SEISMIC HAZARD ZONE REPORT 014

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

1998

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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CONTENTS

ILLUSTRATIONS

Executive Summary

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Pasadena 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 57 square miles at a scale of 1 inch = 2,000 feet.

The Pasadena Quadrangle contains parts of the City of Pasadena, the City of Glendale and the Los Angeles community of Eagle Rock. Access to these areas is by the Foothill Freeway (I-210), Ventura Freeway (State Route 134), Glendale Freeway (State Route 2) or the Pasadena Freeway (State Route 110). The unincorporated Los Angeles County communities of La Crescenta, Verdugo City, and Montrose, as well as the City of La Canada Flintridge, are north of the Verdugo Mountains and the San Rafael Hills. The unincorporated community of Altadena lies north of Pasadena. The San Gabriel Mountains cover the northeastern third of the quadrangle. The valley portions of the Pasadena Quadrangle are the sites of alluvial deposits of various ages. La Crescenta and Altadena are built upon recent alluvial fans from the San Gabriel Mountains. The central Glendale area is on the Verdugo Wash fan. Pasadena is largely on an older, inactive alluvial surface. Residential and commercial development is concentrated in the valley areas. Hillside residential development is continuing locally in the Verdugo Mountains and San Rafael Hills.

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 Pasadena Quadrangle the liquefaction zone is restricted to the bottom of Verdugo Canyon, Arroyo Seco, the Eagle Rock area and a few other canyon bottoms. The steepness of the slopes in the San Gabriel and eastern Verdugo Mountains strongly influences the designation of the landslide zone, which is widespread in these mountains. In the San Rafael Hills the zone is limited to areas where steep slopes and weak rocks are concentrated. The earthquake-induced landslide zone covers about 21 percent of the quadrangle including Angeles National Forest land.

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 Pasadena 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

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

By
Christopher J. Wills

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

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

BACKGROUND

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

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the Pasadena 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 Pasadena 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 Pasadena Quadrangle covers an area of about 62 square miles in central Los Angeles County. The southeastern quarter of the quadrangle contains the City of Pasadena, the Civic Center of which lies about 10 miles northeast of the Los Angeles Civic Center. The City of Glendale lies in the southwestern corner of the map area and is separated from Pasadena by the community of Eagle Rock, which is part of the City of Los Angeles. East-west access to these areas is by means of the Foothill Freeway (I-210) and Ventura Freeway (State Route 134). From the south, access is via the Glendale Freeway (State Route 2) or the Pasadena Freeway (State Route 110). North of the Verdugo Mountains and the San Rafael Hills, which lie within the west-central and central portions of the quadrangle, respectively, are the unincorporated Los Angeles County communities of La Crescenta, Verdugo City, and Montrose, as well as the City of La Canada Flintridge. These communities are arranged across the floor of the Tujunga

Valley between the San Gabriel Mountains and the Verdugo Mountains. In the east-central part of the map area the unincorporated community of Altadena lies between the San Gabriel Mountains and the City of Pasadena. The San Gabriel Mountains cover the northeastern third of the quadrangle. The northern communities are accessible via the Foothill Freeway (I-210) or Foothill Boulevard.

The quadrangle includes the drainage divide between two of the major basins of southern California. The La Crescenta and Glendale areas are on the eastern edge of the San Fernando Valley. Pasadena is on the western edge of the San Gabriel Valley. The San Gabriel Mountains, which bound both valleys on the north, cover the northern portion of the Pasadena Quadrangle. The two major streams within quadrangle are the Verdugo Wash and the Arroyo Seco, which drain from north to south across the area. The Verdugo Wash drains from the north side of the Verdugo Mountains, where several tributaries from the San Gabriel Mountains join it, through the Verdugo Canyon between the Verdugo Mountains and the San Rafael Hills to the Glendale area, where it has deposited a major alluvial fan. The Arroyo Seco has cut a major canyon in the San Gabriel Mountains and incised a channel along the east side of the San Rafael Hills and the Eagle Rock and Highland Park area south to the Los Angeles River.

The valley portions of the Pasadena Quadrangle are covered with alluvial deposits of various ages. The La Crescenta and Altadena areas are built on recent alluvial fans from the San Gabriel Mountains. The central Glendale area is on the Verdugo Wash fan. Pasadena is largely on an older alluvial surface that is no longer active because of uplift and the incision of the Arroyo Seco through it. The Eagle Rock valley is an isolated valley within the uplift between the two major basins and has received sediment only from the surrounding hills.

GEOLOGY

Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. Late Quaternary geologic units in the Pasadena Quadrangle were compiled for this study from mapping by McCalpin (unpublished) and Smith (1986). McCalpin mapped the Quaternary geology of the San Gabriel Valley for the Southern California Areal Mapping Project (SCAMP). Smith (1986) mapped the bedrock geology and Quaternary geology of the northern half of the quadrangle. Crook and others (1987) also mapped the Quaternary geology of the northern part of the quadrangle, concentrating on the different alluvial units cut by the Sierra Madre and Raymond faults.

In preparing the Quaternary geologic map for the Pasadena Quadrangle, geologic maps prepared by Lamar (1970), Crook and others (1987), Dibblee (1989), Smith (1986) and McCalpin (unpublished) were referred to. We began with the maps of McCalpin (unpublished) and Smith (1986) as files in the DMG Geographic Information System. These maps were in good agreement for most of the Quaternary units. McCalpin had completed his mapping more recently, primarily using soil surveys to 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). Smith mapped the bedrock geology of the north half of the quadrangle in detail, and also showed the geologic boundaries within the Quaternary units with more detail than McCalpin. The completed map of Quaternary geology primarily uses boundaries between the geologic units as mapped by Smith (1986) 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 Pasadena Quadrangle is reproduced as Plate 1.1.

	Alluvial Fan Deposits	**Alluvial Valley Deposits**	**Age**
Active	Qf- active fan Qw- active wash	Qa- active depositional basin	
Young	Qyf2 Qyf1	Qya, Qya2 Qya1	Holocene
Old	Qof2 Qof1		Pleistocene
Very old	Qvof	Qvoa	

Some unit names include the "characteristic grain size" (e.g. Qyf2a, Qvofg)
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 Pasadena Quadrangle.

The Quaternary geologic map (Plate 1.1) shows that the valley areas of the Pasadena Quadrangle are covered by alluvial fans of various ages, including 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 north and west. The sources of the sediment that make up the young fans have been the small drainages, usually with only a few square miles of watershed, in the San Gabriel Mountains. The largest drainage in the area, the Arroyo Seco, has incised its channel through the Pasadena area to the Los Angeles River. Very little of the sediment from that drainage has been deposited in the incised channel. Sedimentation on the alluvial fans is primarily sand, silt, and gravel, the compositions of which reflects the crystalline rocks of the San Gabriel Mountains. On the Pasadena Quadrangle, the alluvial units have been subdivided into the Saugus Formation, very old alluvium, two generations of older alluvium (Qof1, Qof2), two generations of young alluvium (Qyf2, Qyf1) and active wash and fan deposits (Plate 1.1).

ENGINEERING GEOLOGY

The geologic units described above were mapped primarily from their surface expression, including descriptions of the soils from soil surveys used by McCalpin. This mapping was compared with the subsurface properties described in about 200 borehole logs in the study area. Subsurface data used for this study include the database compiled by John Tinsley for previous studies (Tinsley and Fumal, 1985; Tinsley and others, 1985), a database of shear wave velocity measurements originally compiled by Walter Silva (Wills and Silva, 1998), and additional data collected for this study. Subsurface data were collected for this study at Caltrans, the Los Angeles County Department of Public Works, CDMG files of seismic reports for hospital and school sites, the Regional Water Quality Control Board and from Law Crandall, Inc. In general, the data gathered for geotechnical studies appear to be complete and consistent. Data from environmental geology reports filed with the Water Quality Control Board is well distributed areally and provides reliable data on water levels. Geotechnical data, particularly SPT blow counts, from environmental studies are sometimes less reliable however, due to non-standard equipment and incomplete reporting of procedures.

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 $(N_1)_{60}$.

Data from previous databases and additional borehole logs were entered into the CDMG's "geotec" database, contained within the project GIS. Locations of all exploratory boreholes considered in this investigation are shown on Plate 1.2. Construction of cross sections from the borehole logs, using the GIS, enabled the correlation of soil types from one borehole to another and outlining of areas of similar soils.

