SEISMIC HAZARD ZONE REPORT 069

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

2002

DEPARTMENT OF CONSERVATION
California Geological Survey

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ILLUSTRATIONS

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Los Gatos 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 57 square miles at a scale of 1 inch = 2,000 feet. Only the Santa Clara County portion of the quadrangle is zoned. Approximately 3 square miles in the southwestern corner that lies within Santa Cruz County has not been evaluated for zoning.

Parts of the cities of Los Gatos, San Jose, and Saratoga occupy the northern quarter of the Los Gatos Quadrangle. The cities lie mostly in gently sloping Santa Clara Valley and extend into the adjoining low foothills of the Santa Cruz Mountains. Most of the city land has been developed for residential and commercial uses. The remainder of the quadrangle is mostly steep, forested terrain in the Santa Cruz Mountains that is unincorporated county land. Major streams in the map area include Los Gatos Creek and Guadalupe Creek, which flow into southern San Francisco Bay. Three reservoirs are located along Los Gatos Creek and one is located on Guadalupe Creek at the eastern edge of the map area. The highest point in the map area is Mount Umunhum, at 3,485 feet. The lowest point is at the northeastern corner in the quadrangle at slightly less than 200 feet. The major highway is State Route 17, which extends across the Santa Cruz Mountains from San Jose to Santa Cruz.

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 Los Gatos Quadrangle the liquefaction zone is primarily coincident with Los Gatos Creek and Guadalupe Creek canyon bottoms. Shorter stretches of San Tomas Aquinas Creek and Ross Creek canyons also are zoned. The bedrock units in the quadrangle are separated into structural blocks as a result of a complex structural history and are strongly deformed by faults and folds. The combination of dissected hilly to mountainous terrain and weak rock units has produced widespread and abundant landslides. These conditions contribute to an earthquake-induced landslide zone that covers about 75 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.conservation.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
945 Bryant Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at 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/webdocs/sp117.pdf

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed 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 Los Gatos 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Los Gatos 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/webdocs/sp117.pdf

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 Los Gatos 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.conservation.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 Los Gatos 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 and unpublished 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 Los Gatos Quadrangle consist of gently sloping alluvial fans and areas bordering 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 Los Gatos 7.5-minute Quadrangle covers approximately 60 square miles in Santa Clara and Santa Cruz counties, southeast 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 Summit Road. This evaluation report and accompanying Seismic Hazard Zone Map cover only that portion of the Los Gatos Quadrangle that lies within Santa Clara County. Approximately 3 square miles (5 percent of the quadrangle) within Santa Cruz County is outside of the area currently evaluated for zoning.

Parts of the cities of Los Gatos, San Jose, and Saratoga occupy the northern quarter of the quadrangle. The cities lie mostly in gently sloping Santa Clara Valley and upon the adjoining low foothills of the Santa Cruz Mountains. Most of the area within the cities has been developed for residential and commercial uses. The remainder of the quadrangle is unincorporated county land, which is primarily steep, forested terrain in the Santa Cruz Mountains. Large areas are sparsely populated, although scattered residential development has taken place in the mountains. Timber harvesting has continued in the region for more than a century in some of the mountainous areas and second-growth stands of large trees are common.

Major streams in the map area include Los Gatos Creek and Guadalupe Creek, which flow northward toward the Santa Clara Valley and then into southern San Francisco Bay. Numerous small tributaries that originate on the steep slopes of the Santa Cruz Mountains feed these streams. The Vasona Reservoir (dam crest elevation about 300 feet), Lexington Reservoir (spillway elevation 645 feet) and Lake Elsman (spillway elevation 1,145 feet) have been constructed along Los Gatos Creek. Guadalupe Reservoir (spillway elevation 614 feet) has been constructed on Guadalupe Creek at the eastern edge of the map area.

The highest point in the map area is Mount Umunhum, at 3,485 feet. The lowest point in the map area is on the floor of the Santa Clara Valley at the northeastern corner of the map area, where the elevation is slightly less than 200 feet. The major highway in the map area is State Route 17, which extends across the Santa Cruz Mountains from San Jose to Santa Cruz. A number of other county roads extend into the hills. Some rugged areas are inaccessible to vehicles.

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 map units in the Los Gatos Quadrangle, a large-scale geologic map must be obtained or developed. For the Los Gatos Quadrangle, unpublished mapping of the Quaternary deposits by K.L. Knudsen and bedrock mapping of McLaughlin and others (2001) were used. These maps were combined, with minor modifications along the contact between bedrock and Quaternary units, to form a single, 1:24,000-scale geologic map of the Los Gatos 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 geologic 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), Haugerud and Ellen, (1990), Seed and others (1990), McLaughlin and others, (1991), Geomatrix Consultants, Inc. (1992), Hitchcock and others (1994), Helley and others (1994), Campbell and others (1995), Iwamura (1995), and McLaughlin and others (2001). 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 Los Gatos Quadrangle, Knudsen (unpublished) identified 16 Quaternary map units and the Plio-Pleistocene Santa Clara Formation (QTsc). The Quaternary geologic mapping methods used by Knudsen in the Los Gatos Quadrangle are the same as those described by Knudsen and others (2000), which consist of interpretation of topographic maps, aerial photographs, and soil surveys, as well as compiled published and unpublished geologic maps. The age of each unit is 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.

The developed, northern part of the Los Gatos Quadrangle is covered by Quaternary alluvial material that was derived from the Santa Cruz Mountains to the southwest (Plate 1.1). The alluvial deposits primarily consist of late Pleistocene alluvial fan material (Qpf) deposited by Guadalupe and Los Gatos creeks. The alluvial fan surfaces slope gently to the north and northeast. Most of the alluvial fan sediment shown by Knudsen (unpublished) is latest Pleistocene in age, although a veneer of Holocene alluvial fan sediment (Qhf) has been deposited upon latest Pleistocene deposits along the downstream part of Guadalupe Creek (Plate 1.1). Additionally, Knudsen (unpublished) mapped Holocene stream terrace deposits (Qht, Qhty) along Guadalupe and Los Gatos creeks and artificial fill (af) along Ross Creek where the channel has been straightened and cutoff meanders have been filled.

UNIT	Knudsen and others (2000)	Helley and others (1994)	Wentworth and others (1999)	Helley and others (1979)	CGS GIS database
Artificial fill	af		af		af
Artificial fill, levee	alf				alf
Gravel quarries and percolation ponds	gq	PP,GP	PP,GP		gq
Artificial stream channel	ac				ac
Modern stream channel deposits	Qhc	Qhsc	Qhc	Qhsc	Qhc
Latest Holocene stream terrace deposits	Qhty				Qhty
Holocene alluvial fan deposits	Qhf	Qhaf, Qhfp	Qhf, Qhfp	Qham, Qhac	Qhf
Holocene stream terrace deposits	Qht	Qhfp	Qht		Qht
Holocene alluvium, undifferentiated	Qha		Qha		Qha
Late Pleistocene to Holocene alluvial fan deposits	Qf				Qf
Late Pleistocene to Holocene stream terrace deposits	Qt				Qt
Late Pleistocene to Holocene alluvium, undifferentiated	Qa		Qa		Qa
Late Pleistocene alluvial fan deposits	Qpf	Qpaf	Qpf	Qpa	Qpf
Late Pleistocene stream terrace deposits	Qpt				Qpt
Early to middle Pleistocene alluvial fan deposits	Qof		Qof		Qof
Early to middle Pleistocene undifferentiated alluvial deposits	Qoa		Qoa	Qpea, Qpmc	Qoa
bedrock	br	br			br

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

Bedrock exposed in the Los Gatos Quadrangle is characterized by two basement assemblages that are separated by the San Andreas Fault, which extends through the southwestern corner of the quadrangle (McLaughlin and others, 2001). Southwest of the San Andreas Fault is the Salinian Terrane, a basement assemblage of granitic to gabbroic intrusive rocks with roof pendants of high-temperature metamorphic 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. McLaughlin and others (2001) further subdivide bedrock sequences in the area into individual fault-bound bedrock structural blocks based on contrasting stratigraphic sequences and geologic histories of the basement assemblages and overlying Tertiary rocks. See the earthquake-induced landslide part (Section 2) of this report for further details.

Structural Geology

The Los Gatos 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 Los Gatos Quadrangle, the Calaveras Fault is 10 to 12 miles east of the eastern border, and the Hayward Fault is about 15 miles to the northeast. 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 and Shannon faults are mapped in the northern portion of the quadrangle, 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, McLaughlin and others, 2001). The oblique-slip Sargent Fault diverges from the San Andreas in the southern portion of the quadrangle, and the reverse-slip Santa Clara Fault is a few miles to the northeast of the study area (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 31 borehole logs collected from the files of the California Department of Transportation (CalTrans) and the City of San Jose 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 145 feet of Holocene materials and 717 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) median values for penetration resistance suggest Holocene materials are less dense and more readily penetrated than Pleistocene materials; 2) penetration resistance values measured from the same map unit can vary considerably, the standard deviation is often 50 to 100 percent of the mean; 3) late Pleistocene alluvial fan deposits (Qpf) are predominantly coarse grained; and 4) Holocene units consist of both fine- and coarse-grained materials, 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
f	ine	0	-	-	-	-	-	0	-	-	-	-	-
	oars	0	-	-	-	-	-	1	19	-	-	-	-
alf	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
q	ine	0	-	-	-	-	-	0	-	-	-	-	-
	oars	0	-	-	-	-	-	0	-	-	-	-	-
ac	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qhc	ine	0						0	-	-	-	-	-
	oars	0						0	-	-	-	-	-
Qhty	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qhf	ine	2	110.1	0.01	110.1	10[illegible]	111	4	45	1.44	16	[illegible]	[illegible]9
	oars	1	107.2	-	-	-	-	4	29	0.49	34	[illegible]	39
Qht	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	4	30	0.79	25	9	61
Qha	ine	0	-	-	-	-	-	0	-	-	-	-	-
	oars	0	-	-	-	-	-	0	-	-	-	-	-
Qf	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	4	63	0.08	64	58	68
Qt	ine	0	-	-	-	-	-	0	-	-	-	-	-
	oars	0	-	-	-	-	-	3	54	0.65	71	[illegible]	78
Qa	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qpf	ine	18	109.0	0.10	107.3	96	139	21	44	0.53	46	[illegible]	[illegible]9
	oars	21	115.7	0.09	115.0	97	36.	52	63	0.79	45	[illegible]	[illegible]9
Qpt	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qof	ine	0	-	-	-	-	-	0	-	-	-	-	-
	oars	0	-	-	-	-	-	0	-	-	-	-	-
Qoa	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
QTsc	ine	2	107	0	107	107	107	3	55	0.35	56	[illegible]	73
	oars	1	121	-	-	-	-	1	>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 Geologic Units in the Los Gatos 7.5-Minute Quadrangle.

