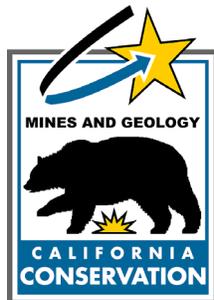


**SEISMIC HAZARD ZONE REPORT FOR THE
CANOGA PARK 7.5-MINUTE QUADRANGLE,
LOS ANGELES COUNTY, CALIFORNIA**

1997



DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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SEISMIC HAZARD ZONE REPORT 07

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CANOGA PARK 7.5-MINUTE QUADRANGLE,
LOS ANGELES COUNTY, CALIFORNIA**

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CONTENTS

EXECUTIVE SUMMARY	viii
INTRODUCTION	1
SECTION 1 LIQUEFACTION EVALUATION REPORT Liquefaction Zones in the Canoga Park 7.5-Minute Quadrangle, Los Angeles County, California.....	3
PURPOSE.....	3
BACKGROUND	4
METHODS SUMMARY.....	4
SCOPE AND LIMITATIONS.....	5
PART I.....	5
PHYSIOGRAPHY.....	5
GEOLOGY	6
ENGINEERING GEOLOGY	9
GROUND-WATER CONDITIONS	15
PART II.....	16
LIQUEFACTION POTENTIAL	16
LIQUEFACTION SUSCEPTIBILITY.....	17
LIQUEFACTION OPPORTUNITY	18
LIQUEFACTION ZONES	20
ACKNOWLEDGMENTS	23
REFERENCES	23

SECTION 2 EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT Earthquake-Induced Landslide Zones in the Canoga Park 7.5-Minute Quadrangle, Los Angeles County, California	27
PURPOSE.....	27
BACKGROUND	28
METHODS SUMMARY.....	28
SCOPE AND LIMITATIONS.....	29
PART I.....	30
PHYSIOGRAPHY.....	30
GEOLOGY	31
ENGINEERING GEOLOGY	33
PART II.....	36
EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL.....	36
EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE	40
ACKNOWLEDGMENTS	42
REFERENCES	42
AIR PHOTOS.....	45
APPENDIX A Source of Rock Strength Data.....	45
SECTION 3 GROUND SHAKING EVALUATION REPORT Potential Ground Shaking in the Canoga Park 7.5-Minute Quadrangle, Los Angeles County, California	46
PURPOSE.....	46
EARTHQUAKE HAZARD MODEL	47
APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS	51
USE AND LIMITATIONS.....	54
REFERENCES	55

ILLUSTRATIONS

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record from the 17 January 1994 Northridge, California Earthquake.	38
Figure 3.1. Canoga Park 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Firm rock conditions.	49
Figure 3.2. Canoga Park 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Soft rock conditions.	50
Figure 3.3. Canoga Park 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Alluvium conditions.	51
Figure 3.4. Canoga Park 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration—Predominant earthquake.	53
Figure 3.5. Canoga Park 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years magnitude-weighted pseudo-peak acceleration for alluvium - Liquefaction opportunity	54
Table 1.1. Units of the Southern California Areal Mapping Project (SCAMP) Nomenclature Used in the San Fernando Valley.....	7
Table 1.2. General Geotechnical Characteristics and Liquefaction Susceptibility of Younger Quaternary Units.....	14
Table 2.1. Summary of the Shear Strength Statistics for the Canoga Park Quadrangle.....	34
Table 2.2. Summary of the Shear Strength Groups for the Canoga Park Quadrangle.....	34
Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Canoga Park Quadrangle.....	40
Plate 1.1. Quaternary Geologic Map of the Canoga Park 7.5-Minute Quadrangle, California.	58
Plate 1.2. Historically Highest Ground Water Contours and Borehole Log Data Locations, Canoga Park 7.5-Minute Quadrangle, California.	59
Plate 2.1. Landslide inventory, shear test sample locations, Canoga Park 7.5-Minute Quadrangle.....	60

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Canoga Park 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 62 square miles at a scale of 1 inch = 2,000 feet.

The Canoga Park Quadrangle is in central San Fernando Valley, about 20 miles northwest of the Los Angeles Civic Center. All or parts of the Los Angeles City communities of Reseda, Tarzana, Encino, Canoga Park, Woodland Hills, and Northridge are within the quadrangle. The northern half of the quadrangle includes part of the San Fernando Valley, part of the Simi Hills and part of the Northridge Hills. The southern half includes terrain of the Santa Monica Mountains, the crest of which lies near the southern boundary, and the Chalk Hills, which are bisected by the Ventura Freeway (U.S. 101). Residential and commercial development is concentrated in the flat-lying valley areas. Hillside residential development continues at present. Other land uses include golf courses, Sepulveda Dam Flood Control and Recreation Area, State parkland, and reservoirs. Encino Reservoir is located in the southeast corner, and Chatsworth Reservoir (now dry) is located in the northwestern part of the quadrangle.

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

In the Canoga Park Quadrangle the liquefaction zone is widespread within the southern San Fernando Valley, especially within about one mile of the Los Angeles River. The part of the zone that extends northeastward into Northridge is related to young, loose alluvial sediments and a shallow water table. Liquefaction-related effects were observed in the quadrangle from the 1994 Northridge earthquake. The presence of rocks that are highly susceptible to landsliding and deep dissection of the hillsides on the northern slope of the Santa Monica Mountains contribute to an earthquake-induced landslide zone that covers about 12 percent of the quadrangle. However, except for areas within the Simi Hills and Chalk Hills approximately 50 percent of the upland terrain is within the zone.

How to view or obtain the map

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

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

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

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

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Canoga Park 7.5-minute Quadrangle.

SECTION 1

LIQUEFACTION EVALUATION REPORT

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

By
Christopher J. Wills and Allan G. Barrows

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

1996). Additional information on seismic hazards zone mapping in California is on DMG's Internet web page: <http://www.conservation.ca.gov/CGS/index.htm>

BACKGROUND

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

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

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

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

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Canoga Park Quadrangle covers an area of about 62 square miles in western Los Angeles County. The center of the quadrangle lies almost 20 miles northwest of the Los Angeles Civic Center. Most of the quadrangle lies within the San Fernando Valley, although, south of U.S. Highway 101 (Ventura Freeway), the northern slopes of the Santa Monica Mountains rise toward the mountain crest, which nearly coincides with the southern border of the area.

The San Fernando Valley is an east-trending structural trough within the Transverse Ranges geologic province of southern California. The mountains that bound it to the north and south are actively deforming anticlinal ranges bounded on their south sides by thrust faults. As these ranges have risen and been deformed, the San Fernando Valley has subsided and filled with sediment.

The western portion of the valley, including most of the Canoga Park Quadrangle has received sediment from small drainage courses originating in the Santa Monica Mountains, Simi Hills and Santa Susana Mountains. These small streams have deposited their sediment in the form of channel deposits, alluvial fans and floodplain deposits in the valley. Composition of these deposits is dependent on the source areas of the streams. Streams with source areas dominated by Modelo Formation shale tend to deposit clayey alluvium while those with sources in Saugus, Chatsworth, or Topanga formations tend to deposit silty or sandy alluvium.

The eastern portion of the valley, including much of the eastern part of the Canoga Park Quadrangle, has received sediment from Pacoima and Tujunga washes. These washes are associated with very large river systems that originate in the high, steep, crystalline bedrock terrain of the San Gabriel Mountains. These large river systems have deposited a broad, composite alluvial fan consisting of sand, silt and gravel, which covers much of the adjacent Van Nuys Quadrangle.

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 San Fernando Valley area were completely re-mapped for this study and a concurrent study by engineering geologist Chris Hitchcock of William Lettis and Associates (Hitchcock and Wills, 1998; 2000). Lettis and Associates received a grant from the National Science Foundation (NSF) to study the activity of the Northridge Hills uplift. As part of the research for this study, Hitchcock mapped Quaternary surficial units by interpreting of their geomorphic expression on aerial photographs and topographic maps. The primary source for this work was 1938 aerial photographs taken by the U.S. Department of Agriculture (USDA). His interpretations were checked and extended for this study using 1952 USDA aerial photos, 1920's topographic maps and subsurface data. The resulting map (Hitchcock and Wills, 2000) represents a cooperative effort to depict the Quaternary geology of the San Fernando Valley combining surficial geomorphic mapping and information about subsurface soil engineering properties. The portion of this map that covers the Canoga Park Quadrangle is reproduced as Plate 1.1.

For the Quaternary geologic map for the Canoga Park Quadrangle, geologic maps prepared by Tinsley and others (1985), Yerkes and Campbell (1993), and Dibblee (1992) were referred to. We began with the map of Yerkes and Campbell (1993) as a file in the DMG Geographic Information System. The Quaternary geology shown by Yerkes and Campbell (1993) was compiled from Tinsley and others (1985). For this study, we did not review or revise the mapping of bedrock units by Yerkes and Campbell (1993), except at the contacts between bedrock and Quaternary units. Within the Quaternary units, mapping by Hitchcock (and for this study) was used to refine and substantially revise the mapping of Tinsley and others (1985). For this map, geologic units were defined based on the geomorphic expression of Quaternary units (based on aerial

photographs and historic topographic maps) and subsurface characteristics of those units (based on boreholes). The nomenclature of the Southern California Areal Mapping Project (SCAMP) (Morton and Kennedy, 1989) was applied to all Quaternary units (Table 1.1).

	Alluvial fan deposits	alluvial valley deposits	
Active	Qf- active fan	Qa- active depositional basin	Holocene?
	Qw- active wash		
Young	Qyf2	Qyt	Pleistocene?
	Qyf1		
Old	Qof2	Qt	
	Qof1		
Very old	Qvof2	Qvoa2*	
		Qvoa1*	

*may have been alluvial fan, depositional form not preserved

Table 1.1. Units of the Southern California Areal Mapping Project (SCAMP) Nomenclature Used in the San Fernando Valley.

