SEISMIC HAZARD ZONE REPORT 091

SEISMIC HAZARD ZONE REPORT FOR THE HAYWARD 7.5-MINUTE QUADRANGLE, ALAMEDA COUNTY, CALIFORNIA

2003

DEPARTMENT OF CONSERVATION
California Geological Survey

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ILLUSTRATIONS

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Hayward 7.5-Minute Quadrangle, Alameda County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 60 square miles at a scale of 1 inch = 2,000 feet.

Nearly the entire quadrangle lies within Alameda County. About one-half square mile in the northeastern corner, in Contra Costa County, was not evaluated at this time. Flatlands on the eastern side of San Francisco Bay and Castro Valley occupy the southwestern and central portions of the quadrangle. Much of the lowland area has been developed for residential, commercial and industrial uses. The rest of the area consists of relatively steep hills that border the lowlands. Major developed areas include portions of the cities of Hayward and Oakland and the Alameda County communities of Ashland, San Lorenzo, and Castro Valley. Elevations in the map area range from less than 10 feet above sea level in the southwestern corner to nearly 1,500 feet above sea level on Walpert Ridge in the East Bay Hills near the eastern boundary of the map.

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.

The eastern boundary of the zone of required investigation for liquefaction that runs through the southwestern corner of the quadrangle is defined by the surface projection of the contact between ground water and the base of Holocene alluvial fan deposits. Additional areas of liquefaction zone in the quadrangle are associated with creeks and their associated young deposits east of this boundary. The combination of dissected hills and weak rocks in the elevated regions east of the Hayward Fault has produced widespread and abundant landslides. These conditions contribute to an earthquake-induced landslide zone that covers about 22 percent of the quadrangle.

How to view or obtain the map

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

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

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

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

INTRODUCTION

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

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

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

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10 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 Hayward 7.5-Minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Hayward 7.5-Minute Quadrangle, Alameda County, California

By
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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 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 Hayward 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://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

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.

Sites 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 risk, especially in areas marginal to the bay, including areas in the Hayward 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 Hayward 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 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 Hayward 7.5-Minute Quadrangle map covers approximately 60 square miles of land on the eastern side of San Francisco Bay. The map area is within Alameda County except for an area of about one-half square mile in the northeastern corner of the map area that lies in Contra Costa County. This report addresses liquefaction zones of required investigation only for the Alameda County portion of the map. The Contra Costa County portion will be evaluated in the future.

The southwestern and central portions of the quadrangle are occupied by flatlands on the eastern side of San Francisco Bay and Castro Valley, respectively. The remainder of the map area consists of relatively steep hills that border the lowlands. Major developed areas in the Hayward Quadrangle include portions of the cities of Hayward and Oakland, and the Alameda County communities of Ashland, San Lorenzo, and Castro Valley. Large tracts of hillside lands are only sparsely developed.

Several streams flow from the hills in the Hayward Quadrangle. The largest stream is San Lorenzo Creek, which flows westward through Dublin Canyon, across the central part of the map area. San Lorenzo Creek is fed by a number of tributary streams that flow through deeply incised canyons, including Cull Creek, Crow Creek and Palomares Creek. San Leandro Creek flows through the northwestern part of the map area into Lake Chabot, which is impounded behind a dam that straddles the boundary between Oakland and unincorporated Alameda County land. Ward Creek flows through the southern part of the map area.

Elevations in the map area range from less than 10 feet above sea level in the southwestern corner, to nearly 1,500 feet above sea level on Walpert Ridge near the eastern boundary. Much of the lowland area on the East Bay Plain and in Castro Valley has been developed for residential, commercial and industrial uses. Hillside areas have scattered residential developments, open ranchland and several active or inactive quarries. Major highways include Interstate Highway 880, which extends northwesterly across the East Bay Plain, and Interstate Highway 580, which extends westward through Dublin Canyon and the East Bay Hills from Dublin.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. To evaluate the areal and vertical distribution of shallow Quaternary deposits and to provide information on subsurface geologic, lithologic and engineering properties of the units in the Hayward Quadrangle, digital maps were obtained from the U.S. Geological Survey. These include a map of Quaternary deposits by Janet M. Sowers (unpublished) and a published map of the Oakland metropolitan area (Graymer, 2000). These GIS maps were combined, with minor modifications along the bedrock/Quaternary units contact, to form a single, 1:24,000-scale geologic map of the Hayward Quadrangle. The distribution of Quaternary deposits on this map (summarized on Plate 1.1) was used in combination with other data, discussed below, to evaluate liquefaction susceptibility and develop the seismic hazard zone map.

Other geologic maps and reports were reviewed, including Radbruch-Hall (1974), Dibblee (1980), Lienkamper (1992), Graymer and others (1996), Helley and Graymer (1997), Graymer (2000), and Knudsen and others (2000). 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.

Quaternary deposits cover approximately 40 percent of the Hayward Quadrangle. The majority of the Quaternary deposits are found west of the Hayward Fault, in the southwestern corner of the quadrangle. Near the center of the map area a large Holocene alluvial fan complex developed as a result of the combined flow of San Lorenzo and Ward creeks. Sedimentary deposits associated with the fan vary compositionally according to the distance from the active channel. Proximal to the mouth the creek, near the head of the fan, coarser sediments (Qhf) occur, whereas finer-grained sediments (Qhff) are distributed on the distal portions of the fan, and linear levee deposits (Qhl) are mapped adjacent to the active channel. Accumulations of undifferentiated Holocene alluvium (Qhay, Qha) occur in upland valleys, with the most extensive deposits found in Castro Valley. Holocene stream terrace deposits (Qhty, Qht) and modern stream channel deposits (Qhc) accumulated in canyons in the hills in the northern and eastern portions of the quadrangle. Latest Pleistocene to Holocene alluvial fan deposits (Qf, Qpf) and early to late Pleistocene undifferentiated alluvial deposits (Qoa) occur east of the Hayward Fault in Castro Valley. Artificial fill (af) in the Hayward Quadrangle primarily consists of linear stretches associated with large-scale transportation infrastructure including highways, railroads, and airports, and in areas of mass grading, such as the east end of Harder Road. Finally, artificial stream channel deposits (ac) occur where the downstream reaches of active rivers and creeks, including San Lorenzo and Ward creeks, have been re-routed in developed areas.

In the Hayward Quadrangle, Sowers' (unpublished) Quaternary geologic mapping methods are the same as those described by Knudsen and others (2000), and consist of interpretation of topographic maps, aerial photographs, and soil surveys, as well as compiled published and unpublished geologic maps. The authors estimate the ages of deposits 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 (2000) and the CGS GIS database, with that of several previous studies performed in northern California.

Bedrock exposed in the Hayward Quadrangle is almost exclusively confined to the eastern side of the Hayward Fault. Rock units consist of Mesozoic Great Valley Complex (Jgb, Jpb, Jpb?, Jsv, KJkc, KJkv, Kcv, Kc, Kull, Kcg, Kjm, Ko, Kr, Ksc, Kslto) and Franciscan Complex (KJfm, KJk, spFR) basement rocks. These highly deformed rocks are unconformably overlain by Tertiary sedimentary (Tbr, Tcs, Th, To, To?, Tr, Tsso, Tt, Tt?, Tbe, Tbg, Tbi, Tn, Tr?, Tro) and minor volcanic rocks (Tusv). See the earthquake-induced landslide portion (Section 2) of this report for additional discussion of bedrock.

UNIT	Knudsen and others (2000)	Helley and others (1994)	Helley and others (1979)	Wentworth and others (1999)	CGS GIS database
Artificial fill	af			af	af
Artificial stream channel	ac				ac
Modern stream channel deposits	Qhc	Qhsc	Qhsc	Qhc	Qhc
Latest Holocene stream terrace deposits	Qhty				Qhty
Latest Holocene alluvial deposits, undifferentiated	Qhay				Qhay
Holocene alluvial fan deposits	Qhf	Qhaf, Qhfp		Qhf, Qhfp	Qhf
Holocene alluvial fan deposits, fine grained facies	Qhff	Qhfp			Qhff
Holocene alluvial fan levee deposits	Qhl	Qhl		Qh1	Qhl
Holocene stream terrace deposits	Qht	Qhfp		Qht	Qht
Holocene alluvium, undifferentiated	Qha			Qha	Qha
Latest Pleistocene to Holocene alluvial fan deposits	Qf				Qf
Latest Pleistocene alluvial fan deposits	Qpf	Qpaf		Qpf	Qpf
Early to middle Pleistocene undifferentiated alluvial deposits	Qoa	Qru, Qrl	Qoa	Qpa	Qoa
Bedrock	br	br			br

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 (2000).

Structural Geology

The Hayward Fault is the primary geologic structure in the study area. It is an active right-lateral strike-slip fault, with an estimated late Holocene slip rate of about 9 mm per year. The Hayward Fault is undergoing active creep in the Hayward Quadrangle, as manifested by offset curbs, streets, buildings and other structures in numerous locations (Lienkaemper, 1992). Lienkaemper (1992) has mapped in detail the inferred active trace of the Hayward Fault. A variety of additional traces are shown on earlier geologic maps (Radbruch-Hall, 1974; Smith, 1980; Dibblee, 1980). Associated with the main trace are numerous splays and subsidiary traces that may accommodate secondary movements or that may be slightly older abandoned traces. Bedrock units in the vicinity of the Hayward Fault zone have been complexly offset by the main trace and its associated subsidiary traces.

The Miller Creek/Palomares fault lies east of the Hayward Fault. It is a west-vergent reverse or thrust fault that juxtaposes Mesozoic rocks of the Great Valley Complex against Miocene sedimentary rocks. Paleoseismic studies on the Miller Creek Fault indicate evidence of Quaternary displacement (Wakabayashi and Sawyer, 1998).

Between the Hayward and Miller Creek/Palomares faults, sedimentary rocks of the Great Valley Sequence generally dip steeply to the northeast and locally are overturned to the southwest. These rocks are cut by numerous faults that cut and disrupt fold axes between the Hayward Fault and Miller Creek/Palomares Fault. On the northeast side of the Miller Creek/Palomares Fault, Tertiary rocks are broadly folded and cut by widely spaced thrust faults. Several fold axes in Tertiary rocks are preserved in the eastern part of the map area.

