SEISMIC HAZARD ZONE REPORT 118

SEISMIC HAZARD ZONE REPORT FOR THE MT. SIZER 7.5-MINUTE QUADRANGLE, SANTA CLARA COUNTY, CALIFORNIA

2006

DEPARTMENT OF CONSERVATION
California Geological Survey

SEISMIC HAZARD ZONE REPORT 118

Seismic Hazard Zone Report for the Mt. Sizer 7.5-Minute Quadrangle, Santa Clara County, California

How to view or obtain the map

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

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

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

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SEISMIC HAZARD ZONE MAP AND EVALUATION REPORT FOR THE MT. SIZER QUADRANGLE

April 18, 2006	Preliminary Release for 90-day review period.
October 18, 2006	Official Release

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Mt. Sizer 7.5-Minute Quadrangle, Santa Clara county, California. The map displays the boundaries of *zones of required investigation* for liquefaction and earthquake-induced landslides over an area of approximately 62 square miles at a scale of 1 inch = 2,000 feet.

Mt. Sizer Quadrangle covers southeastern Santa Clara County and consists almost entirely of the rugged terrain of the Diablo Range, except for a few square miles of flat land in the southwest corner partially occupied by the city of Morgan Hill. The rest of the quadrangle consists mainly of sparsely populated land, including an undeveloped area within the jurisdiction of the City of San Jose. The map designates *Zones of Required Investigation* for liquefaction and earthquake-induced landslides only for the southwestern half of the quadrangle because mountainous terrain and projected land use in the northeastern half make urbanization unlikely.

Zones for liquefaction hazard within the Mt. Sizer quadrangle are generally limited to a few narrow canyon bottoms and stream valleys, such as Packwood and Hoover valleys. Zones for earthquake-induced landslides, however, cover much of the southwest half of the quadrangle because of the predominance of steep slopes combined with relative low rock strength.

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

INTRODUCTION

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

The Act 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, which were published in 1992 as CGS Special Publication 118, were revised in 2004. They provide detailed standards for mapping regional liquefaction and landslide hazards. The Act also directed CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

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

In April 2004, significant revisions of liquefaction zone mapping criteria relating to application of historically high ground-water level data in desert regions of the state were adopted by the SMGB. These modifications are reflected in the revised CGS Special Publication 118, which is available on the Internet at: http://gmw.consrv.ca.gov/shmp/webdocs/sp118_revised.pdf .

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Mt. Sizer 7.5-Minute Quadrangle. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

SECTION 1

LIQUEFACTION ZONES OF REQUIRED INVESTIGATION IN THE MT. SIZER 7.5-MINUTE QUADRANGLE

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California Geological Survey

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. City, county, and state agencies are directed to use seismic hazard zone maps developed by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf .

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Santa Clara County portion of the Mt. Sizer 7.5-Minute Quadrangle.

Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking) complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.consrv.ca.gov/CGS/index.htm.

BACKGROUND

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

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 50 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 bay.

METHODS SUMMARY

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

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill
- Maps of shallow ground-water were constructed
- Geotechnical data were collected and analyzed to evaluate the liquefaction potential of deposits
- Information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone of required investigation map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2004).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.8 million years) sedimentary deposits. Such areas within the Mt. Sizer

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

Liquefaction zone of required investigation maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, these 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

The Mt. Sizer 7.5-minute Quadrangle map covers approximately 62 square miles in Santa Clara County. The southwestern part of the map area includes parts of the City of Morgan Hill. The rest of the quadrangle contains unincorporated parts of Santa Clara County and is sparsely inhabited. This report addresses earthquake-induced liquefaction hazards for only the southwestern half of the quadrangle.

Most of the map area is occupied by steeply sloping terrain of the Diablo Range. The Diablo Range includes many northwest-oriented ridges and intervening canyons with creeks flowing northwest or southeast. The gently sloping terrain of the Santa Clara Valley occupies the very southwestern corner of the quadrangle, which is separated from Anderson Lake by a small ridge, some of which has been developed and incorporated into the City of Morgan Hill. There are a few flat-bottomed alluviated valleys within the Diablo Range, the larger of which are Packwood and Hoover Valleys. Packwood Creek flows out of the Packwood and Hoover Valleys and empties into the north side of Anderson Lake reservoir at the western edge of the map. Elevations in the map area vary from just under 350 ft in the gently sloping terrain of the Santa Clara Valley in the southwestern corner of the map, to over 3000 ft towards the northeastern corner.

The gently sloping terrain of the Santa Clara Valley and some hilly terrain between Santa Clara Valley and Anderson Lake have been developed for residential uses. A few ranches lie within the Diablo Range but the majority of the quadrangle has not been developed. Henry Coe State Park occupies most of the northeastern part of the quadrangle and Anderson Lake County Park occupies land adjacent to the shore at the southeastern end of Anderson Lake.

GEOLOGY

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial sedimentary deposits and artificial fill. To evaluate the areal and vertical distribution of shallow Quaternary deposits and to provide information on subsurface geologic, lithologic and engineering properties of the deposits in the Mt. Sizer Quadrangle, recently completed maps of the nine-county San Francisco Bay Area showing Quaternary deposits (Knudsen and others, 2000; and Witter and others, 2003, for the deposits along the Calaveras fault) and bedrock mapping (Wentworth and others, 1999) were obtained from the U. S. Geological Survey in digital form. The GIS maps were combined, with some modifications along the bedrock/Quaternary contact. The result was a single 1:24,000-scale geologic map of the Mt. Sizer Quadrangle. Limited field reconnaissance was conducted to confirm the location of geologic contacts, map recently modified ground surfaces, observe properties of near-surface deposits, and characterize the surface expression of individual geologic units. The distribution of Quaternary deposits on this map (Plate 1.1) was used in combination with other data, discussed below, to evaluate liquefaction susceptibility and develop the liquefaction *zones of required investigation*.

Knudsen and others (2000), and Witter and others (2003) (Table 1.1) mapped nine Quaternary map units in the Mt. Sizer Quadrangle. 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, cross cutting relationships, superposition, depth and degree of surface dissection, and relative degree of soil profile development. Table 1.1 compares stratigraphic nomenclature used in Knudsen and others (2000), Witter and others (2003) and the CGS GIS database, with that of several previous studies performed in northern California.

Late Quaternary deposits cover less than 10% of the Mt. Sizer Quadrangle. These areas include the gently sloping alluviated terrain in the southwestern corner of the quadrangle, flat-bottomed Packwood and Hoover Valleys and small areas flanking steep-sided stream channels and along Anderson Lake shoreline (Plate 1.1).

Holocene alluvial deposits have been divided into the following units: Qhf, Qht, Qhb and Qha. Holocene undifferentiated alluvial deposits (Qha) are mapped along the valley floors of both Packwood Valley and Hoover Valley and along Packwood Creek where it empties into Anderson Lake. One Holocene stream terrace deposit (Qht) is mapped along Packwood Creek. Holocene alluvial fan deposits (Qhf) are mapped along the edges of Packwood Valley and Hoover Valley and also on the northeast side of the Santa Clara Valley in the southwestern corner of the map. Holocene basin deposits (Qhb) are mapped in small basin areas resulting from massive landsliding mostly along the Calaveras fault. Undifferentiated Late Pleistocene to Holocene alluvium (Qa) is mapped along creeks within the Diablo Range and in minor drainages such as along Otis Canyon and along Coyote Creek upstream of Anderson Lake. Late Pleistocene to Holocene alluvial fan deposits (Qf) are mapped along the northeastern edge of the Santa Clara Valley and in a few places on the flanks of the Packwood Valley. Late Pleistocene alluvial fan deposits (Qpf) cover much of the gently sloping terrain in the southwest corner of the map. Late Pleistocene undifferentiated alluvium (Qpa) is mapped around Dairy Flat at the southern end of the Packwood Valley and also within Oak Flat, within the Diablo Range.

Bedrock exposed in the Diablo range, in which most of the Mt. Sizer Quadrangle is situated, consists of Franciscan Complex rocks that are structurally overlain by the Coast Range Ophiolite and Mezozoic marine deposits of the Great Valley Sequence (Wentworth and others, 1999). Wentworth and others (1999) divided this area into several distinct structural blocks, each with a contrasting geologic history. These fault-bounded blocks are generally elongate along a northwest-southeast trend. In the Mt. Sizer Quadrangle these include, from the southwest: the Silver Creek Block; the Coyote Block, separated from the Silver Creek Block by the northwest-striking Calaveras Fault; and the Mt. Hamilton Block, separated from the Coyote Block by the Madrone Springs Fault, and which occupies approximately the northeastern half of the quadrangle.

The Silver Creek Block is comprised of serpentinized Coast Range Ophiolite (Jos), Pliocene Silver Creek Gravel (Tsg), minor Pliocene basalt (Tba), Plio-Pleistocene Packwood Gravel (QTp) and undivided Franciscan complex mélange (fm) and greenstone (gs) (Wentworth and others, 1999). The Coyote Block contains faulted blocks of Cretaceous sedimentary rocks (Kcusm), and Tertiary age sandstone, siltstone, shale and mudstone (Tbr, Tcc, Tbmw, Tgsm, Tts). The Mt. Hamilton block within the Mt. Sizer Quadrangle is comprised of Cretaceous and Jurassic Franciscan Eastern belt, most of which is mapped as mélange (fm) containing minor chert blocks (ch), the lower thin-bedded, fine-grained sandstone and mudstone unit of the Upper Cretaceous Burnt Hills Terrane (fb1) and the lower unit of the Yolla Bolly Terrane (fy2), which is thick-bedded, coarse-grained arkosic sandstone and minor mudstone (Wentworth and others, 1999).

See the earthquake-induced landslide part (Section 2) of this report for additional description of bedrock geology.

