SEISMIC HAZARD ZONE REPORT 097

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

2003

DEPARTMENT OF CONSERVATION
California Geological Survey

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5/27/05	BPS address corrected, web link updated
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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 Santa Teresa Hills 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 62 square miles at a scale of 1 inch = 2,000 feet.

The City of San Jose is the only incorporated city within the quadrangle, which lies at the southern end of the Santa Clara Valley. The rest of the quadrangle is hilly Santa Clara County land. The Santa Teresa Hills define the southern margin of the Santa clara Valley in the northern third of the quadrangle. The Santa Cruz Mountains lie in the southern half of the quadrangle. From north to south elevations range from about 160 feet to more than 3,000 feet. Coyote Creek on the east and Alamitos Creek on the west flow toward San Francisco Bay. U.S. Highway 101 traverses the northeastern corner of the map area and the Almaden Expressway runs from the northwest corner into the central part. Significant development has occurred on the gently sloping lands in the northern and west-central parts of the quadrangle.

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

In the Santa Teresa Hills Quadrangle the liquefaction zone of required investigation covers the Santa Clara Valley floor, the lowlands along Coyote Creek, Alamitos Creek and its tributary in the Arroyo Calaro, and the bottoms of several other creek canyons. Approximately 56 percent of the Santa Teresa Hills Quadrangle lies within the earthquake-induced landslide zone of required investigation. Almost all of the zoned areas fall within the hills and mountains, with virtually none within the Santa Clara Valley and just a few small zoned areas in the Almaden Valley.

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 percent 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 Santa Teresa Hills 7.5-Minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

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

By
Jacqueline D. J. Bott 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 Santa Teresa Hills 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 some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard especially in land marginal to the bay and along some of the larger creeks, including areas in the Santa Teresa Hills 7.5-Minute Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill

- Construction of shallow ground-water maps showing the historically highest known ground-water levels

- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits

- Information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Santa Teresa Hills Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. 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 of require investigation 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 Santa Teresa Hills 7.5-Minute Quadrangle covers approximately 60 square miles at the southern margin of the Santa Clara Valley. The City of San Jose, which lies in the gently sloping northern third of the map, is the only incorporated city within the quadrangle. The rest of the quadrangle is hilly and under the jurisdiction of Santa Clara County. The northwest-trending Santa Teresa Hills define the southern margin of the Santa Clara Valley. The hills separate the Santa Clara Valley and Coyote Creek watershed, which emanates from the hills on the eastern side of the valley, from the Almaden Valley and Alamitos Creek watershed, which lie south and west of the hills. A small part of the Diablo Range extends into the northeast corner of the quadrangle. Elevations within the quadrangle range from about 160 feet in the north to more than 3,000 feet in the south.

The Santa Cruz Mountains occupy the southern half of the quadrangle and are characterized by steep, forested slopes and high-gradient streams. Calero Reservoir, Almaden Reservoir and Guadalupe Reservoir are located within the mountainous southern half of the quadrangle. Major streams in the map area include Coyote Creek, Alamitos Creek and Llagas Creek. Coyote Creek cuts across the northeastern corner of the quadrangle and flows across the southern part of Santa Clara Valley. Alamitos Creek emanates from the Almaden Valley. Llagos Creek flows from the Santa Cruz Mountains and eventually joins the Pajaro River southeast of the map area. Numerous smaller streams also are present in the map area.

Highway 101 traverses the northeastern corner of the map in a northwesterly direction. The Almaden Expressway runs from the northwest corner of the map area into the central part. Significant development has occurred on the gently sloping lands in the northern part of the quadrangle and in the west-central part of the quadrangle over the past several decades. The 1953 version of the U.S. Geological Survey 7.5-minute quadrangle map shows that little construction had occurred anywhere in the quadrangle at the time and most of the gently sloping areas that are now developed were devoted to agriculture.

The map area includes the historic New Almaden quicksilver mining district, which was active for more than a century and, for a time, in the nineteenth century was the nation's largest mercury producer. The mining district is on the southwest side of the Almaden Valley and is now public parkland. The map area also includes several stone quarries that supplied building stone for some significant structures, including buildings on the Stanford University campus. Some of the quarried areas have been converted to residential developments and a golf course.

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 distribution of Quaternary deposits in the Santa Teresa Hills Quadrangle, bedrock mapping by McLaughlin and others (2001) was obtained from the U.S. Geological Survey in digital form and merged with unpublished mapping of Quaternary deposits by Keith Knudsen. These GIS maps were combined, with minor modifications along the bedrock/Quaternary contact, to form a single, 1:24,000-scale geologic map of the Santa Teresa Hills 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.

Additional geologic maps and reports were reviewed to evaluate the areal and vertical distribution of shallow Quaternary deposits and to acquire information on subsurface geologic, lithologic and engineering properties. Among the references consulted were: Crittenden (1951), State Water Resources Board (1955), 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), Geomatrix Consultants Inc. (1992), Helley and others (1994), Iwamura (1995), Wentworth and others (1998), and Knudsen and others (2000a). 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 Santa Teresa Hills Quadrangle, Knudsen (unpublished) identified about 20 Quaternary map units. The Quaternary geologic mapping methods used by Knudsen in the Santa Teresa Hills Quadrangle are the same as those described by Knudsen and others (2000a), 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, crosscutting 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 (2000a) and the CGS GIS database, with that of previous studies performed in northern California.

Holocene deposits underlie the rapidly urbanizing northern part of the quadrangle within the City of San Jose. The primary source of these deposits is the Coyote Creek watershed. Coyote Creek flows northwestward through the “Coyote narrows” east of the quadrangle boundary across the northeastern corner of the quadrangle. A low topographic saddle southeast of Tulare Hill (Plate 1.1) may have been an earlier location of Coyote Creek and an earlier manifestation of the “Coyote narrows.” Much of the sediment in the Coyote Creek system likely is derived from rocks in the hills to the east of the stream. Rock types in this area primarily consist of Jurassic and Cretaceous sedimentary and metamorphosed sedimentary rocks, Coast Range Ophiolite, Pliocene

Silver Creek gravels and Plio-Pleistocene Packwood gravels (Wentworth and others, 1998; McLaughlin and others, 2001). These rock types, when eroded, may have led to the production of the abundant fine-grained sediment observed in Holocene deposits of the Santa Clara Valley. After Coyote Creek crosses through the Coyote narrows it flows onto the wide, gently north-northwestward-sloping southern margin of the Santa Clara Valley. Holocene alluvial fan (Qhf) and Holocene alluvial fan levee (Qhl) deposits underlie the valley in this vicinity. The area adjacent to Coyote Creek has Holocene and latest Holocene stream terrace deposits (Qht or Qhty) incised into the alluvial fan deposits. The north-central part of the quadrangle is underlain by fine-grained distal and/or low-gradient alluvial fan deposits that are mapped as Holocene alluvial fan deposits, fine-grained facies (Qhff) by Knudsen (unpublished). A drainage network was built in this area early in the 20th century (shown on a 15-minute topographic map from 1919), presumably to keep the fertile agricultural land from being too wet to farm. The Santa Teresa Hills may shed sediment to the north into this area, but these hills do not have very large watersheds or high-energy streams that flow to the north toward the valley floor.

Late Quaternary sediment in the northwestern part of the quadrangle is derived from the Alamitos Creek watershed, which is a smaller system than the Coyote Creek watershed. Rock types in the upland parts of this watershed primarily consist of Cretaceous and Jurassic Franciscan Complex melange and metagraywacke along with basaltic rocks of the Permanente Terrane (Wentworth and others, 1998; McLaughlin and others, 2001). Late Quaternary units mapped by Knudsen (unpublished) in the Almaden Valley include Holocene alluvial fan deposits (Qhf), Holocene stream terrace deposits (Qht), latest Pleistocene alluvial fan deposits (Qpf), and early to middle Pleistocene undifferentiated alluvium (Qoa). Higher in the watershed, undifferentiated latest Pleistocene to Holocene alluvium (Qa) is mapped by Knudsen (unpublished) adjacent to some of the larger creeks (Alamitos Creek and Arroyo Calero). Where Alamitos Creek flows past the northwestern tip of the Santa Teresa Hills and enters the Santa Clara Valley in the northwestern part of the quadrangle its nature changes. At this point the stream changes from one with inset Holocene stream terrace deposits to a broad alluvial fan setting with Holocene and latest Holocene alluvial fan levees.

UNIT	Knudsen and others (2000, unpublished)	Helley and others (1994)	McLaughlin and others (2001)	Wentworth and others (1998)	CGS GIS database
Artificial fill	af		af, md	af	af
Gravel quarries and percolation ponds	gq	PP,GP	gp, pp	PP,GP	gq
Artificial stream channel	ac				ac
Modern stream channel deposits	Qhc	Qhsc	Qhc	Qhc	Qhc
Latest Holocene alluvial fan levee deposits	Qhly				Qhly
Latest Holocene stream terrace deposits	Qhty				Qhty
Holocene basin deposits	Qhb	Qhb	Qhb	Qhb	Qhb
Holocene alluvial fan deposits	Qhf	Qhaf, Qhfp	Qhf, Qhfp	Qhf, Qhfp	Qhf
Holocene alluvial fan deposits, fine grained facies	Qhff				Qhff
Holocene alluvial fan levee deposits	Qhl	Qhl	Qhl	Qh1	Qhl
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	Qt	Qt
Late Pleistocene to Holocene alluvium, undifferentiated	Qa		Qal	Qa	Qa
Late Pleistocene alluvial fan deposits	Qpf	Qpaf	Qpf	Qpf	Qpf
Late Pleistocene stream terrace deposits	Qpt				Qof
Early to middle Pleistocene undifferentiated alluvial deposits	Qoa		Qoa, Qpf	Qoa	Qoa
bedrock	B	B			B

Table 1.1. Correlation Chart of Quaternary Stratigraphic Nomenclatures Used in Previous Studies. For this study, CGS has adopted the nomenclature of Knudsen and others (2000a).

The geologic map by McLaughlin and others (2001) that was used for bedrock mapping in this project identifies three individual stratigraphic assemblages that lie within discrete fault-bounded bedrock structural blocks in southwestern Santa Clara County and the southern Santa Cruz Mountains. Two of these bedrock structural blocks extend into the Santa Teresa Hills Quadrangle. These are the Sierra Azul Block, which occupies the southwestern corner of the quadrangle and also is exposed as a fault-bounded outlier in the Santa Teresa Hills, and the New Almaden Block, which underlies the northeastern flanks of the Santa Cruz Mountains, portions of the Santa Teresa Hills and portions of the southwestern flank of the Diablo Range. See the Earthquake Induced Landslide portion (Section 2) of this report for additional descriptions of bedrock geology and geologic structure.

