SEISMIC HAZARD ZONE REPORT 051

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

2001

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Santa Clara County portion of the Milpitas 7.5-minute Quadrangle. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over approximately 40 square miles at a scale of 1 inch = 2,000 feet.

The southern two-thirds of the Milpitas Quadrangle lie within Santa Clara County along the southeastern margin of San Francisco Bay and include portions of the cities of Milpitas, Sunnyvale, Santa Clara, San Jose and unincorporated county land. Salt evaporation ponds and associated levees occupy the northwestern part of the quadrangle along San Francisco Bay. The gently sloping floor of the Santa Clara Valley, which is extensively developed for residential, commercial and industrial uses, occupies most of the map area. Interstate 80, Interstate 680, U.S. Highway 101 and State Highway 237 all cross the valley floor. The hills on the east have scattered residential developments, open ranch land and several active and inactive quarries.

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

Most of the Santa Clara County portion of the Milpitas Quadrangle is underlain by gently sloping alluvial fan and nearly flat bay mud deposits. Ground water is very shallow in this area, typically within 10 feet of the surface. These conditions result in nearly the entire area west of Interstate Highway 680 being designated as a liquefaction hazard zone. Upland terrain occupies a small area in the northeastern part of the quadrangle. A significant fraction of this upland area is included within the landslide zone because of the generally weak rock and abundant existing landslides. Greater than 50% of the limited uplands in the Santa Clara County part of the quadrangle lie within an earthquake-induced landslide hazard zone east of Interstate Highway 680.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet page: http://www.consrv.ca.gov/dmg/shezp/

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

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

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

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

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

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

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

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

SECTION 1
LIQUEFACTION EVALUATION REPORT

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

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

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Milpitas 7.5-minute Quadrangle. This section, along with Section 2 (addressing earthquake-induced landslides), and Section 3 (addressing potential ground shaking), form a report that is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on DMG's Internet web page: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in northern California. During the 1989 Loma Prieta earthquake and the 1906 San Francisco earthquake, significant damage to roads, utility pipelines, buildings, and other structures in the San Francisco Bay area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions are widespread in the San Francisco Bay Area, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard, especially in areas marginal to the San Francisco Bay, including areas in the Milpitas 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:

1. 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

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

3. Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits

4. Information on potential ground shaking intensity based on DMG probabilistic shaking maps

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

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas consist

mainly of low-lying shoreline regions, alluviated valleys, floodplains, and canyon regions. DMG's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

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

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

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Milpitas 7.5-minute Quadrangle includes approximately 60 square miles of land surface in Alameda and Santa Clara counties, along the southeastern margin of San Francisco Bay. The boundary between Alameda and Santa Clara Counties trends east-west through the northern half of the quadrangle, along Scott Creek and Coyote Creek. Approximately 20.5 square miles (33 percent of the quadrangle) along the northern boundary of the quadrangle is within Alameda County and outside the limits of the current study area. This evaluation report and accompanying Seismic Hazard Zones Map cover only that portion of the Milpitas Quadrangle that lies within Santa Clara County.

The cities of Sunnyvale and Santa Clara are in the southwestern part of the quadrangle. The northern part of the City of San Jose lies within the central part of the quadrangle and the western half of the City of Milpitas is in the eastern part of the quadrangle. The former City of Alviso, in the southwestern part of the quadrangle, is now under the jurisdiction of the City of San Jose. Salt evaporation ponds and associated levees occupy the northwestern portion of the quadrangle, along the San Francisco Bay margin. The remainder of the quadrangle is heavily urbanized.

Broad, low-lying alluvial fan deposits of the Santa Clara Valley that slope gently toward the bay dominate most of the quadrangle. A small portion of the foothills of the Diablo Range (also informally called the San Jose Foothills) occupies the northeastern corner of the quadrangle. Three perennial drainages, Coyote Creek, Saratoga Creek and the Guadalupe River, along with numerous intermittent streams, drain the Santa Clara Valley in this area. Saratoga Creek and the Guadalupe River originate in the Santa Cruz Mountains on the western margin of the Santa Clara Valley, whereas Coyote Creek drains the foothills of the Diablo Range. These drainages flow northward into the tidal marshes that delimit the active margin of San Francisco Bay.

Four freeways and several other arterial roadways cross the map area. Subparallel, north-northwesterly trending Interstate 80 and Interstate 680 are in the eastern half of the map area. U.S. Highway 101 (Bayshore Freeway) trends east-southeast, and State Highway 237 trends east-northeast in the southern half of the map area. A network of secondary roads links these major highways. The City of Milpitas operates four large, man-made, sewage treatment ponds in the center of the quadrangle.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial sedimentary deposits and artificial fill. To identify and characterize deposits susceptible to liquefaction in the Milpitas Quadrangle, recently completed maps of the nine-county San Francisco Bay Area showing Quaternary deposits (Knudsen and others, 2000) and bedrock units (Wentworth and others, 1999) were obtained from the U.S. Geological Survey in digital form. These Geographic Information Systems (GIS) maps were combined, with minor modifications along the bedrock/Quaternary contact, to form a single, 1:24,000-scale geologic map of the Milpitas Quadrangle. This map (Plate 1.1) was used to evaluate liquefaction susceptibility and develop the Seismic Hazard Zone Map.

The Quaternary geologic mapping methods described by Knudsen and others (2000) 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 DMG GIS database, with that of several previous studies performed in northern California.

Other geologic maps and reports were reviewed to evaluate the areal and vertical distribution of shallow Quaternary deposits and to provide information on subsurface geologic, lithologic and engineering properties of the map units. Among the references consulted were Crittenden (1951), California Department of Water Resources (1967), Helley and Brabb (1971), Poland (1971), Nilsen and Brabb (1972), Brown and Jackson

(1973), Cooper-Clark and Associates (1974), Rogers and Williams (1974), Atwater and others (1976), Helley and others (1979), Falls (1988), Helley and Wesling (1989), Helley (1990), Geomatrix Consultants Inc. (1992a, 1992b), Helley and others (1994), and Iwamura (1995). Limited field reconnaissance was conducted to confirm the location of geologic contacts, map recently modified ground surfaces, observe properties of near-surface deposits, and characterize the surface expression of individual geologic map units.

UNIT	Knudsen and others (2000)	Helley and Wesling (1989)	Helley and others (1994)	Helley and others (1979)	Wentworth and others (1999)	DMG GIS database
Artificial fill	af	Qha			af	af
Artificial fill over Bay Mud	afbm					afbm
Artificial fill, levee	alf					alf
Artificial stream channel	ac					ac
Modern stream channel deposits	Qhc	Qhsc	Qhsc	Qhsc	Qhc	Qhc
Latest Holocene alluvial fan deposits	Qhfy					Qhfy
Latest Holocene alluvial fan levee deposits	Qhly					Qhly
Latest Holocene stream terrace deposits	Qhty					Qhty
Holocene San Francisco Bay Mud	Qhbm	Qhbm	Qhbm	Qhbm	Qhbm	Qhbm
Holocene basin-estuarine complex deposits	Qhfe	Qhbs	Qhbs			Qhfe
Holocene alluvial fan deposits	Qhf	Qhaf, Qhfp	Qhaf, Qhfp	Qham, Qhac	Qhf, Qhfp	Qhf
Holocene alluvial fan deposits, fine grained facies	Qhff			Qhaf		Qhff
Holocene alluvial fan levee deposits	Qhl	Qhl	Qhl		Qh1	Qhl
Latest Pleistocene to Holocene alluvial fan deposits	Qf					Qf
Latest Pleistocene alluvial fan deposits	Qpf	Qpaf	Qpaf		Qpf	Qpf
Latest Pleistocene alluvium, undifferentiated	Qpa	Qpaf	Qpaf	Qpa	Qpa	Qpa
Bedrock	br		br			br

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

Bedrock exposed in the Milpitas Quadrangle consists of a sequence of marine and non-marine sedimentary rocks of late Mesozoic and middle to late Cenozoic age (Wentworth and others, 1999). The units generally consist of indistinctly bedded sandstone, conglomerate, and siltstone and are cut by a series of northwest-trending, steeply dipping, transpressional faults. See the Earthquake Induced Landslide portion (Section 2) of this report for further details.

In the Santa Clara County portion of the Milpitas Quadrangle there are 14 Quaternary map units that cover approximately 95 percent of the study area. Most of these units are non-marine in origin. The most areally extensive deposit is San Francisco Bay Mud (Qhbm), an estuarine deposit, in the northwestern portion of the quadrangle. In addition to the Quaternary deposits within the gently sloping Santa Clara Valley, a small upland valley in the foothills to the east also contains undifferentiated late Pleistocene alluvium (Qpa).

The three major drainages of the northwest-sloping Santa Clara Valley, Saratoga and Coyote creeks and the Guadalupe River, which flow northward across the valley, are the primary source of sediment deposited throughout the southern portion of the study area. Along these drainages, narrow, latest Holocene alluvial fan levee deposits (Qhly) grade laterally into latest Holocene alluvial fan (Qhfy) and fine-grained, Holocene alluvial fan deposits (Qhff) (Knudsen and others, 2000). Where drainages empty into San Francisco Bay, alluvial material grades into Holocene basin-estuarine complex deposits (Qhfe), and San Francisco Bay Mud deposits (Qhbm) (Knudsen and others, 2000). The eastern margin of the study area is characterized by greater relief and is covered by coarser-grained Holocene alluvial fan deposits (Qhf) deposited from smaller drainages emanating from the foothills. The oldest Quaternary deposits are composed of undifferentiated late Pleistocene alluvium (Qpa). These deposits are confined to two small valleys within the foothills to the northeast, above the floor of the Santa Clara Valley.