Geologic Map Unit (1)	Description	Length of boreholes 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)	13	SM 58; CL 19; ML 15; GP 8	/H-l	H-L	M-L	VL
alf	Artificial fill, levee	0	n/a (5)	VH-L	H-L	M-L	VL
gq	Gravel quarries and percolation ponds	0	n/a	/H-l	H-L	M-L	VL
ac	Artificial stream channel	0	n/a	VH-L	H	M	VL
Qhc	Modern stream channel deposits	6	SP 100	VH	H	M	VL
Qhty	Latest Holocene stream terrace deposits	0	n/a	VH	H	M	VL
Qhf	Holocene alluvial fan deposits	38	CL 43; SM 32; SP 25	H	M	L	VL
Qht	Holocene stream terrace deposits	48	SM 56; CL 19 other 25	M	M	L	VL
Qha	Holocene alluvium, undifferentiated	0	n/a	M	M	L	VL
Qf	Late Pleistocene to Holocene alluvial fan deposits	30	SW 100	M	L	L	VL
Qt	Late Pleistocene to Holocene stream terrace deposits	10	SW-SM 100	M	L	L	VL
Qa	Late Pleistocene to Holocene alluvium, undifferentiated	0	n/a	M	L	L	VL
Qpf	Late Pleistocene alluvial fan deposits	669	CL 30; SM 15; GP 15; GC 10; other 30	L	L	VL	VL
Qpt	Late Pleistocene stream terrace deposits	11	SM 100	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	37	SM 22; ML-CL 22; CH 14; other 42	VL	VL	VL	VL

Notes:
(1) Susceptibility assignments are specific to the materials within the Los Gatos 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 Los Gatos 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 Los Gatos 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 City of San Jose 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 ground-water contours on Plate 1.2 show historical-high water depths, as interpreted from boring logs from investigations between the 1950's and the year 2000. Depths to first-encountered water range from 5 to 54 feet below the ground surface (Plate 1.2). In general, ground-water levels are highest where Los Gatos and Guadalupe creeks flow from the foothills (Plate 1.2). Numerous boreholes located west of Los Gatos Creek at the base of the foothills indicate an area of elevated ground water. Additionally, Vasona Reservoir and other reservoirs may locally elevate ground-water levels due to infiltration and management of the reservoirs for recharge of local aquifers. Ground-water levels are deepest, greater than 30 feet, in the north-central area of the quadrangle between Los Gatos and Guadalupe creeks (Plate 1.2).

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 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) 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. Therefore, these units 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. Such units are given a low (L) susceptibility assignment where ground water depth is shallower than 30 feet. The Santa Clara Formation (QTsc) is occasionally 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 Los Gatos Quadrangle, PGAs of 0.59g 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 31 geotechnical borehole logs reviewed in this study (Plate 1.2), 25 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 Los Gatos Quadrangle is summarized below.

Areas of Past Liquefaction

Knudsen and others (2000) have completed a digital compilation of data from Tinsley and others (1998), who compiled observations of evidence for liquefaction for the 1989 Loma Prieta earthquake, and Youd and Hoose (1978), who compiled them for earlier earthquakes, including the 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 separated into two or more where the greater base map detail allowed. There are no known reports of liquefaction effects in the Los Gatos Quadrangle.

Artificial Fills

In the Los Gatos Quadrangle, there are two kinds of artificial fill mapped by Knudsen (unpublished), artificial fill (af) and artificial fill, levee (alf). Artificial fill areas large enough to show at the scale of mapping include dams at Guadalupe and Lexington reservoirs and fill for highways and Guadalupe Creek levees. Because these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata.

Areas with Sufficient Existing Geotechnical Data

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. In Pleistocene alluvial deposits that cover much of the Los Gatos Quadrangle, most of the borehole logs that were analyzed show sediment layers that likely will not liquefy under the expected earthquake loading due to high densities. These areas are not included in the zone. The few boreholes that provided information on Holocene deposits indicate that most of the material is fine grained. However, the deposits may contain coarser, saturated lenses of material that may liquefy under expected earthquake loading.

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, and Qa) generally is lacking. These deposits, therefore, are evaluated and included or excluded from the liquefaction zone for reasons presented in criteria 4-a, -b, and -c, above. These deposits along Los Gatos and Guadalupe creeks likely contain loose, granular, late Holocene material that is saturated because of the proximity of active stream channels. Undifferentiated, late Pleistocene to Holocene alluvium (Qa) mapped along the western shore of Lexington Reservoir was examined in the field and is not included within the zone of required investigation because of the interpreted thickness, fine-grained composition, and lack of saturation of the deposits.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

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

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called the 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/webdocs/sp117.pdf

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 Los Gatos 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.conservation.ca.gov/CGS/index.htm

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Los Gatos 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 Los Gatos 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 Los Gatos 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 Los Gatos 7.5-minute Quadrangle covers approximately 60 square miles in Santa Clara and Santa Cruz counties, southeast 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 Summit Road. This evaluation report and accompanying Seismic Hazard Zone Map cover only that portion of the Los Gatos Quadrangle that lies within Santa Clara County. Approximately 3 square miles (5 percent of the quadrangle) within Santa Cruz County is outside of the area currently evaluated for zoning.

Parts of the cities of Los Gatos, San Jose, and Saratoga occupy the northern quarter of the quadrangle. The cities lie mostly on the gently sloping Santa Clara Valley and upon the adjoining low foothills of the Santa Cruz Mountains. Most of the area within the cities has been developed for residential and commercial uses. The remainder of the quadrangle is unincorporated county land, which is primarily steep, forested terrain in the Santa Cruz Mountains. Large areas are sparsely populated, although scattered residential development has taken place in the mountains. Timber harvesting has continued in the region for more than a century in some of the mountainous areas and second-growth stands of large trees are common.

Major streams in the map area include Los Gatos Creek and Guadalupe Creek, which flow northward toward the Santa Clara Valley and then into southern San Francisco Bay. Numerous small tributaries that originate on the steep slopes of the Santa Cruz Mountains feed these streams. Three reservoirs have been constructed along Los Gatos Creek: Vasona Reservoir (dam crest elevation about 300 feet); Lexington Reservoir (spillway elevation 645 feet) and Lake Elsman (spillway elevation 1,145 feet). Guadalupe Reservoir (spillway elevation 614 feet) has been constructed on Guadalupe Creek at the eastern edge of the map area.

The highest point in the map area is Mount Umunhum, at 3,485 feet. The lowest point in the map area is on the floor of the Santa Clara Valley at the northeastern corner of the map area, where the elevation is slightly less than 200 feet. The major highway in the map area is State Route 17, which extends across the Santa Cruz Mountains from San Jose to Santa Cruz. A number of other county roads extend into the hills. Some rugged areas are inaccessible to vehicles.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface. Within the Los Gatos Quadrangle, a

Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours that are based upon 1948 photography and 1953 plane-table surveys, 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 two meters (Intermap Coporation, 1998). The most significant large-scale grading has occurred in the vicinity of the Guadalupe Mines north and east of Guadalupe Creek, part of which is now being operated as a landfill. In addition, a moderate-size quarry exists on the north side of Limekiln Canyon. An interferomertic 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 Los Gatos 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 map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The DEM was also used to make a slope aspect map. The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The primary source of 1:24,000-scale bedrock geologic mapping used in this slope stability evaluation was the digital geologic map database of McLaughlin and others (2001). Knudsen (unpublished) prepared the map of unconsolidated surficial (Quaternary) geologic units for Los Gatos Quadrangle at a scale of 1:24,000. Surficial geology is discussed in more detail in Section 1 of this report.

For the purposes of this investigation, CGS geologists merged the surficial and bedrock geologic map and contacts between surficial and bedrock units were modified in some areas to resolve differences between the two maps. Geologic reconnaissance was performed to assist in adjusting contacts and to review the lithology and structure of geologic units.

The geology of the Los Gatos Quadrangle is characterized by two basement assemblages that are separated by the San Andreas Fault, which extends through the southwestern corner of the quadrangle. Southwest of the San Andreas Fault is the Salinian Terrane, a basement assemblage of granitic to gabbroic intrusive rocks with roof pendants of high-temperature metamorphic 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.