Structural Geology

The Santa Theresa Hills Quadrangle is within the active San Andreas Fault system, which distributes shearing across a complex group of primarily northwest-trending, right-lateral, strike-slip faults that include the San Andreas, Hayward, and Calaveras faults. The northwest-trending San Andreas Fault is about 8 km from the southwestern corner of the Santa Teresa Hills Quadrangle. The Calaveras Fault is about 7 km northeast of the northeastern corner of the quadrangle. The Berrocal and Sargent faults are about 3 km from the southwestern corner of the quadrangle. Historical ground surface-rupturing earthquakes have occurred on the San Andreas and Calaveras faults (Lawson, 1908; Keefer and others, 1980).

The Santa Teresa Hills Quadrangle area has undergone a complex structural history and is strongly deformed by faults and folds of various ages. As discussed in the previous section, the bedrock units in the Santa Teresa Hills Quadrangle are separated into two bedrock structural blocks, each of which has undergone a separate depositional and deformational history (McLaughlin and others, 2001). See the Earthquake Induced Landslide portion of this report (Section 2) for additional description of the structural setting.

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of flatland deposits was obtained from borehole logs collected from reports on geotechnical projects. For this investigation, about 85 borehole logs were collected from the files of the City of San Jose, Caltrans and Santa Clara County. Data from 83 borehole logs were entered into a CGS geotechnical GIS database (Table 1.1).

Standard Penetration Tests (SPTs) provide a standardized measure of the penetration resistance of geologic deposits and are commonly used as an index of soil density. This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil at the bottom of a borehole. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and

Materials in test method D1586 (ASTM, 1999). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts are normalized to a common-reference, effective-overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60 percent 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 and environmental borehole logs provided information on lithologic and engineering characteristics of Quaternary deposits within the study area. Geotechnical characteristics of the Quaternary map units are summarized in Table 1.2 and their composition by soil type is presented in Table 1.3. These tables reveal that:

- Holocene materials generally are less dense and more readily penetrated than Pleistocene materials;

- latest Pleistocene alluvial fan deposits (Qpf) have higher dry density and much higher penetration resistance than Holocene alluvial fan deposits (Qhf);

- latest Pleistocene alluvial fan deposits (Qpf) contain more gravel and are coarser than Holocene alluvial fan deposits (Qhf);

- Holocene alluvial units are predominantly fine grained, but have silt and sand lenses throughout that have the potential to liquefy; and

- most units have a wide range in their dry density and penetration resistance.

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	Mean	C (3)	Median	Min	Max	Number of Tests	Mean	C (3)	Median	Min	Max
af	ine	4	106.	.0	105.7	97	8	5	38	.9	29		9
	oars	0	-	-	-	-	-	1	35	-	-	.	-
Qhty	Fine	0	-	-	-	-	-	3	30	0.23	29	24	38
	Coarse	1	104.0	-	-	-	-	0	-	-	-	-	-
Qh	ine	3	72.2	.0	71.5	71	74	0	-	-	-	.	-
	oars	0	-	-	-	-	-	0	-	-	-	.	-
Qhf	Fine	80	104.4	0.08	105.0	87	119.7	143	17	0.74	14	3	93
	Coarse	10	103.5	0.07	109.0	91	110.2	24	15	0.51	12	6	36
Qh	ine	18	101.	.0	109.2	84.	7	16	17	.5	15		4
	oars	0	-	-	-	-	-	0	-	-	-	.	-
Qhl	Fine	24	106.3	0.09	109.9	92.1	130	33	24	0.54	21	7	57
	Coarse	1	116.2	-	-	-	-	6	24	0.40	23	12	40
Qf	ine	25	105.	.0	104	93	2	27	22	.6	16		4
	oars	3	102.	.1	104.7	90.	1	21	30	.7	26		9
Qpf	Fine	35	108.9	0.09	110.0	87	135	45	32	0.65	29	6	98
	Coarse	16	115.7	0.11	115.0	96.6	140	79	44	0.56	37	14	>99
Qo	ine	8	117.	.0	111.5	09.	4	12	40	.6	39		8
	oars	2	112.	.1	110.1	105	0	8	62	.3	63		2

Notes:
(1) See Table 1.3 for names of the units listed here.
(2) Fine soils (silt and clay) contain a greater percentage passing the #200 sieve (<.074 mm); coarse soils (sand and gravel) contain a greater percentage not passing the #200 sieve.
(3) C = coefficient of variation (standard deviation divided by the mean)

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

Geologic Unit (1)	Description	Length in feet	Composition by Soil Type (Unified Soil Classification System Symbols)	Depth to ground water (ft) (2) and liquefaction susceptibility category assigned to geologic unit			
				<10	10 to 30	30 to 40	>40
f	Artificial fill (3)	72	CL 32%; SM 24%; Other 44%	/H - I	I - I	I - I	VL
ac	Artificial stream channel	0		VH	H	M	VL
Qhc	Modern stream channel deposits	0		VH	H	M	VL
Qhly	Latest Holocene alluvial fan levee deposits	0		VH	H	M	VL
Qhty	Latest Holocene stream terrace deposits	7	SM 100%	H	H	M	VL
Qhb	Holocene basin deposits	18	CL 100%	M	L	L	VL
Qhf	Holocene alluvial fan deposits	832	CL 52%; ML 34% Other 14%	H	M	L	VL
Qhff	Holocene alluvial fan deposits, fine grained facies	93	ML 52%; CL 45% Other 3%	M	M	L	VL
Qhl	Holocene alluvial fan levee deposit	234	CL 63%; ML 25% SM 9%; Other 3%	H	M	L	VL
Qht	Holocene stream terrace deposits	0		H	H	M	VL
Qha	Holocene alluvium, undifferentiate	0		M	M	L	VL
Qf	Late Pleistocene to Holocene alluvial fan deposits	325	CL 62%; SW 10% GM 9%; Other 19%	M	L	L	VL
Qt	Late Pleistocene to Holocene strear terrace deposits	0		M	L	L	VL
Qa	Late Pleistocene to Holocene alluvium, undifferentiated	0		M	L	L	VL
Qpf	Late Pleistocene alluvial fan deposits	1070	CL 34%; GC 12%; GP 10% SM 9%; GW 8%; Other 27%	L	L	VL	VL
Qpt	Early to middle Pleistocene alluvial fan deposits	0		L	L	VL	V L
Qoa	Early to middle Pleistocene alluvium, undifferentiated	120	CL 49%; SC 21%; ML 14% GC 11%; Other 5%	L	L	VL	VL
B	Bedrock	n/a	n/a (4)	VL	VL	VL	VL

Notes:

(1) Susceptibility assignments are specific to the materials within the Santa Teresa Hills 7.5-Minute Quadrangle.
(2) Based on the Simplified Procedure (Seed and Idriss, 1971; Youd and Idriss, 1997) and a small number of borehole analyses for some units.
(3) 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.
(4) n/a = not applicable

Table 1.3. Liquefaction Susceptibility for Quaternary Map Units in theSantaTeresa Hills 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

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. The historically high ground-water map differs from most ground-water maps, which show the actual water table at a particular time. Plate 1.2 depicts hypothetical ground-water levels within alluviated areas.

Ground-water conditions were investigated in the Santa Teresa Hills Quadrangle to evaluate the depth to saturated materials. Saturation reduces the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on first-encountered water noted in geotechnical borehole logs acquired from City of San Jose, Santa Clara Valley Water District and Caltrans. The depths to first-encountered unconfined ground water were plotted onto a map of the project area and contoured 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 currently at or near their historically highest levels in many areas of the Santa Clara Valley (Figure 1.1). The Santa Clara Valley Water District recently has observed artesian wells, which reflect rising ground-water levels (Reymers and Hemmeter, 2001). Regional ground-water contours on Plate 1.2 show depths to historically highest water levels, as interpreted from borehole logs from investigations conducted between 1953 and the late-1990s. Ground-water levels from geotechnical boreholes for this liquefaction analysis were used to supplement data from the Santa Clara Valley Water District (which provided information from 10 wells within this quadrangle). Many of the ground-water levels in the geotechnical boreholes were measured during the dry periods of annual water-level fluctuations (September-December; see insert within Figure1.1), and thus may not reflect the true high ground water observed during peak recharge periods. Ground-water levels appear to fluctuate on the order of 15-20 feet on an annual basis due to natural recharge and discharge of the aquifers that occurs with changing seasons. Figure 1.1 depicts both these annual water-level fluctuations as well as longer-term fluctuations. The well in Figure 1.1 is located where the ground water is part of a confined system and may not represent the fluctuations in the shallow, unconfined ground water levels but it does adequately depict the type of annual and long-term variability that is expected.