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

Saugus Formation (Qs)

Saugus Formation was mapped in the Pasadena Quadrangle by Smith (1986). Crook and others (1987) and McCalpin (unpublished) map the same areas as parts of the oldest alluvial unit. Smith distinguished the Saugus Formation from overlying Pleistocene alluvium based on stratigraphic position, relative uplift, intensity of deformation and a distinctive suite of clasts, some of which are no longer present in the watersheds adjacent to the deposits.

Smith (1986) describes the Saugus Formation as a conglomeratic arkosic sandstone. Crook and others (1987) describe the same outcrops as part of their oldest alluvial unit, an unconsolidated to well consolidated fine to medium sand with gravel. No subsurface data were collected for this unit because it is described as a well-consolidated unit and is found in an area of deep ground water.

Very old alluvium (Qvoa, Qvof)

Very old alluvium is also mapped along the front of the San Gabriel Mountains. Locally, it extends as alluvial fans into the La Crescenta and La Canada areas. Crook and others (1987) describe these fans as red to reddish brown, or yellow unconsolidated to well consolidated fine to medium sand with gravel (the same as the unit Smith (1986) maps as Saugus Formation). Borehole logs by Caltrans in the very old alluvial fan (Qvof2) northeast of Montrose describe dense to very dense poorly sorted sand with thin interbeds of silty sand. No subsurface data were collected for most of this unit because it is a generally well-consolidated unit and is located in an area of deep ground water.

Older alluvium (Qof1, Qof2)

Older alluvium is mapped as remnants of small alluvial fans in the La Crescenta and La Canada areas and the surface that underlies most of the City of Pasadena. Unit Qof1 in Pasadena is composed of sand and silty sand with some layers of silt. In the La Crescenta area it is described as dense to very dense sandy gravel and gravelly sand. Unit Qof2 in northwest Pasadena is described as very dense gravelly sand and sandy gravel. In the La Canada area it is described as dense to very dense sand with some gravel.

Younger alluvium (Qyf1, Qyf2, Qf, Qw)

Alluvial fans from different drainages can be distinguished by their geomorphic expression and can have differing soil profiles due to different bedrock in their source areas. Within an alluvial fan, the different generations of younger alluvium can be distinguished by their geomorphic relationships. In the subsurface, it is not possible to distinguish among the generations on a young alluvial fan. There may simply be too little difference in age among these units, which probably range from mid-Holocene to historic, for any differences in density or cementation to have formed.

Fans from the San Gabriel Mountains

Young alluvial fans in the La Crescenta area are composed of sand and gravelly sand, generally described as compact to dense. In the La Canada area, young alluvial fans are composed of moderately dense to dense sand and silty sand.

Verdugo Wash and fan

Drainage from the San Gabriel Mountains into the La Crescenta area flows through the Verdugo Canyon to the central Glendale area, where a young alluvial fan has formed. Material deposited in the canyon and on the fan is similar to the fans upstream in the La Crescenta area. In the Verdugo Canyon deposits are described as gravelly sand, silty sand and sandy gravel, and are loose to dense. The Verdugo wash fan in Glendale is composed of similar loose to dense gravelly sand, silty sand, and sandy gravel.

Arroyo Seco

The Arroyo Seco has cut a major canyon in the San Gabriel Mountains and incised its drainage through the Pasadena Quadrangle. Deposits of the Arroyo Seco are found only within the incised canyon. These deposits are described on borehole logs as silty sand and gravelly silty sand. We were not able to acquire borehole logs with the results of SPT tests. The consistency of this material is not well known.

Young alluvium of the Eagle Rock area (Qya1, Qya2)

The Eagle Rock Valley lies within the uplifted area between the Verdugo Wash and the Arroyo Seco. It is surrounded by low hills composed mostly of Topanga Formation sandstone and conglomerate. The alluvium in this valley is composed of silty and clayey sand with interbedded clay. The granular deposits are very loose to medium dense with SPT blow counts as low as 1.

Artificial fill (af)

Artificial fill in the Pasadena Quadrangle consists of engineered fill for freeways and other developments and waste landfills. Engineered fills are generally too thin to have an affect on liquefaction hazard and so were not investigated. The waste landfills are within the San Rafael Hills, where ground water is generally deep.

Geologic Map Unit	Material Type	Consistency	Liquefaction Susceptibility
Qw, stream channels	Sandy gravel, gravelly sand	Loose- dense	high
Qf, active alluvial fans	Sand, gravelly sand,	Loose-moderately dense	high
Qyf2, Qyf1 young alluvial fans	Sand, gravelly sand,	Loose-moderately dense	high
Qya2, Qya1, young alluvial valley deposits	Silty sand, clay, clayey sand	Loose-moderately dense	high
Qof1, older alluvial fan	Sand & gravel	Dense-very dense	low
Qof2, older alluvial fan	Sand & gravel	Dense-very dense	low
Qvoa, very old alluvium	Sand & gravel	Dense-very dense	low
Qvof, very old alluvial fan	Sand & gravel	Dense-very dense	low

Table 1.2. General Geotechnical Characteristics and Liquefaction Susceptibility of Younger Quaternary Units.

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

The Pasadena Quadrangle lies on the drainage divide between two major basins. The San Fernando Valley lies to the west and the San Gabriel Valley is on the east. Both are important sources of ground water. The San Fernando Valley ground-water basin was the subject of a lawsuit by the City of Los Angeles against the City of San Fernando and other operators of water wells in the basin. The "Report of Referee" (California State Water Rights Board, 1962) contains information on the geology, soils and ground-water levels of the San Fernando Valley, including the Glendale area, the La Crescenta area, and the Verdugo Canyon. Mendenhall (1908) studied the San Gabriel Valley's ground-water resources before pumping for agriculture and domestic use caused a decline in ground-water levels.

The Report of Referee shows that ground water in the San Fernando Valley reached its highest levels in 1944, before excessive pumping caused drawdowns throughout the basin. Management of the ground-water resources led to stabilizing of ground-water elevations in the 1960's and, in some cases, rise of ground-water elevations in the 1970's and 1980's to levels approaching those of 1944 (Blevins, 1995).

In order to consider the historically highest ground-water level in liquefaction analyses, the 1944 ground-water elevation contours (State Water Rights Board 1962, Plate 29) and the ground-water elevation contours of Mendenhall (1908) were digitized. A three-dimensional model was created from the digitized contours giving ground-water elevation at any point on a grid. The ground-water elevation values in this grid were then subtracted from the surface elevation values from the USGS Digital Elevation Model (DEM) for the Pasadena Quadrangle. The difference between the surface elevation and the ground-water elevation is the ground-water depth. Subtracting the ground-water elevation grid from the DEM results in a grid of ground-water depth values at any point where the grids overlapped.

The resulting grid of ground-water depth values shows several artifacts of the differences between the sources of ground-water elevation data and surface elevation data. The ground-water elevations were interpreted from relatively few measurements in water wells. The USGS DEM is a much more detailed depiction of surface elevation; it also shows man-made features such as excavations or fills that have changed the surface elevations. Most of these surface changes occurred after the historic ground-water levels were measured. The ground-water depth contours were smoothed and obvious artifacts removed to create the final ground-water depth map (Plate 1.2).

The historical ground-water depths were checked against the water levels measured in boreholes compiled for this study. Measured ground-water levels from the 1970's, 1980's and early 1990's tend to be 10 to 20 feet deeper than the historic water level, but show a similar pattern of deep and shallow ground-water areas. The final map of depth to ground water (Plate 1.2) reflects the historical water levels over most of the quadrangle with minor adjustments to reflect detailed information gathered for this study.

The Eagle Rock Valley is somewhat isolated from the two major basins and was not studied in the same level of detail. Ground-water levels in wells in the Eagle Rock area are within 10 to 20 feet of the surface based on measurements recorded on borehole logs collected for this study. Several borehole logs along Eagle Rock Boulevard near the southern boundary of the quadrangle show saturated granular sediments overlying a clay layer and granular sediments under the clay layer that do not appear to be saturated. This suggests a local water table perched on the clay layer, which may not be related to deeper aquifers.

Ground water is also relatively shallow in all canyons in the San Gabriel Mountains where records were examined. In general, it appears that relatively shallow and impermeable bedrock underlying the canyon alluvium helps to maintain a shallow water table.

