SEISMIC HAZARD ZONE REPORT 068

SEISMIC HAZARD ZONE REPORT FOR THE CUPERTINO 7.5-MINUTE QUADRANGLE, SANTA CLARA COUNTY, CALIFORNIA

2002

DEPARTMENT OF CONSERVATION
California Geological Survey

STATE OF CALIFORNIA
GRAY DAVIS
GOVERNOR

THE RESOURCES AGENCY
MARY D. NICHOLS
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
DARRYL YOUNG
DIRECTOR

CALIFORNIA GEOLOGICAL SURVEY
JAMES F. DAVIS, *STATE GEOLOGIST*

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Cupertino 7.5-minute Quadrangle, Santa Clara County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 60 square miles at a scale of 1 inch = 2,000 feet. Only the Santa Clara County portion of the quadrangle is zoned. Less than one square mile in the southwestern corner that lies within Santa Cruz County has not been evaluated for zoning.

Parts of the cities of Cupertino, Los Altos, Los Altos Hills, Mountain View, San Jose, Santa Clara, Saratoga, and Sunnyvale occupy the northeastern half of the quadrangle. The remainder of the quadrangle is unincorporated, sparsely populated, county land in the Santa Cruz Mountains and foothills between the mountains and the broad alluvial plain of the Santa Clara Valley to the north. Adobe, Calabazas, Hale, Permanente, and Stevens creeks originate in the Santa Cruz Mountains and flow across the Santa Clara Valley into San Francisco Bay. Elevations range from about 60 feet above sea level in the northeastern corner, to 2,912 feet on Castle Rock Ridge in the southwestern corner. Three freeways and several other arterial roadways cross the map area.

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 Cupertino Quadrangle, the liquefaction zone is restricted to canyon bottoms and borders of the larger creek channels. The bedrock units in the quadrangle are separated into structural blocks as a result of a complex structural history and are strongly deformed by faulting. The combination of dissected hilly to mountainous terrain and weak rock units has produced widespread and abundant landslides in the southwestern half of the quadrangle. These conditions contribute to an earthquake-induced landslide zone that covers about 30 percent of the quadrangle.

How to view or obtain the map

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

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

BPS Reprographic Services
149 Second 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 CGS 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) [now called California Geological Survey (CGS)] 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 adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

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 CGS 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 Cupertino 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Cupertino 7.5-Minute Quadrangle, Santa Clara County, California

By
Kevin B. Clahan, M. Elise Mattison, Anne M. Rosinski, and Keith L. Knudsen

California Department of Conservation
California 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) [now called California Geological Survey (CGS)] 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 CGS 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 (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation

committee under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Cupertino 7.5-minute Quadrangle. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking), complete the report, which 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 CGS's Internet web page: http://www.consrv.ca.gov/CGS/index.htm

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in northern California. During the 1989 Loma Prieta and 1906 San Francisco earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the San Francisco Bay 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 are widespread in the San Francisco Bay Area, most notably in alluviated valley floodplains and around the margin of the bay. 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 San Francisco Bay Area, including areas in the Cupertino 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 CGS 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 SMGB (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 Cupertino Quadrangle consist mainly of gently sloping alluvial fans and areas bordering the larger streams. CGS'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 Cupertino 7.5-minute Quadrangle covers approximately 60 square miles in Santa Clara and Santa Cruz counties, south of San Francisco Bay. The boundary between Santa Clara County and Santa Cruz County cuts across the southwestern corner of the

quadrangle, approximately coincident with State Highway 35, Skyline Boulevard. This evaluation report and accompanying Seismic Hazard Zone Map cover only that portion of the Cupertino Quadrangle that lies within Santa Clara County. Approximately 0.25 square mile within Santa Cruz County is outside the area currently evaluated for zoning. Parts of the cities of Cupertino, Los Altos, Los Altos Hills, Mountain View, San Jose, Santa Clara, Saratoga, and Sunnyvale occupy the northeastern half of the quadrangle. The remainder of the quadrangle is unincorporated, relatively uninhabited, county land in the Santa Cruz Mountains and foothills between the mountains and the Santa Clara Valley to the north.

The northeastern half of the Cupertino Quadrangle covers a part of the broad alluvial plain of Santa Clara Valley that slopes gently to the northeast. In the southwestern half of the quadrangle, Adobe, Calabazas, Hale, Permanente, and Stevens creeks originate in the Santa Cruz Mountains. The creeks flow across the Santa Clara Valley into San Francisco Bay. Stevens Creek Reservoir (elevation about 540 feet), in the southwest quarter of the quadrangle, captures water from Stevens and Swiss creeks. Elevations within the quadrangle range from about 60 feet above sea level in the northeastern corner, to 2,912 feet on Castle Rock Ridge in the southwestern corner. A large open-pit mine occupies the west-central part of the quadrangle within the Santa Cruz Mountains. Three freeways and several other arterial roadways cross the map area. U.S. Highway 280 (Junipero Serra Freeway) crosses from northwest to east and intersects State Highway 85 (Stevens Creek Freeway) in the north-central part of the quadrangle. State Highway 82 (El Camino Real) trends northwest in the northeastern quarter of the quadrangle.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. To evaluate the areal and vertical distribution of shallow Quaternary deposits and to provide information on subsurface geologic, lithologic and engineering properties of the units in the Cupertino Quadrangle, recently completed maps of Quaternary deposits (Knudsen, unpublished) and bedrock units (Brabb and others, 1998) were used. These maps were combined, with minor modifications to the bedrock/Quaternary contact lines, to form a single, 1:24,000-scale geologic map of the Cupertino Quadrangle. The distribution of Quaternary deposits on this map (summarized on Plate 1.1) was used in combination with other data, discussed below, to evaluate liquefaction susceptibility and develop the Seismic Hazard Zone Map.

Other maps and reports consulted were California Department of Water Resources (1967), Helley and Brabb (1971), Poland (1971), Brown and Jackson (1973), Cooper-Clark and Associates (1974), Rogers and Williams (1974), Helley and others (1979), Falls (1988), Helley (1990), Seed and others (1990), Geomatrix Consultants, Inc. (1992), Helley and others (1994), Hitchcock and others (1994), Campbell and others (1995), and Iwamura (1995). Limited field reconnaissance was conducted to confirm the location of

geologic contacts, map recently modified ground surfaces, observe properties of near-surface deposits, and characterize the surface expression of individual geologic units.

In the Cupertino Quadrangle, Knudsen (unpublished) identified16 Quaternary map units and the Plio-Pleistocene Santa Clara Formation (QTsc). The Quaternary geologic mapping methods used by Knudsen in the Cupertino Quadrangle are the same as those described by Knudsen and others (2000). These methods consist of interpretation of topographic maps, aerial photographs, and soil surveys, as well as published and unpublished geologic maps. The ages of deposits are estimated using landform shape, relative geomorphic position, cross cutting relationships, superposition, depth and degree of surface dissection, and relative degree of soil profile development. Table 1.1 compares stratigraphic nomenclature used in Knudsen and others (2000) and the CGS GIS database, with that of previous studies performed in northern California.

Roughly the northeastern half of the Cupertino Quadrangle, approximately 30 square miles, is covered by Quaternary alluvial sediment shed from the Santa Cruz Mountains (Plate 1.1). The alluvial deposits primarily consist of Holocene and late Pleistocene alluvial fan material (Qhf, Qpf). The surfaces of the alluvial fans slope gently to the north and northeast. Additionally, Knudsen (unpublished) mapped Holocene stream terrace deposits (Qht, Qhty) along most of the creeks, and Pleistocene to Holocene alluvium and stream terrace deposits (Qa, Qpt, and Qt) along the upper reaches of several creeks. Artificial fill (af) was mapped along Calabazas Creek where the channel has been straightened and cutoff meanders have been filled.

Bedrock exposed in the Cupertino Quadrangle is characterized by two basement assemblages that are separated by the San Andreas Fault, which extends through the southwestern corner of the quadrangle (Brabb and others, 1998). Southwest of the San Andreas Fault is the Salinian Complex, a basement assemblage of granitic and gabbroic plutonic rocks. Northeast of the San Andreas Fault is a composite Mesozoic basement assemblage consisting of the Franciscan Complex, the Coast Range Ophiolite, and the Great Valley Sequence. Brabb and others (1998) further subdivide bedrock sequences in the area into individual fault-bounded structural blocks based on differing stratigraphic sequences and geologic history of the basement assemblages and overlying Tertiary rocks. See the earthquake-induced landslide part (Section 2) of this report for further details.

UNIT	Knudsen and others (2000)	Helley and others (1994)	Helley and others (1979)	Brabb and others (1998)	CGS GIS database
Artificial fill	af			af	af
Gravel quarries and percolation ponds	gq	PP,GP			gq
Artificial stream channel	ac			Qhasc	ac
Modern stream channel deposits	Qhc	Qhsc	Qhsc	Qhsc	Qhc
Latest Holocene stream terrace deposits	Qhty				Qhty
Holocene alluvial fan deposits	Qhf	Qhaf, Qhfp	Qham, Qhac	Qhaf, Qhfp	Qhf
Holocene alluvial fan levee deposits	Qhl	Qhl		Qhl	Qhl
Holocene stream terrace deposits	Qht	Qhfp			Qht
Holocene alluvium, undifferentiated	Qha				Qha
Late Pleistocene to Holocene alluvial fan deposits	Qf			Qhaf, Qhaf1, Qyf, Qyfo, Qpaf	Qf
Late Pleistocene to Holocene stream terrace deposits	Qt				Qt
Late Pleistocene to Holocene alluvium, undifferentiated	Qa				Qa
Late Pleistocene alluvial fan deposits	Qpf	Qpaf	Qpa	Qpaf	Qpf
Late Pleistocene stream terrace deposits	Qpt			Qpaf1, Qof	Qpt
Early to middle Pleistocene stream terrace deposits	Qof			Qof	Qot
Early to middle Pleistocene alluvial fan deposits	Qoa		Qpea, Qpmc	Qpaf, Qof	Qoa
bedrock	br	br			br

Table 1.1. Correlation of Quaternary Stratigraphic Nomenclatures Used within the Cupertino Quadrangle. For this study, CGS has adopted the nomenclature of Knudsen and others (2000).

