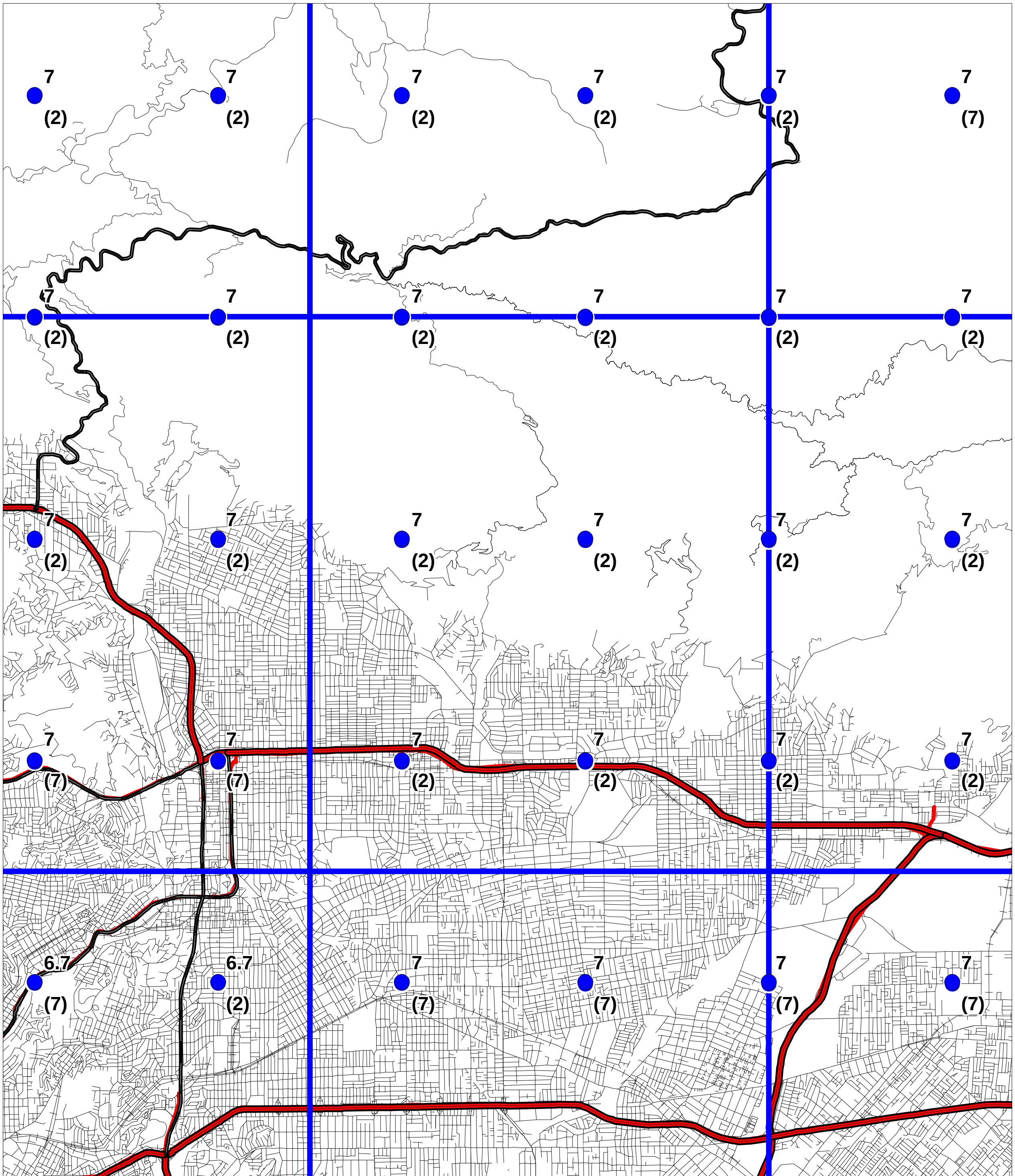
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss' weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

