SEISMIC HAZARD ZONE REPORT 076

SEISMIC HAZARD ZONE REPORT FOR THE VAL VERDE 7.5-MINUTE QUADRANGLE, LOS ANGELES AND VENTURA COUNTIES, CALIFORNIA

2002

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California Geological Survey

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ILLUSTRATIONS

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Val Verde 7.5-minute Quadrangle, Los Angeles and Ventura counties, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 62 square miles at a scale of 1 inch = 2,000 feet.

The Val Verde Quadrangle lies along the boundary between Los Angeles and Ventura counties about 37 miles northwest of the Los Angeles Civic Center. Homes are concentrated in the small, unincorporated community of Val Verde and in Castaic, although residential, commercial, and industrial development is currently spreading westward along the Santa Clara River and Castaic Creek valleys. Los Padres National Forest land intrudes into the northwestern corner and part of Lake Piru is also there. The Santa Clara River Valley cuts across the quadrangle and separates Oak Ridge and the Santa Susana Mountains on the south from the deeply dissected, hilly to mountainous terrain to the north. Elevations range from 700 feet in the Santa Clara River to nearly 2,500 feet near the northern boundary. Numerous large canyons branch off from the Santa Clara River Valley, including Potrero, Tapo, San Martinez Chiquito, and San Martinez Grande canyons. On the east Hasley Canyon and its tributaries drain eastward toward Castaic Creek. Primary access is via State Highway 126. Additional access is via roads in the major canyons. Agriculture and numerous oil fields are the main land uses in the western part of the quadrangle.

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

In the Val Verde Quadrangle the liquefaction zone is within the Santa Clara River Valley and the bottoms of nearly all of the creek canyons because of shallow ground water and sandy deposits. Landslides are extremely abundant and widespread within the uplifted, deformed weak marine sedimentary formations in the Val Verde Quadrangle. The earthquake-induced landslide zone covers about 64 percent of the quadrangle.

How to view or obtain the map

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

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

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

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

INTRODUCTION

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

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

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

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

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Val Verde 7.5-Minute Quadrangle, Los Angeles and Ventura Counties, California

By
Ralph C. Loyd and Allan G. Barrows

California Department of Conservation
California Geological Survey

PURPOSE

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

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

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

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Val Verde 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 region 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, 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, including areas in the Val Verde 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 Val Verde Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

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

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

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Val Verde Quadrangle covers approximately 62 square miles along the boundary between Los Angeles and Ventura counties. Approximately two-thirds of the quadrangle, which is about 37 miles northwest of the Los Angeles Civic Center, is located within Los Angeles County. There are no incorporated cities within the quadrangle. Residential development is concentrated in the small community of Val Verde and in Castaic near the northeastern corner. A very small piece of Los Padres National Forest (misidentified as Angeles National Forest on the topographic map) land intrudes into the northwestern corner of the quadrangle. Part of Lake Piru extends into the Val Verde Quadrangle in the northwestern corner. Hilly to mountainous terrain, dissected by numerous large canyons and their tributaries, characterizes the physiography of the quadrangle. The Santa Clara River Valley cuts across the entire quadrangle and separates Oak Ridge and the Santa Susana Mountains on the south from the deeply dissected country to the north. Elevations range from 700 feet in the Santa Clara River to approximately 2,494 feet at Loma Verde Peak near the northern boundary. The Santa Clara River provides the major drainage in the quadrangle. Numerous large canyons branch off from the Santa Clara River Valley, including Potrero, Tapo, San Martinez Chiquito, and San Martinez Grande canyons. On the east Hasley Canyon and its tributaries drain eastward toward Castaic Creek. Santa Felicia, Oak and Lechler canyons drain the northwestern mountainous region and their creeks flow westward into Lake Piru or Piru Creek.

The primary transportation route, State Highway 126, follows the Santa Clara River valley. Castaic Junction, where Highway 126 joins Interstate 5, is less than 2 miles to the east in the Newhall Quadrangle. San Martinez Grande Canyon Road, San Martinez Chiquito Canyon Road, Hasley Canyon Road, and Holser Canyon Road provide access to the central part of the quadrangle. Residential, commercial and industrial development is currently spreading westward along the Santa Clara River and Castaic Creek valleys. Agriculture and numerous oil fields are the main land uses in the western part of the quadrangle. The primary oil fields include: North Tapo, Newhall Portrero, Del Valle, South Del Valle, Holser, Ramona, Hasley Canyon, Castaic, Oak Canyon, and Castaic Hills.

GEOLOGY

Bedrock and Surficial Geology

The Quaternary geologic map used in this study was obtained from two sources. The Ventura County part of the quadrangle was taken from an unpublished digitized Quaternary geology map prepared by William Lettis and Associates (2000). The Los Angeles County part of the quadrangle was taken from a digital version of the geologic map by Barrows (1986). CGS staff then merged the Quaternary contacts on this map with the geologic map prepared by Dibblee (1993).

Tertiary bedrock in the Val Verde Quadrangle includes: shale and sandstone of the lower to middle Miocene Monterey Shale; clay and siltstone of the mid-Miocene Sisquoc Formation; shale and sandstone of the upper Miocene Castaic Formation; sandstone of the upper Miocene to lower Pliocene Towsley Formation; claystone and siltstone of the

Plio-Pleistocene Pico Formation; and pebble conglomerate of the Plio-Pleistocene Saugus Formation (see section 2 for detailed descriptions of the bedrock geology.

Quaternary surficial deposits consist of older (Pleistocene) and younger (latest Pleistocene through Holocene) alluvial-fan and valley deposits, colluvium, active alluvial fans, and active stream deposits (Qoa, Qyf, Qc, Qoc, Qf, and Qw). These sediments cover the floor of the Santa Clara River Valley and smaller canyons. Artificial fill (map symbol af), typically cut and cast fill from oil field development, and more recently engineered fill from residential, commercial, and road development, occurs in scattered places across the quadrangle.

Structural Geology

The Val Verde Quadrangle lies within the East Ventura Basin (Yeats and others, 1985; 1994), an elongate west-trending synclinal basin whose axis lies generally along the Santa Clara River Valley. The East Ventura basin is truncated by the San Gabriel Fault to the east. The main part of the Val Verde Quadrangle consists of folded Miocene to Quaternary strata cut by several subparallel south-dipping reverse faults. Overall structural configuration of the bedrock materials indicate shallow shortening of the Miocene sedimentary units, accommodated by relatively shallow fold belts. Generally, the Miocene and Pliocene materials thin from west to east across the basin area, and thin sharply close to the San Gabriel Fault.

In addition to folding, the Tertiary units are cut by several south-dipping, reverse faults (Yeats and others, 1985). The Holser Fault, which crosses the central portion of the map area from west to east, and the subparallel Del Valle Fault, are two of the dominant structural features within the map area. The Oak Ridge Fault, a south-dipping reverse fault, is present in the extreme southwestern portion of the map but is hidden beneath modern alluvium in the Santa Clara River Valley. Although the fault segment in this quadrangle does not meet the criteria required for inclusion in the Official Earthquake Fault Zone prepared by DMG, the Oak Ridge Fault is considered to be a major potential seismic source (Cramer and Petersen, 1996; Petersen and others, 1996). Evidence of Holocene surface faulting has not been reported in the Val Verde Quadrangle. The short stretch of the San Gabriel Fault that crosses the northeastern corner of the quadrangle has not been included within an Official Earthquake Fault Zone. Evidence of Holocene surface rupture, such as that found in the Newhall Quadrangle to the east (DOC, 1995), has not been found in the Val Verde Quadrangle.

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of sedimentary deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. For this investigation, 23 borehole logs were collected from the files of the Ventura County Water Resources and Engineering Department, Ventura County Hazardous Substances Control Program, the Los Angeles County Public Works, and the California Department of Transportation (CalTrans). Locations of the exploratory boreholes considered in this investigation are shown on Plate 1.2. Staff entered the data from the geotechnical logs into CGS's GIS in order to create a database that would allow effective examination of subsurface geology through construction of computer-generated cross sections and evaluation of liquefaction potential of sedimentary deposits through the performance of computer-based quantitative analysis.

Standard Penetration Tests (SPTs) provide a standardized measure of the penetration resistance of geologic deposits and are commonly used as an index of soil density. This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil at the bottom of a borehole at chosen intervals while drilling. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 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 $(N_1)_{60}$.

Most of the 23 geotechnical borehole logs entered into the CGS data for this study are from one 290-acre housing/commercial project. These particular logs include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

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

GROUND-WATER CONDITIONS

Depth to ground water is a key factor governing liquefaction hazard. Ground-water saturation reduces the effective normal stress acting on loose, sandy sediments, thus lowering the resistance of sediments to loss of strength when pore-water pressure increases during ground shaking. Liquefaction of subsurface sedimentary layers can result in structure damaging ground failure at the surface through differential settlement or lateral spreading, particularly if the phenomenon occurs at a depth from the surface of less than 40 feet.

Natural processes and human activities over seasons, years, and decades cause large fluctuations in ground-water levels. These fluctuations generally make it impossible to specify what conditions might exist when future earthquakes could cause major ground shaking. To address this uncertainty, CGS develops ground-water maps that show depths to historically shallowest levels recorded from water wells and boreholes drilled over the past century. The evaluations are based on first-encountered water noted in the borehole logs. Water depths from boreholes known to penetrate confined aquifers are not used. The resultant maps, which are based on measurements recorded over the past century or more, differ considerably from conventional ground-water maps that are based on measurements collected during a single season or year.

Historically shallowest depths to ground water in alluviated river valley and canyon regions of the Val Verde Quadrangle are presented on Plate 1.2. As shown on Plate 1.2, historical ground-water depths range from 10 to 20 feet on the floor of the Santa Clara River Valley and up to 30 feet on the elevated surfaces of alluvial fan that have formed along the margins of the river valley. Historical ground-water level measurements in canyon areas are generally shallow, commonly at about 10 feet in depth. Such shallow ground-water conditions commonly exist in these types of depositional environments because canyon lowlands tend to receive and accumulate heavy runoff and near-surface ground water derived from surrounding highlands.

LIQUEFACTION POTENTIAL

Liquefaction can occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and might 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) who apply 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 following 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 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.

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.

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. CGS's qualitative assessment of liquefaction susceptibility relative to various geologic units and depth to ground water is summarized in Table 1.1.