Unit \ Mapper	Knudsen and others (2000); Witter and others (2003)	Helley and others (1994)	Helley and others (1979)	Wentworth and others (1999)	CGS GIS database
Modern stream channel deposits	Qhc	Qhsc	Qhsc	Qhc	Qhc
Holocene alluvial fan deposits	Qhf	Qhaf, Qhfp	Qham, Qhac	Qhf, Qhfp	Qhf
Holocene stream terrace deposits	Qht	Qhfp		Qht	Qht
Holocene alluvium, undifferentiated	Qha			Qha	Qha
Holocene basin deposits	Qhb	Qhb		Qhb	Qhb
Late Pleistocene to Holocene alluvial fan deposits	Qf				Qf
Late Pleistocene to Holocene alluvium, undifferentiated	Qa			Qa	Qa
Late Pleistocene alluvium, undifferentiated	Qpa	Qpaf	Qpa	Qpa	Qpa
Late Pleistocene alluvial fan deposits	Qpf	Qpaf		Qpf	Qpf
bedrock	br	br			br

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

Structural Geology

The Mt. Sizer Quadrangle is within the active San Andreas Fault system, which distributes shearing across a complex system of primarily northwest-trending, right-lateral, strike-slip faults that include the San Andreas, Hayward, and Calaveras faults. The northwest trending Calaveras Fault crosses the southwestern part of the Mt. Sizer Quadrangle. Historical earthquakes (Hoose, 1987) occurred on this fault in the immediate vicinity of the Mt. Sizer Quadrangle in 1979 (Keefer and others, 1980) and 1984.

ENGINEERING GEOLOGY

Soils that are susceptible to liquefaction are mainly late Quaternary alluvial deposits and artificial fill. Deposits that contain saturated loose sandy and silty soils are most susceptible to liquefaction. Lithologic descriptions and soil test results reported in geotechnical borehole logs provide valuable information regarding subsurface geology, ground-water levels, and the engineering characteristics of sedimentary deposits. For this investigation, only 7 borehole logs were available for the area where Quaternary deposits are mapped in the southwestern corner of the map. Data from the neighboring quadrangle (Morgan Hill) also were used to characterize the deposits within the Mt. Sizer Quadrangle.

Of particular value in liquefaction evaluations are logs that report the results of downhole standard penetration tests. Standard Penetration Tests (SPTs) provide a standardized measure of the penetration resistance of geologic deposits and are commonly used as an index of soil density. This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil at the bottom of a borehole at chosen intervals while drilling. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 2004). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differs from that specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts are normalized to a common-reference, effective-overburden pressure of 1 atmosphere (approximately 1 ton per square foot) and a hammer efficiency of 60 percent using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

As stated above, geotechnical and environmental borehole logs provide information on lithologic and engineering characteristics of Quaternary deposits, though this information is rather limited in the Mt. Sizer Quadrangle. Geotechnical borehole logs from the neighboring Morgan Hill Quadrangle provided additional information on lithologic and engineering characteristics of Quaternary deposits within this quadrangle due to lack of data within the Mt. Sizer Quadrangle. Geotechnical characteristics of the Quaternary map units are summarized in Table 1.2 and their composition by soil type is presented in Table 1.3.

GEOLOGIC MAP UNIT		DRY DENSITY (pounds per cubic foot)						STANDARD PENETRATION RESISTANCE (blows per foot, $(N_1)_{60}$)					
Unit (1)	Texture (2)	Number of Tests	Mean	C (3)	Median	Min	Max	Number of Tests	Mean	C (3)	Median	Min	Max
Qhf	Fine	3	114.3	0.05	115	108	120	3	21	0.37	23	13	28
	Coarse	-	-	-	-	-	-	-	-	-	-	-	-
Qpf	Fine	1	114	-	-	-	-	-	-	-	-	-	-
	Coarse	3	103.3	0.15	105.5	84.3	118	13	48	0.49	41	18	90

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

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

GROUND WATER

Saturation reduces the effective normal stress of near-surface sediment, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). CGS compiles and interprets ground-water data to identify areas characterized by, or anticipated to have in the future, near-surface saturated soils. For purposes of seismic hazard zonation, "near-surface" means at a depth less than 50 feet.

Natural hydrologic processes and human activities can cause ground-water levels to fluctuate over time. Therefore, it is impossible to predict depths to saturated soils during future earthquakes. One method of addressing time-variable depth to saturated soils is to establish an anticipated high ground-water level based on historical ground-water data. In areas where ground water is either currently near-surface or could return to near-surface levels within a land-use planning interval of 50 years, CGS constructs regional contour maps that depict these levels. CGS also delineates present or anticipated near-surface saturated soils caused by locally perched water and seepage from surface-water bodies.

Ground-water conditions were investigated in the Mt. Sizer Quadrangle to evaluate the depth to saturated materials. The evaluation was based on ground-water elevation contours in USGS Water Supply Papers (Clark 1917), ground-water information obtained from the Santa Clara Valley Water District (Reymers and Hemmeter, 2002), and from geotechnical borehole logs acquired from the city of Morgan Hill, Santa Clara County, and Pacific Geotechnical Engineering. Water depths from boreholes known to penetrate confined aquifers were not utilized.

Ground-water levels are thought to be at or near their historical highs in many parts of the Santa Clara Valley. However, a well in the Llagas Sub-basin, tracked by the SCVWD from 1969 to 2001, indicates that the highest ground water occurred during 1983 and again during 1998 (Reymers and Hemmeter, 2002). Ground water in 2001 appears to be only about 10 feet deeper than in 1983 for one monitoring well. Ground water elevations for Fall 2001 were contoured in Reymers and Hemmeter (2002) and are very similar to those reported by Clark (1917) for Fall 1914. Clark (1917) compiled detailed precipitation and ground-water information specifically for the Morgan Hill area. The State Water Resources Board (1955) graphed accumulated runoff departure from mean seasonal runoff, which peaked around 1917, thus ground-water information from 1914 should provide a reasonable estimate of historical high ground water for this area. Depth to ground-water contours for the small portion of the Santa Clara Valley within Mt. Sizer quadrangle were constructed from ground-water elevation contours of Clark (1917). The contours appear to be fairly consistent with ground-water levels measured by the SCVWD and in the geotechnical boreholes collected for this study.

Depths to first-encountered water on the alluvial slope in the southwest part of the quadrangle range from just under 30 feet to over 60 feet (Plate 1.2). Ground water is deeper closer to the apex of the latest Pleistocene Coyote Creek fan (Qpf) near Anderson Dam, which is located to the northwest in the adjacent Morgan Hill quadrangle. Ground-water contours on Plate 1.2 show estimated historical-high water depths, and locations of geotechnical borehole logs from investigations between 1988 and the 2002, none of which encountered ground water.

Based on data from the depths of incision to creeks in this quadrangle, it is assumed that ground water lies within about 20 ft of the ground surface in the valley and canyon bottoms within the Diablo Range (Plate 1.2).

PART II

LIQUEFACTION POTENTIAL

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

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the SMGB (DOC, 2004).

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

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

CGS's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. CGS's qualitative relations among susceptibility, geologic map unit and depth to ground water are summarized in Table 1.2.

Most Holocene materials where water levels are within 30 feet of the ground surface have been given susceptibility assignments of moderate (M) to very high (VH) (Table 1.3). The exception to this is for Holocene basin deposits (Qhb), which primarily are composed of fine-grained material and so are assigned a low (L) liquefaction susceptibility where water levels are within 30 feet of the ground surface. These Holocene basin deposits (Qhb) are mapped in small closed depressions within massive landslide deposits in the Mt. Sizer Quadrangle. All late Pleistocene and older deposits within 30 feet of the ground surface have low (L) susceptibility except late Pleistocene to Holocene undifferentiated alluvium (Qa) which is assigned a low (L) to moderate (M) susceptibility assignment depending on the depth to ground water. Late Pleistocene to Holocene alluvial fan deposits (Qf) were assigned a low (L) susceptibility in the Mt. Sizer Quadrangle because these deposits were found to be similar to those of Pleistocene deposits in the adjacent Morgan Hill Quadrangle, with generally higher density and penetration resistance. Modern stream channel deposits and Holocene stream terrace deposits have low (L) to moderate (M) susceptibility assignments where ground water is 30 feet below the ground surface. All other units have been assigned low (L) to (VL) susceptibility assignments at these depths.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10 percent probability of exceedance over a 50-year period (DOC, 2004). The earthquake magnitude used in CGS's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the southwestern half of the Mt. Sizer Quadrangle, PGAs of 0.55 to 0.58g, resulting from an earthquake of magnitude of 6.2 are estimated for alluvium conditions. The PGA and magnitude values are based on de-aggregation of the probabilistic hazard at the 10 percent in 50-year hazard level (Petersen and others, 1996). See the ground motion section (3) of this report for further details.

Geologic Unit (1)	Description	Total layer thickness (feet)	Composition by soil type (Unified Soil Classification System Symbols)	Depth to ground water (ft) and liquefaction susceptibility category assigned to geologic unit(2)			
				<10	10 to 30	30 to 40	>40
Qhc	Modern stream channel deposits	0	n/a	VH	H	M	VL
Qhf	Holocene alluvial fan deposits	19	37% CL, 35% CH, 21% ML, 6% SC	H	M	L	VL
Qht	Holocene stream terrace deposits	0	n/a	H	M	M	L
Qha	Holocene alluvium, undifferentiated	0	n/a	M	M	L	VL
Qhb	Holocene basin deposits	0	n/a	L	L	L	VL
Qf	Late Pleistocene to Holocene alluvial fan deposits	2	100% Gravel	L	L	L	VL
Qa	Late Pleistocene to Holocene alluvium, undifferentiated	0	n/a	M	L	L	VL
Qpa	Late Pleistocene alluvium, undifferentiated	0	n/a	L	L	VL	VL
Qpf	Late Pleistocene alluvial fan deposits	138	35% GP, 20% SW, 16% GC, 13% GM, 10% Sand, 6% CL	L	L	VL	VL

1) Susceptibility assignments are specific to the materials within the Mt. Sizer 7.5-Minute Quadrangle.
2) Based on the Simplified Procedure (Seed and Idriss, 1971; Youd and Idriss, 1997) and a small number of borehole analyses for some units. Relative susceptibility of units to liquefaction is a function of material type and ground water depth within that unit. VH = very high, H = high, M = moderate, L = low, and VL = very low to none.

Table 1.3 Liquefaction Susceptibility for Quaternary Map Units within the Mt. Sizer 7.5-Minute Quadrangle.

Quantitative Liquefaction Analysis

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997; Youd and others, 2001). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading to a M7.5 event. To accomplish this, CGS's analysis uses the Idriss magnitude-scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. CGS uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site-specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures.

The CGS liquefaction analysis program calculates an FS for each geotechnical sample where blow counts were collected. Typically, multiple samples are collected for each borehole. The program then independently calculates an FS for each non-clay layer that includes at least one penetration test using the minimum $(N_1)_{60}$ value for that layer. The minimum FS value of the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing *zones of required investigation*.