MT. WILSON 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

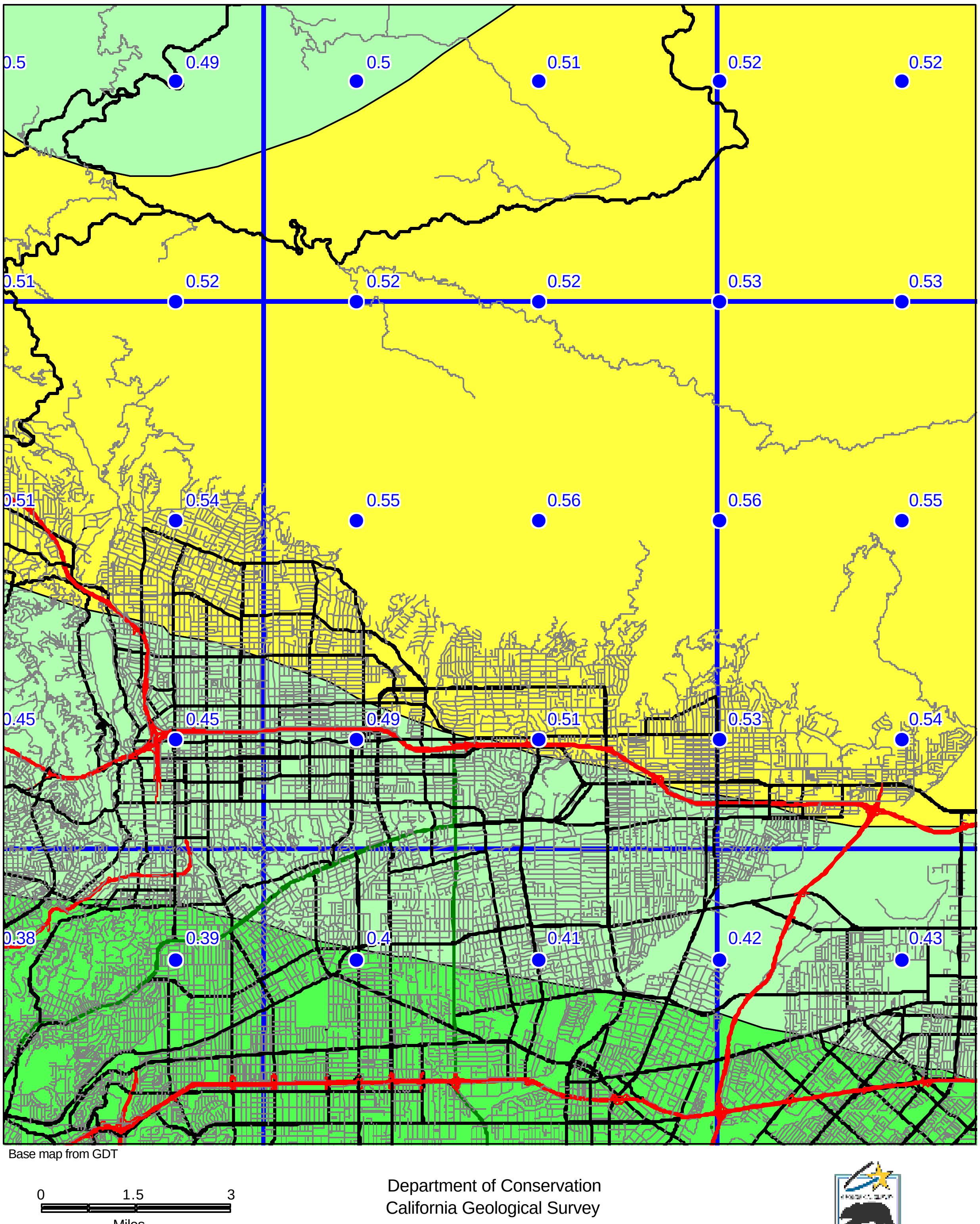
Figure 3.4

MT. WILSON 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



Department of Conservation
California Geological Survey

Figure 3.5

USE AND LIMITATIONS

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

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