Structural Geology

The Cupertino Quadrangle is within the active San Andreas Fault system, which distributes shearing across a complex system of primarily northwest-trending, right-lateral, strike-slip faults that include the San Andreas, Hayward, and Calaveras faults. The San Andreas Fault crosses the southwestern corner of the Cupertino Quadrangle, and the Hayward and Calaveras faults are approximately 10 and 12 miles east of the northeastern corner, respectively. Historical ground surface-rupturing earthquakes have occurred on all of these faults (Lawson, 1908; Keefer and others, 1980). Several oblique and reverse slip faults, including the Berrocal, Shannon, and Monte Vista occur within the study area along or within the foothills at the base of the Santa Cruz Mountains (McLaughlin and others, 1991; Hitchcock and others, 1994; Campbell and others, 1995). The reverse-slip Santa Clara Fault is in the vicinity of the northeastern corner of the quadrangle (Campbell and others, 1995).

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of flatland deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. For this investigation, data from 134 borehole logs collected from the files of the California Department of Transportation (CalTrans) and the cities of Cupertino, Los Altos, Mountain View, Saratoga, and Sunnyvale were analyzed and most were entered into a CGS geotechnical GIS database (Plate 1.2).

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 (American Society for Testing and Materials D1586), were converted to SPT-equivalent blow count values and entered into the CGS 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 $(N_1)_{60}$.

Geotechnical borehole logs provided information on lithologic and engineering characteristics of 720 feet of Holocene materials and 1,774 feet of Pleistocene materials penetrated by boreholes and analyzed for this study. Geotechnical characteristics of the Quaternary map units are generalized in Tables 1.2 and 1.3. Analysis of these data leads to recognition of certain characteristics and relationships among the units, including: 1) Holocene materials are less dense and more readily penetrated than Pleistocene materials; 2) late Pleistocene alluvial fan deposits (Qpf) have higher dry density measurements than Holocene deposits; 3) late Pleistocene alluvial fan deposits (Qpf) contain more gravel and are coarser grained than Holocene deposits; and 4) Holocene units are predominantly fine grained, but have sand lenses throughout that have the potential to liquefy.

GEOLOGIC MAP UNIT		DRY DENSITY (pounds per cubic foot)						STANDARD PENETRATION RESISTANCE (blows per foot, $(N_1)_{60}$)					
Unit (1)	Texture (2)	Number of Tests (3)	Mean	CV (4)	Median	Min	Max	Number of Tests (3)	Mean	CV (4)	Median	Min	Max
af	Fine	4	105.5	0.06	103	101	114.8	6	22	0.32	20	15	35
	Coarse	9	105.3	0.07	106	97	117	15	27	0.58	22	12	62
gq	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
ac	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qhc	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qhty	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qhf	Fine	42	108.1	0.09	109.6	83	126.8	72	21	0.70	16	6	95
	Coarse	15	105.9	0.09	108.3	93	122	33	20	0.95	14	5	>99
Qhl	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qht	Fine	2	109.7	0.04	109.7	106.5	112.8	4	26	0.44	24	14	41
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qha	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	1	122.1	-	-	-	-	0	-	-	-	-	-
Qf	Fine	5	106.1	0.04	5	101.5	112.5	13	38	0.67	28	20	>99
	Coarse	3	110.3	0.03	111	107	113	1	5			-	-
Qt	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qa	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qpf	Fine	61	110.6	0.07	111	90.3	127.1	96	35	0.71	28	5	>99
	Coarse	61	114.1	0.09	113.6	78	142	157	39	0.55	36	8	>99
Qpt	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qof	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qoa	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
QTsc	Fine	16	103.6	0.07	101.5	92	116	23	34	0.65	29	9	84
	Coarse	5	108.6	0.10	113	97	125	13	64	0.38	58	39	>99

Notes:
(1) See Table 1.3 for names of the geologic map units listed here.
(2) Fine soils (silt and clay) contain a greater percentage passing the #200 sieve (<0.074 mm); coarse soils (sand and gravel) contain a greater percentage retained by the #200 sieve.
(3) Number of laboratory samples or field penetration resistance measurements.
(4) CV = coefficient of variation (standard deviation divided by the mean).

Table 1.2. Summary of Geotechnical Characteristics for Quaternary Geological Units in the Cupertino 7.5-Minute Quadrangle.

Geologic Map Unit (1)	Description	Length of borehole penetrating map unit (feet)	Composition by Soil Type (2) (Percent of total sediment column logged)	Depth to ground water (ft) and liquefaction susceptibility category assigned to geologic unit (3)			
				<10	10 to 30	30 to 40	>40
af	Artificial fill (4)	103	SC 31; CL 21; SM 16; GW 9; other 23	VH-L	H-L	M-L	VL
gq	Gravel quarry	0	n/a (5)	VH-L	H-L	M-L	VL
ac	Artificial stream channel	0	n/a	VH-L	H	M	VL
Qhc	Modern stream channel deposits	0	n/a	VH	H	M	VL
Qhty	Latest Holocene stream terrace deposits	0	n/a	VH	H	M	VL
Qhf	Holocene alluvial fan deposits	483	CL 42; ML 21; SM 19 SC 6; other 12	H	M	L	VL
Qhl	Holocene alluvial fan levee deposits	0	n/a	H	M	L	VL
Qht	Holocene stream deposits	30	CL-ML 40; CL 39; ML 13; SW 8	M	M	L	VL
Qha	Holocene alluvium, undifferentiated	15	SC 60; SM 40	M	M	L	VL
Qf	Late Pleistocene to Holocene alluvial fan deposits	89	CL 42; ML 33 SM 25	M	L	L	VL
Qt	Late Pleistocene to Holocene stream terrace deposits	0	n/a	M	L	L	VL
Qa	Late Pleistocene to Holocene to Holocene alluvium, undifferentiated	0	n/a	M	L	L	VL
Qpf	Late Pleistocene alluvial fan deposits	1597	CL 24; SM 22; ML 9; GW 9; SC 9; SP 7; other 20	L	L	VL	VL
Qpt	Late Pleistocene stream terrace deposits	0	n/a	L	L	VL	VL
Qof	Early to middle Pleistocene alluvial fan deposits	0	n/a	L	L	VL	VL
Qoa	Early to middle Pleistocene undifferentiated alluvial deposits	0	n/a	L	L	VL	VL
QTsc	Santa Clara Formation	177	CL 32; CH 21; SC 23; SM 17; GW 4; other 3	VL	VL	VL	VL

Notes:
(1) Susceptibility assignments are specific to the materials within the Cupertino 7.5-minute Quadrangle.
(2) Unified Soil Classification System.
(3) Based on the Simplified Procedure (Seed and Idriss, 1971; Youd and Idriss, 1997) and a small number of borehole analyses for some units.
(4) The liquefaction susceptibility of artificial fill ranges widely, depending largely on the nature of the fill, its age, and whether it was compacted during emplacement.
(5) n/a = not applicable

Table 1.3. Liquefaction Susceptibility for Quaternary Map Units within the Cupertino 7.5-Minute Quadrangle. Units indicate relative susceptibility of deposits to liquefaction as a function of material type and ground water depth within that deposit. VH = very high, H = high, M = moderate, L = low, and VL = very low to none.

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. CGS 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 ground-water surface at a particular time. Plate 1.2 depicts the historically highest ground-water levels that have been measured in alluviated areas.

Ground-water conditions were investigated in the Cupertino Quadrangle to evaluate the depth to saturated materials. Saturation reduces the effective normal stress within a sediment column, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on first-encountered water noted in geotechnical borehole logs acquired from CalTrans and the cities of Cupertino, Los Altos, Mountain View, Saratoga, and Sunnyvale and water-level data provided by the Santa Clara Valley Water District. 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.

Ground-water levels are presently at or near their historical highs in many areas of the Santa Clara Valley. Regional contours on Plate 1.2 show historical-high ground-water depths, as interpreted from borehole logs from investigations between the 1950's and the year 2000. Depths to first-encountered water in the Cupertino Quadrangle range from 4 to 135 feet below the ground surface (Plate 1.2). In general, the proximity of San Francisco Bay to the north influences ground-water levels for most of the lower elevations within the quadrangle. Ground-water levels are deepest, greater than 40 feet, along the base of the foothills (Plate 1.2).

The Santa Clara Valley ground-water basin is recharged by water that infiltrates the subsurface primarily from streams and man-made percolation ponds near the foothills. The southern part of the Cupertino Quadrangle is such a recharge area, with unconfined ground-water conditions and discontinuous aquitards. In the central part of the quadrangle, in the subsurface, a fine-grained, alluvial fan unit dipping subparallel to the ground surface serves as a thick aquitard between two distinct coarse-grained aquifer "zones" (Iwamura, 1995). Above the aquitard, discontinuous shallow aquifers within clayey deposits account for the steep ground-water gradient in the northeast corner of the quadrangle (Plate 1.2). The ground-water level in the upper aquifer zone may in part be controlled by sea level.

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. CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the SMGB (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.

CGS'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. CGS's qualitative relations among susceptibility, geologic map unit and depth to ground water are summarized in Table 1.3.

Most Holocene materials within the quadrangle, where water levels are within 30 feet of the ground surface, have susceptibility assignments of high (H) to very high (VH) (Table 1.3). Holocene alluvial fan deposits (Qhf) and Holocene alluvial fan levee deposits (Qhl) have a moderate susceptibility assignment where ground water is between 10 and 30 feet below the ground surface. Holocene stream terrace deposits (Qht) and Holocene alluvium, undifferentiated (Qha) have moderate susceptibility where ground water is within 30 feet of the ground surface. Late Pleistocene to Holocene alluvial fan deposits (Qf), late Pleistocene to Holocene stream terrace deposits (Qt), and late Pleistocene to Holocene alluvium, undifferentiated (Qa) are primarily fine-grained but have low densities along with lenses of potentially liquefiable material and therefore are assigned moderate susceptibility where ground water is within 10 feet of the ground surface. Late Pleistocene alluvial fan deposits (Qpf), late Pleistocene stream terrace deposits (Qpt), early to middle Pleistocene alluvial fan deposits (Qof), and early to middle Pleistocene undifferentiated alluvial deposits (Qoa) generally are considered to have very low (VL) susceptibility, but are assigned a low (L) susceptibility assignment where ground water is shallower than 30 feet beneath the ground surface. The Santa Clara Formation (QTsc) is sometimes sampled and analyzed as a soil, but the susceptibility of this unit to liquefaction is considered to be very low because it is dense and often lithified.

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 CGS's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Cupertino Quadrangle, PGAs of 0.55g to 0.75g, resulting from an earthquake of magnitude 7.9, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996). See the ground motion portion (Section 3) of this report for additional details.

Quantitative Liquefaction Analysis

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate a soil's resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, CGS's analysis uses the Idriss magnitude-scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. CGS uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures.