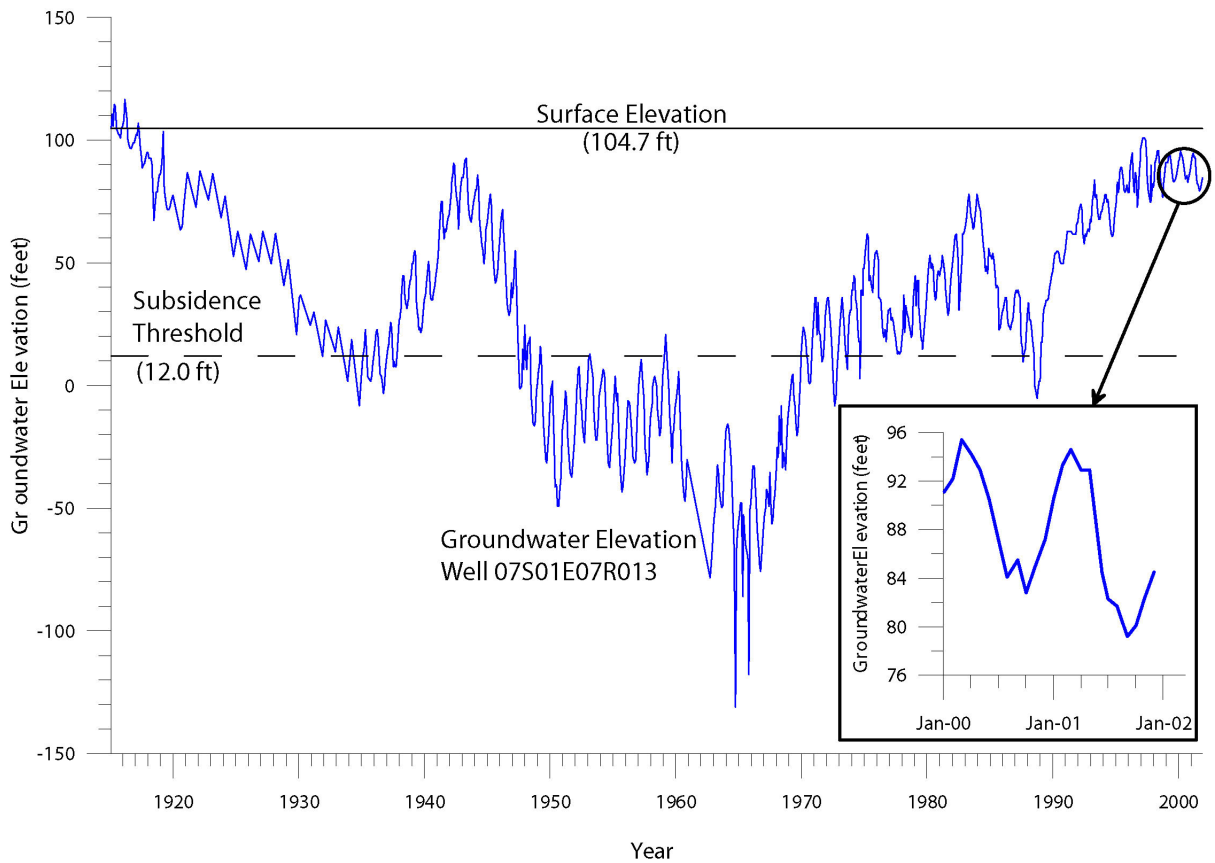

Figure 1.1. Hydrograph for the Santa Clara Valley Sub-Basin Index Well. Modified from Figure 3-2 in (Reymers and Hemmeter, 2001). Well 07S01E07R013 is located near the San Jose Arena at West Santa Clara Street and Delmas Avenue in San Jose.

Depths to first-encountered water range from 2 to 74 feet below the ground surface, although most of the alluviated areas have ground-water levels within 40 feet of the ground surface (Plate 1.2). The Almaden Valley, which is southwest of the Santa Teresa Hills, has ground-water levels between 10 and 50 feet below the ground surface, based on limited data. For much of the Santa Clara Valley, ground-water levels are within about 20 feet of the ground surface. A small finger of ground water deeper than 30 ft extends north and then east from Tulare Hill. The Coyote Narrows, just east of Tulare Hill, separate the Santa Clara Valley from the Coyote Valley hydrologic sub-basins. A small part of the Coyote Valley extends onto the Santa Teresa Hills Quadrangle just south of Tulare Hill and here the ground water is very shallow (2 ft). The ground-water contours shown on Plate 1.2 compare reasonably well with the ground-water map of Roger Pierno, Santa Clara Valley Water District (unpublished computer-generated shallow ground-water map).

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 herein. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

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

CGS's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. CGS's qualitative relations among susceptibility, geologic map unit and depth to ground water are summarized in Table 1.3.

Most Holocene materials 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 basin deposits (Qhb), Holocene alluvial fan fine facies deposits (Qhff), and undifferentiated Holocene alluvium (Qha) primarily are composed of fine-grained material and have correspondingly lower susceptibility assignments of moderate (M) to low (L). However, these units may contain lenses of material with higher liquefaction susceptibility. Limited data indicate a high percentage of silt occurs within the Holocene alluvial fine fan facies (Qhff) within the Santa Clara Valley (Table 1.2). All late Pleistocene and older deposits within 30 feet of the ground surface have low (L) susceptibility assignments except late Pleistocene to Holocene undifferentiated alluvium (Qa), stream terrace deposits (Qt) and alluvial fan deposits (Qf). The latter contains lenses of potentially liquefiable material (Table 1.3) and, therefore, is assigned moderate susceptibility. Due to the lack of available geotechnical data for Qt and Qa, these two units that are of similar age to Qf, are also assigned a moderate susceptibility.

Uncompacted artificial fill, latest Holocene alluvial fan levee and stream terrace deposits, and modern stream channels have moderate (M) susceptibility assignments where they are saturated between 30 and 40 feet. All other units have low (L) to very low (VL) susceptibility assignments where ground water is greater than 30 feet below the ground surface.

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 percent 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 Santa Teresa Hills Quadrangle, PGAs of 0.55-0.79 g, resulting from earthquakes of magnitude 6.4 to 7.9 were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10 percent 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; Youd and others, 2001). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, 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 evaluate 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 83 geotechnical borehole logs reviewed in this study (Plate 1.2), 72 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 percent 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 percent 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 percent 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 Santa Teresa Hills Quadrangle is summarized below.

Areas of Past Liquefaction

In the Santa Teresa Hills Quadrangle, no areas of documented historical liquefaction are known (Knudsen and others, 2000a; Tinsley and others, 1998; Youd and Hoose, 1978).

Artificial Fills

In the Santa Teresa Hills Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for river levees, earth fill dams and in-fill of Holocene channels. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata. Non-engineered fills commonly are loose and uncompacted, and the material varies in size and type.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data were evaluated for zoning based on the liquefaction potential determined by the Seed-Idriss Simplified Procedure. In Holocene alluvial deposits that cover much of the northern third of the quadrangle, many of the borehole logs that were analyzed using the Seed-Idriss Simplified Procedure contain sediment layers that may liquefy under the expected earthquake loading. These areas containing saturated potentially liquefiable material are included in the zone.

The Holocene levee (Qhl) that extends northwestward from Coyote Creek out into the Santa Clara Valley has been included in the zone of required investigation despite depths to ground water greater than 30 ft in this area. Sediment samples in several geotechnical boreholes were found not to be susceptible to liquefaction to the depth of penetration (< 40 ft) because of the lack of ground water. However, some of these wells contain potentially liquefiable material above the ground-water level as shown on Plate 1.2. As discussed in the section on ground water, ground water within the Santa Clara Valley historically has been much deeper than it is today due to long term extraction of ground water and natural variation in rainfall. However, due to cessation of pumping, increasing use of external water sources and the development of ground-water recharge basins, the levels of ground water are currently approaching that of historically high levels of about 100 years ago (Figure 1.1). Depth to ground water also varies seasonally by as much as 15-20 ft (Reymers and Hemmeter, 2001) and many of the water levels from boreholes were collected between August and December, during periods of seasonally low ground water. Many of them also were collected during the 1970's and 1980's, when ground-water levels were lower than today in the center of the Santa Clara Valley sub-basin. Thus, because much of the data used to develop contours of historically high ground water on Plate 1.2 is from decades ago, the present ground water level may be as much as 15-20 ft shallower than indicated by the contours shown on Plate 1.2 during the wet season. To allow for the predicted average seasonal changes in depth to ground water, these areas were included within the zone. When these areas are evaluated for liquefaction during site-specific studies, the seasonal and historical ground-water fluctuations should be taken into account.

The Holocene basin deposits (Qhb) within the Coyote Valley are not included in the zone of required investigation, despite shallow ground water, due to geotechnical borehole information within this quadrangle and in the adjacent Morgan Hill Quadrangle that shows that these basin deposits are predominantly clayey.

Areas with Insufficient Existing Geotechnical Data

There is not enough geotechnical information to adequately characterize the fine-grained facies of the Holocene alluvial fan deposits (Qhff) in the north-central portion of the quadrangle. The few boreholes that penetrated this lithologic unit indicate mostly fine-grained deposits varying from clay to silty clay and clayey silt, with some loose silt layers. Ground water is fairly shallow (10-20 ft) and so the saturated loose silty layers may liquefy under the expected earthquake loading. Due to the lack of subsurface information and the proximity to two large creeks that may have deposited loose sandy or silty layers, this area is included in the zone of required investigation.

Similarly the Holocene fine-grained alluvial fan deposits (Qhff) in the Coyote Valley also are included in the zone of required investigation, due to their proximity to several small drainages and high expected ground shaking.

All Holocene channels and terraces and areas of Late Pleistocene to Holocene valley floor alluvium (Qa) are included in the zone of required investigation due to shallow ground water associated with the active stream channels and potential presence of loose sandy or silty deposits.

Comparison with other liquefaction studies

Results of several previous regional liquefaction studies, which have included the Santa Teresa Hills Quadrangle, are here compared with the results obtained during this study. Rogers and Williams (1974) mapped liquefaction potential as part of a special report on potential seismic hazards for Santa Clara County. Due to a lack of sub-surface information describing Quaternary deposits, they defined their liquefaction hazard zones based on the inferred presence of sandy deposits and depth to ground water. Rogers and Williams (1974) used Quaternary map units from unpublished (at that time) 1:62,500-scale geologic mapping of Earl Brabb and Thomas W. Dibblee of the U.S. Geological Survey. Based on geologic map units and the shallow ground water (less than 20 ft), Rogers and Williams (1974) designated all alluviated areas within the Santa Teresa Hills

Quadrangle as areas of high liquefaction potential requiring mandatory site investigations.

Geomatrix (1992) evaluated liquefaction potential for the Santa Teresa Hills Quadrangle as part of their evaluation for San Jose, California. For their regional map, they sub-divided areas based on ground-water levels into three distinct sub-areas with ranges of ground-water depths of 0-10 ft, 10-30 ft and greater than 30 ft. Their designation of liquefaction susceptibility is based on the ground-water ranges and geologic map units as mapped by Helley and Brabb (1971) and Helley and others (1979). Areas that were designated by Geomatrix (1992) as having moderate liquefaction susceptibility are generally within the zone of required investigation as defined in this report. However, the zone of required investigation includes some areas defined by Geomatrix (1992) as having low liquefaction susceptibility, because Geomatrix (1992) concluded there is deep ground water in these areas. Other areas Geomatrix (1992) mapped as having low susceptibility have been excluded from the zone of required investigation (for example, mapped Pleistocene deposits). Geomatrix (1992) does not provide locations of sub-surface information used in their study, other than that shown on several cross sections (none of these are within this quadrangle), and the liquefaction susceptibility of geologic units are assigned on a regional scale.

