SEISMIC HAZARD ZONE REPORT FOR THE MATILIJA 7.5-MINUTE QUADRANGLE, VENTURA COUNTY, CALIFORNIA

2003

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California Geological Survey

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Matilija 7.5-minute Quadrangle, Ventura County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 40 square miles at a scale of 1 inch = 2,000 feet. About one third of the quadrangle was not evaluated for zoning because it lies within the Los Padres National Forest.

The Matilija Quadrangle includes mostly mountainous terrain in southern Ventura County. About one third of the quadrangle was not evaluated for zoning because it lies within the Los Padres National Forest. The south-flowing Ventura River nearly bisects the quadrangle. Lake Casitas covers a 3-square mile area in the southern part of the quadrangle. Most of the City of Ojai, the only incorporated land within the quadrangle, lies along the eastern boundary. Several unincorporated residential communities, including Meiners Oaks, Mira Monte, Live Oak Acres, and Oak View, are located in the Ventura River Valley. The northern half of the Matilija Quadrangle is characterized by the deeply dissected, rugged mountainous terrain of the Santa Ynez Mountains. Elevations range from 330 feet along the Ventura River to 4,640 feet in the mountains. Sulphur Mountain crosses the southeastern corner of the quadrangle. Ojai Valley lies east of the Ventura River. State Highway 33 is the principal north-south access route. State Highway 150 carries most of the east-west traffic. Land use within the quadrangle is undergoing change from orchards to residential development. Land adjacent to Lake Casitas is also being developed into residential communities and recreational boating facilities. Oil fields on Sulphur Mountain and golf courses near Ojai are additional land uses.

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

In the Matilija Quadrangle the liquefaction zones are restricted to the valleys of the Ventura River, San Antonio Creek, Santa Ana and Poplin creeks north of Lake Casitas, and a small portion of Ojai Valley near the quadrangle boundary. Landslides are widespread but not very abundant in the southern half of the Matilija Quadrangle. However, the combination of dissected hills and weak rock units contributes to an earthquake-induced landslide zone that covers about 36 percent of the evaluated portion of the quadrangle.

How to view or obtain the map

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

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

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

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

INTRODUCTION

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

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

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

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

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

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Matilija 7.5-Minute Quadrangle, Ventura County, California

By
Marvin Woods

California Department of Conservation
California Geological Survey

PURPOSE

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

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC).

The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in part of the Matilija 7.5-minute Quadrangle. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking), complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.conservation.ca.gov/CGS/index.htm

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, 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 in the southern California region in general, including areas in the Matilija Quadrangle.

METHODS SUMMARY

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

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

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

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

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

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

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Matilija Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

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

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

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Matilija 7.5-minute Quadrangle covers approximately 60 square miles in western Ventura County. About one fourth of the quadrangle was not evaluated for zoning because it lies within the Los Padres National Forest in the northwestern quarter and northeastern corner. The quadrangle encompasses the western part of the City of Ojai, as well as the unincorporated communities of Meiners Oaks, Mira Monte, Live Oak Acres, Oak View, and Rancho Matilija. All of these communities are situated within the western end of Ojai Valley and/or the adjoining Ventura River valley. The City of Ojai is approximately 13 miles north of the City of Ventura, which is the county seat of Ventura County. The southern boundary is located about 6.5 miles north of the City of Ventura.

The northern part of the Matilija Quadrangle covers the crest and southern flank of the Santa Ynez Mountains, a west-trending range representing the westernmost extension of the Transverse Ranges geomorphic province. In this mountainous area of the Matilija Quadrangle, the highest elevation is 4640 feet along the crest of the range near the western boundary. Extending from the west into the southwest part of the Matilija Quadrangle is Laguna Ridge, which forms a low-lying hilly area (elevations generally less than 1000 feet). These hills are dissected by the Santa Ana Valley and tributaries, which today are occupied by Lake Casitas, which covers a 3-square mile area. The lake and its shoreline areas comprise the Lake Casitas Recreation Area, which is managed by the U.S. Bureau of Reclamation in conjunction with the Casitas Municipal Water District. The southeast corner of the quadrangle covers the western end of Sulphur Mountain, where the highest elevation is 2000 feet at the eastern quadrangle boundary.

The western end of Ojai Valley and the valley of the south-flowing Ventura River are situated between the Santa Ynez Mountains and the upland areas in the southern part of the quadrangle. Although Ojai Valley generally slopes toward the Ventura River, the valley floor rises near its western end. This results in the valley being drained via San Antonio Creek, which flows southwesterly, slices through the western flank of Sulphur Mountain, and merges with the Ventura River near the southern quadrangle boundary. The Ventura River originates at the confluence of Matilija Creek and its North Fork tributary, both of which flow southward from the north flank of the Santa Ynez Mountains, indicating that these streams were well established before and during the uplift of the Santa Ynez Mountains. The initial stretch of the Ventura River occupies a fairly narrow canyon. At the western end of Ojai Valley the Ventura River valley expands to an alluvial valley approximately one-half mile wide.

State Highway 33, called Ventura Avenue south of Ojai Valley and Maricopa Road to the north, is the principal north-south access route within the Matilija Quadrangle. State Highway 150, called Ojai Avenue or Ventura Avenue east of the river and Baldwin Road and Casitas Pass Road west of the river, carries most of the east-west traffic.

Principal land use within the quadrangle is undergoing change from agricultural (orchards) to residential development, especially in the communities within the Ventura River Valley. Land adjacent to Lake Casitas is also being developed into residential communities and recreational boating facilities. Oil fields on Sulphur Mountain and golf courses near Ojai are additional land uses.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. To evaluate the areal and vertical distribution of shallow Quaternary deposits and to provide information on subsurface geologic, lithologic and engineering properties of the units in the Matilija Quadrangle, we obtained 1:24,000-scale digital Quaternary maps from William Lettis and Associates, Inc. (WLA, 2001). We also digitized a 1:24,000-scale geologic map from the Dibblee Geological Foundation (Dibblee, 1987). These GIS maps were combined, with minor modifications along the bedrock/Quaternary-deposits contact, to form a single geologic map of the Matilija Quadrangle. The distribution of Quaternary deposits on this map (summarized on Plate 1.1) was used in combination with other data, discussed below, to evaluate liquefaction susceptibility and develop the hazard zone map.

Sedimentary deposits of Quaternary age cover approximately 29 percent of the Matilija Quadrangle. These relatively young deposits occur chiefly within western Ojai Valley, the entire Ventura River valley and within its minor tributaries, the valley of San Antonio Creek, the Santa Ana Valley, and within the low-lying area flanking Santa Ana Valley north of Lake Casitas.

Characteristics of Quaternary sedimentary deposits mapped within the Matilija Quadrangle are summarized in Table 1.1. Areally, more than half of the Quaternary sedimentary deposits within the evaluation area are "older" units of Pleistocene age. These include alluvial valley deposits (Qoa), stream terrace deposits (Qoat), alluvial fan deposits (Qof), and pediment gravel deposits (Qog). Each of these deposits may contain a wide range of material, from cobble gravel to clay. The older units tend to be weakly consolidated and dense with little to no susceptibility to liquefaction. These older units are distributed chiefly east of the Ventura River valley, west of San Antonio Creek valley, and west of Ojai Valley. They also occur east of the upper San Antonio Creek valley near the east edge of the quadrangle, immediately west of the Ventura River in the Rancho Matilija area, and in other small areas throughout the quadrangle.

Young (Holocene to late Pleistocene) axial valley deposits (Qya1 and Qya2) of gravel, sand, and silt occur within active stream valleys. This includes the valleys of the Ventura River and its tributaries, San Antonio Creek, and the Santa Ana Creek and its tributaries. In the larger drainages, active, modern stream wash deposits (Qw1 and Qw2), consisting of gravel, sand, and silt, are significant. Both the axial valley and stream wash deposits tend to be loose and, when saturated, susceptible to liquefaction. Small remnants of alluvial fan deposits (Qf, Qyf1, and Qyf2) of Holocene to late Pleistocene age occur immediately east of the San Antonio Creek/Ventura River confluence and just southwest of Rancho Matilija. A large Qyf2 deposit occurs prominently in the west end of Ojai Valley. Detritus comprising this fan came mainly from Stewart Canyon, which extends northward into Eocene shale and sandstone strata in the Santa Ynez Mountains.

The remaining younger Quaternary deposits are sparsely distributed. Young stream terrace deposits (Qyat1 and Qyat2) occur as small patches flanking younger Qya deposits within the San Antonio valley, flanking Qoa or Qog deposits in the upland between San Antonio Creek and Ventura River valleys, or flanking stream wash gravels in the upper Ventura River valley. Small, isolated patches of colluvium (Qc) and artificial fill (af) are also present within the quadrangle.

Pre-Quaternary bedrock exposed in the Matilija Quadrangle as mapped by Dibblee (1987) consists of clastic sedimentary rocks deposited within the Ventura Basin. All of these rocks are Tertiary except for a small exposure of Upper Cretaceous clastic sedimentary rocks located near the northern quadrangle boundary. The entire sequence of pre-Quaternary rocks consists of sandstone, shale, and siltstone. Dibblee (1987) interprets all strata except those assigned to the Oligocene Sespe Formation to have been deposited under marine conditions. The Sespe, which dominates the western and central parts of the Matilija Quadrangle, is a non-marine redbed unit that includes pebble-cobble conglomerate in addition to shale and sandstone. See the earthquake-induced landslide portion of this report (Section 2) for further details on pre-Quaternary geology.