The CGS liquefaction analysis program calculates an FS for each geotechnical sample where blow counts were collected. Typically, multiple samples are collected for each borehole. The program then independently calculates an FS for each non-clay layer that includes at least one penetration test using the minimum $(N1)_{60}$ value for that layer. The minimum FS value of the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

Of the 134 geotechnical borehole logs reviewed in this study (Plate 1.2), 91 include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed primarily for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts using an SPT sampler. However, many of the Holocene alluvial deposits in

the study area contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

LIQUEFACTION ZONES

Criteria for Zoning

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

Areas of Past Liquefaction

Knudsen and others (2000) compiled data from Tinsley and others (1998), who mapped evidence for liquefaction for the 1989 Loma Prieta earthquake, and Youd and Hoose (1978), who compiled them for earlier earthquakes, including 1868 Hayward and 1906 San Andreas earthquakes. This digital database differs from earlier compilation efforts in that the observations were located on a 1:24,000 scale base map versus the smaller scale base maps used in the earlier publications. Sites were reevaluated and some single sites were broken into two or more where the greater base map detail allowed. Within the Cupertino Quadrangle, Youd and Hoose (1978) identified one historical liquefaction site (Plate 1.2), recorded following the 1906 earthquake by Lawson and others (1908). In this instance a bridge over Stevens Creek was reportedly “shoved a foot out of place” (site 80, Plate 1.2), and the movement is attributed to lateral spread of the stream bank.

Artificial Fills

In the Cupertino Quadrangle, Knudsen mapped artificial fill (af) along Stevens, Calabazas, and Permanente creeks. Some or all of this may be non-engineered fill, which is commonly loose and uncompacted, with a mixture of material of various size and shape. The dam at Stevens Creek Reservoir, and another at a small lake west of the reservoir, are considered to be properly engineered fill, and are not in the zone of required investigation because the underlying material is bedrock. Artificial fill along the creeks is included in the zone of required investigation.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential as determined by the Seed-Idriss Simplified Procedure. Geotechnical data for Holocene alluvial fan deposits (Qhf) in the Cupertino Quadrangle show that some material is loose and granular, but very little of it is saturated. Therefore, the Holocene alluvial fan deposits (Qhf) are not in the zone of required investigation. One borehole contained Pleistocene material with the potential to liquefy, but the continuity of this deposit is unknown. Most of the study area is excluded from the zone because none of the boreholes revealed saturated potentially liquefiable Holocene material.

Areas with Insufficient Existing Geotechnical Data

Adequate geotechnical borehole information for artificial and modern stream channel deposits (ac and Qhc) and other Holocene stream deposits (Qhty, Qht, Qa) generally is lacking. These deposits, therefore, are included in the liquefaction zone for reasons presented in criteria 4-a, and -b above. These deposits likely contain granular, late

Holocene material and likely have elevated ground-water levels due to the proximity of active stream channels.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Cupertino 7.5-Minute Quadrangle, Santa Clara County, California

By
Catherine F. Slater, Mark O. Wiegers, and
Timothy P. McCrink

California Department of Conservation
California 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) [now called California Geological Survey (CGS)] 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 CGS 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). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing landslide hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee in 1998 under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of landslide analysis, evaluation, and mitigation techniques (SCEC, 2002). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Cupertino 7.5-minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking), complete the report, which 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 the California Geological Survey's Internet page: http://www.consrv.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 Cupertino 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 CGS 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 CGS 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 Cupertino 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 Cupertino 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 Cupertino 7.5-minute Quadrangle covers approximately 60 square miles in Santa Clara and Santa Cruz counties, including parts of the western side of the Santa Clara Valley and the eastern side of the Santa Cruz Mountains. The boundary between Santa Clara County and Santa Cruz County extends through the southwestern corner of the quadrangle, approximately coinciding with State Highway 35, Skyline Boulevard. Only about a quarter of a square mile of the Cupertino Quadrangle lies within Santa Cruz County and outside the limits of the current study area. Parts of the cities of Cupertino, Los Altos, Los Altos Hills, Mountain View, San Jose, Santa Clara, Saratoga, and Sunnyvale occupy the northeastern half of the quadrangle. The remainder of the quadrangle lies within unincorporated parts of Santa Clara County.

The topography of the Santa Cruz Mountains ranges from steep, forested slopes in the southwestern part of the quadrangle to gentle foothills along the margins of the Santa Clara Valley. The Santa Clara Valley is a broad nearly level alluvial plain that slopes generally less than one-percent to the northeast. Much of the floor of the Santa Clara Valley and the lower foothills of the Santa Cruz Mountains have been developed for residential and commercial uses. Residential development is sparse in the steep mountainous areas in the southwestern part of the quadrangle.

The northeastern half of the Cupertino Quadrangle covers a part of the broad alluvial plain of Santa Clara Valley that slopes gently to the northeast. In the southwestern half of the quadrangle, Adobe, Calabazas, Hale, Permanente, and Stevens creeks originate in the Santa Cruz Mountains. The creeks flow across the Santa Clara Valley into San Francisco Bay. Stevens Creek Reservoir (elevation about 540 feet), in the southwest quarter of the quadrangle, captures water from Stevens and Swiss creeks. Elevations within the quadrangle range from about 60 feet above sea level in the northeastern corner, to 2912 feet on Castle Rock Ridge in the southwestern corner. A large open-pit mine occupies the west-central part of the quadrangle within the Santa Cruz Mountains. Three freeways and several other arterial roadways cross the map area. U.S. Highway 280 (Junipero Serra Freeway) crosses from northwest to east and intersects State Highway 85 (Stevens Creek Freeway) in the north-central part of the quadrangle. State Highway 82 (El Camino Real) trends northwest in the northeastern quarter 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. For the Cupertino Quadrangle, a Level-2 digital elevation model (DEM) was obtained from the U.S. Geological Survey (1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours based on 1948 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

To calculate slope gradient for hillside areas that have undergone large-scale grading, a digital elevation model (DEM) was obtained from an airborne interferometric radar platform flown in 1998, with an estimated vertical accuracy of approximately 2 meters (Intermap Corporation, 1998). The most significant large-scale grading has occurred in several large quarries around Stevens and Permanente creeks, south and west of Monta Vista in the central part of the Cupertino Quadrangle. A smaller closed quarry in Los Altos Hills in the northwest corner of the quadrangle is currently being developed for single family housing. An interferometric radar DEM is prone to creating false topography where tall buildings, metal structures, or trees are present. Due to the prevalent grassy vegetation and relatively small residential-type buildings present in the hilly areas, this type of DEM is appropriate for use in the Cupertino Quadrangle. Nevertheless, the final hazard zone map was checked for potential errors and corrected where necessary. Recently graded areas where radar terrain data were used are shown on Plate 2.1.

A slope gradient 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 gradient and aspect maps were used to prepare the zone map is described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The primary source of bedrock geologic mapping used in this slope stability evaluation was the digital geologic map database "Geology of Palo Alto 30 X 60 minute Quadrangle, California" prepared by the U.S. Geological Survey (Brabb and others, 1998). This digital geologic database was compiled from a variety of published and unpublished maps of various scales, and from new mapping and field checking by Brabb and others (1998). The spatial resolution of the geologic databases is 1:62,500. Additional geologic mapping by Sorg and McLaughlin (1975) was also reviewed for this project. A Quaternary (surficial deposits) geologic map of the Cupertino Quadrangle was prepared by K. L. Knudsen (unpublished) at a scale of 1:24,000. Surficial geology is discussed in detail in Section 1 of this report.

CGS geologists merged the surficial and bedrock geologic maps. Contacts between surficial and bedrock units were modified in some areas to resolve differences between

the two maps. Geologic field reconnaissance was performed to assist in adjusting contacts and to review the lithology and structure of the various geologic units.

Bedrock units in the Palo Alto 30 x 60-minute Quadrangle have been divided into ten individual stratigraphic assemblages that lie within a series of fault-bounded bedrock structural blocks (Brabb and others, 1998). Each stratigraphic assemblage differs from its neighbors in depositional and deformational history. Two of these stratigraphic assemblages extend into the Cupertino Quadrangle (Brabb and others, 1998). These are the Mindego Hill and Woodside assemblages. These two assemblages are separated by the San Andreas Fault, which extends through the southwestern corner of the map area.

The bedrock units of the Mindego Hill assemblage and the Woodside assemblage are exposed in the upland area in the southwestern half of the quadrangle. Thick Quaternary alluvial deposits cover bedrock units within the northeastern half of the map area on the floor of the Santa Clara Valley.

Mindego Hill Assemblage

The Mindego Hill assemblage consists of Eocene through Pliocene marine sedimentary rocks and basalt. The Tertiary rocks overlie a Mesozoic basement complex of granitic to gabbroic intrusive rocks and high-grade metamorphic rocks of the Salinian Terrane. The basement complex rocks are not exposed in the Cupertino Quadrangle. The Tertiary units of the Mindego Hill assemblage, exposed in the Cupertino Quadrangle, are discussed below.

Butano Sandstone (Tb) of middle and lower Eocene age consists of thin to very thick beds of fine- to very coarse-grained sandstone. Sandstone is interbedded with mudstone and shale layers that typically make up 10 to 40 percent of the unit (Brabb and others, 1998). In the Cupertino Quadrangle, the Butano Sandstone includes a separate unit of uncertain affinity that is mapped as conglomerate of the lower member of the formation (Tblc?). This unit consists of thick to very thick beds of sandy pebble conglomerate.

The Vaqueros Sandstone (Tvq) of Oligocene to lower Miocene age consists of fine- to medium-grained and, locally, coarse-grained arkosic sandstone with interbedded mudstone and shale (Brabb and others, 1998).

The Mindego Basalt and related volcanic rocks (Tmb) of Miocene and/or Oligocene age consist of both extrusive and intrusive volcanic rocks. Extrusive rocks primarily are basaltic flow breccias with lesser amounts of tuff, pillow lavas and flows. Intrusive rocks consist of medium to coarsely crystalline basaltic rocks (Brabb and others, 1998).

The Lambert Shale (Tla) of Oligocene to lower Miocene age consists of moderately well cemented mudstone, siltstone and claystone. The unit includes some sandstone beds (Brabb and others, 1998).

