SEISMIC HAZARD ZONE REPORT 053

SEISMIC HAZARD ZONE REPORT FOR THE SAN JUAN CAPISTRANO 7.5-MINUTE QUADRANGLE, ORANGE COUNTY, CALIFORNIA

2001

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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EXECUTIVE SUMMARY

This report summarizes the methodology and sources of information used to prepare the Seismic Hazard Zone Map for the San Juan Capistrano 7.5-minute Quadrangle, Orange County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of about 62 square miles at a scale of 1 inch = 2,000 feet.

The southwestern corner of the San Juan Capistrano Quadrangle intersects the coastline in southern Orange County. Numerous creek canyons and arroyos dissect the mostly hilly terrain within quadrangle. All or parts of the cities of Laguna Beach, Laguna Hills, Laguna Nigel, Mission Viejo, and San Juan Capistrano, as well as parts of three regional parks, occur within the quadrangle. Primarily following the course of Oso Creek, Interstate Highway 5 bisects the area. During the past 30 years, this area has undergone widespread development and intensive urbanization, especially in the form of residential construction.

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 San Juan Capistrano Quadrangle the liquefaction zone is restricted to the bottoms of narrows canyons and the beach. The quadrangle is underlain by several geological formations that consist of relatively weak strata such as siltstone and shale. The combination of dissected hills and weak rocks has produced widespread and abundant landslides. These conditions contribute to an earthquake-induced landslide zone that covers about 35 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 Division of Mines and Geology's Internet page: http://www.conservation.ca.gov/CGS/index.htm

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

BPS Reprographic Services
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 DMG offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

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

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

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

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

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the San Juan Capistrano 7.5-Minute Quadrangle, Orange County, California

By
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Division of Mines and Geology

PURPOSE

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

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

BACKGROUND

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

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the San Juan Capistrano 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 DMG probabilistic shaking maps

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

SCOPE AND LIMITATIONS

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

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

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

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The San Juan Capistrano Quadrangle covers an area of about 62 square miles in southeastern Orange County. It lies at the northwestern edge of the Peninsular Ranges geomorphic province. It includes the hilly, locally rugged San Joaquin Hills to the west and southwestern foothills of the Santa Ana Mountains to the east. The hills are cut by numerous canyons, most of which drain to the south toward the Pacific Ocean. The largest drainages include Arroyo Trabuco, Oso Creek, Horno Creek, San Juan Creek, Aliso Creek, Arroyo Salada, Sulphur Creek, and Salt Creek. A small portion of the northwestern part of the quadrangle drains to the north toward San Diego Creek. Elevations range from sea level to 1000 feet in the northeastern portion of the quadrangle. The top of Niguel Hill, approximately one mile from the ocean, is 936 feet above sea level.

Within the past 30 years there has been significant urbanization in the San Juan Capistrano Quadrangle. The quadrangle includes all or parts of the cities and communities of Lake Forest, Irvine, Aliso Viejo, Laguna Woods, Laguna Hills, Laguna Niguel, South Laguna, Laguna Beach, San Juan Capistrano, Mission Viejo, Tustin, and Rancho Santa Margarita as well as unincorporated areas of Orange County. Portions of O'Neill, Salt Creek and Aliso and Wood Canyons regional parks are in the northeast, south, and southwest portions of the quadrangle, respectively. The major transportation routes through the quadrangle include the San Diego Freeway (Interstate Highway 5), the San Joaquin Hills Transportation Corridor, Ortega Highway (State Highway 74), and a short segment of Pacific Coast Highway (State Highway 1). These are supplemented by El Toro Road, Moulton Parkway, La Paz Road, Oso Parkway, Alicia Parkway, Crown Valley Parkway, Marguerite Parkway and Street of the Golden Lantern.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. To evaluate the areal and vertical distribution of shallow Quaternary deposits and to provide information on subsurface geologic, lithologic and engineering properties of the units in the San Juan Capistrano Quadrangle a geologic map digitized by the Southern California Areal Mapping Project [SCAMP] (Morton and Kennedy, 1989) from 1:12,000-scale mapping by Morton and others (1974). Morton and others (1974) worked from the earlier work of Vedder and others (1957) and incorporated new information provided from the numerous exposures afforded by the widespread development during the 1960's and early 1970's. This detailed map was produced in cooperation with the County of Orange (Road Department, Department of Building and Safety, and Flood Control District) to provide sufficient detail for use as a basic reference for determining potential hazards to urban development. For the purpose of this seismic hazard evaluation, additional linework and nomenclature modification was done by DMG. The generalized Quaternary geology of the quadrangle is shown in Plate 1.1.

The bedrock in the quadrangle consists of Tertiary marine and non-marine sedimentary strata ranging in age from late Eocene through Pliocene. These units are chiefly composed of sandstone, siltstone, and breccia and are discussed in more detail in Section 2 of this report. Approximately 25% of the study area is covered by alluvial deposits of Quaternary age. The Pleistocene to Holocene surficial units unconformably overlie bedrock and have been divided into several subunits that reflect depositional environment (Table 1.1). The oldest of these units consists of flat-lying nonmarine and marine terrace deposits (Qvom, Qom, Qvoa, Qoa) and alluvial fan deposits (Qvof). The remaining younger alluvial units consist of stream channel deposits (Qya, Qw), slopewash and colluvial debris (Qc), beach sediment (Qm), landslide debris, and artificial fill materials (af). Landslides are not shown on the generalized geologic map (Plate 1.1) but are specifically addressed in Section 2.

Map Unit	Environment of Deposition	Age
Qvom	marine	middle to early Pleistocene
Qvoa	axial channel/ valley deposits	middle to early Pleistocene
Qvof	alluvial fans	middle to early Pleistocene
Qom	marine	late to middle Pleistocene
Qoa	axial channel/ valley deposits	late to middle Pleistocene
Qya	axial channel/ valley deposits	Holocene and late Pleistocene
Qw	wash	modern
Qc	colluvium/ slopewash	Holocene
Qm	marine	late Holocene
af	artificially placed	modern

Table 1.1. Units of the Southern California Areal Mapping Project (SCAMP) Nomenclature Used in the San Juan Capistrano Quadrangle.

ENGINEERING GEOLOGY

Review of more than 400 borehole logs from 113 soil reports in the study area yielded abundant information on subsurface properties. Sources of subsurface data used for this investigation include borehole logs collected from Leighton and Associates, the California Department of Transportation (Caltrans), the Hazardous Material Management Section of the Orange County Health Care Agency and the Materials Laboratory of the Orange County Public Facilities & Resources Department. Additional data for this study came from DMG files of seismic reports for hospital and school sites.

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

Lithologic, soil test, and related data from 353 logs were entered into the DMG (Geographic Information System) database. The remaining logs were reviewed and aided in stratigraphic correlation. Locations of all exploratory boreholes in the database for the San Juan Capistrano Quadrangle are shown in Plate 1.2. Cross sections were constructed from borehole data to correlate soil types and engineering properties and to extrapolate geotechnical data into outlying areas containing similar soils.

The characteristics of geologic units recorded on the borehole logs are given below and summarized in Table 1.2. These descriptions are generalized but give the most commonly encountered characteristics of the unit.

Very old marine deposits (Qvom)

The only deposits of this unit on the San Juan Capistrano are located along a ridge south of Niguel Hill. They consist of very old marine and nonmarine terrace deposits that rest upon a marine wave-cut platform. The age of the platform is estimated to be greater than 500,000 years based on correlations made for the same unit in the Dana Point Quadrangle (Kern and others, 1996; Tan, in preparation). Surfaces are well dissected.

Subsurface data are not readily available for this unit. In general, it consists of reddish-brown to yellowish-brown, weakly cemented fine sand and silty sand with some gravel (Morton and others, 1974).

Very old axial channel/alluvial valley deposits (Qvoa)

These units consist of very old (middle to early Pleistocene) stream and river deposits located above the Aliso Creek, Trabuco Creek, and San Juan Creek drainages (Morton, 1999). Surfaces are well dissected. Limited subsurface data were available for this unit. In general, it consists of medium dense to very dense, brown to reddish-brown, gravel, silty sand, silt and clay.

Very old fan deposits (Qvof)

These units consist of very old (middle to early Pleistocene) alluvial fan deposits (Morton, 1999). The fan surface is well dissected. Numerous subsurface reports were evaluated for this unit because of shallow ground water conditions near El Toro Road.