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Age	Susceptible To Liquefaction? *
Af	gravel, sand, silt, clay	artificial, un-engineered fill	Generally loose	Historical	yes**
Qc	gravel, sand, silt, clay	colluvium, slopewash	loose to moderately dense	Holocene & Pleistocene	yes**
Qf, Qyf1, Qyf2	gravel, sand, silt, clay	alluvial fans	loose to moderately dense	Historical to Pleistocene	yes**
Qw, Qw2	gravel, sand, silt	stream channels	Loose	Active & Historical	yes
Qya1, Qya2	gravel, sand, silt	young axial-valley deposits	loose to moderately dense	Late Holocene to Pleistocene	yes
Qyat1, Qyat2	Sand, silt, clay	young stream terrace	loose to moderately dense	Late Holocene to Pleistocene	yes**
Qoa	gravel, sand, silt, clay	old alluvial valley deposits	moderately dense to very dense	Pleistocene	not likely
Qoat	gravel, sand, silt, clay	old stream terrace	moderately dense to very dense	Pleistocene	not likely
Qof	gravel, sand, silt, clay	old alluvial fan deposits	moderately dense to very dense	Pleistocene	not likely
Qog	cobble-boulder gravel, sand	old pediment gravel deposits	dense to very dense	Pleistocene	no

* when saturated ** Not likely if deposit is mostly clay or sand and silt layers are clayey

Table 1.1. Quaternary Map Units Used in the Matilija 7.5-minute Quadrangle and Their Geotechnical Characteristics and Liquefaction Susceptibility

Structural Geology

The Matilija Quadrangle lies within the north-central part of the 165-mile long Ventura Basin in the Transverse Ranges geomorphic province. The Ventura Basin is characterized by an unusually thick, nearly continuous sequence of Upper Cretaceous through Quaternary sedimentary rocks, which has been deformed into a series of east-trending folds associated with thrust and reverse faults. The Tertiary formations in the Santa Ynez Mountains generally strike east-west and dip steeply south or are spectacularly overturned and dip moderately to steeply to the north. The prominent large fold in the Tertiary rocks (Dibblee, 1987) dissected by the Ventura River is a manifestation of the “Matilija Overturn” (Kerr and Schenck, 1928). This structure is part of the south limb of a faulted, 40-mile long anticlinal fold with extensive areas of upside-down sandstone and shale beds.

The structural framework of the region is believed to be the result of both crustal-block rotation and north-south compression within a restraining bend of the San Andreas Fault (Sorlien and others, 2000). The main structural elements in the quadrangle include: the Matilija Overturn, the Arroyo Parida Fault, a series of down-to-the-north faults called the Oak View faults east of Oak View, and numerous anticlinal and synclinal folds that have deformed Sespe Formation rocks in the Lake Casitas region. Due to their recency of activity several of the Oak View faults meet the criteria required for inclusion in the Official Earthquake Fault Zone prepared by DMG (DOC, 1986).

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of young sedimentary deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. For this investigation, 21 borehole logs were collected from the files of the Ventura County Public Works Agency. Data from 19 borehole logs were entered into a CGS geotechnical GIS database.

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. Dropping a 140-pound hammer weight 30 inches provides the driving force. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 1999). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts are normalized to a common-reference, effective-overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60% using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

Geotechnical and environmental borehole logs provided information on lithologic and engineering characteristics of Quaternary deposits within the study area. Geotechnical characteristics of the Quaternary map units mapped by WLA (2001) within the evaluated part of the Matilija Quadrangle are generalized in Table 1.1.

GROUND-WATER CONDITIONS

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

Ground-water conditions were investigated in the Matilija Quadrangle to evaluate the depth to saturated materials. Saturated conditions reduce the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on first-encountered water noted in geotechnical borehole logs acquired from the Ventura County Public Works Agency (Leaking Underground Fuel Tank Program and the Water Resources and Engineering Department). The depths to first-encountered unconfined ground water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water. Water depths from boreholes known to penetrate confined aquifers were not utilized.

Turner (1971) investigated ground-water occurrence and quality within the Ventura River system (the Ventura River valley, San Antonio Creek valley, and Ojai Valley). He showed that the aquifer is unconfined. He used well data from 1951 through 1970, which showed significant fluctuation in overall water depth during that period. We selected the dataset from spring 1969 as representing the highest overall water levels. We digitized ground-water elevation contours from Turner's Plates 6A and 6B, formed a 10-meter grid of ground-water *elevation* values from the contours, then subtracted that grid from a 10-meter digital elevation model of the land surface (U.S. Geological Survey, 1993) to yield a grid of ground-water *depth* values. From these activities we created a contour map based on the ground-water depth grid (Plate 1.2).

Historically high ground-water depths are less than 10 feet over most of the area of the Ventura River and San Antonio Creek valleys (Plate 1.2). Depths greater than 40 feet are observed only locally near valley margins and within most minor tributaries. The large, young fan deposit of western Ojai Valley is characterized by ground water with depths generally greater than 40 feet; only a small area along the eastern quadrangle boundary appears to have ground water at depths of less than 40 feet.

Turner's ground-water investigation did not cover the Santa Ana Valley area (west of Ventura River and generally north of Lake Casitas). For that area, the general water depths depicted on Hazards Plate 5 of the Ventura County General Plan Safety Element (Ventura County Planning Department, 1974) guided us. In this area, anticipated ground-water depths are at most 40 feet within nearly the entire alluviated/water-bearing area, with some areas having depths of 15 feet or less (Plate 1.2).

PART II

LIQUEFACTION POTENTIAL

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

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

LIQUEFACTION SUSCEPTIBILITY

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

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

CGS's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. CGS's qualitative relations between susceptibility and geologic map unit within the Matilija Quadrangle are summarized in Table 1.1.

LIQUEFACTION OPPORTUNITY

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

For the Matilija Quadrangle, PGAs of 0.55 to 0.65 g, resulting from earthquakes of magnitude 6.8 to 7.0, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion portion (Section 3) of this report for further details.

Quantitative Liquefaction Analysis

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

The CGS liquefaction analysis program calculates an FS for each geotechnical sample where blow counts were collected. Typically, multiple samples are collected for each borehole. The program then independently calculates an FS for each non-clay layer that includes at least one penetration test using the minimum $(N1)_{60}$ value for that layer. The minimum FS value of the layers penetrated by the borehole is used to 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 19 geotechnical borehole logs reviewed in this study (Plate 1.2), 16 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 flagged and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

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

LIQUEFACTION ZONES

Criteria for Zoning

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

1. Areas known to have experienced liquefaction during historical earthquakes

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

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

4. Areas where existing geotechnical data are insufficient

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

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

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

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

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

Areas of Past Liquefaction

We are not aware of any historical occurrences of liquefaction or related ground failure within the Matilija Quadrangle, and none are reported in the literature.

Artificial Fills

In general, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for river levees and elevated freeways. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata. However, no such applications of artificial fill are known to occur within the Matilija Quadrangle. Non-engineered fills are commonly loose and uncompacted, and the material varies in size and type. The few small patches of artificial fill that are otherwise adjacent to or contained by more extensive natural deposits that are included with a zone of required investigation for liquefaction hazard are incorporated within that zone. However, small, isolated patches of artificial fill are neglected; i.e., by themselves, they do not form a sufficient basis for delineation of a one of required investigation for liquefaction hazard.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. However, with only 16 borehole logs within the Matilija Quadrangle that provide such data, the quantitative liquefaction analysis performed serves mainly to supplement and confirm the delineation of zones of required investigation developed pursuant to SMBG criterion #4 (see above). Thus there are no extensive areas within the Matilija Quadrangle where the primary basis for evaluation of the liquefaction potential was application of the Seed-Idriss Simplified Procedure using sufficient geotechnical data. Nevertheless, in Holocene alluvial deposits that cover much of the Ventura River valley, most of the borehole logs that were analyzed using the Seed-Idriss Simplified Procedure contain sediment layers that may liquefy under the expected earthquake loading. These areas containing saturated potentially liquefiable material are included in the zone. Several of the boreholes are located within older Quaternary sediments, such as Qoa, where as expected, application of the Seed-Idriss Simplified Procedure confirms that little if any potential for liquefaction exists within these older, denser deposits.

Areas with Insufficient Existing Geotechnical Data

As noted in the previous paragraph, the relatively few and sparsely located geotechnical boreholes reviewed during this evaluation provide mainly confirmatory evidence for the potential for liquefaction. The zones of required investigation for liquefaction hazard were primarily developed by application of SMBG criterion #4 (see above). All of the zones of required investigation for liquefaction hazard fall within valleys characterized by Holocene or active alluviation. Fortunately, nearly all development to date within the Matilija Quadrangle appears to have occurred elsewhere, mainly upon older deposits (for example, Qoa) that have little to no potential for liquefaction.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Matilija 7.5-Minute Quadrangle, Ventura County, California

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). 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 Matilija 7.5-minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking), complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://www.conservation.ca.gov/CGS/index.htm

BACKGROUND

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

METHODS SUMMARY

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

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

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

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

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

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a DMG pilot study (McCrink and Real, 1996; McCrink, 2001) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

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

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

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

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Matilija Quadrangle covers approximately 60 square miles of mostly mountainous terrain in the southern portion of Ventura County. About one fourth of the quadrangle was not evaluated for zoning because it lies within the Los Padres National Forest in the northwestern quarter and northeastern corner of the quadrangle. The south-flowing Ventura River nearly bisects the quadrangle. Almost all of Lake Casitas covers a 3-square mile area in the southern part of the quadrangle. Most of the City of Ojai, which is the only incorporated land within the quadrangle, lies along the eastern boundary. Several small, unincorporated residential communities, including Meiners Oaks, Mira Monte, Live Oak Acres, and Oak View, are located in the Ventura River Valley. The southern boundary is located about 6.5 miles north of the City of Ventura.