Woodside Assemblage

The Woodside assemblage includes a sequence of Eocene through Plio-Pleistocene rocks that unconformably overlies a composite Mesozoic basement assemblage consisting of the Franciscan Complex, the Coast Range Ophiolite, and the Great Valley Sequence. Franciscan Complex rocks and small, fault-bounded bodies of the Coast Range Ophiolite are exposed in steep hilly areas in the west and southwest parts of the quadrangle along the northeast side of the San Andreas Fault. Great Valley Sequence rocks of the Mesozoic basement assemblage are not exposed in the map area. Tertiary marine and non-marine rocks of the Woodside assemblage are exposed primarily in a belt of the low foothills in the south and central portions of the quadrangle adjacent to the western margin of the Santa Clara Valley.

Several distinct units of the Franciscan Complex are mapped in the Cupertino Quadrangle (Brabb and others, 1998). Sheared rock or melange (fm) consists of sandstone, siltstone, and shale that has been extensively sheared but locally contains resistant blocks of relatively unsheared rock. Greenstone (fg) consists of basaltic flows, pillow lavas, breccias, tuffs and minor related intrusive rocks. Chert (fc) consists of thin to thick layers and commonly is rhythmically interbedded with thin shale layers. Limestone (fpl) is fine to coarsely crystalline and crops out in lenticular bodies usually associated with greenstone. Sandstone (fss) consists of fine- to coarse-grained graywacke with interbedded siltstone and shale. Argillite (fh) includes shale and minor beds of sandstone.

Two lithologies of the Coast Range Ophiolite are mapped in the Cupertino Quadrangle (Brabb and others, 1998). Serpentinite (sp) is exposed in small fault-bounded bodies enclosed by Franciscan rocks. Serpentinite is extensively to slightly sheared and contains some altered ultramafic rock. Diabase and gabbro (db) are exposed in a fault-bounded belt that extends along the northeast side of the San Andreas Fault.

The Monterey Formation (Tm) of middle Miocene age consists of porcelaneous mudstone and shale, impure diatomite, calcareous claystone with small amounts of sandstone and siltstone near the base (Brabb and others, 1998). California Geological Survey geologists observed fossil bivalves within sandstone of this unit along Regart Creek.

Unnamed marine sandstone and shale (Tmsu) of upper Miocene age consists of fine- to medium-grained sandstone with some siliceous mudstone and shale (Brabb and others, 1998). Unnamed sedimentary rocks (Tu) are possibly of Eocene age.

The Santa Clara Formation (QTsc) of upper Pliocene to lower Pleistocene age consists of non-marine, poorly indurated conglomerate, sandstone and mudstone in lenticular beds. The lower part of the Santa Clara Formation includes lacustrine beds (QTsl) consisting of fine-grained sandstone, mudstone and marl with late Pliocene fossils (Brabb and others, 1998).

Structural Geology

The stratigraphic assemblages of the Santa Cruz Mountains were deposited and deformed in separate depositional basins. Later, these stratigraphic assemblages were truncated and juxtaposed against one another by a complex system of Tertiary and Quaternary strike-slip and dip-slip faults.

The most prominent fault in the map area is the San Andreas Fault, which juxtaposes the Mindego Hill assemblage on the southwest against the Woodside assemblage on the northeast. The San Andreas Fault is a right-lateral strike-slip fault with an estimated 35 km of displacement in the last 8 million years (Brabb and others, 1998). The San Andreas Fault includes many individual fault strands in a zone that ranges in width from several hundred to more than a thousand feet. Some of the individual fault strands ruptured during the 1906 earthquake.

Two faults with reverse or thrust sense of displacement, the Berrocal Fault and the Monte Vista Fault, displace rocks of the Woodside assemblage northeast of the San Andreas Fault zone. The Berrocal Fault forms a prominent topographic lineament in the map area and juxtaposes rocks of the Franciscan Complex against rocks of the Plio-Pleistocene Santa Clara Formation. Sorg and McLaughlin (1975) report that the Franciscan rocks on the southwest side of the fault have been uplifted and displaced laterally to the northwest. The Monte Vista Fault is mapped as a thrust fault in the map area (Brabb and others, 1998). It juxtaposes Miocene and older rocks against Plio-Pleistocene rocks of the Santa Clara Formation in the northwest part of the map area. The Monte Vista Fault is buried beneath Quaternary alluvial deposits in the southeast part of the map area.

Folding has occurred in both stratigraphic assemblages in the map area. Miocene rocks in the Mindego Hill assemblage dip moderately to steeply to the southwest. A series of synclines and anticlines are present in the Mindego Hill assemblage southwest of the Cupertino Quadrangle. Plio-Pleistocene rocks of the Santa Clara Formation are complexly folded in the Woodside assemblage, indicating rapid and likely on-going Quaternary deformation.

Landslide Inventory

To evaluate earthquake-induced landsliding, it is necessary to identify previous occurrences of landsliding in the study area. An inventory of existing landslides in the Cupertino Quadrangle was prepared for this study by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previous landslide mapping (William Cotton and Associates, 1977, 1978, 1980; Terratech, 1985). 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. A version of this landslide inventory is included with Plate 2.1.

Detailed landslide maps prepared by geotechnical consultants were available for review for three cities in the Cupertino Quadrangle. The largest area of detailed landslide mapping covers the Town of Saratoga (William Cotton and Associates, 1980; Terratech, 1985). The Town of Saratoga landslide maps are at a scale of one inch equal to 200 feet and include an area of hillside terrain in the southern part of the quadrangle. Detailed landslide maps were also available for the Town of Los Altos Hills at a scale of one inch equal to 200 feet (William Cotton and Associates, 1978). A small portion of the Town of Los Altos Hills extends into the northwest part of the Cupertino Quadrangle. In addition, a landslide map of the Congress Springs study area (William Cotton and Associates, 1977) was available for review at a scale of one inch equal to 250 feet. A small portion of the Congress Springs study area extends into the southernmost portion of the quadrangle on the south side of Congress Springs Road. Each of these landslide maps was reviewed in detail and checked in the field. Most of the mapped landslides are included in the current landslide inventory, although some landslides were modified based on field observations or aerial photo interpretation.

In general, landslides are abundant in the hillside areas of the Cupertino Quadrangle. One area where landslides are particularly abundant is the belt of low foothills in the Town of Saratoga between the Berrocal and Monte Vista faults. These slopes are underlain by the Santa Clara Formation, which contains weak smectite-bearing claystone (Nelson, 1992). Many of the landslides are on slopes that are not particularly steep, often less than 50 percent. These landslides generally are shallow, though some may range up to several tens of feet in thickness. The shallow landslides likely formed in clay-rich soils developed on the Santa Clara Formation, whereas some of the deeper slides may have developed in underlying claystone beds.

West of the Berrocal Fault, the terrain is considerably steeper. Monte Bello Ridge, the predominant topographic feature between the Berrocal Fault and the San Andreas Fault is underlain primarily by rocks of the Franciscan Complex. There are several deep-seated landslide complexes developed in the Franciscan rocks on the slopes of Monte Bello Ridge. The most prominent of these is a very large block slide on the western side of Stevens Creek Reservoir. This block slide may be 300 feet or more in depth and appears to override Santa Clara Formation rocks at the toe (Sorg and McLaughlin, 1975).

The San Andreas Fault rift zone extends across the southwest corner of the map area. Several moderate to large landslide blocks have developed in Tertiary marine rocks on the southwest side of the fault. It appears that the toes of some of these landslides have been offset or truncated by the fault.

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 strengths. Generally, the primary source for shear-strength measurements is geotechnical reports

prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the Cupertino Quadrangle geologic map have been obtained from Cotton, Shires and Associates (consultants for the cities of Cupertino and Saratoga); Santa Clara County Planning Department; California Department of Transportation (CalTrans); and CGS environmental review program files, as detailed in the Appendix at the end of this section. The locations of rock and soil samples taken for shear testing within the Cupertino Quadrangle are shown on Plate 2.1. Shear test data from adjoining portions of Mountain View, Mindego Hill, San Jose West, Castle Rock Ridge, and Los Gatos quadrangles were used to augment data for several geologic units for which little or no shear-test information is available within the Cupertino Quadrangle.

Shear-strength data gathered from the above sources were compiled for each geologic map unit. Geologic map units were grouped on the basis of average angle of internal friction (average phi) and/or lithologic characteristics. 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 (Table 2.2) in the map area, a single shear strength was assigned and used in our slope stability analysis. The Santa Clara Formation is the only unit subdivided into two strength groups, as further discussed in the next section. A geologic material strength map was made based on the groupings presented in Table 2.1 and Table 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

Geologic map units without any shear tests were grouped as follows: the geomorphic units, ac and gq, are grouped with their most common hosting geologic units, Qhf and Qpf respectively. Tb, Tblc, Tu, db, fc, and fpl have lithology and/or competency similar to units in strength group 2, whereas the finer-textured Tla, Tmb, fh, sp and QTsl are characteristic of strength group 3. Holocene terrace deposits are grouped with stream channel and alluvial fan deposits of similar age and lithology, while the older terrace deposits are grouped with the higher-strength Qt.

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 have used geologic structural data combined with digital terrain data to identify areas with potentially adverse bedding, using methods similar to Brabb's (1983). Structural data from the bedrock geology (Brabb and others, 1998) has been used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, where the same, the dip magnitude and slope gradient categories were also compared. Where the dip magnitude is 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.

Adverse bedding conditions have been considered for dipping geologic map units whose lithology and shear strengths exhibit bimodal distributions and where the geologic structure can be adequately characterized. As a result, adverse bedding was incorporated into the evaluation of the Santa Clara Formation. This unit consists of conglomerate, sandstone and mudstone and was subdivided based on the differences in shear strength between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear-strength values for the coarse- and fine-grained lithologies were then applied to areas of favorable and adverse bedding orientation, as determined from structural and terrain data discussed above. This analysis assumes 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 to areas where potential adverse bedding conditions are identified. The favorable and adverse bedding shear strengths for the Santa Clara Formation are included in Table 2.1.

Not all mapped areas of the Santa Clara Formation could be characterized for adverse bedding because of insufficient to non-existent strike-and-dip measurements. In these cases, an average shear strength for both fine- and coarse-grained material was applied, which conservatively corresponds to strength group 3. The areas where this average strength was applied include the southeast corner of the quadrangle and several of the smaller fault blocks.

Existing Landslides

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide hazard 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 slip surfaces tested in direct- or ring-shear equipment. Within the Cupertino Quadrangle, results from 12 direct-shear tests of landslide slip surface materials were obtained and are summarized in Table 2.1.