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 relations among susceptibility, geological map unit and consistency are summarized in Table 1.2.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% 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 Pasadena Quadrangle, peak accelerations of 0.53 g to 0.82 g, resulting from a predominant earthquake of magnitude 6.4 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 portion (Section 3) of this report for further details.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-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 200 borehole logs compiled for this study, only about 120 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 2 1/2-inch inside diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. Few borehole logs, however, include all of the information (soil density, moisture content, sieve analysis, etc.) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values, or using average test values of similar materials from Standard Penetration Tests or from tests that could be converted to SPT's. Few included all of the required information (SPTs, density, water content, percentage of silt and clay size grains) for a complete Seed Simplified Analysis. For those boreholes where SPTs were recorded, the liquefaction analysis was conducted using data extrapolated from other boreholes nearby or in 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 Pasadena Quadrangle is summarized below.

Areas of Past Liquefaction

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

Artificial Fills

In the Pasadena Quadrangle, two kinds of artificial fill are large enough to show at the scale of mapping, engineered fill for freeways, and waste landfills. The engineered fills are generally too thin to have an impact on liquefaction hazard and so were not investigated.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data were evaluated for zoning based on the liquefaction potential determined by the Seed-Idriss Simplified Procedure. Younger alluvial deposits (Qyf1, Qyf2, Qw) in the Pasadena Quadrangle fan have generally high liquefaction susceptibility. All younger alluvium where ground water historically has been less than 40 feet from the surface are included in a liquefaction zone.

Areas with Insufficient Existing Geotechnical Data

We were not able to collect borehole logs from the alluvial channel deposits of the Arroyo Seco that recorded results of SPT tests. Consequently, we were not able to quantitatively analyze the liquefaction susceptibility of these deposits. Based on the shallow water table and young age of the deposits, they meet the criteria for zoning of the State Mining and Geology Board (4a above).

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

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

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PURPOSE

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

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Pasadena 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 Pasadena 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 Pasadena 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 Pasadena 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 Pasadena Quadrangle covers an area of about 62 square miles in central Los Angeles County. The southeastern quarter of the quadrangle contains the City of Pasadena, the Civic Center of which lies about 10 miles northeast of the Los Angeles Civic Center. The City of Glendale lies in the southwestern corner of the map area and is separated from Pasadena by the community of Eagle Rock, which is part of the City of Los Angeles. East-west access to these areas is by means of the Foothill Freeway (I-210) and

Ventura Freeway (State Route 134). From the south, access is via the Glendale Freeway (State Route 2) or the Pasadena Freeway (State Route 110). North of the Verdugo Mountains and the San Rafael Hills, which lie within the west-central and central portions of the quadrangle, respectively, are the unincorporated Los Angeles County communities of La Crescenta, Verdugo City, and Montrose, as well as the City of La Canada Flintridge. These communities are arranged across the floor of the Tujunga Valley between the San Gabriel Mountains and the Verdugo Mountains. In the east-central part of the map area the unincorporated community of Altadena lies between the San Gabriel Mountains and the City of Pasadena. The San Gabriel Mountains cover the northeastern third of the quadrangle. The northern communities are accessible via the Foothill Freeway (I-210) or Foothill Boulevard.

The quadrangle includes the drainage divide between two of the major basins of southern California. The Glendale area lies on the eastern edge of the San Fernando Valley and La Crescenta lies within the Tujunga Valley, which is a tongue of the San Fernando Valley. Altadena, Pasadena, and La Canada Flintridge are on the western edge of the San Gabriel Valley. The San Gabriel Mountains bound both valleys on the north. The San Gabriel Mountains are composed of plutonic rocks of Precambrian through Cretaceous age that have been thrust to the south over the adjacent basins. The Verdugo Mountains and the San Rafael Hills are also composed of crystalline rocks similar to those of the San Gabriel Mountains. South of the Eagle Rock fault, which bounds the San Rafael Hills north of the Ventura Freeway, the hills are composed of sandstone and conglomerate of the Topanga Formation, with some areas of plutonic rock.

The two major stream courses within quadrangle are Verdugo Wash and Arroyo Seco, both of which drain from north to south across the area. Verdugo Wash drains from the north side of the Verdugo Mountains, where several tributaries from the San Gabriel Mountains join it, through Verdugo Canyon between the Verdugo Mountains and the San Rafael Hills to the Glendale area, where it has deposited a major alluvial fan. Arroyo Seco has cut a major canyon in the San Gabriel Mountains and incised a channel along the eastern side of the San Rafael Hills and the Eagle Rock and Highland Park area south to the Los Angeles River.

The valley portions of the Pasadena Quadrangle are covered with alluvial deposits of various ages. The La Crescenta and Altadena areas are built on recent alluvial fans from the San Gabriel Mountains. The central Glendale area is on the Verdugo Wash fan. Pasadena is largely on an older alluvial surface that is no longer active because of uplift and the incision of the Arroyo Seco through it. The Eagle Rock valley is an isolated valley within the uplift between the two major basins and has received sediment only from the surrounding hills. For details of the properties of the Quaternary geologic units see Section 1.

Residential and commercial development is concentrated in the valley areas. 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 continues today with small residential developments in the Verdugo Mountains and San Rafael Hills.

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 Pasadena 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 Pasadena Quadrangle were identified on a separate map (see Palte 2.1). Terrain data for these areas were obtained from an airborne interferometric radar (TOPSAR) DEM flown and processed in August 1994 by NASA's Jet Propulsion Laboratory (JPL), and reprocessed by Calgis, Inc. (GeoSAR Consortium, 1995 and 1996). These terrain data were also smoothed prior to analysis.

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 Pasadena Quadrangle and the geologic map of the north half of the Pasadena quadrangle by Smith (1986). The maps were compared with geologic maps of the area by Lamar (1970), Dibblee (1989), and 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, and their southern outliers the Verdugo Mountains and San Rafael Hills, are blocks of plutonic igneous and metamorphic rocks that are being thrust over the adjacent valleys from the north.

Bedrock geology in the crystalline bedrock of the Verdugo and San Gabriel Mountains shown by McCalpin (unpublished) is simplified to just one unit called Mx (Mesozoic crystalline rocks). Smith (1986) mapped the bedrock geology of the northern part of the quadrangle in great detail, and also shows 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 uses primarily the boundaries between the geologic units as mapped by Smith (1986) in the northern half, and those mapped by McCalpin in the southern half, with unit designations from Smith (1986) for the bedrock units.

Major crystalline bedrock units mapped by Smith (1986) in the Pasadena Quadrangle include gneissic rocks mapped as augen gneiss (ag), metamorphic-granitic complex (mg; lgm), alaskite (ga), and metasedimentary rocks (ms; mp). These have been intruded by dioritic igneous rocks mapped as biotite-hornblende diorite (bhd), hornblende diorite (hd; hdw), hornblende-biotite diorite (hbd), biotite-quartz diorite (bqd), monzonite (ml), cataclastic quartz monzonite (qmc), and coarse-grained hornblende diorite (hdr). Smaller intrusions of granitic rocks, including granite (ge), leucocratic granodiorite (gl), and granitic complex (gc), and zones of cataclastic rocks (cc), also occur.

South of the Eagle Rock Fault, in the southern San Rafael Hills, Miocene Topanga Formation (Tt) of probable marine origin (Lamar, 1970) is exposed in a number of low-lying hills. The Topanga Formation consists of primarily crudely bedded conglomerate with sandstone and, to a lesser extent, silty shale interbeds.

Late Tertiary (?) to Quaternary sedimentary rocks exist within the southern flank of the San Gabriel Mountains. The Saugus and Pacoima formations (Qs and Qp, respectively), both mapped by Smith (1986), consist of conglomeratic arkosic sandstone of stream channel, flood plain, and alluvial fan origin.

Other surficial units in the mountainous areas include older alluvial fan deposits (Qof, Qoa), colluvium (Qc, Qco), talus (Qta, Qto), slopewash (Qsw, Qswo), and sand and gravel in the active stream channel (Qw, Qwg). Elevated terraces of young alluvium (Qyf) and older alluvium (Qoa) are present locally along the canyon edges above the modern channel level. In some areas of mass grading and residential development, artificial fill (af) has been mapped in and around the mountainous areas.

The valley areas of the Pasadena Quadrangle are covered by alluvial deposits derived from the San Gabriel Mountains and Verdugo Hills. 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 Pasadena Quadrangle can be found in Section 1.

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, they must first be ranked on the basis of their overall shear strength. The primary source for rock shear-strength measurements for the Pasadena Quadrangle are geotechnical reports prepared by consultants, on file with: 1) the Los Angeles County Public Works Department, 2) City of Los Angeles, Department of Public Works, and 3) the City of Glendale, Public Works Division. Geotechnical and engineering geologic reports contained in Environmental Impact Reports and Hospital Review Project files at DMG are additional sources. Where shear strength information was lacking for certain rock units within the Pasadena Quadrangle itself, it was collected from adjacent areas. The locations of rock and soil samples taken for shear testing are shown on Plate 2.1.