Of the 8 geotechnical borehole logs reviewed in this study (Plate 1.2), 4 include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory

Committee and adopted by the SMGB (DOC, 2004). 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 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 subsurface data are not sufficient for quantitative evaluation of liquefaction hazard. Within such areas, zones may be delineated by geologic criteria as follows:

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

   b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.20 g and the anticipated depth to saturated soil is less than 30 feet; or

   c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 g and the anticipated depth to saturated soil is less than 20 feet.

Application of these criteria allows compilation of liquefaction *zones of required investigation*, which are useful for preliminary evaluations, general land-use planning and delineation of special studies zones (Youd, 1991).

Areas of Past Liquefaction

In the Mt. Sizer Quadrangle, minor historical liquefaction sand boils and lateral spreading along the east shore of Lake Anderson were reported by Youd (1987) from the 1984 Morgan Hill earthquake.

Artificial Fills

There are no artificial fills mapped in the Mt. Sizer Quadrangle.

Areas with Sufficient Existing Geotechnical Data

Only 8 geotechnical borings were collected for the Mt. Sizer Quadrangle all of which reached relatively shallow depths (17 feet to 35 feet). Four of these are located in Late Pleistocene alluvial fan deposits (Qpf), three in Holocene alluvial fan deposits (Qhf) and one within a landslide deposit. Holocene alluvial fan deposits appear to drape the Late Pleistocene alluvial fan deposits on the northeast flank of the Santa Clara Valley, and, based on the borehole data and lack of a large source area, appear to be relatively thin (less than 10 feet). There appear to be no saturated Holocene deposits and therefore no areas are included within the zone of required investigation for the Santa Clara Valley portion of the Mt. Sizer Quadrangle.

Areas with Insufficient Existing Geotechnical Data

Geotechnical data was not available for any of the valley regions within the steeply sloping terrain of the Diablo Range that covers the majority of the Mt. Sizer Quadrangle. The liquefaction zone of required investigation includes areas mapped as modern stream channels (Qhc), Holocene undifferentiated alluvium (Qha) and stream terraces (Qht), and late Quaternary to Holocene undifferentiated alluvium (Qa). These deposits are near active stream channels, where ground water is at or close to the surface and so are likely to be saturated. A small area of Holocene alluvial fan deposits (Qhf) along the flank of Anderson Lake is also included within the zone of required investigation as it is low-lying and also likely to be saturated. Therefore, these areas have been included in the zone of required investigation based on the critieria 4a and 4b as described above. Small areas of Holocene basin deposits (Qhb), Late Pleistocene to Holocene undifferentiated alluvium (Qa) and Holocene undifferentiated alluvium (Qha) that are mapped within large landslide deposits are not included in the zone of required investigation as these deposits, though saturated, are probably not likely to be very deep and have very small catchment areas. Holocene alluvial fan deposits (Qhf) and Late Pleistocene to Holocene alluvial fan deposits (Qf) that flank the Packwood Valley are not included within the zone of required investigation as ground water is likely deeper than 30 feet and so according to Table 1.2 are assigned a low level of liquefaction susceptibility.

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SECTION 2

EARTHQUAKE-INDUCED LANDSLIDE ZONES OF REQUIRED INVESTIGATION IN THE MT. SIZER 7.5-MINUTE QUADRANGLE

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at: http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

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

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Mt. Sizer 7.5-minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking) complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on the CGS's Internet page: http://www.consrv.ca.gov/CGS/index.htm.

BACKGROUND

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

METHODS SUMMARY

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

- Digital terrain data were used to provide an up-to-date representation of slope gradient in the study area
- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared
- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area
- Seismological data in the form of CGS probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink and Real, 1996; McCrink, 2001) and adopted by the State Mining and Geology Board (DOC, 2004).

SCOPE AND LIMITATIONS

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

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

The Mt. Sizer 7.5-minute Quadrangle map covers approximately 62 square miles in Santa Clara County. The southwestern part of the map area includes parts of the City of Morgan Hill. The rest of the quadrangle contains unincorporated parts of Santa Clara County and is sparsely inhabited. This report addresses earthquake-induced landslide hazards for only the southwestern half of the quadrangle.

Most of the map area is occupied by steeply sloping terrain of the Diablo Range. The Diablo Range includes many northwest-oriented ridges and intervening canyons with creeks flowing northwest or southeast. The gently sloping terrain of the Santa Clara Valley occupies the very southwestern corner of the quadrangle, which is separated from Anderson Lake by a small ridge, some of which has been developed and incorporated into the City of Morgan Hill. There are a few flat-bottomed alluviated valleys within the Diablo Range, the larger of which are Packwood and Hoover Valleys. Packwood Creek flows out of the Packwood and Hoover valleys and empties into the north side of Anderson Lake reservoir at the western edge of the map. Elevations in the map area vary from just under 350 ft in the gently sloping terrain of the Santa Clara Valley in the southwestern corner of the map, to over 3000 ft towards the northeastern corner.

The gently sloping terrain of the Santa Clara Valley and some hilly terrain between Santa Clara Valley and Anderson Lake have been developed for residential uses. A few ranches lie within the Diablo Range but the majority of the quadrangle has not been developed. Henry Coe State Park occupies most of the northeastern part of the quadrangle and Anderson Lake County Park occupies land adjacent to the shore at the southeastern end of Anderson Lake.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface in the form of a digital topographic map. A Level-2 digital elevation model (DEM) was obtained from the U.S. Geological Survey (USGS) for the Mt. Sizer Quadrangle. The USGS (1993) prepared this DEM from the 7.5-minute quadrangle topographic contours based on 1953 aerial photography and from 1955 planetable surveys. It has a 10-meter horizontal ground sample distance (GSD; commonly called pixel size) and a 7.5-meter vertical accuracy.

A slope map was made from the DEM using a third-order, finite-difference, center-weighted algorithm (Horn, 1981). The manner in which the slope map was used to prepare the zone map is described in a subsequent section of this report.

GEOLOGY

The primary source of 1:24,000-scale bedrock geologic mapping used in this slope stability evaluation was the digital geologic map database of Wentworth and others (1999), which covers the Diablo Range northeast of Santa Clara Valley. Knudsen and others (2000) prepared a map of unconsolidated surficial (Quaternary) geologic units for the Mt. Sizer Quadrangle at a scale of 1:24,000.

For the purposes of this investigation, CGS geologists merged the surficial and bedrock geologic maps. Contacts between surficial and bedrock units were modified in some areas to resolve differences between the two maps and findings from this study. Geologic field reconnaissance and analysis of stereo-paired aerial photographs were performed to assist in adjusting contacts and to review the lithology and structure of geologic units.

The geologic map of Wentworth and others (1999) identifies a number of distinct stratigraphic assemblages that are exposed in fault-bounded, bedrock structural blocks in the mountains of the Diablo Range. Three of these bedrock structural blocks extend into the Mt. Sizer Quadrangle. The Silver Creek, Coyote, and Mount Hamilton blocks are each exposed in the Diablo Range on the northeastern side of the Santa Clara Valley.

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

The following sections describe bedrock units in each of the bedrock structural blocks mapped by Wentworth and others (1999) that extend into the Mt. Sizer Quadrangle. Unconsolidated Quaternary deposits overlie the bedrock units on the floor of the Santa Clara Valley and in smaller alluvial areas within the hillside areas. Quaternary deposits in the map area are described in Section 1.

Silver Creek Block

The Silver Creek Block is exposed on the east side of the southern Santa Clara Valley and is characterized by Tertiary stratigraphy that is distinct from adjoining bedrock structural blocks. The basement rocks of the Silver Creek Block consist of Franciscan mélange (fm) and serpentinite of the Coast Range Ophiolite (Jos). The Mesozoic basement rocks of the Silver Creek Block structurally underlie and overlie Cretaceous and Tertiary strata. All of the rocks are, in turn, unconformably overlain by the Packwood Gravels (QTp) (Wentworth and others, 1999).

Mica-rich Miocene sandstone, Miocene andesite and basalt, and Pliocene volcanic rocks (Tba) are distinctive units of the Silver Creek Block. However, only the latter is exposed in the Mt. Sizer Quadrangle. Overlying this unit is the upper Miocene to Pliocene Silver Creek Gravels (Tsg), which are exposed in the hills on the east side of the Santa Clara Valley. The Silver Creek Gravels consist of interbedded conglomerate, sandstone, siltstone, tuffaceous sediment, tuff and basalt. The Silver Creek Gravels are distinguished from similar gravels, such as the Packwood Gravels and the Santa Clara Formation, by the presence of interbedded white tuff layers and other volcanic rocks, beds of nonmarine red and green mudstone, by the relatively well-consolidated nature of the conglomerate beds, and by the characteristic clast composition. About 75 percent of the clasts are Franciscan Complex rocks with the remaining 25 percent consisting of volcanic rocks, Claremont siliceous shale and chert, and other Cenozoic rocks. The Pliocene Basalt of Anderson and Coyote Reservoirs (Tba) consists of pyroclastic andesite and alkali olivine basalt flows, which include mafic and ultramafic xenoliths (Wentworth and others, 1999). It is exposed in contact with the Silver Creek Gravels (Tsg), Coast Range Ophiolite rocks (Jos) and Franciscan mélange (fm) south of the southern end of the Anderson Lake Reservoir.

The Plio-Pleistocene Packwood Gravels (QTp) consist of silty and fine sandy pebble conglomerate, fine silty sandstone, pebbly to fine sandy siltstone, and minor olive-green claystone beds. Numerous nonmarine red mudstone beds also are present. Most of the clasts are derived from rocks of the Great Valley Sequence rather than the Franciscan Complex. The Packwood Gravels are exposed in the area between the northeast shore of Anderson Lake and the Calaveras Fault, and to the south of the lake where they overlie the Pliocene Basalt (Tba), the Coast Range Ophiolite and Franciscan mélange. In other places the Packwood Gravels are in fault contact with Pliocene Basalt (Tba) and the Silver Creek Gravels (Tsg).

Some Lower Tertiary (?) to Upper Cretaceous Franciscan mélange (fm) is exposed in a few small areas. Franciscan mélange consists of sheared black argillite, greywacke and metagraywacke, and also contains some mapped greenstone blocks (gs) in the Mt. Sizer Quadrangle. Coast Range Ophiolite (Jos), which is mainly sheared serpentinite but includes massive serpentinized harzburgite, is also mapped on the southwest side of Anderson Lake (Wentworth and others, 1999).