Artificial levee fill (alf), and artificial stream channels (ac) are mapped along the three major drainages. To accommodate larger flows in the winter months, portions of these watercourses have been confined within concrete-lined structures that are, locally, as much as 30 feet deep and have artificial levees along their banks in places.

Structural Geology

The Milpitas Quadrangle is within the active San Andreas Fault system, which distributes shearing across a complex system of primarily northwest-trending, right-lateral, strike-slip faults that include the Hayward and Calaveras faults. Western traces of the Calaveras Fault are within the foothills of the Diablo Range east of the quadrangle boundary. The Hayward Fault extends along the base of the foothills in the northeastern part of the quadrangle. Historical ground-rupturing earthquakes have occurred on both of these faults (Lawson, 1908; Keefer and others, 1980).

ENGINEERING GEOLOGY

Geotechnical and environmental borehole logs provided lithologic and engineering characteristics of Quaternary deposits within the study area. All materials identified in the borehole logs were assigned unit names based on the unit descriptions of Knudsen and others (2000) as well as characteristics identified in the field. Summaries of the geotechnical characteristics of the units as interpreted from the GIS database are presented in Tables 1.2 and 1.3.

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit and commonly are used as an index of density. Many geotechnical investigations record SPT data, including the number of blows by a 140-pound drop weight required to drive a sampler of specific dimensions one foot into the soil. Recorded blow counts for non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), were converted to SPT-equivalent blow count values and entered into the DMG GIS. The actual and converted SPT blow counts were normalized to a common reference effective overburden pressure of 1 atmosphere (approximately 1 ton per square foot) and a hammer efficiency of 60% using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

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, about 190 borehole logs were collected from the files of the California Department of Transportation and departments of public works and engineering in the cities of San Jose, Milpitas, and Santa Clara. Data from 148 borehole logs were entered into a DMG geotechnical GIS database (Table 1.2, Plate 1.2). This database is used to assess the susceptibility of subsurface materials to earthquake-induced liquefaction. Additional ground-water information from approximately 125 boreholes within the Milpitas Quadrangle was obtained from the Santa Clara Valley Water District, Underground Storage Tank Monitoring Program.

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit, and commonly are used as an index of density. Many geotechnical investigations record SPT data, including the number of blows by a 140-pound drop weight required to drive a sampler of specific dimensions one foot into the soil. Recorded blow counts for acceptable non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D 1586), were converted to SPT-equivalent blow count values and entered into the DMG GIS. The actual and converted SPT blow counts were normalized using an effective overburden pressure and adjusted for equipment and operational procedures using a method described by Seed and Idriss (1982) and Seed and others (1985). Different blow count corrections are used for silty sand and nonplastic silt than for clean sand (Seed and others, 1985). This normalized blow count is referred to as $(N_1)_{60}$.

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	CV (3)	Median	Min	Max	Number of Tests	Mean	CV (3)	Median	Min	Max
Af	Fine	19	105.7	0.11	107	86.0	133	36	23	0.86	16	6	94
	Coarse	5	104.5	0.10	110	86.0	113	4	20	0.60	20	9	32
Qhfy	Fine	13	99.9	0.07	103	84.0	108	19	21	0.49	16	11	43
	Coarse	1	104	-	104	104.0	104	3	17	0.83	9	9	34
Qhly	Fine	11	99.6	0.07	99	87.5	107	7	17	0.26	17	12	26
	Coarse	3	93.4	0.19	87	80.0	113	4	18	0.66	15	8	35
Qhty	Fine	3	102.2	0.11	97	95.0	115	11	32	0.76	24	10	80
	Coarse	0	-	-	-	-	-	1	9	-	9	9	9
Qhfe	Fine	3	100.3	0.07	101	93.0	107	6	12	0.59	8	6	24
	Coarse	0	-	-	-	-	-	2	5	0.25	5	4	6
Qhf	Fine	168	102.6	0.08	103	76.0	124	341	18	0.67	15	2	97
	Coarse	59	106.5	0.14	107	22.2	132	167	19	0.65	16	1	63
Qhff	Fine	57	98.7	0.09	97	75.0	120	89	21	0.58	17	4	60
	Coarse	5	105.3	0.06	107	96.1	111	10	15	0.69	12	1	33
Qhl	Fine	4	101.5	0.09	102	90.0	112	7	20	0.47	16	10	35
	Coarse	0	-	-	-	-	-	3	22	0.64	27	6	33
Qf	Fine	17	103.7	0.06	106	93.0	115	21	25	0.71	22	3	73
	Coarse	1	-	-	-	116	116	4	15	0.23	15	12	20
Qpf	Fine	59	107.0	0.13	107	85.1	195	54	19	0.80	14	3	69
	Coarse	29	115.6	0.10	114	98.5	140	49	33	0.68	29	7	89

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 (<0.074 mm); coarse soils (sand and gravel) contain a greater percentage not passing the #200 sieve.

(3) CV = coefficient of variation (the standard deviation divided by the mean).

Table 1.2. Summary of Geotechnical Characteristics for Quaternary Map Units in the Milpitas Quadrangle.

Geologic Unit (1)	Description	Number of Records	Hist. Liq. (2)	Composition by Soil Type (Unified Soil Classification System)	Depth to ground water (ft) and liquefaction susceptibility category assigned to geologic unit (3)			
					<10	10 to 30	30 to 40	>40
Af	Artificial fill (4)	43	1	CL 47%; SM 9% other 44%	VH - L	H - L	M - L	VL
Afbm	Artificial fill over Bay Mud	0	2	-	VH	H	M	VL
Alf	Artificial fill, levee	0	1	-	VH-L	H-L	M-L	VL
Ac	Artificial stream channel	1	0	GC 100%	VH-L	H	M	VL
Qhc	Modern stream channel deposits	0	2	-	VH	H	M	VL
Qhfy	Latest Holocene alluvial fan deposits	28	3	CL 50%; CH 18%; ML 14% SC 11%; other 7%	VH	H	M	VL
Qhly	Latest Holocene alluvial fan levee deposits	14	2	CL 37%; CH 21%; ML 21% SC 14%; GP 7%	VH	H	M	VL
Qhty	Latest Holocene stream terrace deposits	14	0	CL 72%; CH 7%; ML 7% SM 7%; other 7%	VH	H	M	VL
Qhbm	Holocene San Francisco Bay Mud	0	0	-	H	M	L	VL
Qhfe	Holocene fine grained alluvial fan-estuarine complex deposits	10	1	CH 30%; CL 30%; ML 30% SM-SP 5%; other 5%	H	M	L	VL
Qhf	Holocene alluvial fan deposits	511	2	CL 42%; SC 11%; SM 10% ML 8%; other 29%	H	M	L	VL
Qhff	Holocene alluvial fan deposits, fine grained facies	93	4	CL 52%; CH 26% CL-ML 5%; other 17%	M	M	L	VL
Qhl	Holocene alluvial fan levee deposits	10	0	ML 30%; CL 20% SC, SM, SW 30%; other 20%	H	M	L	VL
Qf	Late Pleistocene to Holocene alluvial fan deposits	20	0	CL 50%; CL-CH 15% Other 35%	M	L	L	VL
Qpf	Late Pleistocene alluvial fan deposits	185	0	CL 43%; SM 12%; SP 9% SW 5%; SC 5%; other 26%	L	L	VL	VL
Qpa	Latest Pleistocene alluvium, undifferentiated	0	0	-	L	L	VL	VL
B	Bedrock	n/a	n/a	n/a (5)	VL	VL	VL	VL

Notes:

(1) Susceptibility assignments are specific to the materials within the Milpitas 7.5-minute Quadrangle.

(2) Number of recorded sites with historical ground failures related to liquefaction in the Milpitas 7.5-minute Quadrangle within each map unit (Knudsen and others, 2000). See Plate 1.2 for type and location of historical ground failure effects.

(3) Based on the Simplified Seed Procedure (Seed and Idriss, 1971; Youd and Idriss, 1987) and a small number of borehole analyses for some units.

(4) The liquefaction susceptibility of artificial fill ranges widely, depending largely on the nature of the fill, its age, and whether it was compacted during emplacement.

(5) n/a = not applicable

Table 1.3. Liquefaction Susceptibility for Quaternary Map Units in the Milpitas Quadrangle. Units indicate relative susceptibility of deposits to liquefaction as a function of material type and ground-water depth within

that deposit. VH = very high, H = high, M = moderate, L = low, and VL = very low to none.

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. DMG uses the highest known ground-water levels because water levels during an earthquake cannot be anticipated because of the unpredictable fluctuations caused by natural processes and human activities. A historical-high ground-water map differs from most ground-water maps, which show the actual water table at a particular time. Plate 1.2 depicts a hypothetical ground-water table within alluviated areas.