The Quaternary geologic map (Plate 1.1) shows that the Canoga Park Quadrangle is occupied by an alluvial basin deposit, surrounded by alluvial fans, which are, in turn, surrounded by mountains (off the map to the west north and east). This basin is part of an east-west trending structural trough that has been filled from the north and south. The Los Angeles River, which flows from west to east across the basin, has contributed very little to the sedimentation of the basin. The major sources of the sediment that fills the San Fernando Valley have been the drainage systems that culminate in Tujunga and Pacoima washes, both of which receive sediment from large regions in the San Gabriel Mountains. These river systems begin in high, rugged mountains composed of crystalline rocks. Periodic torrential rainfall and associated flooding characterize the drainage regimes of these washes. Sedimentation in the San Fernando Valley has formed a large alluvial fan composed primarily of sand, silt, and gravel, reflecting the crystalline rocks of the source area. This alluvial fan extends from its head on the San Fernando and Sunland quadrangles, across most of the Van Nuys and Burbank quadrangles (northeast

and east of the Canoga Park Quadrangle). Only the western fringe of this alluvial fan is on the Canoga Park Quadrangle.

The Pacoima/Tujunga alluvial fan on the Van Nuys and Canoga Park quadrangles can be subdivided based on relative ages of different surfaces. The oldest of these surfaces, Qof2, on the western Van Nuys and eastern Canoga Park quadrangles appears to be cut off from its upstream source area by uplift of the Northridge Hills. Qof2 appears to form a fan within the larger fan with its apex near the Bull Creek gap in the Northridge Hills (in the northwestern corner of the Van Nuys Quadrangle).

This fan surface may have been abandoned when continuing uplift of the Northridge Hills deflected the Pacoima Wash (San Fernando and Van Nuys quadrangles) drainage to the east. Although this surface is older than any other part of the Pacoima/Tujunga fan, it probably formed in early to mid Holocene time.

Parts of the San Fernando Valley west of the Pacoima/Tujunga fan have been filled by sediments transported by much smaller streams, which have sources in the lower, less rugged Santa Susana Mountains, Santa Monica Mountains, and Simi Hills. These streams have built alluvial fans out into the valley but the fans have not completely covered the valley, as has the Pacoima/Tujunga fan. Deposition of these fans has also been altered and interrupted by tectonism, particularly along the Northridge Hills.

The oldest alluvial units in the San Fernando Valley are found within the Northridge Hills and on the south flank of the Santa Susana Mountains. The Saugus Formation, a Plio-Pleistocene alluvial unit makes up much of the south flank of the Santa Susana Mountains and is exposed in the core of anticlinal hills along the Northridge Hills uplift.

Overlying Saugus Formation in the Northridge Hills are very old alluvial deposits (Qvoa1, Qvoa2 and Qvof2). These deposits are uplifted, deformed, have reddish soils and are typically dense to very dense.

Overlying very old alluvial deposits in the Northridge Hills are deposits that formed as alluvial fans from the Santa Susana Mountains. These deposits are composed of sands, silts and gravels and form recognizable alluvial fans. These fan surfaces are no longer active because continuing deformation has lifted them out of the area of deposition.

Along the front of the Santa Susana Mountains, all major streams are incised into the Qof1 surface. At the Northridge Hills, the largest stream, Limekiln Wash, is incised completely through the hills, leaving remnants of the Qof1 surface as terraces. Smaller stream courses, especially Wilbur Wash and Aliso Wash, have apparently been blocked by the Northridge Hills, causing deposition of younger alluvium on top of Qof1.

The Qof1 surface re-emerges from beneath these younger sediments in the Northridge Hills. It is warped over the hills and buried by younger sediments also on the south side.

The streams that cross the Northridge Hills, as well as others from the south and west, have built alluvial fans into the main San Fernando Valley basin south of the hills. These

alluvial fans can be subdivided into young (Qyf1 and Qyf2) and active (Qf) fan deposits on the basis of geomorphology.

The alluvial fans from all sides of the valley interfinger with an alluvial basin or flood plain deposit (Qa) in the Canoga Park-Reseda area. This deposit is dominantly clay with some silt and sand layers. In contrast to the alluvial fan deposits, layers in this alluvial basin deposit can be easily correlated between wells, in one case for over a mile.

The alluvial basin deposit occurs just west of the Pacoima/Tujunga fan deposits, suggesting that deposition on that major fan has partially blocked the west-to-east surficial drainage. The smaller streams have not been able to deposit enough sediment to maintain a continuous eastward drainage gradient and the low gradient has resulted in a marsh or low-energy stream deposit on the central and eastern Canoga Park Quadrangle.

This blockage of the eastward drainage in the valley appears to occur again farther to the west. The youngest fan of Browns Canyon wash from the north nearly meets the youngest fan of Arroyo Calabasas from the southwest. West of these fans, the small streams from the Simi Hills have not been able to maintain their drainage gradient and a clayey basin deposit (Qa) has formed.

Historical flood plain deposits that formed within the Sepulveda Flood Control Basin are also mapped as active alluvial basin deposits (Qa).

ENGINEERING GEOLOGY

The geologic units described above and listed in Table 1.2 were primarily mapped from their surface expression, especially geomorphology as shown on aerial photos and old topographic maps. The geomorphic mapping was compared with the subsurface properties described in over 850 borehole logs in the study area. Subsurface data used for this study includes the database compiled by John Tinsley for previous liquefaction studies (Tinsley and Fumal, 1985; Tinsley and others, 1985), a database of shear wave velocity measurements originally compiled by Walter Silva (Wills and Silva, 1996), and additional data collected for this study. Subsurface data were collected for this study at Caltrans, the California Department of Water Resources, DMG files of seismic reports for hospital and school sites, the Regional Water Quality Control Board and from Law Crandall, Inc., Leighton and Associates, Inc., and Woodward-Clyde Consultants. 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 are well distributed areally and provide reliable data on water levels, but geotechnical data, particularly SPT blow counts, are sometimes less reliable, due to non-standard equipment and incomplete reporting of procedures. Water-well logs from the Department of Water Resources tend to have very sketchy lithologic descriptions and generally unreliable reports of shallow, unconfined water levels. Apparently, water-well drillers may note the level of "productive water," ignoring shallower perched water or water in less permeable layers.

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 DMG GIS database. 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 the outlining of areas of similar soils.

In most cases, the subsurface data allow mapping of different alluvial fans. Different generations of alluvium on the same fan, which are very apparent from the geomorphology, are not distinguishable from the subsurface data.

The subsurface data were particularly valuable in mapping the alluvial basin or flood plain deposits (Qa). On previous maps (Tinsley and Fumal, 1985), these deposits had been mapped as part of the adjoining alluvial fans. Geomorphically, they appear to be the lower parts of alluvial fans. In the subsurface, however, the alluvial fan deposits are composed of layers of silt, silty sand and clay, which are not easily correlatable between boreholes. The flood plain deposits, in contrast, are composed mainly of clay and thin silt or sand beds that can be easily correlated between boreholes, in one case for over a mile. Because the basin deposits could be most easily distinguished from the subsurface data the areal extent of these deposits was mapped from the subsurface data.

Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are generalized but give the most commonly encountered characteristics of the unit (see Table 1.2).

Saugus Formation (Qs)

The Plio-Pleistocene Saugus Formation is an alluvial unit, which is often very difficult to distinguish from younger overlying alluvium on logs of boreholes. In the few boreholes where it is certain that Saugus Formation was encountered, Saugus Formation is described as "sandstone." In others, descriptions of dense or very dense sand may indicate the presence of Saugus Formation but could just as well reflect old or very old alluvium.

Very old alluvium (Qvoa1)

Very old alluvium, mapped in the Northridge Hills, is represented in the subsurface data by several boreholes in unit Qvoa1. The material in these boreholes is dense to very dense silt and very stiff to hard clay with minor dense sand.

Older alluvium (Qof1, Qof2)

Two major older alluvial units were mapped in the study area. Older alluvium is distinguished from younger alluvium by position (uplifted), is usually incised by younger drainage courses, and by displaying relatively even tonal patterns on pre-development aerial photographs. Younger alluvium, in contrast, typically has a braided stream tonal pattern even when the stream channels have no geomorphic expression. Qof1 consists of small alluvial fans from the Santa Susana Mountains that have been warped over the Northridge Hills. Qof2 is a portion of the large Pacoima/Tujunga fan that has been cut off from its source by uplift. These units are probably slightly different in age, because Qof2 probably overlies Qof1 on the south side of the Northridge Hills. The main difference between them is due to the difference in their source areas, which yields different subsurface characteristics.

Qof1 in the Northridge Hills consists of silt sand and sandy silt with lesser amounts of clay. Colors of sandy units are described as light brown or grayish brown, suggesting that they are relatively young and little soil formation has taken place. The granular deposits are loose to moderately dense, based on few SPT blow counts.

Younger alluvium (Qyf1, Qyf2, Qyt, Qf, Qw)

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 of an alluvial fan. There may simply be too little difference in age among the various units, which probably range in age from mid-Holocene to historic, for any differences in density or cementation to have formed. In addition, since no geotechnical data were obtained from locally developed, thin, veneer-like, young terrace deposits adjacent to watercourses (Qyt), this unit is not included in Table 1.2.

On the other hand, differences in source area can readily be distinguished from the subsurface data. Accordingly, the following descriptions are arranged by alluvial fan, beginning in the northeast and proceeding counterclockwise around the basin.

Fans from the Santa Susana Mountains

The fans of Bull, Aliso, Wilbur, Limekiln and Browns canyons are mostly composed of silt, silty sand and clay. This is finer-grained material than found in the Pacoima/Tujunga fan to the east and it reflects source areas in the Santa Susana Mountains. These fans are also smaller and have been disrupted by uplift of the Northridge Hills. Several of these fans are discussed in more detail below.

Bull Canyon

The most recent fan of Bull Canyon is along the border between the Canoga Park and Van Nuys quadrangles, on the south side of the Northridge Hills. Bull Canyon Creek appears to be underfit for this gap, which is probably related to an older branch of the Pacoima/Tujunga fan. The Bull Canyon fan also overlies the older Pacoima/Tujunga fan and appears to be at least partly reworked from material that originated in the Pacoima/Tujunga fan. Although the Bull Canyon fan is poorly represented in the subsurface data, the material recorded is silt and silty sand, which is indistinguishable from the underlying Qof2.