SHEAR-STRENGTH STATISTICS FOR THE CUPERTINO 7.5-MINUTE QUADRANGLE

	Formation Name (1, 2)	Number Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (3) (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1	fss	14	31.2 / 32.0	33.1 / 31.8	790 / 550	gq	33
	QTsc fbc	28	34.8 / 33.0				
	Qpf	56	32.7 / 30.5				
GROUP 2	fg	43	27.4 / 28.0	27.5 / 28.0	680 / 565	db, fc	28
	Tvq	5	25.4 / 25.0			fpl, Tb	
	Qt	1	31.0			Tblc,Tu	
						Qot, Qpt	
GROUP 3	fm	9	27.0 / 25.0	24.4 / 24.0	995 / 820	fh, sp	24
	Tm	26	25.0 / 22.0			Tla, Tmb	
	Tmsu	1	25.3			QTsl, Qf	
	QTsc abc	100	23.9 / 25.0			Qht, Qhty	
	Qhc	5	25.6 / 21.0			ac	
	Qhf	29	24.1 / 20.0				
GROUP 4	af	27	20.1 / 20.0	20.2 / 20.0	651 / 560	Qa	20
	Qha	4	16.6 / 18.5				
	Qhl	5	23.2 / 22.0				
	Qoa	1	20.0				
GROUP 5	Qls	12	13.8 / 15.5	13.8 / 15.5	532 / 600	- - -	14

(1) Formation names for strength groups from Brabb and others (1998); Knudsen and others (2000)
(2) abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength
(3) Cohesion

Table 2.1. Summary of Shear-Strength Statistics for the Cupertino Quadrangle.

SHEAR-STRENGTH GROUPS FOR THE CUPERTINO 7.5-MINUTE QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
fss	db, fc	fh, fm, sp	af	Qls
QTsc fbc	fg, fpl	Tla, Tmb	Qa	
Qpf	Tb, Tblc	Tm, Tmsu	Qha	
	Tu, Tvq	QTsc abc, QTsl	Qhl	
	Qot, Qpt	Qhc, Qhf, Qf	Qoa	
	Qt	Qht, Qhty, ac, qg		

Table 2.2. Summary of Shear-Strength Groups for the Cupertino Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide hazard zones, the Newmark method necessitates selecting a design earthquake strong-motion record to provide the "ground shaking opportunity." For the Cupertino Quadrangle, selection of a strong-motion record is based on the probabilistic ground-motion parameters of modal magnitude, modal distance, and peak ground acceleration (PGA). These parameters are estimates from maps prepared by CGS for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used for selecting the record are:

Modal Magnitude:	7.9
Modal Distance:	2.5 to 16 km
PGA:	0.55 – 0.98 g

The strong-motion record selected for the slope stability analysis of the Cupertino Quadrangle is the Lucerne record of the 1992 Landers earthquake, which had a moment magnitude (M_W) of 7.3. The east-west component of this record had a source-to-recording-site distance of 1.1 km and a PGA of 0.73 g. Although the magnitude and distance parameters from the Lucerne record do not fall within the range of the probabilistic parameters, this record is the closest fit to the above criteria that is currently available. 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 are 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 CGS 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 0.142, 0.182 and 0.243 g. Because these yield accelerations are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Cupertino Quadrangle.

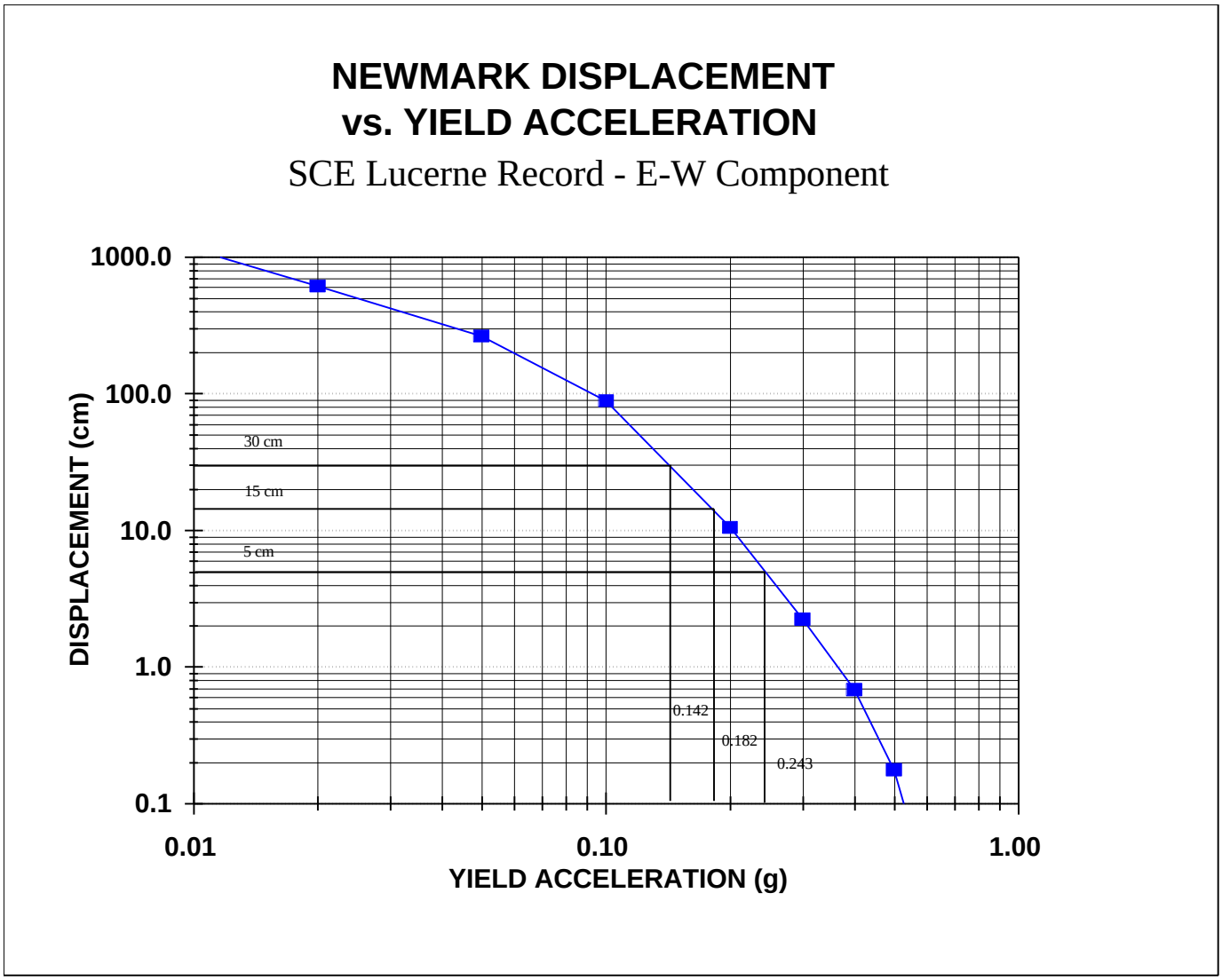

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Lucerne Record from the 1992 Landers Earthquake.

Slope Stability Analysis

A slope stability analysis was performed for each geologic strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions has been assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration (a_y) 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 strength group for a range of slope gradients. Based on the relation between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials are assigned as follows:

1. If the calculated yield acceleration was less than 0.142 g, 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 0.142 g and 0.182 g, 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 0.182 g and 0.243 g, 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 0.243 g, 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 gradient map according to this table.

HAZARD POTENTIAL MATRIX FOR THE CUPERTINO 7.5-MINUTE QUADRANGLE

GEOLOGIC STRENGTH GROUP	MEAN PHI	SLOPE CATEGORY (% SLOPE)									
		I	II	III	IV	V	VI	VII	VIII	IX	X
		< 6	6–12	12–19	19–21	21–26	26–28	28–34	34-40	40–46	> 46%
1	33	VL	VL	VL	VL	VL	VL	VL	VL	L	H
2	28	VL	VL	VL	VL	VL	VL	L	M	H	H
3	24	VL	VL	VL	VL	L	M	H	H	H	H
4	20	VL	VL	L	M	H	H	H	H	H	H
5	14	L	M	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides for the Cupertino 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 toes of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

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

2. Geologic Strength Group 4 is included for all slopes steeper than 12 percent.

3. Geologic Strength Group 3 is included for all slopes steeper than 21 percent.

4. Geologic Strength Group 2 is included for all slopes steeper than 28 percent.

5. Geologic Strength Group 1 is included for all slopes greater than 40 percent.

Approximately 30 percent of the Cupertino Quadrangle is within the earthquake-induced landslide hazard zone. Much of the hilly or mountainous area in the southwest half of the quadrangle falls within the zone. Only small areas within Santa Clara Valley are in the zone such as along the steep banks of Stevens and Saratoga creeks.

ACKNOWLEDGMENTS

Cotton, Shires and Associates, the California Department of Transportation, and the County of Santa Clara generously assisted by allowing us full access to their files for compiling shear-strength data. Jim Baker, Santa Clara County geologist, and Cotton, Shires and Associates provided insightful reviews of the preliminary seismic hazard zone map that resulted in changes that are incorporated in the official zone map. At CGS, Ellen Sander processed most of the shear tests by digitizing sample locations and entering the information into our database. Barbara Wanish, Terilee McGuire, Lee Wallinder, and Bob Moscovitz provided invaluable GIS and database support. Ross Martin and Barbara Wanish prepared the final landslide hazard zone maps and graphic displays for this report. Rick Wilson provided additional assistance that, in part, included preparation of the DEM.

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AIR PHOTOS

WAC Corporation, WAC-C-99CA, 3-1 through 3-11, 3-82 through 3-98, 3-190 through 3-200, scale 1”=2000’, date 4-13-99.

APPENDIX
SOURCE OF SHEAR-STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Cotton, Shires and Associates	**182**
Santa Clara County	**19**
California Geological Survey	**17**
CalTrans	**12**
Total Number of Shear Tests	**230**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Cupertino 7.5-Minute Quadrangle, Santa Clara County, California

By

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

California Department of Conservation
California Geological Survey
***Formerly with CGS, 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) [now called California Geological Survey (CGS)] 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. The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

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 the California Geological Survey's Internet page: http://www.consrv.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 [California Geological Survey], 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.