Borehole data show it to consist predominantly of brown to reddish-brown, loose to very dense, silty clayey sand, silt and clay.

Old marine deposits (Qom)

Older marine and non-marine terrace deposits occur above marine wave-cut platforms located atop the coastal bluffs. Based on similar units mapped in the Dana Point Quadrangle, the ages of the platforms are estimated to range between 450,000 years to 120,000 years (Kern and others, 1996; Tan, in preparation). Borehole data indicate that this unit is predominantly composed of fine to coarse sand with varying amounts of clay, silt, and gravel. It ranges from loose to very dense to indurated.

Old axial channel/alluvial valley deposits (Qoa)

These units consist of late to middle Pleistocene stream and river deposits adjacent to Aliso Creek, Oso Creek, Trabuco Creek, San Juan Creek and some smaller drainages. Borehole logs for this unit indicate it is predominantly composed of brown gravel, sand, silt, and clay and ranges from medium dense to very dense.

Young axial channel/alluvial valley deposits (Qya)

These stream and river deposits occur within all the major drainages and in the downstream portions of smaller drainages. Borehole logs for this unit indicate it is predominantly composed of gray to brown gravel, sand, silt, and clay. Compactness of sand layers ranges from loose to medium dense.

Wash deposits (Qw)

This unit represents alluvium in active and recently active washes. Borehole logs for this unit typically encountered gray to brown, fine to coarse sand with varying amounts of gravel, silt and clay. It is usually loose and unconsolidated.

Colluvial deposits (Qc)

Colluvium, also known as slope wash, occurs in small drainages, upstream portions of major drainages and bottom portions of slopes. It interfingers and is gradational with other alluvial units. Borehole logs within the colluvium indicate it consists of loose to medium dense, gravel, sand, silt and clay. Its composition is highly variable and dependent on adjacent bedrock source.

Marine deposits (Qm)

No borehole logs were collected for this unit within the San Juan Capistrano Quadrangle. Borehole data from the adjacent Dana Point Quadrangle indicate that the active or recently active beach deposits are composed of loose unconsolidated sand.

Artificial fill (af)

This unit consists of materials resulting from grading and construction activities. Subsurface data collected within this unit show this material to be variable from site to site. Artificial fill areas large enough to show at the scale of mapping consist of engineered fill for elevated freeways and small reservoir dams. Since these fills are generally considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata.

GROUND-WATER CONDITIONS

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

Ground-water conditions were investigated in the San Juan Capistrano Quadrangle to evaluate the depth to saturated materials. Saturated conditions reduce the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on first-encountered water noted in geotechnical borehole logs acquired from geotechnical boreholes and water-well logs. The depths to first-encountered unconfined ground water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water. Water depths from boreholes known to penetrate confined aquifers were not utilized.

Shallow and near surface water levels were well documented throughout the floodplain area of San Juan Creek, Oso Creek, and Aliso Creek. Due to limited records of water levels for the smaller drainages and canyon areas the historically highest ground water was taken to be the highest measurement encountered for a drainage and then applied to the extent of the drainage. This is considered a reasonable assumption for seasonal rises in ground-water level. The assumed historical high ground-water levels used for this evaluation are shown on Plate 1.2.

PART II

LIQUEFACTION HAZARD POTENTIAL

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

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

LIQUEFACTION SUSCEPTIBILITY

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

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

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

Geologic Map Unit	Sediment Type	Consistency	Susceptible to Liquefaction?*
Qvom	sand, silty sand	weakly cemented	no
Qvoa	gravel, silty sand, silt, clay	medium to very dense	no
Qvof	silty sand, clayey sand, silt, clay	loose to very dense	not likely
Qom	sand, silty sand	medium to very dense	not likely
Qoa	gravel, sand, silt, clay	medium to very dense	not likely
Qya	gravel, sand, silt, clay	loose to medium dense	yes
Qw	gravel, sand	loose	yes
Qc	gravel, sand, silt, clay	loose to medium dense	yes
Qm	sand	loose	yes

Table 1. 2. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Sedimentary Units (*when saturated).

LIQUEFACTION OPPORTUNITY

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

For the San Juan Capistrano Quadrangle, a peak acceleration of 0.31 to 0.36 g resulting from an earthquake of magnitude 6.8 to 6.9 was used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion portion (Section 3) of this report for further details.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, DMG's analysis uses the Idriss magnitude scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures. The DMG liquefaction analysis program calculates an FS for each geotechnical sample for which blow counts were collected. Typically, multiple samples are collected for each borehole. The lowest FS in each borehole is used for that location. FS values vary in reliability according to the quality of the geotechnical data used in their calculation. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

Of the 353 geotechnical borehole logs selected for this study (Plate 1.2), 325 include blow-count data from SPT's or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 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.

LIQUEFACTION ZONES

Criteria for Zoning

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

1. Areas known to have experienced liquefaction during historical earthquakes

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

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

4. Areas where existing geotechnical data are insufficient

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

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

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

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

Application of SMGB criteria to liquefaction zoning in the San Juan Capistrano Quadrangle is summarized below.

Areas of Past Liquefaction

The City of Laguna Niguel's General Plan Draft Seismic/Safety Element (The Planning Center, 1992) noted that small areas of ground failures from liquefaction have been found during development projects. Specific locations, type(s) of ground failure or reasons why these ground failures are attributed to liquefaction were not identified. Aside from the above-mentioned suggestion there are no areas of historic or paleoseismic liquefaction documented in the San Juan Capistrano Quadrangle.

Artificial Fills

In the San Juan Capistrano Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for elevated freeways and small reservoir dams. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data were evaluated for zoning based on the liquefaction potential determined by the Seed-Idriss Simplified Procedure. In Holocene alluvial deposits most of the borehole logs that were analyzed using the Seed-Idriss Simplified Procedure contain sediment layers that may liquefy under the expected earthquake loading.

Areas with Insufficient Existing Geotechnical Data

Younger alluvium deposited in stream channel areas generally lacks adequate geotechnical borehole information. The soil characteristics and ground-water conditions in these deposits are assumed to be similar to deposits where subsurface information is available. The stream channel deposits, therefore, are included in the liquefaction zone for reasons presented in criteria item 4a above.

There are two areas within the liquefaction zone at the border of the adjacent Laguna Beach Quadrangle that do no extend into the San Juan Capistrano Quadrangle. No borehole data were available for these colluvium covered areas. In the San Juan Capistrano Quadrangle colluvium on bedrock slopes is generally not considered susceptible to liquefaction because borehole logs indicate that it is clayey, thin, and unsaturated. Revisions will be considered before the next release of the Laguna Beach Quadrangle Seismic Hazard Zone Map.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the San Juan Capistrano 7.5-Minute Quadrangle, Orange County, California

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PURPOSE

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

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the San Juan Capistrano 7.5-minute Quadrangle. This section, along with Section 1 (addressing liquefaction), and Section 3 (addressing earthquake shaking), form a report that is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet web page: http://www.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 San Juan Capistrano Quadrangle.

METHODS SUMMARY

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

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

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

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

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

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a DMG pilot study (McCrink and Real, 1996) 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 San Juan Capistrano 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 San Juan Capistrano 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 San Juan Capistrano Quadrangle covers an area of about 62-square-miles in southeastern Orange County. It lies at the northwestern edge of the Peninsular Ranges geomorphic province. It includes the hilly, locally rugged terrane of the San Joaquin Hills and southwestern foothills of the Santa Ana Mountains. The hills are cut by numerous canyons, most of which drain to the south toward the Pacific Ocean. The largest drainages include Arroyo Trabuco, Oso Creek, Horno Creek, San Juan Creek, Aliso Creek, Arroyo Salada, Sulphur Creek, and Salt Creek. A small portion of the northwestern part of the quadrangle drains to the north toward San Diego Creek. Elevations range from sea level to 1000 feet in the northeastern portion of the quadrangle. The top of Niguel Hill, approximately one mile from the ocean, is 936 feet above sea level.