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

PASADENA QUADRANGLE SHEAR STRENGTH GROUPS							
	Formation Name	**Number of Tests**	**Mean/Median Phi (deg)**	**Mean/Median Group Phi (deg)**	**Mean/Median Group C (psf)**	**No Data: Similar Lithology**	**Phi Values Used in Stability Analyses**
GROUP 1	grantic	35	37/37	38/37	557/500	cc	38
	dioritic	14	37/36				
	granodioritic	7	44/42				
	gneissic	1	35/35				
GROUP 2	Tt(fbc)	52	34/35	34/35	487/338		34
GROUP 3	Qoa	29	32/30	31/30	285/250	Qs, Qp	31
	Qof	6	29/29			Qvoa	
	Qyf	11	30/30			Qta,Qto	
	Qw	10	32/31			Qya	
	Qc	3	28/28			Qsw, Qswo	
	af	40	31/31			Qwg	
GROUP 4	Tt(abc)	12	26/28	26/28	494/425		26
GROUP 5	Qls	22	15/16	15/16	440/315		15

* Generic rock types identified in this column can be linked to more-specific rock types discussed in the Surface and Bedrock Geology section.

abc=adverse bedding condition, fine-grained material strength
fbc=favorable bedding condition, coarse-grained material strength

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

SHEAR STRENGTH GROUPS FOR THE PASADENA QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Ga	Tt(fbc)	Qs	Tt(abc)	Qls
mp		qp		
bhd		Qvoa		
hbd		Qc		
bqd		Qco		
gc		Qsw		
hd		Qswo		
lgm		Qto		
gl		Qta		
ag		Qw		
mg		Qwg		
ms		Qya		
hdr		Qyf		
ge		af		
qmc				
hdw				
ml				
cc				

Table 2.2. Summary of the Shear Strength Groups for the Pasadena Quadrangle.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Pasadena Quadrangle was prepared (Treiman, unpublished) by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping. Aerial photos taken the U.S. Department of Agriculture (1952/53) 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 (Dibblee, 1989; Smith, 1986; Morton and Streitz, 1969; Crook and others, 1987). The completed hand-drawn landslide map was scanned and digitized at a scale of 1:24,000 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). All landslides on the digital geologic map (from Smith, 1986) 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. 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. 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: 1) the Los Angeles County Public Works Department, 2) City of Los Angeles, Department of Public Works, and 3) the City of Glendale, Public Works Division (see Appendix A). Geotechnical and engineering geologic reports contained in Environmental Impact Reports and Hospital Review Project files at DMG are additional sources. Where shear strength information was lacking for certain rock units within the Pasadena Quadrangle itself, it was collected from adjacent areas. 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.

Adverse Bedding Conditions

Adverse bedding conditions are an important consideration in slope stability analyses. Adverse bedding conditions occur where the dip direction of bedded sedimentary rocks is roughly the same as the slope aspect, and where the dip magnitude is less than the slope gradient. Under these conditions, landslides can slip along bedding surfaces due to a lack of lateral support.

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, provided with the digital geologic map (Smith, 1986) and from Dibblee (1989), was used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude was less than or equal to the slope gradient category but greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area.

The formations, which contain interbedded sandstone and shale, were subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material (higher strength) dominates where bedding dips into a slope (favorable bedding) while fine-grained (lower strength) material dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. The favorable and adverse bedding shear strength parameters for the formations are included in Table 2.1.

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 Pasadena 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 7.0
Modal Distance:	2.5 to 7.4 km
PGA:	0.60 to 0.83g

The strong-motion record selected for the slope stability analysis in the Pasadena 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 PGA of 0.69 g. The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

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

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 0.13 and 0.23g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Pasadena Quadrangle.

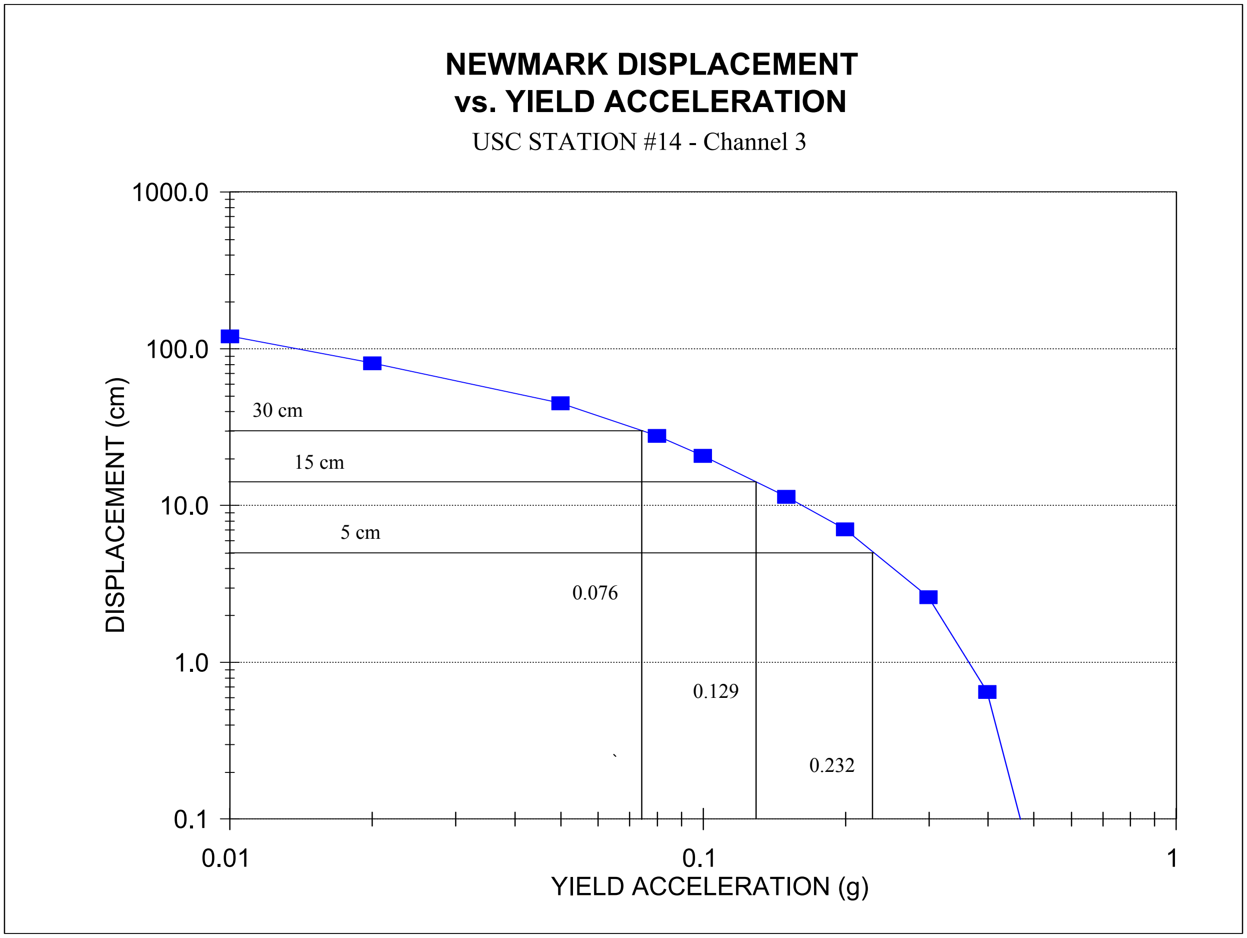

Figure 2.1. Yield acceleration vs. Newmark displacement for the USC Station #14 strong-motion record From the 17 January 1994 Northridge, California Earthquake.

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.

PASADENA QUADRANGLE HAZARD POTENTIAL MATRIX										
		SLOPE CATEGORY								
Geologic Material Group	**Mean Phi**	**I 0-13%**	**II 14-19%**	**III 20-24%**	**IV 25-35%**	**V 36-41%**	**VI 42-52%**	**VII 53-64%**	**VIII 65-69%**	**IX >70%**
1	38	VL	VL	VL	VL	VL	VL	L	M	H
2	34	VL	VL	VL	VL	VL	L	M	H	H
3	31	VL	VL	VL	VL	L	M	H	H	H
4	26	VL	VL	VL	L	M	H	H	H	H
5	15	L	M	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Pasadena 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 Pasadena Quadrangle resulting from the 5.8 ML Sierra Madre earthquake of June 28, 1991 (Barrows and Irvine, 1991). Beginning at about the 2,000-foot level in the Wilson Diorite, rockfalls were common along the Angeles Crest Highway. Although rock falls from very steep, cracked, and shattered basement-rock roadcut exposures were abundant, they were neither large enough or numerous enough to cause closure of the highway.