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of flatland deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. For this investigation, a total of 150 borehole logs were collected from the files of the Alameda County Water District, BART, CalTrans, the City of Hayward, and William Lettis & Associates. Data from 125 borehole logs were entered into a CGS geotechnical GIS database (Table 1.2).

Standard Penetration Tests (SPTs) provide a standardized measure of the penetration resistance of geologic deposits and commonly are 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 at chosen intervals while drilling. 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 2,053 feet of Holocene materials and 2,114 feet of Pleistocene materials deposited within the study area.

Quaternary map units are summarized in Table 1.2 and Table 1.3. Analysis of these data leads to recognition of certain characteristics and relationships among units.

1. Median values for penetration resistance suggest fine-grained Holocene materials are less dense and more readily penetrated than Pleistocene materials. However, coarse-grained Holocene and Pleistocene materials have similar densities.

2. Early to middle Pleistocene alluvium, undifferentiated deposits (Qoa) have higher dry densities than Holocene alluvium, undifferentiated deposits (Qha).

3. Holocene alluvial fan deposits (Qhf) are finer grained than latest Pleistocene alluvial fan deposits (Qpf).

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

5. Standard penetration resistance and dry density values can vary considerably within a single unit.

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	31	103.4	[illegible]	102.0	91	[illegible]	15	26	[illegible]	23	[illegible]	[illegible]
	oarse	3	111.3	[illegible]	112.0	[illegible]	[illegible]	8	78	[illegible]	58	[illegible]	[illegible]
ac	Fine	2	107.0	0.03	107	105.0	109.0	3	18	0.26	17	14	23
	Coarse	-	-	-	-	-	-	-	-	-	-	-	-
)hf	ine	137	104.1	[illegible]	104.0	83.0	[illegible]	157	21	[illegible]	17	[illegible]	[illegible]
	oarse	26	107.9	[illegible]	108.5	93.5	[illegible]	25	17	[illegible]	13	[illegible]	[illegible]
Qhff	Fine	27	97.5	0.20	101.0	10.0	114.0	36	23	0.74	17	3	63
	Coarse	6	103.8	0.08	104.4	93.0	114.0	10	1	18.72	28	6	71
)hl	ine	18	101.3	[illegible]	102.5	78.2	[illegible]	45	17	[illegible]	14	[illegible]	[illegible]
	oarse	8	105.4	[illegible]	106.0	97.0	[illegible]	5	8	[illegible]	8	[illegible]	[illegible]
Qht	Fine	-	-	-	-	-	-	-	-	-	-	-	-
	Coarse	-	-	-	-	-	-	4	8	0.40	9	4	10
)ha	ine	9	106.4	[illegible]	107.0	95.0	[illegible]	6	13	[illegible]	11	[illegible]	[illegible]
	oarse	-	-	-	-	-	-	-	-	-	-	-	-
Qf	Fine	4	104.8	0.05	106.0	98.0	106.0	6	23	0.77	17	7	54
	Coarse	1	-	-	-	-	-	2	15	0.57	15	9	20
)pf	ine	132	104.1	[illegible]	104.0	89.5	[illegible]	60	16	[illegible]	13	[illegible]	[illegible]
	oarse	63	111.1	[illegible]	109.0	95.5	[illegible]	38	21	[illegible]	16	[illegible]	[illegible]
Qoa	Fine	9	110.2	0.07	110.0	95.0	121.0	20	70	1.21	48	9	>99
	Coarse	4	112.6	0.05	114.7	105.0	116.0	6	35	0.67	31	10	67

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 Hayward 7.5-Minute Quadrangle.

Geologic Unit (1)	Description	Length of boreholes penetrating map unit (feet)	Composition by Soil Type (2) (Percent of total sediment column logged)	Depth to ground water (feet) (3) and liquefaction susceptibility category assigned to geologic unit			
				<10	10 to 30	30 to 40	>40
f	Artificial fill (4)	35	CL 50; SC-SM 12; ML 6; SP 3; other 30	/H - l	I - l	I - l	VL
ac	Artificial stream channel	n/a	n/a	VH	H	M	VL
Qhc	Modern stream channel deposits	n/a	n/a	VH	H	M	VL
Qhty	Latest Holocene stream terrace deposits	n/a	n/a	VH	H	M	VL
Qhay	Latest Holocene alluvial deposits, undifferentiated	n/a	n/a	M	M	L	L
Qhf	Holocene alluvial fan deposits	1378	CL 60; ML 14; SD 12; CH 8; other 5	H	M	L	VL
Qhff	Holocene alluvial fan deposits, fine grained facies	264	L 51; SD 22; CH 16; ML (other 2	M	M	L	VL
Qhl	Holocene alluvial fan levee deposits	346	CL 53; ML 18; SM 14; CH 5; other 11	H	M	L	VL
Qht	Holocene stream terrace deposits	20	SM 20; SP 80	H	H	M	VL
Qha	Holocene alluvium, undifferentiated	45	CL 29; CL-ML 25; ML 47	M	M	L	VL
Qf	Latest Pleistocene to Holocene alluvial fan deposits	71	CL 44; SC 31; CH 9; SD 8 other 8	M	L	L	VL
Qpf	Latest Pleistocene alluvial fan deposits	1864	CL 60; SM-SC 20; ML 11; SP-SW 9	L	L	VL	VL
Qoa	Early to middle Pleistocene alluvium, undifferentiated	179	CL 61; SC 18; SM-SP 6; other 16	L	L	VL	VL
B	Bedrock	n/a	n/a	VL	VL	VL	VL

Notes:
(1) Susceptibility assignments are specific to the materials within the Hayward 7.5-Minute Quadrangle.
(2) Unified Soils Classification System
(3) Based on the Simplified Procedure (Seed and Idriss, 1971; Youd and Idriss, 1997) and a small number of borehole analyses for some units.
(4) The liquefaction susceptibility of artificial fill ranges widely, depending largely on the nature of the fill, its age, and whether it was compacted during emplacement.

Table 1.3. Liquefaction Susceptibility for Quaternary Map Units within the Hayward 7.5-Minute Quadrangle. Units indicate relative susceptibility of deposits to liquefaction as a function of material type and groundwater 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 due to of the unpredictable fluctuations caused by natural processes and human activities. A historical-high ground-water map differs from most ground-water maps, which show the actual water levels at a particular time. Plate 1.2 depicts a hypothetical ground-water surface within alluviated areas.

Ground-water conditions were investigated in the Hayward Quadrangle to evaluate the depth to saturated materials. Saturated conditions reduce the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on first-encountered water noted in geotechnical borehole logs acquired from the Regional Water Quality Control Board, BART, CalTrans, City of Hayward, Alameda County, and William Lettis & Associates. 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 used.

Regional ground-water contours on Plate 1.2 show historic-high water depths, as interpreted from borehole logs from investigations between 1955 and 2001. Depths to first-encountered water range from one to 70 feet below the ground surface, although most of the valley floor has ground-water levels within 40 feet of the ground surface (Plate 1.2). The Hayward Fault, which trends northwest through the central part of the map area, acts as a ground-water barrier in the Hayward Quadrangle. On the western side of the fault, ground water is deepest near the fault, and ranges from greater then 50 feet where San Lorenzo Creek crosses the fault, to less then 10 feet at the southwestern corner of the map. On the eastern side of the fault, ground water is much shallower, with depths of from 10 to 30 feet in the flatland areas in the vicinity of Castro Valley (Plate 1.2).

PART II

LIQUEFACTION POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the SMGB (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

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

CGS's 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 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 alluvial fan fine facies (Qhff) primarily is composed of fine-grained material and has a correspondingly lower susceptibility assignment. Undifferentiated Holocene alluvium also has been assigned moderate susceptibility. These units may, however, contain lenses of material with higher liquefaction susceptibility. All late Pleistocene and older deposits where ground water is within 30 feet of the ground surface have low (L) susceptibility assignments, except late Pleistocene to Holocene alluvial fan deposits (Qf). This unit has a low density along with lenses of potentially liquefiable material (Table 1.3) and, therefore, is assigned moderate susceptibility. Uncompacted artificial fill (af), artificial stream channel (ac), modern stream channel deposits (Qhc), and latest Holocene stream terrace deposits (Qhty) have moderate (M) susceptibility assignments where they are saturated between 30 and 40 feet. All other units have low (L) to (VL) susceptibility assignments below 30 feet from 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 Hayward Quadrangle, PGAs of 0.58 to 0.88 g, resulting from earthquakes of magnitude 6.8 to 7.1, 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 discussion of potential ground motion.

Quantitative Liquefaction Analysis

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate 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 $(N_1)_{60}$ value for that layer. The minimum FS value of the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

Of the 125 geotechnical borehole logs reviewed in this study (Plate 1.2), 94 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.

The results of liquefaction analysis for many boreholes within the zone of required investigation in the Hayward Quadrangle are inconclusive. In particular, if a borehole did not reach a depth of 40 feet and a liquefiable layer was found in the borehole but no samples were collected for that layer or if a sample collected for a non-liquefiable layer was unreliable, the uncertainty was carried through the analysis and noted in the results. Cross sections were used to examine each individual borehole record in the context of its unique geologic setting in the Hayward Quadrangle and in comparison with surrounding boreholes for which more conclusive information may have been available. Interpretation of the cross sections revealed that most boreholes within the zone of required investigation have materials with the potential to liquefy. The majority of borehole records captured within the zone of required investigation on the Hayward Quadrangle contain low density, saturated, coarse- grained Holocene sediments, and, in cases where borehole data are lacking conclusive evidence, surrounding boreholes provided evidence used to infer inclusion within the zone.

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 Hayward Quadrangle is summarized below.

Areas of Past Liquefaction

Knudsen and others (2000) compiled data from Tinsley and others (1998) and Youd and Hoose (1978) for earthquakes in the San Francisco Bay region. Tinsley and others (1998) compiled observations of evidence for liquefaction for the 1989 Loma Prieta earthquake. Youd and Hoose (1978) compiled them for earlier events, including the 1868 Hayward and 1906 San Francisco earthquakes. The Knudsen and others (2000) digital database differs from earlier compilation efforts in that the observations were located on a 1:24,000-scale base map rather than the smaller-scale base maps used in earlier publications. Sites were reevaluated and some single sites were separated into two or more where the greater scale of the base-map scale.