Coyote Block

The Coyote Block consists of Coast Range Ophiolite rocks overlain by Cretaceous strata of the Great Valley Sequence and Tertiary strata. The strata dip steeply to the east and are cut by numerous transpressive faults (Wentworth and others, 1999). The Coyote Block forms a northwest striking strip that crosses through the center of the Mt. Sizer Quadrangle.

The oldest rocks in the map area consist of abundant Cretaceous sandstone, mudstone and conglomerate (Kcusm) within the Great Valley Sequence. Sandstone is fine to coarse grained with interbedded biotite-rich siltstone and dark gray mudstone. Conglomerate layers contain boulder to pebble clasts of silicic to intermediate volcanic rocks, limestone, metavolcanics and rip-up clasts of mica-rich sandstone (Wentworth and others, 1999).

The oldest Tertiary unit of the Coyote Block in the map area is an unnamed Lower Eocene and or/upper Paleocene glaucanitic sandstone and red mudstone (Tgsm). Minor amounts of Eocene brown-weathering mudstone (Tbmw) that locally contains fine-grained sandstone outcrop in the Mt. Sizer Quadrangle. Middle to Lower Miocene Temblor Sandstone (Tts) also is mapped within the Mt. Sizer Quadrangle and is comprised of thickly and indistinctly bedded, olive, fine to coarse-grained sandstone and pebble conglomerate, which contains invertebrate fossils of middle Miocene age (Wentworth and others, 1999). The upper to middle Miocene Claremont Formation (Tcc) also is also present in the map area. This unit consists of chert and siliceous shale that locally contains lenses of dolomite and some thin beds of quartz sandstone and siltstone. The upper Miocene Briones Formation (Tbr) unconformably overlies the Claremont Formation. The Briones Formation is predominantly sandstone with conglomeratic sandstone, shell-hash conglomerate containing interlocking mollusk and barnacle shells, and siltstone (Wentworth and others, 1999).

Mount Hamilton Block

The Mount Hamilton Block forms the core of the Diablo Range and primarily consists of Franciscan rocks with scattered small bodies of serpentinite derived from the Coast Range Ophiolite (Wentworth and others, 1999). The Franciscan rocks are overlain unconformably by Miocene marine sedimentary rocks that are exposed in limited areas at the margins of the block. The Mount Hamilton Block is exposed in the northeast portion of the map area. In the map area, the block contains Franciscan mélange (fm) and bodies of chert (ch) as described above in the section on the Silver Creek Block. The block also contains rocks from two distinctive Franciscan terranes. These are the lower unit of the Upper Cretaceous Burnt Hills terrane and the middle unit of the Jurassic Yolla Bolly Terrane, both of which are structurally interleaved with Franciscan mélange (Wentworth and others, 1999). The lower unit of the Cretaceous Burnt Hills terrane consists of thin bedded, fine-grained sandstone and mudstone (turbidites) with local interbedded coarse-grained arkosic sandstone. The middle unit of the Jurassic Yolla Bolly Terrane consists mainly of metagraywacke, slaty mudstone and conglomerate. Metagraywacke of the Yolla Bolly terrane contains blueschist-facies metamorphic minerals such as lawsonite, pumpellyite and aragonite.

Structural Geology

The bedrock units in the Mt. Sizer Quadrangle have undergone a complex structural history and are strongly deformed by faults and folds of various ages. As discussed in the previous section, the bedrock units in the Mt. Sizer Quadrangle are separated into a number of separate bedrock structural blocks, each of which has undergone a unique depositional and deformational history (Wentworth and others, 1999).

The oldest fault is the Coast Range fault, which was formed during Jurassic subduction of Franciscan rocks below the Coast Range Ophiolite. Originally, the sense of displacement across the Coast Range fault was reverse, but subsequent attenuation displacements have taken place associated with Cenozoic uplift and unroofing of Franciscan basement rocks. Discontinuous segments of the Coast Range fault occur in the map area where Coast Range Ophiolite is juxtaposed against Franciscan rocks.

Numerous northwest-trending transpressive and strike-slip faults extend through the area. The youngest of these is the Calaveras Fault, which is Holocene-active based on active seismicity, offset Holocene deposits observed in exploratory trenches at Lydell Creek, north of the map area, and prominent linear geomorphic features observed at many places along the fault. The Calaveras Fault extends along the east side of Anderson Lake and continues into adjacent quadrangles south and west of the Mt Sizer quadrangle. Two large earthquakes with epicenters in the immediate vicinity of the Mt. Sizer Quadrangle occurred on the Calaveras Fault in 1979 (Keefer and others, 1980) and 1984 (Hoose, 1984). Numerous other transpressive faults displace Cenozoic rocks and, in some cases, Pleistocene gravels in or near the map area.

Deformational features differ in each of the bedrock structural blocks in the map area. The Silver Creek Block contains Mesozoic basement rocks that have been thrust over tightly folded Cretaceous and Tertiary strata along the Silver Creek Thrust (Wentworth and others, 1999). The Coyote Block also consists of steeply dipping strata that are cut by reverse and transpressive faults. The Mount Hamilton Block is a massive uplifted block of complexly interleaved Franciscan rocks.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the southwest half of the Mt. Sizer Quadrangle has been prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide maps (Nilsen, 1975; Wagner et al., 1978). Landslides were mapped at a scale of 1:24,000. For each landslide included on the map, a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were incorporated into the landslide zoning as described later in this report. Landslides rated as questionable were not carried into the landslide zoning due to the uncertainty of their existence. Photo-interpretive mapping and compilation of landslide geometries into a GIS database were performed in a single-step process through heads-up digitizing over a spatially referenced image of the topographic base map for horizontal control. Other digital data layers, including digital orthophoto quarter quadrangles (DOQQ's) and geologic maps also were used as backdrops for reference during the landslide mapping/digitizing process. A version of this landslide inventory is included on Plate 2.1.

Landslides are relatively abundant over much of the mapped portion of the Mt. Sizer Quadrangle, but most markedly concentrated near the Calaveras Fault. Movement along the fault has produced over-steepened slopes, structurally weakened bedrock, and periodic strong ground shaking, which all contribute to slope instability in the varied bedrock units along the fault. To the east of the fault, Cretaceous sandstone, mudstone, and conglomerate (Kcusm) of the Coyote Block has been extensively impacted by deep-seated rock slides, which are mapped over most of the steep terrain that ascends to Finley Ridge and Nesbit Ridge. To the east of the Calaveras Fault, the number and size of mapped landslides generally decrease, to where they are comparatively sparse on the flanks of Palassou Ridge and on the hillsides around Packwood Valley. A prominent exception to this trend is controlled by a change in the geology near the northwest corner of the quadrangle. Here, concentrations of large landslide complexes are mapped within a northwest-trending band of inherently weak Franciscan mélange on either side of Carlin Canyon.

Along the west side of the Calaveras Fault, numerous large, deep seated landslides are also mapped in the varied rock types of the Silver Creek Block, including over most of the slopes along Coyote Creek and the shores of Anderson Lake. Smaller rotational slides or "slumps" and shallow earthflows are also common in the young (Plio-Pleistocene), poorly consolidated Packwood Gravels that underlie most of the area between the fault and northeast shores of the lake, as well as some areas to the south of the lake. Landslides are less common in the Pliocene Silver Creek Gravels that underlie most of the slopes along the eastern margin of the Santa Clara

Valley within the study area, although a prominent landslide complex is mapped in this unit where Diana Avenue ascends from the valley.

Most of the larger, deep-seated landslides in the study area appear to be older, dormant features. However, it is common to observe secondary slides or flows that exhibit indication of historic activity within the larger landslide bodies. Also, pavement distress observed along East Dunne Avenue and other paved roads in the study area suggest on-going or intermittent creep within many large and small landslide bodies that otherwise appear dormant.

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

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the Mt. Sizer Quadrangle geologic map were obtained from Pacific Geotechnical Engineering, the City of Morgan Hill, and Santa Clara County, as outlined in Appendix A. The locations of rock and soil samples taken for shear testing within the Mt. Sizer Quadrangle are shown on Plate 2.1. Shear tests from the adjoining Lick Observatory, Morgan Hill, Mt. Madonna and Gilroy quadrangles were used to augment data for several geologic units for which little or no shear-test information was available within the Mt. Sizer Quadrangle.

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

Due to their similar ages and lithologies, all Holocene deposits were combined for our statistical evaluation of shear strength, as were Pleistocene units. The median value of 31^{o} for Group 1 was used for the stability analysis because the sample population was too small to justify the use of the mean, 32^{o}.

Existing Landslides

As discussed later in this report, the criteria for landslide zone mapping state that all existing landslides that are mapped as definite or probable are automatically included in the landslide zone of required investigation. Therefore, an evaluation of shear-strength parameters for existing landslides is not necessary for the preparation of the zone map. However, in the interest of completeness for the material strength map, to provide relevant material strength information to project plan reviewers, and to allow for future revisions of our zone mapping procedures, we have collected and compiled shear-strength data considered representative of existing landslides within the quadrangle.

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available. We collect and compile primarily "residual" strength parameters from direct shear or ring shear tests of slip surface materials. For the Mt. Sizer Quadrangle, only one direct shear test of landslide slip surface materials was obtained, and the results are summarized in Table 2.1.