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Susceptible to Liquefaction?*
Qw, Qw2	Gravel, sand, silt	Stream channels	Very loose to loose	Yes
Qf	Sand, silt, clay	Active alluvial fans	Very loose to loose	Yes**
Qyf1-2 , Qya, Qya1-2, Qyat11-2	Sand, silt, clay	Young alluvial fan and valley deposits	Loose to moderately dense	Yes**
Qc	clay, silt, rock clasts	Colluvium, slope wash, rubble	loose to firm	Not Likely***
Qoa, Qoat1-2	Clay, silt, sand, and gravel deposits.	Older alluvial deposits	Dense to very dense	Not likely

* When saturated ** Not likely if all clay or sand and silt layers are clayey *** Usually thin surficial covering

Table 1. 1. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Sedimentary Units.

LIQUEFACTION OPPORTUNITY

Analysis of in-situ liquefaction potential requires assessment of liquefaction opportunity. Liquefaction opportunity is the estimation of the severity of expected future ground shaking over the region at a specific exceedance probability and exposure time (Real, 2002). 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 of liquefaction potential is the magnitude that contributes most to the calculated PGA for an area.

For the Val Verde Quadrangle, PGAs of 0.53g to 0.99g (for alluvium conditions), resulting from predominant earthquakes of magnitudes ranging from 6.6 to 7.8, 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 additional discussion of ground motion characterization.

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

The CGS liquefaction analysis program calculates an FS for each geotechnical sample for which standardized blow counts were collected. Typically, multiple samples are collected from each borehole. The program then calculates an FS for each non-clay layer that includes at least one penetration test. If a layer contains more than one penetration test, the minimum $(N1)_{60}$ value is used. 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 values, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil throughout a project area, are evaluated to delineate areas of relative high liquefaction potential. These areas then translate directly to "Zones of Required Investigation."

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 Val Verde Quadrangle is summarized below.

Areas of Past Liquefaction

Following the 1994 Northridge Earthquake, ground fractures, differential settlement, and lateral spreading, in part consistent with earthquake-induced liquefaction, was mapped in Tapo Canyon, in and along the Santa Clara River just west of Tapo Canyon, and also in Potrero Canyon by Rymer and others (2001).

Artificial Fills

In the Val Verde Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for river levees, home development, and road construction. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata. Non-engineered fills are commonly loose and uncompacted, and the material varies in size and type.

Areas with Sufficient Existing Geotechnical Data

Santa Clara River Valley Deposits West of Castaic Creek. Test drilling conducted on a proposed 291-acre residential development site (Tentative Tract 53108, Los Angeles County Public Works) provided considerable subsurface geotechnical data regarding liquefaction potential of alluvium deposited in the Santa Clara River Valley. The lithologic logs of the boreholes indicate that alluvium deposited within this segment of the Santa Clara River consists of older, dense sandy material (Qoa) that is slightly elevated above younger river deposits (Qw) consisting of loose to very loose sand with interbedded gravel and, locally, silty sand. Also, first-encountered ground water recorded in the logs of these boreholes and previously drilled water wells show depths ranging from 3 to 30 feet, which is typical of historically shallow depths elsewhere within the Santa Clara River Valley. Accordingly, areas within the Santa Clara River valley that are characterized by saturated, loose, sandy material are designated zones of required investigation.

Areas with Insufficient Existing Geotechnical Data

Alluvial fans along the margin of the Santa Clara River Valley. Several large, isolated alluvial fan surfaces present along the northern and southern margins of the Santa Clara River are delineated as zones of required investigation. Little is known about the soil characteristics and ground-water hydrology of the individual alluvial fans. However, observations reported on one such surface just west of Tapo Canyon by Rymer and others (2001) suggest that earthquake-induced ground fractures, lateral spreading, and differential settlement could occur in similar geologic environments in the Val Verde Quadrangle.

Canyon Floors. Canyons throughout the Val Verde Quadrangle are designated zones of required investigation. Geologic mapping by Dibblee (1993) and Barrows (1986), along with limited geotechnical borehole information indicate that canyon alluvium over most of the region is composed mainly of sandy material eroded from adjacent, predominantly sandstone, bedrock formations.

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REFERENCES

American Society for Testing and Materials, 1999, Standard test method for penetration test and split-barrel sampling of soils, Test Method D1586-99, *in* Annual Book of ASTM Standards, v. 4.08.

Argus, D.F., Heflin, M.B., Donnellan, A., Webb, F.H., Dong, D., Hurst, K.J., Jefferson, D.C., Lyzenga, G.A., Watkins, M.M. and Zumberge, J.F., 1999, Shortening and thickening of metropolitan Los Angeles measured and inferred using geodesy: Geology, v. 27, p. 703-706.

Barrows, A.G., 1986, Landslide hazards in the east half of the Val Verde Quadrangle, Los Angeles County, California: Department of Conservation, Division of Mines and Geology, Open-File Report 86-9, map scale 1:24,000.

Budiman, J.S. and Mohammadi, Jamshid, 1995, Effect of large inclusions on liquefaction of sands, *in* Evans, M.D. and Fragaszy, R.J., *editors*, Static and Dynamic properties of Gravelly Soils: American Society of Civil Engineers Geotechnical Special Publication no. 56, p. 48-63.

California Department of Conservation, Division of Mines and Geology, 1991, Revised Official Map of Earthquake Fault Zones, Val Verde Quadrangle, scale 1:24,000.

California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California, Special Publication 117, 74 p.

California Department of Conservation, Division of Mines and Geology, 1999, Revised Official Map of Earthquake Fault Zones, Moorpark Quadrangle, scale 1:24,000.

California Department of Conservation, Division of Mines and Geology, 2000, Recommended criteria for delineating seismic hazard zones in California, Special Publication 118, 12 p.

California Division of Mines and Geology, 1976, Seismic hazards study of Ventura County, California: Open-File Report 76-5 LA, 396 p., map scale 1:48000.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange, and Ventura counties, California: Bulletin of Seismological Society of America, v. 86, no. 5, p. 1,645-1,649.

Dibblee, T.W. Jr., 1990, Geologic map of the Val Verde Quadrangle, Ventura County, California: Dibblee Geological Foundation Map DF-27, map scale 1:24,000.

Dolan, J.F. and Rockwell, T.K., 2001, Paleoseismologic evidence for a very large (Mw > 7), post- A.D. 1660 surface rupture on the eastern San Cayetano Fault, Ventura County, California: Was this the elusive source of the damaging 21 December 1812 earthquake?: Seismological Society America Bulletin, v. 91, p. 1417-1432.

Donnellan, A., Hager, B.H. and King, R.W., 1993 a, Rapid north-south shortening of the Ventura Basin, southern California: Nature, v. 366, p. 333-336.

Donnellan, A., Hager, B.H., King, R.W. and Herring, T.A., 1993 b, Geodetic measurement of deformation in the Ventura Basin, southern California: Journal Geophysical Research, v. 98, p. 21,727- 21,739.

Evans, M.D. and Zhou, Shengping, 1995, Liquefaction behaviour of sand-gravel composites: American Society of Civil Engineers, Journal of Geotechnical Engineering, v. 121, no. 3, p. 287-298.

Harder, L.F. and Seed, H.B., 1986, Determination of penetration resistance for coarse-grained soils using the Becker hammer drill: University of California at Berkeley, College of Engineering, Earthquake Engineering Research Center, report no. UCB/EERC-86/06, 126 p.

Ishihara, Kenji, 1985, Stability of natural deposits during earthquakes, *in* Proceedings of the Eleventh International Conference on Soil Mechanics and Foundation Engineering, San Francisco, v. 1, p. 321-376.

National Research Council, 1985, Liquefaction of soils during earthquakes: National Research Council Special Publication, Committee on Earthquake Engineering, National Academy Press, Washington, D.C., 240 p.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, Tianqing, Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology, Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.

Real, C.R., 2002, California's Seismic Hazards Mapping Act: Geoscience and Public Policy, *in* Babrowsky, P.T., *editor*, Geoenvironmental Mapping - Method, Theory and Practice: A.A. Balkema, Rotterdam, Netherlands, p. 93-120.

Rymer, M.J., Treiman, J.A., Powers, T.J., Fumal, T.E., Schwartz, D.P., Hamilton, J.C. and Cinti, F.R., 2001, Surface fractures formed in the Potrero Canyon, Tapo Canyon, and McBean Parkway areas in association with the 1994 Northridge, California, earthquake: U.S. Geological Survey Miscellaneous Field Studies Map 2360.

Seed, H.B. and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundations Division of ASCE, v. 97: SM9, p. 1,249-1,273.

Seed, H.B. and Idriss, I.M., 1982, Ground motions and soil liquefaction during earthquakes: Monograph Series, Earthquake Engineering Research Institute, Berkeley, California, 134 p.

Seed, H.B., Idriss, I.M. and Arango, Ignacio, 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, v. 109, no. 3, p. 458-482.

Seed, H.B., Tokimatsu, Kohji, Harder, L.F., and Chung, R.M., 1985, Influence of SPT procedures in soil liquefaction resistance evaluations: Journal of Geotechnical Engineering, ASCE, v. 111, no. 12, p. 1,425-1,445.

Seed, R.B. and Harder, L.F., 1990, SPT-based analysis of cyclic pore pressure generation and undrained residual strength: Proceedings of the H. Bolton Seed Memorial Symposium, v. 2, p. 351-376.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Southern California Earthquake Center, 1999, Recommended procedures for implementation of DMG Special Publication 117 guidelines for analyzing and mitigating liquefaction in California: Southern California Earthquake Center, University of Southern California, 63 p.

Sy, Alex, Campanella, R.G. and Stewart, R.A., 1995, BPT-SPT correlations for evaluations of liquefaction resistance in gravelly soils, *in* Evans, M.D. and Fragaszy, R.J., *editors*, Static and Dynamic Properties of Gravelly Soils: American Society of Civil Engineers Geotechnical Special Publication no. 56, p. 1-19.

Tinsley, J.C., Youd, T.L., Perkins, D.M. and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I., *editor*, Evaluating earthquake hazards in the Los Angeles region — An earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-316.

William Lettis and Associates, 1999, Digital Quaternary geologic map of the Ventura County portion of the Val Verde 7.5-minute Quadrangle: digitized at scale 1:24000.

Yeats, R.S., 2001, Neogene tectonics of the East Ventura and San Fernando Basins, California: An overview *in* Wright, T.L. and Yeats, R.S., *editors*, Geology and tectonics of the San Fernando Valley and East Ventura Basin, California: Pacific Section American Association Petroleum Geologists Guidebook GB 77, p.9-36.