Within the last 30 years there has been significant urbanization within the San Juan Capistrano Quadrangle. The quadrangle includes all or parts of the cities and communities of Lake Forest, Irvine, Aliso Viejo, Laguna Woods, Laguna Hills, Laguna Niguel, South Laguna, Laguna Beach, San Juan Capistrano, Mission Viejo, Tustin, and Rancho Santa Margarita as well as unincorporated areas of the county. Portions of O'Neill, Salt Creek and Aliso and Woods Canyons regional parks are in the northeast, south, and southwest portions of the quadrangle, respectively. The major transportation routes through the quadrangle include the San Diego Freeway (I-5), the San Joaquin Hills Transportation Corridor, Ortega Highway (State Highway 74), and a small segment of Pacific Coast Highway (State Highway 1). These are supplemented by El Toro Road, Moulton Parkway, La Paz Road, Oso Parkway, Alicia Parkway, Crown Valley Parkway, Marguerite Parkway, and Street of the Golden Lantern.

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 San Juan Capistrano 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 1968 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

Areas that have undergone large-scale grading since 1968 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 1998, with an estimated vertical accuracy of approximately 2 meters (Intermap Corporation, 2000). An interferometric radar DEM is prone to creating false topography where tall buildings, metal structures, or trees are present. Due to the low-lying chaparral vegetation and relatively small-structure/residential construction types present, this type of DEM is appropriate for use in the San Juan Capistrano Quadrangle. Nevertheless, the final hazard zone map was checked for potential errors of this sort and corrected.

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

GEOLOGY

Bedrock and Surficial Geology

The bedrock geologic map for the San Juan Capistrano Quadrangle was digitized by the Southern California Areal Mapping Project [SCAMP](2000) from DMG 1:12,000-scale mapping by Morton and others (1974). The digital bedrock geologic map was modified during this project to reflect field observations and the most recent mapping in the area. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to the development and abundance of slope failures was noted.

DMG geologists merged the bedrock and surficial geologic map databases, and made adjustments to contacts between bedrock and surficial units to resolve differences. Geologic reconnaissance was performed to assist in adjusting contacts, to review the geologic unit lithology and the geologic structure.

Bedrock of the San Juan Capistrano Quadrangle consists of the following Tertiary formations from oldest to youngest: Sespe, Vaqueros, Topanga, San Onofre Breccia, Monterey, Capistrano, and Niguel formations.

The late Eocene (?) to early Miocene Sespe Formation (map symbol Ts) crops out only in the northwestern corner and northeastern fringes of the quadrangle. It consists of non-marine medium to coarse-grained arkosic sandstone and minor beds of conglomeratic sandstone and mudstone that are reddish to very pale-orange, poorly bedded and generally dip homoclinally to the east. The early Miocene Vaqueros Formation (Tv) which overlies and apparently interfingers with the Sespe Formation is composed of marine arkosic sandstone with siltstone and shale interbeds. It occurs in the northwest and extreme northeast corners of the quadrangle.

Unconformably overlying the Vaqueros Formation is the Topanga Formation (Tt) of middle Miocene age. The Tt is made up of marine fine silty sandstone, locally conglomeratic, interbedded brownish and olive-gray siltstone (Tt-slt) and interbedded sandstone and siltstone (Tt-ss, slt). It crops out on the northeastern corner and west-southwestern portions of the quadrangle. The middle Miocene San Onofre Breccia (Tso) consists of marine, locally non-marine reddish-brown, greenish-gray and bluish-gray sandy to clayey breccia and sandstone (Tso-ss), siltstone (Tso-slt), conglomerate, and minor light-gray to white diatomaceous shale and tuff (Tso-d). It unconformably overlies and locally interfingers with Topanga Formation. These massive to poorly bedded sediments are exposed on the southwestern and extreme northeastern corners of the quadrangle.

Extensively exposed on the west and southeast portions of the area is the late Miocene Monterey Formation (Tm). The Tm unconformably overlies the older formations and is probably locally conformable on San Onofre Breccia. It is composed of marine white to yellowish-gray, siliceous shale and siltstone, minor sandstone (Tm-ss), sandy limestone (Tm-ls), and discordant travertine-limestone (Tm-tls) near the base. The late Miocene to early Pliocene Capistrano Formation (Tc) unconformably overlies the Monterey Formation west of Oso Creek but appears to be gradational in most areas. The Tc consists of marine yellow-gray to light brownish-gray siltstone with interbedded fine-grained sandstone, basal calcareous sandstone (Tc-ss), and sandstone and breccia (Tc-ss+bc). It becomes richer in sand in northeastern exposures where it grades into the Oso Member (Tco). The Pliocene Niguel Formation (Tn) lies with angular unconformity on Capistrano and Monterey formations. It occupies the central portion of the quadrangle and consists of marine white to very-light-gray fine to coarse-grained sandstone with interbedded yellow-gray siltstone (Tn-slt), basal reddish-brown conglomerate (Tnc) and light-gray to reddish-brown breccia.

Pleistocene to Holocene surficial units unconformably overlie the bedrock units. The oldest of these units consist of flat-lying nonmarine and marine terrace deposits (Qvom, Qom, Qvoa, Qoa) and alluvial fan deposits (Qvof). The remaining younger alluvial units consist of stream channel deposits (Qya, Qw), slope wash and colluvial debris (Qc), beach sediment (Qm), landslide debris, and artificial fill materials (af). A detailed discussion of Quaternary units can be found in Section 1.

Structural Geology

The pre-Pliocene sedimentary sequence is gently folded into a broad north-trending syncline whose axis approximately occupies the central portion of the quadrangle. Here the late Miocene to early Pliocene Capistrano Formation is extensively exposed. The east and west limbs of the syncline are underlain by successively older Monterey, San Onofre Breccia, Topanga, Vaqueros, and Sespe formation rocks. The flat lying to gently dipping late Pliocene Niguel Formation, which postdates the synclinal structure, unconformably overlies and caps the older formations.

Several large faults transect the east and west margins of the quadrangle. The most notable are the Cristianitos, Laguna Canyon, Shady Canyon and the Temple Hill faults. The north- and northwest-trending Cristianitos Fault Zone is a regional structural feature that crosses the eastern margin of the quadrangle. It consists of a complex system of anastomosing shears with two principal branches, the west and the main branch. Both branches are vertical to steeply west dipping normal faults with the east blocks uplifted relative to the west blocks. The Laguna Canyon Fault Zone strikes north-northwesterly and occurs in the southwestern corner of the quadrangle. It consists of two principal, nearly parallel normal faults with moderate to steep westerly dips. The Shady Canyon Fault extends northwesterly for six miles through the northeast block of the San Joaquin Hills and the northeast side appears to have been uplifted. The Temple Hill Fault, an east-west trending fault, apparently displaces the Laguna Canyon Fault Zone. It dips from about 60 degrees south to nearly vertical and the northern block appears to have been displaced upward relative to the southern block.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the San Juan Capistrano Quadrangle was prepared by field reconnaissance, analysis of stereopaired aerial photographs and a review of previously published landslide mapping (Morton and others, 1974). 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.

In general, landslides are abundant in areas underlain by shale and siltstone bedrock materials. The bedrock units most susceptible to landsliding are the Capistrano (Tc) and Monterey (Tm) formations. There also appears to be a correlation between landslide density and dip slope within the Topanga (Tt) Formation.

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. For the San Juan Capistrano Quadrangle shear strength data for rock units identified on the geologic map were obtained from the Orange County Office of Planning and Development Services, and the DMG Environmental Review Program's files (Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1. Shear tests from the adjacent Laguna Beach, Dana Point, and Canada Gobernadora quadrangles were used to augment data for several geologic formations that had little or no shear test information available in the San Juan Capistrano Quadrangle.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean and median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1.

For most of the geologic strength groups in the map area, a single shear strength value was assigned and used in our slope stability analysis. The mappable geologic subunits of the Tt, Tso, Tm, Tc, and Tn formations were grouped together for the statistical analysis because of the lack of data to separate the subunits from the undifferentiated formations. Where there were shear strength values for these subunits, they were too few to determine whether they were different from the rest of the formation. A geologic material strength map was made based on the groupings presented in Tables 2.1 and 2.2 and it provides a spatial representation of material strength for use in the slope stability analysis.

Four map units, Tt, Tv, Ts, and Tn, were subdivided further, as discussed below.

Adverse Bedding Conditions

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

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

The Tt, Tv, Ts, and Tn formations, which are generally composed of sandstone with interbeds of siltstone, shale, or mudstone, were subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material (higher strength) dominates where bedding dips into a slope (favorable bedding) while fine-grained (lower strength) material dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. The favorable and adverse bedding shear strength parameters for Tt, Tv, Ts, and Tn are included in Table 2.1.