The northern half of the Matilija Quadrangle is characterized by the deeply dissected, rugged mountainous terrain of the Santa Ynez Mountains, most of which was not evaluated because it is national forest land. The highest elevation in the quadrangle, 4,640 feet, is located along a ridge close to the western boundary of the quadrangle. The lowest elevation, less than 330 feet, is along the Ventura River at the southern boundary. The crest of Sulphur Mountain, which rises more than 1000 feet above the Ventura River Valley, crosses the southeastern corner of the quadrangle. Ojai Valley lies east of the river between Sulphur Mountain and the mountainous terrain that rises toward Nordhoff Ridge.

The Ventura River and its tributaries dominate drainage within the quadrangle. Some of the creeks are seasonal, some are perennial, and there are springs and seeps at the heads of a few. The major tributaries, clockwise from north are Matilija Creek and North Fork Matilija Creek (which become the Ventura River where they join near Matilija Hot Springs), Cozy Dell Canyon, McDonald Canyon, Stewart Canyon, San Antonio Creek, Lion Canyon, Coche Canyon, Canada de Aliso, Fresno Canyon, Ventura River, Chismahoo Creek, Willow Creek, Coyote Creek, Santa Ana Creek, Lime Canyon, Cooper Canyon, Wills Canyon, Rice Canyon, and Kennedy Canyon.

State Highway 33, called Ventura Avenue south of Ojai Valley and Maricopa Road to the north, is the principal north-south access route within the Matilija Quadrangle. State Highway 150, called Ojai Avenue or Ventura Avenue east of the river and Baldwin Road and Casitas Pass Road west of the river, carries most of the east-west traffic.

Principal land use within the quadrangle is undergoing change from agricultural (orchards) to residential development, especially in the communities within the Ventura River Valley. Land adjacent to Lake Casitas is also being developed into residential communities and recreational boating facilities. Oil fields on Sulphur Mountain and golf courses near Ojai are additional land uses.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. To calculate slope gradient for the terrain within the Matilija Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours, based on 1952 topography, has a 10-meter horizontal resolution 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 DEM was also used to make a slope-aspect map. The slope map was used first in conjunction with the aspect map and geologic structural data to identify areas of potential adverse bedding conditions, and then again with the geologic strength map in the preparation of the earthquake-induced landslide hazard potential map.

GEOLOGY

Bedrock and Surficial Geology

The bedrock geologic mapping used in this slope stability evaluation was obtained from the Dibblee Geological Foundation (Dibblee, 1987) and digitized by DMG staff for this study. A map of the Quaternary (surficial) geology was obtained in digital form from William Lettis and Associates (2000). The bedrock units are described in detail in this section. Surficial geologic units are only briefly described here but are discussed in more detail in Section 1.

DMG geologists modified the digital geologic map in the following ways. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the landslide inventory created during this study would exist on separate layers for the hazard analysis. Contacts between bedrock and surficial units were also revised based upon comparisons between the two source maps. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to the development and abundance of slope failures was noted.

Bedrock units of the Matilija Quadrangle range in age from Cretaceous to Pliocene. Except for the non-marine Sespe Formation (Tsp), which is widespread in the western half of the quadrangle, all of the bedrock units are of marine origin. Surficial deposits are limited to areas along active stream channels, river floodplains and dissected older alluvial and fan gravels.

The oldest geologic unit mapped in the Matilija Quadrangle is the late Cretaceous "unnamed marine strata" (possibly Jalama [?] Formation according to Dibblee, 1987). These strata, which consist of an older conglomerate (Kucg) and a younger clay shale (Kush) and sandstone sequence, are exposed in the extreme northwestern corner of the quadrangle.

Tertiary formations in the Matilija Quadrangle include: the Juncal Formation (Tj, Tjsh, Tjss), the Matilija Sandstone (Tma, Tmash), the Cozy Dell Shale (Tcd, Tcdss), the Coldwater Sandstone (Tcw, Tcwsh), the Sespe Formation (Tsp), the Vaqueros Sandstone (Tvq), the Rincon Shale (Tr), the Monterey (or Modelo) Formation (Tm, Tml, Tmd), the Sisquoc Shale (Tsq), and the Pico Formation (Tp). The Juncal Formation (Tj) of early (?) to middle Eocene age extends across the entire northern edge of the quadrangle. Most of the Juncal Formation consists of marine, dark gray micaceous shale (Tjsh) with minor interbeds of hard, gray-white to tan arkosic sandstone. Interlayered with the shale are beds of Juncal Formation sandstone (Tjss) that are mostly hard gray-white to tan arkosic sandstone.

The middle to late Eocene marine Matilija Sandstone lies conformably upon the Juncal Formation. Matilija Sandstone is also exposed across the width of the quadrangle and is subdivided into two units. Most of the formation consists of hard, thick bedded, tan to mottled light greenish-gray arkosic sandstone (Tma) with partings and thick interbeds of gray micaceous shale. Near the western boundary is a layer of gray micaceous shale (Tmash) with minor tan sandstone interbeds.

Cozy Dell Shale of late Eocene age is conformable upon the Matilija Sandstone. Most of the unit consists of dark-gray argillaceous to silty, micaceous shale (Tcd), with minor light gray to tan arkosic sandstone. Minor light gray to tan arkosic sandstone (Tcdss) with minor interbeds of gray micaceous shale is interlayered with the Tcd shale.

The late Eocene marine Coldwater Sandstone has a sandstone member (Tcw) and a shale member (Tcwsh). Coldwater Sandstone forms a prominent white ledge at the base of the Santa Ynez Mountains. Coldwater Sandstone (Tcw) consists of hard, tan, bedded arkosic sandstone, with interbeds of greenish-gray siltstone and shale. It also includes some red siltstone. Locally, oyster shell beds are common in the upper part. The Tcwsh member consists of greenish-gray siltstone and shale with occasional interbeds of tan sandstone.

The predominantly Oligocene Sespe Formation (Tsp) is the only Tertiary unit of non-marine origin in the quadrangle. It is typically reddish or maroon and contrasts with the thick sequence of marine rocks beneath it, although it is apparently conformable on the Coldwater Sandstone. West of the Ventura River, Sespe Formation is exposed over nearly a quarter of the quadrangle within a series of anticlinal and synclinal folds. East of the Ventura River, just west of the City of Ojai, Sespe Formation beds are overturned within the Matilija Overturn. The Sespe Formation consists of a maroon to red, locally green, silty shale or claystone, and interbedded red to pinkish-gray sandstone. Some sandstone beds in the lower part are coarse-grained and include pebble-cobble conglomerate. The lowest part of the formation consists of pink sandstone and red claystone.

The early Miocene Vaqueros Sandstone (Tvq) of shallow marine origin conformably overlies the Sespe Formation. It consists of massive to poorly bedded, light gray to tan, fine-grained sandstone that is locally calcareous.

Early Miocene Rincon Shale (Tr) consists of poorly bedded gray clay shale and siltstone, with occasional gray dolomitic concretions. Rincon Shale is widespread east and south of Lake Casitas and is exposed in scattered fault blocks east of the Ventura River.

The early to late Miocene Monterey Formation (also known as the Modelo Formation), has two members. The lower shale unit (Tml), is a white-weathering, soft, fissile to punky, clay shale, with interbeds of hard siliceous shale and thin limestone. The upper shale unit (Tm) consists of white-weathering, thin bedded, hard, platy to brittle, siliceous shale. The Monterey Formation is conformable on the Rincon Shale. The primary outcrop area of Monterey Formation rocks is on the northwest-facing slope of Sulphur Mountain.

The late Miocene Sisquoc Shale (Tsq) consists of shallow marine light gray silty shale or claystone that is, locally, slightly siliceous and diatomaceous and conformable on the upper Monterey Formation. Dip slopes in Sisquoc Shale are found on the southeastern slopes of Sulphur Mountain.

The youngest Tertiary marine unit in the quadrangle is the Pliocene Pico Formation (Tp). It consists of massive to bedded, gray siltstone, mudstone, and minor, locally pebbly, tan sandstone. The Pico Formation is conformable on the Sisquoc Shale and only present on dip slopes on Sulphur Mountain in the extreme southeastern corner of the quadrangle.

Pleistocene to Holocene surficial units unconformably overlie the Tertiary bedrock units. To resolve differences between the bedrock geologic map (Dibblee, 1987) and the surficial geologic map (William Lettis and Associates, 2000) DMG geologists merged them and made adjustments to contacts between bedrock and Quaternary units. The oldest Quaternary units in the Matilija Quadrangle are older alluvial terrace deposits (Qoat1, Qoat2), older alluvial fan deposits (Qof, Qof1), older alluvial valley deposits (Ooa, Qoa2), and older alluvial gravel (terrace?) deposits (Qog). The younger alluvial deposits consist of terrace (Qyat1, Qyat2), alluvial fan (Qyf1, Qyf2, Qf), and alluvial valley (Qya1, Qya2) deposits. Other surficial deposits include colluvium (Qc), stream wash (Qw, Qw2), and landslide deposits (Qls). Artificial fill (af) also exists within the Matilija Quadrangle. A detailed discussion of Quaternary units can be found in Section 1.