Bedrock sequences in the area are further subdivided into individual fault-bounded structural blocks based on contrasting stratigraphic sequences and geologic history of the basement assemblages and overlying Tertiary rocks (McLaughlin and others, 2001). In southwestern Santa Clara County and the southern Santa Cruz Mountains, four bedrock structural blocks have been identified. Two blocks, the Ben Lomond Block and the La Honda Block, are in the Salinian Terrane southwest of the San Andreas Fault. The other two blocks, the Sierra Azul Block and the New Almaden Block, are in the composite Mesozoic terrane northeast of the San Andreas Fault. From southwest to northeast, the three structural blocks within the Los Gatos Quadrangle are the La Honda Block, the Sierra Azul Block and the New Almaden Block. The following descriptions of bedrock units in these blocks are based primarily on the work of McLaughlin and others (2001) and are supplemented based on field reconnaissance by CGS geologists.

La Honda Block

The La Honda Block occupies the southwestern corner of the Los Gatos Quadrangle and is separated from the Sierra Azul Block by the San Andreas Fault. The basement complex of the La Honda Block is not exposed in the Los Gatos Quadrangle. The exposed Tertiary rocks consist of a thick section of Eocene through Pliocene strata. The total thickness of the Tertiary strata is as much as 6 km (McLaughlin and others, 2001). The following units of the La Honda Block are exposed in the Los Gatos Quadrangle.

Two members of the Butano Sandstone of Eocene age are exposed in the Los Gatos Quadrangle: an undivided sandstone and mudstone member (Tbu) and a mudstone member (Tbm) (McLaughlin and others, 2001). The undivided sandstone and mudstone member (Tbu) consists of yellowish-gray, fine-to medium-grained arkosic sandstone with thin interbeds of olive-gray mudstone and shale. This unit also includes a lower unit of dark gray, nodular mudstone interbedded with thin- to thick-bedded arkosic sandstone. The mudstone member (Tbm) consists of thin-bedded nodular mudstone with interbedded thin- to thick-bedded arkosic sandstone.

Two members of the San Lorenzo Formation of Oligocene to Eocene age are exposed in the Los Gatos Quadrangle: the Twobar Shale Member (Tst) and the Rices Mudstone Member (Tsr) (McLaughlin and others, 2001). The Twobar Shale Member consists of thin-bedded to laminated shale with lenses and laminae of very fine arkosic sandstone. The Rices Mudstone Member consists of nodular light gray mudstone that is locally bioturbated and glauconitic.

The Vaqueros Formation (Tv) of lower Miocene and Oligocene age consists of thick-bedded to massive, yellowish-gray, fine- to coarse-grained arkosic sandstone with a thick bed of glauconitic sandstone in the lower part (McLaughlin and others, 2001). Locally, the Vaqueros Formation also contains basalt flows (Tvb) near the base of the unit.

The Purisima Formation (Tp) of upper Miocene and Pliocene age consists of thick-bedded to massive, bluish-gray, fine- to medium-grained sandstone and very thick-bedded, yellowish-gray, tuffaceous and diatomaceous siltstone (McLaughlin and others, 2001).

Sierra Azul Block

The Sierra Azul Block is composed of a sequence of ophiolitic rocks and marine Mesozoic through early Tertiary strata. It overlies the New Almaden Block, which is exposed north of the Sierra Azul Block. The boundary between the Sierra Azul Block and the New Almaden Block consists of a series of faults that are superimposed on the Coast Range Thrust (McLaughlin and others, 2001), which separates basal ophiolitic rocks of the Sierra Azul Block from Franciscan Complex rocks of the New Almaden Block. An outlier of the Sierra Azul Block underlies a small area in the northeastern part of the Los Gatos Quadrangle and extends farther northeast into the Santa Theresa Hills Quadrangle. The San Andreas Fault bounds the Sierra Azul Block on the southwest and juxtaposes it against the La Honda Block. The following units of the Sierra Azul Block are exposed in the Los Gatos Quadrangle.

The Coast Range Ophiolite of Jurassic age includes several units mapped in the Los Gatos Quadrangle by McLaughlin and others (2001). Serpentinized ultramafic rocks (Jos) consist of serpentinized and extensively sheared peridotite, harzburgite and ultramafic cumulates. A separately mapped ultramafic cumulate unit (Jou) consists of layered ultramafic rocks with a cumulate texture that contain some residual plagioclase but are mostly partially to extensively serpentinized pyroxene and olivine. Gabbro cumulates (Jog) consist of layered gabbro with pyroxene-feldspar segregation layering. Intrusive complexes (Joi) consist of dioritic and diabasic sheeted dikes. Basalt, andesite and dacite (Jov) consist of spilitic pillow basalt and dacite flows along with breccia and tuff.

Two additional Jurassic volcanic units are present in the Mount Umunhum area (McLaughlin and others, 2001). Diabase breccia of Mount Umunhum (Jdb) consists of angular clasts of diabase and diorite derived from underlying dikes and sills of Coast Range Ophiolite. Altered tuff of Mount Umunhum (Jt) consists of deeply weathered, hydrothermally altered tuffaceous volcanic rocks.

Great Valley Sequence rocks of Cretaceous and Jurassic age overlie the Coast Range Ophiolite. Mudstone (KJm) consists of dark gray to green, locally siliceous argillite and mudstone with minor thinly interbedded lithic arkosic wacke. Conglomerate (Kuc) consists of massive to thick-bedded lenses of pebble to boulder conglomerate that is interbedded with basal beds of overlying sandstone and shale. Sandstone and shale (Kus) consists of arkosic to feldspathic wacke, rhythmically interbedded dark gray to green shale and an upper zone of massive shale with carbonate concretions (McLaughlin and others, 2001).

Mottled mudstone and sandstone of Mount Chual (Tcm) of lower Eocene age is the oldest Tertiary unit in the Sierra Azul Block. This unit consists of maroon red to olive green mudstone locally containing glauconitic, bioclastic, conglomerate and lithic sandstone at the base. In the northeastern part of the quadrangle, this unit contains lenticular limestone bodies (Tcml) consisting of reworked bioclastic debris. These limestone lenses may be submarine slide blocks (McLaughlin and others, 2001).

Sandstone and shale of Loma Chiquita Ridge (Tls) of Eocene age is exposed in the southeastern part of the Los Gatos Quadrangle (McLaughlin and others, 2001). This unit consists of thick- to thin-bedded, locally pebbly, quartzo-feldspathic and arkosic sandstone and interbedded micaceous, carbonaceous mudstone.

New Almaden Block

The New Almaden Block underlies the Sierra Azul Block and is separated from it by a system of faults superimposed on the Coast Range Thrust. The New Almaden Block has a basement consisting of rocks of the Franciscan Complex that are tectonically interleaved with rocks of the Coast Range Ophiolite. The basement is overlain by Miocene marine strata and by Pliocene and Pleistocene fluvial strata. Miocene and later strata have been deformed by reverse faulting along the Sargent, Berrocal and Shannon fault zones (McLaughlin and others, 2001).

McLaughlin and others (2001) have mapped units from three lithologic terranes of the Franciscan Complex in the Los Gatos Quadrangle. These terranes include the melange of the Central Belt Terrane, the Marin Headlands Terrane and the Permanente Terrane.

The melange of the Central Belt Terrane (fm) of Upper Cretaceous age consists of a matrix of penetratively sheared argillite and lithic metasandstone. This matrix encloses blocks and slabs of various rock types that range from less than a meter to more than a kilometer in diameter. Larger blocks mapped in the Los Gatos Quadrangle include blueschist (bs), amphibolite (am), chert (ch) and basaltic volcanic rocks (v) (McLaughlin and others, 2001).

Three units of the Marin Headlands Terrane are exposed in the Los Gatos Quadrangle (McLaughlin and others, 2001). Sandstone (fms) consists of coherent, locally conglomeratic lithic graywacke. Radiolarian chert (fmc) consists of red to green radiolarian chert. Basaltic volcanic rocks (fmv) consist of massive to pillow basalt flows with minor tuff and breccia.

Two units of the Permanente Terrane are exposed in the Los Gatos Quadrangle (McLaughlin and others, 2001). Foraminiferal limestone (fpv) consists of pelagic gray, gray-green, black and pink foraminiferal limestone and minor black to gray nodular to lenticular radiolarian chert. Volcanic rocks (fpv) include pillow basalt flows, flow breccias and andesitic tuff.

Serpentinized ultramafic rocks (Jos) are complexly interleaved with the melange in the Franciscan Complex. These rocks are intensively sheared and are considered to be related to the ophiolitic basement rocks of the Sierra Azul Block described above (McLaughlin and others, 2001).

The oldest Tertiary unit in the New Almaden Block is the Temblor Sandstone (Tt) of middle Miocene to possibly Oligocene age. This unit consists of pebbly, lithic arkosic sandstone and fossiliferous conglomerate. The Temblor Sandstone locally contains volcanic and intrusive rocks (Ttv) of dacitic composition (McLaughlin and others, 2001).

The Monterey Shale (Tms) of middle to early Miocene age consists of siliceous mudstone, diatomite and porcellanite (McLaughlin and others, 2001).

An unnamed sandstone (Tus) of middle Miocene or younger age locally overlies the Monterey Shale. This unit consists of quartzo-feldspathic sandstone or lithic arkose (McLaughlin and others, 2001).

Silica carbonate rock (sc) consists of siliceous and calcareous deposits resulting from hydrothermal alteration of serpentinite. This rock is most abundant in the vicinity of the New Almaden mercury mines (McLaughlin and others, 2001).