Youd, T.L., 1973, Liquefaction, flow and associated ground failure: U.S. Geological Survey Circular 688, 12 p.

Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation: Earthquake Engineering Research Institute, Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 111-138.

Youd, T.L. and Idriss, I.M., 1997, *editors*, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research Technical Report NCEER-97-0022, 276 p.

Youd, T.L. and Perkins, D.M., 1978, Mapping liquefaction-induced ground failure potential: Journal of Geotechnical Engineering, v. 104, p. 433-446.

SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Val Verde 7.5-Minute Quadrangle, Los Angeles and Ventura Counties, California

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PURPOSE

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

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

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Val Verde 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 Val Verde Quadrangle.

METHODS SUMMARY

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

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

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

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

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

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

SCOPE AND LIMITATIONS

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

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Val Verde 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 Val Verde 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 Val Verde Quadrangle covers approximately 62 square miles along the boundary between Los Angeles and Ventura counties. Approximately two-thirds of the quadrangle, which is about 37 miles northwest of the Los Angeles Civic Center, is located within Los Angeles County. There are no incorporated cities within the quadrangle. Residential development is concentrated in the small community of Val Verde and in Castaic near the northeastern corner. A very small piece of Los Padres National Forest (misidentified as Angeles National Forest on the topographic map) land intrudes into the northwestern corner of the quadrangle. Part of Lake Piru extends into the Val Verde Quadrangle in the northwestern corner. Hilly to mountainous terrain, dissected by numerous large canyons and their tributaries, characterizes the physiography of the quadrangle. The Santa Clara River Valley cuts across the entire quadrangle and separates Oak Ridge and the Santa Susana Mountains on the south from the deeply dissected country to the north. Elevations range from 700 feet in the Santa Clara River to approximately 2,494 feet at Loma Verde Peak near the northern boundary. The Santa Clara River provides the major drainage in the quadrangle. Numerous large canyons branch off from the Santa Clara River Valley, including Potrero, Tapo, San Martinez Chiquito, and San Martinez Grande canyons. On the east Hasley Canyon and its tributaries drain eastward toward Castaic Creek. Santa Felicia, Oak and Lechler canyons drain the northwestern mountainous region and their creeks flow westward into Lake Piru or Piru Creek.

The primary transportation route, State Highway 126, follows the Santa Clara River valley. Castaic Junction, where Highway 126 joins Interstate 5, is less than 2 miles to the east in the Newhall Quadrangle. San Martinez Grande Canyon Road, San Martinez Chiquito Canyon Road, Hasley Canyon Road, and Holser Canyon Road provide access to the central part of the quadrangle. Residential, commercial and industrial development is currently spreading westward along the Santa Clara River and Castaic Creek valleys. Agriculture and numerous oil fields are the main land uses in the western part of the quadrangle. The primary oil fields include: North Tapo, Newhall Portrero, Del Valle, South Del Valle, Holser, Ramona, Hasley Canyon, Castaic, Oak Canyon, and Castaic Hills.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface. Within the Val Verde Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours that are based on 1947 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

Areas that have undergone large-scale grading since 1947 in the hilly portions of the quadrangle were updated to reflect the new topography. A DEM reflecting this recent grading was obtained from an airborne interferometric radar platform flown in 2001, with an estimated vertical accuracy of approximately 1.5 meters (Intermap Corporation, 2000). An interferometric radar DEM is prone to creating false topography where tall buildings, metal structures, or trees are present. The DEM used for graded areas in the Val Verde Quadrangle underwent additional processing to remove these types of artifacts (Wang and others, 2001). Nevertheless, the final hazard zone map was checked for potential errors resulting from the use of the radar DEM and corrected if necessary. Graded areas where the radar DEM was applied are shown on Plate 2.1

A slope map was made from both the USGS and the radar DEMs using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The manner in which the slope maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The bedrock geologic map used in this slope stability evaluation was obtained from the Dibblee Geological Foundation (Dibblee, 1993) and digitized by CGS staff for this study. Two sources of Quaternary surficial geology were used in this study. For the Ventura County part of the quadrangle an unpublished digitized Quaternary geology map from William Lettis and Associates (2000) was used. For the Los Angeles County part of the quadrangle a digital version of the geologic map by Barrows (1986) was used. Surficial geologic units are briefly described here and are discussed in more detail in Section 1, Liquefaction Evaluation Report

CGS 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 newly created landslide inventory would exist on separate layers for the hazard analysis. Contacts between bedrock and surficial units were revised to better conform to the topographic contours of the U.S. Geological Survey 7.5-minute quadrangle. Bedrock geology was modified in some areas to reflect more recent mapping. In addition, geologic mapping by Yeats and others (1985) and Barrows (1986) was consulted. CGS staff then merged the bedrock contacts on this map with the digital Quaternary geologic maps prepared by William Lettis and Associates (1999) and Barrows (1986). Air-photo interpretation and field reconnaissance were performed to assist in adjusting contacts between bedrock and surficial geologic units and to review geologic unit lithology and geologic structure. 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 development and abundance of landslides was noted.

Tertiary bedrock in the Val Verde Quadrangle consists of Monterey Shale, and the Sisquoc, Castaic, Towsley, Pico and Saugus formations.

The oldest geologic unit in the Val Verde Quadrangle is the lower to middle Miocene Monterey Shale (map symbol Tm, Dibblee, 1993). Many other workers have mapped these rocks as Modelo Formation of Eldridge and Arnold (1907). Monterey Shale crops out in the northwestern corner of the quadrangle, within the Temescal Anticline and the Devil Canyon Anticline, and in the extreme southwestern corner on Oak Ridge. However, at depth, this formation underlies most of the map area (Yeats and others, 1986). Monterey Shale consists of gray, thin-bedded, white-weathering, platy, hard to soft, fissile, semi-siliceous marine shale and contains thin calcareous beds. Additionally, this formation includes a tan sandstone unit (map symbol Tmss) which is semi-friable with thin interbeds of silty shale.

Conformably overlying the Monterey Shale is the mid-Miocene Sisquoc Formation (map symbol Tsq, Dibblee, 1993; originally included in the Modelo Formation by Eldridge and Arnold, 1907), which consists of grayish-brown, crumbly marine micaceous silty clay-shale to siltstone. Sisquoc Formation is somewhat siliceous, bedded, locally contains dolomitic lenses, and crops out in the same areas and structures where Monterey Shale occurs.

The upper Miocene Castaic Formation (map symbol Tc), which consists of gray, shallow marine shale with thin sandstone beds, is only exposed in a small area in the extreme northeastern corner of the quadrangle, east of the San Gabriel Fault.

West of the San Gabriel Fault, the upper Miocene to lower Pliocene Towsley Formation (map symbol Ttos) of Winterer and Durham (1962) consists of light gray to tan marine sandstone with interbedded silty shale. Towsley Formation is widespread in the northwestern part of the quadrangle and along Oak Ridge and the Santa Susana Mountains on the south. Two members are mapped within the Towsley Formation. One member is gray, crumbly micaceous clay shale to siltstone (map symbol Ttoc). The other is a gray basal conglomerate (map symbol Ttog, called the Hasley Conglomerate by Stitt, 1986, and Yeats and others, 1986) with rounded cobbles and pebbles of mostly granitic composition and scattered metavolcanic clasts and a sandy matrix. The Hasley Conglomerate is exposed along the contact between the Towsley Formation and the underlying Sisquoc Formation.

Plio-Pleistocene bedrock units include the Pico and Saugus formations. The Pico Formation (map symbol Tp; Dibblee, 1993) is mostly Pliocene in age and is the dominant bedrock unit in the central and southern parts of the map area. Pico Formation consists of light gray marine claystone and siltstone, with thin sandstone beds, and includes a pebbly tan sandstone member (map symbol Tps). Additionally, materials consisting of light gray to tan sandstone and pebble conglomerate (map symbol Tpsg) are mapped mostly in the western half of the map, and a gray cobble conglomerate in a clayey sandstone matrix (map symbol Tpc) is exposed in the southern part of the quadrangle.

The Saugus Formation is extensively exposed in the eastern half of the map area. It overlies the Pico Formation and is composed of interbedded non-marine, light gray pebble conglomerate (map symbol QTs), with sandstone and claystone, deposited under primarily fluvial conditions.

Younger Quaternary surficial deposits consist of older and younger alluvial-fan and valley deposits, colluvium, active alluvial fans, and active stream deposits (Qoa, Qyf, Qc, Qf, and Qw). They cover the floors of both the Santa Clara River Valley and smaller canyons. Pleistocene and Holocene landslide deposits are widespread throughout the Val Verde Quadrangle, especially in the fine-grained Tertiary sedimentary units such as the Monterey, Towsley, and Pico formations, where bedding planes are inclined in the same direction as the slope (a dip slope). Landslide deposits are not included in the bedrock/Quaternary geologic materials map used in this study, but are shown on a separate landslide inventory map (Plate 2.1). Modern fill (map symbol af), likely cut and cast fill from oil field development, and more recently engineered fill from residential and commercial development, occurs in scattered areas across the map. A more detailed discussion of the Quaternary deposits in the Val Verde Quadrangle can be found in Section 1.

Structural Geology

The Val Verde Quadrangle lies within the East Ventura Basin (Yeats and others, 1985; 1994), an elongate west-trending synclinal basin whose axis lies generally along the Santa Clara River Valley. The East Ventura basin is truncated by the San Gabriel Fault to the east. The main part of the Val Verde Quadrangle consists of folded Miocene to Quaternary strata cut by several subparallel south-dipping reverse faults. Overall structural configuration of the bedrock materials indicate shallow shortening of the Miocene sedimentary units, accommodated by relatively shallow fold belts. Generally, the Miocene and Pliocene materials thin from west to east across the basin area, and thin sharply close to the San Gabriel Fault.