The 1994 Northridge earthquake caused a number of relatively small, shallow slope failures in the Pasadena Quadrangle (Harp and Jibson, 1995). Landslides attributed to the Northridge earthquake covered approximately 2 acres of land in the western half of the quadrangle, which is less than 1/2 of 1 percent of the total area covered by the map. Of the area covered by these Northridge earthquake landslides, 77% falls within the area of the hazard zone based on a computer comparison of the zone map and the Harp and Jibson (1995) inventory.

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 5 is included for all slope gradient categories. (Note: Geologic Strength Group 5 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 4 is included for all slopes steeper than 24 percent.

3. Geologic Strength Group 3 is included for all slopes steeper than 35 percent.

4. Geologic Strength Group 2 is included for all slopes steeper than 41 percent.

5. Geologic Strength Group 1 is included for all slopes greater than 52 percent.

This results in approximately 21 percent of the quadrangle, including National Forest land, lying within the earthquake-induced landslide hazard zone for the Pasadena 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: 1) the Los Angeles County Department of Public Works with the assistance of Robert Larsen, James Shuttleworth, Charles Nestle, and Dave Poplar, 2) the City of Los Angeles with the assistance of Nicky Girmay, and 3) the City of Glendale with the assistance of Kurt Erickson, Bruce Thompson, and William A'Hearn. Digital terrain data were provided by Randy Jibson of the U.S. Geological Survey (USGS DEM), Scott Hensley of JPL, and Gerald Dildine and Chris Bohain of Calgis, Inc. (Radar DEM). Technical review of the methodology was provided by Bruce Clark, Randy Jibson, Robert Larson, Scott Lindvall, and J. David Rogers, who are members of the State Mining and Geology Board's Seismic Hazards Mapping Act Advisory Committee Landslides Working Group. At DMG, special thanks to Bob Moskovitz, Teri McGuire, Barbara Wanish, 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
City of Glendale, Public Works Division	**42**
Los Angeles County Public Works Department	**59**
Geotechnical reports from environmental impact documents and DMG staff on file at DMG	**8**
City of Los Angeles, Department of Public Works	**133**
Total Number of Shear Tests	**242**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Pasadena 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.

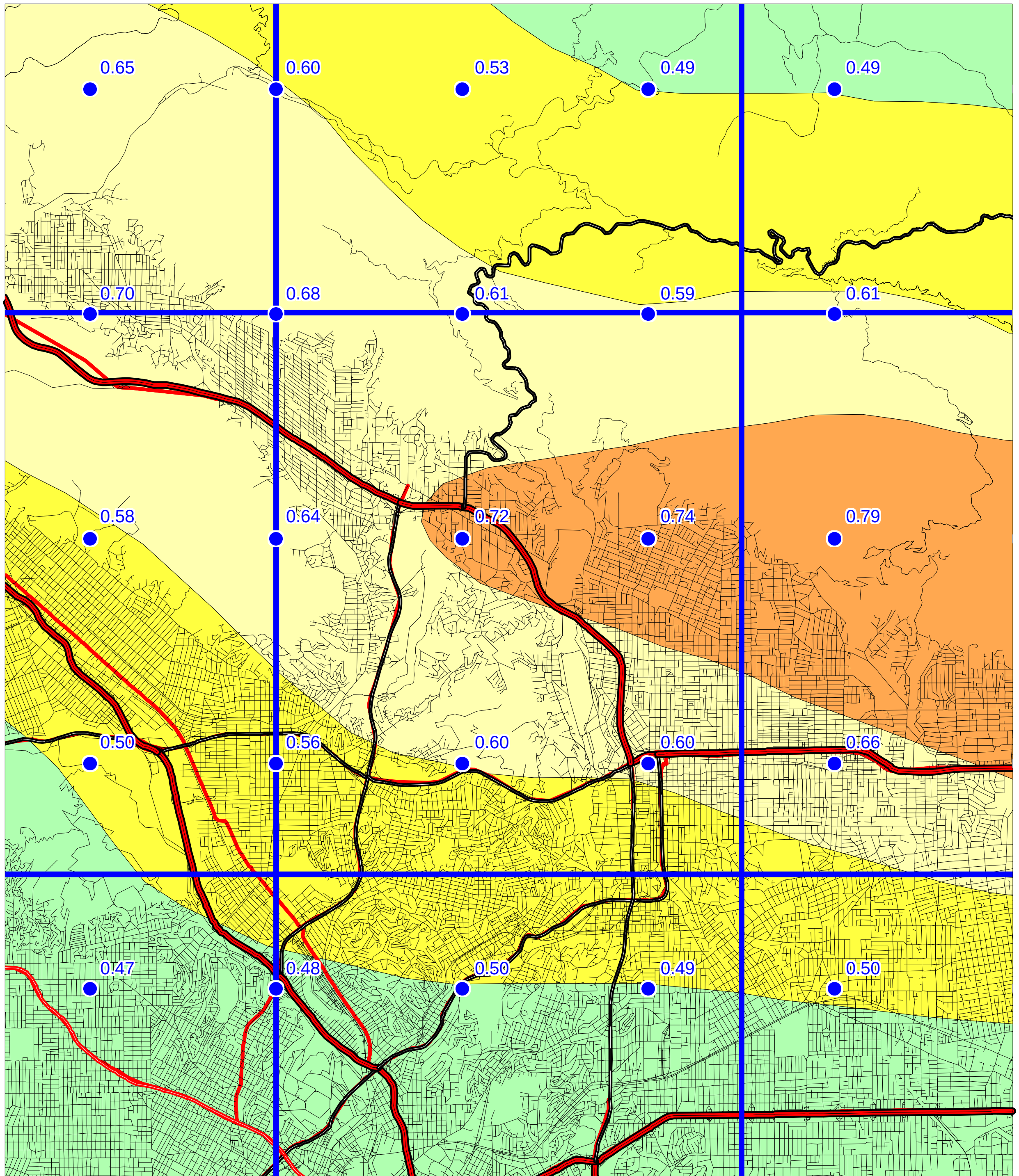
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