SHEAR-STRENGTH STATISTICS FOR THE MT. SIZER 7.5-MINUTE QUADRANGLE

	Formation Name (1)	Number of Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (2) (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Tba	4	31.9 / 37	32.0 / 31	975 / 800	- -	31
	Tbr	1	31.0				
	Tsg	6	32.3 / 34.5				
GROUP 2	gs	1	21.0	27.4 / 28	545 / 350	ch	27
	Jos	19	25.8 / 25			fy2 fys	
	Qp	35	28.5 / 30			Kcusm	
						Tbmw	
GROUP 3	fm	2	18.8 / 22.5	22.8 / 22	662 / 570	Tcc	23
	Qh	9	23.9 / 20			Tgsm	
	QTp	13	22.6 / 22			Tts	
Existing LS	Qls	1	4.0	4.0	410	- - -	N/A

(1) Formation name abbreviations from Wentworth and others (1999);
The Quaternary is grouped as Qh for Holocene units and Qp for Pleistocene units.
(2) Cohesion

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

SHEAR-STRENGTH GROUPS FOR THE MT. SIZER 7.5-MINUTE QUADRANGLE			
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**
Tba	**ch Jos**	**fm Tcc**	**Qls**
Tbr	**fy2 Kcusm**	**Qh Tgsm**	
Tsg	**fys Qp**	**QTp Tts**	
	gs Tbmw		

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

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Records

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

Modal Magnitude:	6.2
Modal Distance:	2 to 7 km
PGA:	0.44 to 0.53*g*

Based on these anticipated ground motion parameters, two strong-motion recording stations (4 strong motion recording components) with rock site conditions from the 1984 Morgan Hill earthquake were selected to represent the anticipated shaking in the Mt. Sizer Quadrangle. The Morgan Hill earthquake had a moment magnitude of 6.2. The recording stations are the Coyote Lake Dam, SW Abutment and Gilroy Array #6 stations operated by CGS (Shakal, and others, 1986). The Morgan Hill earthquake recordings were 0.2 and 10 km from the seismic source and recorded PGAs between 1.3 and 0.2g, respectively. Additional parameters of these recordings are presented in Appendix B.

Displacement Calculation

Each of the selected strong-motion records were 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 each 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). Various statistics of the resulting displacements were compared to those calculated for larger earthquakes in order to develop a relationship that is both reasonably conservative but not greater than displacements predicted for larger earthquakes. It was judged that the median values of the displacements calculated from the Morgan Hill earthquake approximated the range of values appropriate for the magnitude/distance criteria from the PSHA parameters for the study area. This resulting relationship is shown in Figure 2.1. 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 centimeters were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.055, 0.09 and 0.17 *g*. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground-shaking opportunity thresholds that are significant in the Mt. Sizer Quadrangle.

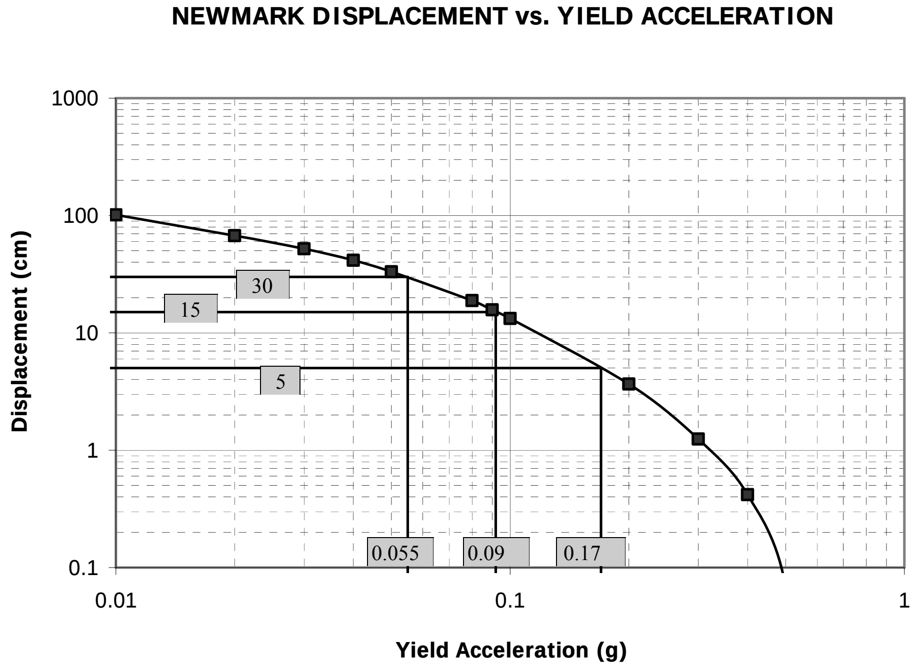

Figure 2.1. Yield Acceleration vs. Newmark Displacement representing the median displacement values from two recordings of the 1984 Morgan Hill, California earthquake. Appendix B contains more information on these recordings.

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 relation between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

- If the calculated yield acceleration was less than 0.055 *g*, Newmark displacement greater than 30 centimeters is indicated, and a HIGH hazard potential was assigned.

- If the calculated yield acceleration fell between 0.055 *g* and 0.09 *g*, Newmark displacement between 15 and 30 centimeters is indicated, and a MODERATE hazard potential was assigned.

- If the calculated yield acceleration fell between 0.09 *g* and 0.17 *g*, Newmark displacement between 5 and 15 centimeters is indicated, and a LOW hazard potential was assigned.

- If the calculated yield acceleration was greater than 0.17 *g*, Newmark displacement of less than 5 centimeters is indicated, and a VERY LOW potential was assigned.

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.

HAZARD POTENTIAL MATRIX FOR THE MT. SIZER 7.5-MINUTE QUADRANGLE					
Geologic Strength Group	**Average Phi**	**HAZARD POTENTIAL (Percent Slope)**			
		Very Low	**Low**	**Moderate**	**High**
1	**31**	**0 to 41%**	**42 to 49%**	**50 to 53%**	**> 54%**
2	**27**	**0 to 32%**	**33 to 40%**	**41 to 44%**	**> 45%**
3	**23**	**0 to 23%**	**24 to 32%**	**33 to 36%**	**>37%**

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

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide hazard zones 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 soil and rock materials that are generally weaker than adjacent undisturbed soil and rock 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 landslides have moved during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; McCrink, 2001), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

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

- Geologic Strength Group 3 is included for all slopes steeper than 23 percent.
- Geologic Strength Group 2 is included for all slopes steeper than 32 percent.
- Geologic Strength Group 1 is included for all slopes greater than 41 percent.

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AIR PHOTOS

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WAC Corporation, Inc. dated 4-15-99, Flight No. WAC--C-99CA, Photo Nos. 8-16 through 22, 8-94 through 101, and 8-176 through 180, approximate scale 1:24,000, color.

WAC Corporation, Inc., dated 4-2-85, Flight No. WAC-85CA, Photo Nos. 7-136 through 141, and 6-109 to 111, enlarged format, black & white.

United States Department of Agriculture (USDA), dated 10-26-39, Flight CIV 299, photos 19 through 28, approximate scale 1:20,000, black & white.

Digital Orthophoto Quarter Quadrangle Photographs, dated 08/21/1998, entire quadrangle area, Mt. Sizer Quadrangle. (DOQQ and information concerning them can be obtained at: http://www-wmc.wr.usgs.gov/doq/).

APPENDIX A

SOURCE OF SHEAR STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Pacific Geotechnical Engineering	**8**
City of Morgan Hill, Planning Department	**27**
Santa Clara County, Planning Department	**5**
Total Number of Shear Tests	**40**

APPENDIX B

STRONG MOTION RECORDS USED IN THE NEWMARK ANALYSIS

Earthquake	Focal Mech.	Year	Mw	PGA (g)	Station Name (Component)	Dist. - Closest to rupture	Dist. – Closest surf proj	Site Class.
Morgan Hill	SS	1984	6.2	0.222	Gilroy Array #6 (000)	11.8	9.9	Soft rock
Morgan Hill	SS	1984	6.2	0.292	Gilroy Array #6 (090)	11.8	9.9	Soft rock
Morgan Hill	SS	1984	6.2	0.711	Coyote Lake Dam (SW Abut) (195)	0.1	0.2	Hard rock
Morgan Hill	SS	1984	6.2	1.298	Coyote Lake Dam (SW Abut) (285)	0.1	0.2	Hard rock

SECTION 3

POTENTIAL GROUND SHAKING IN THE MT. SIZER 7.5-MINUTE QUADRANGLE

By

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use 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://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

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

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

EARTHQUAKE HAZARD MODEL

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

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

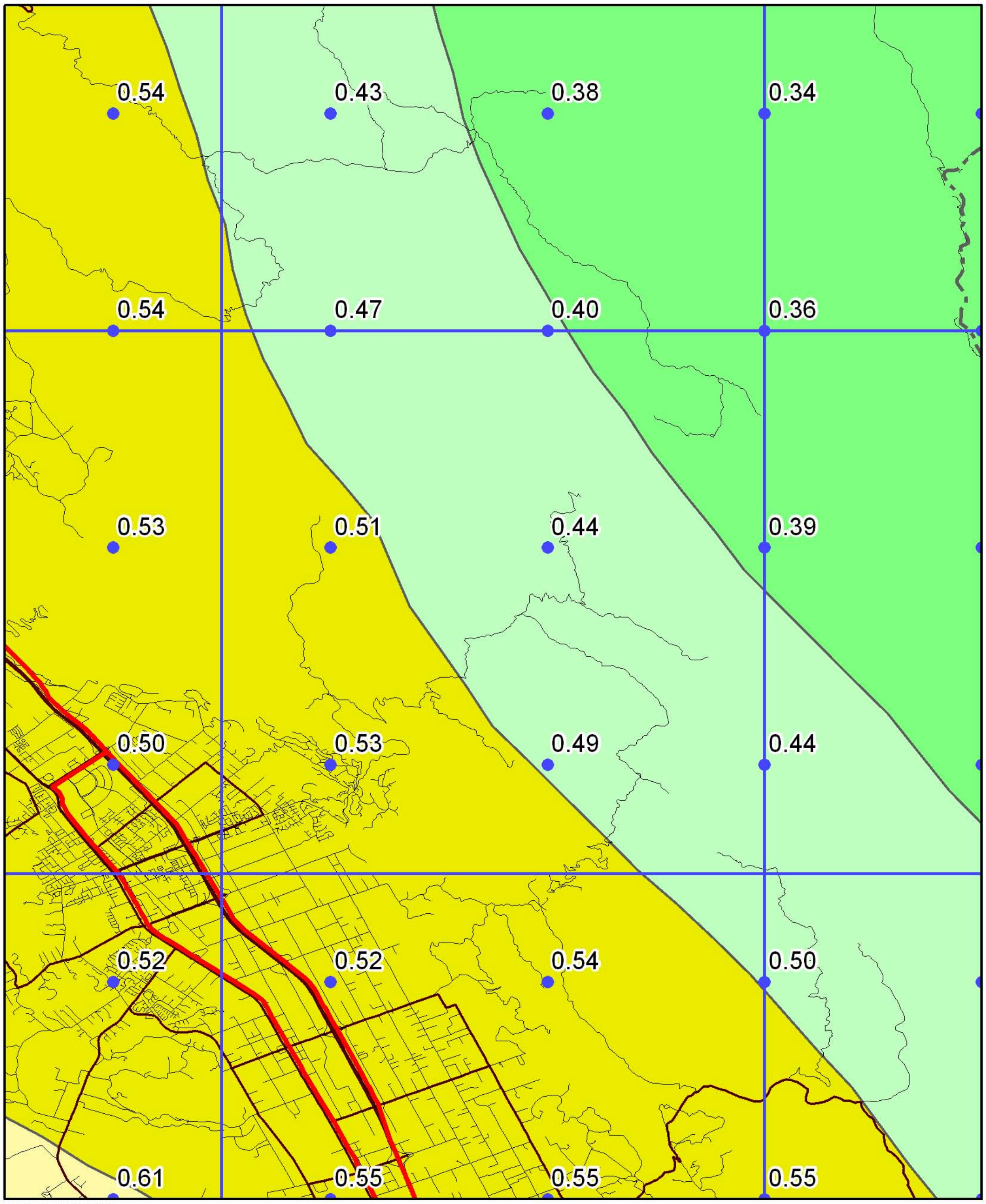
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