Structural Geology

The bedrock units in the Los Gatos Quadrangle have undergone a complex structural history and are strongly deformed by faults and folds of various ages. As discussed in the previous section, the bedrock units in the Los Gatos Quadrangle are separated into three bedrock structural blocks, each of which has undergone a separate depositional and deformational history (McLaughlin and others, 2001).

The thick Tertiary sequence of the La Honda Block has been compressed into several northwest-trending folds, including the Summit Syncline and the Laurel Anticline, that extend into the southwest corner of the Los Gatos Quadrangle. Beds on the limbs of these folds mostly dip moderately to steeply to the northeast and southwest. The San Andreas Fault Zone forms the northeastern boundary of the block and cuts younger Pleistocene and Holocene terrace deposits in the fault zone. Surface rupture along this section of the San Andreas Fault occurred in both the 1906 San Francisco and 1989 Loma Prieta earthquakes. The San Andreas Fault Zone is up to two kilometers wide in this area and consists of a complex zone of right-lateral faulting. A number of gigantic intact landslide blocks are present in the La Honda Block adjacent to the San Andreas Fault.

The Sierra Azul Block is bounded by several late Cenozoic faults that are superimposed on the older Coast Range Fault. McLaughlin and others (2001) suggest that these faults are attenuation faults that developed within the older Coast Range Fault system during uplift and unroofing of the underlying Franciscan Complex. These bounding faults, which include the Aldercroft, Soda Springs and Sierra Azul faults, partially extend into the interior of the Sierra Azul Block as well as into the adjacent New Almaden Block. The Sierra Azul Block also is transected by several northwest-trending reverse faults. There are few consistent bedding trends shown on the geologic map in the Sierra Azul Block.

The New Almaden Block has been warped by northeast-southwest compression into broad antiformal and synformal structures. The axes of these structures are east of the Los Gatos Quadrangle. Within the Los Gatos Quadrangle, Miocene and younger strata have been tilted and folded by reverse faulting along the Berrocal and Sargent faults since middle Pleistocene time (McLaughlin and others, 2001). In addition, movement along the Lexington Fault near Lexington Reservoir has displaced the Santa Clara Formation and possibly the overlying terrace deposits. There are few consistent bedding trends shown on the geologic map in the New Almaden Block.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Los Gatos Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping (Dibblee, 1949; Rogers, 1972; Dibblee and Brabb, 1978; USGS Staff, 1989; Spittler and Harp, 1990; McNutt and Sydnor, 1990; Ponti and others, 1990; Bryant, 1991; McLaughlin and others, 1991; Prentice and Schwartz, 1991; Ponti and Wells, 1991; Manson and others, 1992; Martosudarmo and others, 1997; Keefer and others, 1998; Nolan and Weber, 1998; Nolan Associates, 1999; and McLaughlin and others, 2001). 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. The completed hand-drawn landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

Landslides are most abundant in the south-southwestern part of the Los Gatos Quadrangle, where the Franciscan Complex rocks have been deformed by folding and faulting along the San Andreas Fault Zone. The areal distribution of landslides identified in the map area is shown on Plate 2.1. Numerous large, deep-seated landslides occur in the Vaqueros and San Lorenzo formations directly adjacent to the San Andreas Fault Zone, east of the crest of the Santa Cruz Mountains and west of Lexington Reservoir. Some of these landslides appear to be several hundred feet deep and up to 400 feet wide. Several landslides were partially reactivated during the 1989 Loma Prieta earthquake. It appears that the toes of some of the landslides on this slope have been offset or truncated by the San Andreas Fault.

The central part of the quadrangle does not contain as many landslides as the slopes directly adjacent to the San Andreas Fault. The landslides in this area range from minor surficial failures resulting from soil and rock creep, rock fall, and debris flows to large rotational and translational landslides. Three areas in the central part of the quadrangle contain large landslide complexes. The slopes of Mt. Umunhum, the mouth of Soda Spring Canyon, and the area known as Aldercroft Heights contain several large landslide complexes developed in Coast Range Ophiolite and Franciscan rocks.

The northern part of the quadrangle, where the Santa Cruz Mountains meet the Santa Clara Valley, has relatively few landslides, most of which are moderate to deep-seated translational landslides. The landslides in this area also primarily occur within the Franciscan Complex, with a few landslides on Blossom Hill occurring within Monterey Shale.

The top of Summit Road Ridge contains numerous anomalous geomorphic features, many of which exhibited surface ground cracking caused by the 1989 Loma Prieta earthquake. None of the surface cracks are attributed to surface fault rupture on the San Andreas or nearby faults but are believed to be a result of ridge top spreading (Ponti and others, 1990; Ponti and Wells 1991; Prentice and Schwartz, 1991). Where cracks associated with the 1989 Loma Prieta earthquake cannot be directly attributed to recognized landslides, these cracks and anomalous ridge top features are included within an area described as "rock spread" in the landslide inventory. This area of "rock spread" was not carried into the slope stability analysis due to the uncertainty associated with characterizing the geometry of these features. However, this area of rock spread may represent a seismic hazard. Accordingly, careful analysis is recommended for development in this area.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear strength measurements is geotechnical reports prepared by consultants that are on file with local government permitting departments or with their reviewing geotechnical consultants. Shear-strength data for the rock units identified on the Los Gatos Quadrangle geologic map were obtained from the counties of Santa Clara and Santa Cruz, the cities of Los Gatos and San Jose and offices of Cotton, Shires and Associates, Inc, geotechnical reviewers for the cities of Saratoga and Cupertino (see Appendix A). The locations of rock and soil samples taken for shear testing within the Los Gatos Quadrangle are shown on Plate 2.1. Shear tests from the adjoining Cupertino, Castle Rock Ridge, Laurel and San Jose East quadrangles were used to augment data for several geologic formations for which little or no shear test information was available within the Los Gatos Quadrangle.

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

The Butano Sandstone (Tb), was subdivided further, as discussed below.

Adverse Bedding Conditions

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

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

The Butano Sandstone (Tb), which contains interbedded sandstone and shale, was subdivided based on shear-strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. The geologic material strength map was modified by assigning the lower, fine-grained shear strength value to areas where adverse bedding was identified. The favorable and adverse bedding shear strength parameters for the Butano Sandstone are included in Table 2.1.

Existing Landslides

The strength characteristics of existing landslides (Qls) should be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used.

Within the Los Gatos Quadrangle no shear tests of landslide slip surfaces were available. The phi value selected to characterize the landslide areas for this study is 12 degrees. This value is based on a shear test of a slip surface in the Penetencia Creek landslide on the east side of the City of San Jose, and from published residual shear test results for samples obtained from the Santa Clara Formation in the Town of Saratoga (Nelson, 1992).

LOS GATOS QUADRANGLE SHEAR STRENGTH GROUPS

	Formation Name	Number of Tests	Mean/Median Phi (degrees)	Mean/Median Group Phi (degrees)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Tbu(fbc)	9	36	34	656/444	Jdb	34
	Jov	4	35/36			Jog	
	fm	17	34/35			Joi	
	Tv	27	34/32			Kuc	
						Kus	
						Ttv	
						am	
						bs	
						ch	
						v	
GROUP 2	fpv	14	33/31	32/31	800/599	Jou	31
	fms	8	31/30			Jt	
	Qp	39	32/31			KJm	
						Tcm	
						Tcml	
						Tls	
						Tp	
						dbm	
						fmc	
						fmv	
						fpl	
						sc	
GROUP 3	Jos	33	28/24	28/26	709/523	af	28
	Tst	6	27				
	Qh	18	27/29				
GROUP 4	QTsc	114	27/25	26/25	1009/797	Tus	25
	Tm	34	26/25				
	Tsr	8	26				
	Tt	4	25/26				
	Tbm	5	25/28				
	Tbu(abc)	13	25/24				
GROUP 5	Qls	1	12	12	745		12
	fbc = favorable bedding conditions						
	abc = adverse bedding conditions						
	Formations for strength groups from McLaughlin and others, 2001						

Table 2.1. Summary of the Shear Strength Statistics for the Los Gatos Quadrangle.

SHEAR STRENGTH GROUPS FOR THE LOS GATOS 7.5-MINUTE QUADRANGLE				
GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Tbu(fbc)	fpv	Jos	QTsc	Qls
Jov	fms	Tst	Tm	
Fm	Qp	Qh	Tsr	
Tv	Jou	af	Tt	
Jdb	Jt		Tbm	
Jog	KJm		Tbu (abc)	
Joi	Tcm		Tus	
Kuc	Tcml			
Kus	Tls			
Ttv				
am	Tp			
bs	dbm			
ch	fmc			
v	fmv			
	fpl			
	fc			

Table 2.2. Summary of Shear Strength Groups for the Los Gatos 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 is used to analyze dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the "ground shaking opportunity." For the Los Gatos Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by CGS for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	7.9
Modal Distance:	2.9-14 km
PGA:	0.59-0.94g

The strong-motion record selected for the slope stability analysis in the Los Gatos Quadrangle was the Southern California Edison Lucerne record from the 1992 magnitude 7.3 Landers, California earthquake. This record had a source to recording site distance of 1.1 km and a peak ground acceleration (PGA) of 0.80g. 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 were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a 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 0.142g, 0.182g and 0.243g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Los Gatos Quadrangle.