PASADENA 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

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.1

PASADENA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS

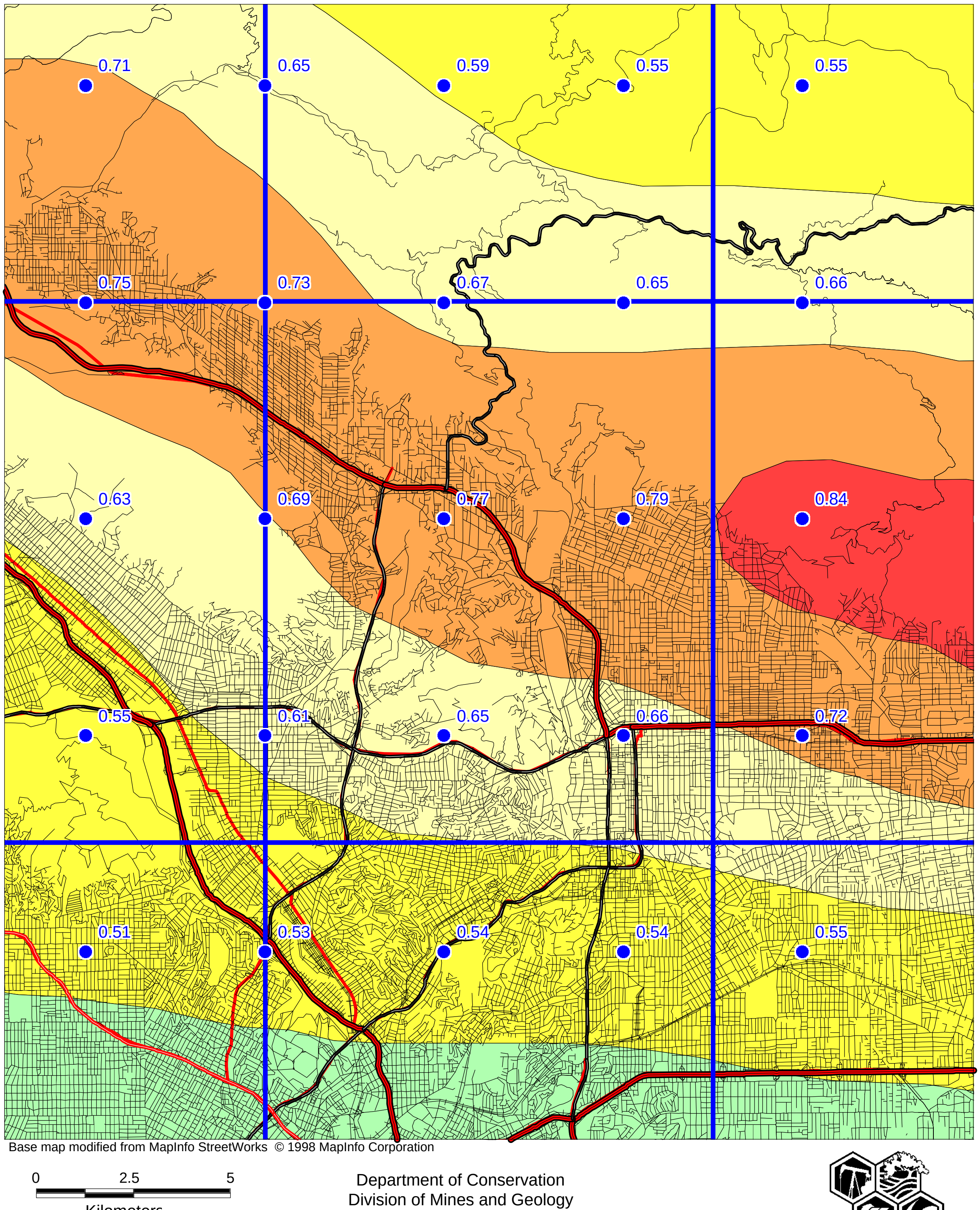


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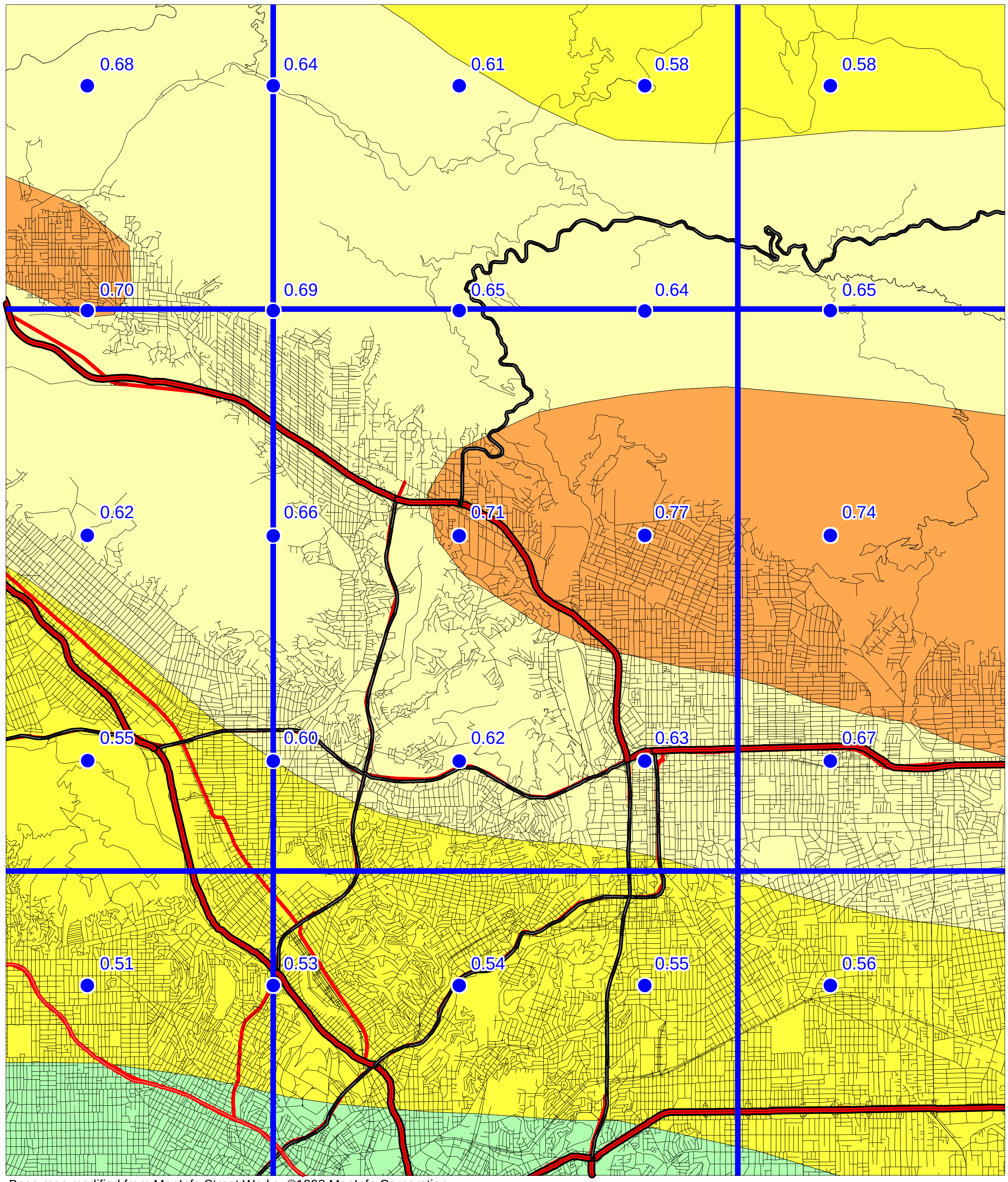
Figure 3.2

PASADENA 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

0 2.5 5
Kilometers

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.