MT. SIZER 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map from GDT

0.0 1.0 2.0 3.0
Miles

Department of Conservation
California Geological Survey

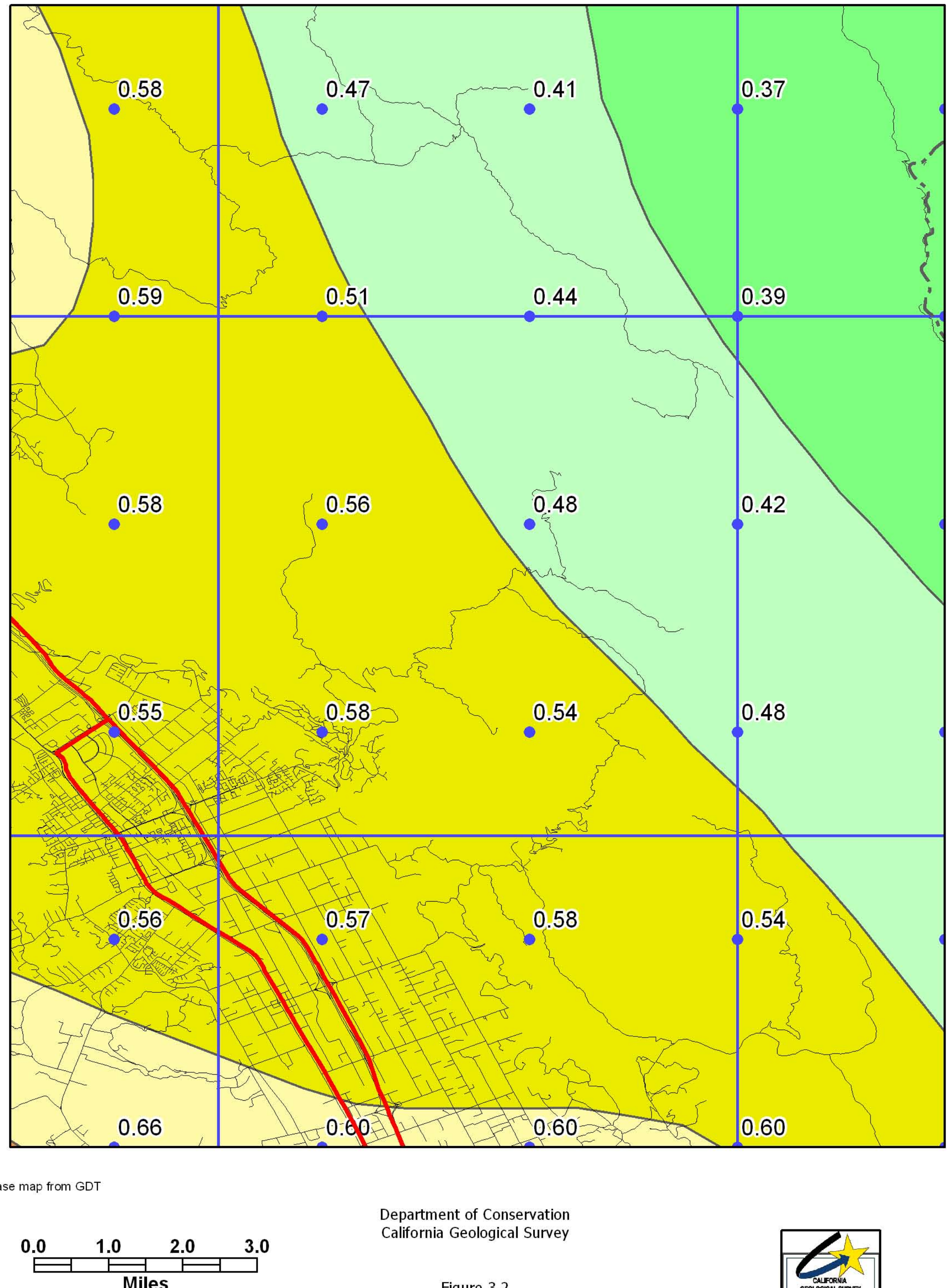
Figure 3.1

MT. SIZER 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map from GDT

Department of Conservation
California Geological Survey

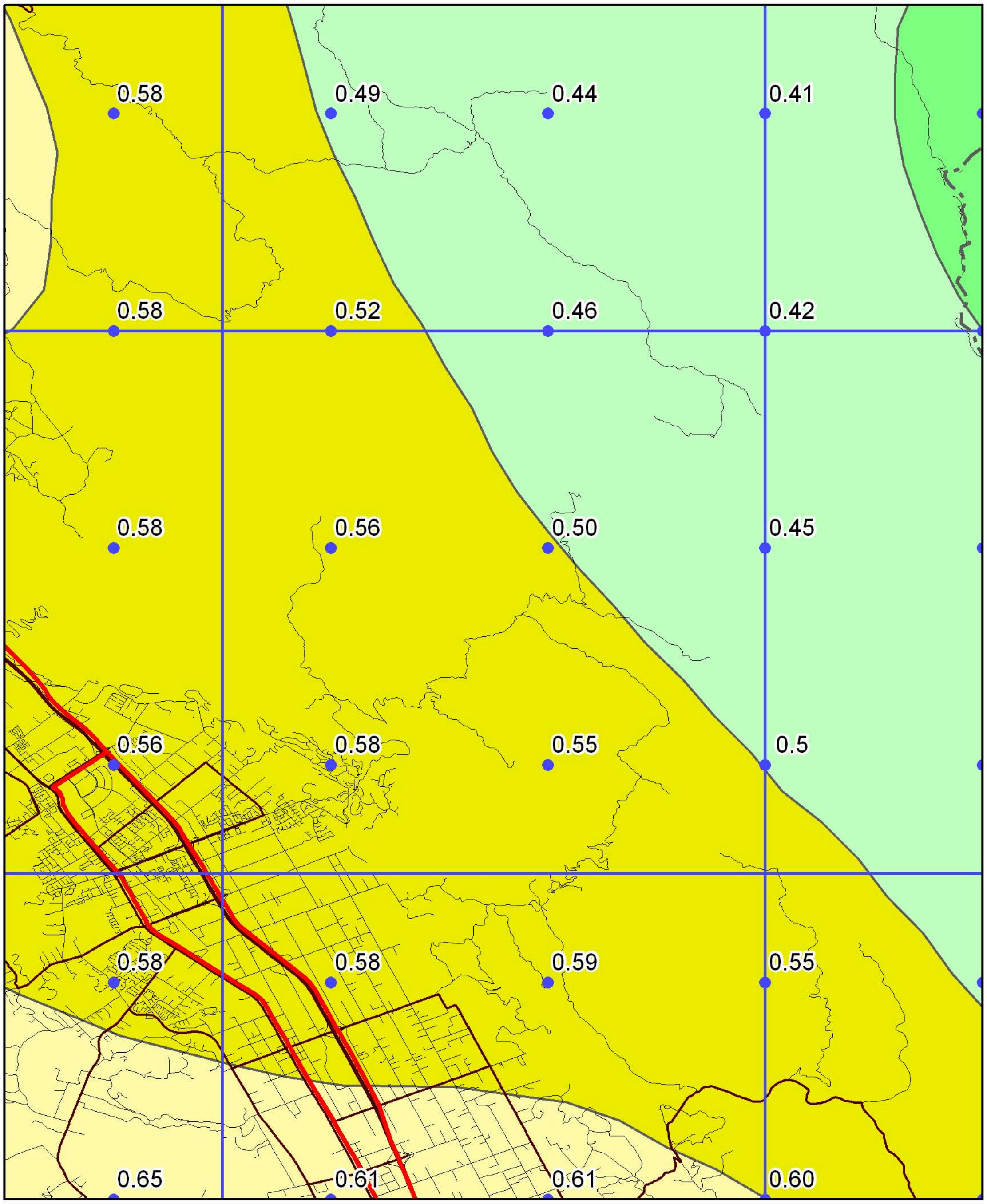
Figure 3.2

MT. SIZER 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



Base map from GDT

0.0 1.0 2.0 3.0
Miles

Department of Conservation
California Geological Survey

Figure 3.3

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

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

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

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

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

MT. SIZER 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

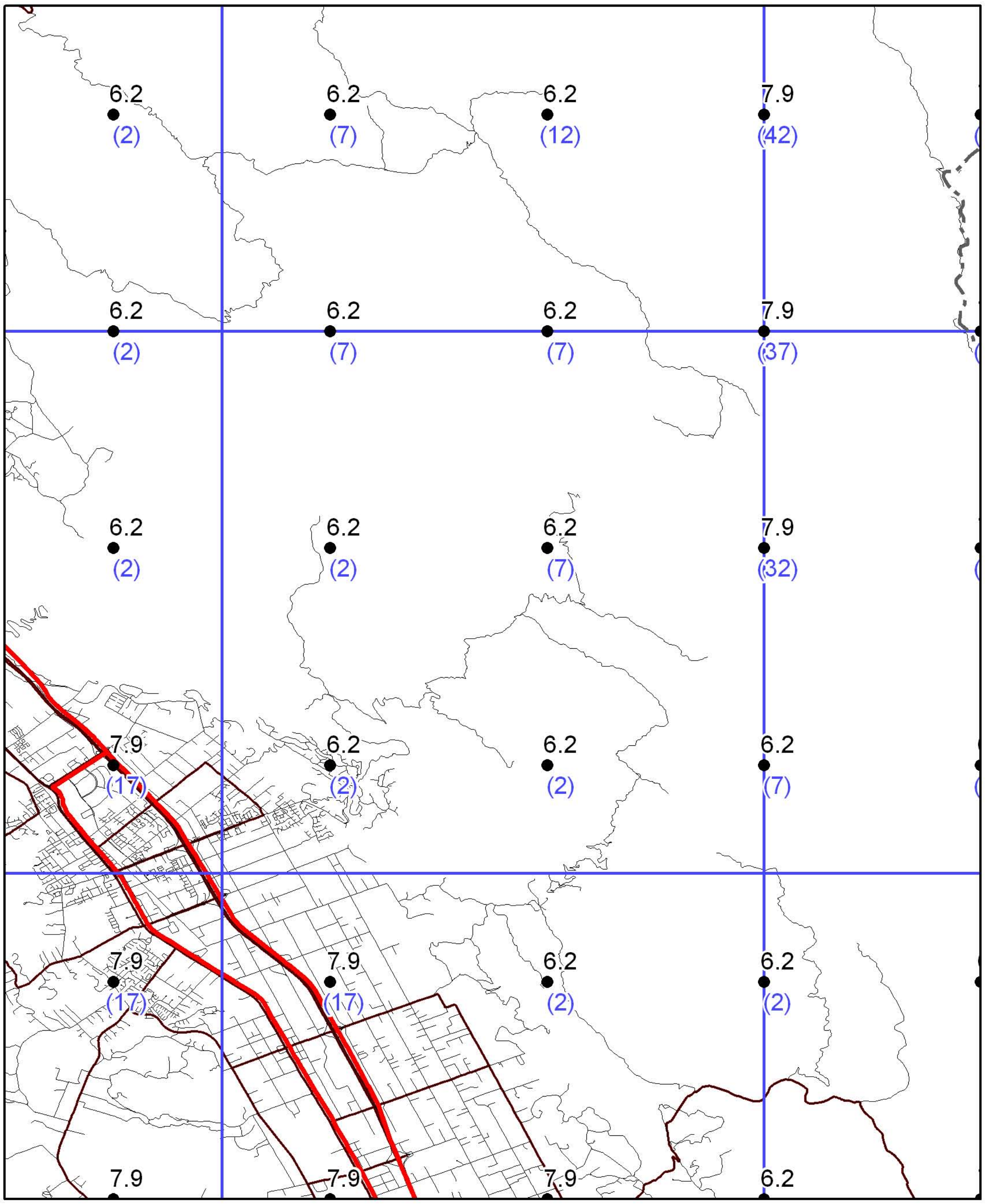
10% EXCEEDENCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