Limekiln Canyon

Limekiln Canyon wash has been able to maintain an incised channel through the Northridge Hills into the main San Fernando basin south of the hills. This is probably due to its larger drainage area (about 3 square miles) and associated erosive power. The apex of the Limekiln Canyon fan is on the south side of the Northridge Hills, from there it extends onto the floor of the valley. The fan is formed of layers of clay, silt, and silty sand.

Browns Canyon

Browns Canyon Wash has the largest drainage basin of the streams with source areas in the Santa Susana Mountains (about 12 square miles), but emerges from the mountains in the complex northwestern corner of the valley. Deposits of Browns Canyon are silty sand, silt and clay. The sands are loose to moderately dense, based on SPT blow counts. This alluvium has filled the Chatsworth basin, which is separated from the main San Fernando basin by the Chatsworth fault. Browns Canyon alluvium then overflowed the Chatsworth basin and built an alluvial fan south of the Northridge Hills onto the floor of the San Fernando Valley. The main alluvial fan has its apex where the trend of the main Northridge Hills uplift crosses Browns Canyon wash, suggesting tectonic control of the young sedimentation. The apex of active fan, however, is once again well south of the main fan apex suggesting southward tilting of the whole San Fernando basin.

Fans from the Santa Monica Mountains

Arroyo Calabasas

Arroyo Calabasas has a drainage basin of about 5 square miles in the Santa Monica Mountains and the southernmost Simi Hills. The apex of the fan is at the southwestern corner of the San Fernando Valley. The arroyo has incised the upper portion of the fan and deposited the youngest material in a fan with its apex northeastward toward the center of the valley. If this represents tilting to the northeast, it may be an indication of tightening of the San Fernando syncline.

Arroyo Calabasas fan consists of clay and silt with beds of sand and silty sand. The sand layers are generally described as medium to coarse sand and are sometimes “pebbly.” SPT field N values of granular deposits are typically between 10 and 20 blows per foot

(BPF). The young Arroyo Calabasas fan appears to be a thin deposit, logs from some boreholes describe a reddish brown (or “gray-orange”) dense to very dense sand with gravel at 15 to 25 feet below the surface.

Fans from small drainage basins in the Santa Monica Mountains

The fans of many small streams originating in the Santa Monica Mountains have merged to form a continuous alluvial apron on the south side of the San Fernando Valley. Generally, these small fans have their apices at the mountain front and extend northward toward the Los Angeles River. Fewer generations of fan deposits are distinguished in these small fans, possibly indicating no major changes in slope or shape of the valley while they were being deposited.

Materials in the fans along the Santa Monica Mountain front are variable, with some drainage courses having more sand than others. Generally, however, these fan deposits consist of clay and silt with sand layers. Granular deposits are medium dense, fine- to medium-grained sand and usually silty.

One exception to the lack of tectonic disruption of these fans may occur at Caballero Creek. A ridge of older alluvium, with a core of Modelo Formation bedrock, extends to the northeast from the mouth of Caballero Creek to the Sepulveda Flood Control Basin. This ridge appears to be partly buried by young alluvial fans from the Santa Monica Mountains (Qyf2) but locally disrupts drainage and possibly ground-water flow, leading to a marsh depicted on the 1926 edition of the U.S. Geological Survey Van Nuys 6-minute Quadrangle.

Geologic Map Unit	Material Type	Consistency	Liquefaction Susceptibility
Qa, alluvial basin	clay, silty clay, some sand	soft/loose	low, locally high
Qw, stream channels	sandy, silty sand	loose-moderately dense	high
Qf, active alluvial fans	silty sand, sand, minor clay	loose-moderately dense	high
Qyf2, younger alluvial fans	silty sand, sand, minor clay	loose-moderately dense	high
Qyf1, young alluvial fan	silty sand, sand, minor clay	loose-moderately dense	high
Qof2, older alluvial fan	silt & silty sand	loose-dense	high
Qof1, older alluvial fan	sand & gravel	dense	low
Qvoa1, very old alluvium	clay-silty sand	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 Canoga Park 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 San Fernando Valley ground-water basin is a major source of domestic water for the City of Los Angeles and, as a result, has been extensively studied. The legal rights to water in the ground within the San Fernando Valley were 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.

The Report of Referee shows that ground water 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. Wells monitored by the Upper Los Angeles River Watermaster (Blevins, 1995) show that in the western San Fernando Valley, including the Canoga Park Quadrangle, water levels have not recovered to the levels of the 1940's.

In order to consider the historically highest ground-water level in liquefaction analysis, the 1944 ground-water elevation contours (California State Water Rights Board 1962, Plate 29) were digitized. A three-dimensional model was created from the digitized contours giving a 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 Canoga Park Quadrangle. The difference between the surface elevation and the ground-water elevation is the ground-water depth. Subtracting the ground-water depth 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 and fills that have changed the surface elevations. Most of these surface changes occurred after the ground-water levels were measured in 1945. The ground-water depth contours were smoothed and obvious artifacts removed to create the final ground-water depth map, which was digitized and used for the liquefaction analysis (Plate 1.2).

In general, the final ground-water depth map shows shallow ground water along the Los Angeles River in the southern portion of the San Fernando Valley and a broad area of shallow ground water in the Reseda-Canoga Park area. Both of these areas were recognized as areas of shallow ground water in the Report of Referee (1962). Ground-water depth maps for the Reseda-Canoga Park area, prepared in 1950 for the years 1948 and 1949, show similar conditions, as well as being the only place where a report of artesian conditions was found during the present study (Donnan and others, 1950).

Shallow ground water is also shown in the Chatsworth sub-basin, where ground water is apparently ponded north of the Chatsworth fault. This fault is recognized mainly as a ground-water barrier and is poorly expressed at the surface.

The 1945 ground-water depths were checked against the water levels measured in boreholes compiled for this study. Measured ground-water levels from the 1970's, 80's and early 90's tend to be 10 to 20 feet deeper than the 1945 water level, but show the same pattern of shallow ground water in the center of the basin and deeper ground water to the north and (to a lesser extent) the south.

The 1945 ground-water contours were only prepared for the San Fernando Valley. For Canyons in the Santa Monica Mountains we compiled ground-water levels from geotechnical borehole logs. Ground water is shown to be relatively shallow in all canyons in the Santa Monica Mountains, where records were obtained. 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. The susceptibility of the younger Quaternary geologic units in the Canoga Park Quadrangle to liquefaction is outlined below and summarized in Table 1.2.

Very old alluvium (Qvoa1)

Very old alluvium consists of dense to very dense silt and clay deposits in an area of deep groundwater. Liquefaction susceptibility of this unit is low.

Old alluvium (Qof1, Qof2)

Old alluvium on the Canoga Park Quadrangle consists of loose to moderately dense silt and silty sand. Qof1 is found only in the Northridge Hills, where ground water is deep, so it has a low liquefaction susceptibility. Qof2 extends onto the floor of the valley south of the Northridge Hills. In the southern part of area underlain by this unit, ground water is shallower than 40 feet. Those portions with shallow ground water have a high liquefaction susceptibility.

Young alluvium (Qyf1, Qyf2, Qf, Qw)

Younger alluvium on the Canoga Park Quadrangle consists of silty sand with sand, silt and clay. Most boreholes in these units contain loose to moderately dense sand or silty sand. Where ground water is within 40 feet of the surface liquefaction susceptibility of these units is high.

Alluvial basin deposits (Qa)

Alluvial basin deposits consist of clay with minor interbeds of silty sand and silt. Most of this unit is within an area of shallow ground water. Despite the shallow ground water, the clay deposits are non-liquefiable. Sand and silt layers are concentrated in the southern part of this unit within 2000 feet of the Los Angeles River. These layers may represent either interbeds of fan deposits from the Santa Monica Mountains or basin deposits reworked (winnowed) by the Los Angeles River. Because of these granular deposits the liquefaction susceptibility in the southern 2000 feet of the alluvial basin deposits is considered high.

The alluvial basin deposit on the western edge of the quadrangle is more uniformly clay. Due to the absence of layers of granular materials this unit is considered to have low liquefaction susceptibility.

The deposits formed in historic times behind Sepulveda Dam are similar to the other basin deposits and are mapped as Qa, but these deposits are too thin to affect the liquefaction susceptibility of the area. This area has high liquefaction susceptibility reflecting susceptibility of the underlying alluvium (Qof2 and Qyf2).

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 Canoga Park Quadrangle, a peak acceleration of 0.60g resulting from an earthquake of magnitude 6.5 was used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion portion (Section 3) of this report for further details.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and others, 1985; National Research Council, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (SPT) results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The factor of safety (FS) relative to liquefaction is: $FS = CRR/CSR$. FS, therefore, is a quantitative measure of liquefaction potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the “trigger” for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site related structures. For a regional assessment DMG normally has a range of FS that results from the liquefaction analyses. The DMG liquefaction analysis program calculates an FS at each sample that has blow counts. The lowest FS in each borehole is used for that location. These FS vary in reliability according to the quality of the geotechnical data. These FS as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil are evaluated in order to construct liquefaction potential maps, which then directly translate to zones of required investigation.

Of the over 850 geotechnical borehole logs reviewed in this study (Plate 1.2), fewer than 150 include blow-count data from SPT's or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2 1/2-inch inside diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (soil density, moisture content, sieve analysis, etc) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values or using average test values of similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes
2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated
3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable
4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

- a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or
- b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or
- c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the Canoga Park Quadrangle is summarized below.