Ground-water conditions were investigated in the Milpitas 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 cities of San Jose, Milpitas, and Santa Clara, as well as water-level data provided by the Santa Clara Valley Water District. The depths to first-encountered unconfined ground water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water (Plate 1.2). Depth to water surface in stream channels, creeks, and drainage ditches was observed in the field. Water depths from boreholes known to penetrate confined aquifers were not utilized.

DMG uses the historically highest known ground-water levels because water levels during an earthquake can not be anticipated due to the unpredictable fluctuations caused by natural processes and human activities. An historically high ground-water map differs from most ground-water maps, which show the actual water table at a particular time. Plate 1.2 depicts a hypothetical ground-water table. The Santa Clara Valley Water District recently has observed an increasing number of artesian wells, which reflects rising ground-water levels (Seena Hoose, SCVWD, oral communication, 2000). Regional ground-water contours on Plate 1.2 show historical-high water depths, as interpreted from borehole logs from 1953 through the 1990s.

Depths to first-encountered water range from 2.5 to 38 feet below the ground surface. Most of the study area has ground-water levels within 10 feet of the ground surface (Plate 1.2). The proximity to San Francisco Bay in the northwestern part of the study area influences the ground-water levels for most of the quadrangle. Ground-water levels gradually deepen towards the southeast, away from the Bay. Ground-water levels are deepest, approximately 30 feet, in the eastern portion of the study area near the base of the foothills.

PART II

LIQUEFACTION HAZARD POTENTIAL

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

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

LIQUEFACTION SUSCEPTIBILITY

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

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils)

typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

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

Most Holocene materials within the quadrangle, where water levels are within 30 feet of the ground surface, have susceptibility assignments of high (H) to very high (VH) (Table 1.3). This differs from Geomatrix's (1992) susceptibility assignments. Geomatrix (1992) mapped Holocene alluvial fan deposits having water table depths within 30 feet of the ground surface as having low susceptibility. This difference in susceptibility mapping is evident in dissimilar zone lines in the southeastern corner of the quadrangle. Holocene basin-estuarine complex deposits (Qhfe), undifferentiated Holocene alluvium (Qha) and Holocene alluvial fan fine facies deposits (Qhff) primarily are composed of fine-grained material in this area and have correspondingly lower susceptibility assignments. Undifferentiated latest Pleistocene alluvium (Qpa) in the upland valley within the foothills has a low (L) susceptibility assignment.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in DMG's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Milpitas Quadrangle, PGA's of 0.57 g to 0.73 g, resulting from earthquakes of moment magnitude 6.4 to 7.9, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996). See the ground motion portion (Section 3) of this report for further details.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-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, DMG'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. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures. The DMG liquefaction analysis program calculates an FS for each geotechnical sample for which blow counts were collected. Typically, multiple samples are collected for each borehole. The lowest FS in each borehole is used for that location. FS values vary in reliability according to the quality of the geotechnical data used in their calculation. 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 148 geotechnical borehole logs analyzed in this study (Plate 1.2), 134 include blow-count data from SPT's or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2 1/2-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Simplified Seed Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using average test values of similar materials.

The liquefaction evaluation procedures used in the Simplified Seed Procedure were 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 (N) using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant gravel content. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils 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 some 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. These tests are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations

were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

LIQUEFACTION ZONES

Criteria for Zoning

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

1. Areas known to have experienced liquefaction during historical earthquakes

2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable

4. Areas where existing geotechnical data are insufficient

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

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

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

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

Areas of Past Liquefaction

Tinsley and others (1998) compiled observations of evidence for liquefaction caused by the 1989 Loma Prieta earthquake and Youd and Hoose (1978) compiled them for the 1868 Hayward and 1906 San Andreas earthquakes. Knudsen and others (2000) have developed a digital compilation of these two previous sources. This digital database differs from earlier compilation efforts in that the observations are plotted on a 1:24,000 scale base map versus the smaller scale base maps used in the earlier publications. Site locations were reevaluated and single sites were sometimes broken into two or more where the greater base map detail allowed. These sites of past liquefaction-related ground failure are shown on Plate 1.2. The Milpitas Quadrangle contains a high density of recorded historical ground failures resulting from liquefaction.

Historical liquefaction events within the study area are concentrated within three distinct areas: 1) adjacent to the Guadalupe River; 2) adjacent to Coyote Creek; and 3) east of Coyote Creek along the east side of the Milpitas Quadrangle. In the vicinity of the Guadalupe River and Coyote Creek, ground failures caused by liquefaction are found in the following geologic map units: artificial fill (af), artificial fill over Bay Mud (afbm), artificial levee fill (alf), modern stream channel deposits (Qhc), latest Holocene alluvial fan deposits (Qhfy), latest Holocene alluvial fan levee deposits (Qhly), Holocene fine grained alluvial fan-estuarine complex deposits (Qhfe), Holocene alluvial fan deposits (Qhf) and Holocene alluvial fan deposits, fine-grained facies (Qhff) (Table 1.3). In the area on the east side of the quadrangle, ground failures caused by liquefaction are recognized in Holocene alluvial fan deposits (Qhf) and Holocene alluvial fan deposits, fine-grained facies (Qhff) (Table 1.3). Common characteristics associated with all historical liquefaction events within the Milpitas Quadrangle include young, saturated, poorly consolidated sediment.

Near the Guadalupe River, Youd and Hoose (1978) recorded historical ground failures due to liquefaction caused by the 1906 earthquake. Near Alviso, trees sliding away from the rest of an orchard and into the slough, ground fractures with muddy and/or sandy water flowing out of them, and disturbances of a railroad bed indicate ground failure characterized by lateral spread, sand boils, and settlement, respectively. Reports of disturbed wells, characterized by free-flowing water also are recorded. Within the city of Alviso, reports of a hotel sinking “at least 10 feet” indicate ground failure characterized by settlement. Tinsley and others (1998) collected additional reports of liquefaction along the Guadalupe River associated with the 1989 Loma Prieta earthquake. During the 1989 Loma Prieta earthquake, ground failure characterized by settlement occurred near the Gold Street Bridge in Alviso and to the north of today’s San Jose Municipal Airport.

In the vicinity of Coyote Creek, Youd and Hoose (1978) record a total of 9 instances of ground failure attributed to liquefaction. Reports of two instances associated with the 1868 earthquake include water pouring out of ground fractures, failures along the banks of Coyote Creek, and a rise in the level of water within Coyote Creek. Damage similar to that induced by the 1868 earthquake was recorded during the 1906 earthquake as well. Also in the vicinity of Coyote Creek, structural damage to bridge foundations and houses, and subsidence of roads indicate ground failure caused by lateral spreading and/or ground

settlement. The absence of damage or ground failures associated with the 1989 Loma Prieta earthquake was recorded in the vicinity of Coyote Creek, north of the Highway 237 bridge (Tinsley and others, 1998).

Finally, on the east side of the Milpitas Quadrangle, Youd and Hoose (1978) recorded four cases of historical liquefaction. Two instances associated with the 1868 earthquake include reports of water pouring out of ground fractures and sand boils near the City of Milpitas. Several occurrences of liquefaction during the 1906 earthquake include slumping and small ground fractures associated with lateral spreading in the vicinity of the City of Milpitas.

Artificial Fills

In the Milpitas Quadrangle, areas of artificial fill large enough to show at the scale of mapping consist of engineered fill for some river levees and elevated freeways, as well as non-engineered fill along the margin of San Francisco Bay. Engineered fills emplaced since 1965 tend to be better engineered and compacted, so zoning for liquefaction in such areas depends on soil conditions in underlying strata. Non-engineered fills are commonly loose, uncompacted fills of varying sizes and types of material. Large deposits of likely non-engineered fill exist within and along the margin of San Francisco Bay and in the area occupied by the former city of Alviso.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and reasonably sufficient lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data are evaluated for zoning based on the liquefaction potential calculated using the Simplified Seed Procedure. For Holocene alluvial deposits that cover much of the Milpitas Quadrangle, most of the borehole logs that were analyzed using the Simplified Seed Procedure contain sediment layers that may liquefy under the expected earthquake loading (Petersen and others, 1996). Table 1.2 indicates approximately 25 percent of all deposits are coarser than silt. However, nearly all boreholes within the zone contain either sandy or silty material that may liquefy under the given earthquake parameters. These areas containing saturated potentially liquefiable material are included in the zone.

Along the base of the foothills in the eastern section of the Milpitas Quadrangle, the liquefaction zone boundary is in part delineated by the depth to denser material, primarily late Pleistocene alluvial fan deposits (Qpf), and the depth to ground water. Where lower density, younger material is above the water table (i.e. unsaturated) and only denser Pleistocene material is saturated, these areas are excluded from the zone.

The areas of the Milpitas Quadrangle mapped as latest Holocene alluvial fan deposits (Qhfy), latest Holocene stream terrace deposits (Qhty), Holocene alluvial fan deposits (Qhf), and Holocene alluvial fan deposits, fine-grained facies (Qhff) are included in the zone where they are saturated above 40 feet. These units have a relatively small percentage of sandy and/or gravelly deposits; however, they do contain layers of fine

sand and silt, are young and loosely consolidated, and in many places have experienced historical liquefaction. In a fluvial environment, potentially liquefiable layers commonly are discontinuous and lens-shaped deposits, which may not have been sampled by the geotechnical investigations that were compiled in our regional analysis.