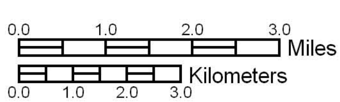
PREDOMINANT EARTHQUAKE

Magnitude (Mw)

[Distance (km)]



Base map from GDT



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California Geological Survey

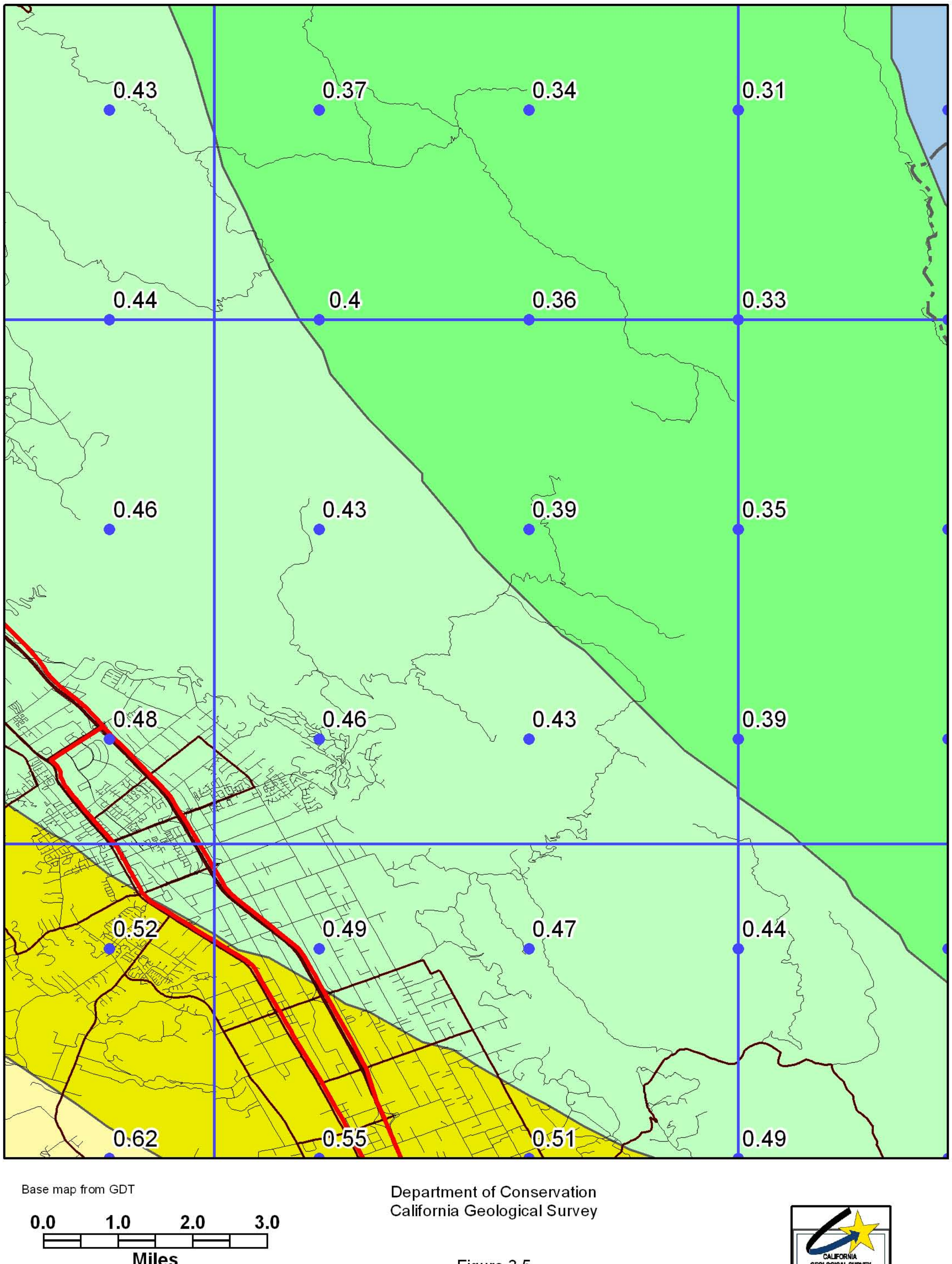
Figure 3.4

MT. SIZER 7.5-MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDENCE IN 50 YEARS MAGNITUDE WEIGHTED PSEUDO-PEAK ACCELERATION (g)

1998

LIQUEFACTION OPPORTUNITY



Department of Conservation
California Geological Survey

Figure 3.5

USE AND LIMITATIONS

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

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

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

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

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

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

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

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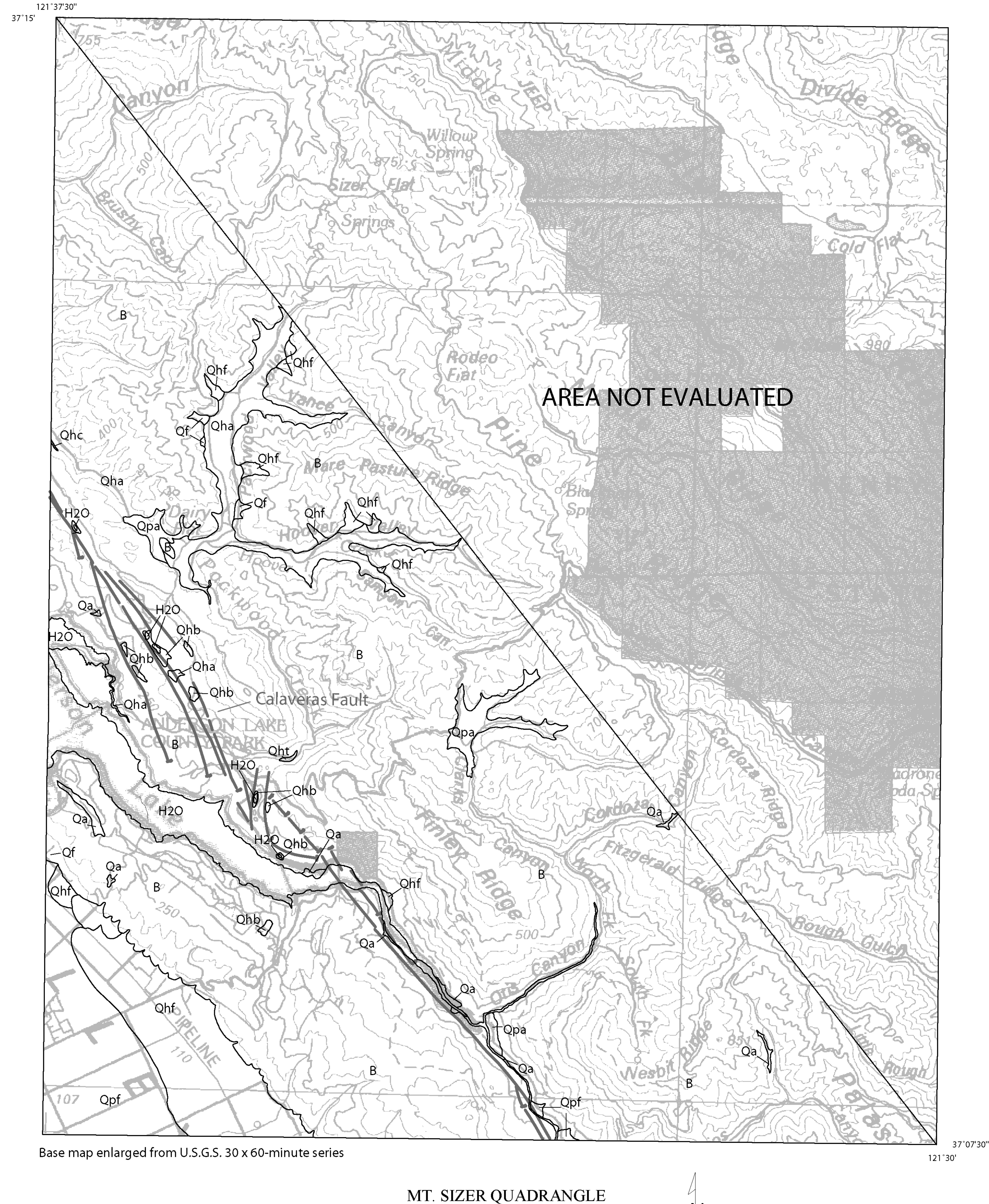
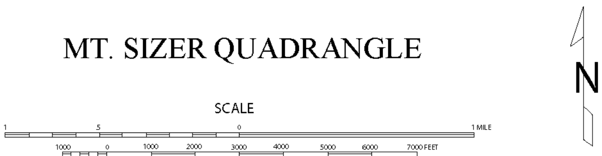