Structural Geology

The Matilija Quadrangle lies within the north-central part of the 165-mile long Ventura Basin in the Transverse Ranges geomorphic province. The Ventura Basin is characterized by an unusually thick, nearly continuous sequence of Upper Cretaceous through Quaternary sedimentary rocks, which has been deformed into a series of east-trending folds associated with thrust and reverse faults. The Tertiary formations in the Santa Ynez Mountains generally strike east-west and dip steeply south or are spectacularly overturned and dip moderately to steeply to the north. The prominent large fold in the Tertiary rocks (Dibblee, 1987) dissected by the Ventura River is a manifestation of the “Matilija Overturn” (Kerr and Schenck, 1928). This structure is part of the south limb of a faulted, 40-mile long anticlinal fold with extensive areas of upside-down sandstone and shale beds.

The structural framework of the region is believed to be the result of both crustal-block rotation and north-south compression within a restraining bend of the San Andreas Fault (Sorlien and others, 2000). The main structural elements in the quadrangle include: the Matilija Overturn, the Arroyo Parida Fault, a series of down-to-the-north faults called the Oak View faults east of Oak View, and numerous anticlinal and synclinal folds that have deformed Sespe Formation rocks in the Lake Casitas region. Due to their recency of activity several of the Oak View faults meet the criteria required for inclusion in the Official Earthquake Fault Zone prepared by DMG (DOC, 1986).

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Matilija Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping. Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the slope stability analysis. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed hand-drawn landslide map was scanned, digitized, and the attributes compiled in a database. A version of this landslide inventory is included with Plate 2.1.

The distribution of landslides mapped for this study is roughly similar to that previously mapped by DMG (Evans and others, 1972; Morton, 1973). In previous maps, however, although many landslide deposits were mapped, the entire scarp area was not included as part of the mapped feature in all landslides. Including the scarp area as part of the landslide, as is done during current mapping, results in significant differences in interpretation between this inventory and that of previous maps. Most of the land within the Los Padres National Forest was not evaluated for landslides in this study. Exceptions include a narrow stretch along the Ventura River and North Fork Matilija Creek and two square miles north of Meiners Oaks and Ojai.

Landslides mapped in the quadrangle range from minor surficial failures resulting from soil and rock creep, rock fall, soil and debris slumps, and debris flows to large rotational and translational landslides, some of which are relatively old and deeply eroded. On the slopes of Sulphur Mountain numerous recently active landslides occur within older, larger landslide complexes. Also in this vicinity landslides are especially common within areas underlain by the Rincon Shale and Monterey, Sisquoc, and Pico formations. West of the Ventura River, landslides are also most abundant in areas underlain by Rincon Shale. Additional landslides occur in the Sespe Formation. Individual debris-flow tracks and deposits smaller than 200 feet across were not mapped during this study.

Landslides identified on old aerial photos within the area now covered by Lake Casitas were not mapped.

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 Matilija Quadrangle geologic map were obtained from the County of Ventura, Public Works Agency (see Appendix A). The locations of rock and soil samples taken for shear testing by consultants are shown on Plate 2.1. Shear test information from the Ojai, Santa Paula Peak, and Santa Paula quadrangles were considered for several geologic formations for which little or no shear test information was available within the Matilija Quadrangle.

Shear strength data gathered from the above source were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean and median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1. For most of the geologic strength groups (Table 2.2) in the map area, a single shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Table 2.1 and Table 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis. Two strength groups (Group 1 and Group 5) are based on data from adjacent quadrangles and information given in Weber and others (1973) concerning relative strength and possible dip-slope conditions.

Several geologic map units were subdivided further, as discussed below.

Adverse Bedding Conditions

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

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, derived from the geologic map database, was used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared.

If the dip magnitude was less than or equal to the slope gradient category but greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area.

Formations that contain interbedded sandstone and shale were subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material (higher strength) dominates where bedding dips into a slope (favorable bedding) while fine-grained (lower strength) material dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. Where data was not available for certain formations to make a determination about adverse bedding conditions, other DMG geologists and references (Weber and others, 1973) were consulted. The favorable and adverse bedding shear strength parameters for the affected formations are shown in Table 2.1 and 2.2.

Existing Landslides

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

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily "residual" strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used. Within the Matilija Quadrangle, no shear tests of landslide slip surface materials were available, and the value used was derived from shear tests in nearby quadrangles.

MATILIJA QUADRANGLE
SHEAR STRENGTH GROUPS

	Formation Name	Number Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1						Kucg Kush Tj(fbc) Tjsh(fbc) Tjss(fbc) Tma(fbc) Tmash(fbc)	38*
GROUP 2	**Tr**	1	32/32	34/34	288/254	Tcw(fbc)	34
	Tm	3	36/34			Tcwsh(fbc)	
	Qoat2	1	33/33			Tvq(fbc), Qoat1	
	Qya2	6	33/33			Qyf1, Qyf2 Qya1, Qf Qw, Qw2	
GROUP 3	**Tsp(fbc)**	5	30/30	30/29	346/225	Tj(abc)	29
	Qoa	46	30/29			Tjsh(abc), Tjss(abc) Tma(abc), Tmash(abc) Tcd(fbc), Tcdss(fbc) Tsq(fbc), Tp Qoa2, Qyat1 Qyat2, Qc	
GROUP 4	**Tcw(abc)**	3	23/22	25/26	336/259	Tcd(abc)	25
	Tsp(abc)	2	24/24			Tcdss(abc)	
	Tml	16	24/26			Tcwsh(abc)	
	Qof	5	26/27			Tvq(abc), Tmd	
	Qog	18	26/27			Tsq(abc), Qof1	
	af	3	26/28				
GROUP 5						Qls	15*

Formational Subunits on Map Combined in Analysis

*** = phi values selected based on data from surrounding quadrangles**

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength

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

SHEAR STRENGTH GROUPS FOR THE MATILIJA 7.5-MINUTE QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Kucg	Tcw(fbc)	Tj(abc)	Tcd(abc)	Qls
Kush	Tcwsh(fbc)	Tjsh(abc)	Tcdss(abc)	
Tj(fbc)	Tvq(fbc)	Tjss(abc)	Tcw(abc)	
Tjsh(fbc)	Tr, Tm	Tma(abc)	Tcwsh(abc)	
Tjss(fbc)	Qoat1	Tmash(abc)	Tsp(abc)	
Tma(fbc)	Qoat2	Tcd(fbc)	Tvq(abc)	
Tmash(fbc)	Qyf1, Qyf2	Tcdss(fbc)	Tmd, Tml	
	Qya1, Qya2	Tsp(fbc)	Tsq(abc)	
	Qw, Qw2	Tsq(fbc), Tp	Qof, Qof1	
	Qf	Qoa, Qoa2	Qog, af	
		Qyat1, Qyat2		
		Qc		

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

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

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

Modal Magnitude:	6.8 to 7.0
Modal Distance:	2.5 km to 4.9 km
PGA:	0.58 g to 0.70 g

The strong-motion record selected for the slope stability analysis in the Matilija Quadrangle was the USC-14 record (Trifunac and others, 1994) from the magnitude 6.7 Northridge earthquake of January 17, 1994. This record had a source to recording site distance of 8.5 km and peak ground acceleration (PGA) of 0.59g. Although the magnitude and distance from the USC-14 record do not fall within the range of the probabilistic parameters, this record was considered to be sufficiently conservative to be used in the stability analyses. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

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

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 0.129, and 0.232 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 Matilija Quadrangle.