Areas of Past Liquefaction

After the Northridge earthquake, ground cracking showing downslope movement, suggestive of lateral spreading, was recorded in the Northridge area, between Tampa and Vanalden avenues just south of Parthenia Street (locality 1, Plate 1.1). A rupture zone trending N20°W, across Napa Street, showed right-lateral offset. The cracks were followed to the north, where their trend became easterly and the sense of offset changed

to extensional. The zone of cracks suggests a lateral spread that moved a few centimeters to the southeast (Hart and others, 1995). A N 45 E-trending zone of cracks to the southwest at the intersection of Malden Street and Beckford Avenue formed a graben 4 inches deep and extending for 250-320 feet. Subsurface conditions at this location were investigated by Holzer and others (1996; 1999), who found that sediments in this area are Holocene clayey silts overlying Pleistocene silty sand. Holzer and others (1996; 1999) suggest that shear failure in parts of the Holocene clay may have occurred during the mainshock. Collapse of very soft clayey silt may have contributed to the ground deformation at this location, particularly in the most prominent graben at Malden Street, but the overall downslope movement suggests lateral spreading. Although Holzer and others (1996; 1999) did not find liquefiable sediments at the Malden Street site, there are Holocene interbedded sands and silty sands nearby, particularly to the north and west where the Holocene alluvial basin deposits grade into the adjacent alluvial fans. At a site just northwest of the intersection of Parthenia Street and Tampa Avenue, three of four boreholes collected for this study encountered saturated, Holocene interbedded sands and silty sands. Although clear evidence of liquefaction is lacking, there is evidence of lateral spreading, and liquefiable sediments in the area.

Deformation in this zone was also investigated by Cruikshank and others (1996) who examined surface survey records. They documented a zone of extension trending northeasterly and a parallel zone of compression downslope. Cruikshank and others (1996) show that the deformation in this zone is consistent with shallow blind-thrust faulting, but provide no corroborating evidence that a fault exists. They apparently did not consider the possibility that deformation could be due to shallow downslope movement.

Other zones of cracking in the Northridge and Reseda areas, described by Hart and others (1995), show settlement and offset of pavements, curbs and floor slabs. One locality at Roscoe Boulevard, west of Winnetka Avenue (locality 2, Plate 1.1), suggests "possible incipient lateral spreading" according to Hart and others (1995).

Another zone of ground cracking at Wynne Avenue in Northridge was investigated by Holzer and others (1996; 1999). Damage at that location (locality 3, Plate 1.1) was apparently localized above a silty sand lens within the clayey basin deposits. This locality, however, also corresponds to a step in the contact between relatively compact Pleistocene deposits and soft Holocene deposits. Average SPT blow counts in the silty sand lenses were 20 and 22, yielding factors of safety against liquefaction of less than one, so liquefaction appears likely and could also have caused this ground deformation. The silty sand lens that appears to have been most likely to liquefy, however, is less than 50 m wide from north to south and the other silty sand layer becomes more silty south of the area of failure.

Artificial Fills

In the Canoga Park Quadrangle the only areas of artificial fill large enough to show at the scale of the map are engineered fill for dams and freeways. Generally, the engineered fills are too thin to have an impact on liquefaction hazard and so were not investigated.

Areas with Sufficient Existing Geotechnical Data

The dense consistency of the very old alluvium exposed in the Northridge Hills (Qvoa1) and deep ground water encountered in boreholes that penetrate it indicate a low susceptibility to liquefaction. Accordingly, this geologic unit has not been included in a liquefaction zone in this area.

Older alluvial fans from the Santa Susana Mountains (Qof1) are also generally dense and are located in an area of low groundwater. They are not included in a liquefaction zone.

Older alluvial fan deposits (Qof2) in the eastern part of the Canoga Park Quadrangle are generally silt and silty sand of loose to moderately dense consistency. Such material properties lead to moderate to high liquefaction susceptibility under conditions characterized by the projected earthquake shaking. Although all of this unit does not have high susceptibility, it is not possible to map subunits of moderate and high susceptibility separately. The ground-water table becomes deeper toward the north and the northern portions of this unit do not have ground water within 40 feet of the surface. All younger alluvium, where ground water has been identified less than 40 feet from the surface, is included within a liquefaction zone.

Younger alluvial deposits (Qyf1, Qyf2, Qyt Qw) of the alluvial fans from all sides of the valley contain layers of loose to moderately dense sand or silty sand. Although these units are largely composed of silt and clay, sand layers occur in nearly all boreholes. Such sand layers generally have a factor of safety against liquefaction of less than one in the anticipated earthquake shaking. The low factors of safety indicate generally high liquefaction susceptibility for these units. Ground water becomes deeper to the north, however, so the northern portions of these units have not had recorded ground water within 40 feet of the surface. All younger alluvial fan deposits and stream channel deposits where ground water has been recorded as less than 40 feet from the surface have been included in a liquefaction zone.

Alluvial Basin deposits (Qa) are composed dominantly of clay and silty clay, with few interbeds of sand and silty sand. The clayey deposits have a low liquefaction susceptibility. Within the large alluvial basin deposit in the Reseda-Canoga Park area, sand layers become more common near the Los Angeles River. These sand layers suggest interfingering of basin deposits with alluvial fan deposits from the south or reworking of the material by the Los Angeles River. In any case, factors of safety against liquefaction are less than one for the anticipated ground motion. Those parts of the basin deposits where sandy layers are found have a moderate to high liquefaction susceptibility. For this reason, an area within 3000 feet of the southern boundary and an area within 1000 feet of the northwestern boundary of the alluvial basin deposit are included within liquefaction zones. Liquefaction is possible in minor, thin, discontinuous layers within the remainder of the alluvial basin deposit. Liquefaction of an isolated sandy layer may have caused surface damage at Wynne Avenue in Northridge during the 1994 Northridge Earthquake. Despite this instance of surface damage, the potential for liquefaction is low and confined to small deposits of sandy material that cannot be mapped from the surface. The central and eastern parts of the alluvial basin deposits are not included in a

liquefaction zone. The western alluvial basin deposit, on the border of the Canoga Park Quadrangle and the adjacent Calabasas Quadrangle, does not have the sandy layers. The liquefaction susceptibility of this unit is low and it is not included in a liquefaction zone.

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SECTION 2

EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

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

By

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Division of Mines and Geology**

PURPOSE

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

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Canoga Park 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 Canoga Park 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 Canoga Park 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 Canoga Park 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 Canoga Park Quadrangle covers approximately 62 square miles of Los Angeles County in the central San Fernando Valley, about 20 miles northwest of the Los Angeles Civic Center. The map includes the Los Angeles City communities of Reseda, Tarzana, Encino, Canoga Park, Woodland Hills, and Northridge. The northern half of the quadrangle includes gently sloping to flat-lying terrain of the San Fernando Valley, hilly areas that form the eastern edge of the Simi Hills near Chatsworth Reservoir in the northwest corner, and low hills in the northeast corner that mark the southeastern end of the Northridge Hills. The southern half of the quadrangle is characterized by hilly and mountainous terrain of the Santa Monica Mountains and gentle to moderate slopes and numerous small knobs in the Chalk Hills, which are bisected by the Ventura Freeway. The crest of the west-trending Santa Monica Mountain range lies near the southern border of the quadrangle. Within the map area, several large north-trending canyons extend from the range crest to the valley floor. Access to the hilly areas is provided by residential streets, dirt roads, and State Highway 27 (Topanga Canyon Boulevard).

Residential and commercial development is concentrated in the flat-lying valley area. Hillside residential development began after World War II and continues at present. Several large residential developments, characterized by mass grading, are under construction. Other land uses include golf courses, Sepulveda Dam Flood Control and Recreation Area, State parkland, and reservoirs. Encino Reservoir is located in the southeast corner, and Chatsworth Reservoir (now dry), is located in the northwest part of the quadrangle.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface. Within the Canoga Park 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 1927 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

To update the terrain data, areas that have recently undergone large-scale grading in the hilly portions of the Canoga Park Quadrangle, essentially the Santa Monica Mountains, were identified (see Plate 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 processed by Calgis, Inc. (GeoSAR Consortium, 1995; 1996). The terrain data were also smoothed and filtered prior to analysis. This corrected terrain data was digitally merged with the USGS DEM.

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

GEOLOGY

Bedrock and Surficial Geology

For the Canoga Park Quadrangle, a recently compiled geologic map was obtained from the U.S. Geological Survey (USGS) in digital form (Yerkes and Campbell, 1993). In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted.

The oldest geologic unit mapped in the Canoga Park Quadrangle is the Jurassic Santa Monica Slate (Yerkes and Campbell map symbols Jsm and Jsms), which is exposed in the southeast corner of the quadrangle. Locally, it consists of intensely jointed and fractured slate and phyllite with well-developed slaty cleavage and a thick weathered zone characterized by angular chips and thin slabs of slate surrounded by clay. The spotted slate (Jsms) contains abundant crystals of cordierite believed to have formed as a result of contact metamorphism of the Santa Monica Slate by granitic intrusions. Cretaceous granite, quartz diorite, and granodiorite are exposed in the southeast, near Encino Reservoir (Kgr). Locally, at the surface, the granitic rocks are soft and crumbly due to weathering.

Overlying the Jurassic slate is a sequence of Upper Cretaceous marine clastic rocks of the Tuna Canyon Formation (massive pebble conglomerate, sandstone, and thin-bedded shale; Ktc) and Trabuco Formation (cobble conglomerate and soft, red, clayey sandstone; Kt). The Upper Cretaceous Chatsworth Formation (Kc) is mapped in the northwest corner of the quadrangle and consists of massive, thick-bedded marine sandstone and conglomerate interbedded with siltstone and mudstone. The Chatsworth Formation is overlain by unnamed Paleocene and/or Eocene strata (conglomerate and coarse-grained sandstone; Tss), which may be equivalent to the Simi Conglomerate or Santa Susana Formation in the Simi Valley area.