In addition to folding, the Tertiary units are cut by several south-dipping, reverse faults (Yeats and others, 1985). The Holser Fault, which crosses the central portion of the map area from west to east, and the subparallel Del Valle Fault, are two of the dominant structural features within the map area. The Oak Ridge Fault, a south-dipping reverse fault, is present in the extreme southwestern portion of the map but is hidden beneath modern alluvium in the Santa Clara River Valley. Although the fault segment in this quadrangle does not meet the criteria required for inclusion in the Official Earthquake Fault Zone prepared by CGS, the Oak Ridge Fault is considered to be a major potential seismic source (Cramer and Petersen, 1996; Petersen and others, 1996). The short stretch of the San Gabriel Fault that crosses the northeastern corner of the quadrangle has not been included within an Official Earthquake Fault Zone. Evidence of Holocene surface rupture, such as that found in the Newhall Quadrangle to the east (DOC, 1995), has not been found in the Val Verde Quadrangle.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Val Verde Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping (Weber and others, 1973, Morton, 1976; Barrows, 1986; Harp and Jibson, 1995). 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 were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

Landslides are widespread and very abundant in the Val Verde Quadrangle. Very large landslide complexes are common on the western half of the quadrangle, especially within the claystone and siltstone parts (Tp) of the Pico Formation. Landslides are less common within the friable sandstone unit (Tps). Other large landslides exist within most of the remaining mapped formations, including the gray micaceous siltstone of the Towsley Formation (Ttoc), the micaceous clay shale of the Sisquoc Formation (Tsq), and the thin bedded, platy shale of the Monterey Shale Formation (Tm). Rock falls and shallow rock slides are exhibited on many slopes comprised of the Saugus Formation, represented as gravel conglomerate, sandstone and claystone (QTs).

Landslides in the mapped area range from debris slides, rock falls and debris flows, to large rotational and translational landslides, some of which are old and deeply eroded. Landslide identification in the Val Verde Quadrangle is somewhat difficult in particular bedrock units, due to the folded orientation, and effects of weathering on the geomorphic expression of landslide features. Individual debris-flow tracks and deposits were not mapped for this study.

The quadrangle was strongly impacted by the M 6.7 Northridge earthquake of January 17,1994. Shaking was very intense in the region because the faulting that triggered the event was inclined upward from the focal area, to much shallower depths in this region. Vertical and horizontal ground motion, as measured in the nearby Newhall area was very strong (CSMIP Station 23279 in Shakal and others, 1994, p. 46). The Northridge event triggered abundant slope failures in the Val Verde Quadrangle. Prominent features and areal extent of landslide occurrence from the Northridge event is discussed in separate reports (Barrows and others, 1995; Harp and Jibson, 1995).

Several large older landslide complexes that were reactivated as a result of the Northridge event have been given names. These include the Del Valle Landslide, located near the Del Valle oil field, near the center of the quadrangle. The Del Valle Landslide is an earthquake-triggered progressive failure of previously intact bedrock that formed the main scarp of an older, large rock slide. It formed in Pico Formation claystone and siltstone that dips moderately to steeply to the south, and much of the sliding may have been along bedding planes. The upper portion of this landslide created spectacular grabens and large areas of back-tilted blocks formed during the intense shaking along the ridgetop. The main scarp of the Del Valle Landslide, which extended over the crest to the north-facing slope during the Northridge event, was affected by ridge-top shattering (Barrows and others, 1995). Other large older landslides, some of which also exhibited reactivation during the Northridge earthquake, have been mapped in the northern and western parts of the quadrangle, including the Loma Verde Landslide, the Ramona Oil Field Landslide and the Rancho Camulos Landslide.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the Val Verde Quadrangle geologic map were obtained from Los Angeles County (see Appendix A). The locations of rock and soil samples taken for shear testing within the Val Verde Quadrangle are shown on Plate 2.1. Shear tests from the adjoining Whitaker Peak, Newhall and Warm Springs Mountain quadrangles were used to augment data for several geologic formations for which little or no shear test information was available within the Val Verde Quadrangle.

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

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 Val Verde Quadrangle, 6 direct shear tests of landslide slip surface materials were obtained, and the results are summarized in Table 2.1.

VAL VERDE QUADRANGLE SHEAR STRENGTH GROUPS

	Formation Name	Number of Tests	Mean/Median Phi (degrees)	Mean/Median Group Phi (degrees)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	af	4	32	31/32	313/260	Qc, Qf, Qoa	31
	Qya	30	30/31			Qoat1, Qoat2	
	QTs	108	31/32			Qw, Qw2	
	Tp	12	32/31			Qya1, Qya2	
						Qyat1, Qyat2	
						Qyf1, Qyf2	
						Tm, Tmss	
						Tpc, Tpsg	
						Ttog, Ttos	
GROUP 2	Tps	7	28/25	27/28	570/420	Tsq	27
	Tc	47	27/28			Ttoc	
GROUP 3	Qls	6	13	13	508/325		13
	Formations for strength groups from Dibblee, 1993 and William Lettis and Associates, 1999						

Table 2.1. Summary of the Shear Strength Statistics for the Val Verde Quadrangle.

SHEAR STRENGTH GROUPS FOR THE VAL VERDE 7.5-MINUTE QUADRANGLE		
GROUP 1	**GROUP 2**	**GROUP 3**
af	Tc	Qls
Qc, Qf, Qoa	Tps	
Qoat1, Qoat2	Tsq	
Qw, Qw2	Ttoc	
Qya, Qya1, Qya2		
Qyat1, Qyat2		
Qyf1, Qyf2		
QTs		
Tm, Tmss		
Tp, Tpc		
Tpsg		
Ttog		
Ttos		

Table 2.2. Summary of Shear Strength Groups for the Val Verde 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 Val Verde 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 CGS for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.6 - 6.7
Modal Distance:	2.5 to 11.2 km
PGA:	0.59 to 1.18 g

The strong-motion record selected for the slope stability analysis in the Val Verde Quadrangle was the USC-14 record from the magnitude 6.7 Northridge earthquake of January 17, 1994 (Trifunac and others, 1994). This record had a source to recording site distance of 8.5 km and peak ground acceleration (PGA) of 0.59g. 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 CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 0.129 and 0.232g. 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 Val Verde Quadrangle.

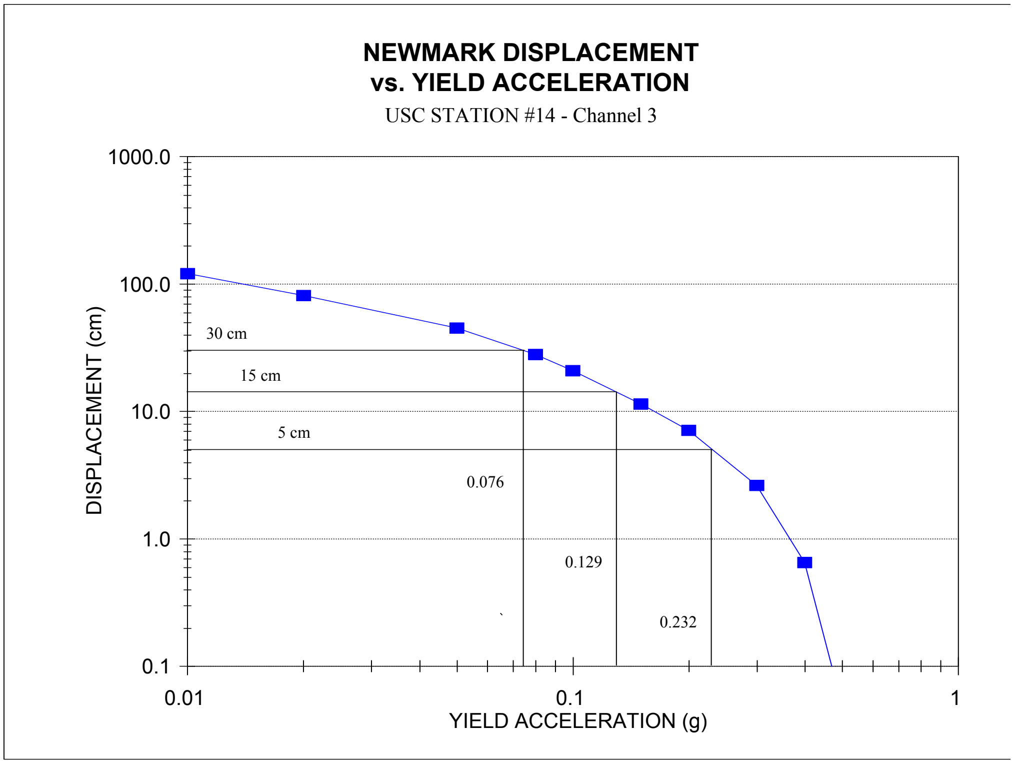

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake.

Slope Stability Analysis

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

VAL VERDE QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Group	MEAN PHI	SLOPE CATEGORY (% SLOPE)								
		I	II	III	IV	V	VI	VII	VIII	IX
		0-10	10-15	15-28	28-36	36-38	38-44	44-46	46-53	>53
1	31	VL	VL	VL	VL	L	L	L	M	H
2	27	VL	VL	VL	L	L	M	H	H	H
3	13	L	M	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Val Verde 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.

No earthquake-triggered landslides had been identified in the Val Verde Quadrangle prior to the Northridge earthquake. The Northridge earthquake caused a large number of relatively small shallow slope failures and several very large landslides in the Val Verde Quadrangle (Harp and Jibson, 1995; Barrows and others, 1995; see landslide inventory discussion for a detailed description). Soil falls, debris falls, and debris slides occurred in poorly indurated or highly fractured sedimentary rock on steep slopes and along roadcuts. Seismic shaking also enhanced previously existing headscarps of massive bedrock landslides and created additional cracks on steep slopes and ridge tops. Landslides attributed to the Northridge earthquake covered approximately 1,438 acres of land in this quadrangle, which is 3.6 percent of the total area covered by the map. All the verifiable landslides triggered by the Northridge earthquake from the Harp and Jibson (1995) inventory were included in the seismic hazard zone.

Geologic and Geotechnical Analysis

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

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

1. Geologic Strength Group 3 is included for all slope gradient categories. (Note: Geologic Strength Group 3 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 2 is included for all slopes steeper than 28 percent.

3. Geologic Strength Group 1 is included for all slopes steeper than 36 percent.

This results in 64 percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the Val Verde Quadrangle.

ACKNOWLEDGMENTS

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REFERENCES

Barrows, A.G., 1986, Landslide hazards in the east half of the Val Verde Quadrangle, Los Angeles County, California: Department of Conservation, Division of Mines and Geology, Open File Report 86-9, map scale 1:24,000.

Barrows, A.G., Irvine, P.J. and Tan, S.S., 1995, Geologic surface effects triggered by the Northridge earthquake, *in* Woods, Mary C. and Seiple, W. Ray, *editors*, The Northridge, California, earthquake of 17 January 1994: California Department of Conservation, Division of Mines and Geology Special Publication 116, p. 65-88.