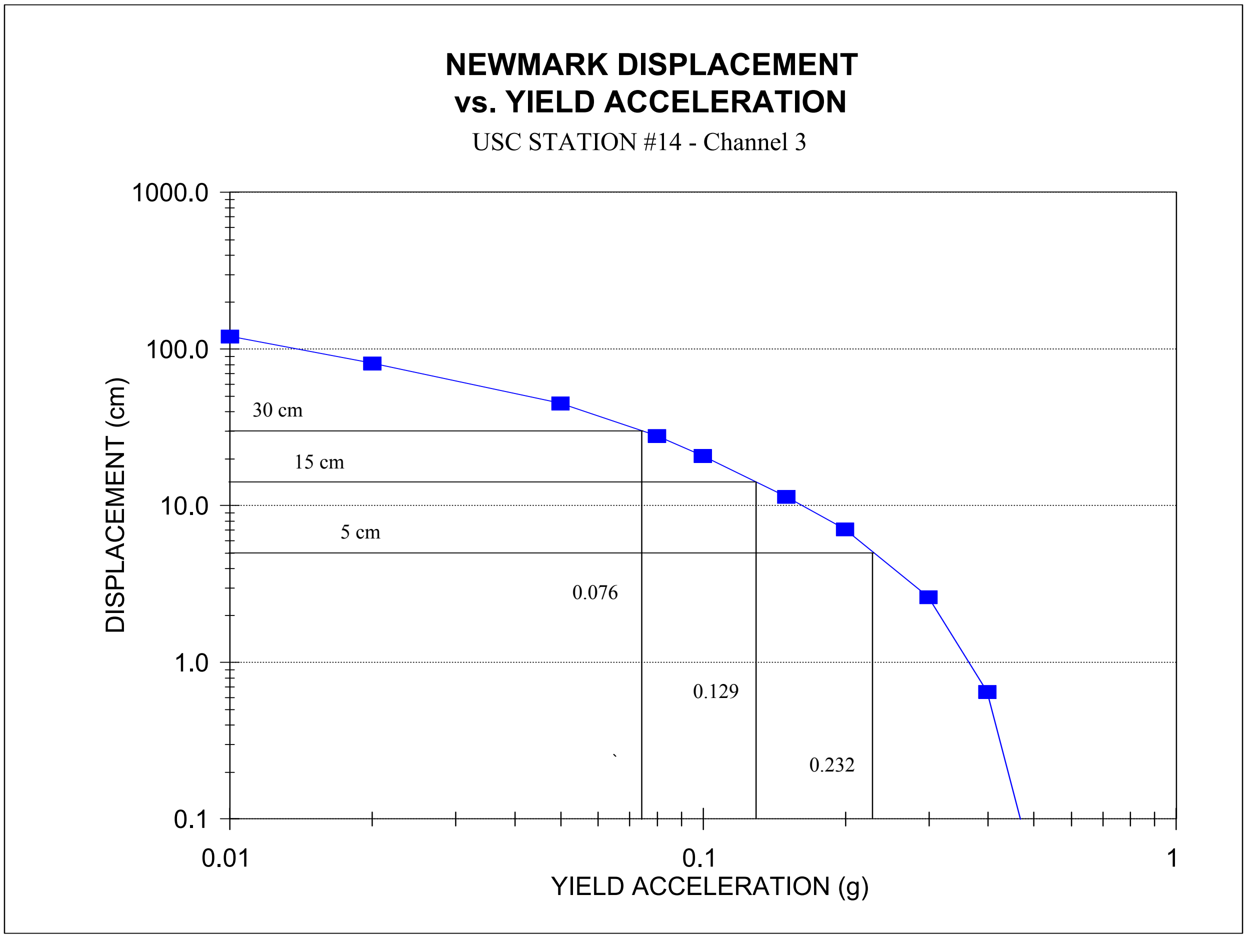

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC 14 Record.

Slope Stability Analysis

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

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

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

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

1. If the calculated yield acceleration was less than 0.076g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)

2. If the calculated yield acceleration fell between 0.076g and 0.129g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)

3. If the calculated yield acceleration fell between 0.129g and 0.232g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)

4. If the calculated yield acceleration was greater than 0.232g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

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

MATILIJA QUADRANGLE HAZARD POTENTIAL MATRIX												
		SLOPE CATEGORY (% SLOPE)										
Geologic Material Group	MEAN PHI	I	II	III	IV	V	VI	VII	VII	IX	X	XI
		0-13	14-18	19-22	23-33	34-39	40-42	43-52	53-59	60-63	64-69	>69
1	38	VL	VL	VL	VL	VL	VL	VL	L	L	M	H
2	34	VL	VL	VL	VL	VL	VL	L	M	H	H	H
3	30	VL	VL	VL	VL	L	L	M	H	H	H	H
4	25	VL	VL	VL	L	M	H	H	H	H	H	H
5	15	L	M	H	H	H	H	H	H	H	H	H

Table 2.2. Hazard Potential Matrix for Earthquake-Induced Landslides in the Matilija Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone. H = High, M = Moderate, L = Low, VL = Very Low.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

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

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

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

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

Existing Landslides

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

Geologic and Geotechnical Analysis

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

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

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

2. Geologic Strength Group 4 is included for all slopes steeper than 22 percent.

3. Geologic Strength Group 3 is included for all slopes steeper than 33 percent.

4. Geologic Strength Group 2 is included for all slopes steeper than 42 percent.

5. Geologic Strength Group 1 is included for all slopes greater than 52 percent.

This results in approximately 36 percent of the area mapped in the quadrangle lying within the earthquake-induced landslide hazard zone for the Matilija Quadrangle.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Ventura County	**109**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Matilija 7.5-Minute Quadrangle, Ventura County, California

By

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PURPOSE

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

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

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

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology [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% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

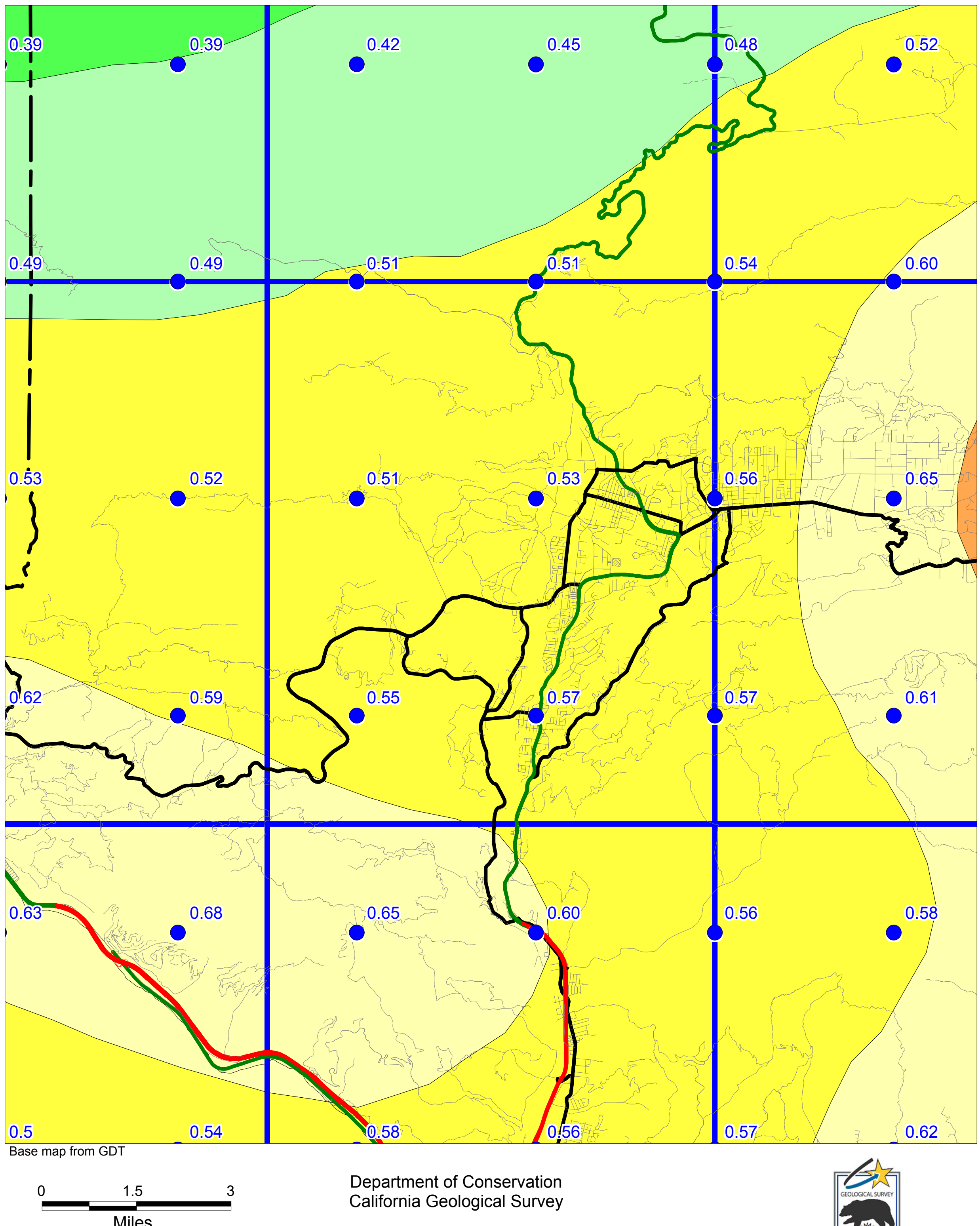
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

MATILIJA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Department of Conservation
California Geological Survey