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

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

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

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

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

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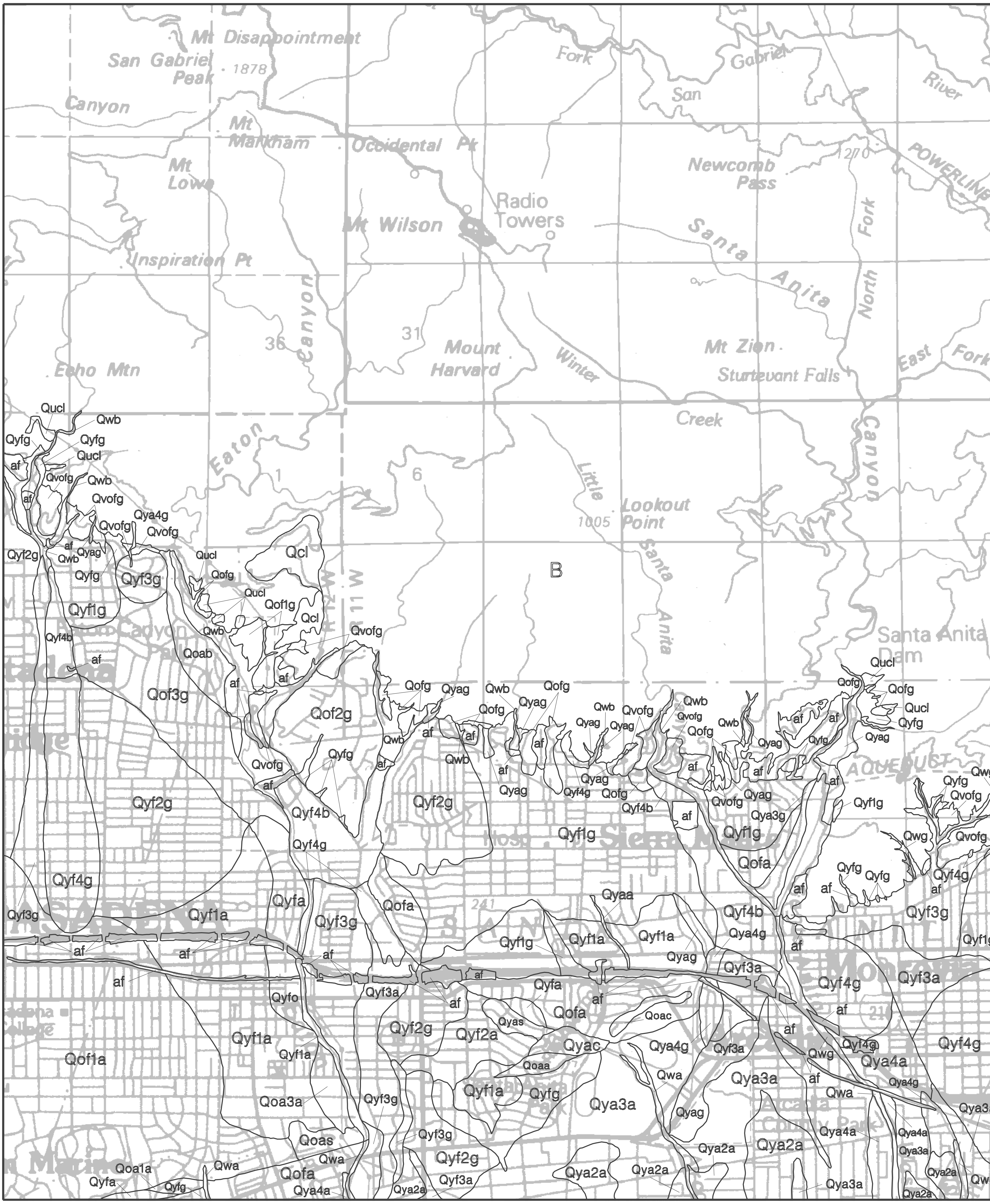