Areas with Insufficient Existing Geotechnical Data

Adequate geotechnical borehole information for Quaternary geologic units including artificial fill over Bay Mud (afbm), modern stream channel deposits (Qhc), and Holocene San Francisco Bay Mud (Qhbm) is generally lacking. Soil characteristics for these units are assumed to correspond to similar deposits where subsurface information is available. These deposits, therefore, are included in the liquefaction zone for reasons presented in criterion 4-a, above. Conversely, undifferentiated latest Pleistocene alluvium (Qpa) in an upland valley on the east side of the Milpitas Quadrangle is not included in the liquefaction zone for reasons presented in criterion 4-c, above.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

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

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Milpitas 7.5-minute Quadrangle. This section,

along with Section 1 (addressing liquefaction), and Section 3 (addressing earthquake shaking), form a report that is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet web page: http://www.consrv.ca.gov/dmg/shezp/.

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 Milpitas 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:

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

6. 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

7. 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

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

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a DMG pilot study (McCrink and Real, 1996) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Milpitas 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 Milpitas 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 Milpitas 7.5-minute Quadrangle covers approximately 60 square miles in Alameda and Santa Clara counties, along the southeastern margin of San Francisco Bay. Two-

thirds of the map area lies in Santa Clara County and includes portions of the cities of Milpitas, Sunnyvale, Santa Clara, San Jose and unincorporated parts of Santa Clara County. This report addresses earthquake-induced landslide zones only for those parts of the map that lie within Santa Clara County.

Most of the map area is occupied by the gently sloping floor of the Santa Clara Valley and by tidal marsh and salt evaporation ponds on the southeast margin of San Francisco Bay. Major streams include the Guadalupe River and Coyote Creek, which extend across the valley floor and flow into San Francisco Bay. The northeastern portion of the map area is occupied by hills on the southeast flank of the Diablo Range. The hills are drained by a system of steep stream channels that extend to the valley floor. Elevations in the map area range from sea level along the bay to a little more than 2,000 feet above sea level in the northeastern part of the quadrangle.

Much of the valley floor is developed for residential, commercial and industrial uses. Several major highways extend across the valley floor, including Interstate 80, Interstate 680, U.S. Highway 101 and State Highway 237. Tidal marshes along the shore of San Francisco Bay have been diked and converted to salt evaporation ponds in many areas. The hills have scattered residential developments, open ranchland and several active and inactive quarries.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface. Within the Milpitas Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours that are based on 1960 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

Areas that have undergone large-scale grading since 1960 in the hilly portions of the quadrangle were updated to reflect the new topography. Terrain data reflecting this recent grading, in the form of digital contours, was obtained from the City of Milpitas. The original data was derived from low altitude photography flown in 1995. The contour data were converted into a DEM format and merged with the USGS DEM. The new DEM data covers most of the hilly areas of the Milpitas Quadrangle. However, two areas were not included in the new DEM and were not updated for this project. The first is the large active quarry area south of Scott Creek Road and north of Calera Creek. The other is the landfill area along Coyote Creek in otherwise flat terrain northwest of the City of Milpitas. The portion of the quadrangle where City of Milpitas terrain data was used is shown on Plate 2.1.

A slope map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The DEM 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 bedrock geologic mapping used in this slope stability evaluation was obtained from the digital database "Preliminary Geologic Map of the San Jose 30 x 60 minute Quadrangle" prepared by the U.S. Geological Survey (Wentworth and others, 1999). A 1:24,000-scale digital geologic map of the Milpitas 7.5-minute Quadrangle was obtained from this database. Knudsen and others (2000) prepared a surficial geologic map for the Milpitas Quadrangle also at a scale of 1:24,000. Surficial geology is discussed in detail in Section 1 of this report.

DMG geologists merged digital versions of 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 reconnaissance was performed to assist in adjusting contacts and to review the lithology of geologic units and geologic structure.

Bedrock sequences in the 30 x 60 Minute San Jose Quadrangle have been divided into eight individual fault-bounded structural blocks based on differing stratigraphic sequences and geologic histories (Wentworth and others, 1999). One of these structural blocks, the Alum Rock Block, extends into the Milpitas 7.5-Minute Quadrangle. The following descriptions of bedrock units exposed in the Milpitas Quadrangle are based primarily on the work of Wentworth and others (1999), supplemented by observations made during field reconnaissance by DMG geologists.

The Alum Rock Block consists of Jurassic through Quaternary strata that were deposited on the Jurassic Coast Range Ophiolite and associated intermediate and silicic volcanic rocks (Wentworth and others, 1999). Franciscan melange of Cretaceous age occurs as small fault-bounded slivers that are juxtaposed against the Coast Range Ophiolite. The ophiolitic rocks and melange are overlain by Cretaceous rocks that are in turn overlain by Middle Miocene through Quaternary rocks and sediment. The Alum Rock Block is cut by a system of strike-slip and transpressional faults that displace units as young as Holocene. Bedrock units exposed within the Milpitas 7.5-minute Quadrangle are described below.

The Cretaceous Berryessa Formation is the oldest bedrock unit exposed in the map area. The Berryessa Formation is part of the Great Valley Sequence and is divided into a basal conglomerate unit (Kbc) and an overlying sandstone and mudstone unit (Kbs) (Wentworth and others, 1999). The conglomerate (Kbc) occurs as thick, indistinct beds with pebble, cobble, and occasional boulder clasts, intercalated with coarse-grained mica-quartz-lithic wacke. Clasts include silicic to intermediate volcanic rocks, black chert and argillite, quartz, mica schist, meta-andesite, granodiorite and granite, black hornfels, and rip-up clasts of mudstone and lithic wacke. The sandstone and mudstone unit (Kbs) consists of layers of massive, indistinctly bedded, coarse- to fine-grained, mica-quartz-lithic wacke interbedded with poorly bedded mica-bearing siltstone and claystone. Locally, small lenses of conglomerate occur within the sandstone and mudstone unit.

The Middle to Upper Miocene Claremont Formation (Tcc) is the oldest Tertiarty unit in the map area and unconformably overlies the Mesozoic rocks of the Alum Rock Block. The Claremont Formation primarily consists of interbedded chert and siliceous shale (Wentworth and others, 1999). Siltstone and fine-grained quartz sandstone are present locally.

The Upper Miocene Briones Formation (Tbr) unconformably overlies the Claremont Formation. It consists of interbedded sandstone and siltstone, shell-hash conglomerate, cross-bedded sandstone, and occasional pebble and cobble conglomerate beds (Wentworth and others, 1999). The lower part is thin-bedded, fine-grained sandstone and shale interbedded with thick, massive sandstone beds. Indistinctly bedded conglomeratic shell beds occur in the middle part of this unit and are characteristic of this formation. The shell-rich beds typically form prominent ridges and peaks due to a resistant calcareous matrix. The upper part of the unit consists of distinctly to indistinctly bedded, massive to cross-bedded, fine- to coarse-grained sandstone.

The non-marine Upper Miocene Orinda Formation (Tor) unconformably overlies the Briones Formation. It is comprised of non-marine pebble to boulder conglomerate, conglomeratic sandstone, and coarse- to medium-grained lithic sandstone (Wentworth and others, 1999).

The Plio-Pleistocene Irvington Gravels (QTi) consist of poorly to well-consolidated sand and sandy conglomerate. These deposits are exposed in the lower foothills along the margins of the Santa Clara Valley.

Unconsolidated Quaternary deposits underlie the floor of the Santa Clara Valley as well as small valleys in the hillside areas. A detailed discussion of Quaternary units can be found in Section 1.

Structural Geology

The Mesozoic and Tertiary bedrock units in the Milpitas Quadrangle are strongly deformed by faults and folds. Most of the major faults and fold axes trend in a northwesterly direction. Sedimentary units generally dip moderately to steeply to the northeast and locally are overturned (Dibblee, 1972). A prominent northwest-trending syncline extends through the northeast corner of the map area. Resistant ridge-forming beds of the Briones Formation are exposed on the limbs of this syncline. Weak landslide-prone beds of the Orinda Formation are exposed in the core of this syncline. Major faults in the study area include strike-slip and transpressive faults (Graymer, 1995). Faults with the most recent displacements in the region are the Hayward and Calaveras faults. These faults are predominantly right-lateral strike-slip faults with active seismicity and Holocene displacement. The southernmost part of the Hayward Fault extends into the map area whereas the Calaveras Fault lies a few miles east of the map area. Transpressional faults include the Warm Springs and Mission Peak faults.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Milpitas Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping. Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map a number of characteristics were compiled. These characteristics included 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, and landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence.

The distribution of landslides mapped for this study is roughly similar to that mapped by Nilsen (1975). However, Nilsen mapped the landslide deposits and did not include the source areas as part of his mapped landslide features. In some areas, there are some significant differences in interpretation between DMG's inventory and that of Nilsen. Landslides mapped for this inventory generally include landslide deposits mapped by Wentworth and others (1999), with some modifications.