Within the Hayward Quadrangle, Youd and Hoose (1978) identified three main liquefaction sites from the 1868 Hayward earthquake (Plate 1.2). All liquefaction-induced ground failure effects occurred within the City of Hayward. Water and sand were ejected as sand boils at all three locations shown on Plate 1.2. At the north end of Hayward, a small berm 3 feet long by 2 feet wide formed. Below Haywards Hotel, a 12-inch wide crack opened. A fence that crossed over the crack was observed to deform over a period of several weeks following the earthquake. In addition, the ground was deformed into ‘waves’, causing one house to tip towards the south, whereas the neighboring house was tipped to the north. Along B Street, a 2-inch crack opened and, nearby, another branching crack opened. Two sites of past liquefaction fall outside of the zone of required investigation for liquefaction hazard. However, because of the scale at which the locations were originally mapped, and the vague description of the location of each event, the margin of error for mapping would allow for the sites to fall within the zone.

Artificial Fills

In the Hayward Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for river levees and elevated freeways. 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 are commonly loose and uncompacted, and the material varies in size and type. In the Hayward Quadrangle, only the fill underlying the eastern extent of Interstate Highway 680 is included in the zone of required investigation because the fill was placed in a creek channel. There are several small to medium bodies of fill that border on, or are close to, the eastern side of the Hayward Fault that are also included in the zone of required investigation. These fill areas are included because ground water is shallower on the eastern side of the fault, and/or because the fill was placed more than 35 years ago and may not have been engineered to resist liquefaction.

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 a large area within the Hayward Quadrangle, most 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 of required investigation.

The boundary for the zone of required investigation that runs through the southwestern corner of the Hayward Quadrangle is defined by the surface projection of the contact between ground water and the base of Holocene alluvial fan deposits (Qhf). Analysis of geotechnical boreholes in this portion of the quadrangle indicates the presence of potentially liquefiable material. A narrow band of Holocene deposits east of this line, and west of the Hayward Fault, is not saturated and, therefore, is not included within the zone of required investigation. Analysis of geotechnical borehole records in this portion of the map area indicates that the materials penetrated by these boreholes will not liquefy.

Areas with Insufficient Existing Geotechnical Data

The Hayward Fault acts as a ground-water barrier causing the depth to ground water to be significantly less east of the fault. Adequate geotechnical borehole information for artificial and modern stream channel deposits (ac and Qhc) and latest Holocene stream terrace deposits (Qhty), generally is lacking in most areas. These deposits, therefore, are included in the liquefaction zone because of the likely presence of loose, saturated, granular deposits. In the Hayward Quadrangle, ground water and forecast ground motions are sufficiently high to include these Holocene units within the liquefaction zone. These deposits occur along upland creeks and canyons and are likely to contain loose, granular, late Holocene material that is saturated because of the proximity of active stream channels.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Hayward 7.5-Minute Quadrangle, Alameda 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 Hayward 7.5-Minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking) complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://www.conservation.ca.gov/CGS/index.htm

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Hayward Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area.

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared.

- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area.

- Seismological data in the form of CGS probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area.

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink and Real, 1996; 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 zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Hayward Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Hayward Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Hayward 7.5-Minute Quadrangle map covers approximately 60 square miles on the eastern side of San Francisco Bay. Most of the map area is within Alameda County. An area of about one-half square mile in the northeastern corner of the map area lies in Contra Costa County. This report addresses earthquake-induced landslide zones only for the Alameda County portion of the map. The Contra Costa County portion will be evaluated in the future.

The southwestern and central portions of the quadrangle are occupied by flatlands on the east side of San Francisco Bay and Castro Valley. The remainder of the map area consists of relatively steep hills that border the lowlands. Major developed areas in the Hayward Quadrangle include portions of the cities of Hayward and Oakland and the Alameda County communities of Ashland, San Lorenzo, and Castro Valley. Several residential subdivisions with significant amounts of earthwork grading have been constructed in hillside portions of the quadrangle. Significant mass grading also has taken place on the campus of California State University at Hayward. Elsewhere, large tracts of hillside lands are only sparsely developed.

Several streams flow from the hills in the Hayward Quadrangle. The largest stream is San Lorenzo Creek, which flows westward through Dublin Canyon across the central part of the map area. San Lorenzo Creek is fed by a number of tributary streams that flow through deeply incised canyons, including Cull Creek, Crow Creek and Palomares Creek. San Leandro Creek, which flows through the northwestern part of the map area, is impounded by a dam to form Lake Chabot. Ward Creek flows through the southern part of the map area.

Elevations in the map area range from less than 10 feet above sea level in the southwestern corner to nearly 1,500 feet above sea level on Walpert Ridge near the eastern boundary. Much of the lowland area on the East Bay Plain and in Castro Valley has been developed for residential, commercial and industrial uses. Hillside areas in the quadrangle have scattered residential developments, open ranchland and several active or inactive quarries. Major highways include Interstate Highway 880, which extends northwesterly across the East Bay Plain, and Interstate Highway 580, which extends westward through Dublin Canyon and the East Bay Hills from Dublin.

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 Hayward Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM was prepared from the 7.5-minute quadrangle topographic contours generated from 1947 aerial photographs by photogrammetric methods and from plane table surveys. It has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

Updated terrain data for areas that have undergone large-scale grading since 1947 in the hilly portions of the quadrangle were used to revise the topography. A DEM reflecting this recent grading was obtained from an airborne interferometric radar platform flown in 1998, with an estimated vertical accuracy of approximately 1.5 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 Hayward 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. Graded areas where the radar DEM was applied are shown on Plate 2.1

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

GEOLOGY

Bedrock and Surficial Geology

The primary source of bedrock geologic mapping used in this slope stability evaluation was the "Geologic map and map database of the Oakland metropolitan area, Alameda, Contra Costa, and San Francisco counties, California" by Graymer (2000). This digital geologic database was compiled at a scale of 1:24,000 from previously published reports and from new mapping and field checking by Graymer (2000). A geologic map by Dibblee (1980) also was reviewed. Sowers (unpublished) map of Quaternary surficial geology at a scale of 1:24,000 also was used.

Geologists at the California Geological Survey merged the surficial and bedrock geologic maps. Contacts between surficial and bedrock units were modified in some areas to resolve differences between the two maps. Geologic field reconnaissance was performed to assist in adjusting contacts and to review the lithology and structure of the various geologic units.

Bedrock in the Hayward Quadrangle is characterized by two highly deformed Mesozoic basement assemblages that are unconformably overlain by Tertiary sedimentary rocks, minor Tertiary volcanic rocks and Quaternary sediments. These two Mesozoic complexes are the Great Valley Complex and the Franciscan Complex (Graymer, 2000).

The hills in the Hayward Quadrangle are underlain by Great Valley Complex rocks. Included in the complex are the Coast Range Ophiolite, which is composed of serpentinite, gabbro, diabase, basalt and keratophyre (altered silicic volcanic rock), and the Great Valley Sequence, which is composed of sandstone, conglomerate and shale of Jurassic and Cretaceous age (Graymer, 2000). The ophiolitic rocks are the remnants of arc-related oceanic crust. The Great Valley Sequence consists of turbidites that were deposited upon oceanic crustal rocks. The Great Valley Sequence rocks exposed in the map area have been assigned to the Del Puerto Terrane by Graymer (2000) based on the presence of abundant silicic volcanic rock (keratophyre). The type area for the Del Puerto Terrane is on the eastern side of the Diablo Range, east of the map area.

The Franciscan Complex is composed of weakly to strongly metamorphosed graywacke, basalt, argillite, chert and other rocks. The Franciscan Complex was accreted beneath the Great Valley Complex by subduction. During subduction, the Franciscan rocks were intensely sheared and tectonically mixed, producing a melange of small to large blocks of various rock types embedded in a matrix of crushed rock material. Franciscan rocks are exposed near the Hayward Fault and underlie thick Quaternary deposits on the southwest side of the Hayward Fault.

In recent years, bedrock units in much of the San Francisco Bay area have been subdivided into individual stratigraphic assemblages that lie within discrete fault-bounded bedrock structural blocks. The concept of 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 of these fault-bounded stratigraphic assemblages differs from its neighbors in depositional and deformational history. The study area is underlain by three of these stratigraphic assemblages.

The first assemblage is the San Francisco Bay Block west of the Hayward Fault. It consists of a basement of Franciscan Complex rocks that are unconformably overlain by Quaternary deposits with no intervening Tertiary strata.

The second assemblage underlies much of the hilly areas in the Hayward Quadrangle and consists of rocks of the Coast Range Ophiolite and the Great Valley Sequence. This assemblage is bounded on the southwest by the Hayward Fault and on the northeast by the Miller Creek/Palomares Fault.

The third assemblage occurs in the northeastern part of the quadrangle and consists of Miocene marine sedimentary rocks and minor volcanic rocks that unconformably overlie Cretaceous Great Valley Sequence rocks. This assemblage is bounded on the southwestern side by the Miller Creek/Palomares Fault and extends into adjacent quadrangles to the north and east.

The following paragraphs describe the rock types exposed in the map area in more detail. Descriptions of individual map units are based on the work of Graymer (2000).

Franciscan Complex melange (KJfm) of Cretaceous and/or Late Jurassic age consists of sheared argillite, graywacke and green tuff with blocks of graywacke, chert, shale, greenstone basalt, and high-grade metamorphic blocks (glaucophane schist, amphibolite and eclogite).

Several rock types of the Coast Range Ophiolite are exposed in the map area along the western margin of the hills. Gabbro (Jgb) and pillow basalt, basalt breccia and minor diabase (Jpb) are the most common ophiolitic rocks in the map area. Serpentinite (sp) is exposed in a few areas juxtaposed against the mafic rocks. Keratophyre and quartz keratophyre (Jsv), consisting of highly altered intermediate to silicic volcanic and hypabyssal rocks, are also present and are thought to have originated as island arc volcanics.