Knudsen and others (2001) recently published mapping of Quaternary deposits and liquefaction susceptibility for the nine-county San Francisco Bay Region. The Knudsen and others (2001) liquefaction susceptibility designation is again based on age and type of geologic deposit, and ground-water levels. The susceptibility assignments of their geologic map units were calibrated with occurrence of historical liquefaction, limited borehole log data with penetration tests, and some liquefaction analyses of borehole data. The majority of alluviated areas within the Santa Teresa Hills Quadrangle (except areas mapped as Pleistocene deposits) are designated as having low to moderate liquefaction susceptibility, with only the Holocene stream terrace deposits and channels being designated as having high liquefaction susceptibility. Areas mapped as fine-grained deposits (Qhff and Qb) were designated as having moderate susceptibility. However, this assignment was based on the correlation of units with actual occurrences of liquefaction and assumed ground-water levels. About 4 percent of the pre-Loma Prieta earthquake occurrences were observed in this type of deposit (Knudsen and others, 2000b).

In comparison to the regional studies described above, the current report includes new unpublished mapping of the Quaternary deposits by Knudsen and geotechnical data specific to the Santa Teresa Hills Quadrangle. The geologic map units have been characterized for this quadrangle based on data collected from 83 geotechnical boreholes that penetrate most of the geologic deposits located in the quadrangle. Ground-water contours constructed for this study are more detailed than those used in any of the other studies and were based on water levels from boreholes and water wells collected from within this quadrangle.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Santa Teresa Hills 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 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 Santa Teresa Hills 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 CGS'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 Santa Teresa Hills 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 Geographic Information System (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; McCrink, 2001) 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 hazard 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 hazard zone or this report. See Section 1, Liquefaction Evaluation Report for the Santa Teresa Hills Quadrangle, for more information on the delineation of liquefaction hazard 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 Santa Teresa Hills 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 hazard zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Santa Teresa Hills 7.5-Minute Quadrangle covers approximately 60 square miles of Santa Clara County south of San Francisco Bay. The map area includes incorporated portions of the city of San Jose as well as unincorporated portions of Santa Clara County. Incorporated parts of the map area contain residential and commercial areas in the Santa Clara Valley and the Almaden Valley in the northern part of the quadrangle. They also include some sparsely developed hilly areas in the Santa Teresa Hills and the Santa Cruz Mountains in the southern and eastern portions of the quadrangle. Unincorporated areas are generally steep and hilly in the Santa Cruz Mountains throughout the southern part of the quadrangle.

The Santa Teresa Hills are a relatively narrow set of hills that extend across the northern part of the quadrangle and separate the Santa Clara Valley on the north from the Almaden Valley on the south. The Santa Clara Valley occupies the northernmost portion of the Santa Teresa Hills Quadrangle and extends onto a number of adjoining quadrangles to the north and east. A small portion of the Diablo Range extends into the northeastern corner of the quadrangle where it borders the Santa Clara Valley. The Almaden Valley is relatively small and lies between the Santa Teresa Hills to the north and the Santa Cruz Mountains to the south. The Santa Cruz Mountains occupy the southern half of the quadrangle and are characterized by steep, forested slopes and high-gradient streams.

Major streams in the map area include Coyote Creek, Alamitos Creek and Llagas Creek. Coyote Creek extends across the northeast corner of the quadrangle and flows across the southern part of Santa Clara Valley. Alamitos Creek flows from the Almaden Valley. Llagas Creek flows from a portion of the Santa Cruz Mountains and eventually joins the Pajaro River southeast of the map area. Numerous smaller streams also are present in the map area.

Three reservoirs extend into the map area. The upstream end of Guadalupe Reservoir (spillway elevation 616 feet) extends into the western part of the quadrangle. Almaden Reservoir (spillway elevation 606 feet) is in the south central part of the map area. Calero Reservoir (spillway elevation 485 feet) is in the eastern part of the quadrangle.

The highest point in the map area is along a ridge in the southwest corner of the quadrangle, which rises slightly above 3,200 feet. The lowest point in the map area is along Canoas Creek near the northwestern corner, where the elevation is slightly less than 160 feet.

The map area includes the historic New Almaden quicksilver mining district, which was active for more than a century and, for a time in the nineteenth century, was the nation's largest mercury producer. The mining district is on the southwest side of the Almaden Valley and is now public parkland. The map area also includes several stone quarries that supplied building stone for some significant structures, including buildings on the Stanford University Campus. Some of the quarried areas have been converted to residential developments and a golf course.

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 in the form of a digital topographic map. Within the Santa Teresa Hills Quadrangle, a Level-2 digital elevation model (DEM) was obtained from the U.S. Geological Survey (1993). This DEM was prepared from topographic contours of the 7.5-minute quadrangle based on 1948 aerial photography; it has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

Five hilly areas in the northern half of the quadrangle have undergone large-scale grading since 1948 for urban development and quarrying. A DEM reflecting these topographic changes was obtained from an airborne interferometric radar platform flown in 1998, with an estimated vertical accuracy of approximately 2 meters (Intermap Corporation, 2002). An interferometric radar DEM is prone to creating false topography where tall buildings, metal structures, or trees are present. The DEM used for the graded areas within the Santa Teresa Hills Quadrangle underwent additional processing to remove these types of artifacts (Wang and others, 2001). Nevertheless, the final hazard zone map was checked for potential errors resulting from the use of the radar DEM and corrected if necessary. These graded areas where the radar DEM was used are shown on Plate 2.1.

A slope gradient map was made from each DEM using a third-order, finite-difference, center-weighted algorithm (Horn, 1981). The slope gradient map derived from the USGS DEM was updated in the graded areas with slope gradients derived form the radar DEM. The manner in which the slope gradient map was used to prepare the zone map is 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). This geologic map database covers five complete 7.5-minute quadrangles and parts of two additional 7.5-minute quadrangles in southwestern Santa Clara Valley and the southern Santa Cruz Mountains. Knudsen (unpublished) prepared the map of unconsolidated surficial (Quaternary) geologic units for the Santa Teresa Hills 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 maps 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 geologic map by McLaughlin and others (2001) identifies three individual stratigraphic assemblages that lie within discrete fault-bounded bedrock structural blocks in southwestern Santa Clara County and the southern Santa Cruz Mountains. Two of these bedrock structural blocks extend into the Santa Teresa Hills Quadrangle. The Sierra Azul Block occupies the southwest corner of the quadrangle and also is exposed as a fault-bounded outlier in the Santa Teresa Hills. The New Almaden Block underlies the northeast flanks of the Santa Cruz Mountains, portions of the Santa Teresa Hills and portions of the southwest flank of the Diablo Range.

The concept of individual fault-bounded statigraphic assemblages in the Bay area was introduced by Jones and Curtis (1991) and defined further by Graymer (1994). Individual stratigraphic assemblages are considered to have originated in separate depositional basins or in different parts of large basins and were later juxtaposed against one another by large offsets on Tertiary strike-slip and dip-slip faults. Each fault-bounded stratigraphic assemblage differs from its neighbors in depositional and deformational history. The concept of mapping individual stratigraphic assemblages in discrete bedrock structural blocks has been applied to much of the recent mapping that has been compiled by the U.S. Geological Survey in the Bay area (Wentworth and others, 1999; Graymer, 2000).

The following is a description of bedrock units in the Sierra Azul and New Almaden blocks exposed in the Santa Teresa Hills Quadrangle.

Sierra Azul Block

The Sierra Azul Block is composed of a sequence of ophiolitic rocks and marine Mesozoic through early Tertiary strata. The Sierra Azul Block structurally overlies the New Almaden Block. The boundary between the Sierra Azul Block and the New Almaden Block is a complex series of faults that are considered to be part of the regionally extensive Coast Range Fault (McLaughlin and others, 2001). In the map area, this complex fault zone separates basal ophiolitic rocks of the Sierra Azul Block from Franciscan Complex rocks of the New Almaden Block. The Sierra Azul Block underlies the southwest corner of the map and also forms an outlier exposed in the Santa Theresa Hills in the northern part of the quadrangle. Geologic units of the Sierra Azul Block exposed in the Santa Teresa Hills Quadrangle are described below.

The Coast Range Ophiolite of Jurassic age primarily consists of serpentinized ultramafic rocks (Jos) in the Santa Teresa Hills Quadrangle (McLaughlin and others, 2001). This unit includes serpentinized and extensively sheared peridotite, harzburgite and ultramafic cumulates. A small fault-bounded sliver of intrusive complex rocks (Jic) is mapped along the Sierra Azul Fault in the southwest corner of the quadrangle. This unit consists of dioritic and diabasic sheeted dikes.

Great Valley Sequence rocks of Cretaceous and Jurassic age overlie the Coast Range Ophiolite in the Sierra Azul Block. Three units of the Great Valley Sequence are exposed in the Santa Teresa Hills Quadrangle. 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). Sedimentary serpentinite (Jssp) is exposed in one small fault-bounded outcrop near Calero Reservoir in the Sierra Azul Block. It consists of sandstone and mudstone containing serpentinite fragments and is assigned to the lower part of the Great Valley Sequence (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. It is exposed in the Santa Teresa Hills and consists of maroon red to olive green mudstone locally containing glauconitic, bioclastic, conglomerate and lithic sandstone at the base. This unit also contains lenticular limestone bodies (Tcml) consisting of reworked bioclastic debris in the Santa Teresa Hills. 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 at the northwest end of the Santa Teresa Hills (McLaughlin and others, 2001). This unit consists of thick- to thin-bedded, locally pebbly, quartzo-feldspathic and arkosic sandstone and interbedded micaceous, carbonaceous mudstone. The unit forms bold outcrops in the Santa Teresa Hills and has been quarried for building stone.

New Almaden Block

The New Almaden Block underlies the Sierra Azul Block and is separated from it by the Coast Range Fault. 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 deformed Pliocene and Pleistocene fluvial deposits.

McLaughlin and others (2001) have mapped units from three lithologic terranes of the Franciscan Complex in the Santa Teresa Hills 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 Santa Teresa Hills Quadrangle include blueschist (bs), amphibolite (am), chert (ch), basaltic volcanic rocks (gs) and metadiorite (mdi) (McLaughlin and others, 2001).