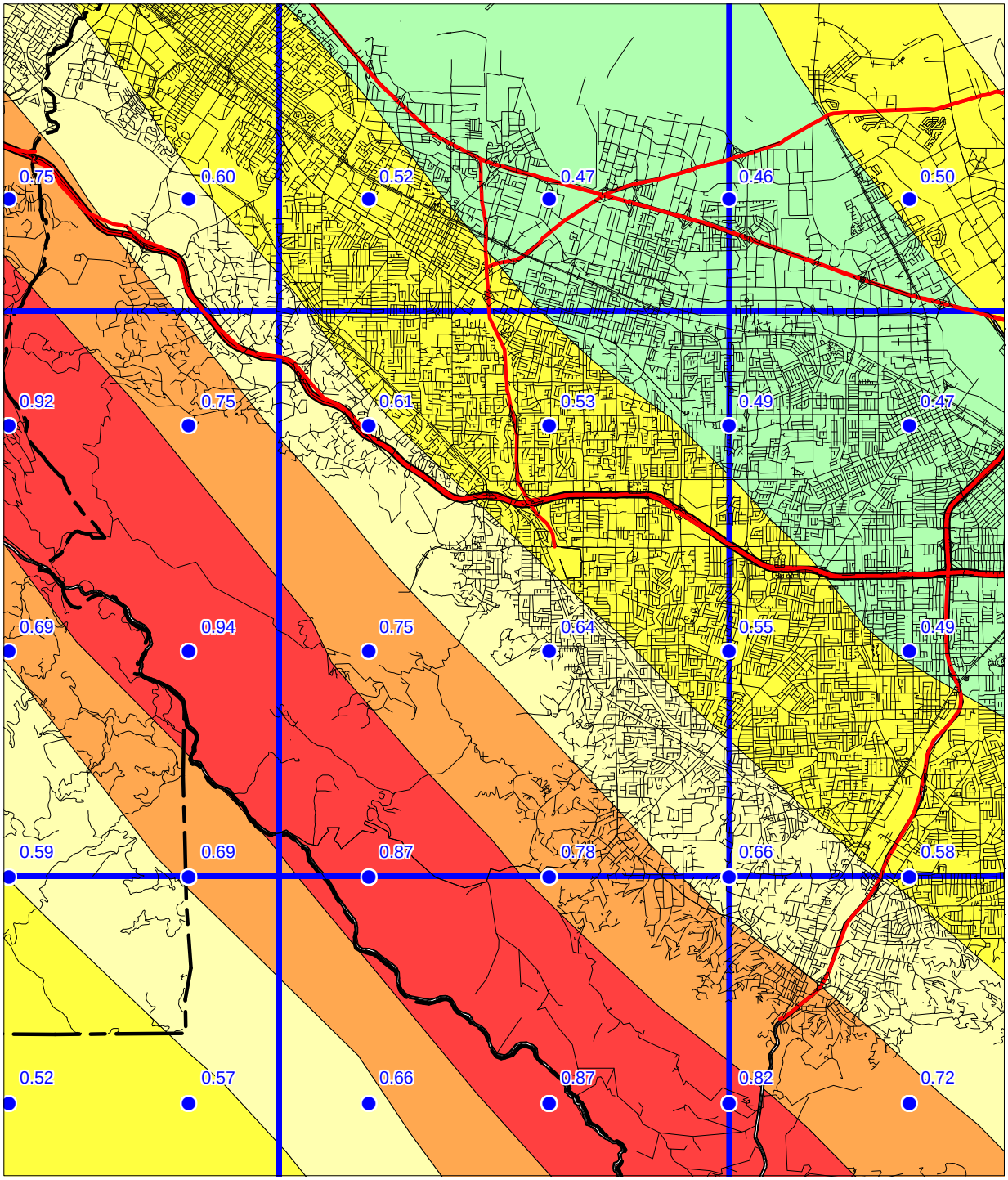
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

CUPERTINO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

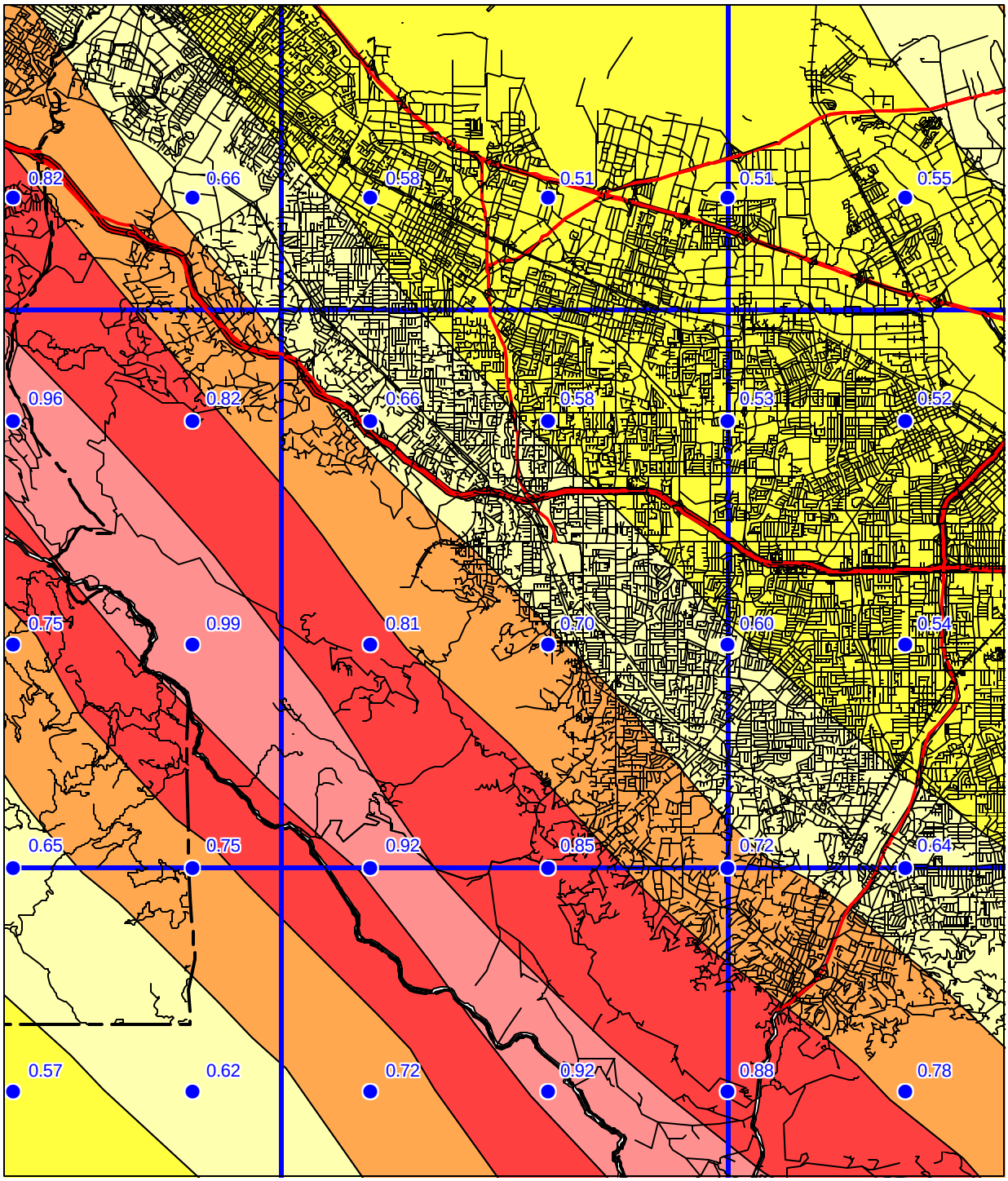
Figure 3.1

CUPERTINO 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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Department of Conservation
Division of Mines and Geology

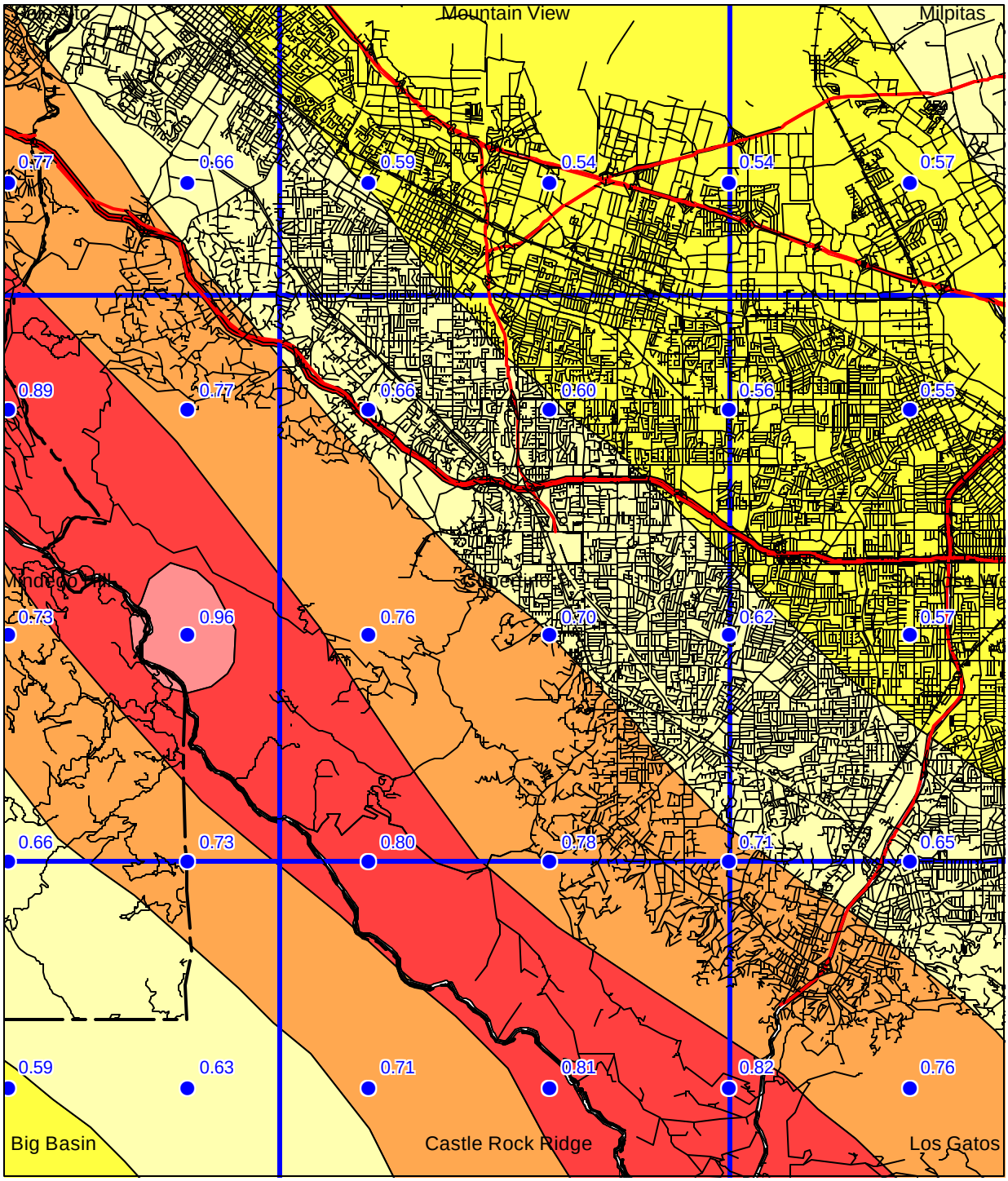
Figure 3.2

CUPERTINO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works © 1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.3