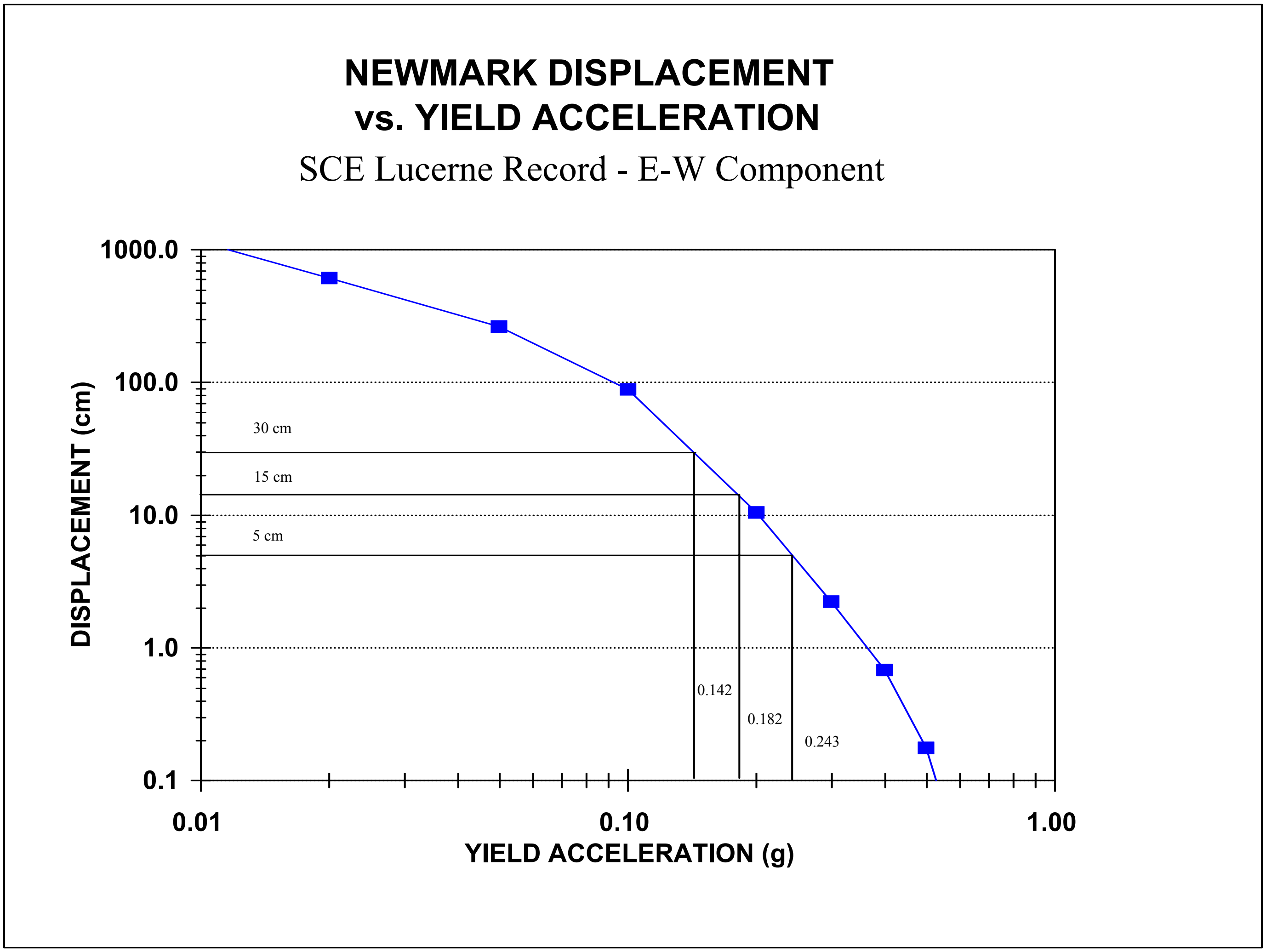

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Lucerne Record from the 1992 Landers Earthquake.

Slope Stability Analysis

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

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

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

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

1. If the calculated yield acceleration was less than 0.142g, 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 0.142g and 0.182g, 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 0.182g and 0.243g, 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 2.42g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

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

LOS GATOS QUADRANGLE HAZARD POTENTIAL MATRIX								
		SLOPE CATEGORY (% SLOPE)						
Geologic Material Group	MEAN PHI	I	II	III	IV	V	VI	VII
		0-21%	21-29%	29-34%	34-42%	42-49%	49-53%	> 53%
1	34	VL	VL	VL	VL	L	M	H
2	31	VL	VL	VL	L	M	H	H
3	28	VL	VL	L	M	H	H	H
4	25	VL	L	M	H	H	H	H
5	12	M	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Los Gatos Quadrangle. Shaded area indicates hazard potential levels included within the earthquake-induced landslide hazard zone. H = High, M = Moderate, L = Low, VL = Very Low.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.

2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by 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 21 percent.

3. Geologic Strength Group 3 is included for all slopes steeper than 29 percent.

4. Geologic Strength Group 2 is included for all slopes steeper than 34 percent.

5. Geologic Strength Group 1 is included for all slopes greater than 42 percent.

This results in approximately 75 percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the Los Gatos Quadrangle.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project: Jim Baker with the County of Santa Clara, Suzanne Davis and Bud Lortz with the Town of Los Gatos, Michael Shimamoto with the City of San Jose, and Bill Cotton, Bill Cole, Ted Sayre and the staff of Cotton, Shires and Associates, Inc. Jim Baker and Cotton, Shires and Associates provided helpful review comments of the preliminary map that resulted in changes that are incorporated in the official map. At CGS, Terilee McGuire, Lee Wallinder and Bob Moscovitz provided GIS support. Luis Acedo assisted in data entry and geologic technical support. Barbara Wanish and Ross Martin prepared the final landslide hazard zone maps and the graphic displays for this report.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of San Jose	25
County of Santa Clara	89
County of Santa Cruz	72
Town of Los Gatos	28
California Geological Survey Hospital and School Review Program	2
California Department of Transportation	10
Cotton, Shires and Associates, Inc. review files for cities of Saratoga and Cupertino	128

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Los Gatos 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/webdocs/sp117.pdf

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (California Department of Conservation, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://www.conservation.ca.gov/CGS/index.htm

EARTHQUAKE HAZARD MODEL

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

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

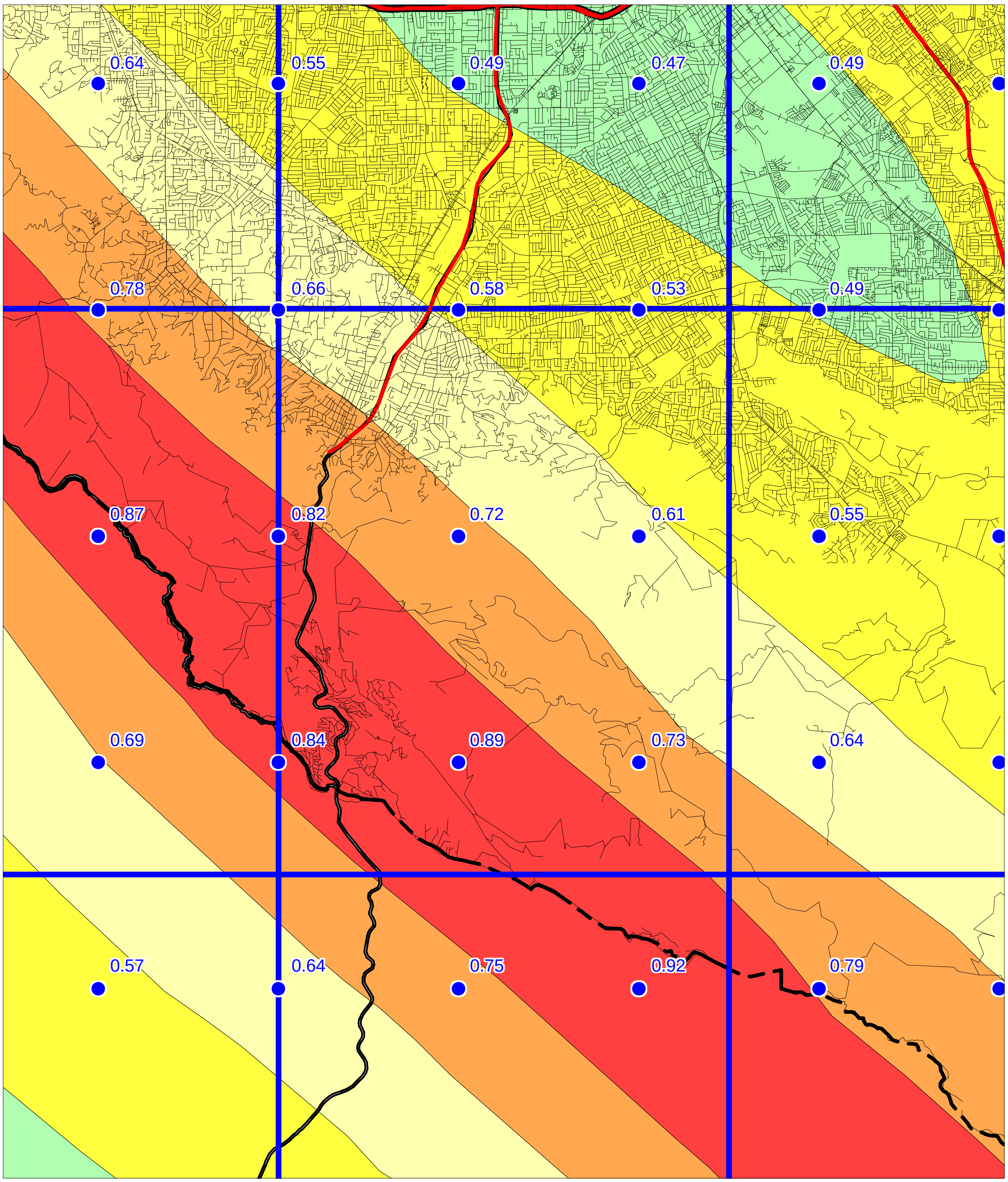
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