Adverse bedding conditions were not considered for the Tc and Tm because they are composed predominantly of siltstone and shale. Over 90% of the test samples tallied for these formations, within and in areas around the San Juan Capistrano Quadrangle, were of a fine-grained nature and, therefore, low shear strength values were used throughout the map area.

Existing Landslides

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

SAN JUAN CAPISTRANO QUADRANGLE
SHEAR STRENGTH GROUPS

	Formation Name	Number Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1	Ts(fbc)	32	38/38	38/38	66/0		38
GROUP 2						Tt(fbc)	34*
GROUP 3	Tn(fbc)	16	31/32	31/31	216/100	Tv(fbc)	31
	Qya	47	31/31			Tso	
	af	23	31/29			ac, afc	
GROUP 4	Ts(abc)	16	28/27	26/26	521/430	Tt(abc)	26
	Tc	62	26/26			Qvoa	
	Tn(abc)	15	26/26			Qvom, Qoa	
	Qvof	4	27/26			Qom, Qm	
GROUP 5	Tm	26	23/24	23/25	810/595	Tv(abc)	23
	Qc	14	22/25				
GROUP 6	Qls	8	15/14	15/14	456/460		15

Formational Subunits on Map Combined in Analysis

Tt = Tt; Tt-slt; and Tt-ss,slt
Tso = Tso; Tso-d; Tso-slt; and Tso-ss
Tm = Tm; Tm-ls; Tm-ls,ss; Tm-ss; Tm-ss,ls; and Tm-tls
Tc = Tc; Tc-ss; Tc-ss+bc; and Tco
Tn = Tn; Tnc; and Tn-slt

* = indicates that the shear strength value was assumed based on data from surrounding quadrangles
abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength

Table 2.1. Summary of the Shear Strength Statistics for the San Juan Capistrano Quadrangle.

SHEAR STRENGTH GROUPS FOR THE SAN JUAN CAPISTRANO 7.5-MINUTE QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6
Ts(fbc)	Tt(fbc)	Tv(fbc)	Ts(abc)	Tv(abc)	Qls
Ts?(fbc)	Tt-slt(fbc)	Tso	Ts?(abc)	Tm	
	Tt-ss,slt(fbc)	Tso?	Tt(abc)	Tm?	
		Tso-d	Tt-slt(abc)	Tm-ls	
		Tso-slt	Tt-ss,slt(abc)	Tm-ls,ss	
		Tso-ss	Tc,Tco,Tco?	Tm-ss	
		Tn(fbc)	Tc-ss	Tm-ss,ls	
		Tnc(fbc)	Tc-ss+bc	Tm-tls	
		Tn-slt(fbc)	Tn(abc)	Qc	
		Qya	Tnc(abc)		
		af	Tn-slt(abc)		
		afc	Qvoa,Qvof		
		ac	Qoa,Qom		
			Qvom		
			Qvom?		
			Qm		

Table 2.2. Summary of Shear Strength Groups for the San Juan Capistrano 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 San Juan Capistrano Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.8 to 6.9
Modal Distance:	5.9 to 27.5 km
PGA:	0.28 to 0.35 g

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

Displacement Calculation

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

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). 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 to the San Juan Capistrano Quadrangle.

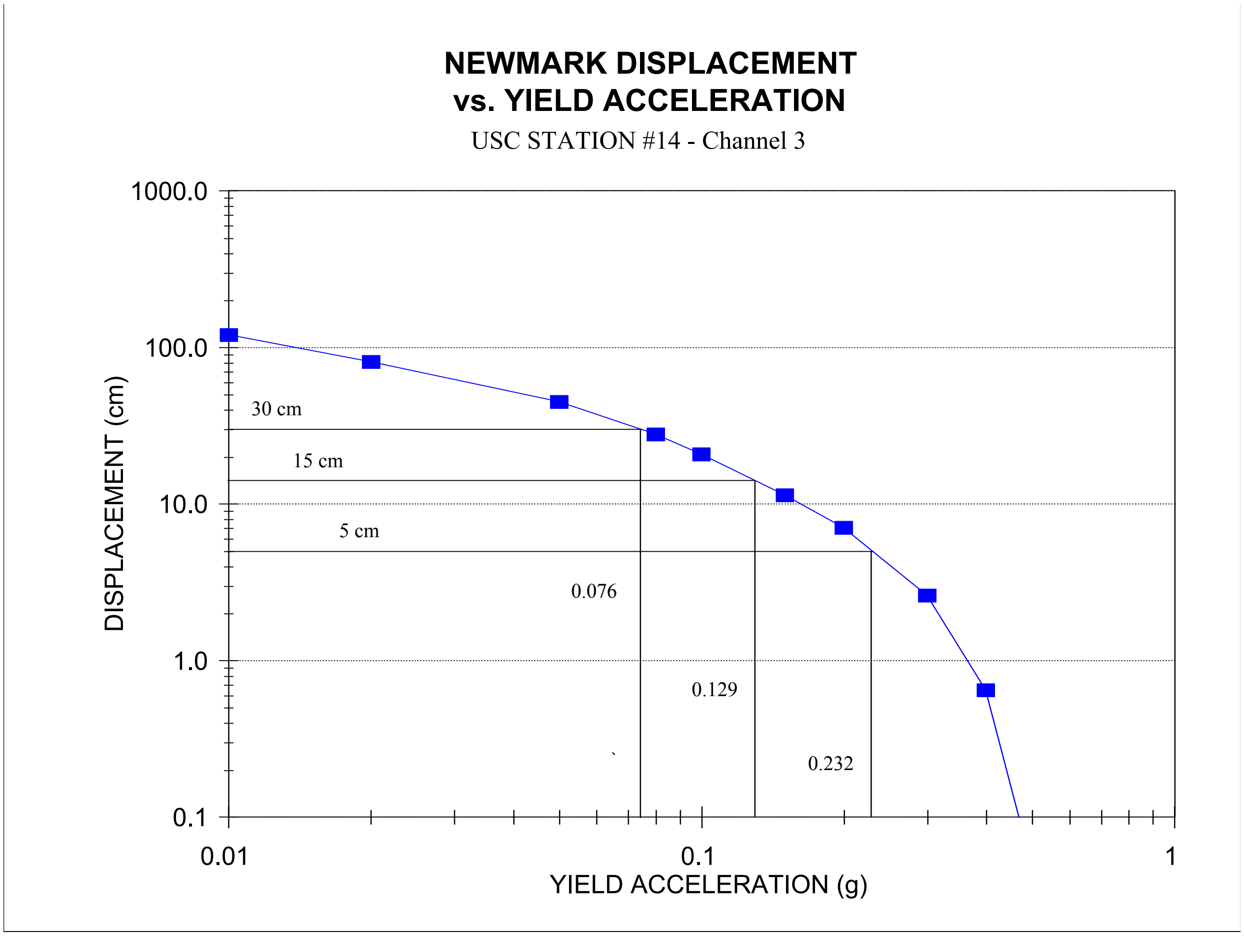

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake.

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.

HAZARD POTENTIAL MATRIX

GEOLOGIC STRENGTH GROUP	MEAN PHI	I 0 to 19%	II 20 to 24%	III 25 to 29%	IV 30 to 35%	V 36 to 42%	VI 43 to 47%	VII 48 to 53%	VIII 54 to 62%	IX 63 to 70%	X >71%
		SLOPE CATEGORY (% SLOPE)									
1	38	VL	VL	VL	VL	VL	VL	VL	L	M	H
2	34	VL	VL	VL	VL	VL	L	L	M	H	H
3	31	VL	VL	VL	VL	L	L	M	H	H	H
4	26	VL	VL	L	L	M	H	H	H	H	H
5	23	VL	L	L	M	H	H	H	H	H	H
6	15	M	H	H	H	H	H	H	H	H	H

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

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

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

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

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

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

Existing Landslides

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

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by DMG (McCrink and Real, 1996), 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 6 is included for all slope gradient categories. (Note: Geologic Strength Group 6 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 5 is included for all slopes steeper than 19 percent.

3. Geologic Strength Group 4 is included for all slopes steeper than 24 percent.

4. Geologic Strength Group 3 is included for all slopes steeper than 35 percent.

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

6. Geologic Strength Group 1 is included for all slopes greater than 53 percent.

The resulting earthquake-induced landslide zones encompass 35 percent of the land area of the San Juan Capistrano Quadrangle.