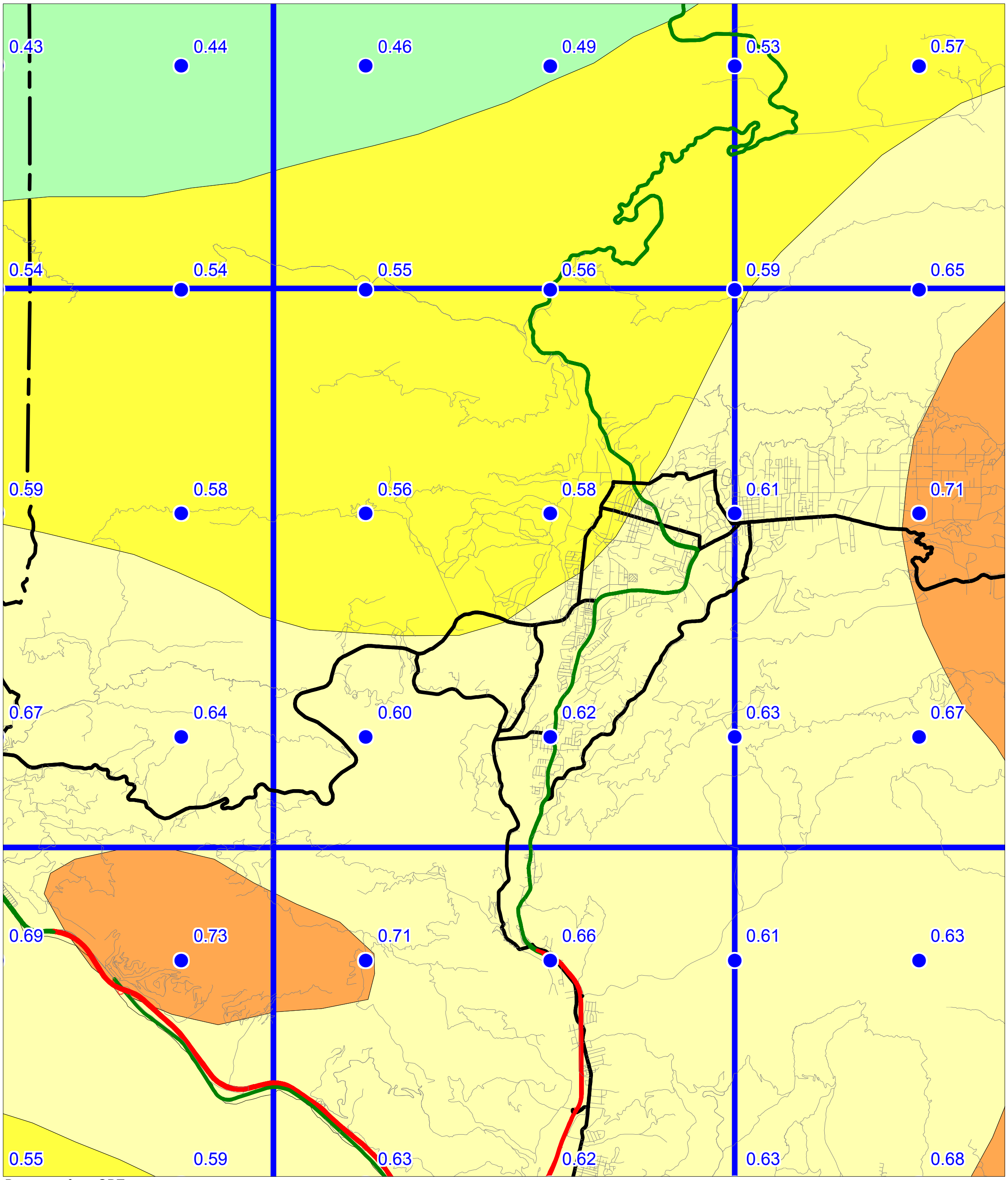
Figure 3.1

MATILIJA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

Figure 3.2

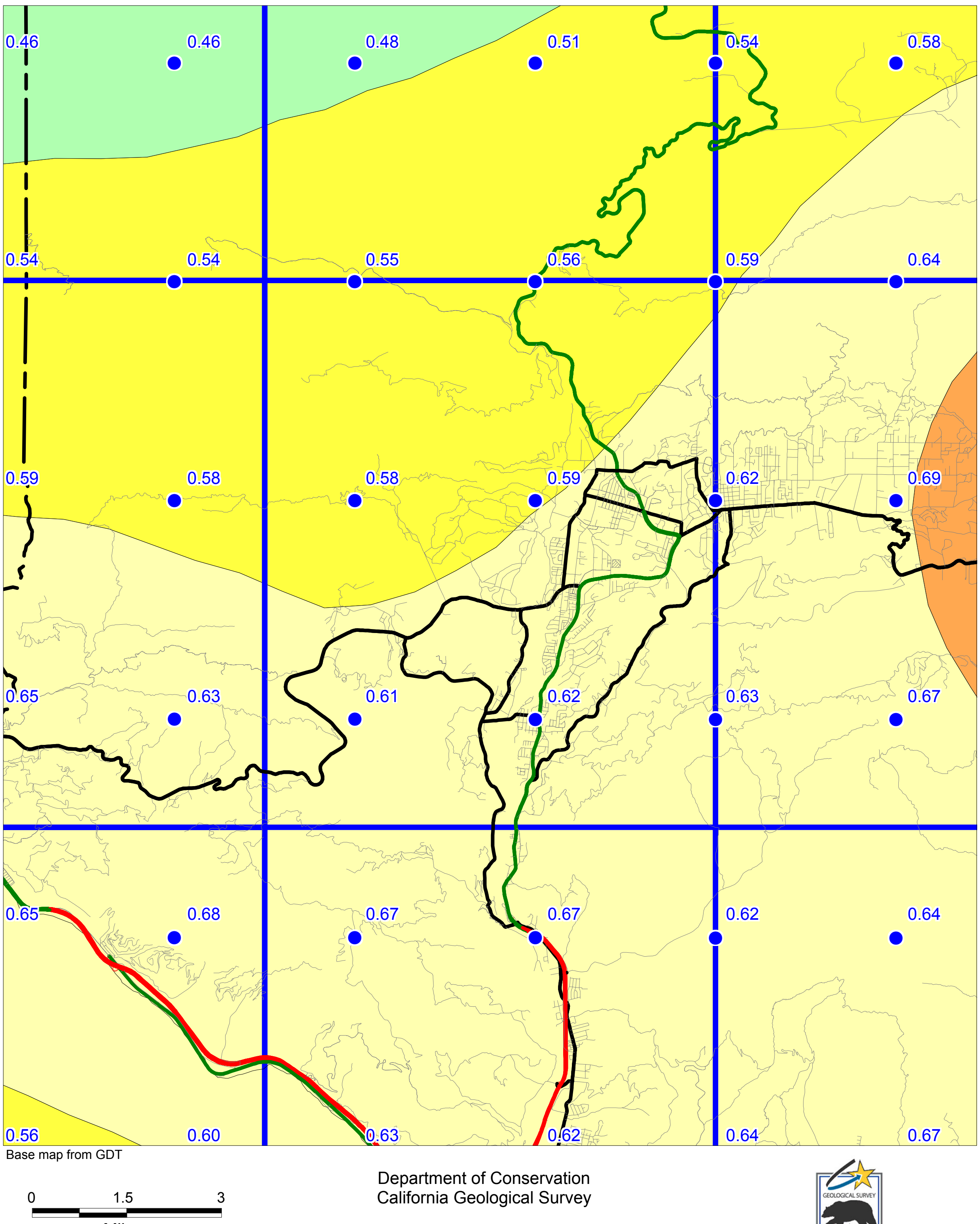
SEISMIC HAZARD EVALUATION OF THE MATILIJA QUADRANGLE

MATILIJA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



Department of Conservation
California Geological Survey

Figure 3.3

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

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

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

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

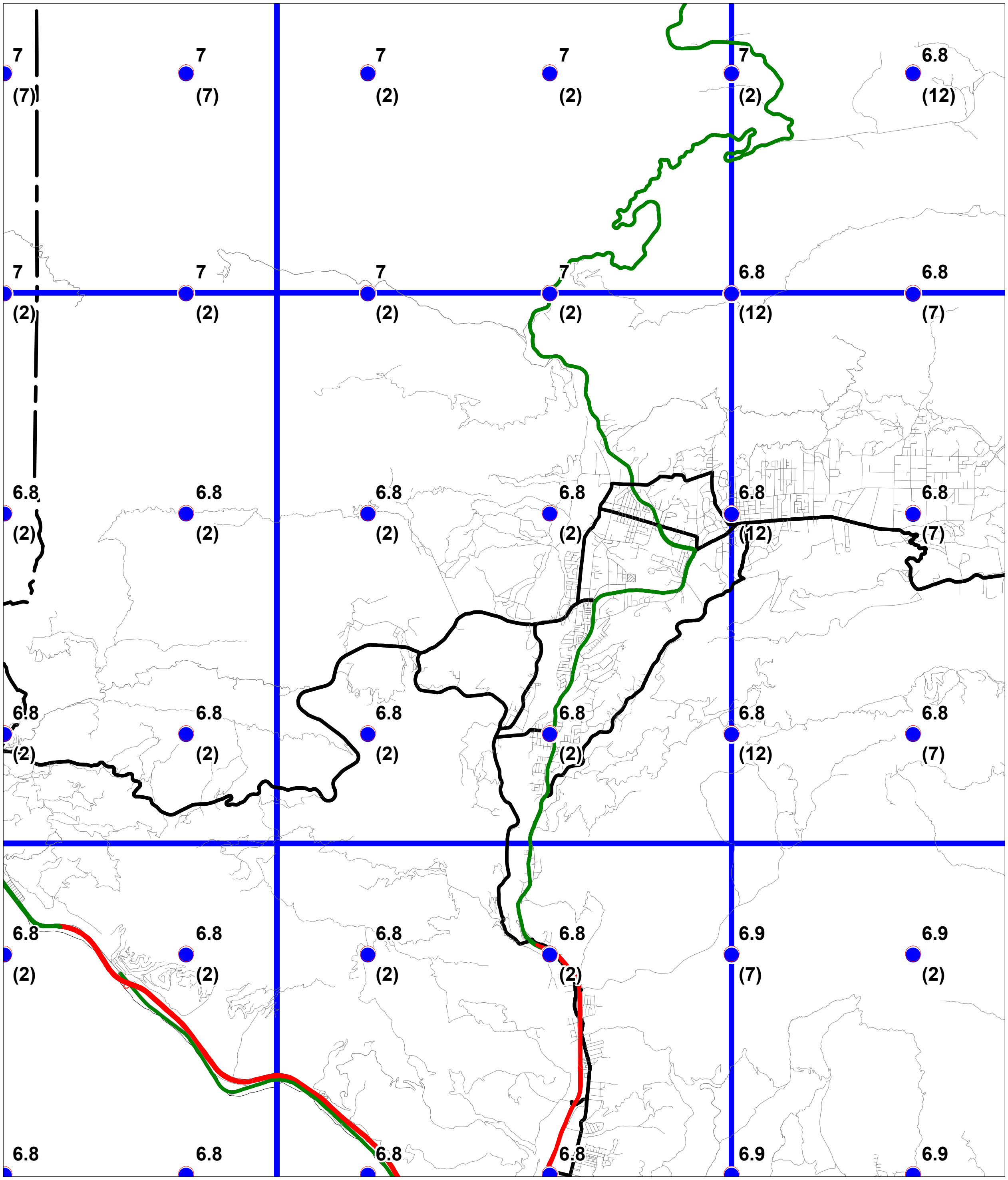
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss' weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