Three units of the Marin Headlands Terrane are exposed in the Santa Teresa Hills 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 Santa Teresa Hills Quadrangle (McLaughlin and others, 2001). Foraminiferal limestone (fpl) 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). A small area in the northeast corner of the quadrangle that lies on the southwest flank of the Diablo Range is underlain by a unit of spilitic pillow basalt and dacite flows, breccia and tuff, locally intruded by diabase sills (Jbk).

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

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

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

The Santa Clara Formation of Pleistocene and Pliocene age (QTsc) consists of non-marine boulder to pebble conglomerate, sandstone, siltstone and, locally, thin-bedded lacustrine mudstone.

Structural Geology

The bedrock units in the Santa Teresa Hills 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 Santa Teresa Hills Quadrangle are separated into two separate bedrock structural blocks, each of which has undergone a separate depositional and deformational history (McLaughlin and others, 2001).

The Sierra Azul Block is bounded by and in places internally cut by several late Cenozoic faults that are superimposed on or merge with 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. In the Santa Teresa Hills Quadrangle, these late Cenozoic faults include the Sierra Azul Fault and the Berrocal Fault. 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 a broad, weakly defined antiform and synform structure. The antiform and synform are defined by the northwest-southeast alignment of lithic elements in the Franciscan Complex and interleaved Coast Range ophiolite rocks and by dips of bedding and shear foliation in the Franciscan Complex and interleaved Coast Range ophiolite rocks. The antiform is called the Uvas antiform (McLaughlin, 2001) and extends along a northwest-southeast trend across the southern part of the quadrangle. The northeast limb of the antiform is warped into a broad synform that underlies the area northeast of New Almaden. 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 Santa Teresa Hills Quadrangle has been prepared by field reconnaissance, analysis of stereo-paired aerial photographs (listed as Air Photos in References) and a review of previously published landslide mapping. Landslides were mapped 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 as described later in this report. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included on Plate 2.1.

Landslides in the Santa Teresa Hills Quadrangle are most abundant in areas underlain by melange of the Central Belt of the Franciscan Complex on slopes in the New Almaden area and in areas southeast of New Almaden. Some of these landslides are large deep-seated complexes that may be more than 1,000 feet in maximum horizontal dimension, and in some cases are probably more than 100 feet deep. Some landslides in the New Almaden area may have been triggered by mining activities.

Landslides are generally less common on upland slopes of the Santa Cruz Mountains south of New Almaden. These slopes are steep and heavily forested but generally appear to be relatively competent. A large, prominent debris flow deposit is present in a steep tributary to Barret Canyon in the south part of the quadrangle.

The Santa Teresa Hills locally host landslides in areas primarily underlain by melange of the Franciscan Complex and by the relatively weak unit of mudstone and sandstone of Mount Chual. There is one large prominent debris flow/avalanche deposit near the eastern end of the Santa Teresa Hills and a few large landslides elsewhere. Landslides are virtually non-existent at the western end of the Santa Teresa Hills, which are underlain by a competent unit of sandstone of Loma Chiquita Ridge.

Because it is not within the scope of the Act to review and monitor grading practices to ensure past slope failures have been properly mitigated, all documented slope failures, whether or not surface expression currently exists, are included in the landslide inventory.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the Santa Teresa Hills Quadrangle geologic map were obtained from the City of San Jose, Santa Clara County Planning Department; California Department of Transportation (CalTrans); and the CGS environmental review program, as detailed in the Appendix. The locations of rock and soil samples taken for shear testing within the Santa Teresa Hills Quadrangle are shown on Plate 2.1. Shear tests from adjoining portions of San Jose West, San Jose East, Los Gatos, Morgan Hill, Loma Prieta and Mount Madonna quadrangles were used to augment data for several geologic units for which little or no shear-test information is available within the Santa Teresa Hills Quadrangle.

Shear-strength data gathered from the above sources were compiled for each geologic unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Mean and median phi values for individual geologic units and corresponding strength groups are presented in Table 2.1. For each strength group in the map area, summarized in Table 2.2, the average 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.

All Holocene units, including Holocene/late Pliestocene units (Qa, Qf and Qt) are combined into Qh because of their similar ages, lithologies and densities. Likewise, all Pleistocene units are combined into Qp/Qo.

Existing Landslides

As discussed later in this report, the criteria for zoning earthquake-induced landslide hazards state that all existing landslides mapped as definite or probable are included in the hazard zone. Therefore, shear-strength parameters for existing landslides are not necessary for preparing the zone map. However, in the interest of completeness for the geologic material strength map, to provide relevant shear-strength data to project plan reviewers, and to allow for future revisions of our zoning procedures, we have compiled shear-strength data considered representative of existing landslides within the quadrangle.

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide hazard zone map, the slip surfaces of all landslides within the quadrangle are assumed to have the same 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. Within the Santa Teresa Hills Quadrangle, four direct shear tests of landslide slip surface materials were obtained, and the results are summarized in Table 2.1.

SHEAR-STRENGTH STATISTICS FOR THE SANTA TERESA HILLS 7.5-MINUTE QUADRANGLE

	Formation Name (1)	Number of Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (2) (psf)	No Data: Similar Lithology	Phi Values for Stability Analysis
GROUP 1	Jbk	4	33.5 / 36.5	33.5 / 36.5	787.5 / 650	- - -	36
GROUP 2	ch	1	29.0	31.2 / 31.5	431.5 / 450	am	31
	fms	4	29.1 / 29			fpl	
	fmv	6	32.0 / 32			Kuc	
	fpv	7	32.1 / 31			scm	
	QTsc	8	31.1 / 33			Tcml	
						Ttv	
GROUP 3	af (3)	8	26.7 / 25	27.3 / 26	680.3 / 550	bs	27
	Jos	39	27.5 / 24			fmc	
	Qp/Qo	95	27.6 / 27			gs	
	Tcm	1	25.0			Jic	
	Tls	6	24.0 / 27				
	Tts	6	25.2 / 25.5				
GROUP 4	fm	30	23.8 / 23.5	22.7 / 21	652.3 / 550	ac (3)	23
	Kus	3	20.0 / 21			gq (3)	
	Qh	69	23.0 / 21			Jssp	
	Tm	18	20.3 / 19			mdi	
GROUP 5	Qls	4	13.3 / 11	13.3 / 11	982.5 / 1245	- - -	11

(1) Formation names are from McLaughlin and others (2001); Knudsen (not published). The Quaternary is grouped as Qh for Holocene units and as Qp/Qo for Pleistocene/Older units.
(2) Cohesion
(3) Artificial fill, af; artificial stream channel, ac; gravel quarry or percolation pond, gq

Table 2.1. Summary of the Shear-Strength Statistics for the Santa Teresa Hills Quadrangle.

SHEAR-STRENGTH GROUPS FOR THE SANTA TERESA HILLS 7.5-MINUTE QUADRANGLE				
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**	**GROUP 5**
Jbk	**am, ch, fms, fmv, fpl, fpv, Kuc, QTsc, scm, Tcml, Ttv**	**af, bs, fmc, gs, Jic, Jos, Qp/Qo, Tcm, Tls, Tts**	**ac, fm, gq, Jssp, Kus, mdi, Qh, Tm**	**Qls**

Table 2.2. Summary of the Shear-Strength Groups for the Santa Teresa Hills Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

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

Modal Magnitude:	6.4 - 7.9
Modal Distance:	2 - 17 km
PGA:	0.55 - 0.83 g

The strong-motion record selected for the slope stability analysis was Southern California Edison's Lucerne record from the 1992 Landers earthquake, which had a moment magnitude (M_W) of 7.3. The east-west component of this record had a PGA of 0.73 g and a source-to-recording-site distance of 1.1 km. Although the distance is closer than the range of the probabilistic parameters, this record is otherwise a close fit to the above criteria for the Santa Teresa Hills Quadrangle. 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 relation between landslide displacement and yield acceleration, defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relation was determined 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 accelerations (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm are used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.14, 0.18 and 0.24 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Santa Teresa Hills Quadrangle.

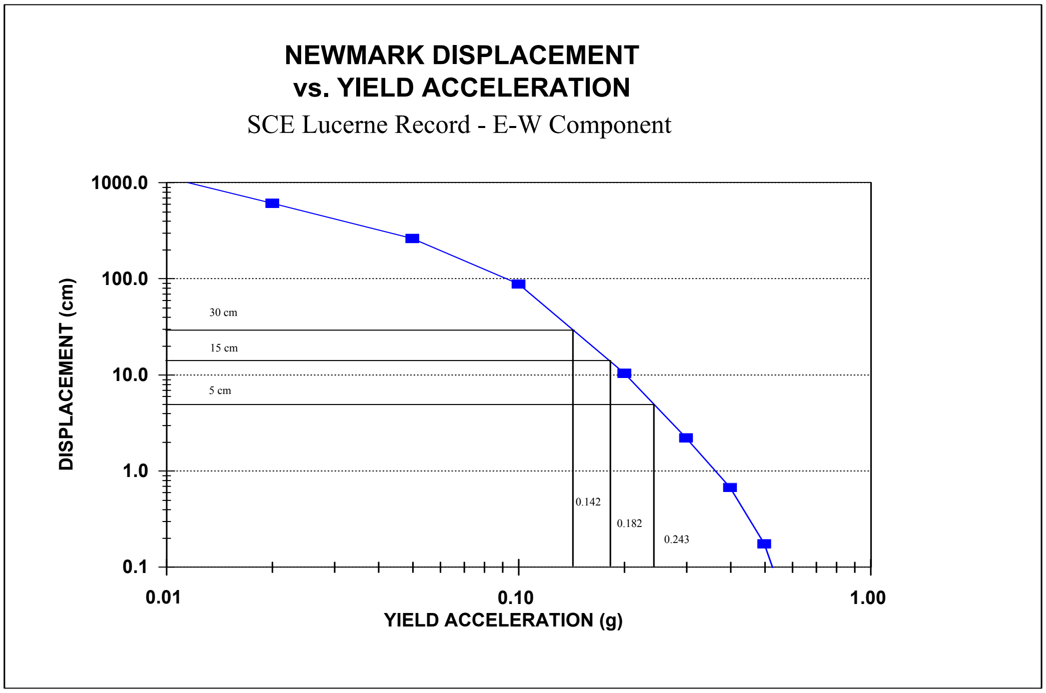

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Lucerne Record from the 1992 Landers Earthquake.

Slope Stability Analysis

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

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

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

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

1. If the calculated yield acceleration was less than 0.14 g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned.

2. If the calculated yield acceleration fell between 0.14 g and 0.18 g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned.