Several units of the Great Valley Sequence are mapped in the study area (Graymer, 2000). The Knoxville Formation (KJk) consists of silt and clay shale with thin interbeds of sandstone. The lower part contains thick pebble to cobble conglomerate beds (KJkc). The Joaquin Miller Formation (Kjm) consists of thin-bedded shale with minor sandstone that grades into thin bedded, fine-grained sandstone at the top of the unit. The Oakland Conglomerate (Ko) consists of medium- to coarse-grained sandstone with prominent lenses of pebble to cobble conglomerate. The percentage of conglomerate is less in the Hayward Quadrangle than it is further north in the Oakland area. An unnamed unit of sandstone, conglomerate and shale of the Castro Valley area (Kcv) is widely distributed in the map area. The lower and upper boundaries of this unit are faults (Graymer, 2000). The Shephard Canyon Formation (Ksc) consists of mudstone, shale, siltstone and thin beds of fine-grained sandstone. The Redwood Canyon Formation (Kr) consists of fine- to coarse-grained sandstone with thin interbeds of mica-rich siltstone. The Pinehurst Shale (Kp) consists of siliceous shale with interbedded sandstone and siltstone. An unnamed unit of Cretaceous rocks (Ku) underlies Tertiary marine rocks along the eastern edge of the map area.

Tertiary rocks in the map area are all middle to late Miocene (Graymer, 2000) and include the following units. The Claremont Shale (Tcs) consists of brown siliceous shale with minor interbedded chert. The Oursan Sandstone (To) consists of greenish-gray sandstone with carbonate concretions. The Tice Shale (Tt) consists of brown siliceous shale. The Hambre Sandstone (Th) consists of massive, medium-grained sandstone. An undivided map unit of middle Miocene rocks (Tro) includes the Oursan Sandstone, Tice Shale, Hambre Sandstone and Rodeo Shale. The Briones Sandstone (Tbr) consists of sandstone, siltstone, conglomerate and shell breccia. The Cierbo Sandstone (Tc) consists of sandstone with minor conglomerate, tuff and shale. The Neroly Sandstone (Tn) consists of blue, gray and brown volcanic-rich sandstone with minor shale, siltstone and tuff. An unnamed unit of late Miocene rocks (Tusv) includes conglomerate, sandstone and siltstone.

Quaternary surficial geologic units are discussed in detail in Section 1 of this report.

Structural Geology

The Hayward Fault is the primary geologic structure in the study area. It is an active right-lateral strike-slip fault with an estimated late Holocene slip rate of about 9 mm per year. The Hayward Fault is undergoing active creep in the Hayward Quadrangle, as manifested by offset curbs, streets, buildings and other structures in numerous locations (Lienkaemper, 1992). Lienkaemper (1992) has mapped in detail the inferred active trace of the Hayward Fault. A variety of additional traces are shown on earlier geologic maps (Radbruch-Hall, 1974; Smith, 1980; Dibblee, 1980). Associated with the main trace are numerous splays and subsidiary traces that may accommodate secondary movements or that may be slightly older abandoned traces. Bedrock units in the vicinity of the Hayward Fault zone have been complexly offset and juxtaposed by the main trace and its associated subsidiary traces.

The Miller Creek/Palomares Fault lies east of the Hayward Fault. It is a west-vergent reverse or thrust fault that juxtaposes Mesozoic rocks of the Great Valley Complex against Miocene sedimentary rocks. Paleoseismic studies on the Miller Creek Fault indicate evidence of Quaternary displacement (Wakabayashi and Sawyer, 1998).

Between the Hayward and Miller Creek/Palomares faults, sedimentary rocks of the Great Valley Sequence generally dip steeply to the northeast and are locally overturned to the southwest. These rocks are cut by numerous faults that cut and disrupt fold axes between the Hayward Fault and Miller Creek/Palomares Fault. On the northeast side of the Miller Creek/Palomares Fault, Tertiary rocks are broadly folded and cut by widely spaced thrust faults. Several fold axes in Tertiary rocks are preserved in the eastern part of the map area.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Hayward Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping (Nilsen, 1975; Majmundar, 1996; Burnett, 1970). 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. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed landslide map was digitized and attributes for each landslide were compiled in a database.

Landslides are most abundant in the northeastern corner of the Hayward Quadrangle and along the trace of the Hayward Fault. The majority of landslides in the northeastern corner of the quadrangle occur within late Miocene unnamed sedimentary rocks (Tusv). Along the Hayward Fault, the landslides occur within a variety of map units including, from north to south, gabbro and basalt of the Coast Range Ophiolite, Franciscan Complex melange, and sedimentary rocks of the Knoxville Formation. The majority of landslides east of the Miller Creek/Palomares Fault within the Miocene sedimentary rocks are shallow soil (earth and debris) slides and flows, with a few deeper rock slides. Most of the earth flows and debris slides have been historically active. The areal distribution of landslides identified in the map area is shown on Plate 2.1.

The area between the Hayward and the Miller Creek/Palomares faults does not contain as many landslides as adjacent areas. Landslides in this area occur mostly within the sedimentary rocks of an unnamed unit in the Castro Valley area, the Joaquin Miller Formation, the Oakland Conglomerate, and another unnamed unit (Kull). About two-thirds of the landslides in this region are shallow soil (earth and debris) flows and slides. The rest are deep-seated rock slides, the majority of which occur in the sedimentary rocks of the Redwood Canyon Formation and the unnamed unit in the Castro Valley area, with some large questionable landslides mapped within the Oakland Conglomerate.

In the southern half of the map (south of Interstate 580), the distribution of landslides shown on the landslide map differs significantly from that of Nilsen (1975) and Majmundar (1996). The map by Burnett (1970) does not cover much of this area and was not compared. Along the Hayward Fault, CGS's landslide inventory map is similar to that of Nilsen (1975) and Majmundar (1996), although there are differences in interpretations of the landslides, which may, in part, result from mapping style. For example, Nilsen does not include source areas (amphitheater walls) within the landslides on his map. In some cases Majmundar included whole hillsides that appear to be susceptible to sliding, rather than separating out each individual landslide. Also, several large questionable landslides mapped in this study along the Hayward Fault, were not included in maps by the other mappers. In contrast, in the area east of the Hayward Fault, Majmundar (1996) mapped a significant number of additional small- to moderate-sized landslides, but rated many of these as questionable. In this region, the landslide map of Nilsen is also very different, depicting many small landslides that were not included in this study. Conversely, Nilsen's map does not include many of the landslides that were identified in this study.

Because it is not within the scope of the Act to review and monitor grading practices to ensure that 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 map 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 Hayward Quadrangle geologic map were obtained from the community development departments of the City of Hayward and the County of Alameda (see Appendix A). The locations of rock and soil samples taken for shear testing within the Hayward Quadrangle are shown on Plate 2.1. Shear tests from the adjoining Oakland East, San Leandro and Niles quadrangles were used to augment data for several geologic formations for which little or no shear test information was available within the Hayward Quadrangle.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean or median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1. For each geologic strength group in the map area, 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 Table 2.1 and Table 2.2. This map provides a spatial representation of material strength for use in the slope stability analysis.

Several formations were subdivided further to account for potentially greater instability on slopes with adverse bedding conditions, as discussed in the following section. Formations that were subdivided further include Kcv, Kjm, Ko, Kr, KJkc, Kull, Tcs, Tn, Tc, To and Th.

Adverse Bedding Conditions

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

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

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

Almost all beds in the map area dip more steeply than the hillslopes. Most beds dip steeper than 45 degrees. As a result, very few areas of potentially adverse bedding were identified in the map area.

Existing Landslides

As discussed later in this report, the criteria for landslide zone mapping state that all existing landslides that are mapped as definite or probable are automatically included in the landslide zone of required investigation. Therefore, an evaluation of shear strength parameters for existing landslides is not necessary for the preparation of the zone map. However, in the interest of completeness for the material strength map, to provide relevant material strength information to project plan reviewers, and to allow for future revisions of our zone mapping procedures, we have collected and 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 zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily "residual" strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, also have been used. For landslides within the Hayward Quadrangle, a residual direct shear test from the Penetencia Creek landslide on the eastern side of San Jose was used as a characteristic residual strength value for landslides. This test was performed on a well-developed landslide slip surface that was obtained from a deep borehole in the landslide mass. This test yielded an internal friction of angle (phi value) of 12 degrees.

HAYWARD QUADRANGLE
SHEAR STRENGTH GROUPS

	Formation Name	Number Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	
GROUP 1	KJk	11	32.5/32.5	32/33	621/47	KJkc(fbc)	32
	Kcv(fbc)	15	33/33			Kcg(fbc)	
	Kjm(fbc)	8	31.4/32.5			Ksc(fbc)	
	Ko(fbc)	9	34/35			Tbe	
	Kr(fbc)	3	28/33			Tbg	
	Tbr***	14	32/32			Tbi	
	Tcs(fbc)*	4	33/30			Th(fbc)	
	Tro	3	30/38			Tn(fbc)	
						To(fbc)	
						Tsso(fbc)	
GROUP 2	Jgb	15	27.9/28	28/27	633/500	KJkc(abc)	28
	Jsv	10	28.7/27			KJkv	
	KJkc(abc)	3	22/25			Kc(fbc)	
	Kcv(abc)	22	27.1/25.7			Kslto	
	Kull(fbc)	11	30.8/27			Th(abc)	
	Tcs(abc)*	3	29/30			Tn(abc)	
	Qha	13	32/30			To(abc)	
	Qhf	7	26/23			Tr(fbc)	
	Qhl	2	28/28			Tt(fbc)	
	af	31	26.8/28.5			Qa	
						Qf	
						Qhay	
						Qhc	
						Qht	
						Qhty	
GROUP 3	Jpb	5	21.4/20	22.5/22.5	815/650	Kcg(abc)	23
	KJfm	9	21.1/18			Ksc(abc)	
	Kjm(abc)	30	22.1/21.5			Tr(abc)	
	Ko(abc)	11	23/24			Tsso(abc)	
	Tusv	3	23.8/23.5			Tt(abc)	
	Qoa2	6	24.8/25			Qhff	
	Qpf	40	24.1/24			ac	
GROUP 4	Kr(abc)	12	17/13	17.3/17.5	694/480	Kc(abc)	18
	Kull(abc)	7	17.1/16				
	Qoa1	9	17.4/18				
	Qhbm	10	17.5/20				
GROUP 5	Qls	1	12	12	745		12