Other Tertiary bedrock formations include the upper Eocene to lower Miocene Sespe Formation (nonmarine sandstone, mudstone and conglomerate; Ts) and middle Miocene Topanga Group (interbedded conglomerate, massive sandstone, concretionary shale and siltstone, and basaltic or andesitic breccia; Tt, Ttc, Ttcc, and Tcob). Basaltic and diabasic volcanic rocks (Ti) intrude middle Miocene and older strata. The upper Miocene Modelo Formation is the most widely exposed bedrock unit in the quadrangle and is composed of interbedded deep marine clay shale, siltstone, and sandstone (Tm), diatomaceous shale and siltstone (Tmd), and massive, fine- to coarse-grained sandstone (Tms). Bedding in the Modelo Formation typically dips in the same direction as the slopes in the area (northward), creating slope-stability problems.

Plio-Pleistocene bedrock units in the area include the Pico and Saugus formations. The Pico Formation (QTp) locally consists of marine fossiliferous siltstone and soft, friable sandstone. In the northeast corner of the quadrangle, nonmarine sandstone, conglomerate and siltstone of the upper Saugus Formation (Qs) are exposed in the Northridge Hills. This unit is characterized by coarse clastic beds composed of angular fragments of porcelaneous shale and sandstone in a silty matrix cemented by caliche, separated by beds of massive siltstone.

Quaternary surficial deposits cover the floor and margins of the San Fernando Valley and extend southward up into the canyons in the Santa Monica Mountains. They generally consist of older and younger alluvial fan and basin deposits of upper Pleistocene and Holocene age (Qa, Qf, Qof1, Qof2, Qt, Qvoa1, Qw, Qyf1, Qyf2, and Qyt). Unconsolidated silt- and clayey silt deposits (res) are mapped in the dry bed of Chatsworth Reservoir. Modern man-made (artificial) fills (af) are also mapped in some areas. Landslides (Qls and Qls?) are widespread in the Canoga Park Quadrangle, occurring primarily on dip slopes in the Modelo Formation. A more detailed discussion of the Quaternary deposits in the Canoga Park Quadrangle can be found in Section 1.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Canoga Park Quadrangle was prepared (Irvine, unpublished) by combining field observations, analysis of aerial photos (NASA, 1994 a and 1994 b; and USDA, 1952/53; see Air Photos in References), and interpretation of landforms on current and older topographic maps. Also consulted during the mapping process were previous maps and reports that contain geologic and landslide data (Byer, 1987; Dibblee, 1992; Harp and Jibson, 1995; Hoots, 1930; Los Angeles Dept. of Public Works, 1963; Weber and others, 1979; Weber and Wills, 1983; Weber and Frasse, 1984; and Yerkes and Campbell, 1993). Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the slope stability analysis. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. All landslides on the digital geologic map (Yerkes and Campbell, 1993) were verified or re-mapped during preparation of the inventory map. To keep the landslide inventory of consistent quality, all landslides originally depicted on the digitized geologic map were deleted, and only those included in the DMG inventory were incorporated into the hazard-evaluation process. A version of this landslide inventory is included with Plate 2.1.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the Canoga Park Quadrangle geologic map were obtained from the City of Los Angeles, Department of Public Works (see Appendix A). The locations of rock and soil samples taken for shear testing by consultants are shown on Plate 2.1. When available, shear tests from adjacent quadrangles were used to augment data for geologic formations that had little or no shear test information.

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.

CANOGA PARK QUADRANGLE SHEAR STRENGTH GROUPINGS							
	Formation Name	Number Tests	Mean/Median Phi	Mean/Median (Group phi) (deg)	Group Mean/Median C (psf)	No Data: Similar Geologic Strength	Phi Values Used in Stability Analysis
GROUP 1	Tep Kc	2 2	46/46 32.5/32.5	39.3 / 34	532/350	Kgr, Kt, Ktc, Ti Ttc, Ttcc, Tcob	39
GROUP 2	Jsm	4	32.9/32.0	32.9/32.0	521/500	Jsms, Ts	32
GROUP 3	Qay2 Qa Tms Tt	25 27 14 1	31.5/31 27.9/27 28.2/29.5 30/30	29.0/29.0	326/200	af, Qf, Qfy2, Qof1 Qof2, Qs, QTp, Qt Qu, Qvoa1, Qyf1 Qyf2, Qw, Qyt	29
GROUP 4	Tm	15	25.1/26	25.1/26	321/240		25
GROUP 5	Tmd	25	19.9/19	19.9/19	344/300		20
GROUP 6	Qls	-	-	-	-		10

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 Canoga Park Quadrangle.

SHEAR STRENGTH GROUPS FOR THE CANOGA PARK QUADRANGLE					
GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6
K c	J s m	a f	T m	T m d	Q l s
K g r	J s m s	Q a			
K t	T s	Q f			
K t c		Q f y 2			
T t c		Q o f 1,2			
T t c c		Q s			
T c o b		Q t			
T s s		Q T p			
T i		Q u			
		Q v o a 1			
		Q w			
		Q y f 1,2			
		Q y t			
		T m s			
		T t			
		T t c			

Table 2.2. Summary of the Shear Strength Groups for the Canoga Park Quadrangle.

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, derived from the geologic map database, 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 (QIs) 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 Canoga Park 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:	6.6 to 7.1
Modal Distance:	5 to 16 km
PGA:	0.42 to 0.7 g

The strong-motion record selected for the slope stability analysis in the Canoga Park Quadrangle was the Channel 3 (N35°E horizontal component) University of Southern California Station # 14 recording from the magnitude 6.7 Northridge Earthquake (Trifunac and others, 1994). This record had a source to recording site distance of 8.5 km and a peak ground acceleration (PGA) of 0.59 g. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record.

This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 1.29 and 0.232 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Canoga Park Quadrangle.

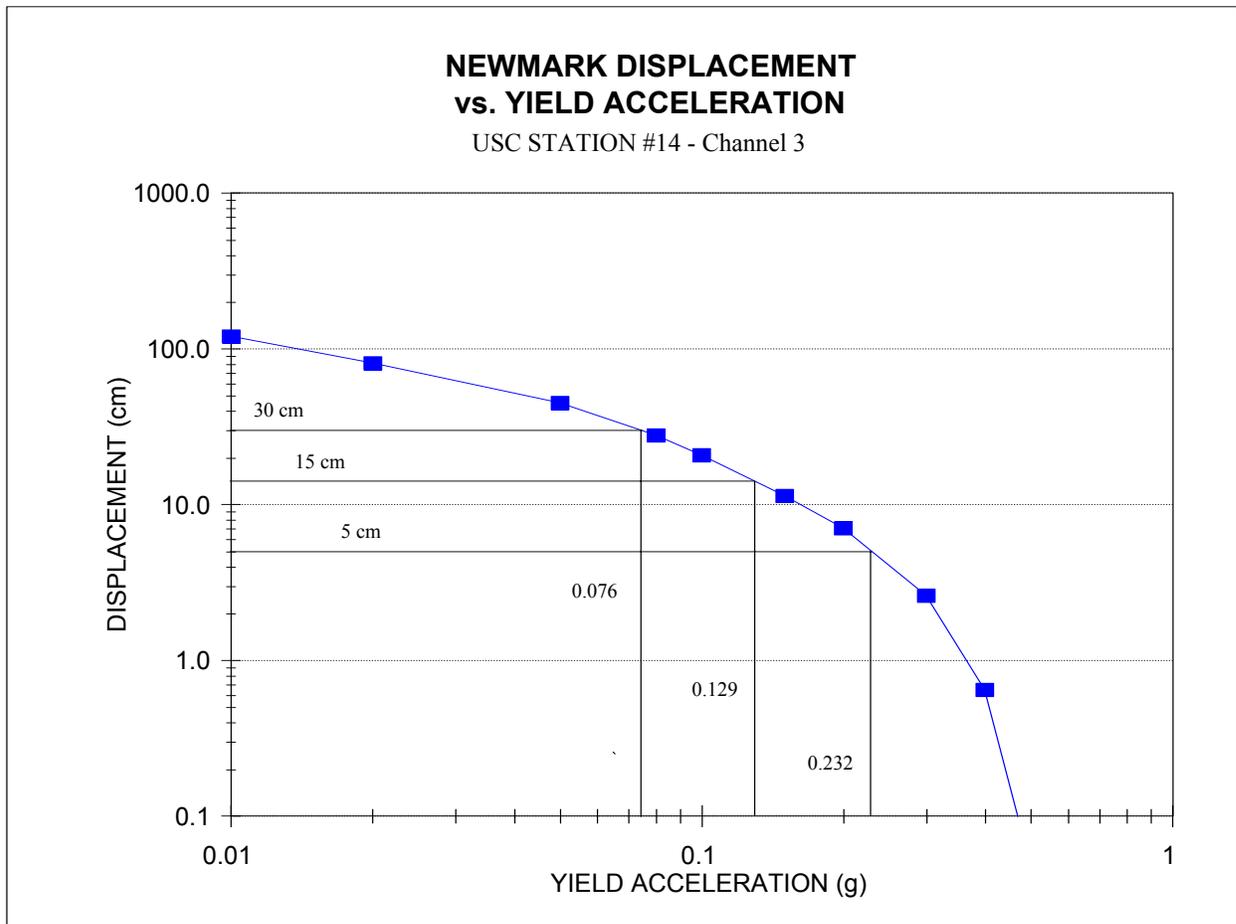


Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record from the 17 January 1994 Northridge, California Earthquake.

Slope Stability Analysis

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

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

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

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

1. If the calculated yield acceleration was less than 0.076g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)
2. If the calculated yield acceleration fell between 0.076g and 0.129g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)
3. If the calculated yield acceleration fell between 0.129g and 0.232g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)
4. If the calculated yield acceleration was greater than 0.232g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

CANOGA PARK QUADRANGLE HAZARD POTENTIAL MATRIX												
SLOPE CATEGORY (% SLOPE)												
Geologic												
Material	MEAN	I	II	III	IV	V	VI	VII	VIII	IX	X	
Group	PHI	0-13	14-22	23-27	28-31	32-37	38-47	48-54	55-66	67-72	>72	percent
1	39	VL	VL	VL	VL	VL	VL	VL	VL	L	M	H
2	32	VL	VL	VL	VL	VL	L	L	H	H	H	H
3	29	VL	VL	VL	VL	L	L	H	H	H	H	H
4	25	VL	VL	L	L	L	M	H	H	H	H	H
5	20	VL	L	M	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Canoga Park 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.