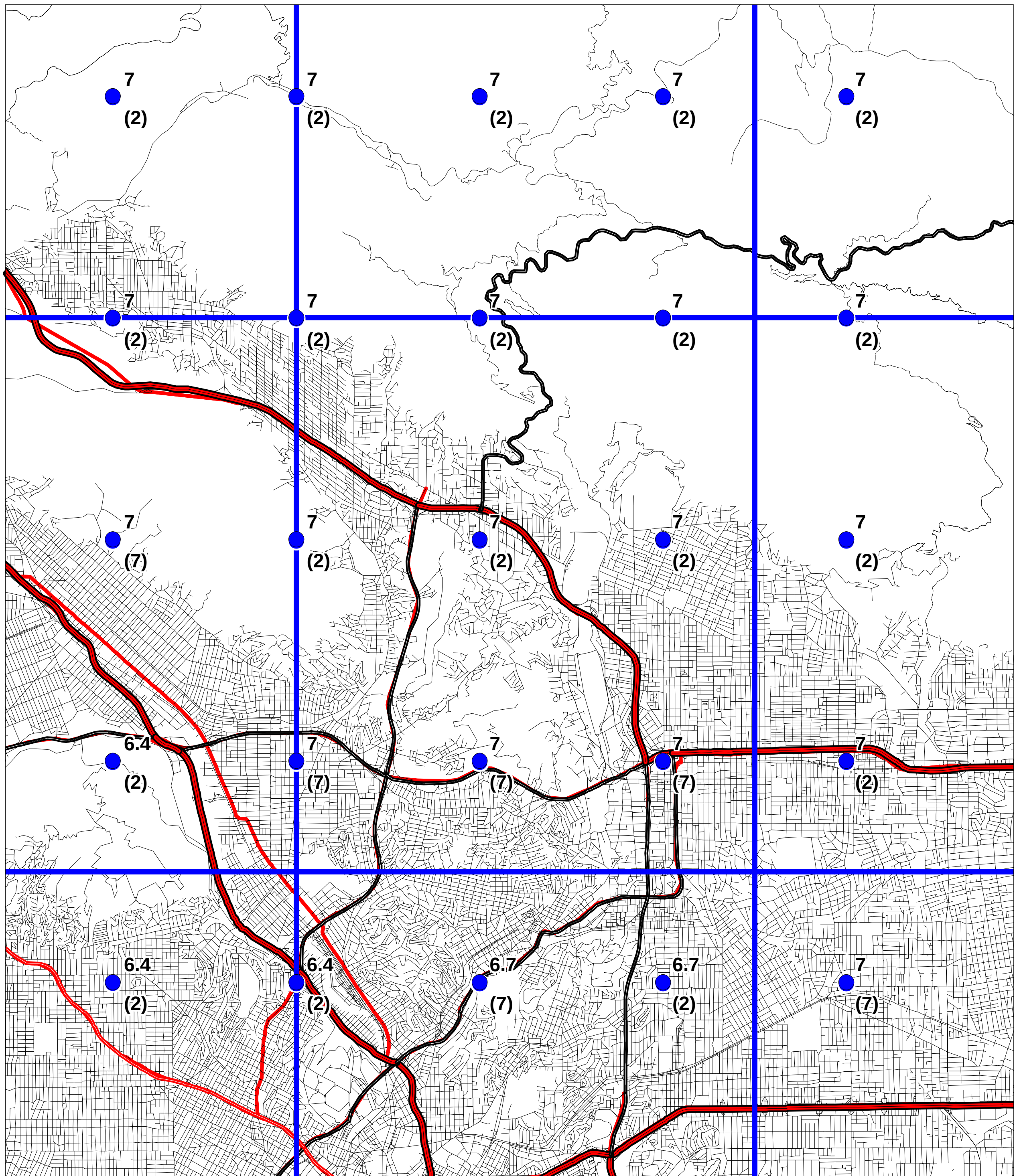
DIVISION OF MINES AND GEOLOGY

PASADENA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

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



0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

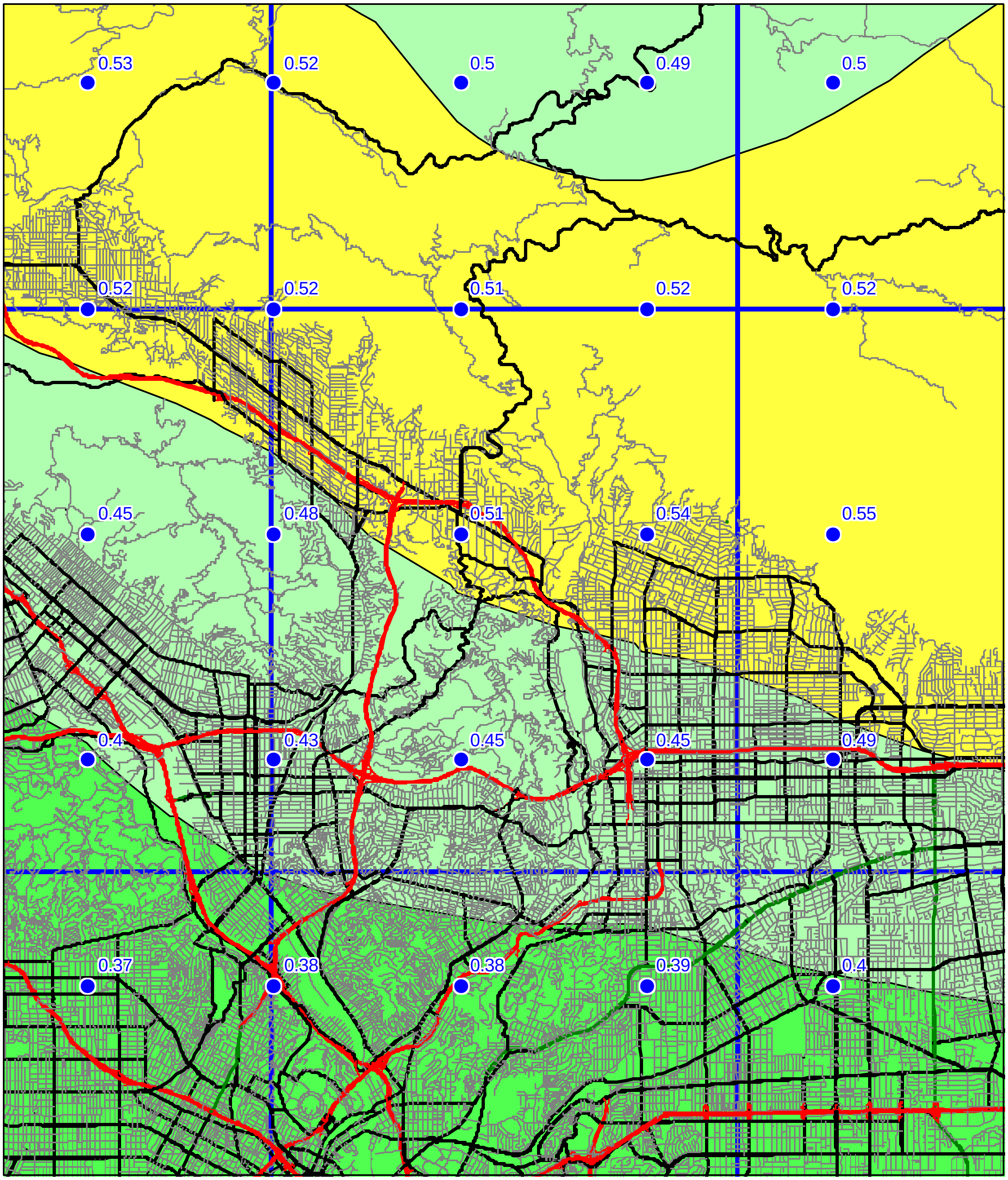
Figure 3.4

PASADENA 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

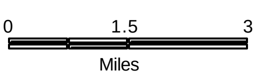
10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g) FOR ALLUVIUM

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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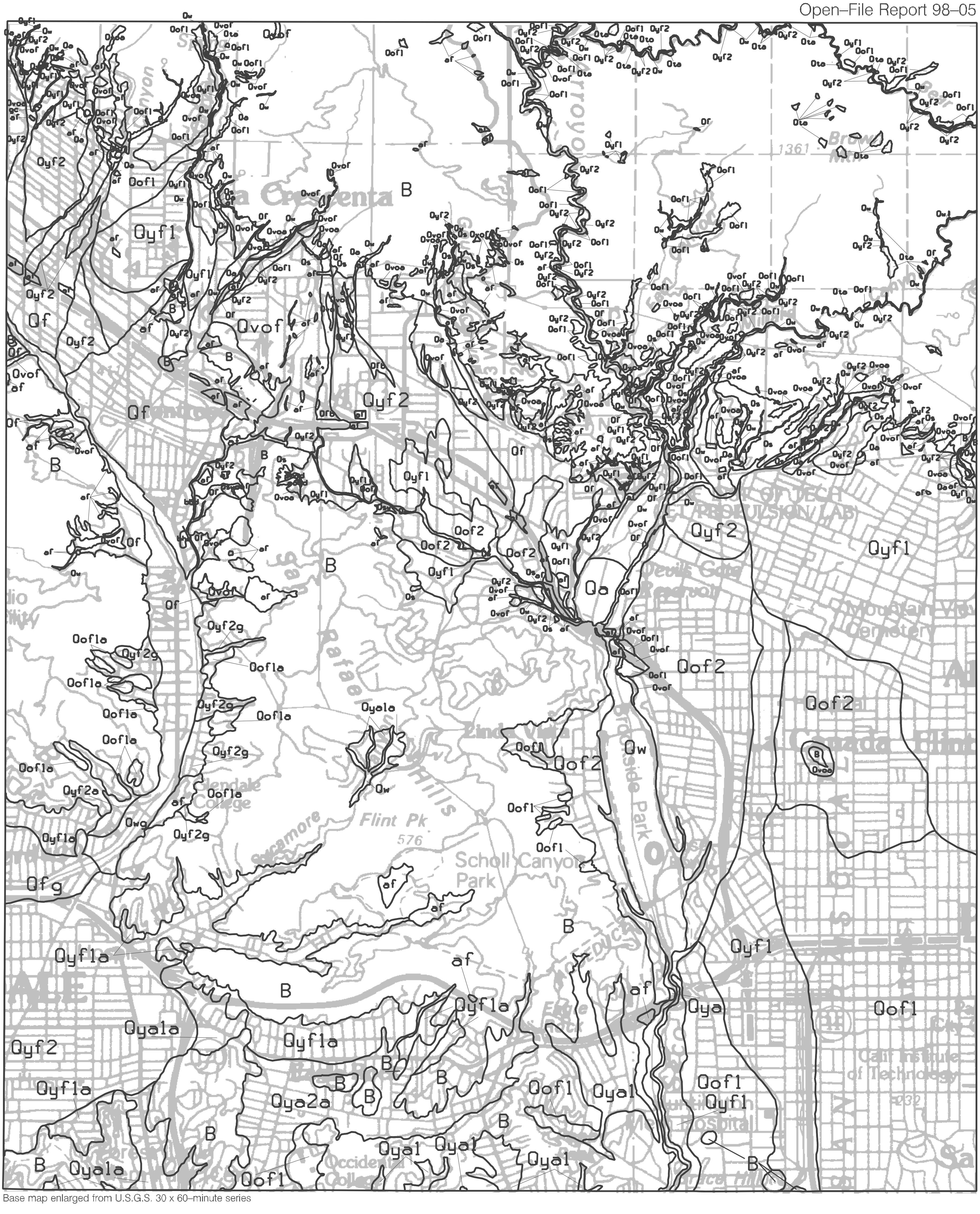


Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 1.1 Quaternary Geologic Map of the Pasadena Quadrangle.