LOS GATOS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

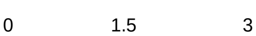
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation



Department of Conservation
California Geological Survey

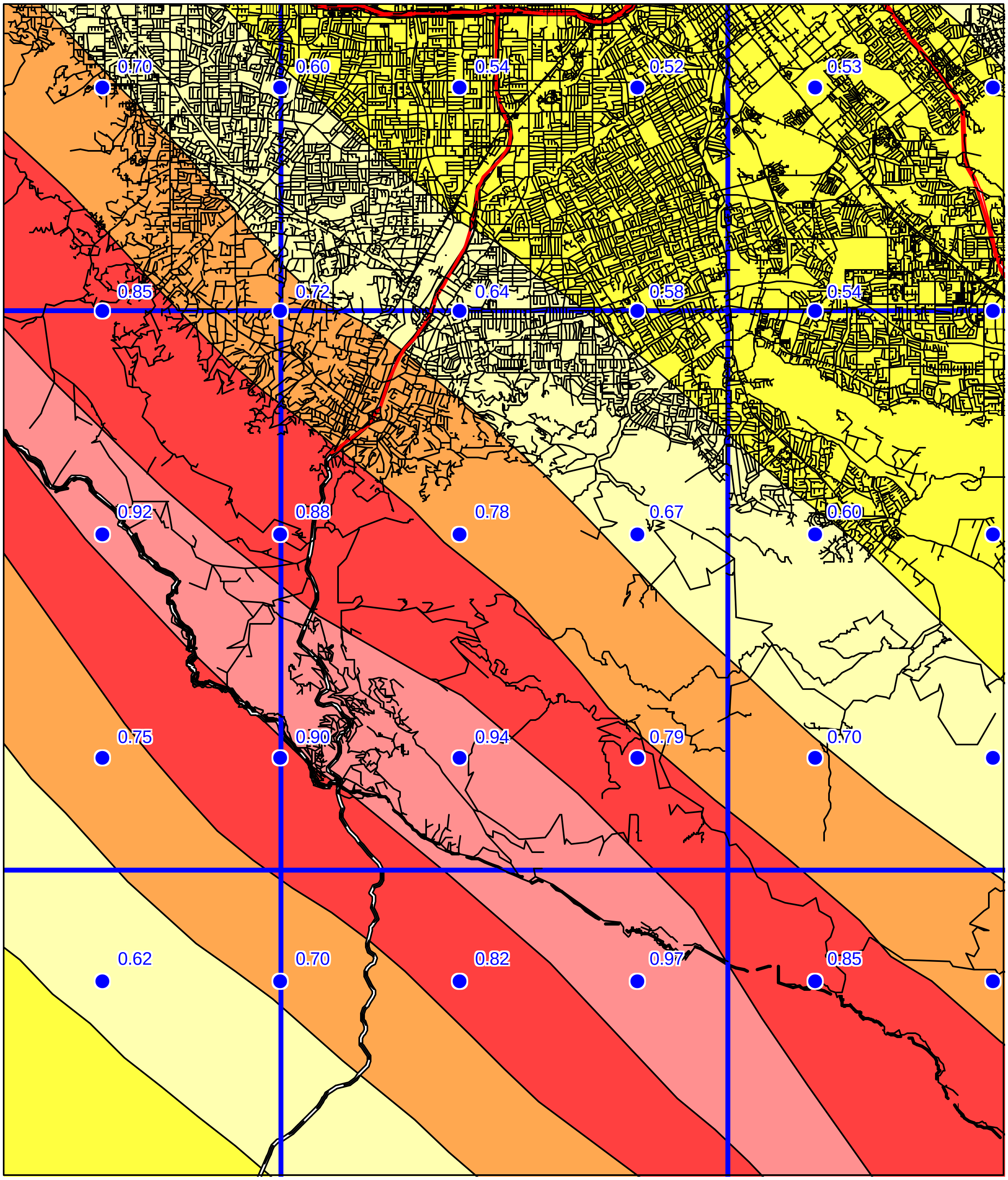
Figure 3.1

LOS GATOS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

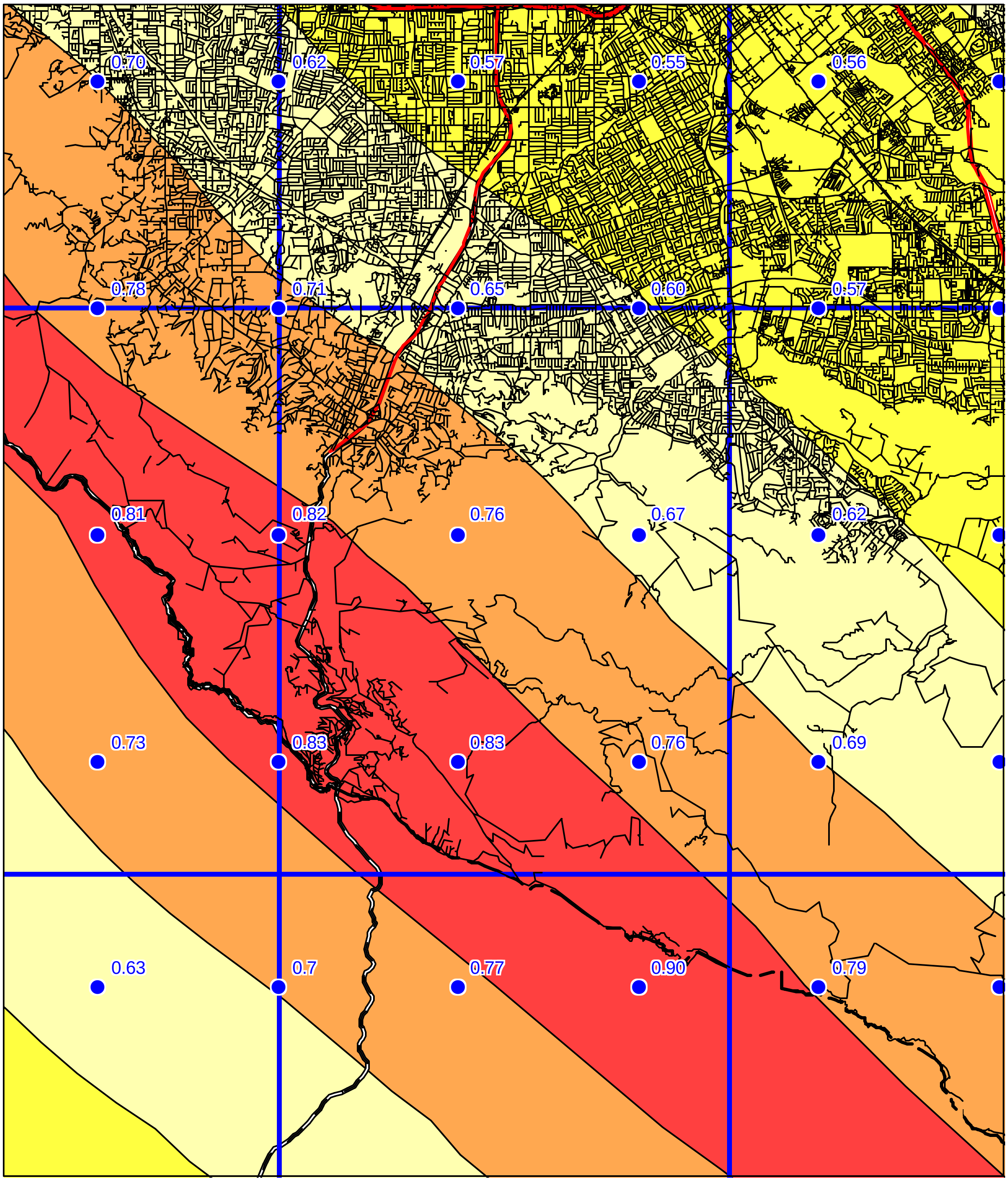
Figure 3.2

LOS GATOS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



0 2.5 5

Kilometers

Department of Conservation
California Geological Survey

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.