No earthquake-triggered landslides had been identified in the Canoga Park Quadrangle prior to the Northridge earthquake. The Northridge earthquake caused a number of relatively small, shallow slope failures in the Canoga Park Quadrangle (Harp and Jibson, 1995). Landslides attributed to the Northridge earthquake covered approximately 40 acres of land in 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, 76% 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 6 is included for all slope gradient categories. (Note: Geologic Strength Group 6 includes all mappable landslides with a definite or probable confidence rating).
2. Geologic Strength Group 5 is included for all slopes steeper than 14 percent.
3. Geologic Strength Group 4 is included for all slopes steeper than 23 percent.
4. Geologic Strength Group 3 is included for all slopes steeper than 32 percent.
5. Geologic Strength Group 2 is included for all slopes greater than 38 percent.
6. Geologic Strength Group 1 is included for all slopes greater than 55 percent.

This results in approximately 12 percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the Canoga Park Quadrangle.

ACKNOWLEDGMENTS

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APPENDIX A SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Los Angeles, Department of Public Works Material Engineering Division	115
Total number of shear tests used to characterize the units in the Canoga Park Quadrangle	115

SECTION 3

GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Canoga Park 7.5-Minute Quadrangle, Los Angeles County, California

By

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

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

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

PURPOSE

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

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

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

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

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

EARTHQUAKE HAZARD MODEL

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

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

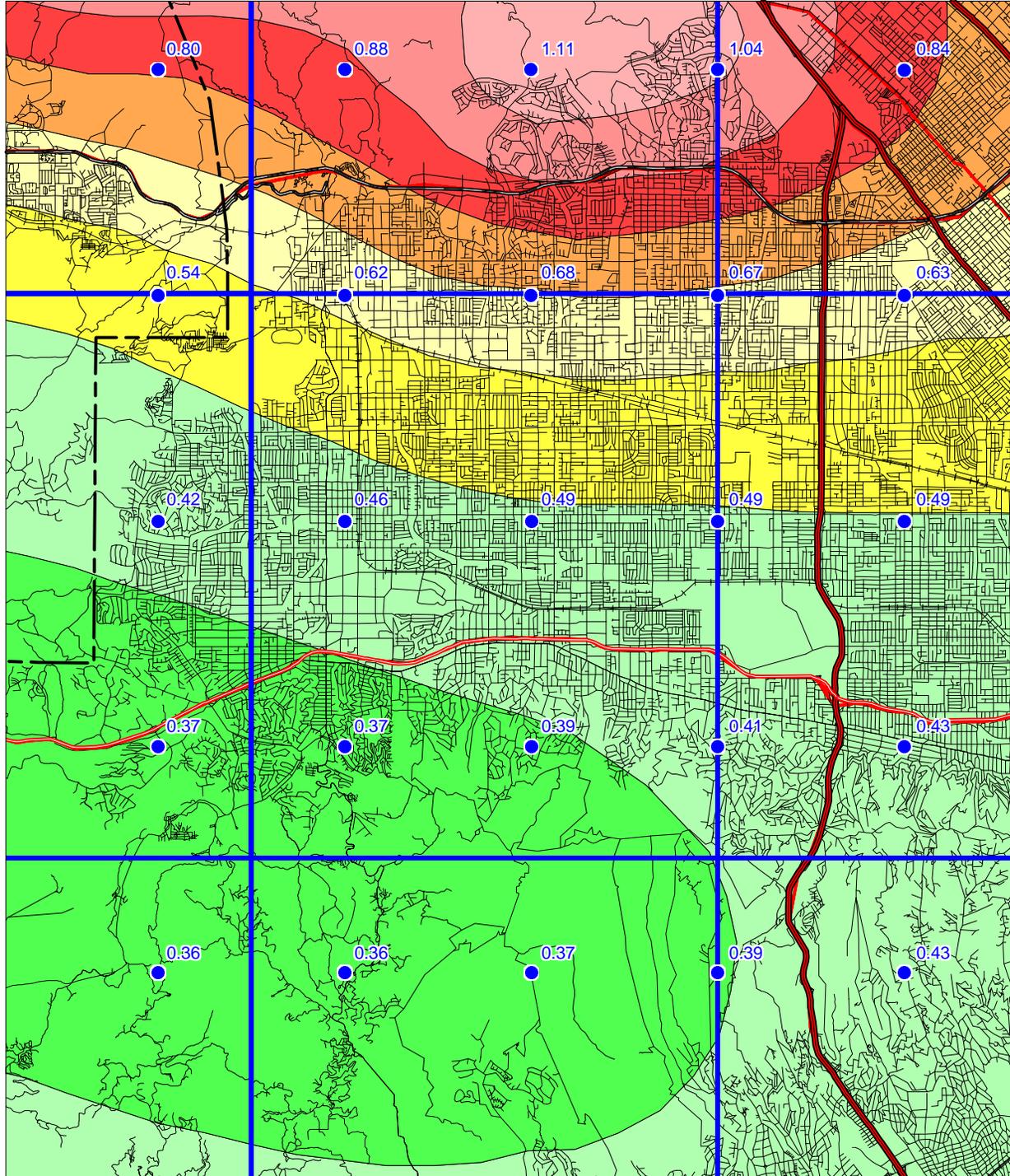
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

CANOGA PARK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation



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Division of Mines and Geology



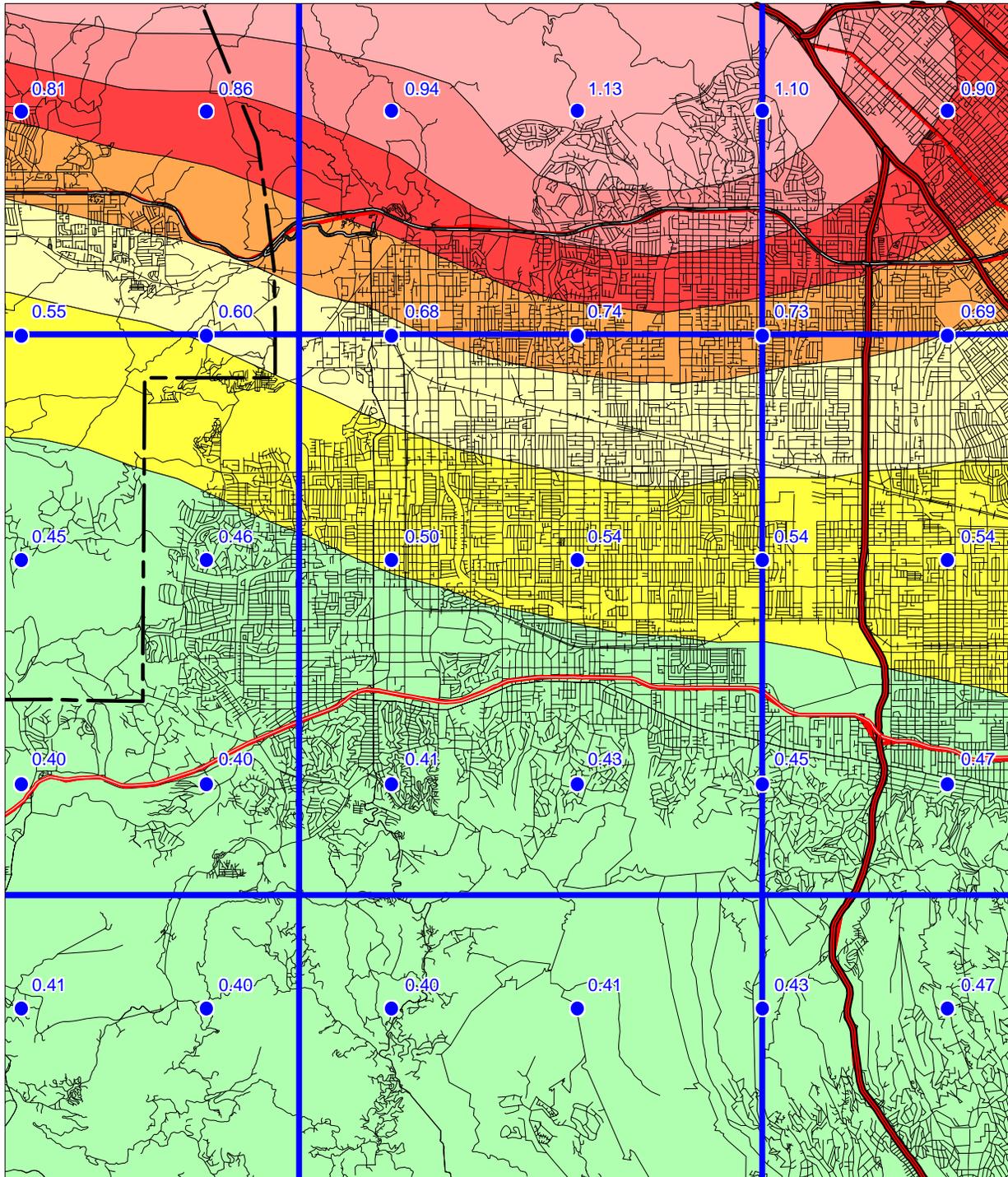
Figure 3.1

CANOGA PARK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

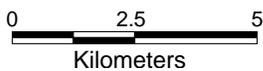
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