California Department of Conservation, Division of Mines and Geology, 1995, Revised Official Map of Earthquake Fault Zones, Newhall Quadrangle, scale 1:24,000.

California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

California Department of Conservation, Division of Mines and Geology, 2000, Recommended criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 12 p.

Dibblee, T.W. Jr., 1993, Geologic map of the Val Verde Quadrangle, Los Angeles and Ventura counties, California: Dibblee Geological Foundation Map DF-50, scale 1:24,000.

Geo-Haz Consulting, Inc., 1999, Ridgetop splitting, spreading and shattering related to earthquakes in southern California: Final Technical Report for the National Earthquake Hazards Reduction Program, U.S. Geological Survey Contract 1434-HQ-GR-1026, U.S. Geological Survey.

Harp, E.L. and Jibson, R.W., 1995, Landslides triggered by the January 17, 1994 Northridge, California earthquake: U.S. Geological Survey Open-File Report 95-213, 17 p., Plate 1 scale 1:100,00; Plate 2 scale 1:50,000.

Horn, B.K.P., 1981, Hill shading and the reflectance map: Proceedings of the IEEE, v. 69, no. 1, p. 14-47.

Intermap Corporation, 2002, Global Terrain product handbook and quick start guide: http://www.intermap.com/images/handbook/producthandbook.pdf

Jibson, R.W., 1993, Predicting earthquake-induced landslide displacements using Newmark's sliding block analysis: Transportation Research Board, National Research Council, Transportation Research Record 1411, 17 p.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406-421.

McCrink, T.P., 1995, Ridge-top landslides triggered by the Northridge earthquake, *in* Woods, Mary C. and Seiple, W. Ray, *editors*, The Northridge, California, earthquake of 17 January 1994: California Department of Conservation, Division of Mines and Geology Special Publication 116, p. 273-278.

McCrink, T.P., 2001, Mapping earthquake-induced landslide hazards in Santa Cruz County *in* Ferriz, H. and Anderson, R., *editors*, Engineering geology practice in northern California: California Geological Survey Bulletin 210 / Association of Engineering Geologists Special Publication 12, p.77-94.

McCrink, T.P. and Real, C.R., 1996, Evaluation of the Newmark method for mapping earthquake-induced landslide hazards in the Laurel 7-1/2 minute Quadrangle, Santa Cruz County, California: California Division of Mines and Geology Final Technical Report for U.S. Geological Survey Contract 143-93-G-2334, U.S. Geological Survey, Reston, Virginia, 31 p.

Morton, D.M., 1976, Reconnaissance surficial geologic maps of the Newhall, Oat Mountain, Santa Susana, and Val Verde 7.5' quadrangles, Los Angeles and Ventura Counties, southern California: U.S. Geological Survey Open-File Report 76-211.

Newmark, N.M., 1965, Effects of earthquakes on dams and embankments: Geotechnique, v. 15, no. 2, p. 139-160.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology, Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.

Shakal, A., Huang, M., Darragh, R., Cao, T., Sherburne, R., Malhotra, P., Cramer, C., Sydnor, R., Graizer, V., Maldonado, G., Petersen C. and Wampole, J., 1994, CSMIP strong-motion records from the Northridge, California earthquake of 17 January 1994: California Department of Conservation, Division of Mines and Geology Strong Motion Instrumentation Program Report OSMS 94-07, 308 p.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Southern California Earthquake Center, 2002, Recommended procedures for implementation of DMG Special Publication 117 guidelines for analyzing and mitigating landslide hazards in California: T.F. Blake, R.A. Hollingsworth, and J.P. Stewart, *editors*, Southern California Earthquake Center, University of Southern California, 108 p.

Stitt, L.T., 1986, Structural history of the San Gabriel Fault and other Neogene structures in the central Transverse Ranges, California, *in* Ehlig, P.L., *compiler*, Guidebook and volume, neotectonics and faulting in southern California: Geological Society of America, p.43-102.

Trifunac, M.D., Todorovska, M.I. and Ivanovic, S.S., 1994, A note on distribution of uncorrected peak ground accelerations during the Northridge, California earthquake of 17 January 1994: Soil Dynamics and Earthquake Engineering, v. 13, no. 3, p. 187-196.

Wang, Y., Mercer, J.B., Tao, V.C., Sharma, J. and Crawford, S., 2001, Automatic generation of bald earth digital elevation models from digital surface models created using airborne IFSAR: http://www.intermap.com/

Weber, H.F. Jr., Cleveland, G. B., Kahle, J.E., Kiessling, E.F., Miller, R.V., Mills, M.F. and Morton, D.M., 1973, Geology and Mineral Resources Study of Southern Ventura County: California Division of Mines and Geology, Preliminary Report 14.

William Lettis and Associates, 1999, Digital Quaternary geologic map of the Ventura County portion of the Val Verde 7.5-minute Quadrangle: digitized at scale 1:24000.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Winterer, E. L. and Durham, D.L., 1962, Geology of southeastern Ventura Basin, Los Angeles County, California: U.S. Geological Survey Professional Paper 334-H, p. 275-366.

Yeats, R.S., McDougall, J.W. and Stitt, L.T., 1985, Cenozoic structure of the Val Verde 7.5’ Quadrangle and south half of the Whitaker Peak 7.5’ Quadrangle, California: U.S. Geological Survey Open File Report 85-587, 32 p., map scale 1:24,000.

Yeats, R.S., Huftile, G.J. and Stitt, L.T., 1994, Late Cenozoic tectonics of the East Ventura Basin, Transverse Ranges, California: American Association Petroleum Geologists Bulletin, v. 78, no. 7, p. 1040-1074.

Yerkes, R.F. and Campbell, R.H., 1995, Preliminary geologic map of the Val Verde 7.5’ Quadrangle, Southern California: U.S. Geological Survey Open File Report 95-504. Scale 1:24,000.

Youd, T.L., 1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tennessee, 1980, v. 2, p. 7-6-2 to 7-6-26.

AIR PHOTOS

National Aeronautics and Space Administration (NASA) dated 1-22-1994, 04689, 94-002-02, photo numbers; 473 – 484, 508 – 518, 594 – 604, 667 – 676, 702 – 713, 773 – 782, 804 – 814, black and white, vertical, approx. scale 1:15,000.

American Aerial Surveys, dated 6-19-80, Flight 80136, photo numbers; 53-67, 106-121, 149-163, scale 1:18,000.

Department of County Engineers, Soil Survey Los Angeles County, dated 3-26-68, photo numbers; 4-1 through 4-4, 3-192 and 3-193, 6-10 through 6-21, 4-100 through 4-107, scale 1:6,000.

I.K. Curtis Services, April 2, 2000, Frame 692, November 13, 2000, Frames 780-781 and 812-813; Color; Vertical; scale 1:42,000.

United States Department of Agriculture, Soil Conservation Service, Flight numbers; AXJ-2K, dated 11-3-52, photo numbers; 25-32, 81 – 90; AXI-2K, dated 12-22-52, photo numbers; 41 – 49; AXI-3K, dated 1-3-53, photo numbers; 17 – 23, approximate scale 1:20,000.

APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Los Angeles County	157
Whitaker Peak Quadrangle	37
Warm Springs Mtn. Quadrangle	10
Newhall Quadrangle	12
Total Number of Shear Tests	216

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Val Verde 7.5-Minute Quadrangle, Los Angeles and Ventura Counties, 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 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

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 hazards zone mapping in California is on CGS's Internet web 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