LOS GATOS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

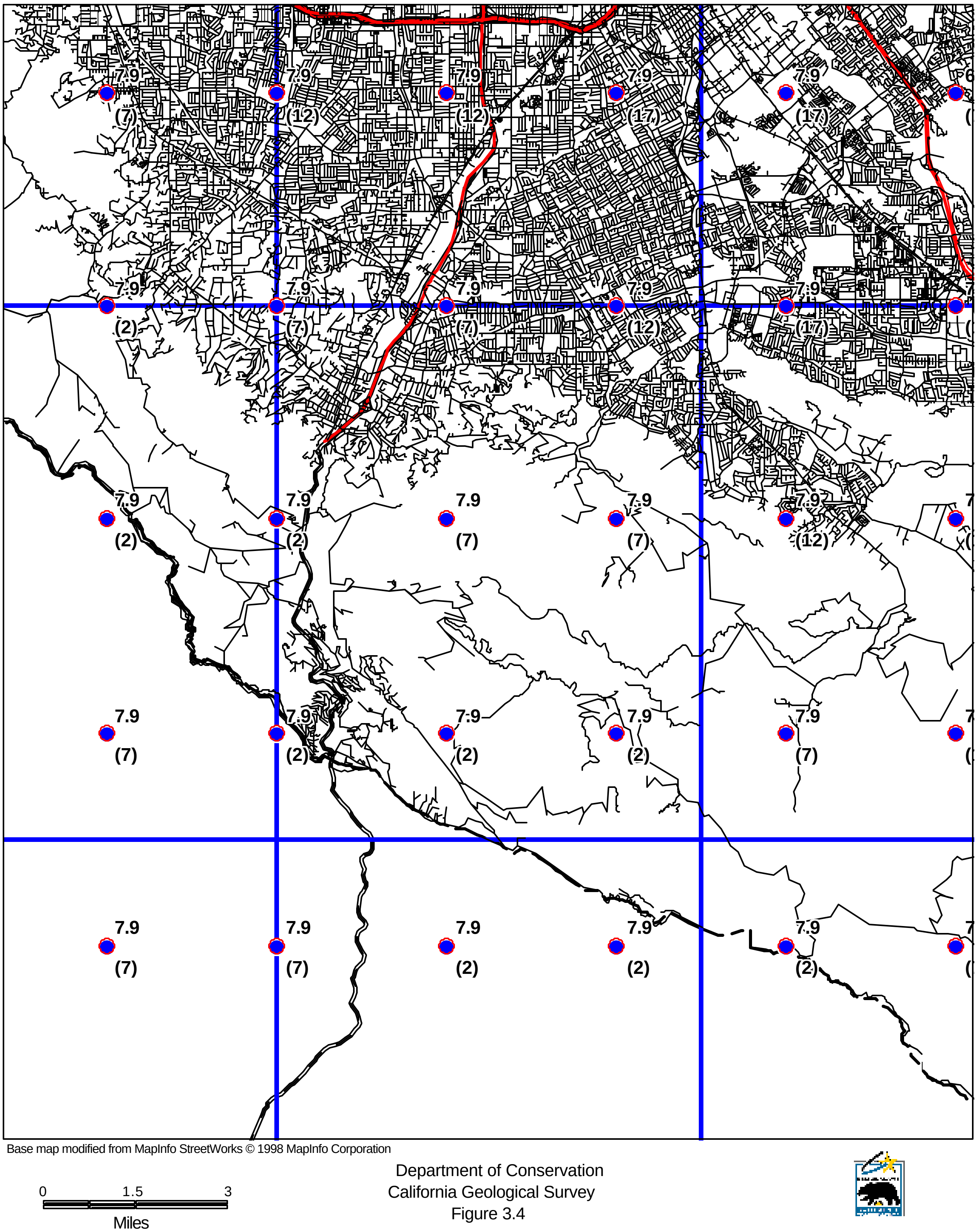
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)

(Distance (km))



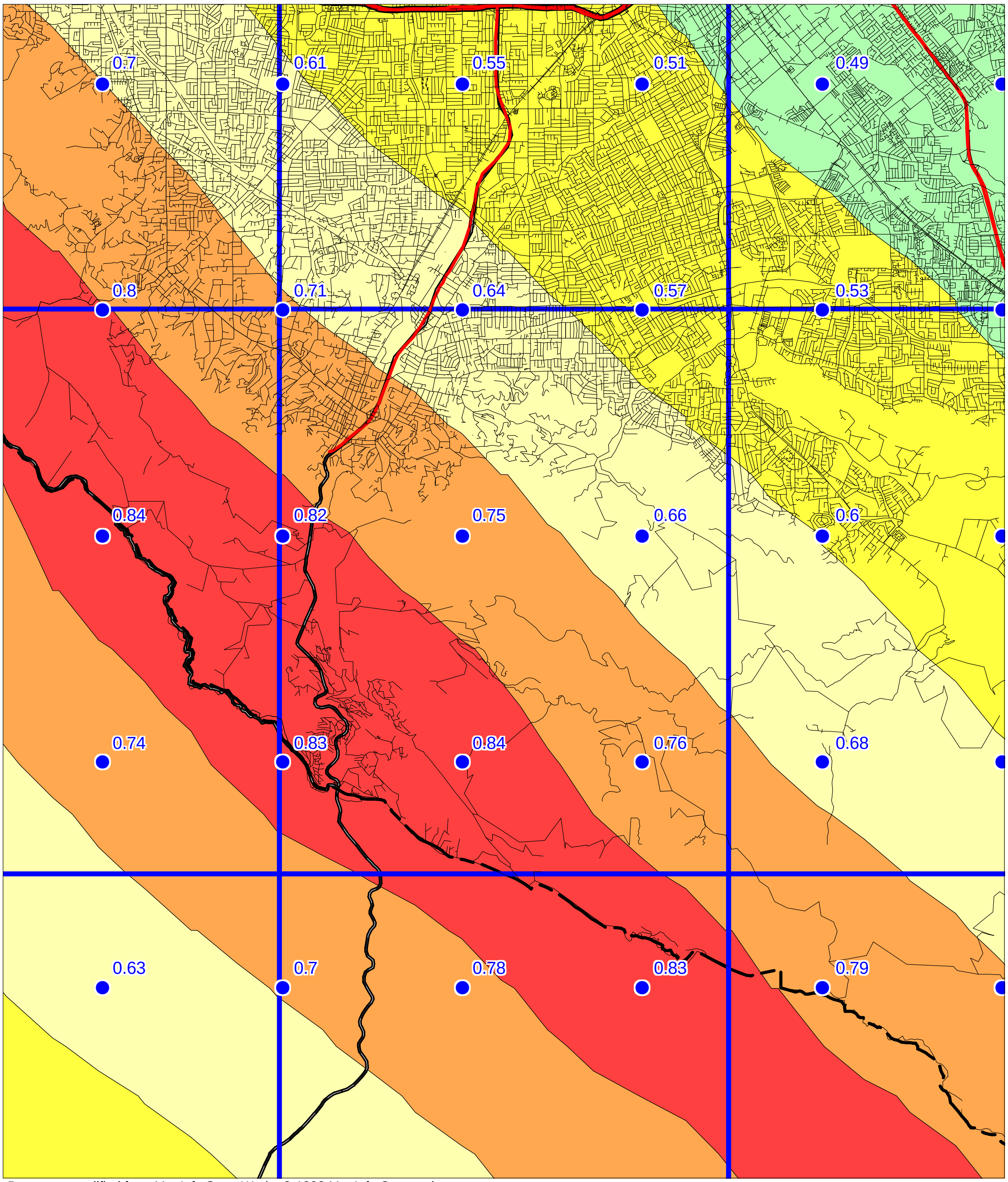
Department of Conservation
California Geological Survey
Figure 3.4

LOS GATOS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

LIQUEFACTION OPPORTUNITY



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3

Miles

Department of Conservation
California Geological Survey

Figure 3.5

USE AND LIMITATIONS

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

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

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

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

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

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

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

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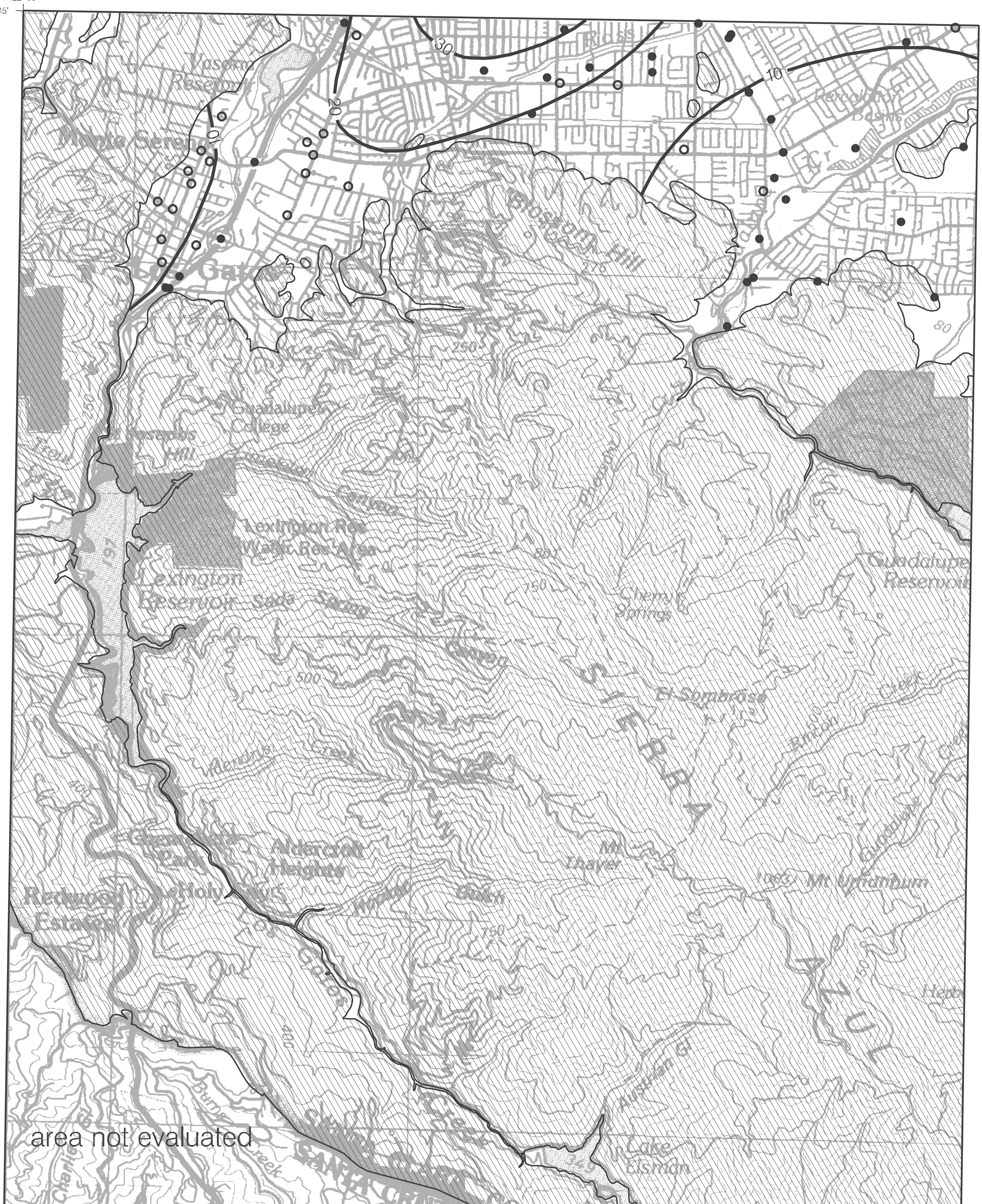
122° 00'
37° 15'