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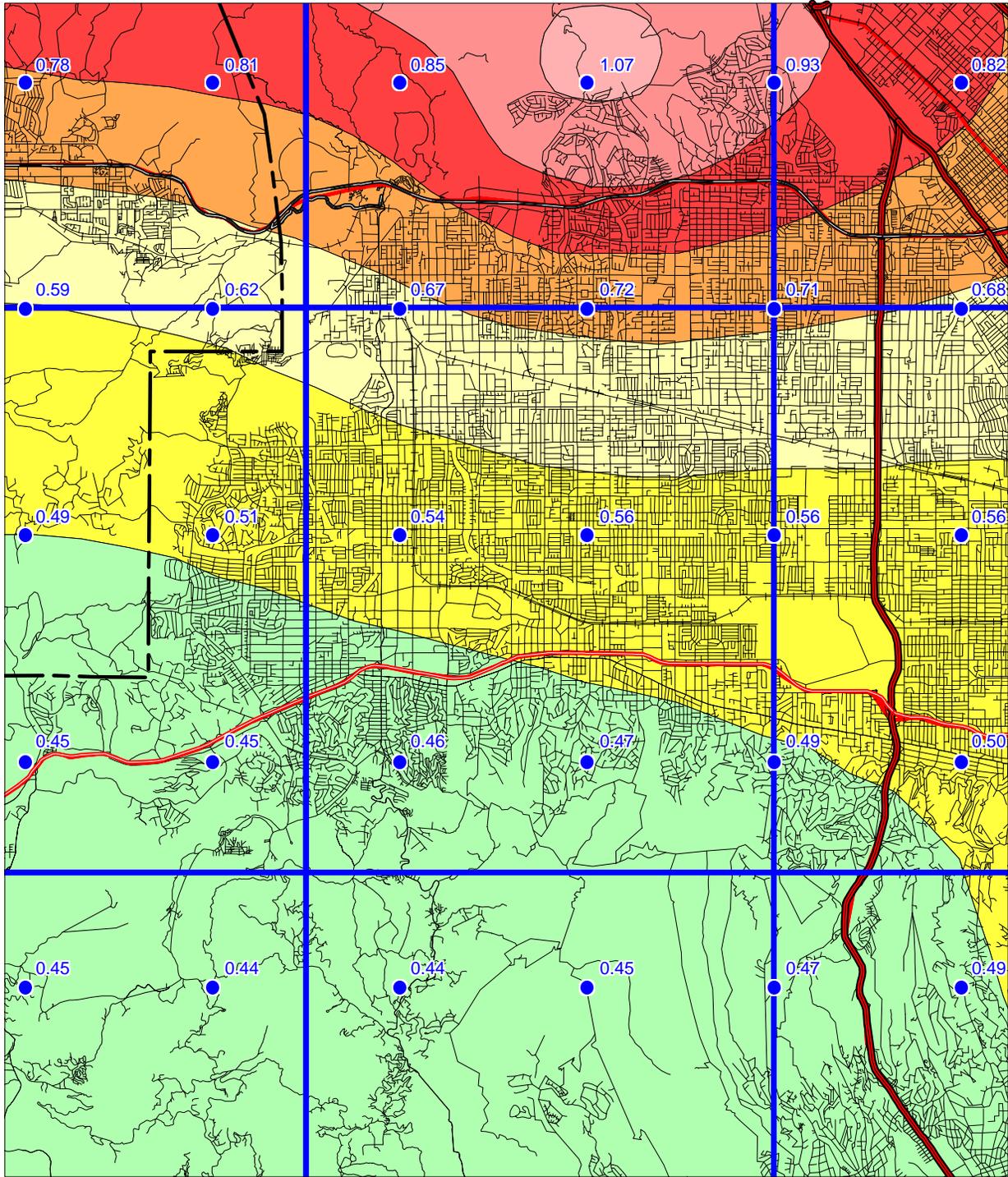


Figure 3.2

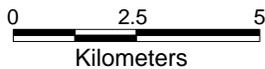
CANOGA PARK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works ©1998 MapInfo Corporation



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Figure 3.3

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

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

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

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

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

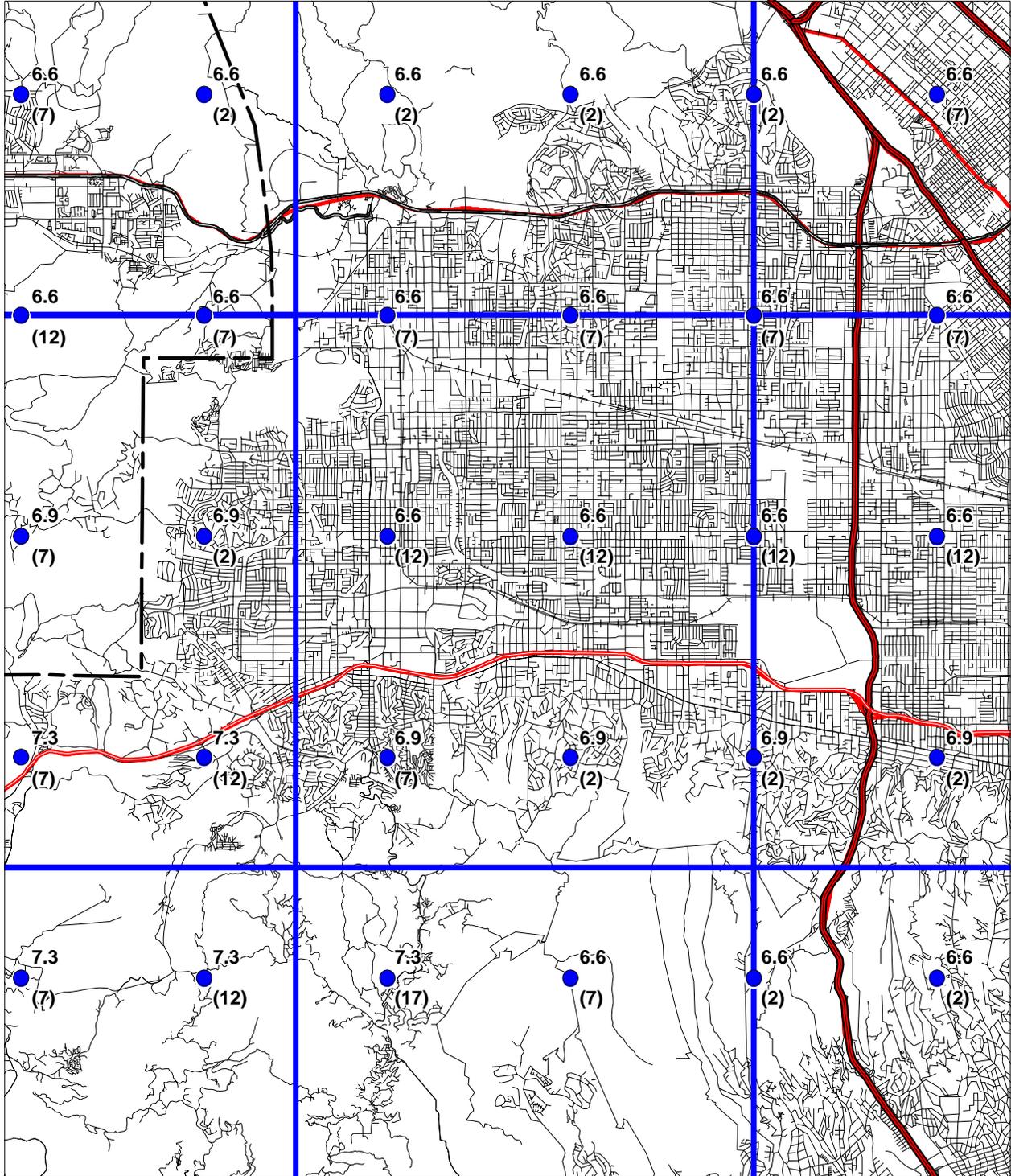
SEISMIC HAZARD EVALUATION OF THE CANOGA PARK QUADRANGLE
CANOGA PARK 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

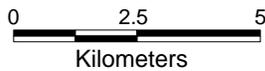
1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation



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Division of Mines and Geology

Figure 3.4

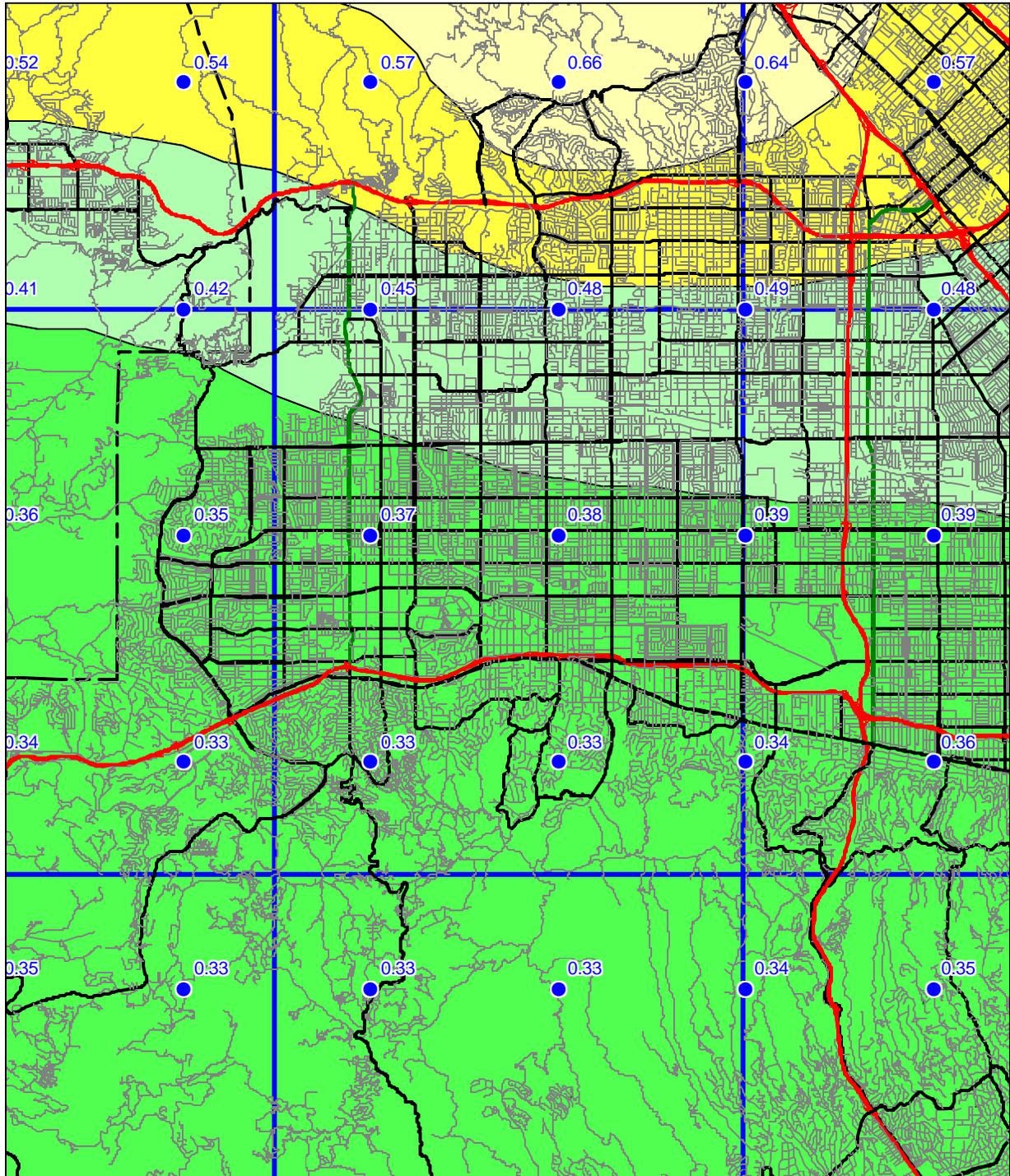


SEISMIC HAZARD EVALUATION OF THE CANOGA PARK QUADRANGLE
CANOGA PARK 7.5-MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