Landslides are relatively abundant in the hillside areas in the northeast part of the Milpitas Quadrangle. In particular, landslides are common on slopes underlain by the Orinda Formation (Tor) and on some slopes underlain by the Irvington Gravels (QTi). Landslides identified in the map area are shown on Plate 2.1.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the Milpitas geologic map were obtained from the City of San Jose, the County of Santa Clara, the City of Milpitas and the City of Fremont (see Appendix A). The locations of rock and soil samples taken for shear testing by consultants are shown on Plate 2.1. Shear tests from the adjoining Calaveras Reservoir, San Jose East and Niles Quadrangles were used to augment data for several geologic formations for which little or no shear test information was available within the Milpitas 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 and median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1. For most of the geologic strength groups in the map area, a single shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was

made based on the groupings presented in Tables 2.1 and 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

MILPITAS 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	Phi Values Used in Stability Analyses
GROUP 1	Tbr(fbc)	5	37/32	37/32	807/278		37
GROUP 2	Tbr(abc)	9	30/32	30/32	873/750		32
GROUP 3	Kbs Tcc QTi Q*	20 19 112 37	22/21 22/20 21/19 22/21	21/20	831/740	ac af	21
GROUP 4	Tor	24	19/17	19/17	1040/970	afbm Qhbm	17
GROUP 5	Qls	1	12		745		12

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength
Q* = Quaternary units except Bay Mud (Qhbm & afbm

Geologic formations for strength groups from Wentworth and others, 1999, except Qls which is from landslide inventory prepared for this study

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

SHEAR STRENGTH GROUPS FOR THE MILPITAS 7.5-MINUTE QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Tbr(fbc)	Tbr(abc)	Kbs Tcc QTi Q* ac	Tor Qhbm afbm	Qls

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength
Q* = Quaternary units except Bay Mud (Qhbm & afbm)

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

Adverse Bedding Conditions

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

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

The Briones Formation, which contains interbedded sandstone and shale, was subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) rocks. Shear strength values for the fine- and coarse-grained rocks were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material (higher strength) dominates where bedding dips into a slope (favorable bedding) while fine-grained (lower strength) material dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. The favorable and adverse bedding shear strength parameters for the Briones Formation is included in Table 2.1.

Existing Landslides

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount 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. Within the Milpitas Quadrangle, only one direct shear test of landslide slip surface materials was obtained, and the results are summarized in Table 2.1.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

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

Modal Magnitude:	6.5 – 7.9
Modal Distance:	2.8 – 17.1
PGA:	0.54 – 0.96 g

The strong-motion record selected for the slope stability analysis in the Milpitas Quadrangle is the Corralitos record from the 1989 magnitude 6.9 (M_w) Loma Prieta earthquake (Shakal and others, 1989). This record had a source to recording site distance of 5.1 km and a peak ground acceleration (PGA) of 0.64. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

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

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.086, 0.133 and 0.234g. 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 Milpitas Quadrangle.

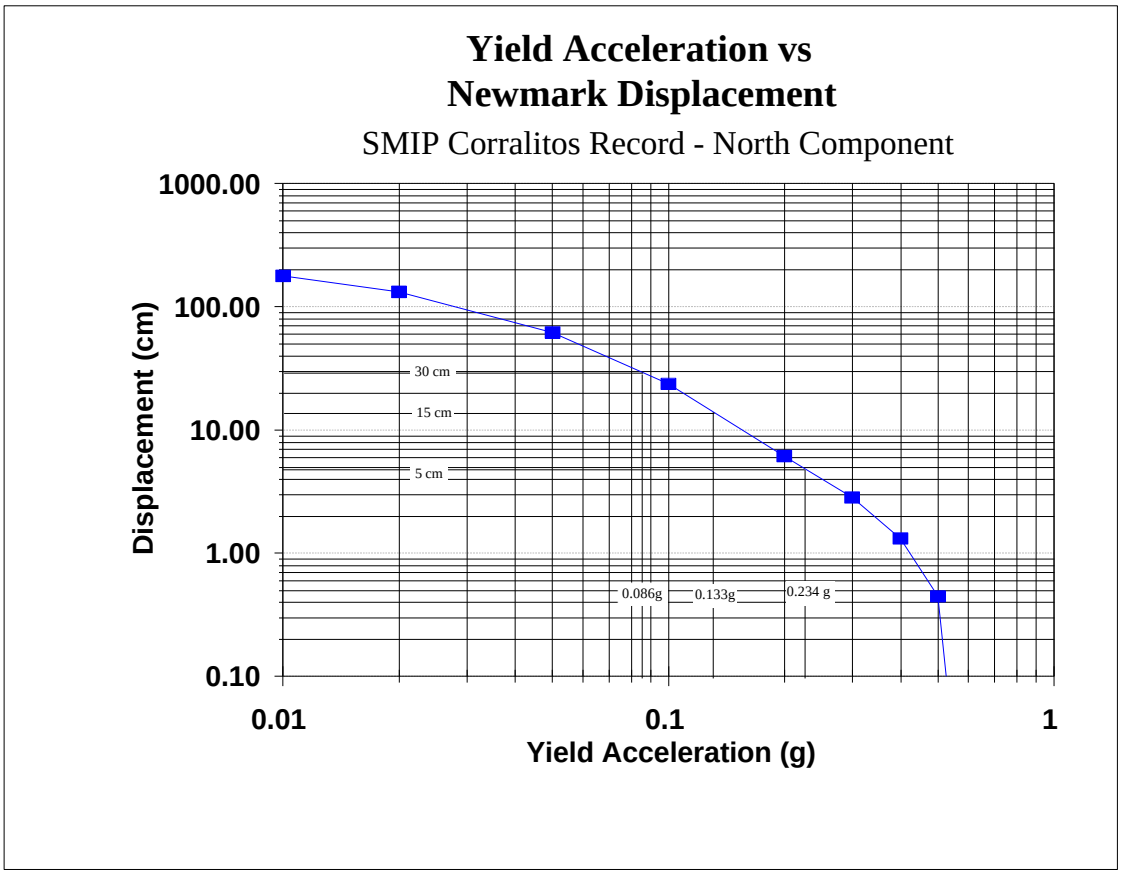

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the 1989 Loma Prieta Earthquake Corralitos Record. Record from California Strong Motion Instrumentation Program (CSMIP) Station 57007.

Slope Stability Analysis

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

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

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

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

1. If the calculated yield acceleration was less than 0.086g, 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 0.086g and 0.133g, 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 0.133g and 0.234g, 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 0.234g, 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.

				MILPITAS QUADRANGLE						
				HAZARD POTENTIAL MATRIX						
					SLOPE CATEGORY (% SLOPE)					
GEOLOGIC										
STRENGTH	MEAN	I	II	III	IV	V	V	VI	VII	VIII
GROUP	PHI	0 to 9%	9 to 15%	15 to 23%	23 to 30%	30 to 38%	38 to 49%	49 to 53%	53 to 67%	> 67%
1	37	VL	VL	VL	VL	VL	VL	L	M	H
2	32	VL	VL	VL	VL	VL	L	M	H	H
3	27	VL	VL	L	M	H	H	H	H	H
4	17	VL	L	M	H	H	H	H	H	H
5	12	L	M	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Milpitas Quadrangle. Shaded area indicates hazard potential levels included within the zone of required investigation. H = High, M = Moderate, L = Low, VL = Very Low.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

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

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

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

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

Existing Landslides

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

probable confidence rating are included within the earthquake-induced landslide hazard zone.

Geologic and Geotechnical Analysis

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

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

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

2. Geologic Strength Group 4 is included for all slopes steeper than 9 percent.

3. Geologic Strength Group 3 is included for all slopes steeper than 15 percent.

4. Geologic Strength Group 2 is included for all slopes steeper than 38 percent.

5. Geologic Strength Group 1 is included for all slopes greater than 49 percent.

Although this results in only 2.2 % of the Santa Clara County land in the quadrangle lying within the landslide hazard zone, more than 50% of the small area of hilly terrain is within the zone.

ACKNOWLEDGMENTS

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AIR PHOTOS

WAC Corporation, Inc. dated 4-12-85, Flight No. WAC85CA, Photos 12-231 through 234, 12-2 through 12-6

WAC Corporation, Inc. dated 4-13-99, Flight No. WAC-C-99CA, Photo Nos. 2-20 through 24, 6-60 through 65, 6-123 through 128.

APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE*	NUMBER OF TESTS SELECTED
City of Milpitas	78
City of Fremont	24
City of San Jose	10
Total Number of Shear Tests	112

*Note: Shear test data from adjoining Calaveras Reservoir and Niles quadrangles used for some units for which we obtained little or no shear test data in the Milpitas Quadrangle

SECTION 3
GROUND SHAKING EVALUATION REPORT

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

By

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

California Department of Conservation
Division of Mines and Geology
***Formerly with DMG, now with U.S. Geological Survey**

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps),

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

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

EARTHQUAKE HAZARD MODEL

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

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

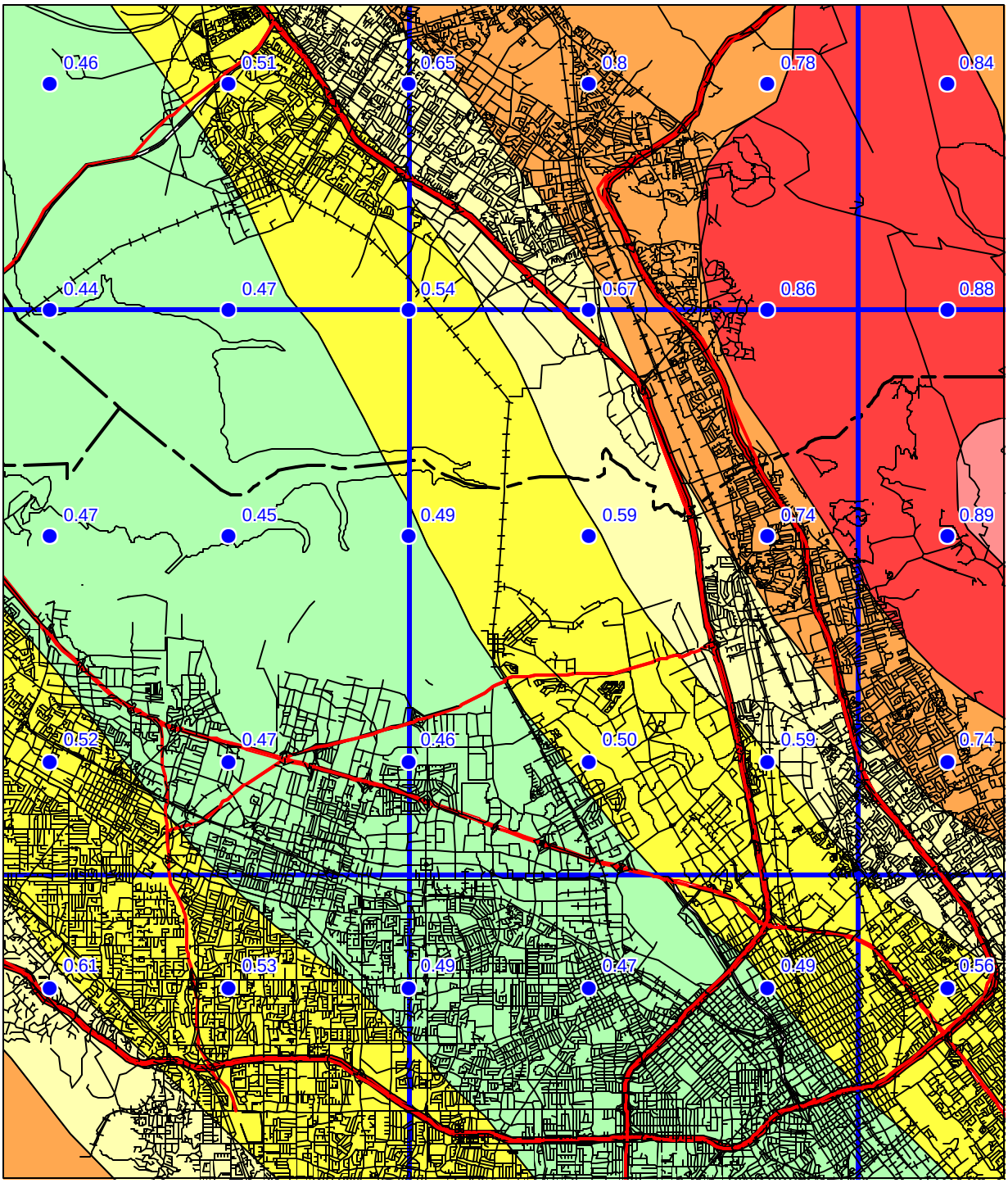
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