VAL VERDE 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS

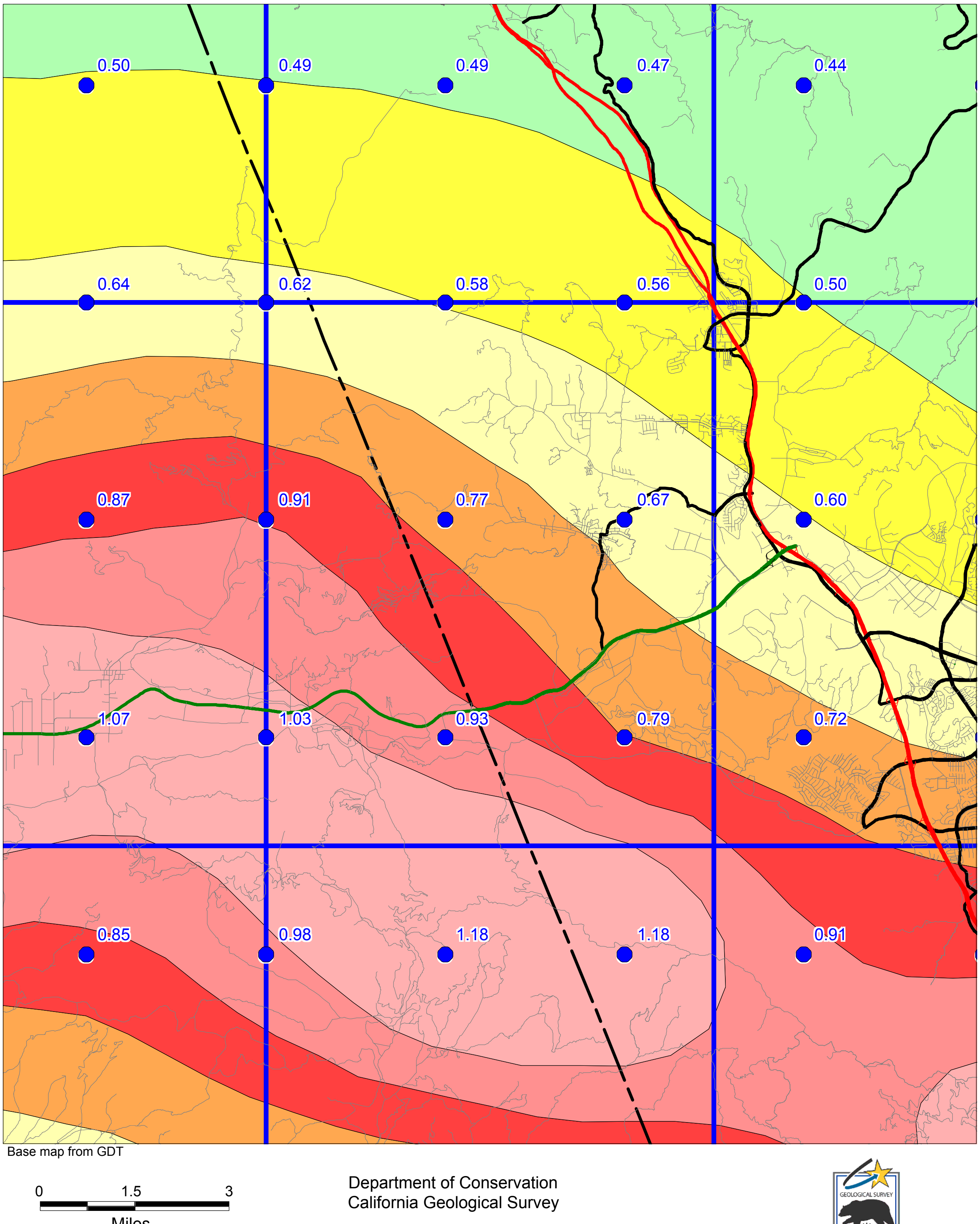

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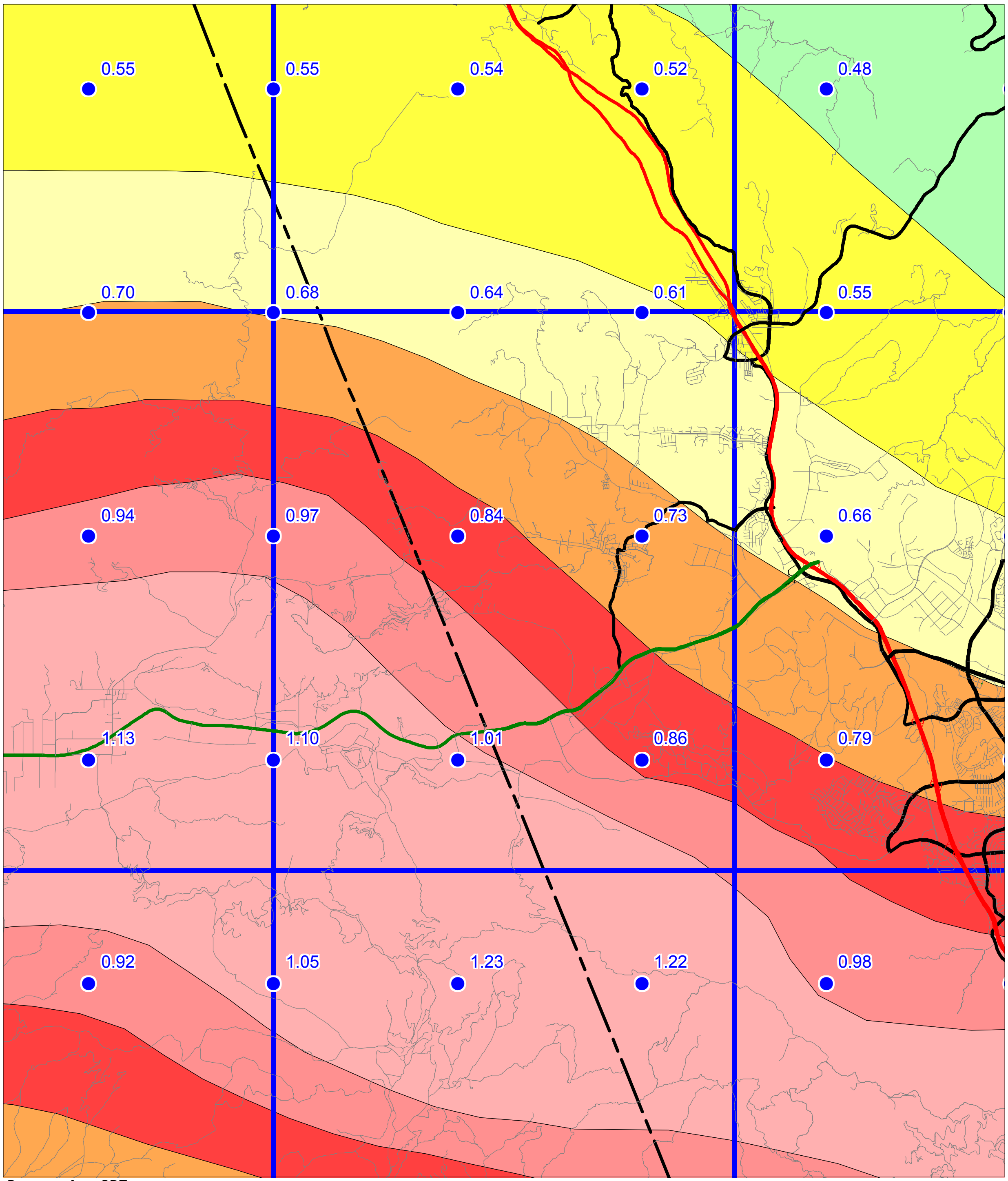
Figure 3.1

VAL VERDE 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

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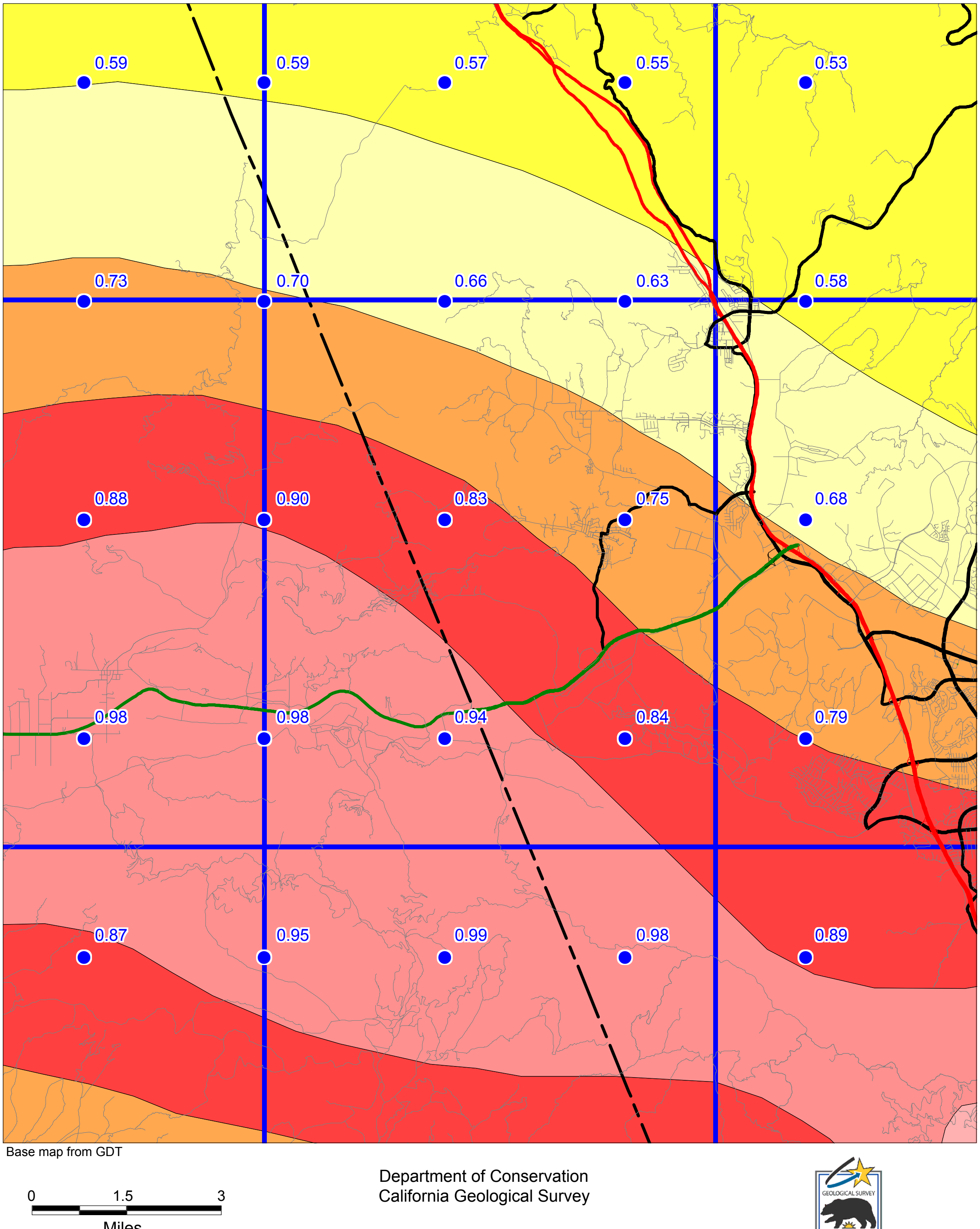
Figure 3.2

VAL VERDE 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



Department of Conservation
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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.