ACKNOWLEDGMENTS

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AIR PHOTOS

Orange County Planning Department, E.L.Pearsons & Associates/Robert J. Lung & Associates July/August 1970 Aerial Photographs, flight 32, frames 15-18, flight 33, frames 16-23, flight 34, frames 15-24, flight 35, frames 14-28, flight 36, frames 12-27, flight 37, frames 11-24, flight 38, frames 12-21, flight 39, frames 13-20, flight 40, frames 17-21, black and white, vertical, approximate scale 1:14000.

APPENDIX A

SOURCES OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Orange County Planning and Development Services	232
DMG Environmental Review Documents	31
TOTAL	**263**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the San Juan Capistrano 7.5-Minute Quadrangle, Orange County, California

By

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

PURPOSE

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

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

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

EARTHQUAKE HAZARD MODEL

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

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

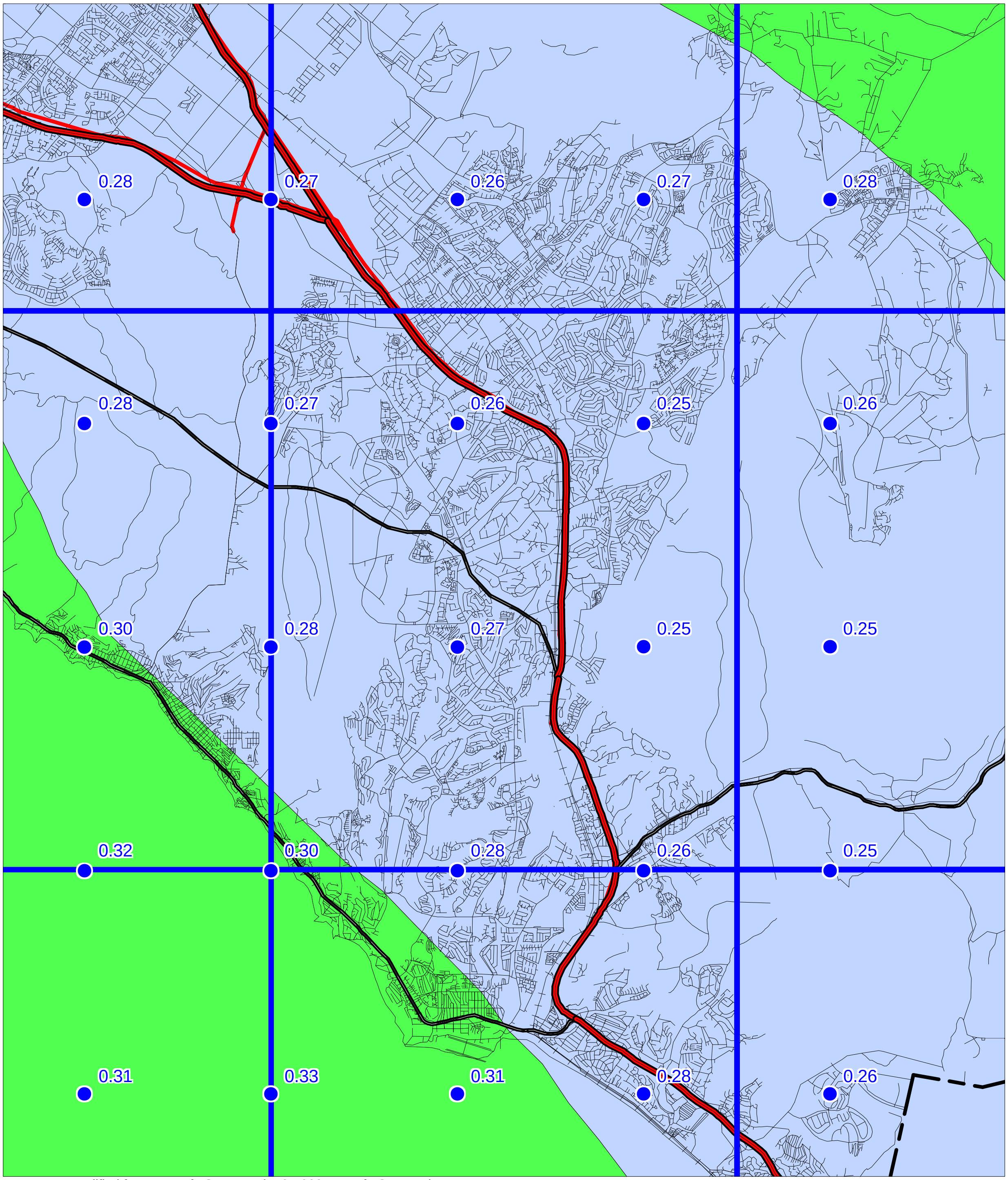
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

SAN JUAN CAPISTRANO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



0 1.5 3
Miles

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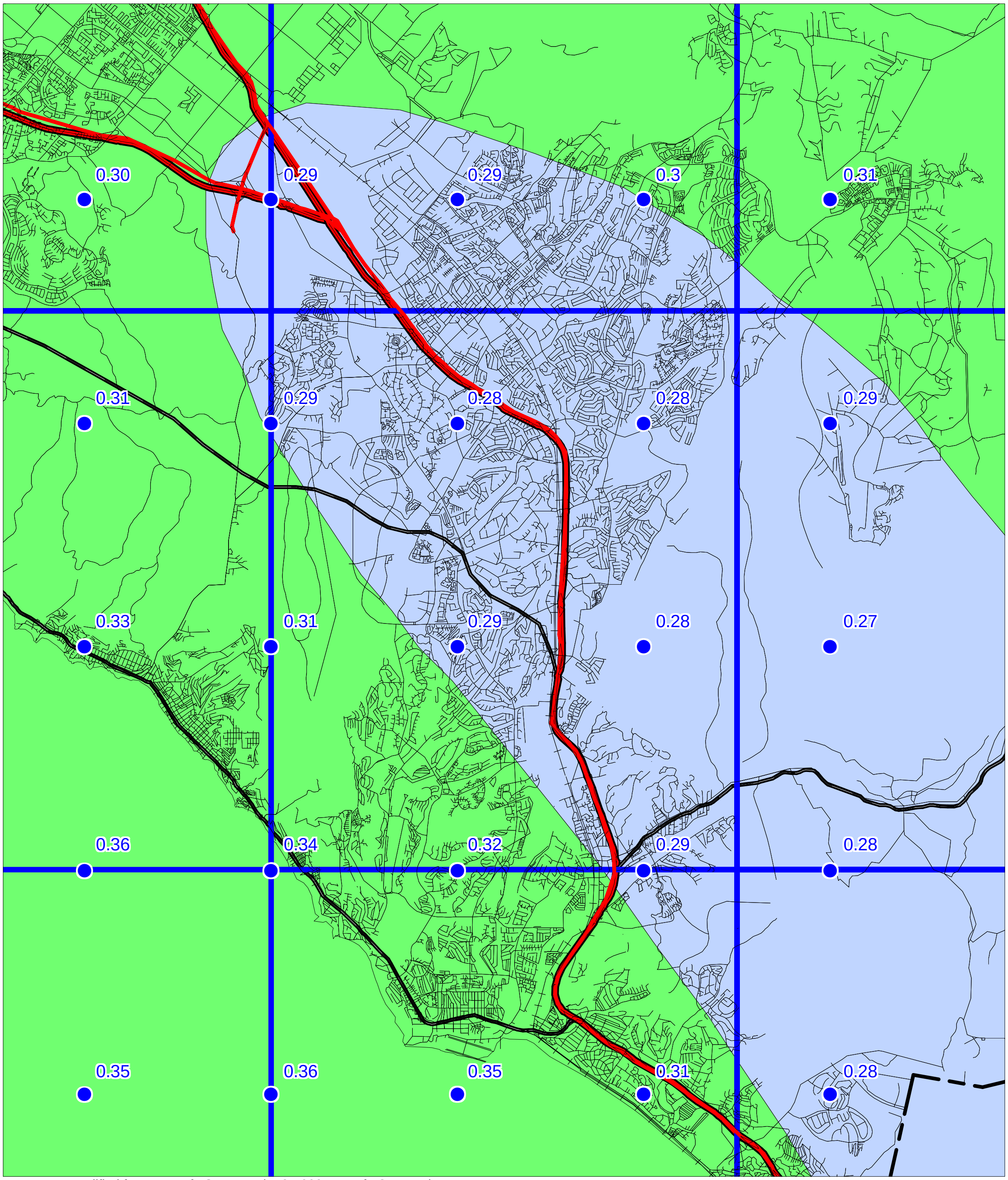
Figure 3.1