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

B = Pre–Quaternary bedrock.

ONE MILE

SCALE

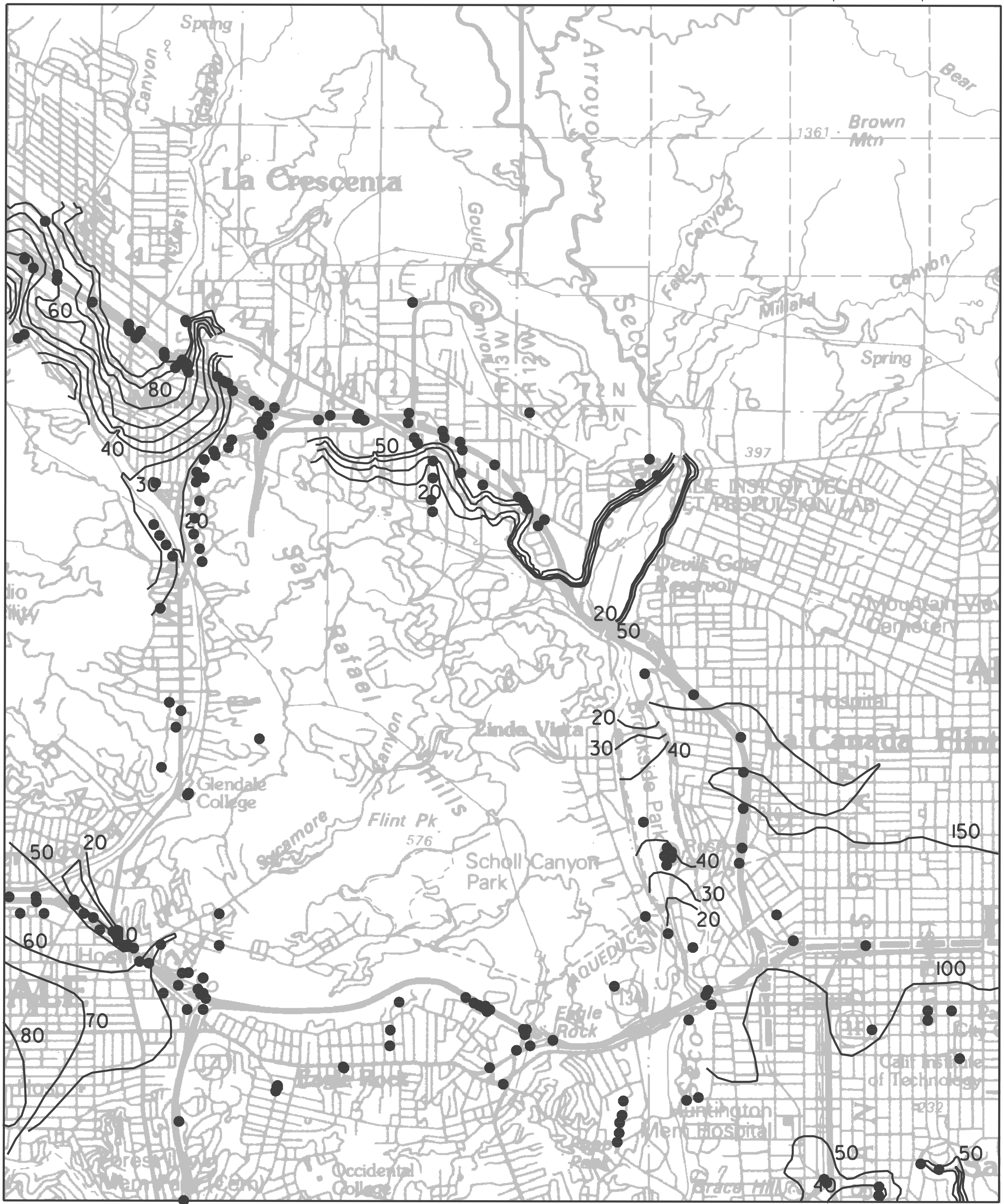
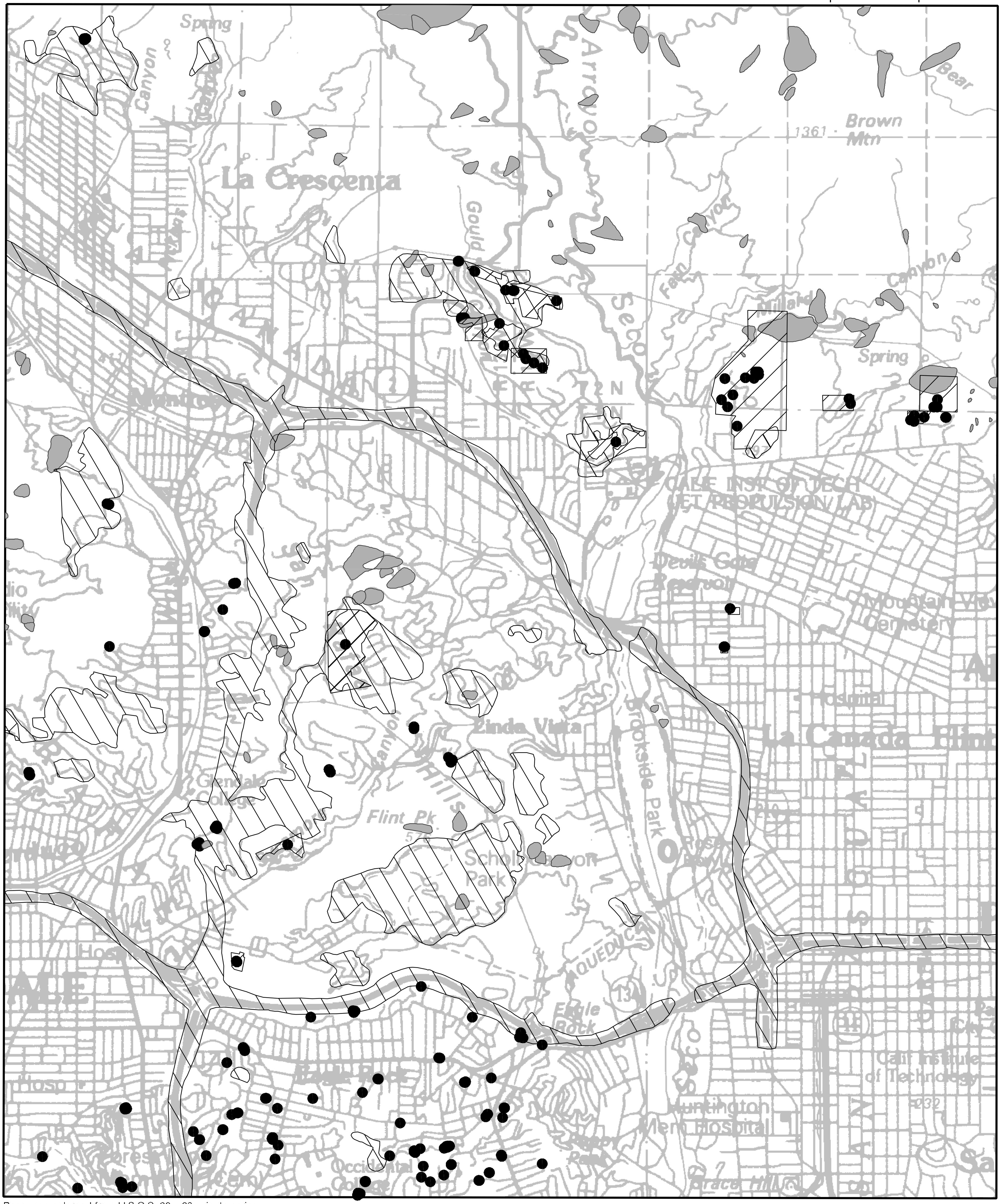


Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Pasadena Quadrangle.

● 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, data collection site and tract location map, Pasadena Quadrangle.

● Boring or sample location — Landslide — Areas of significant grading — Tract report with multiple borings

ONE MILE

SCALE