3. If the calculated yield acceleration fell between 0.18 g and 0.24 g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned.

4. If the calculated yield acceleration was greater than 0.24 g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned.

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

HAZARD POTENTIAL MATRIX FOR THE SANTA TERESA HILLS 7.5-MINUTE QUADRANGLE

Geologic Strength Group	Average Phi	HAZARD POTENTIAL (Percent Slope)			
		Very Low	Low	Moderate	High
1	36	0 to 45%	45 to 51%	51 to 56%	> 56%
2	32	0 to 33%	33 to 40%	40 to 44%	> 44%
3	27	0 to 25%	25 to 31%	31 to 35%	> 35%
4	23	0 to 18%	18 to 23%	23 to 27%	> 27%
5	11	0%	0%	1 to 4%	> 4%

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Santa Teresa Hills Quadrangle. Values in the table show the range of slope gradient (expressed as percent slope) corresponding to calculated Newmark displacement ranges from the design earthquake for each material strength group.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide hazard zones have been 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; McCrink, 2001), 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 groups and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

- Geologic Strength Group 5 is included in the landslide zone for all slope gradients. (Note: The only geologic unit included in Geologic Strength Group 5 is Qls, existing landslides. Existing landslides have been included or excluded from the landslide zones on the basis of the criteria described in the previous section).

- Geologic Strength Group 4 is included for all slopes steeper than 18 percent.

- Geologic Strength Group 3 is included for all slopes steeper than 25 percent.

- Geologic Strength Group 2 is included for all slopes steeper than 33 percent.

- Geologic Strength Group 1 is included for all slopes steeper than 45 percent.

Approximately 50 percent of Santa Teresa Hills Quadrangle area lies within the earthquake-induced landslide hazard zone. Almost all of the zoned areas fall within the hills and mountains, with virtually none within the Santa Clara Valley and just a few small zoned areas the Almaden Valley.

ACKNOWLEDGMENTS

Michael Shimamoto at the City of San Jose, James Baker at the County of Santa Clara, and several people at CalTrans assisted us in retrieving necessary geotechnical data and granted us full access to their files. At the California Geological Survey, Andrea Ygnacio entered the sample and testing information into our database. Barbara Wanish, Terilee McGuire, Lee Wallinder, and Bob Moscovitz provided invaluable GIS and database support. Barbara Wanish and Diane Vaughan prepared the final landslide hazard zone maps and graphic displays for this report.

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APPENDIX
SOURCE OF SHEAR-STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
CalTrans	12
San Jose	40
Santa Clara County	10
California Geological Survey	7
Total Number of Shear Tests	**69**

SECTION 3
GROUND SHAKING EVALUATION REPORT

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

By
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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 (DOC, 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 [California Geological Survey], and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10 percent 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.

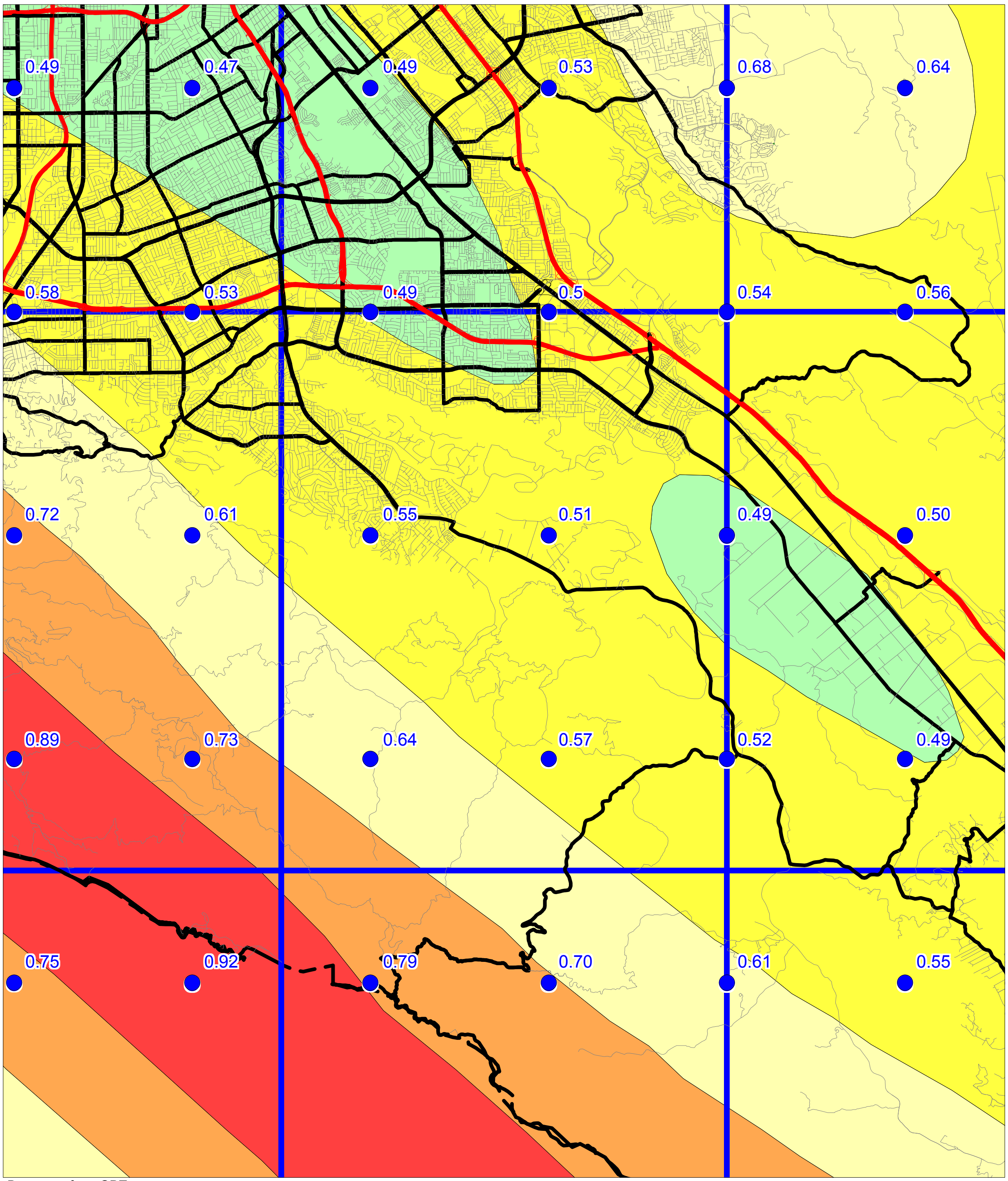
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