Base map enlarged from U.S.G.S. 30 x 60-minute series

MT. SIZER QUADRANGLE

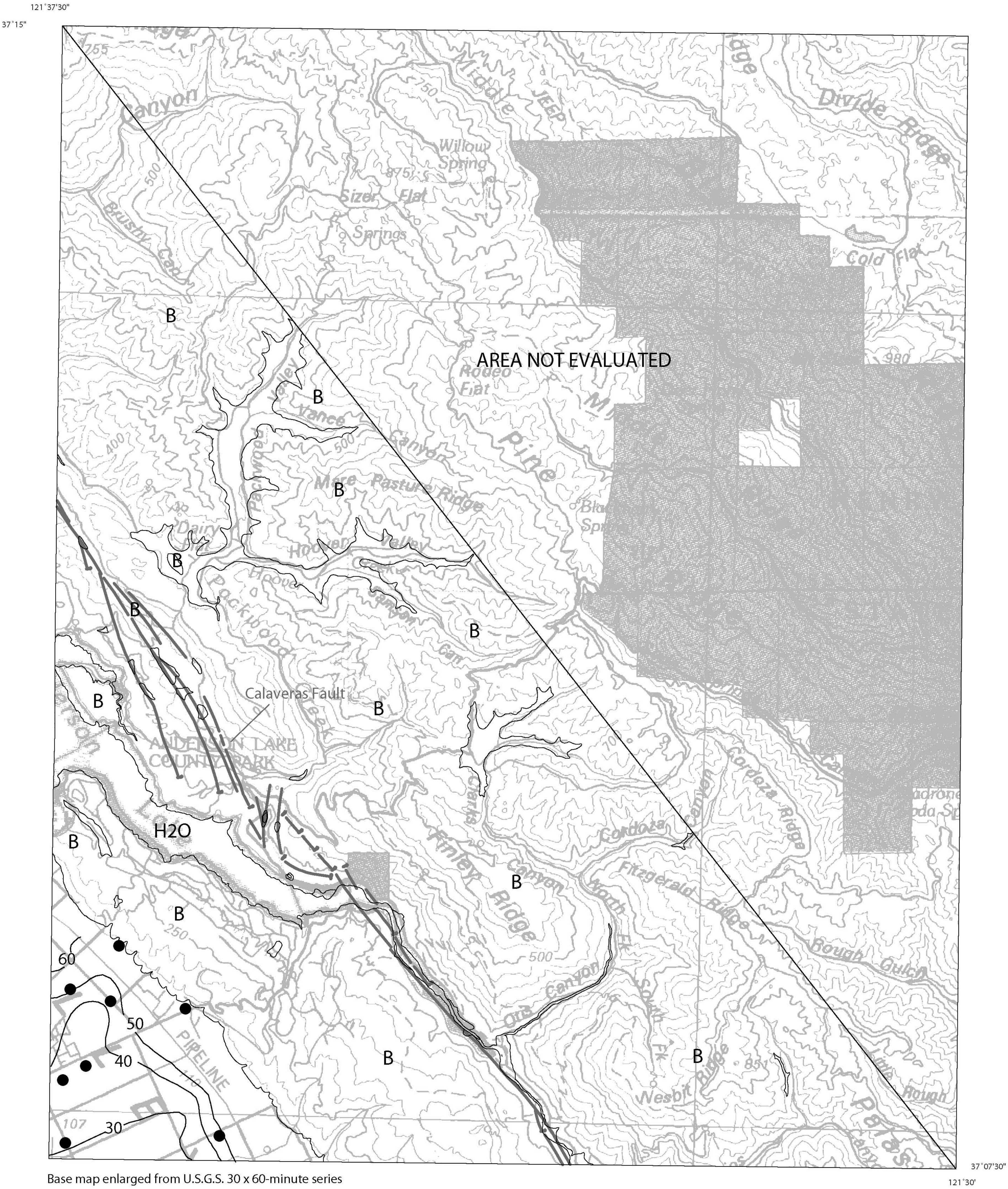


Calaveras Fault trace from Bryant and others (2001)

B = Pre-Quaternary bedrock.

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

Plate 1.1 Quaternary Geologic Map of the Mt. Sizer 7.5-Minute quadrangle (modified from Knudsen and others [2000] and Witter and others [2003])



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

MT. SIZER QUADRANGLE

SCALE

N

Calaveras Fault trace from Bryant and others (2001)

50 Depth to ground water, in feet

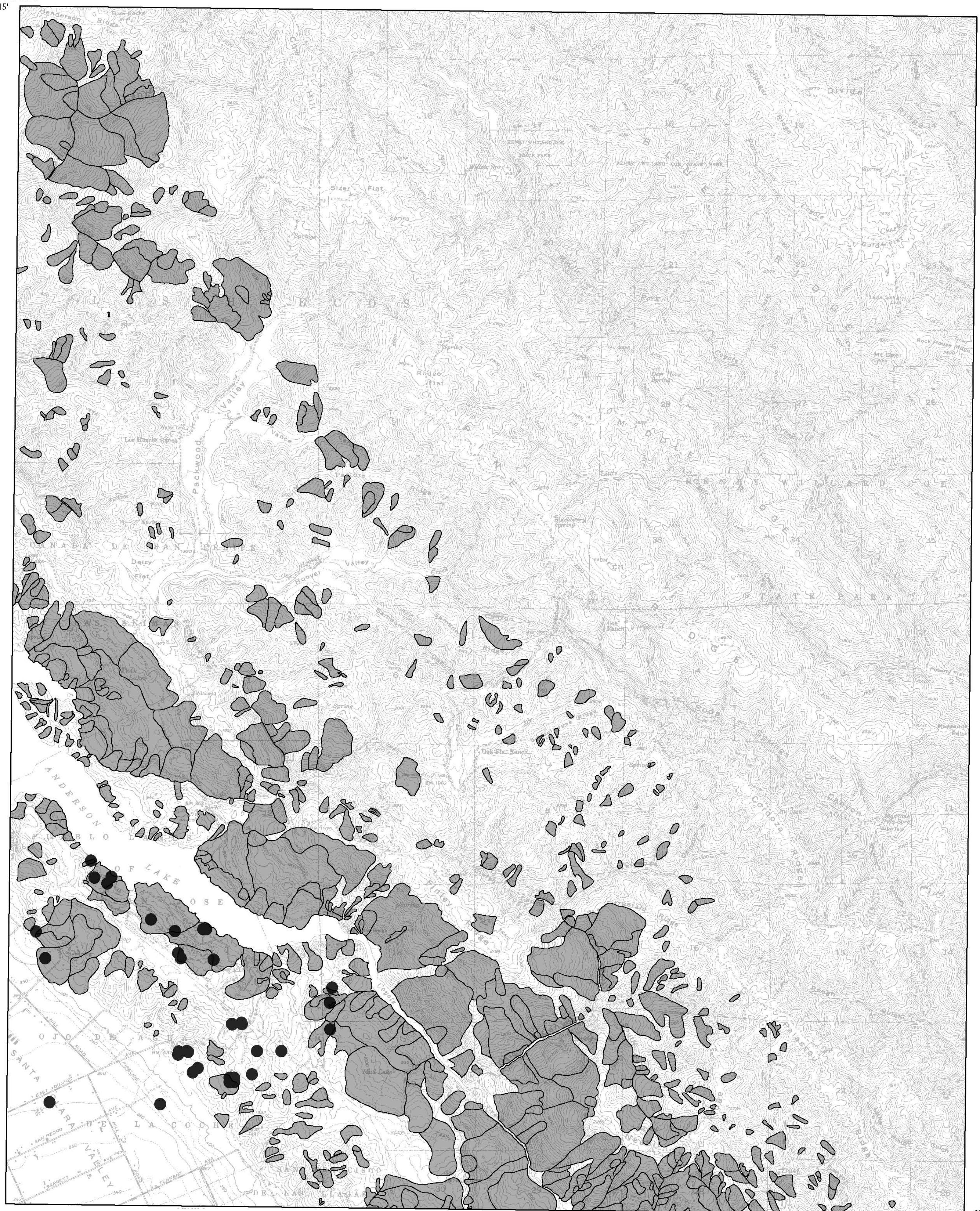
B = Pre-Quaternary bedrock.
See " Geology" in Section 1
for descriptions of units.

Geotechnical borings used in liquefaction evaluation

Plate 1.2 Depth to historically high ground water, and locations of boreholes used in this study, Mt. Sizer 7.5-Minute Quadrangle, California

CALIFORNIA GEOLOGICAL SURVEY
JOHN G. PARRISH, PH.D., STATE GEOLOGIST

STATE OF CALIFORNIA- ARNOLD SCHARZENEGGER, GOVERNOR
THE RESOURCES AGENCY-MIKE CHRISMAN SECRETARY
DEPARTMENT OF CONSERVATION-BRIDGETT LUTHER, DIRECTOR



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

MT. SIZER QUADRANGLE

SCALE

0 .5 0 1 MILE

1000 0 2000 4000 6000 FEET

1 .5 0 1 KILOMETER

N

● Shear test sample location

Landslide

Plate 2.1 Landslide inventory, and shear test sample locations, Mt. Sizer 7.5-Minute Quadrangle, California.