VAL VERDE 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

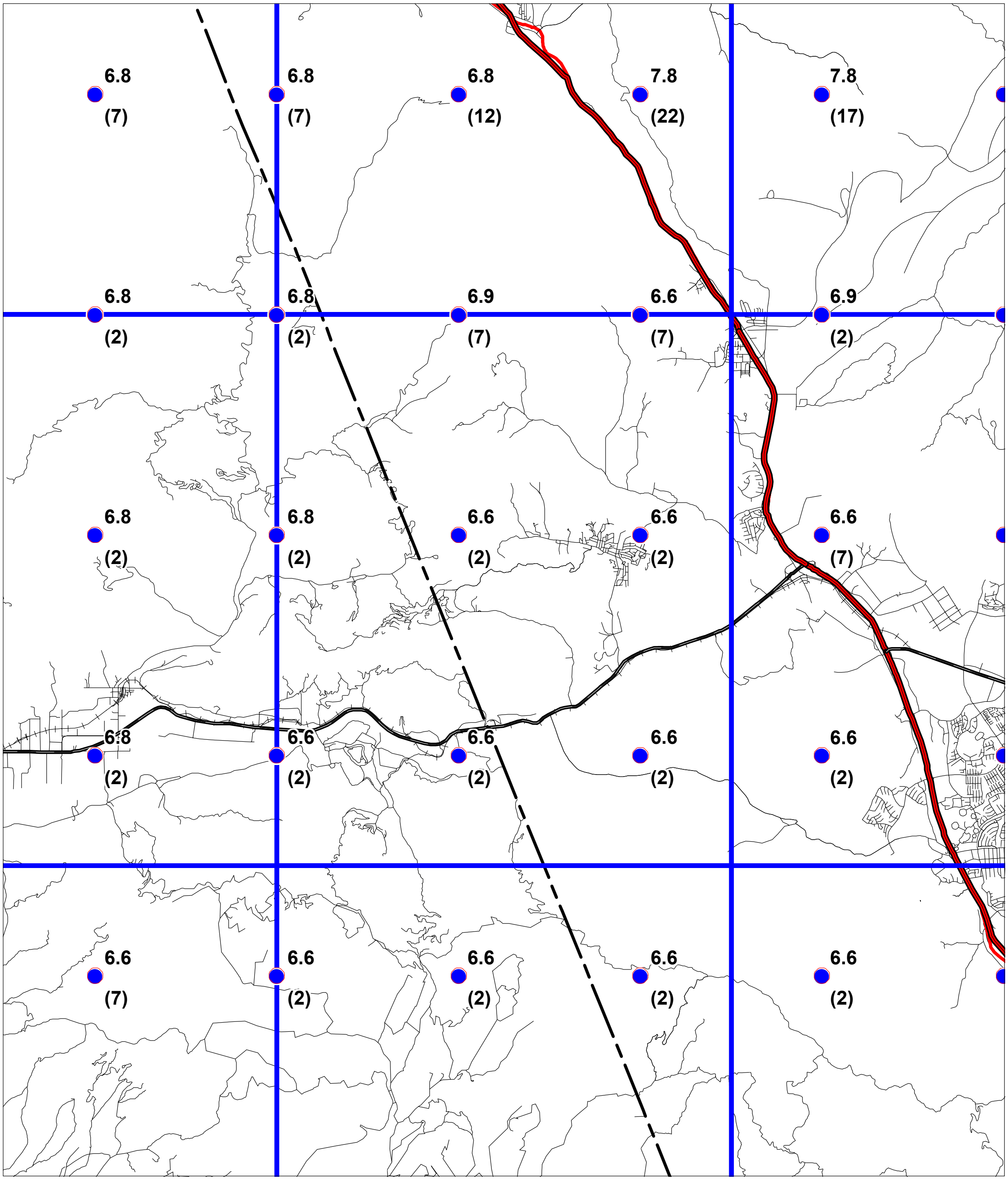
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)

(Distance (km))



Base map from GDT

0 1.5 3

Miles

Department of Conservation

California Geological Survey

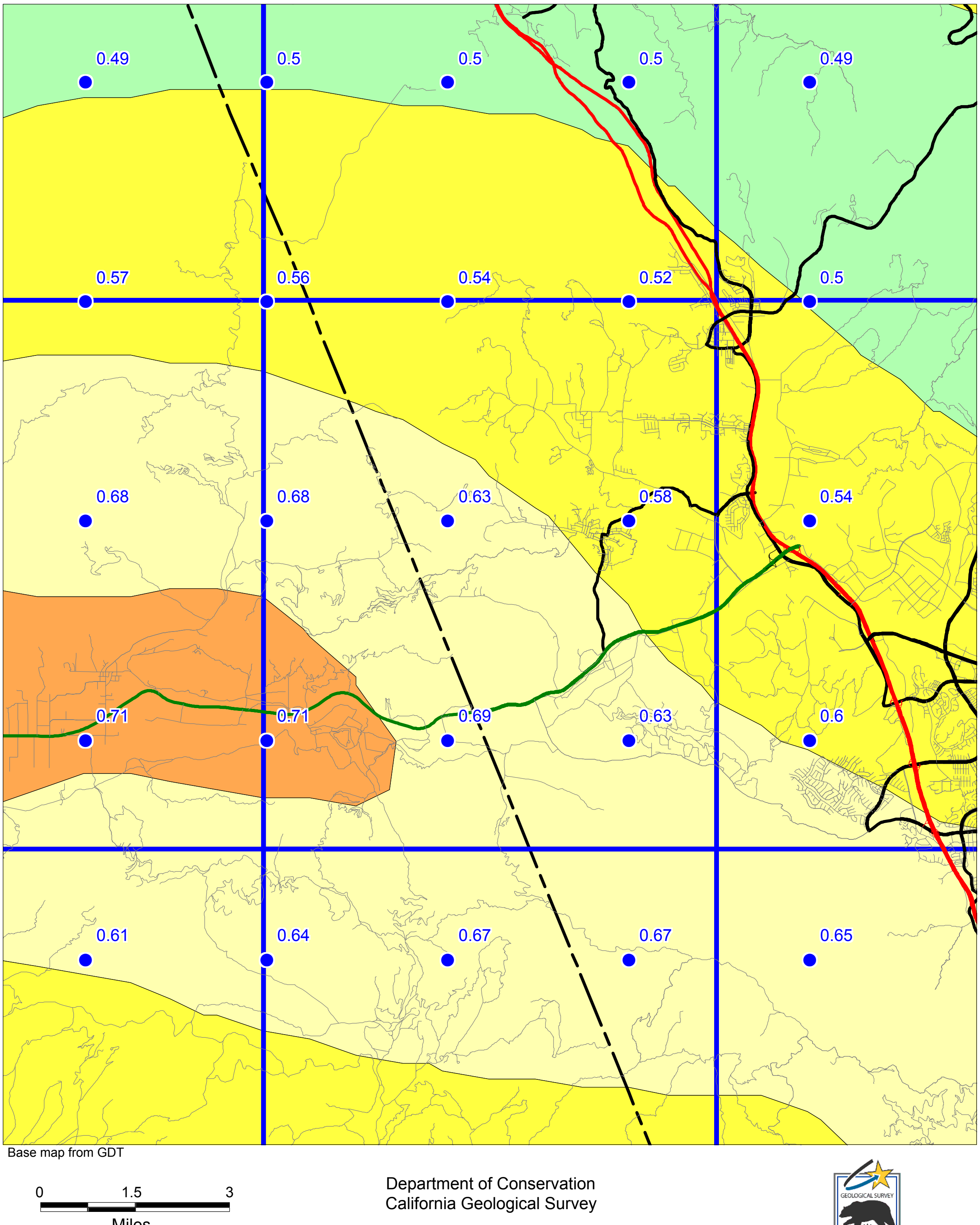
Figure 3.4

VAL VERDE 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.

REFERENCES

Boore, D.M., Joyner, W.B. and Fumal, T.E., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: Seismological Research Letters, v. 68, p. 154-179.

California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California: Special Publication 117, 74 p.

Campbell, K.W., 1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: Seismological Research Letters, v. 68, p. 180-189.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, p. 1645-1649.

Cramer, C.H., Petersen, M.D. and Reichle, M.S., 1996, A Monte Carlo approach in estimating uncertainty for a seismic hazard assessment of Los Angeles, Ventura, and Orange counties, California: Bulletin of the Seismological Society of America, v. 86, p. 1681-1691.

International Conference of Building Officials (ICBO), 1997, Uniform Building Code: v. 2, Structural engineering and installation standards, 492 p.

Jennings, C.W., *compiler*, 1994, Fault activity map of California and adjacent areas: California Department of Conservation, Division of Mines and Geology, California Geologic Data Map Series, map no. 8.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.

Real, C.R., Petersen, M.D., McCrink, T.P. and Cramer, C.H., 2000, Seismic Hazard Deaggregation in zoning earthquake-induced ground failures in southern California: Proceedings of the Sixth International Conference on Seismic Zonation, November 12-15, Palm Springs, California, EERI, Oakland, CA.

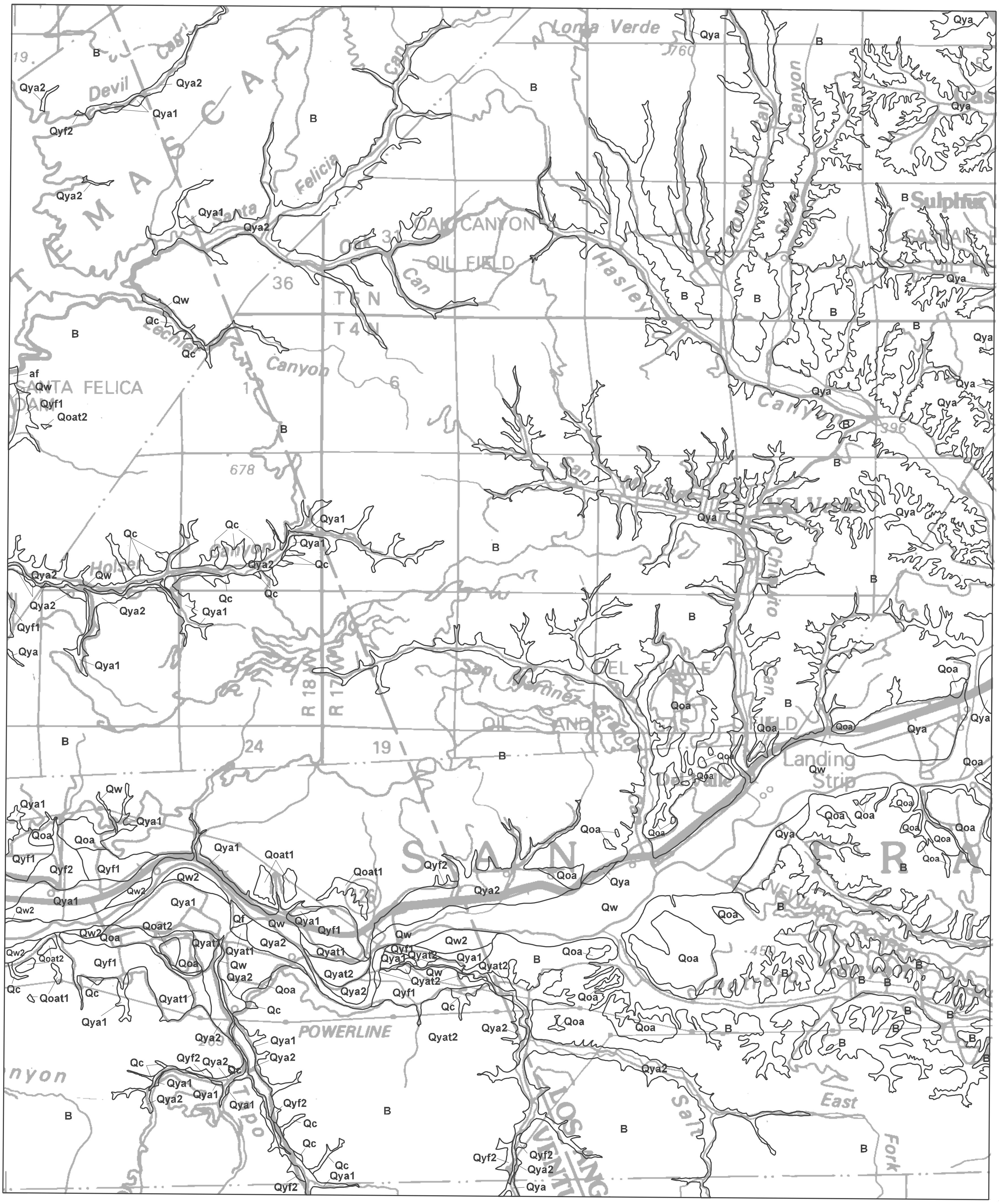
Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F. and Youngs, R.R., 1997, SEA96- A new predictive relation for earthquake ground motions in extensional tectonic regimes: Seismological Research Letters, v. 68, p. 190-198.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Youd, T.L. and Idriss I.M., 1997, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: Technical Report NCEER-97-0022, 40 p.