SAN JUAN CAPISTRANO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

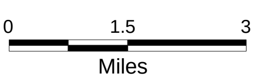


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Figure 3.2

SAN JUAN CAPISTRANO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS

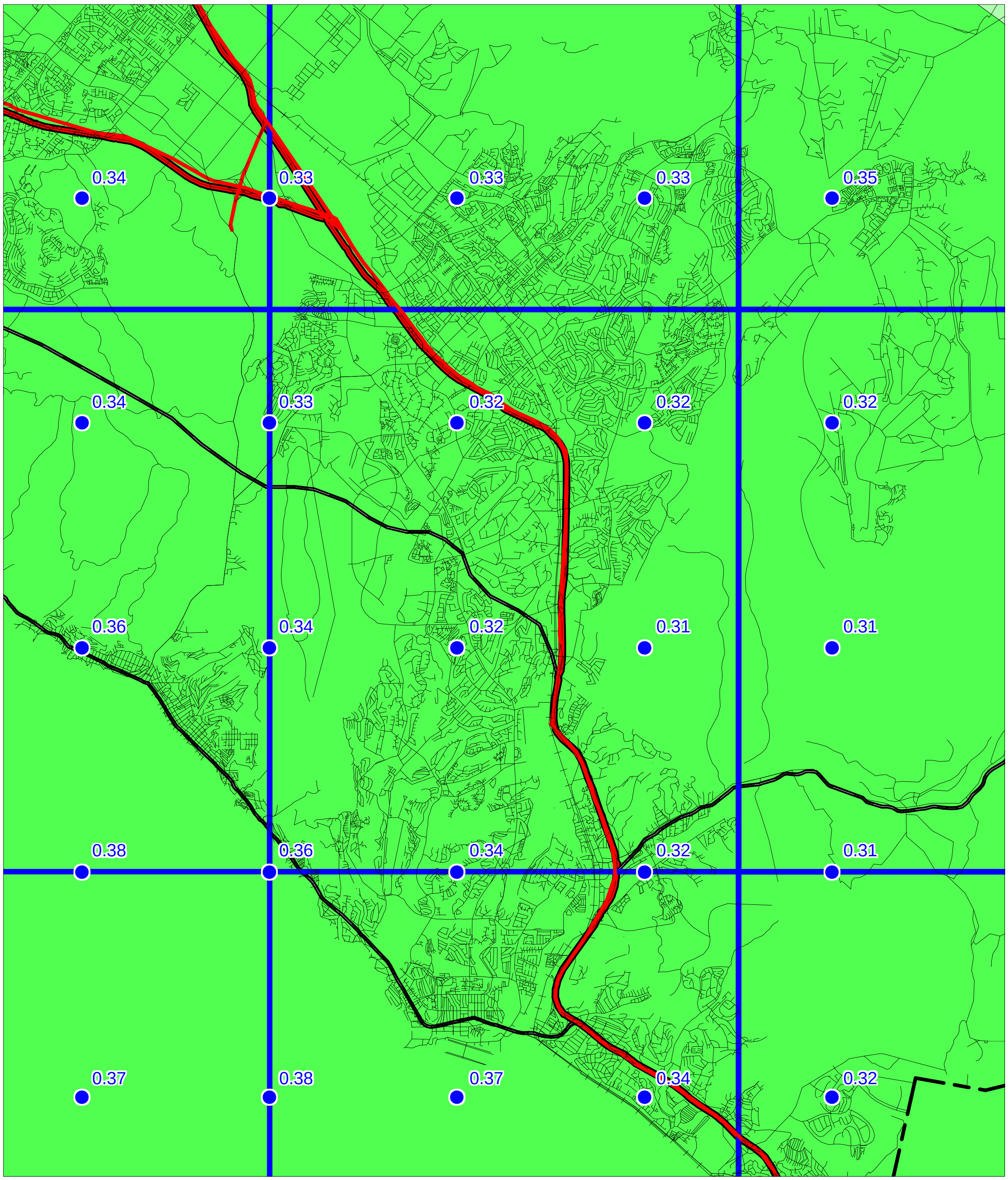

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Figure 3.3

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.

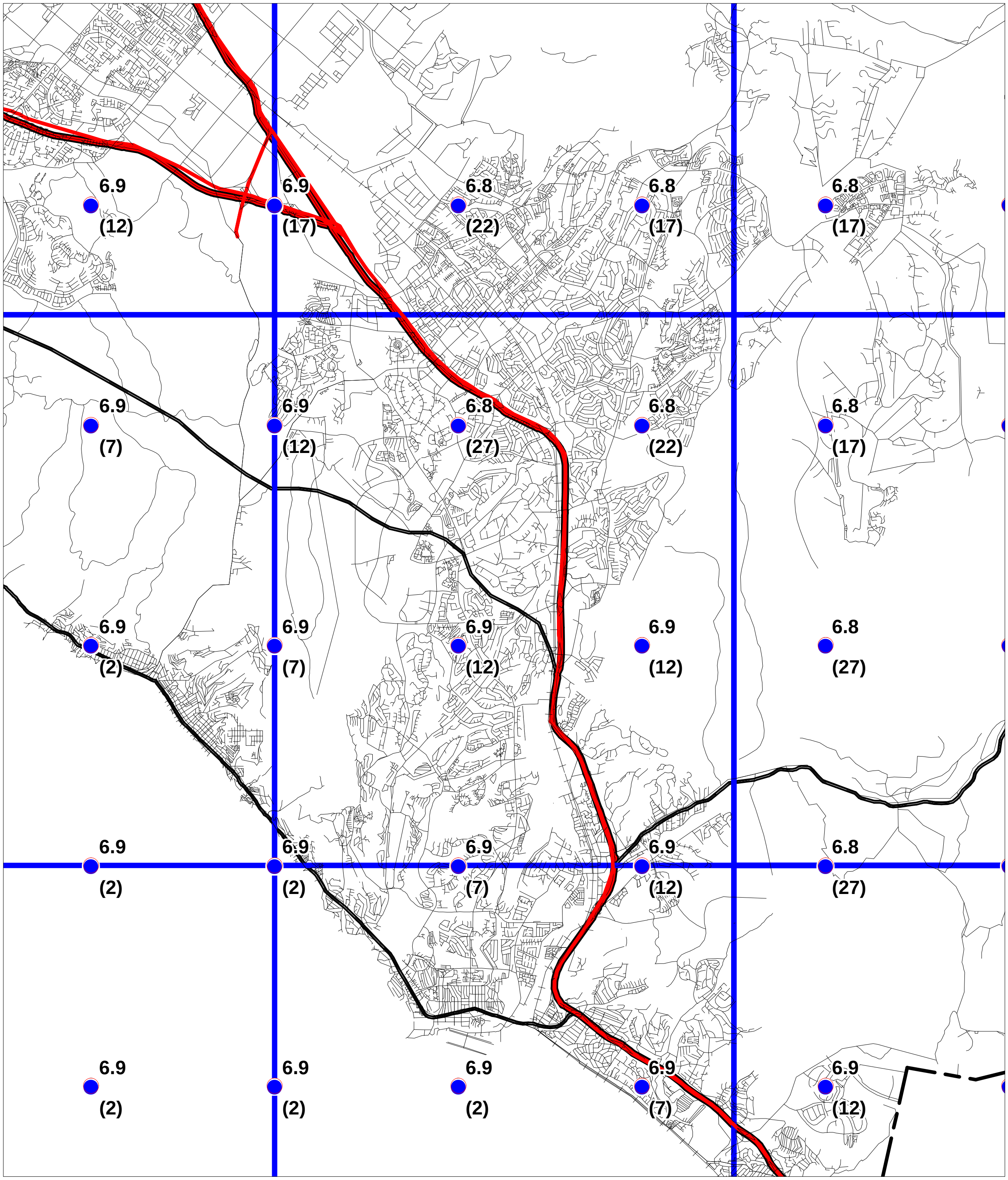
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss' weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