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

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

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

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

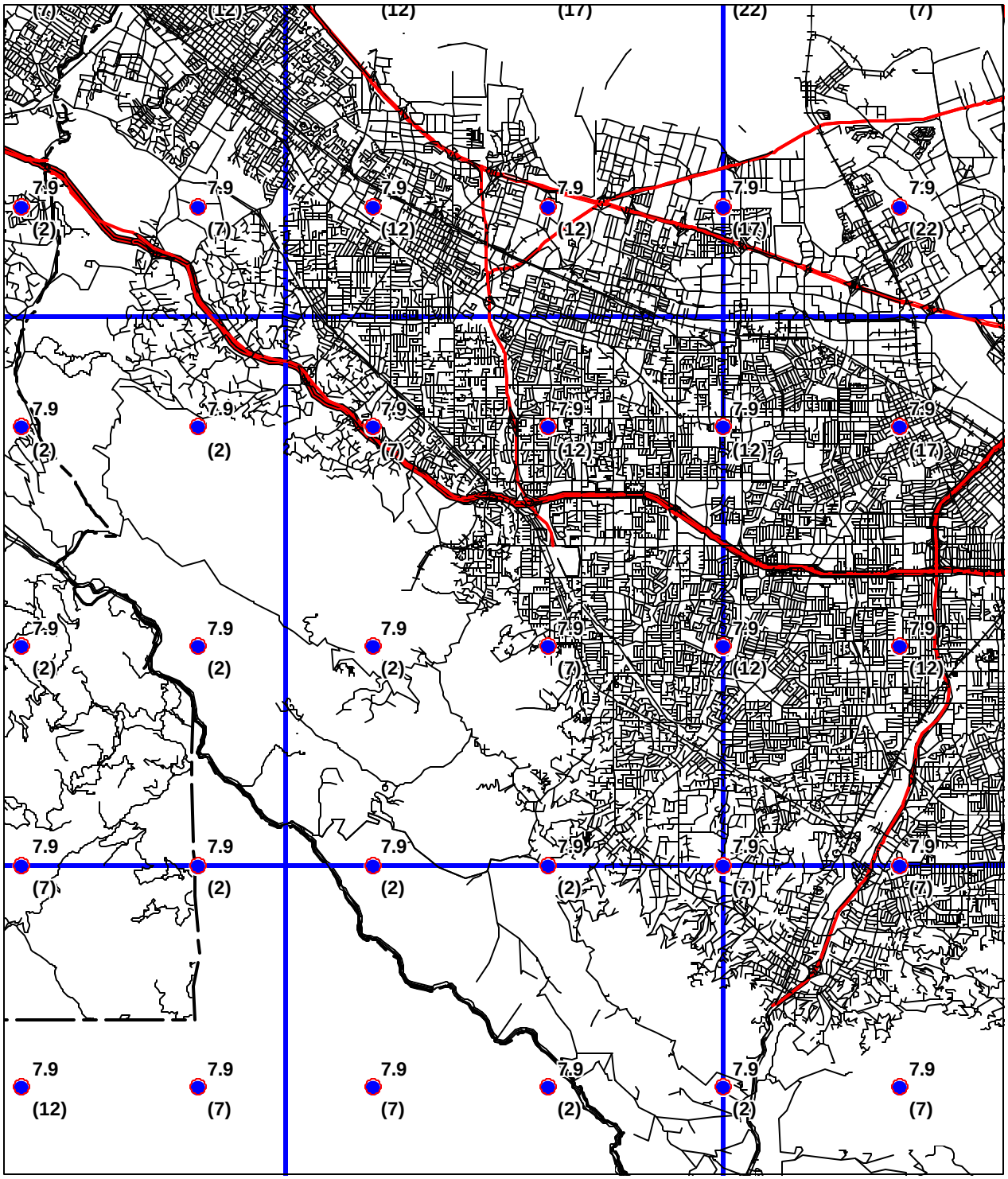
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

CUPERTINO 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

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



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

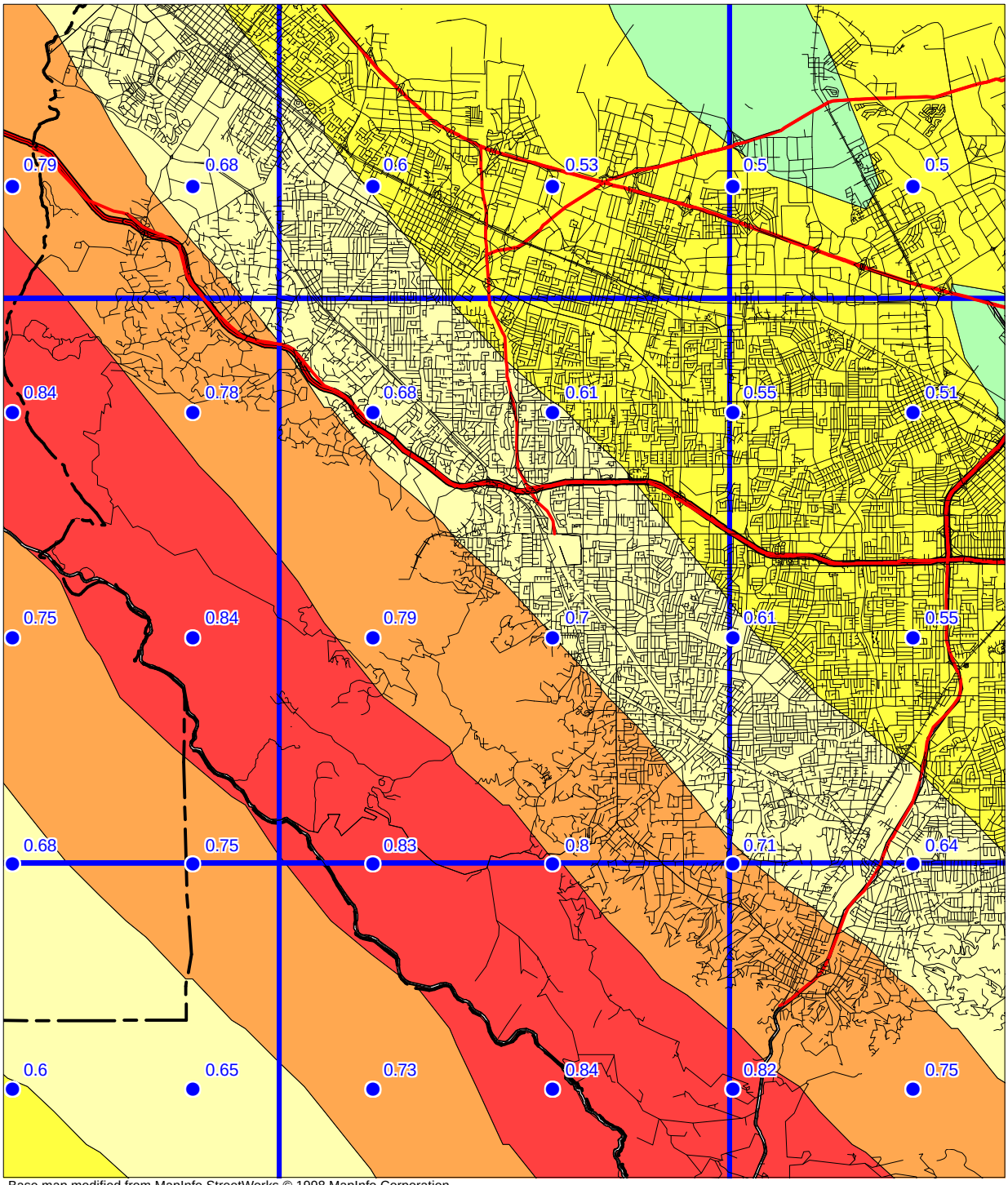
Department of Conservation
Division of Mines and Geology
Figure 3.4

CUPERTINO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

2001

LIQUEFACTION OPPORTUNITY



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

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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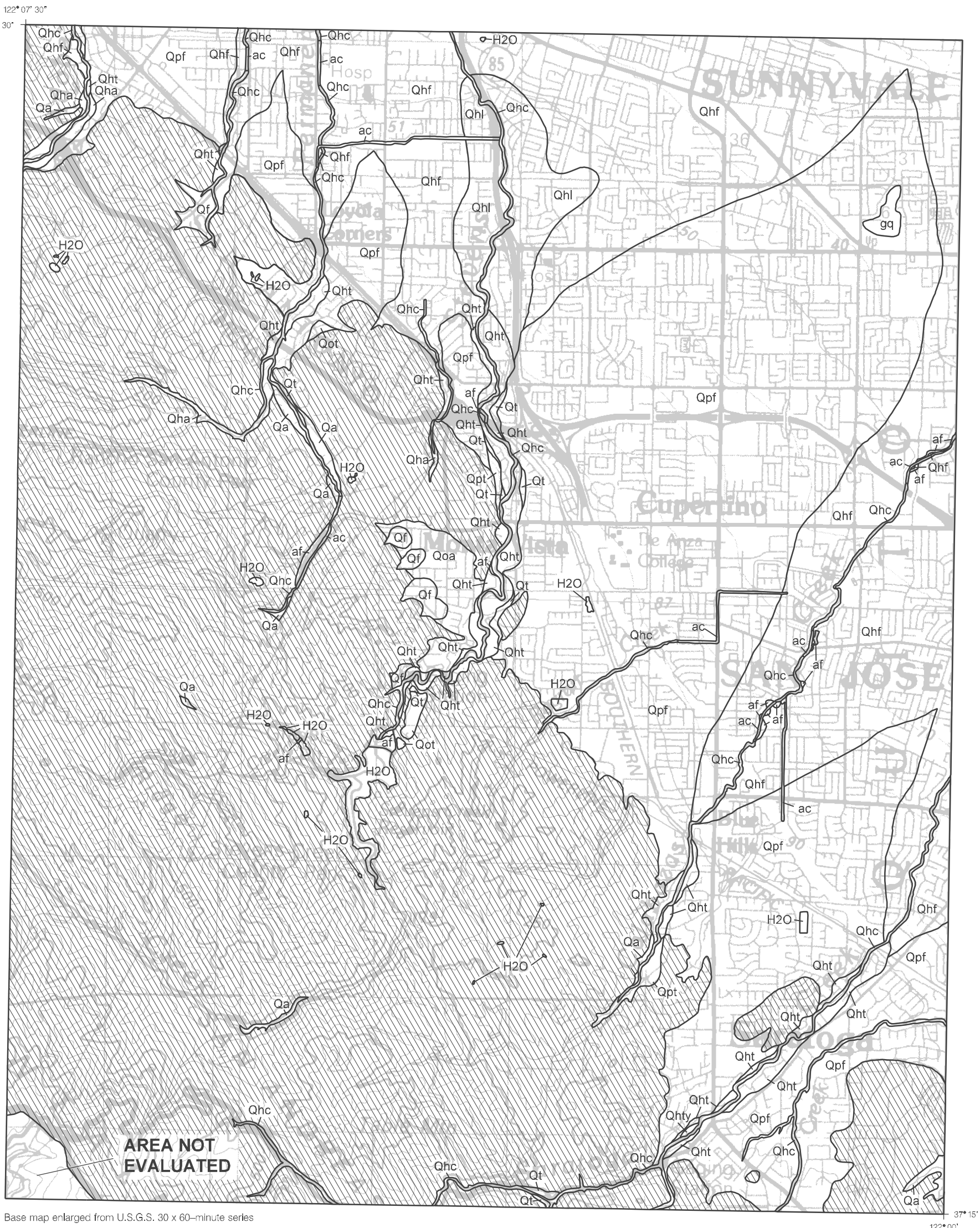