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength
* includes tests from Oakland East Quadrangle
** includes tests from San Leandro and Oakland East Quadrangles
*** includes tests from Niles Quadrangle

Formation name abbreviations from USGS MF-2342 (Graymer, 2000)

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

Hayward Quadrangle Strength Groups				
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**	**GROUP 5**
KJk	Jgb, Jsv	Jpb	Kr(abc)	Qls
Kcv(fbc)	KJkc(abc)	KJfm	Kull(abc)	
KJm(fbc)	Kcv(abc)	Kjm(abc)	Kc(abc)	
Ko(fbc)	Kull(fbc)	Ko(abc)	Qoa1	
Kr(fbc)	KJkc(abc)	Kcg(abc)	Qhbm	
KJkc(fbc)	KJkv, Kc(fbc)	Tusv		
Kcg(fbc)	Kslto	Tr(abc)		
Tbr, Tsc(fbc)	Tcs(abc), Th(abc)	Tt(abc)		
Tro, Tbe, Tbi	Tn(abc), To(abc)	Qoa2		
Tbg, Th(fbc)	Tr(fbc), Tt(fbc)	Qpf		
Tn(fbc, To(fbc)	Qha, Qhf, Qhl	Qhff		
Tsso(fbc)	Qa, Qf	ac		
	Qhay, Qhc, Qht			
	Qhty, af			

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

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

The Newmark analysis used in delineating the earthquake-induced landslide zones requires the selection of a design earthquake strong-motion record. Because the active Hayward Fault traverses diagonally northwestward through the central part of the Hayward Quadrangle, the selection of a strong motion record was based on the desire to simulate a large earthquake on the Hayward Fault. The Hayward Fault is a right lateral strike-slip fault with a total length of approximately 86 km, and an estimated maximum moment magnitude of 7.1 (Petersen and others, 1996). The hilly areas of the Hayward Quadrangle, which would be susceptible to earthquake-induced landsliding,lie northeast of the Hayward Fault and range from zero to about 10 km from the seismic source. Strong-motion records considered in the selection include: the CGS Strong Motion Instrumentation Program (SMIP) Corralitos record from the 1989 Loma Prieta earthquake; the Southern California Edison (SCE) Lucerne record from the 1992 Landers earthquake; and the Japan Meteorological Agency (JMA) Kobe City record from the 1995 Hyogoken-Nambu (Kobe) earthquake. The significant parameters for each of these earthquakes are listed below:

Strong-Motion Record	Moment Magnitude	Source to Site Distance (km)	PGA (g)
SMIP Corralitos	6.9	5.1	0.64
SCE Lucerne	7.3	1.1	0.80
JMA Kobe	6.9	0.6	0.82

The Corralitos record was eliminated because the fault motion was oblique, rather than purely strike-slip, and because of the relatively short rupture length. The Kobe record was eliminated because of uncertainties regarding the effects of topographic and basin-edge amplification at the recording site. Despite the slightly higher than expected magnitude, the Lucerne record from the 1992 Landers earthquake was used because it has many tectonic similarities to an earthquake on the Hayward Fault.

The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

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

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a 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 0.24g. 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 Hayward Quadrangle.

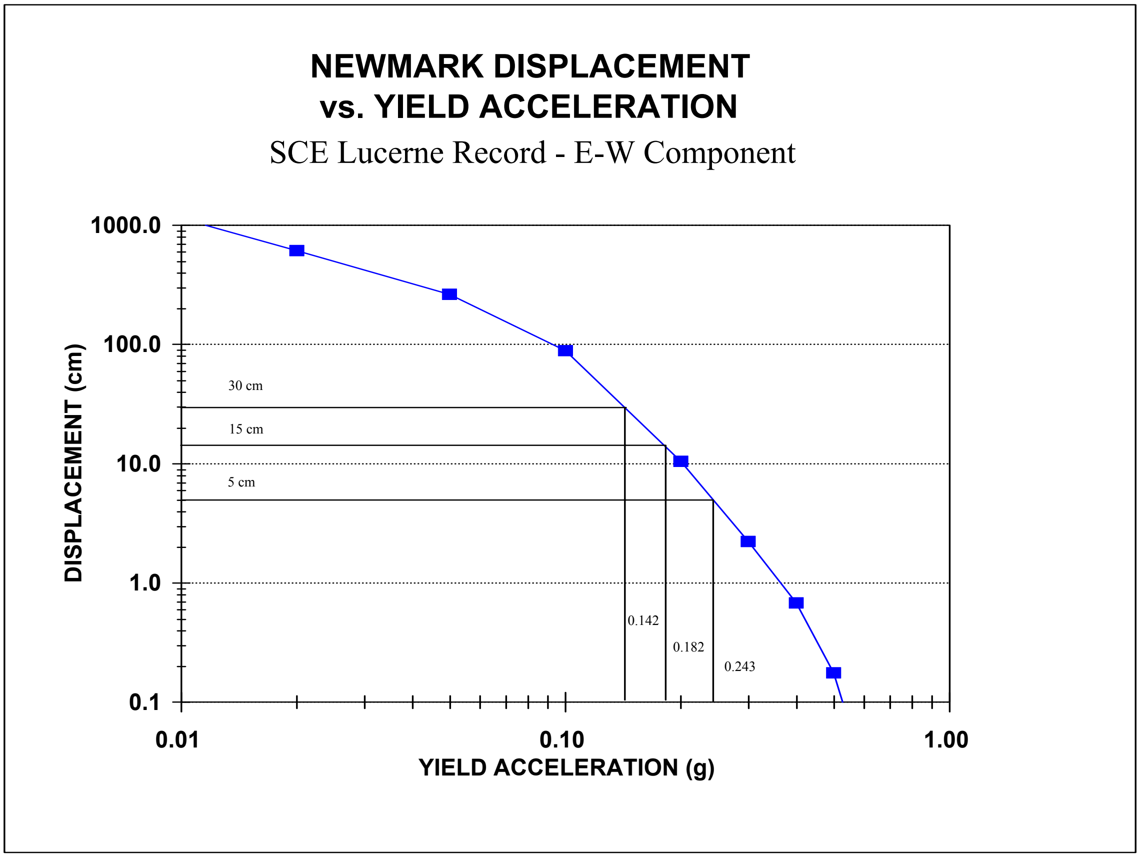

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Lucerne Record for the 1992 Landers Earthquake.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's (1965) equation:

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

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

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

1. If the calculated yield acceleration was less than 0.14g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)

2. If the calculated yield acceleration fell between 0.14g and 0.18g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)

3. If the calculated yield acceleration fell between 0.18g and 0.24g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)

4. If the calculated yield acceleration was greater than 0.24g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

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

HAYWARD QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Strength Group (Average Phi)	HAZARD POTENTIAL (Percent Slope) Very Low	Low	Moderate	High
1 (32)	0 to 37%	37 to 42%	42 to 47%	> 47%
2 (28)	0 to 27%	27 to 33%	33 to 37%	> 37%
3 (23)	0 to 18%	18 to 23%	23 to 27%	> 27%
4 (18)	0 to 7%	7 to 14%	14 to 18%	> 18%
5 (12)	0%	0 to 3%	3 to 7%	> 7%

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Hayward 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 zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

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

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

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

Existing Landslides

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

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; 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 group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 5 is included for all slope gradient categories. Strength Group 5 includes only existing landslides that are included in the zone on the basis of the preceding criterion.

2. Geologic Strength Group 4 is included for all slopes steeper than 7 percent.

3. Geologic Strength Group 3 is included for all slopes steeper than 18 percent.

4. Geologic Strength Group 2 is included for all slopes steeper than 27 percent.

5. Geologic Strength Group 1 is included for all slopes greater than 37 percent.

This results in about 22 percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the Hayward Quadrangle.

ACKNOWLEDGMENTS

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Urban assisted in the shear test data collection and data entry. Barbara Wanish and Diane Vaughan prepared the final landslide hazard zone maps and the graphic displays for this report.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
COUNTY OF ALAMEDA	184
CITY OF HAYWARD	96
CITY OF OAKLAND	32
CITY OF FREMONT	14
TOTAL NUMBER OF SHEAR TESTS	326

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Hayward 7.5-Minute Quadrangle, Alameda County, California

By

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California Geological Survey
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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 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.

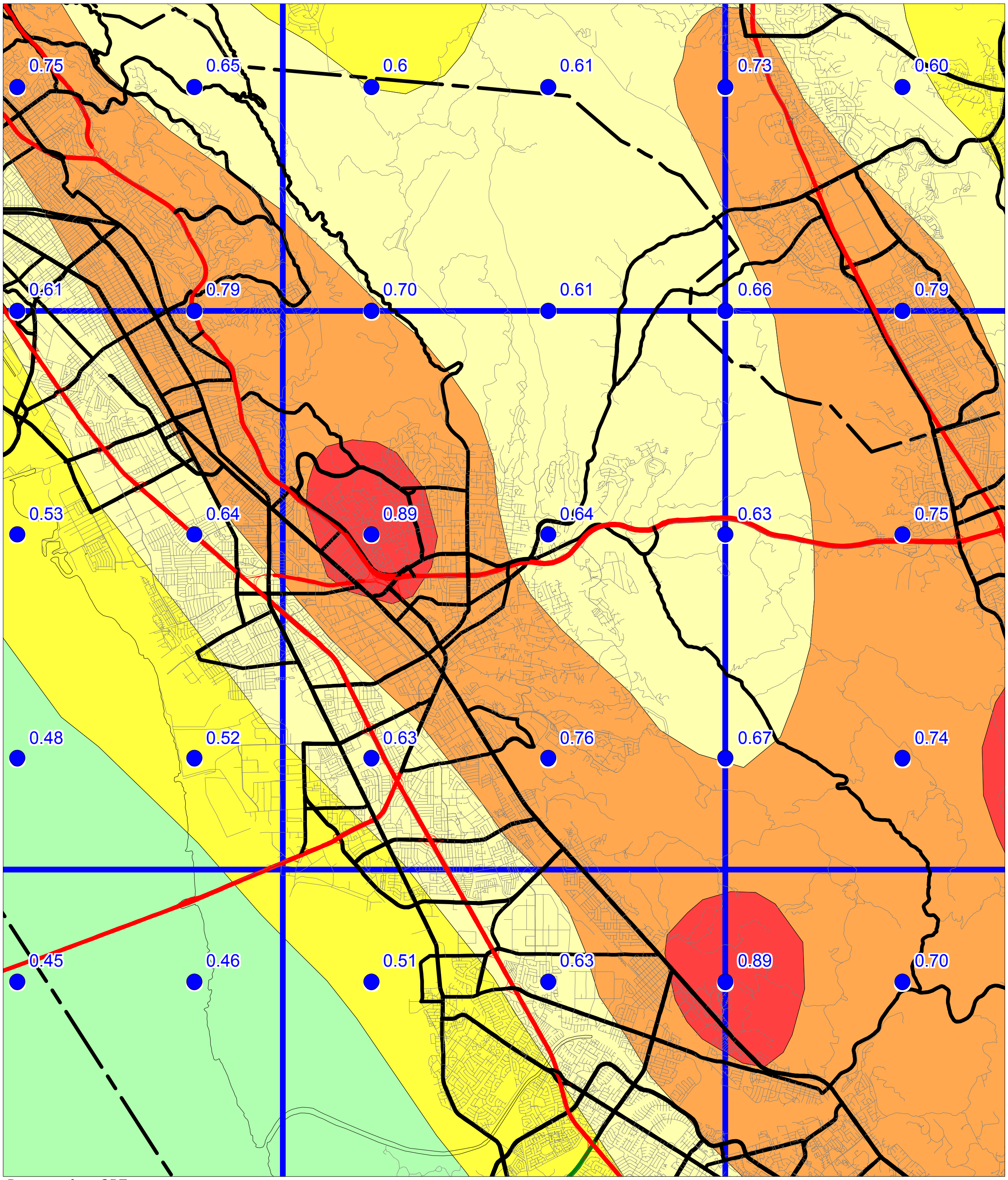
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