MATILIJA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

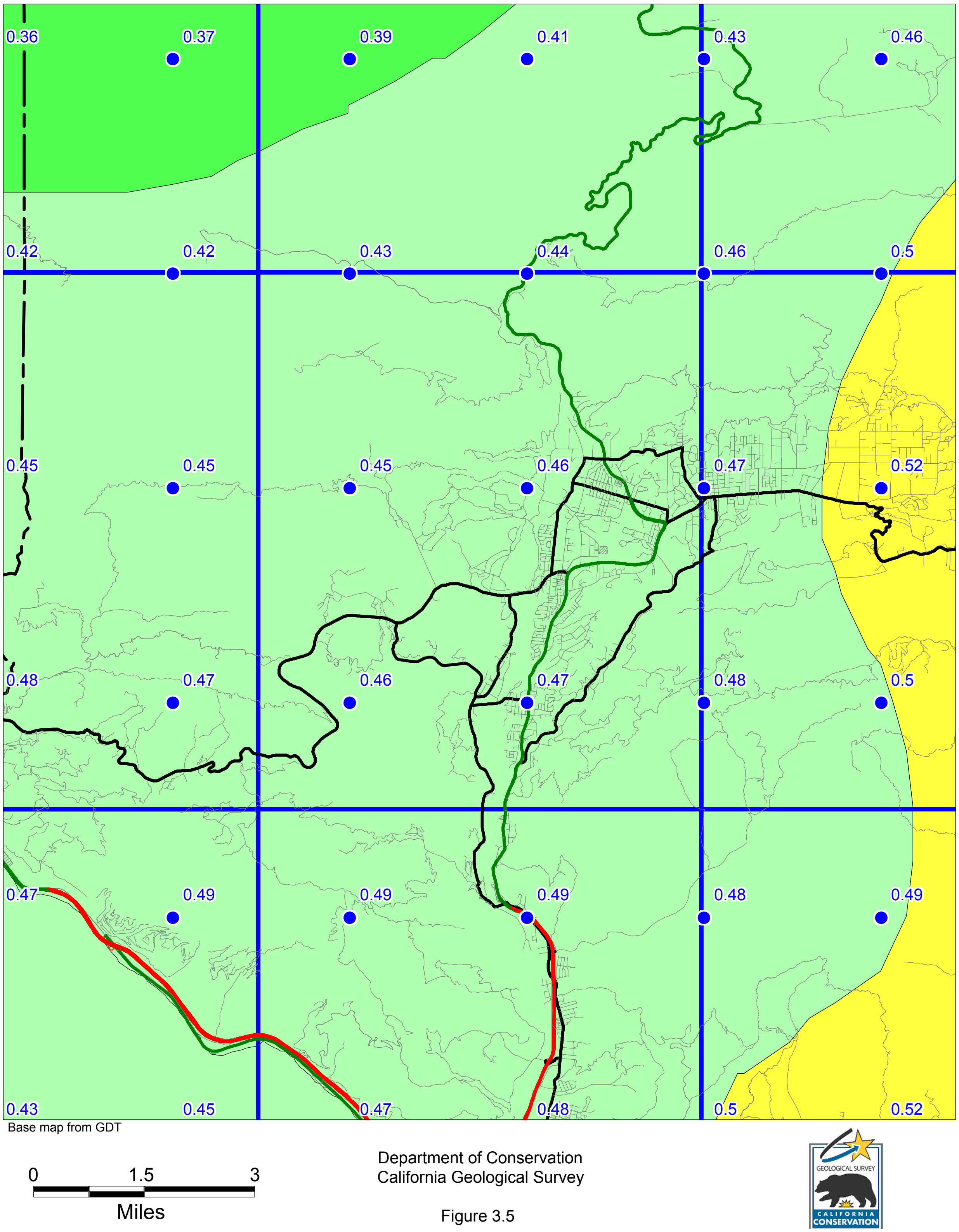
Figure 3.4

MATILIJA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

LIQUEFACTION OPPORTUNITY



Department of Conservation
California Geological Survey

Figure 3.5

USE AND LIMITATIONS

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

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

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

3. Uncertainties in the hazard values have been estimated to be about +/- 50% 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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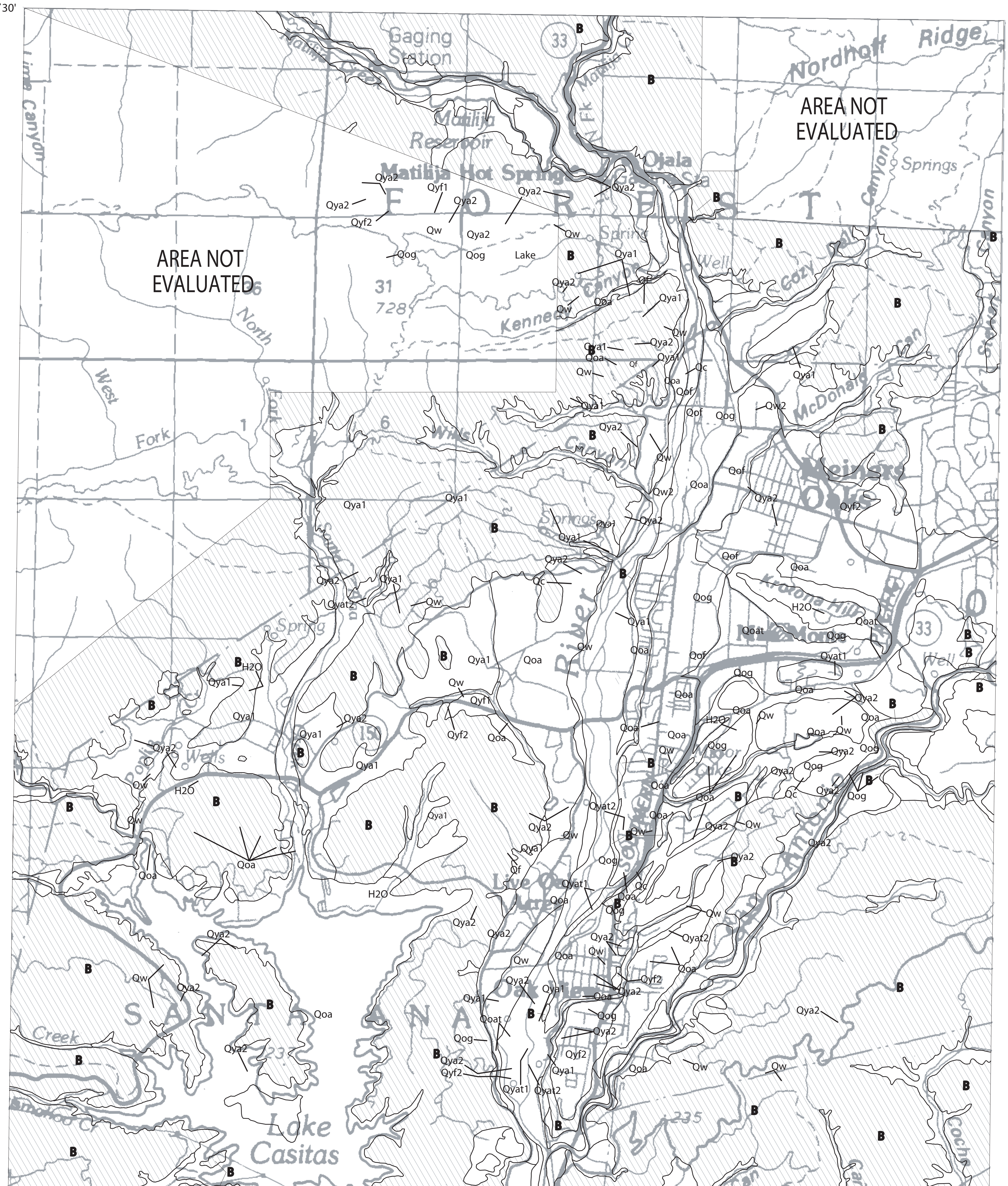
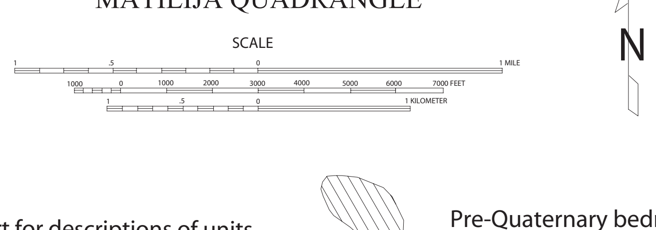
119°22'30"
34°30'