CUPERTINO QUADRANGLE

SCALE

1 .5 0 1 MILE

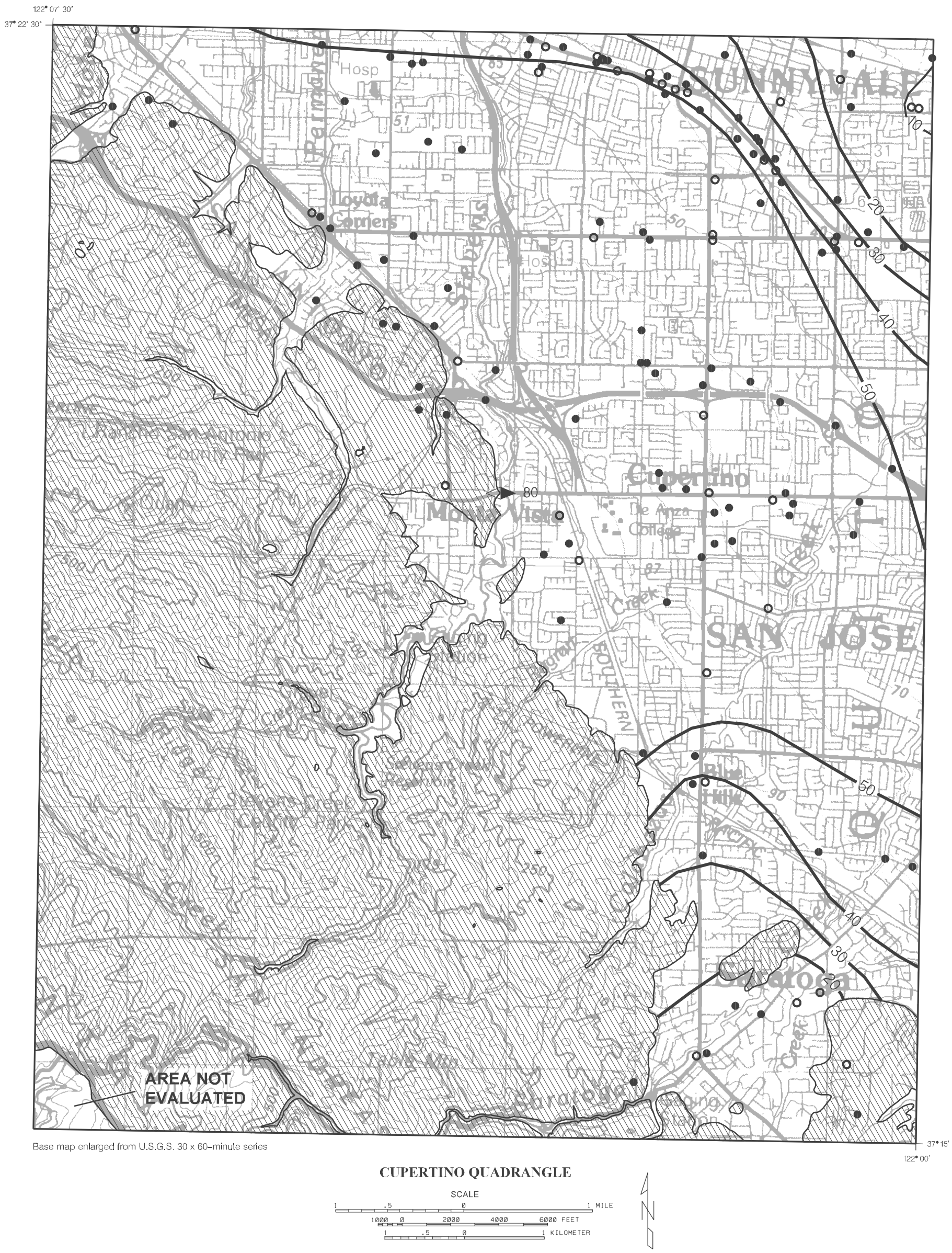
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

Lithologic contact

Pre-Quaternary bedrock and Santa Clara Formation (QTsc)
See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

Plate 1.1 Quaternary geologic map of the Cupertino 7.5-minute Quadrangle, California. *Modified from Knudsen, K.L., unpublished.*



Historical Ground Failures (from Knudsen and others, 2000)

Lateral spread

80 Number assigned to ground failure site (adapted from Youd and Hoose, 1978, by Knudsen and others, 2000)

Pre–Quaternary bedrock and Santa Clara Formation (QTsc)

10 Depth to ground water, in feet

Geotechnical boreholes used in liquefaction evaluation

Ground–water level data provided by the Santa Clara Valley Water District

Plate 1.2 Depth to historically highest ground water, historical liquefaction site, and locations of boreholes used in this study, Cupertino 7.5-minute Quadrangle, California

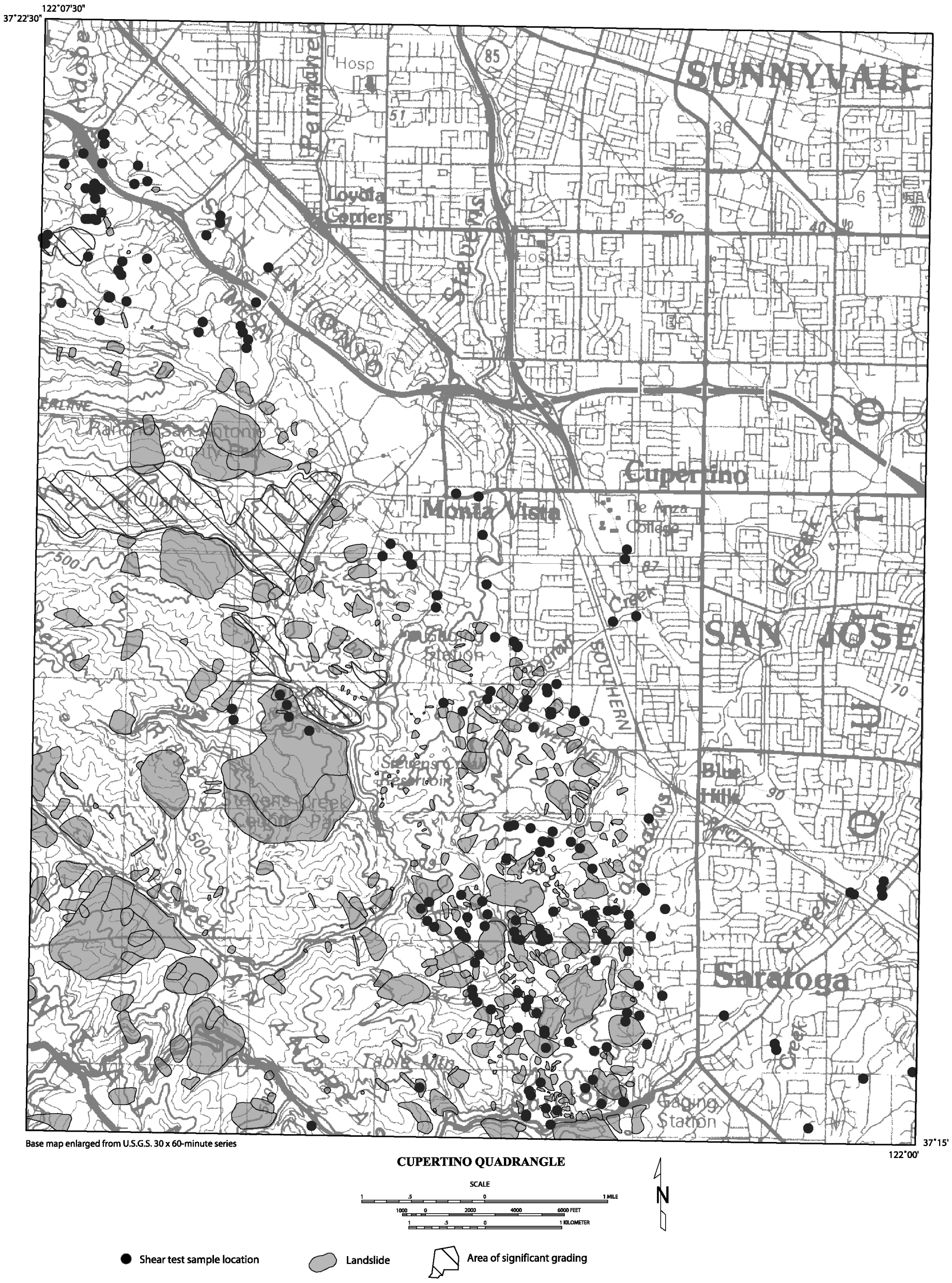


Plate 2.1 Landslide inventory, shear test sample locations, and areas of significant grading, Cupertino 7.5-minute Quadrangle, California.