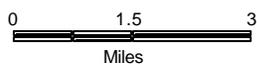
10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g)
FOR ALLUVIUM

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.

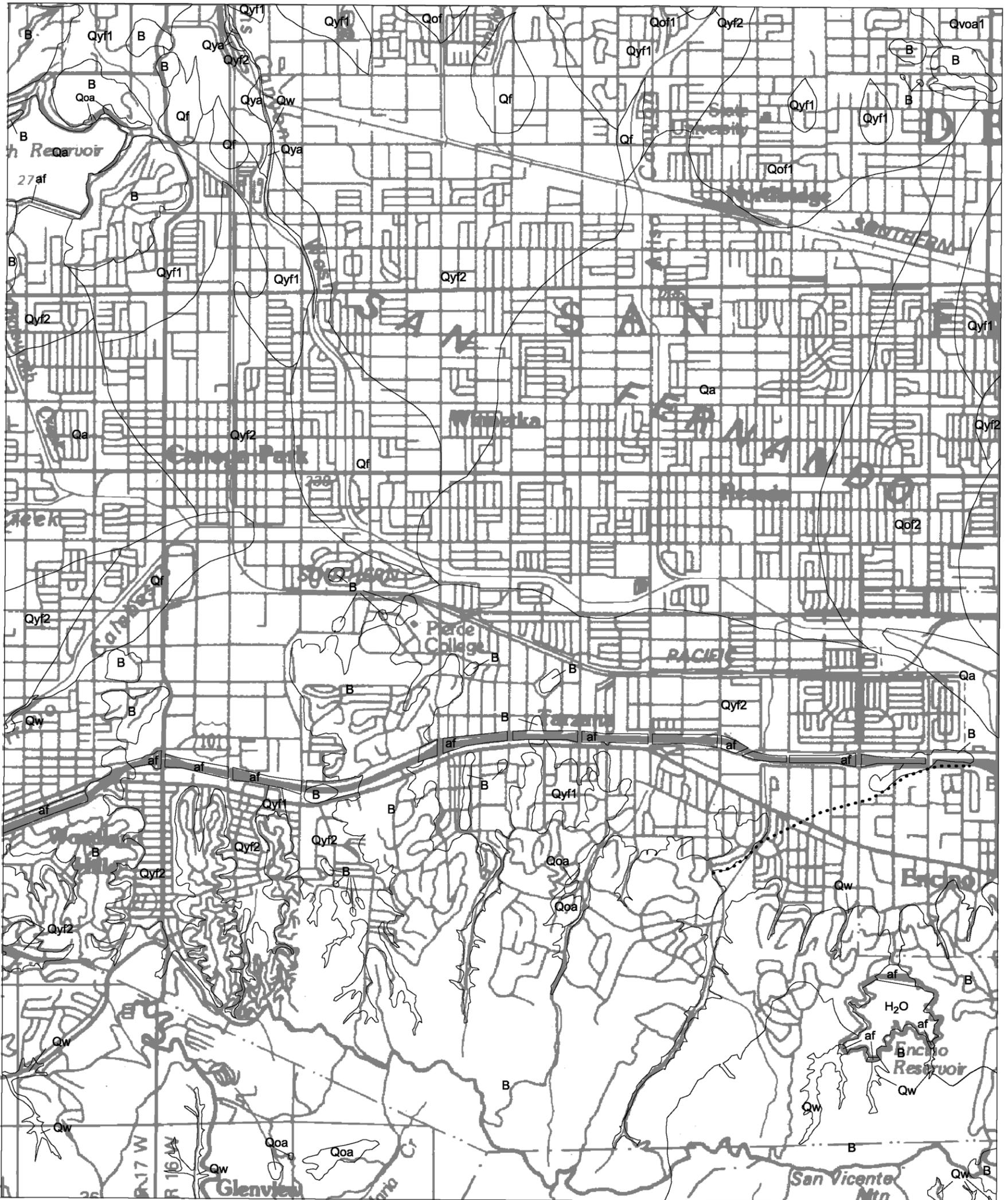
Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific 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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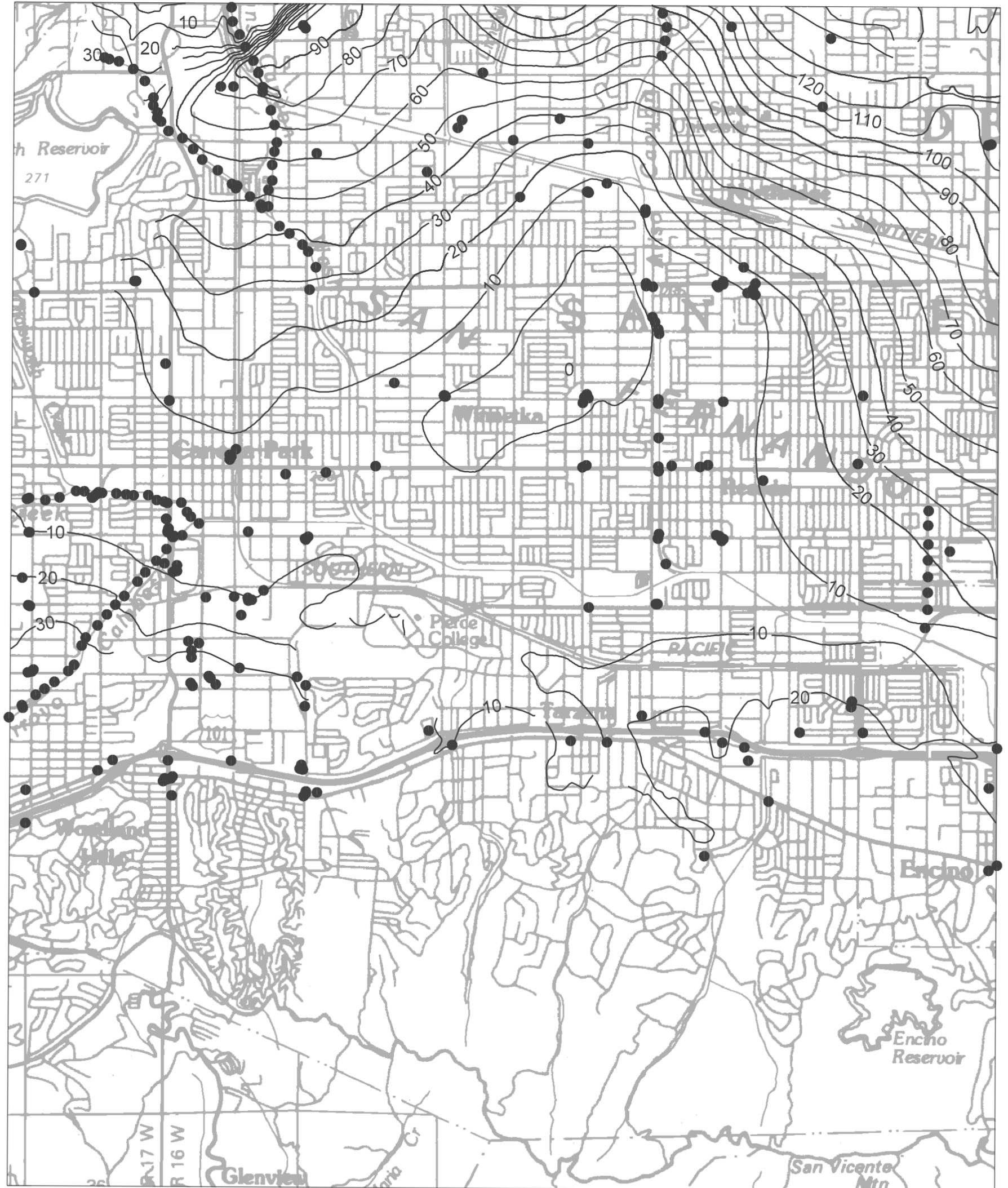


Base map enlarged from U.S.G.S. 30 x 60-minute series

B = Pre-Quaternary bedrock
 See "Bedrock and Surficial Geology" in Section 1 of the report for descriptions of units.



Plate 1.1 Quaternary Geologic Map of the Canoga Park 7.5-minute Quadrangle, California



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

Plate 1.2 Historically highest ground water contours and borehole locations, Canoga Park 7.5-minute Quadrangle, California.

● Borehole Site

— 30 — Depth to ground water in feet

ONE MILE
SCALE

118°37'30"

34°15'



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

34°07'30"

118°15'

Plate 2.1 Landslide inventory, shear test sample locations, Canoga Park Quadrangle, California.

- Shear test sample location
- Landslide

ONE MILE
SCALE