Youngs, R.R., Chiou, S.-J., Silva, W.J. and Humphrey, J.R., 1997, Stochastic point-source modeling of ground motions in the Cascadia Region: Seismological Research Letters, v. 68, p. 74-85.

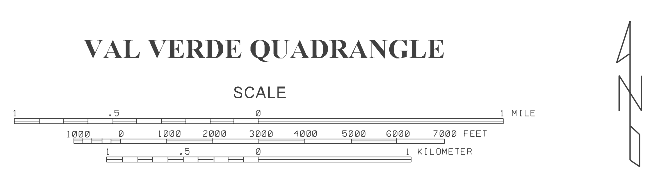
118° 45'
34° 30'



34° 22'30"
118° 37'30"

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

VAL VERDE QUADRANGLE

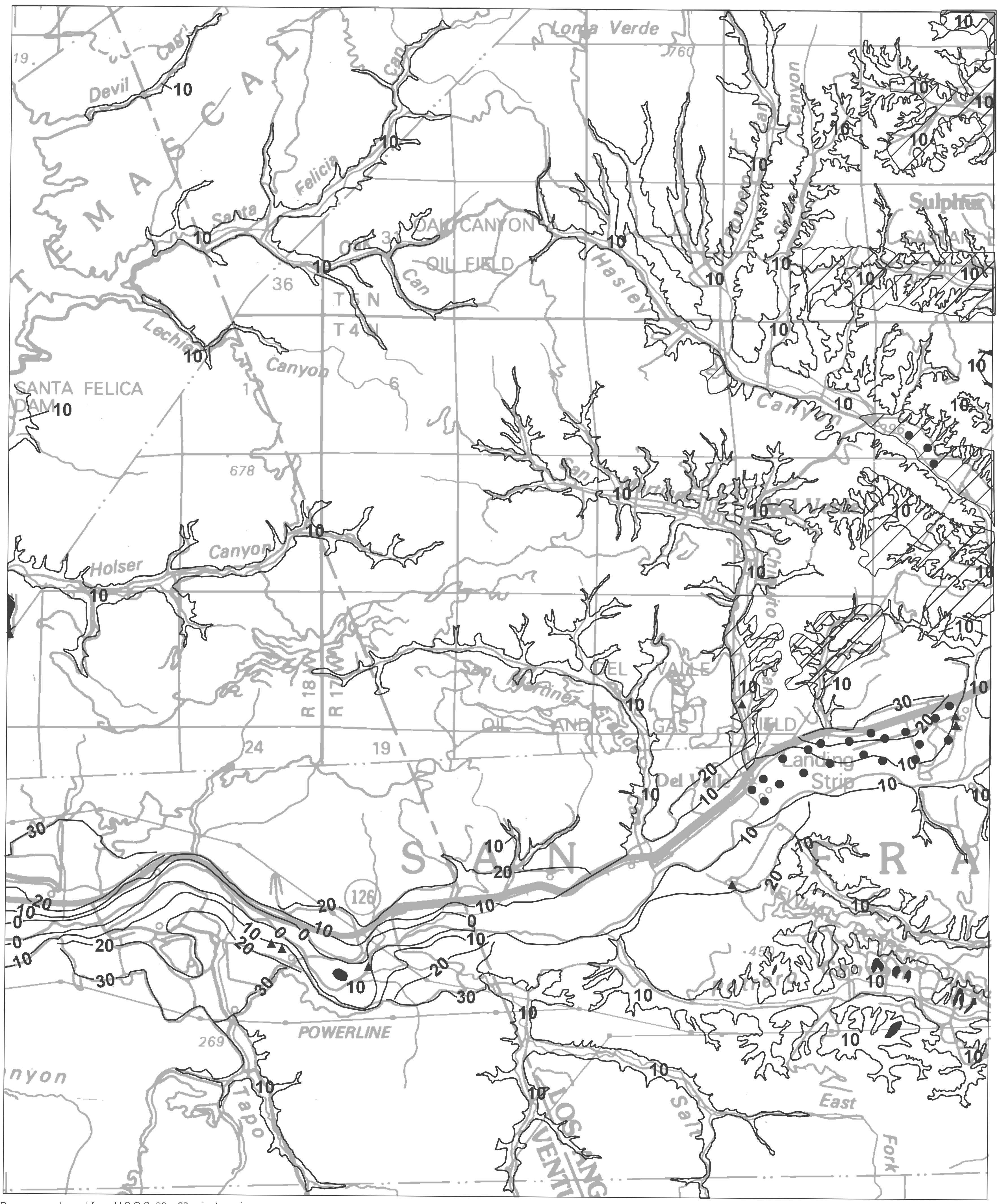


B = Pre-Quaternary bedrock.
See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

Plate 1.1 Quaternary Geologic Map of the Val Verde 7.5-minute quadrangle (Lettis and Associates, 2000).

118° 45'

34° 30'



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

34° 22'30"
118° 37'30"

VAL VERDE QUADRANGLE

SCALE

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 KILOMETER

— 50 — Depth to ground water, in feet

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

● Geotechnical borings used in liquefaction evaluation

▲ Water Wells

Plate 1.2 Depth to historically high ground water, and locations of boreholes used in this study, Val Verde 7.5-minute Quadrangle, California

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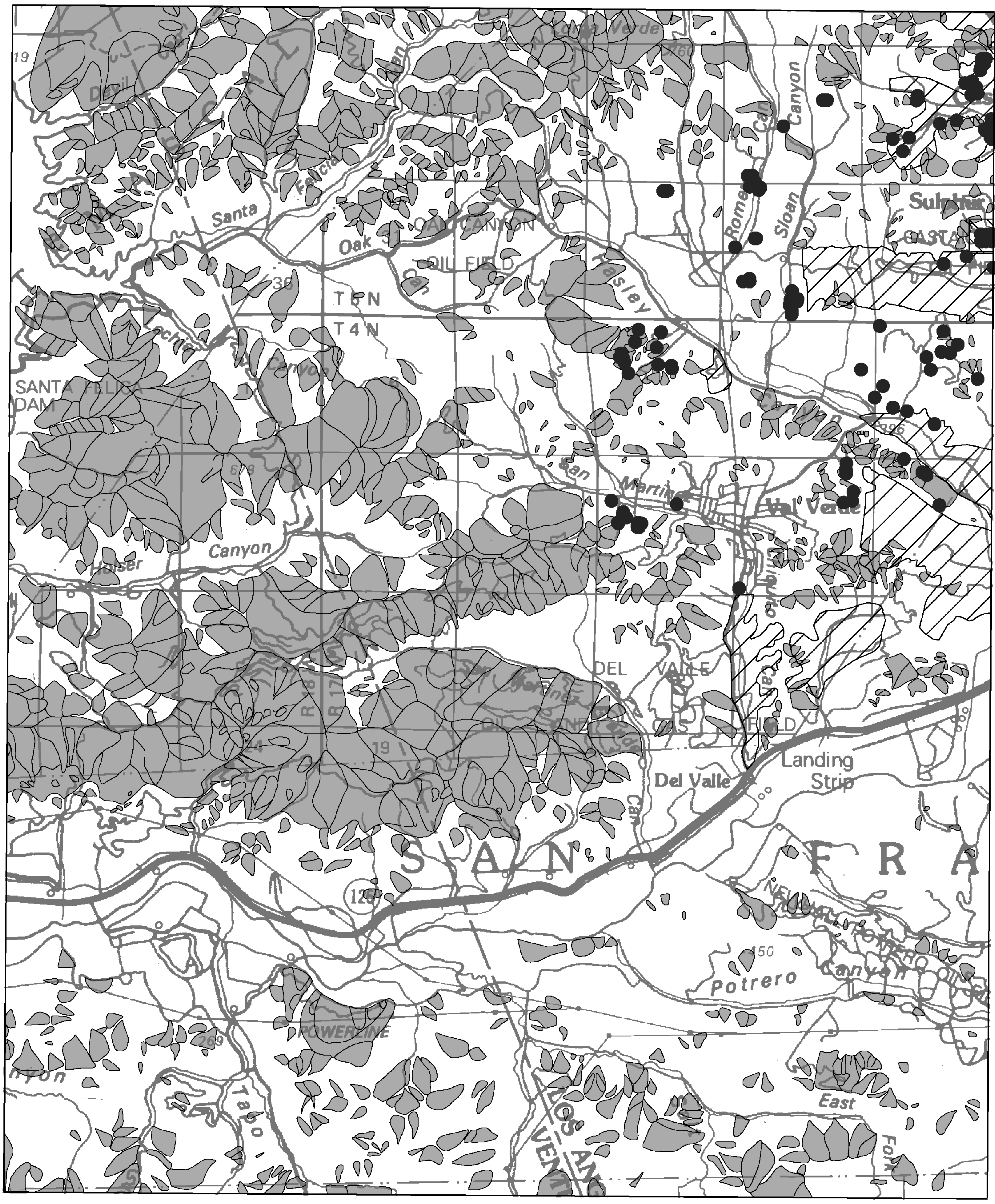
STATE OF CALIFORNIA-GRAY DAVIS, GOVERNOR
THE RESOURCES AGENCY-MARY D. NICHOLS, SECRETARY
DEPARTMENT OF CONSERVATION-DARRYL W. YOUNG, DIRECTOR

Val Verde Quadrangle Plate 2.1
SEISMIC HAZARD ZONE REPORT 076



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

VAL VERDE QUADRANGLE

SCALE

● Shear test sample location
Landslide
Area of significant grading
Tract report with multiple shear tests

Plate 2.1 Landslide inventory, shear test sample locations, and areas of significant grading, Val Verde 7.5-minute Quadrangle, California.