HAYWARD 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

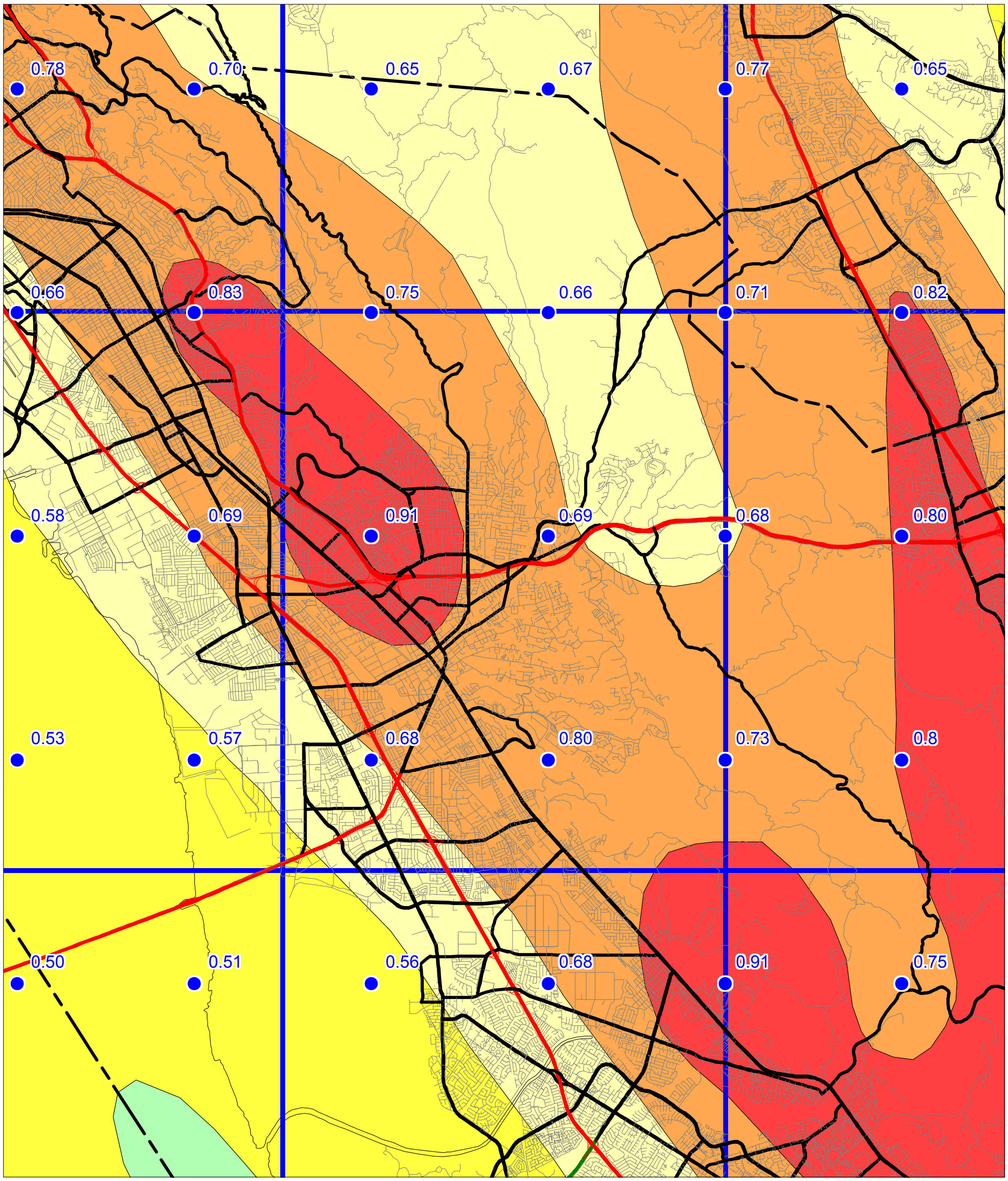
Figure 3.1

HAYWARD 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

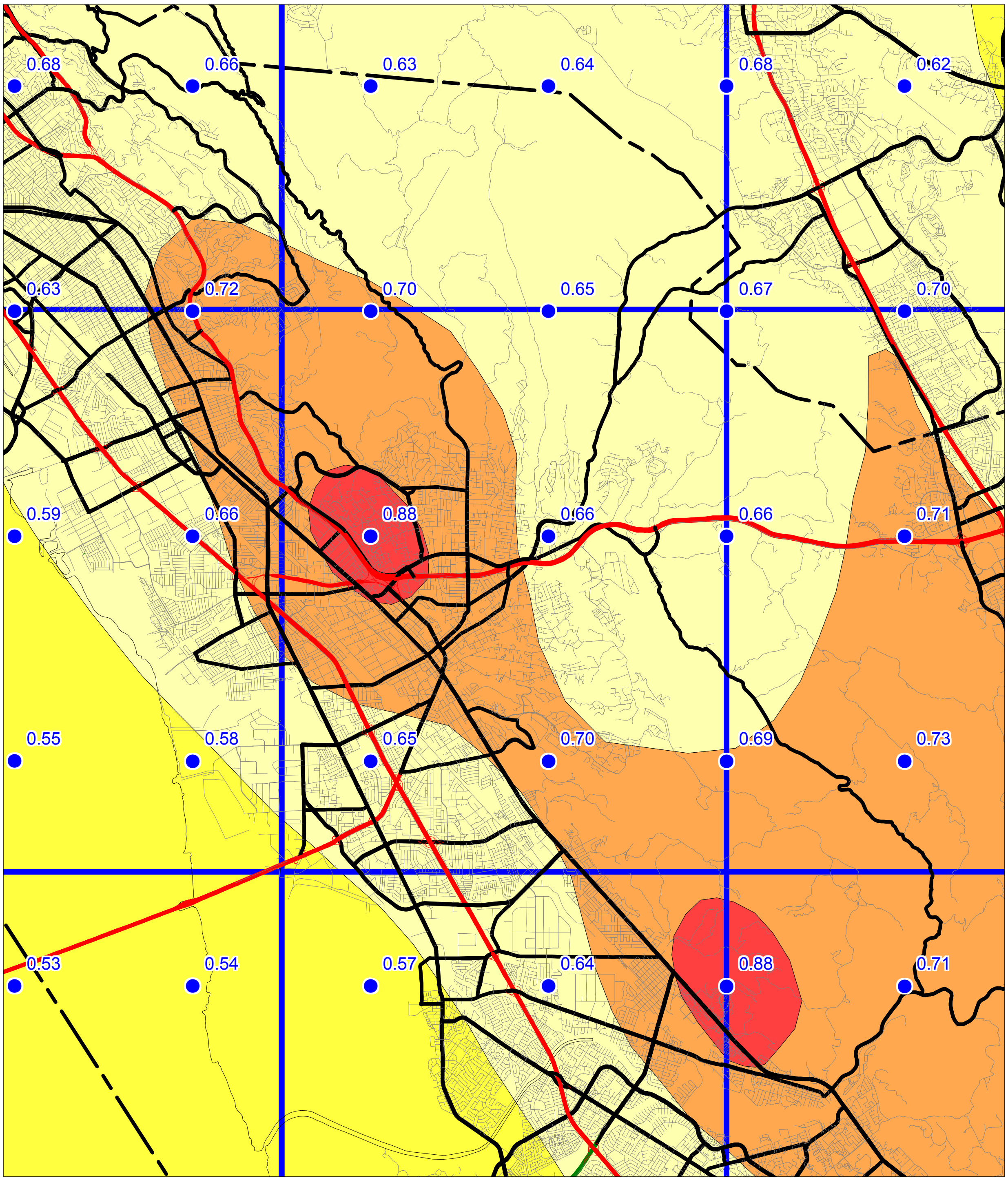
Department of Conservation
California Geological Survey

Figure 3.2

HAYWARD 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 1.5 3
Miles

Department of Conservation
California Geological Survey

Figure 3.3

adjacent 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.