34°22'30"
119°15'

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

MATILIJA QUADRANGLE



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

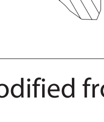
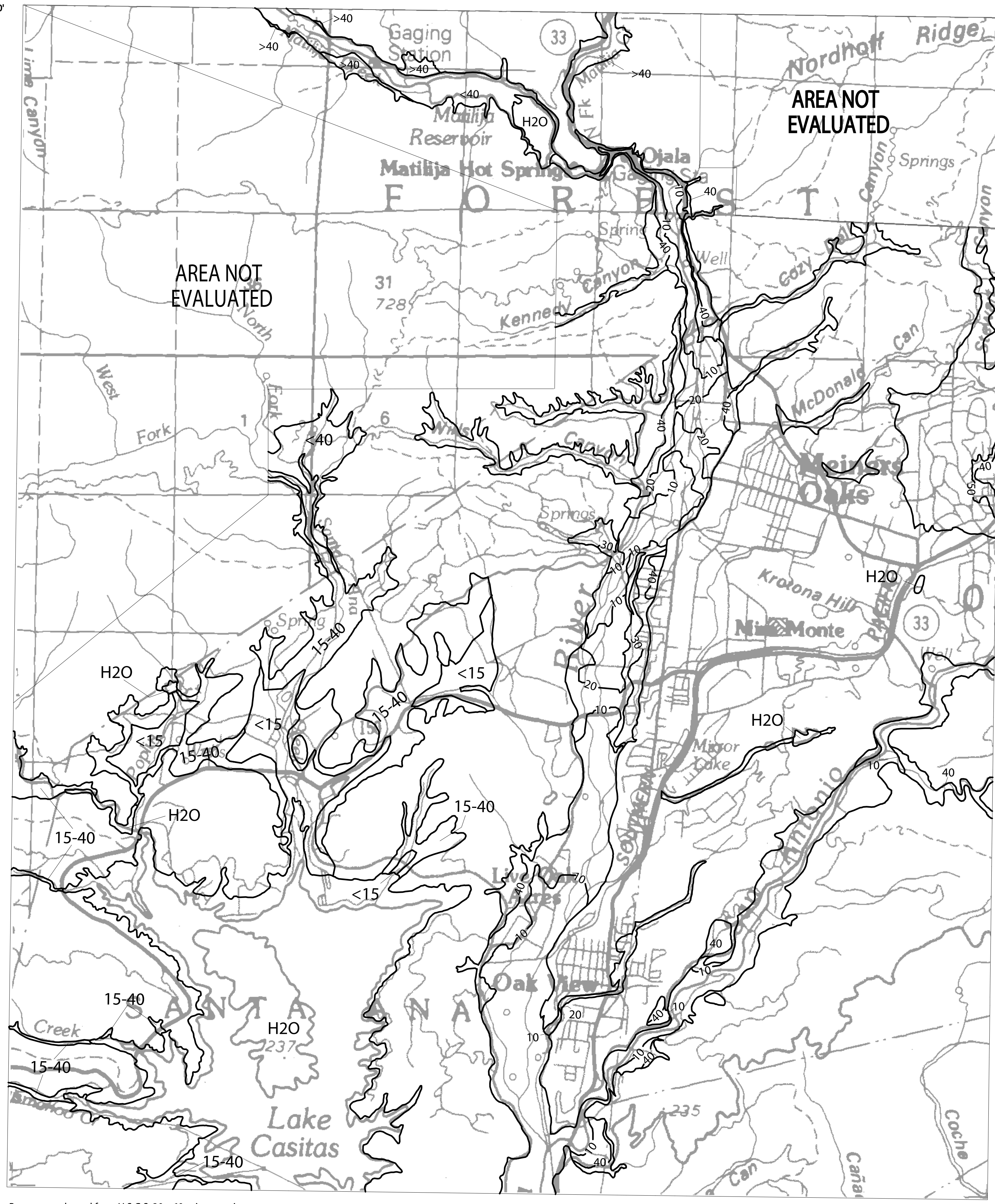

Pre-Quaternary bedrock

Plate 1.1 Quaternary Geologic Map of part of the Matilija 7.5-Minute Quadrangle. Modified from William Lettis & Associates, 2001

119°22'30"
34°30'



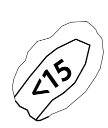
34°22'30"
119°15'

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

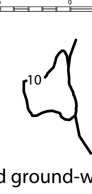
MATILIJA QUADRANGLE

SCALE

N



Generalized ground-water depth, in feet (modified from Ventura County Public Works, 1974)



Countoured ground-water depth, in feet, Spring 1969; modified from Turner, 1971, Plates 6A & 6B)

Geotechnical borehole used in liquefaction evaluation

Ground-water level only borehole

Plate 1.2 Estimated Depth To Historical High Ground Water Within Alluviated Valleys, and locations of boreholes of the Evaluated Part of the Matilija 7.5-Minute Quadrangle, California (modified from Turner, 1971 and Ventura County Public Works, 1974)

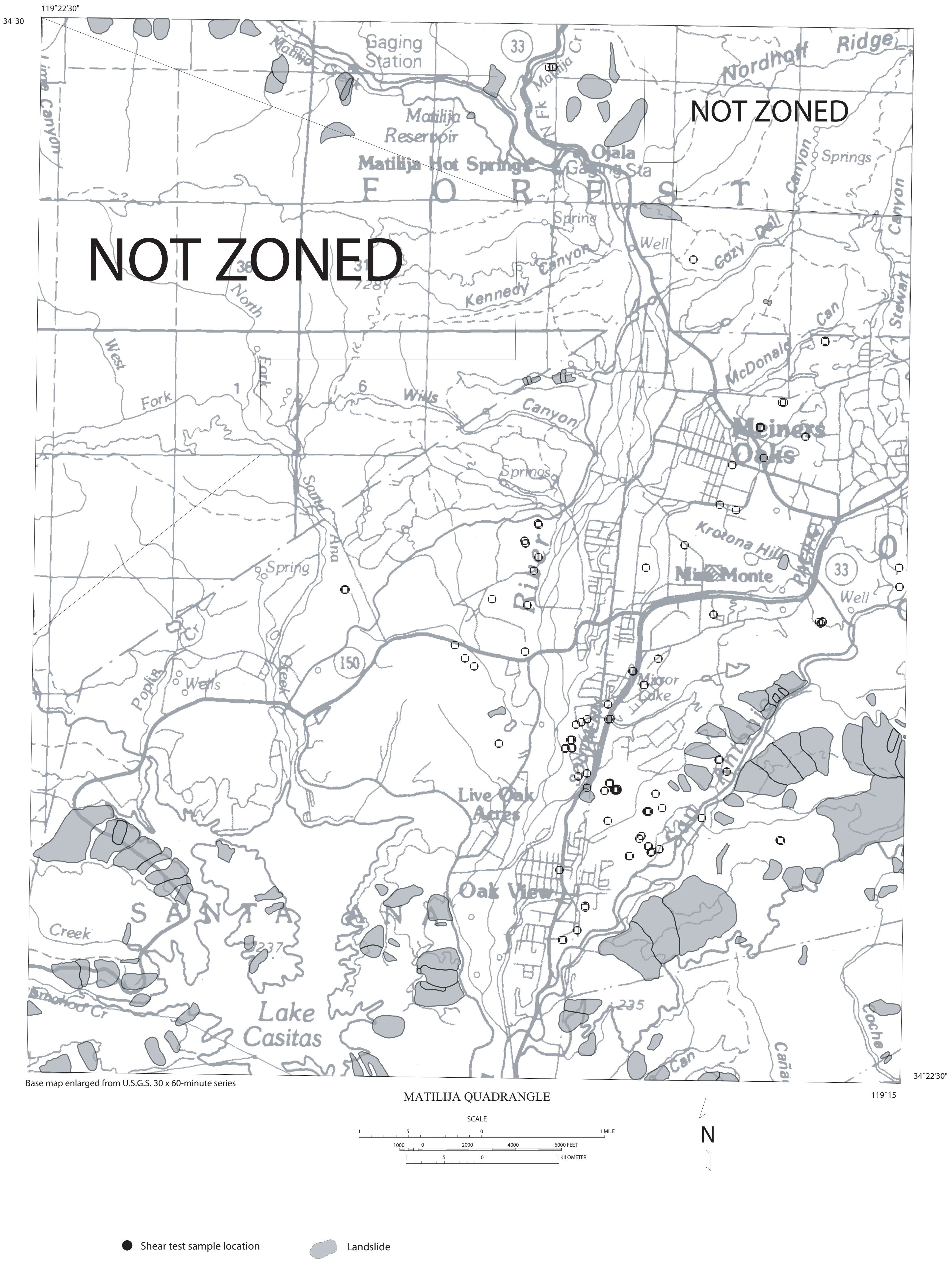


Plate 2.1 Landslide inventory and shear test sample locations, Matilija 7.5 Minute Quadrangle