SAN JUAN CAPISTRANO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

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



0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

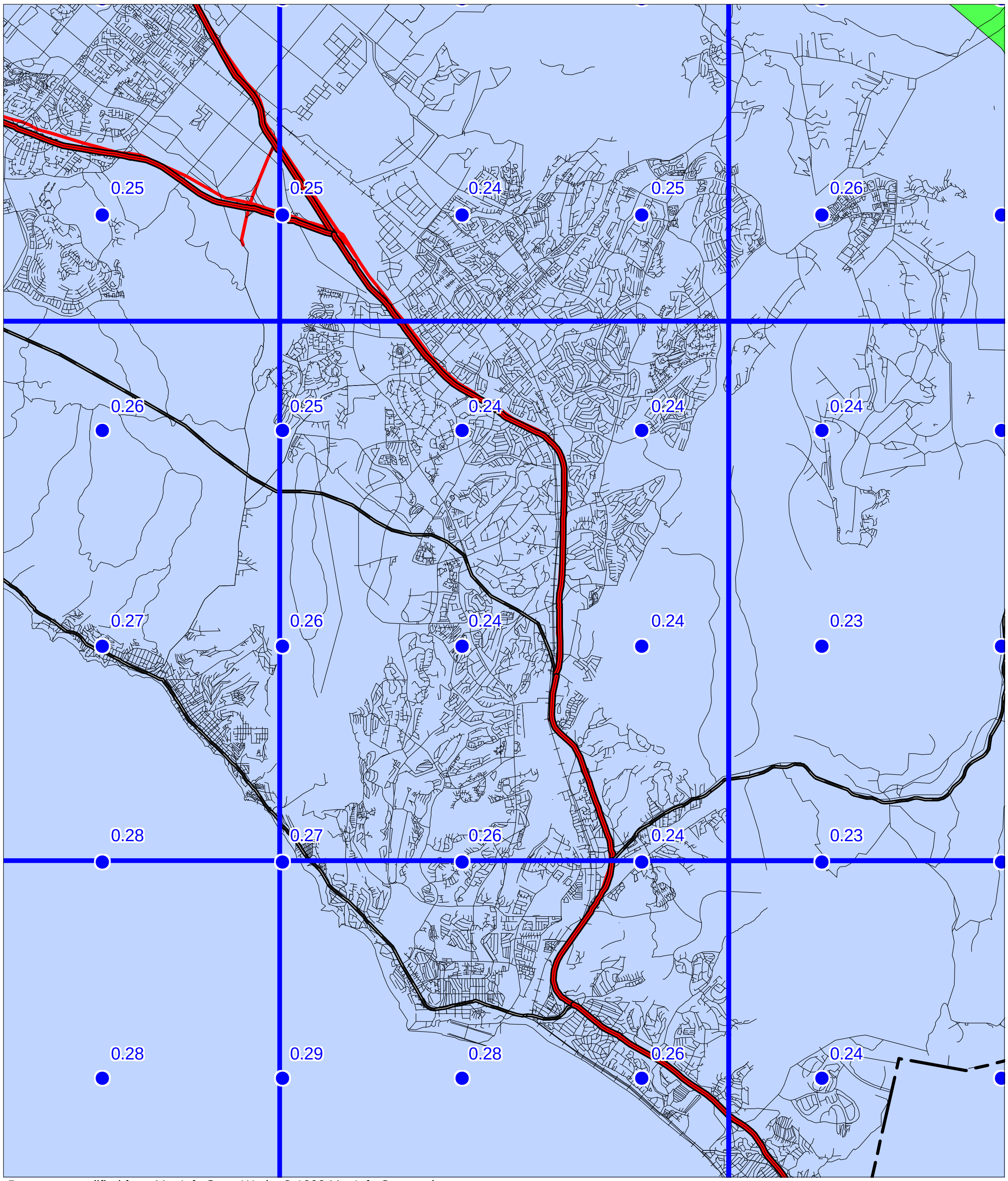
Figure 3.4

SAN JUAN CAPISTRANO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

2001

LIQUEFACTION OPPORTUNITY



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

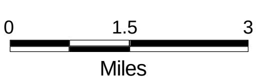


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Figure 3.5

USE AND LIMITATIONS

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

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

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

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

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

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

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

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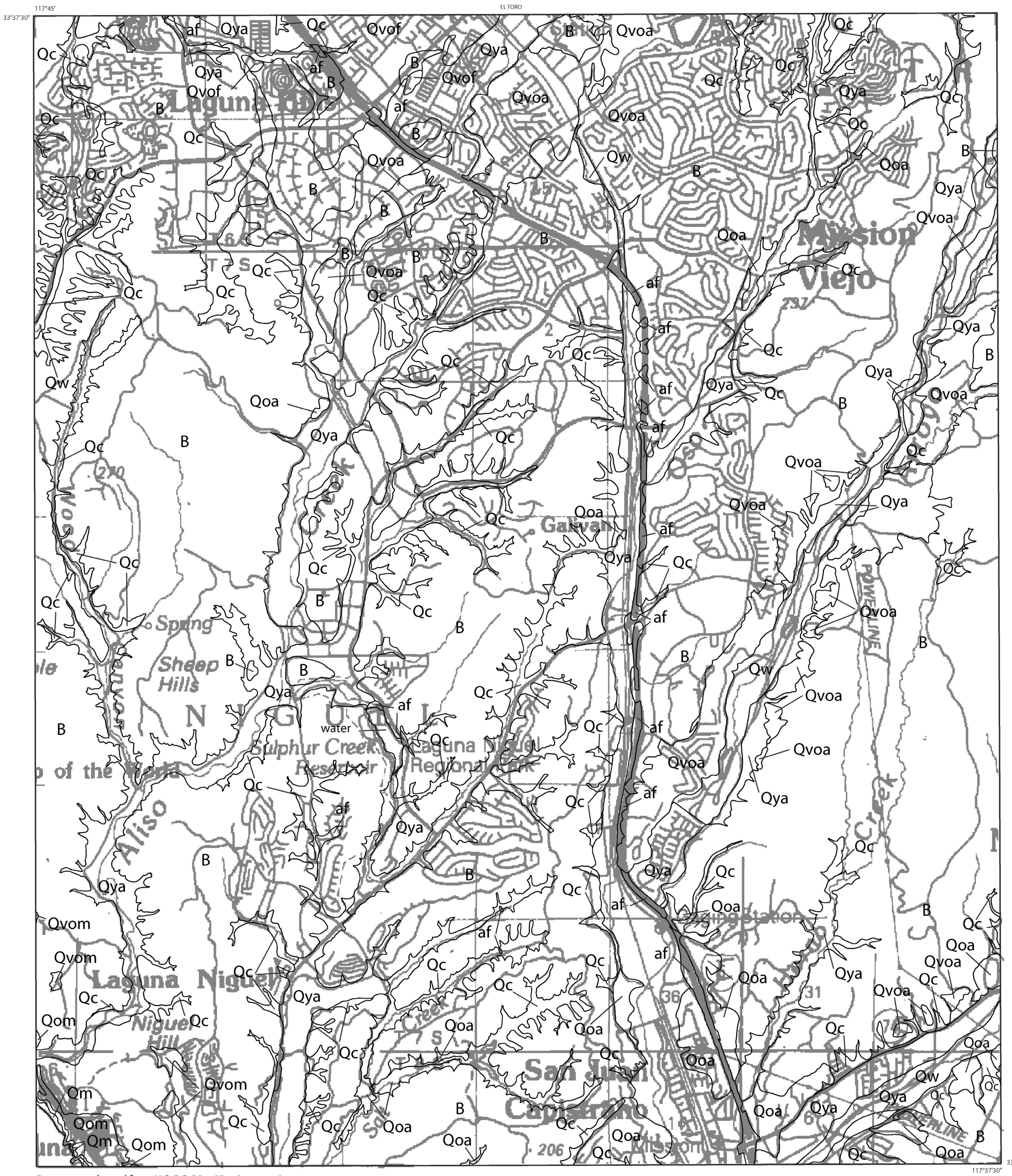