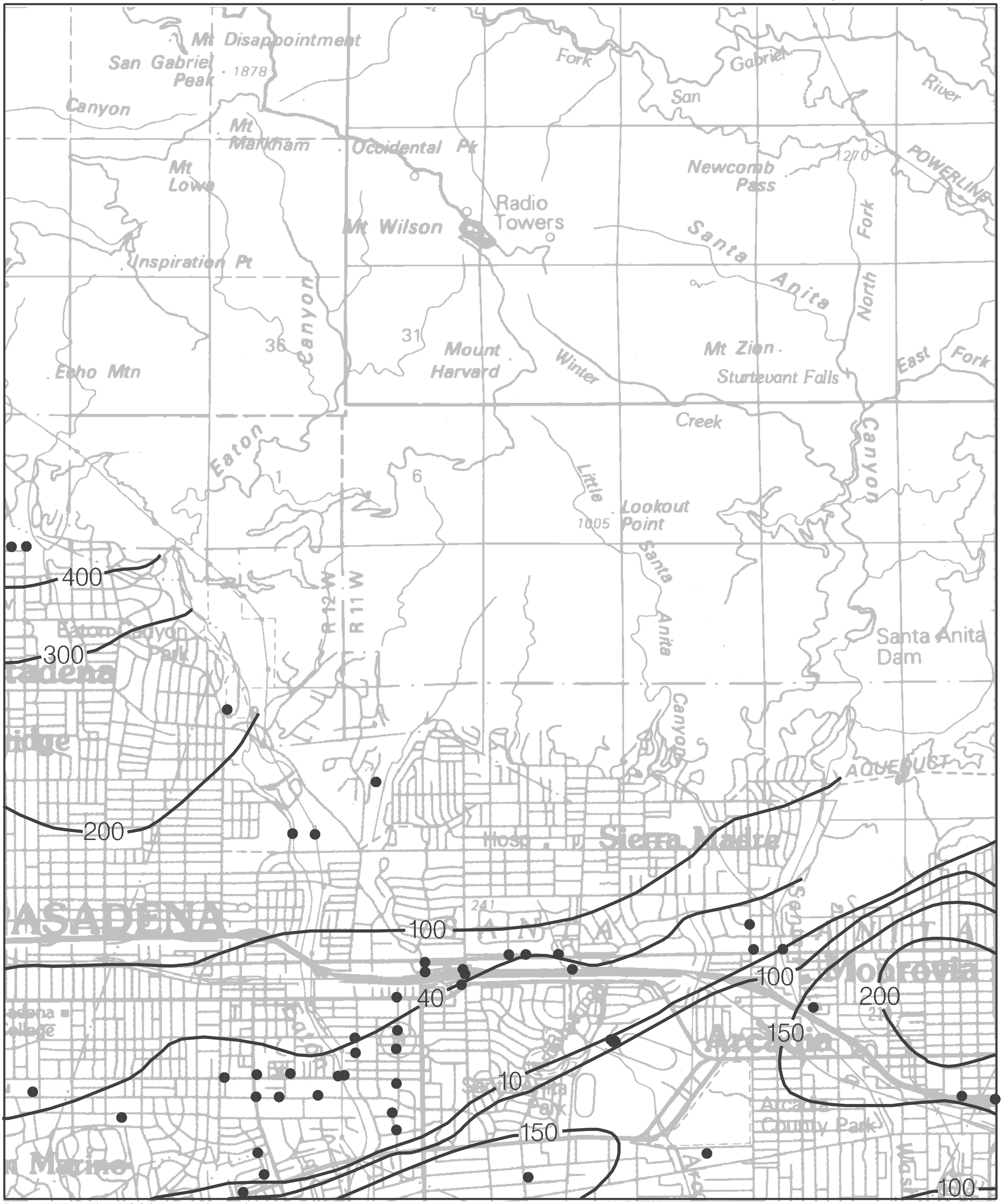
Plate 1.1 Quaternary Geologic Map of the Mt. Wilson Quadrangle.

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

B = Pre–Quaternary bedrock.