MILPITAS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

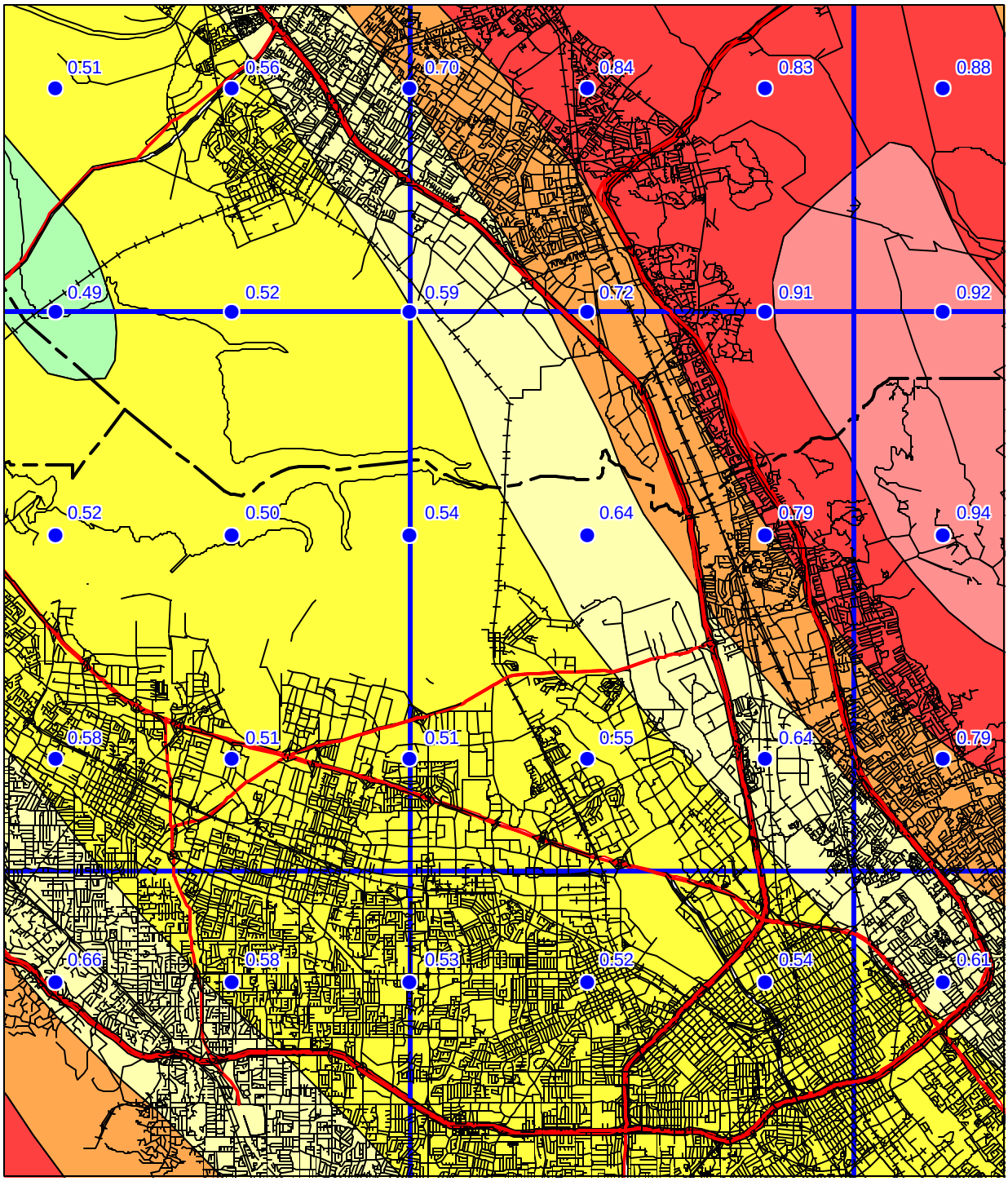
Figure 3.1

MILPITAS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

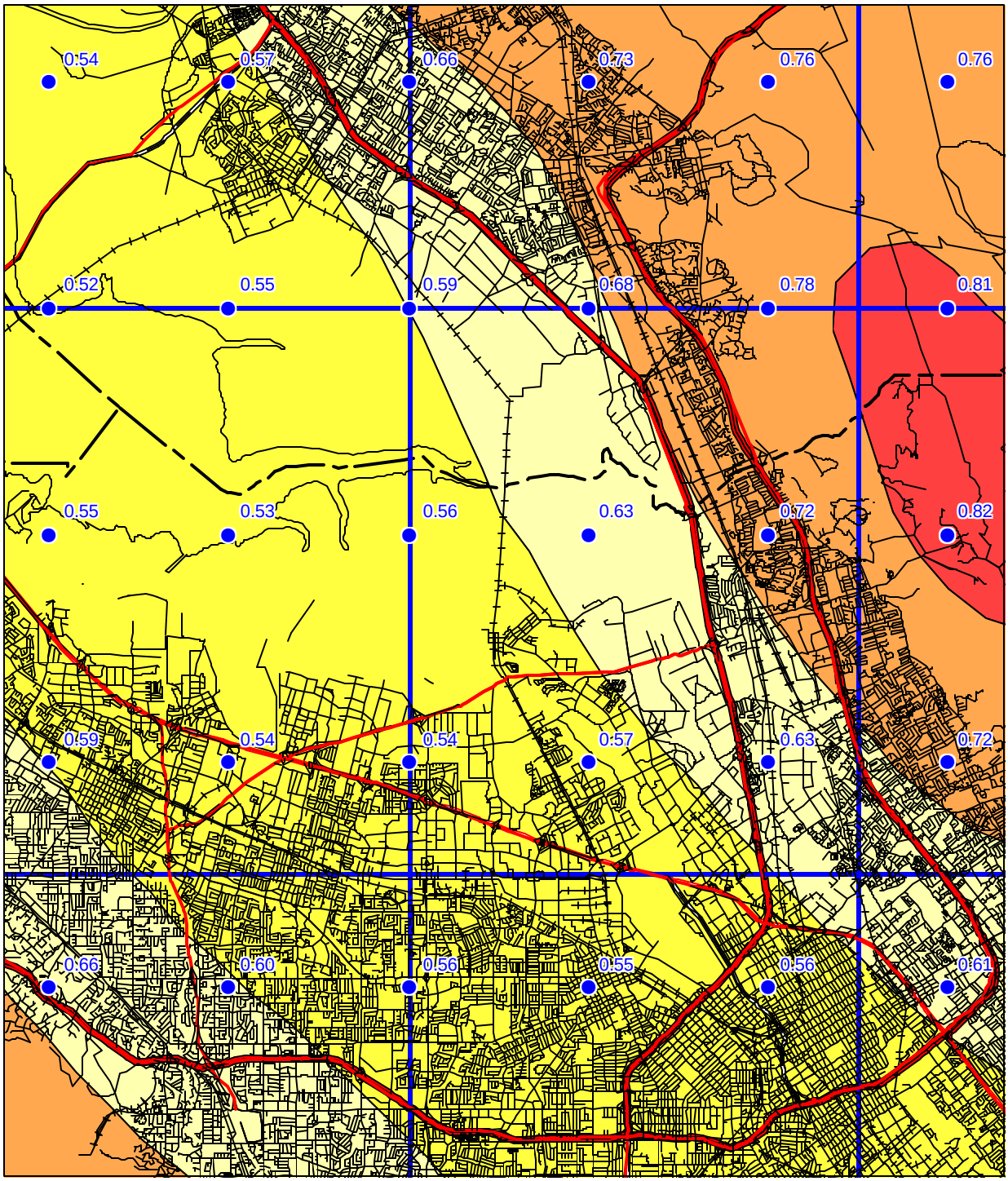
Figure 3.2

MILPITAS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works © 1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.3

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

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

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

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

MILPITAS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

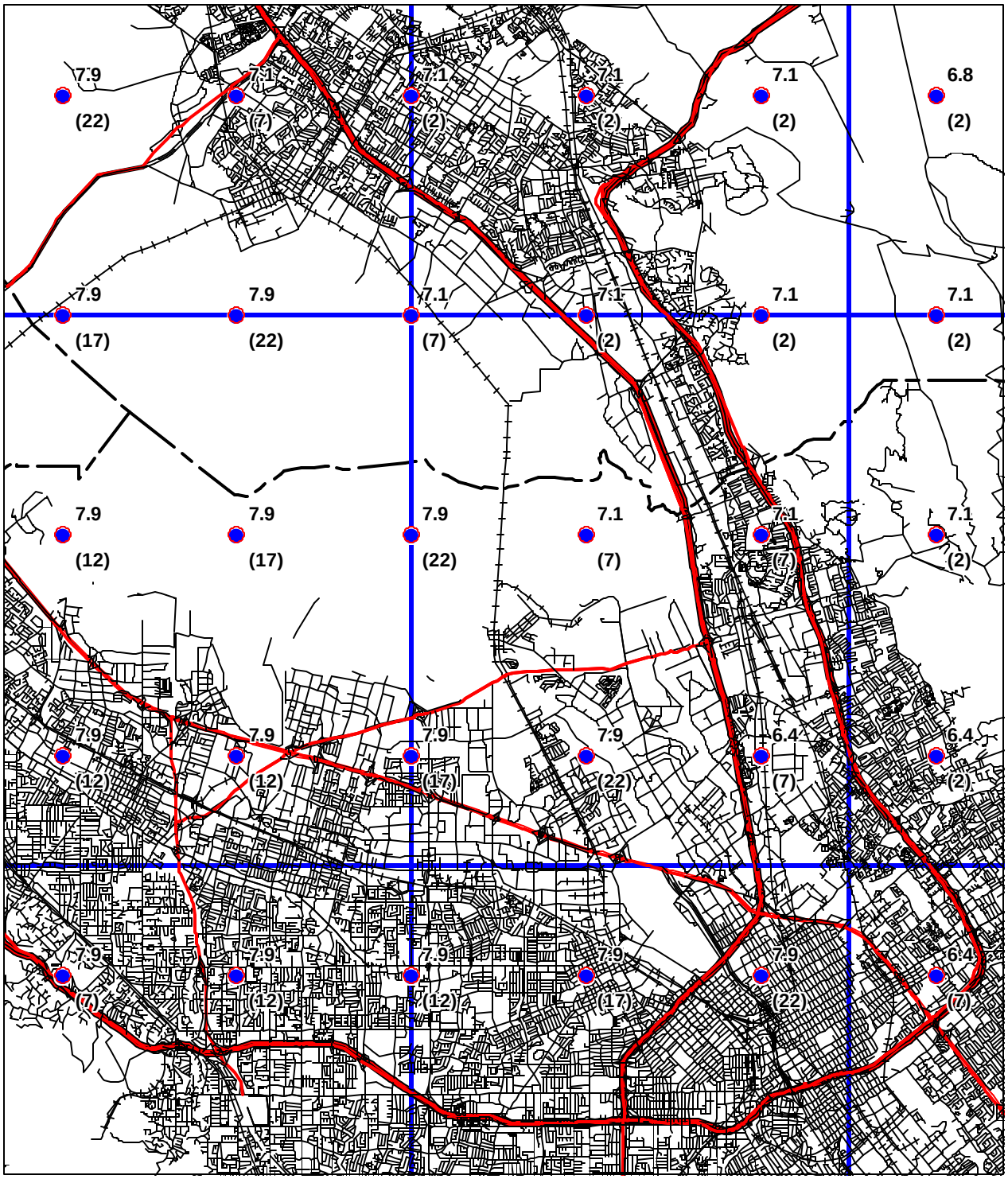
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)

(Distance (km))



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology
Figure 3.4

of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

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

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

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

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

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

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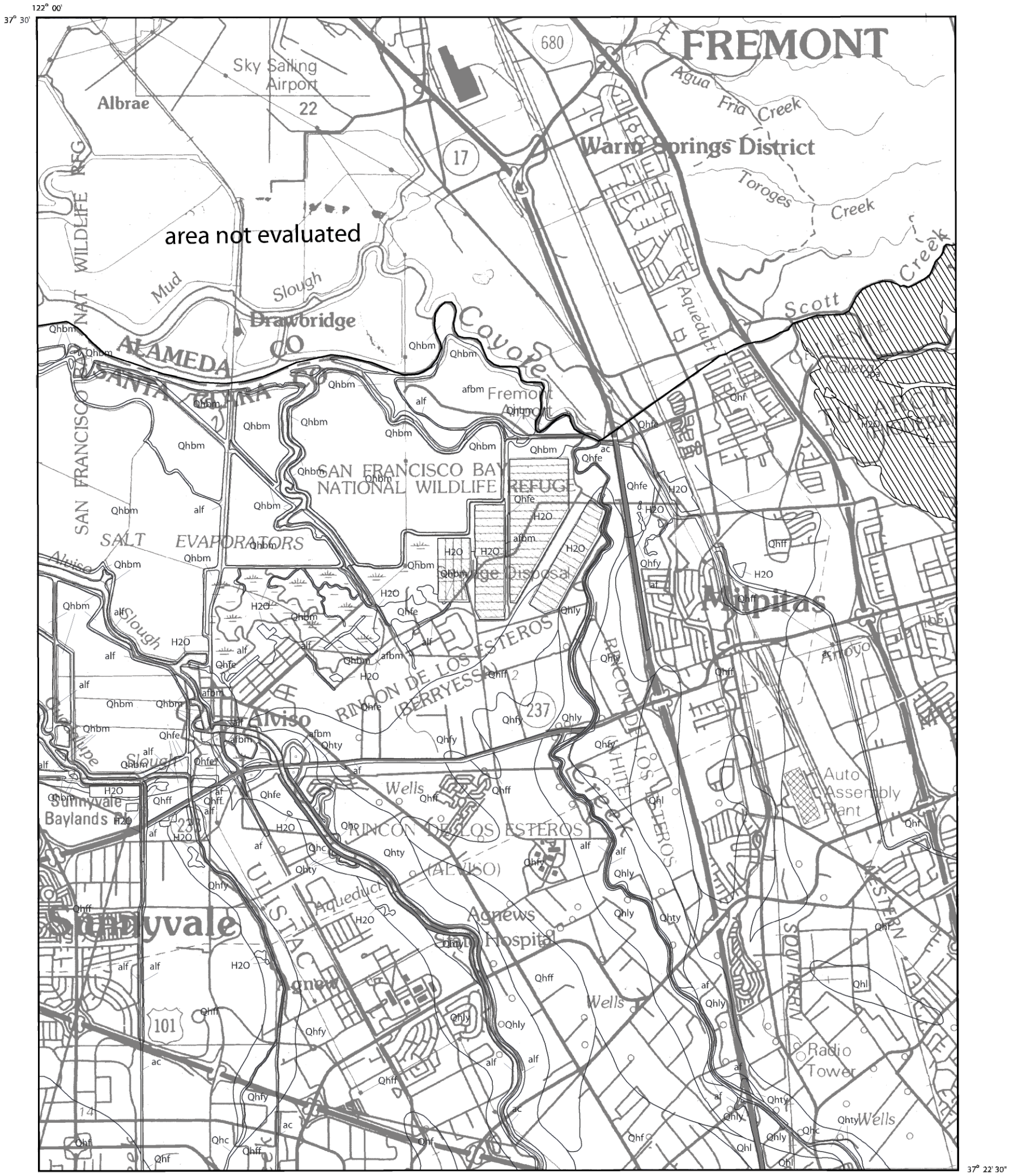