Base map enlarged from U.S.G.S. 30 x 60-minute series

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SCALE

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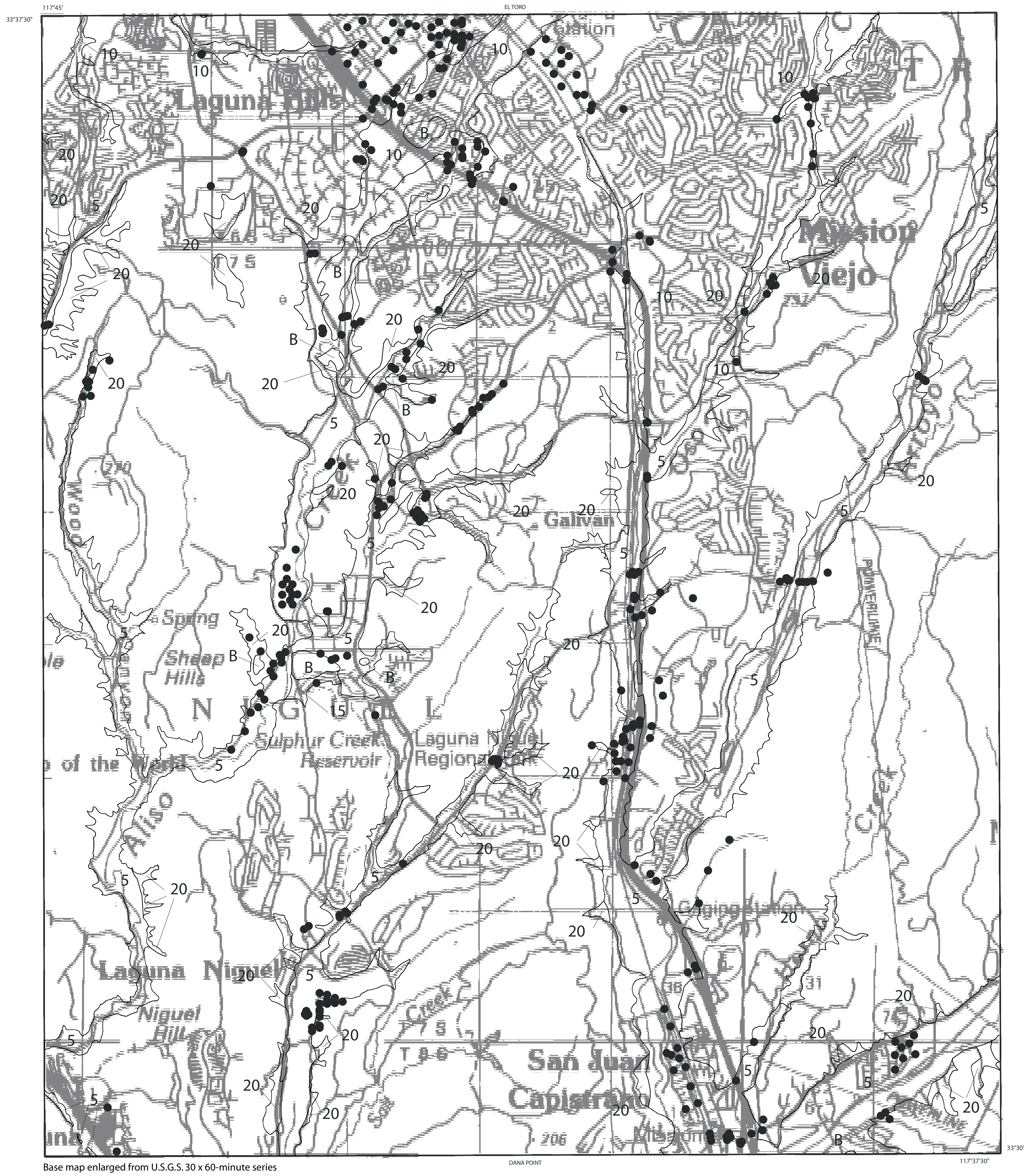
Lithologic contact

B = Pre-Quarternary bedrock.
See Geologic Conditions section in report for descriptions of the units.

Plate 1.1 Quaternary geologic map of the San Juan Capistrano 7.5-minute Quadrangle, California (modified from Morton and others, 1974).



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

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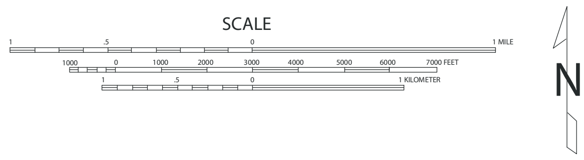
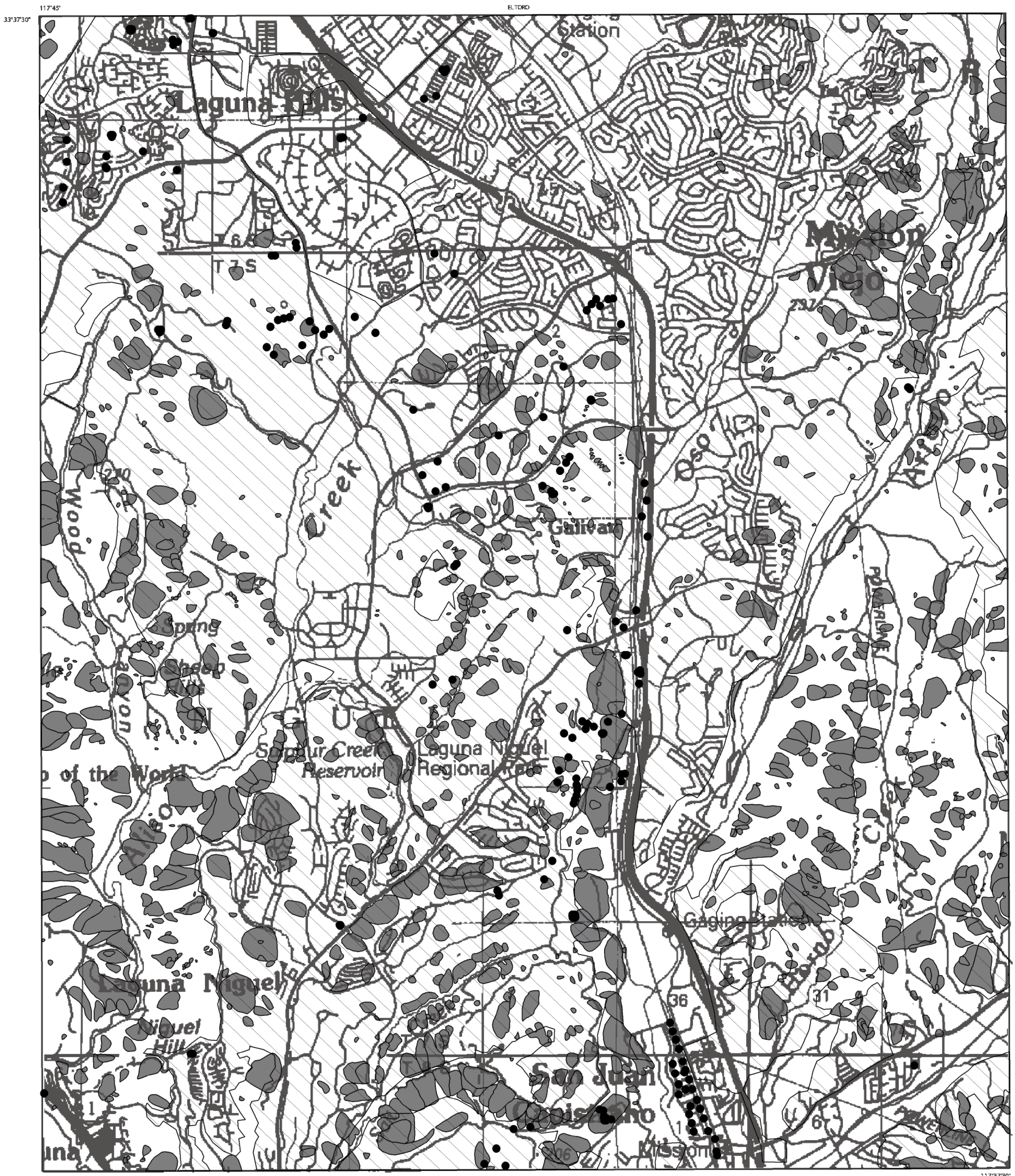


20 Depth to groundwater (in feet)

B = Pre-Quarternary bedrock. See Geologic Conditions section in report for descriptions of the units.

● Geotechnical bore holes used in liquefaction evaluation

Plate 1.2 Depth to historically high ground water, and borehole locations, San Juan Capistrano 7.5-minute Quadrangle, California.



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

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Landslide Inventory

● Shear Test Sample Locations

Areas of significant grading

Plate 2.1 Landslide Inventory, Shear Test sample locations, San Juan Capistrano 7.5-minute Quadrangle.