SANTA TERESA HILLS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

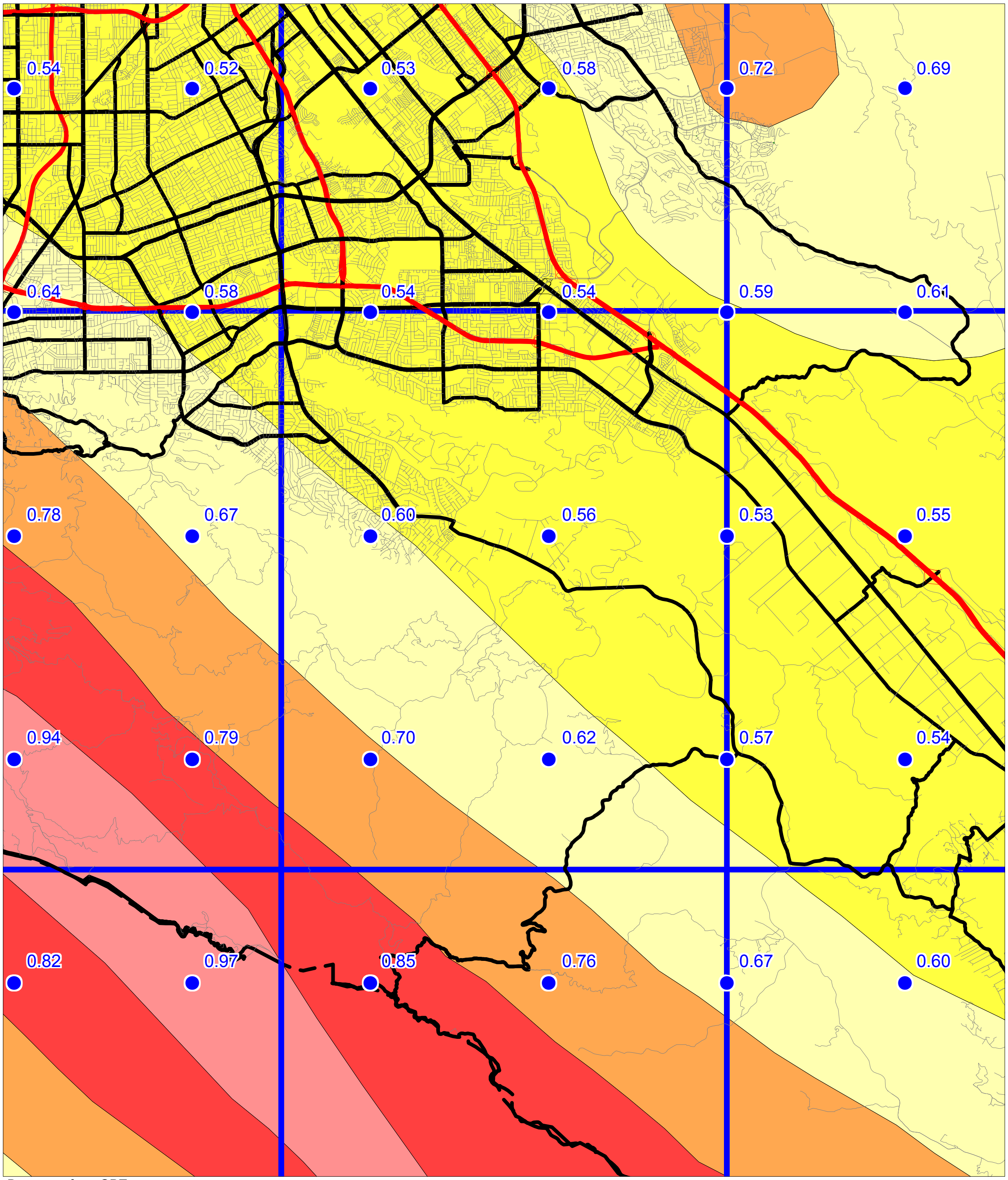
Figure 3.1

SANTA TERESA HILLS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

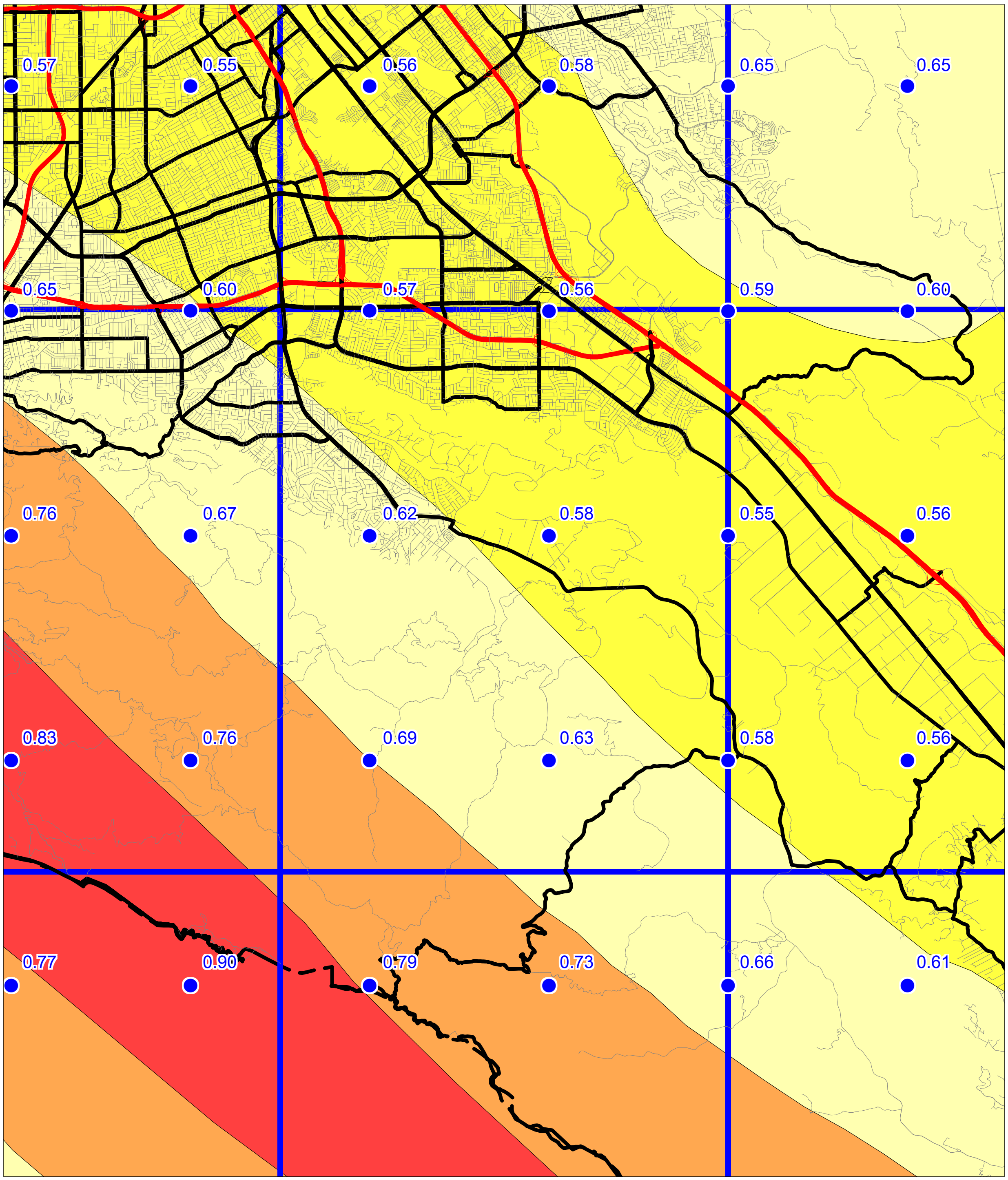
Figure 3.2

SANTA TERESA HILLS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



Base map from GDT

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 percent 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.

SANTA TERESA HILLS 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

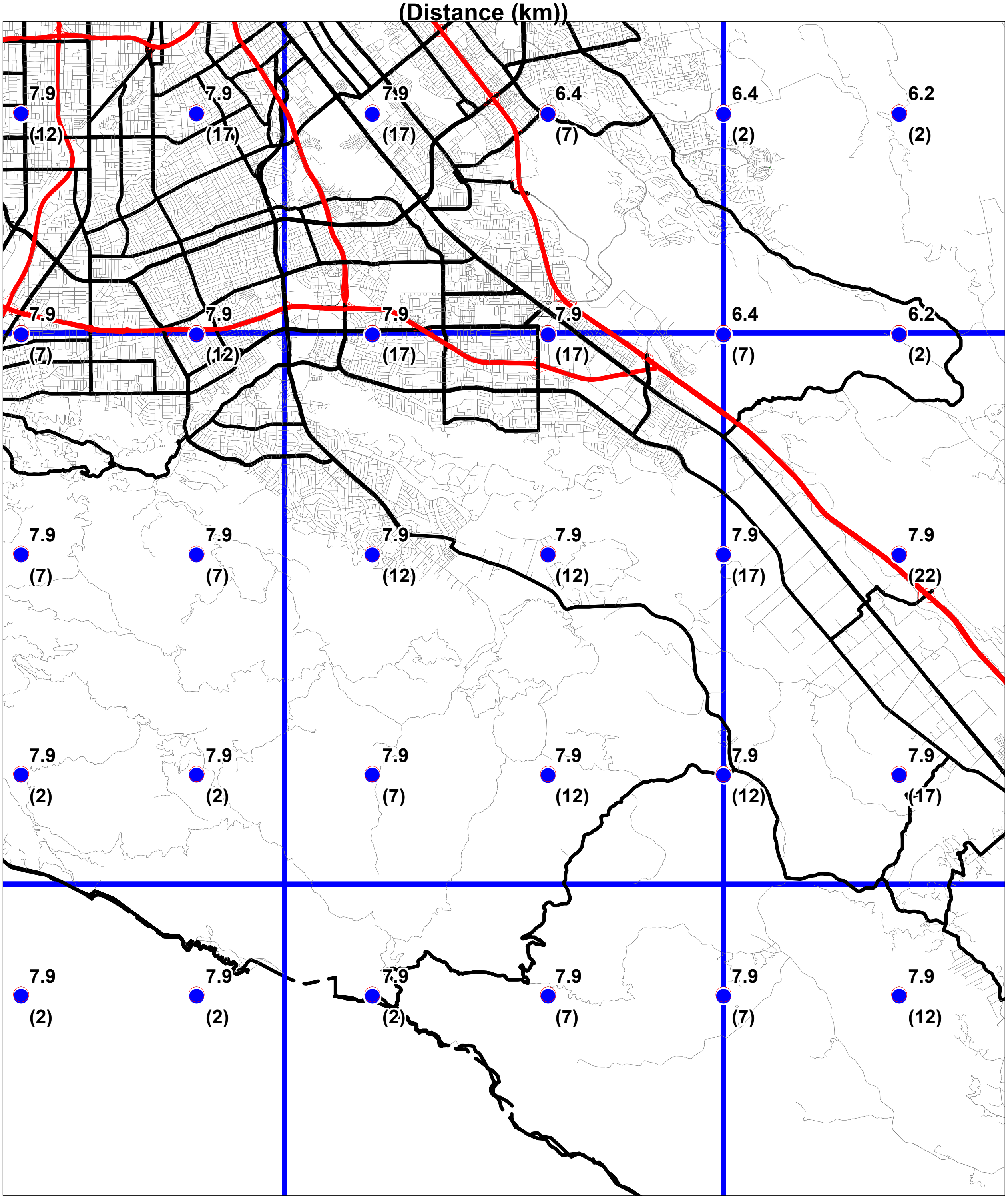
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)

(Distance (km))