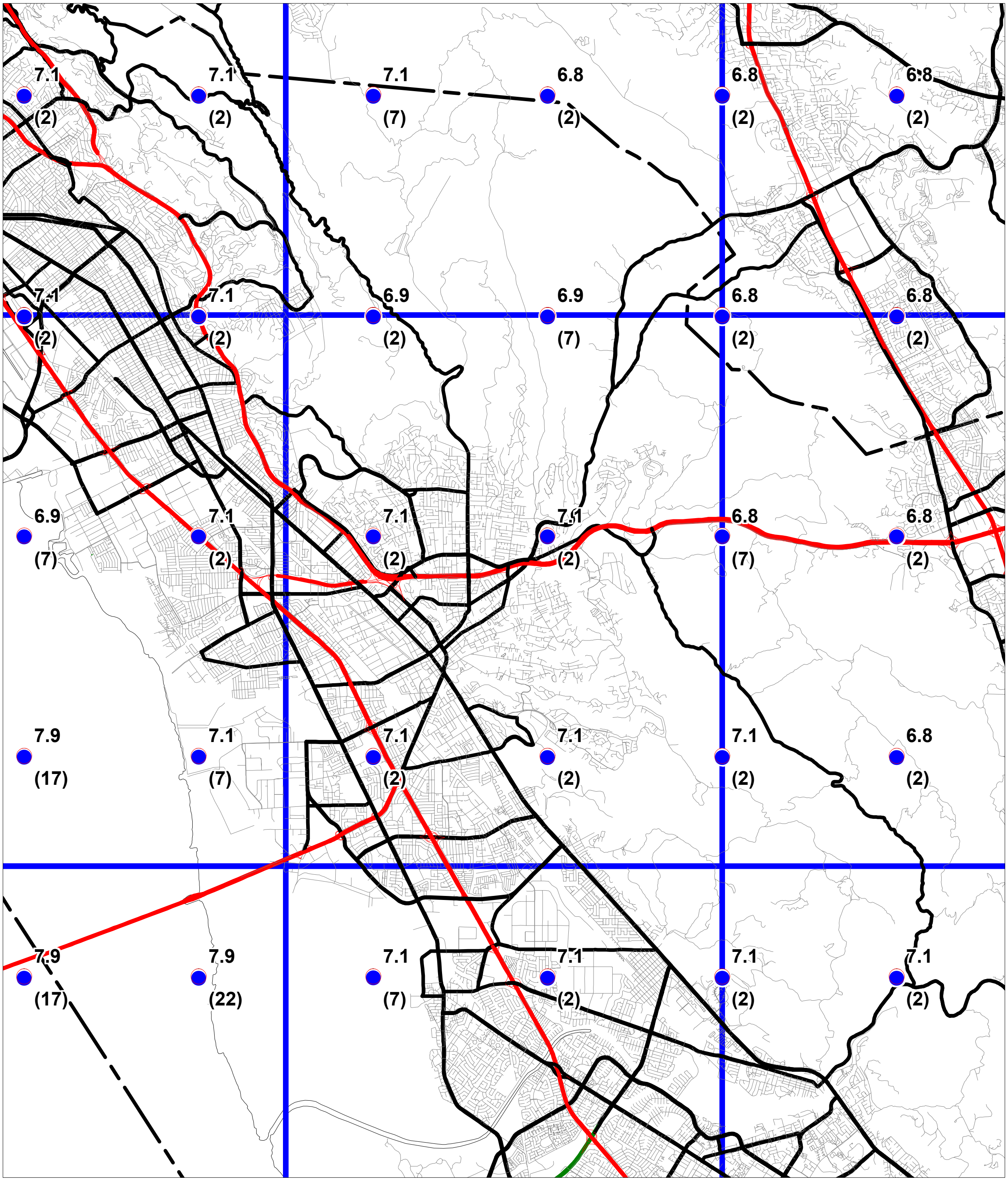
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

HAYWARD 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

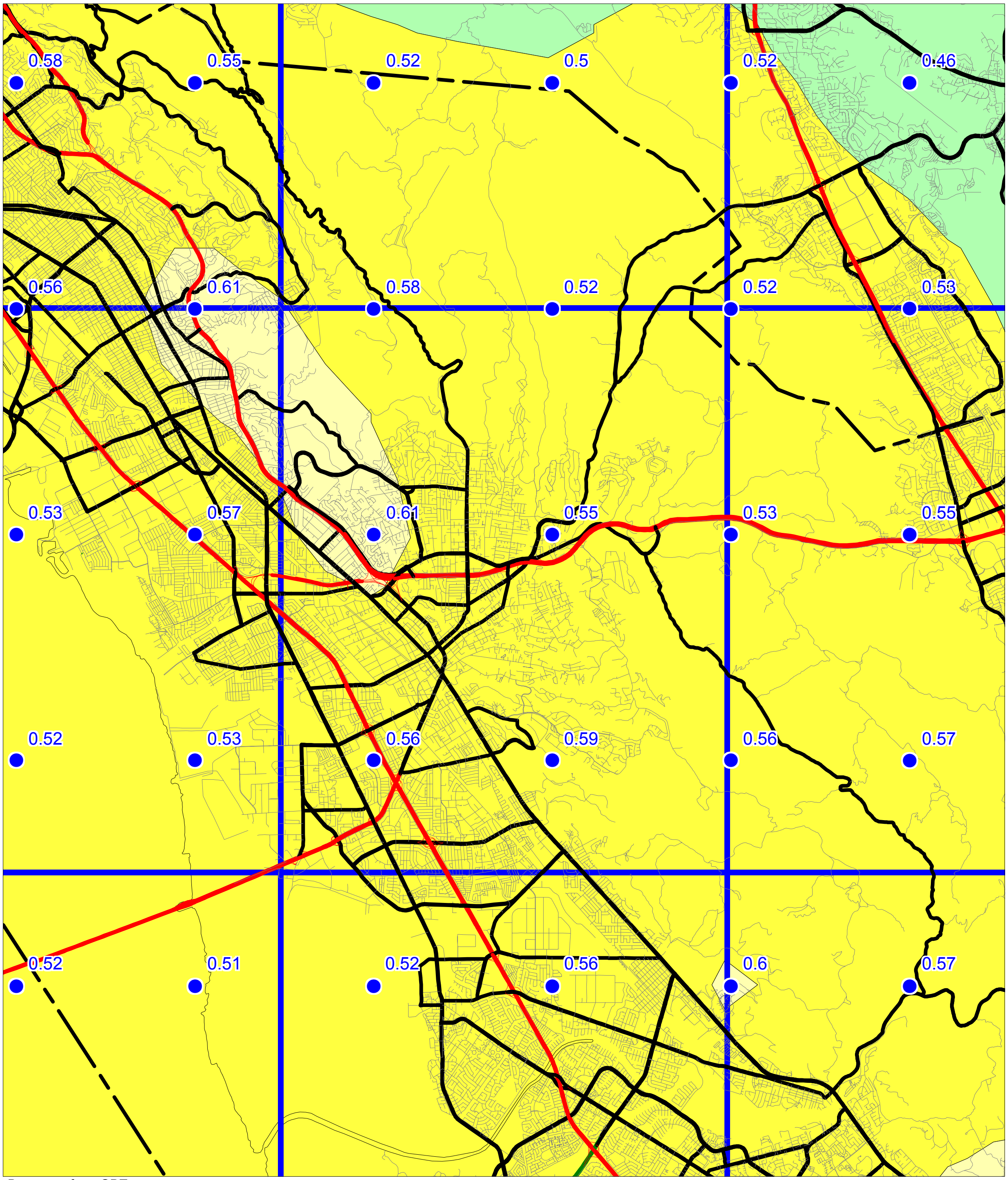
Department of Conservation
California Geological Survey
Figure 3.4

HAYWARD 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

LIQUEFACTION OPPORTUNITY



Base map from GDT

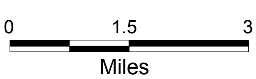


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Figure 3.5

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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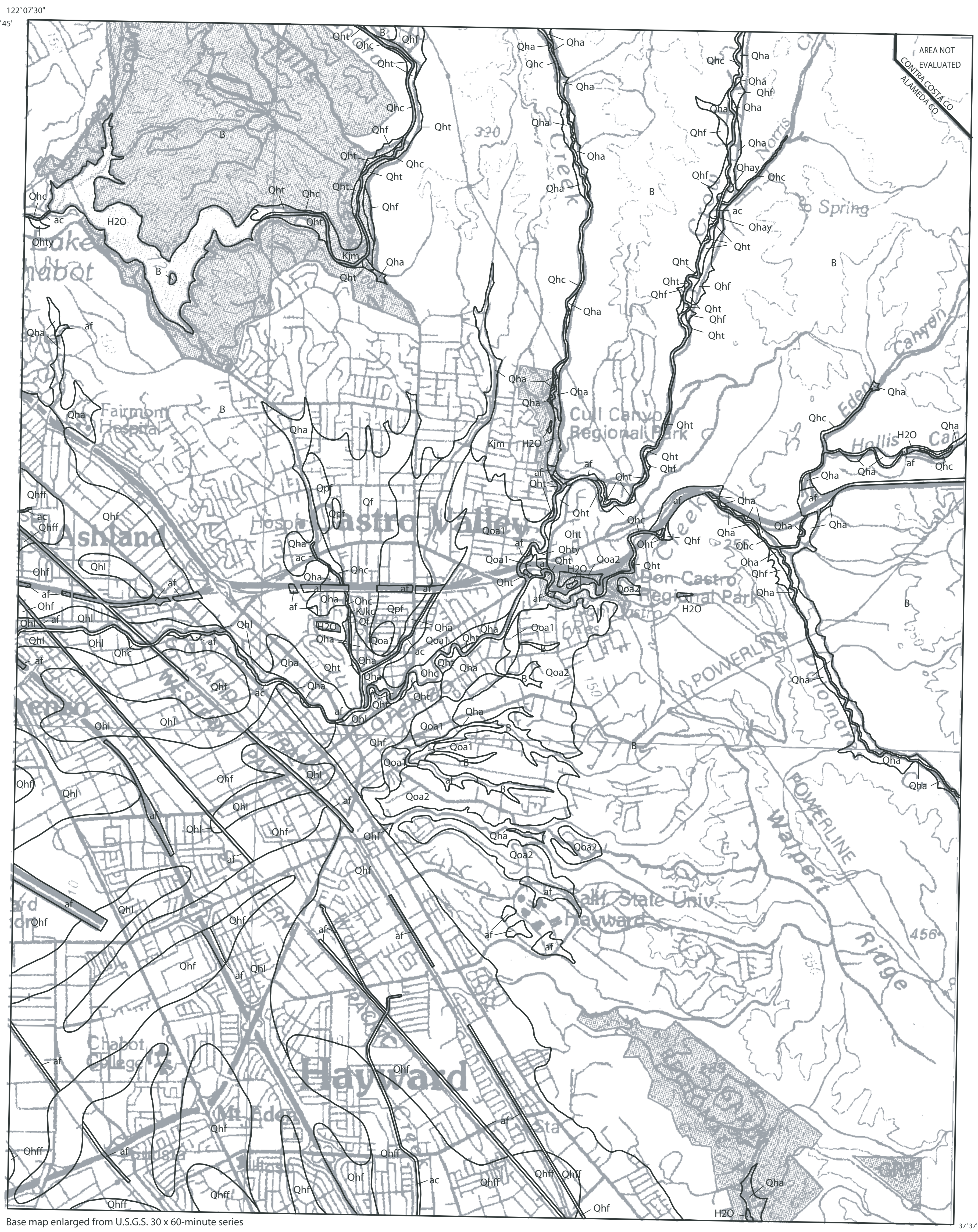
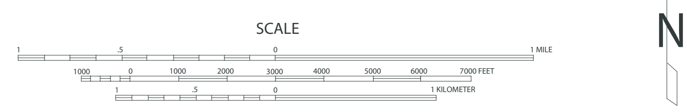
STATE OF CALIFORNIA-GRAY DAVIS, GOVERNOR
THE RESOURCES AGENCY-MARY D. NICHOLS, SECRETARY
DEPARTMENT OF CONSERVATION-DARRYL W. YOUNG, DIRECTOR