ONE MILE

SCALE



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

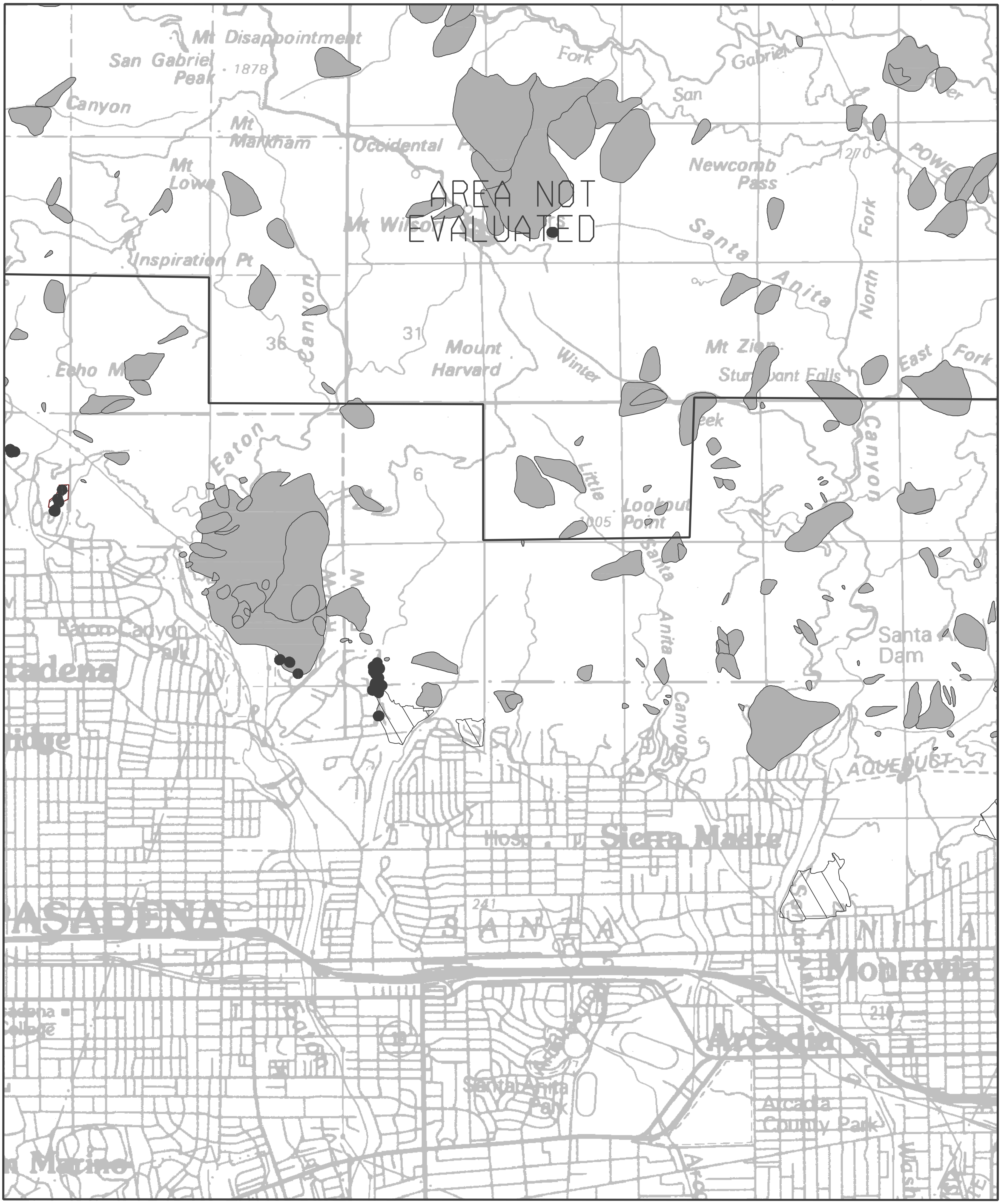
Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Mt. Wilson Quadrangle.

● 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, Mt. Wilson Quadrangle.

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

ONE MILE

SCALE