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

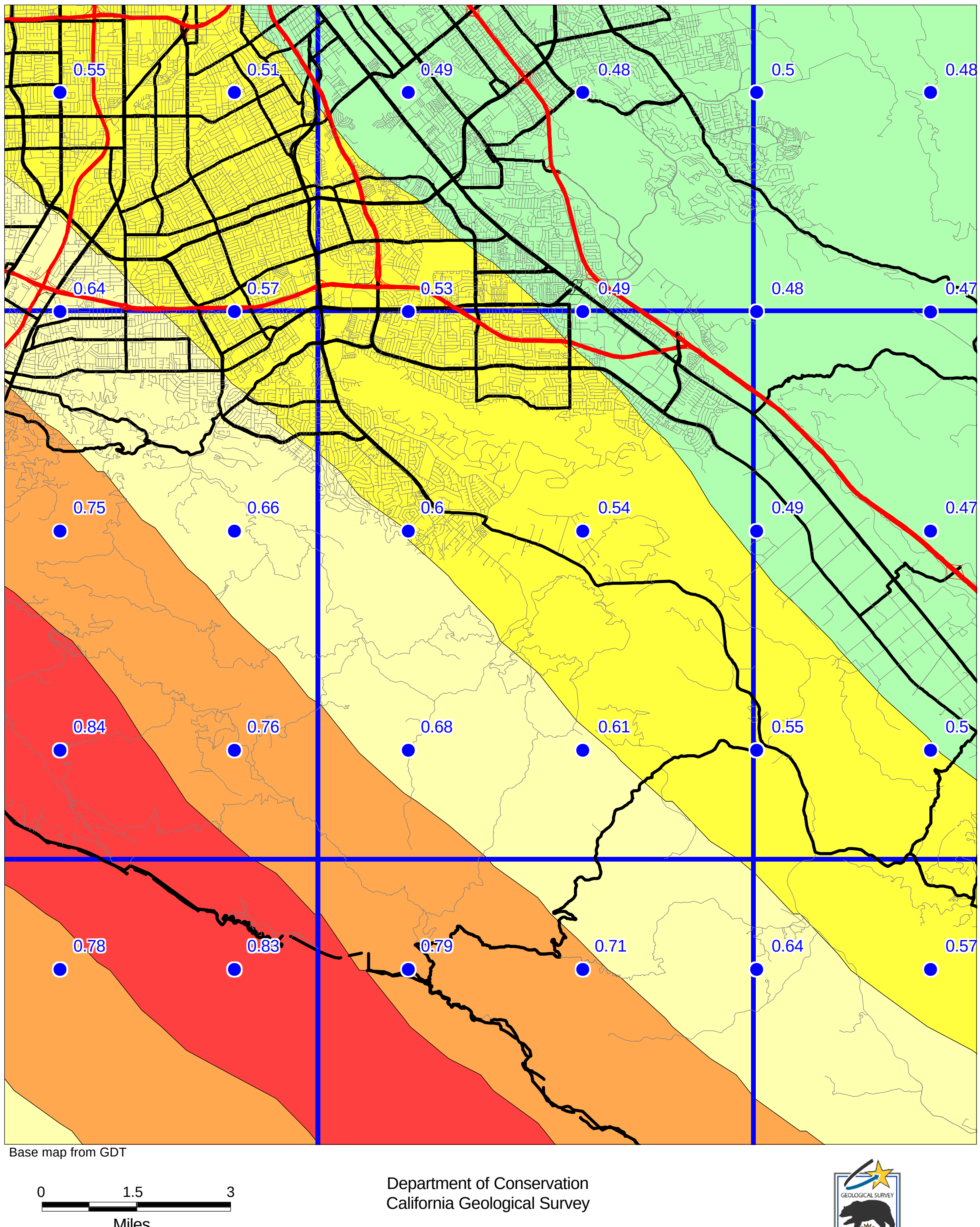
Figure 3.4

SANTA TERESA HILLS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

LIQUEFACTION OPPORTUNITY



Department of Conservation
California Geological Survey

Figure 3.5

USE AND LIMITATIONS

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

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

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

3. Uncertainties in the hazard values have been estimated to be about +/- 50 percent 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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SANTA TERESA HILLS QUADRANGLE

SCALE

1 MILE

7000 FEET

1 KILOMETER

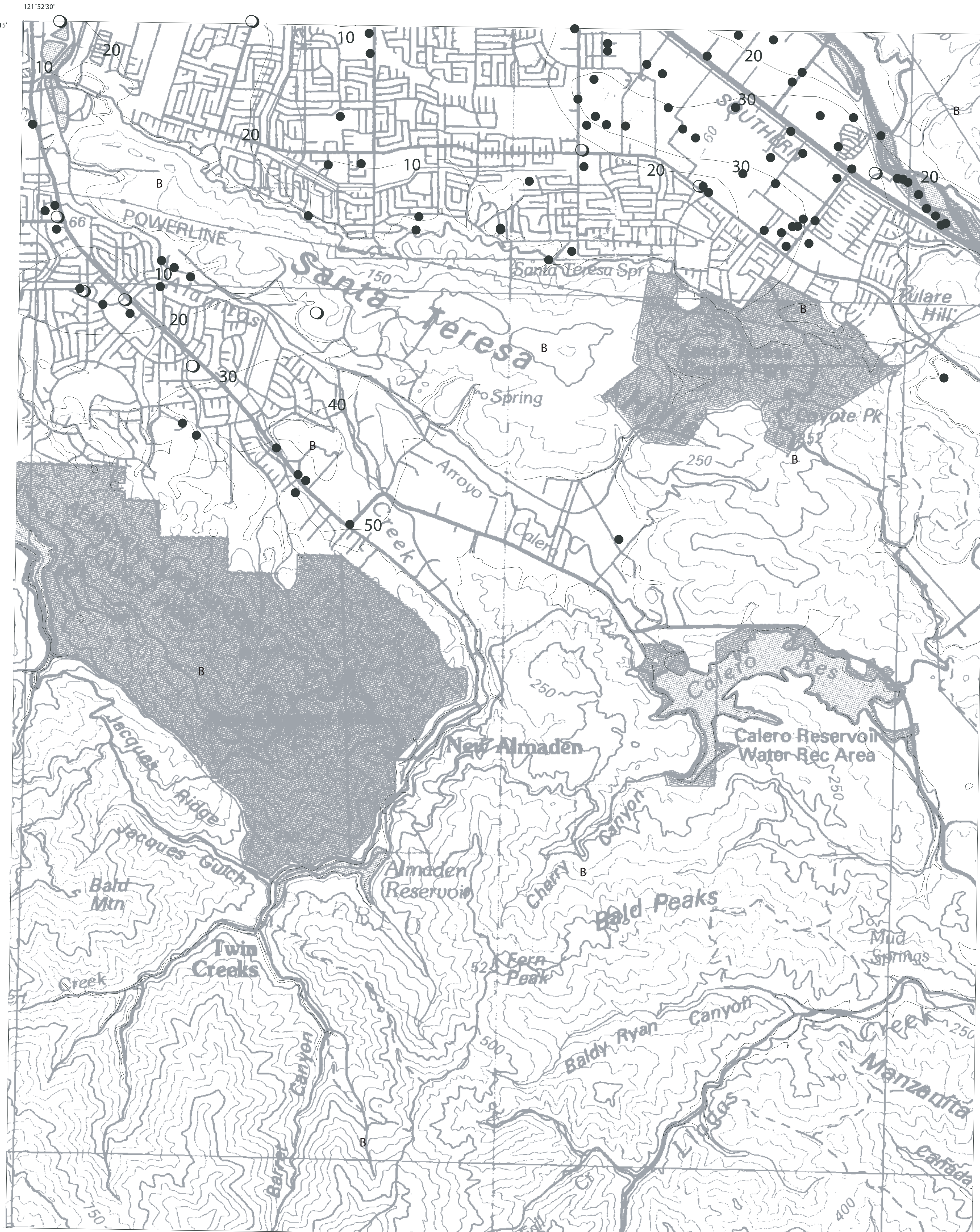
N

Lithologic contact

B = Pre-Quaternary bedrock.

See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

Plate 1.1 Quaternary Geologic Map of the Santa Teresa Hills 7.5-Minute Quadrangle, California. Unpublished mapping by K. Knudsen (2003).



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

SANTA TERESA HILLS QUADRANGLE

SCALE

N

50 Depth to ground water, in feet

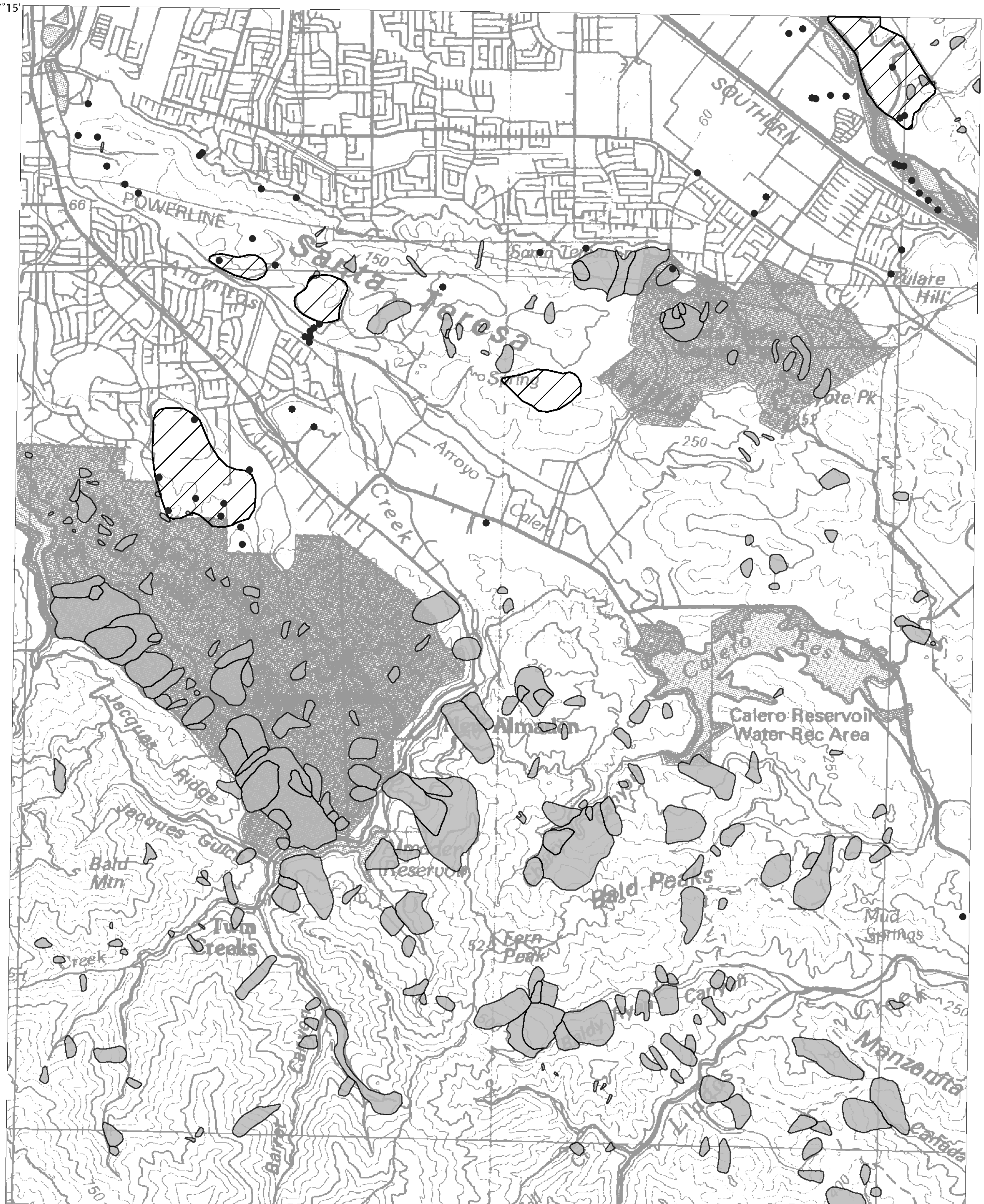
B = Pre-Quaternary bedrock.
See "Bedrock and Surficial Geology"
in Section 1 of report for descriptions of units.

○ Ground-water level data from Santa Clara Valley Water District

● Geotechnical borings used in liquefaction evaluation

Plate 1.2 Depth to historically highest ground water and locations of boreholes used in this study, Santa Teresa Hills 7.5-Minute Quadrangle, California

121°52'30"
37°15'



37°07'30"
121°45'

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

SANTA TERESA HILLS 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, SANTA TERESA HILLS 7.5-Minute Quadrangle, California