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

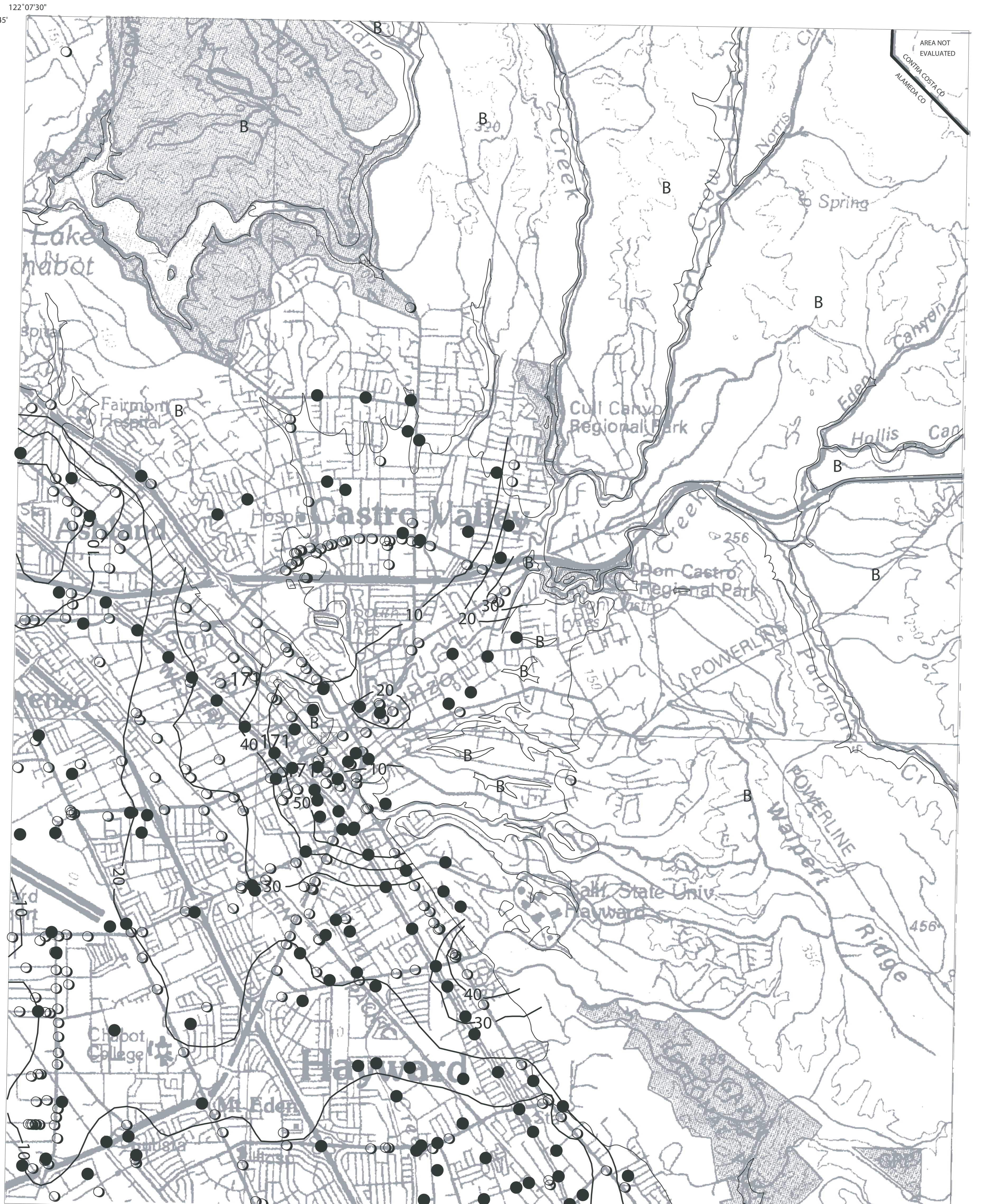
HAYWARD QUADRANGLE



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 Hayward 7.5-Minute Quadrangle, California (modified from unpublished mapping by J. Sowers, William Lettis & Associates, Inc.).



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

HAYWARD QUADRANGLE

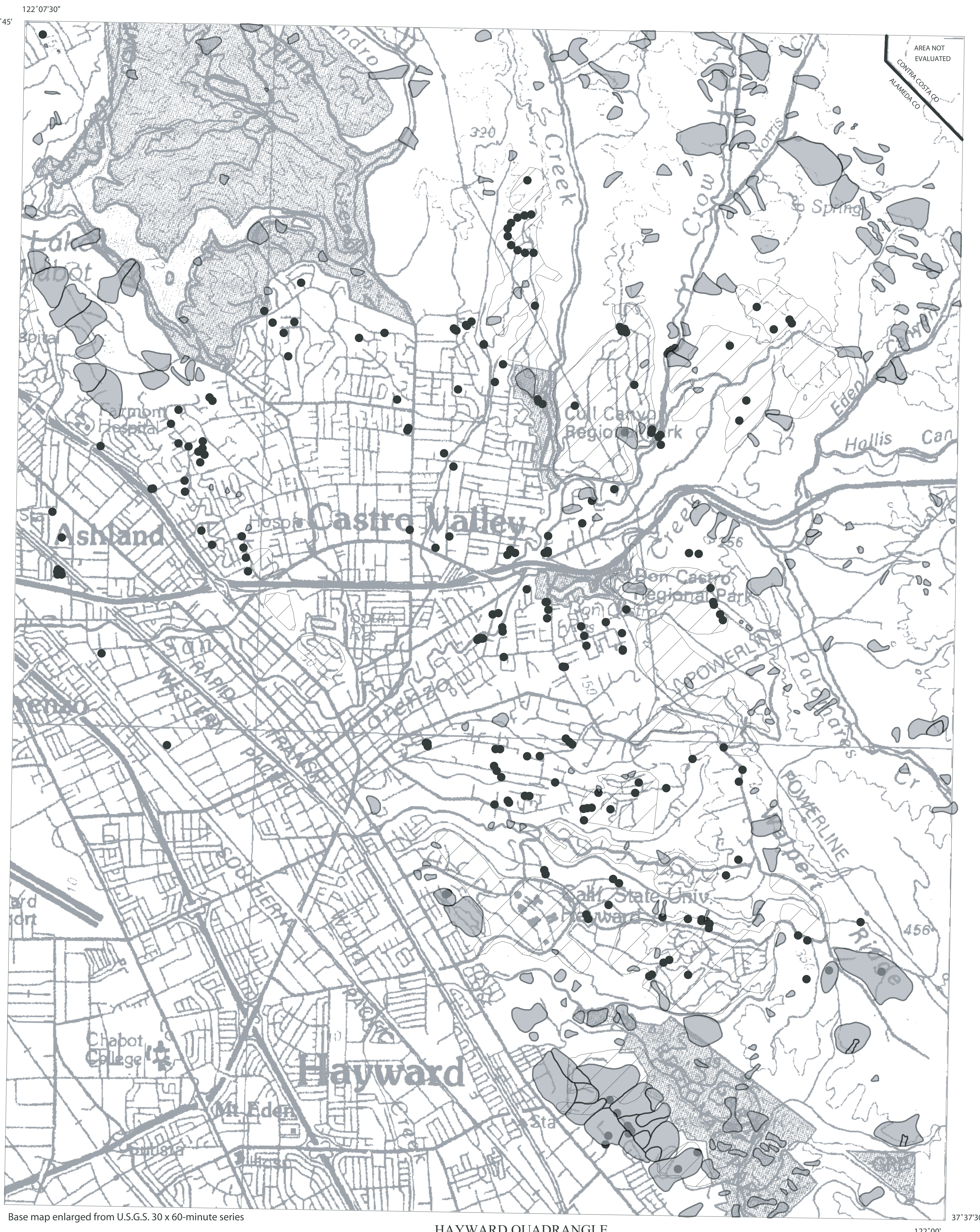
SCALE

N

Historical Ground Failures (modified from Knudsen and others, 2000)

- Miscellaneous effects
- Sand boil
- 171 — Number assigned to ground failure site (adapted from Youd and Hoose (1978) and Tinsley and others (1998) by Knudsen and others (2000))
- B — Pre-Quaternary bedrock. See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.
- —10— Depth to ground water, in feet (5, 10, 20 foot contours)
- Geotechnical boreholes used in liquefaction evaluation
- Ground-water level data provided by the California State Water Resources Control Board

Plate 1.2 Historical liquefaction sites, depth to historically high ground water, and locations of boreholes used in this study, Hayward 7.5-Minute Quadrangle, California



HAYWARD 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, Hayward7.5-Minute Quadrangle, California