Base map enlarged from U.S.G.S. 30 x 60-minute series

MILPITAS QUADRANGLE

SCALE

0 1 2 MILES

2000 2000 4000 6000 FEET

0 1 2 KILOMETERS

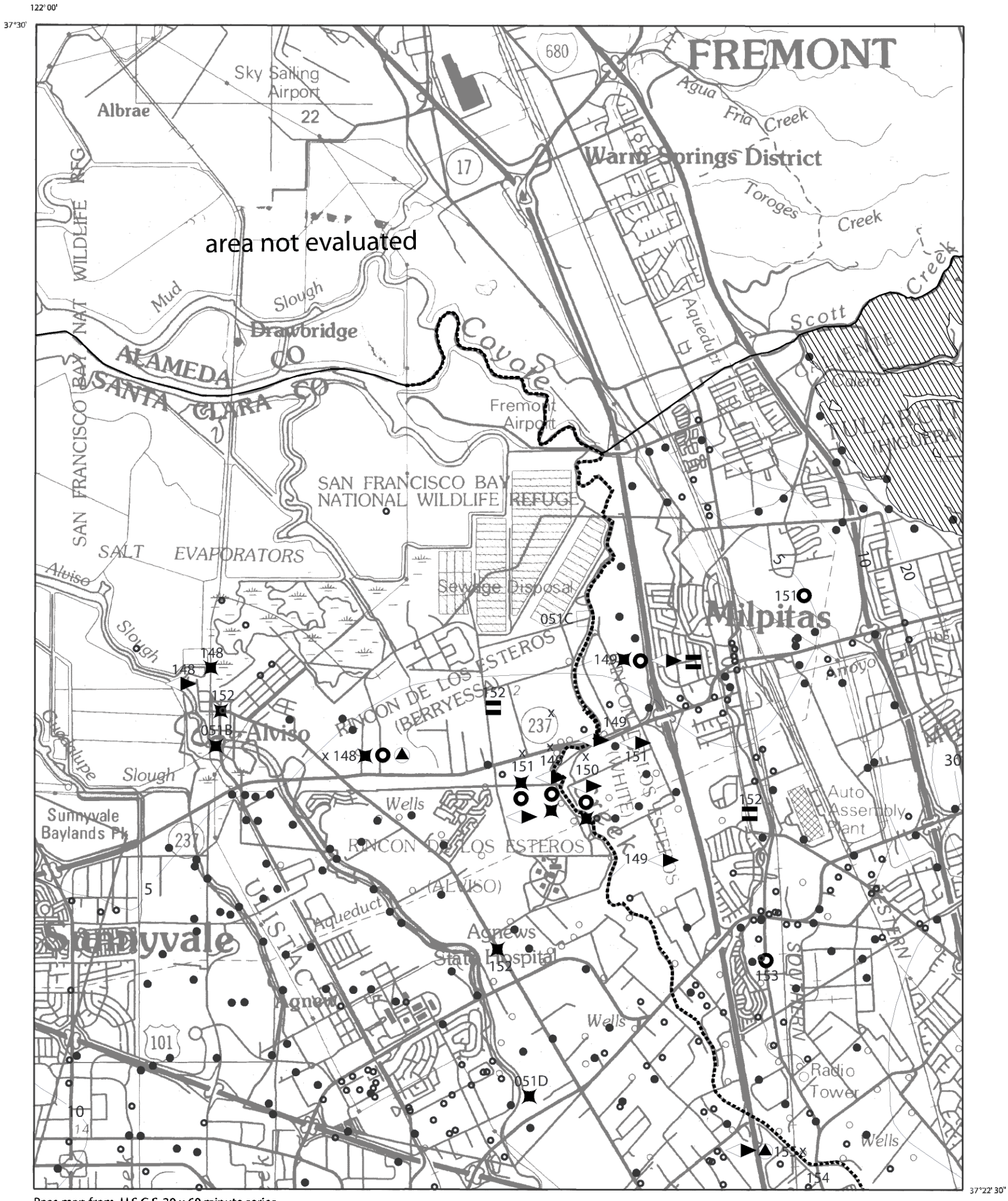
N

Lithologic contact;

Qhfe; geologic unit name (Knudsen and others, 2000).

Bedrock

Plate 1.1 Quaternary geologic map of the Milpitas 7.5-minute Quadrangle, California. Modified from Knudsen and others (2000).



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

MILPITAS QUADRANGLE

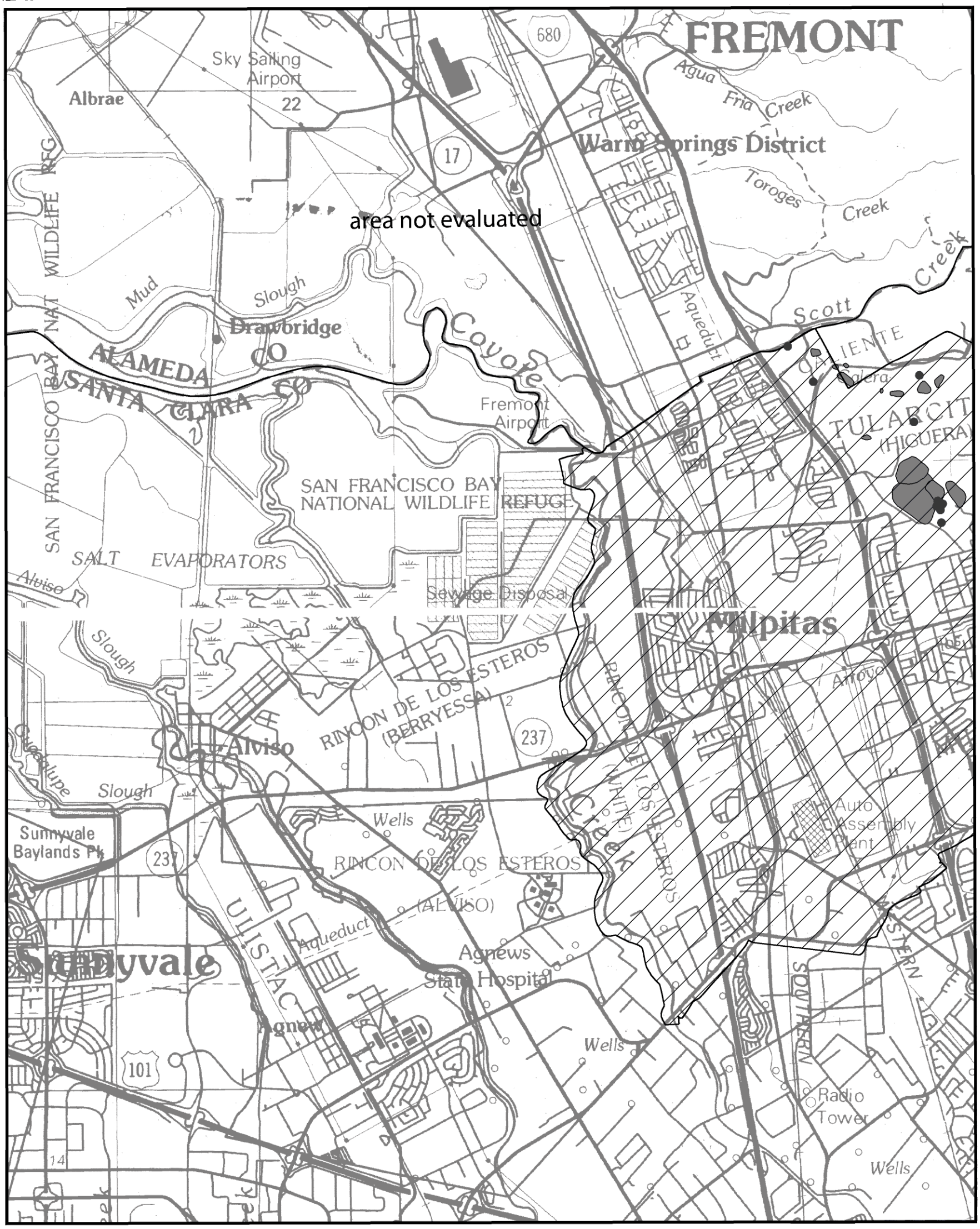
SCALE

N

Historical Ground Failures (From Knudsen and others, 2000)

- x Location of multiple ground effects. (See corresponding symbols)
- Disturbed well
- Sand boil
- Streambank landslides including rotational slump and soil fall
- Ground settlement
- Absence of ground failure noted
- Ground cracks not clearly associated with landslide, lateral spread, settlement, or primary movement
- Reach of river along which multiple failures were recorded. Symbols show failure types.
- Lateral spread
- 152 Number assigned to ground failure site (Knudsen and others, 2000)
- Bedrock
- 10 Depth to ground water, in feet
- Geotechnical borings used in liquefaction evaluation
- Ground-water level data provided by the Santa Clara Valley Water District

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



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

37° 22' 30"
121° 52' 30"

MILPITAS QUADRANGLE

SCALE

N

Landslide Inventory

Shear Test Sample Locations (sample locations from other quadrangles not shown).

Areas of significant grading/updated terrain.

Plate 2.1 Landslide Inventory, Shear Test sample locations, and areas of significant grading, Milpitas 7.5-minute Quadrangle