37° 07' 30"
121° 52' 30"

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

LOS GATOS QUADRANGLE

SCALE

1 .5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

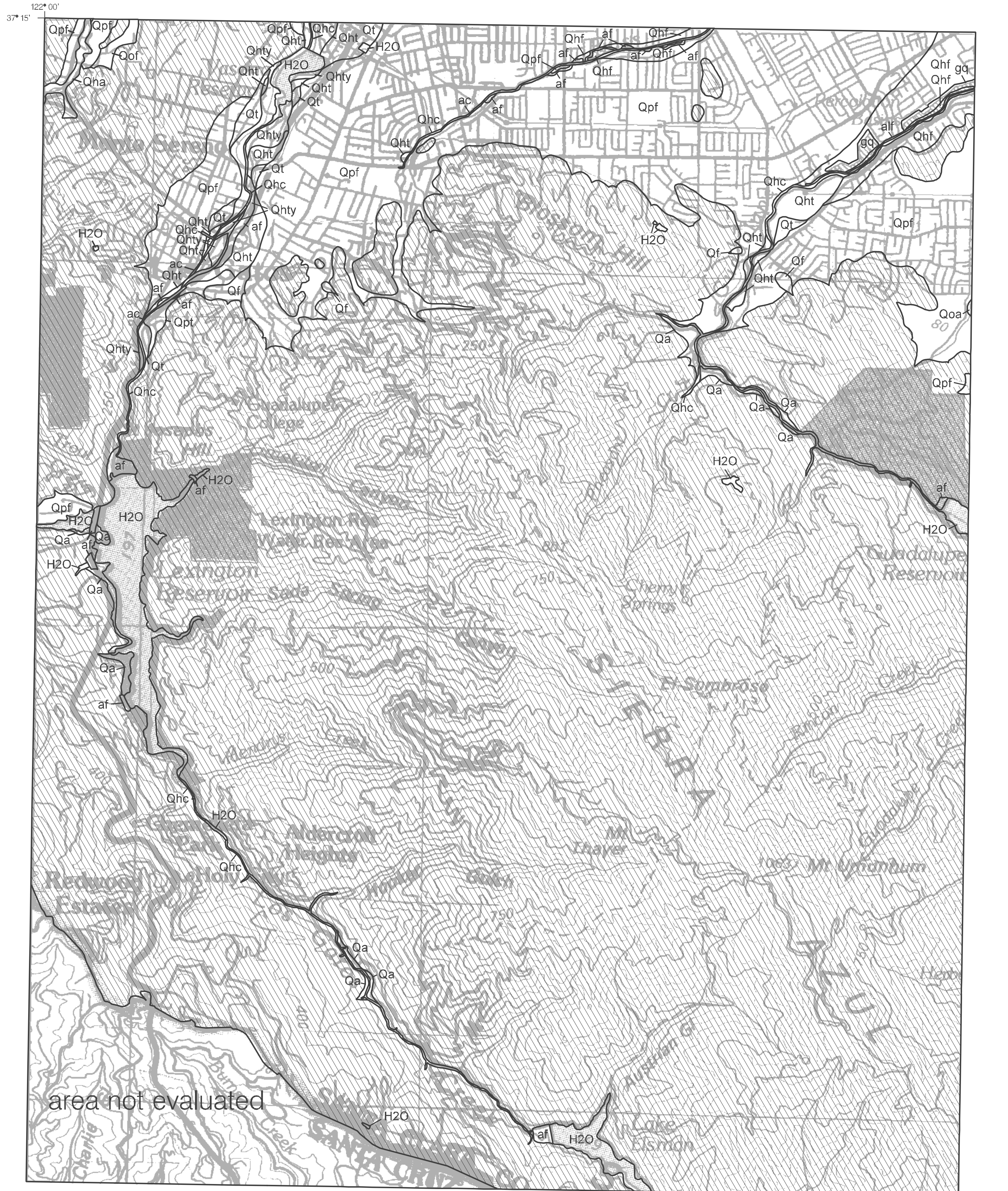
Pre–Quaternary bedrock and Santa Clara Formation (QTsc)

10 — Depth to ground water, in feet

● Geotechnical borings 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 and locations of boreholes used in liquefaction and ground-water analyses, Los Gatos 7.5-minute Quadrangle, California.



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

LOS GATOS QUADRANGLE

SCALE

1 .5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

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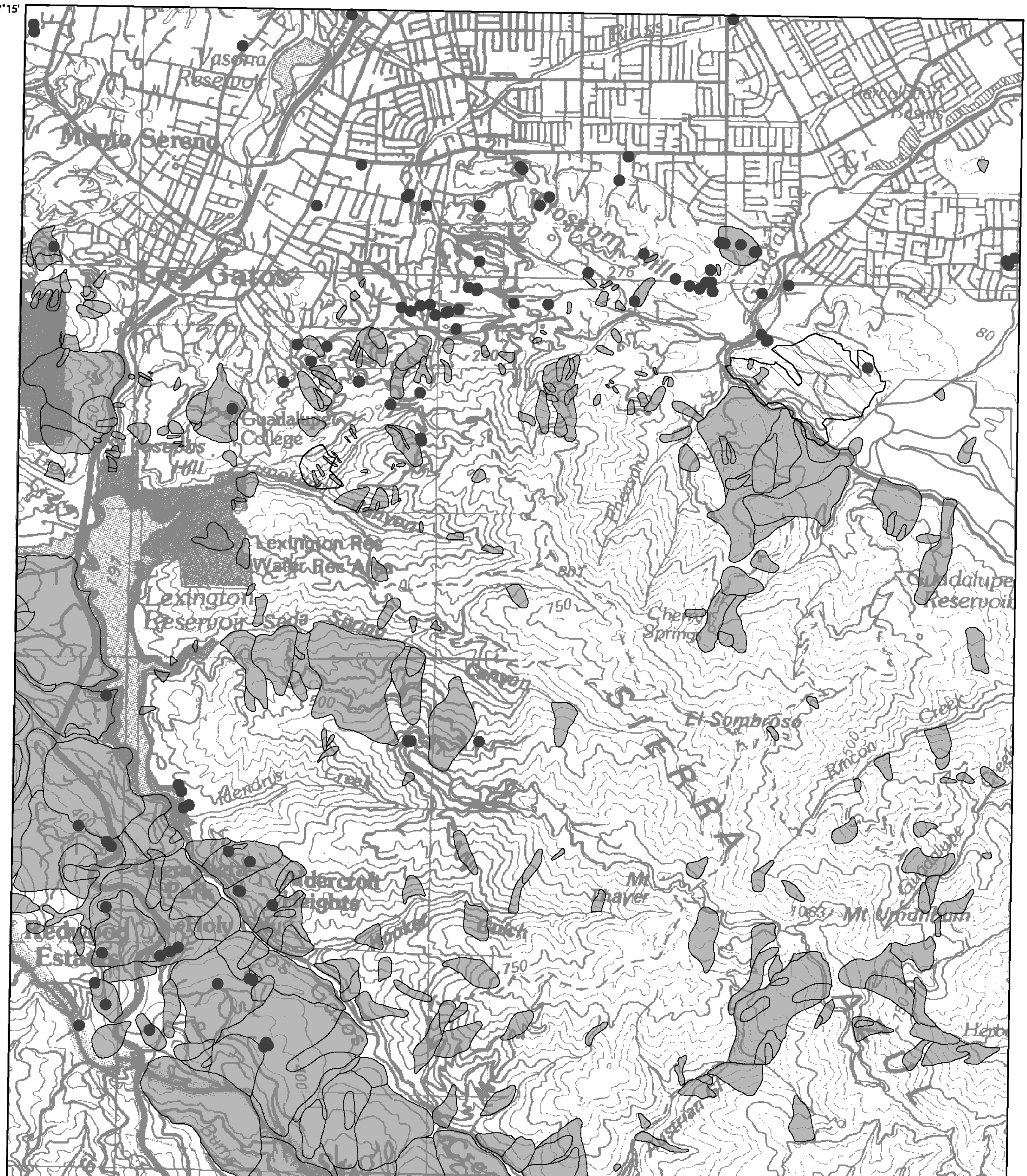
Lithologic contact

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 Los Gatos 7.5-minute Quadrangle, California. *Modified from Knudsen, K.L., unpublished.*



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

LOS GATOS QUADRANGLE

SCALE

1 .5 0 1 MILE

1000 0 2000 4000 6000 FEET

1 .5 0 1 KILOMETER

N

● Shear test sample location — Landslide — Area of significant grading

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