SEISMIC HAZARD ZONE REPORT 013

SEISMIC HAZARD ZONE REPORT FOR THE LAGUNA BEACH 7.5-MINUTE QUADRANGLE, ORANGE COUNTY, CALIFORNIA

1997 (Revised 2001)

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

STATE OF CALIFORNIA
GRAY DAVIS
GOVERNOR

THE RESOURCES AGENCY
MARY D. NICHOLS
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
DARRYL YOUNG
DIRECTOR

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, *STATE GEOLOGIST*

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Laguna Beach 7.5-minute Quadrangle, Orange County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over the onshore portion of the quadrangle (approximately 34 square miles) at a scale of 1 inch = 2,000 feet.

The Laguna Beach Quadrangle includes nearly the entire City of Laguna Beach and portions of the cities of Corona Del Mar, Newport Beach, and Irvine. The rest of the quadrangle consists of undeveloped, unincorporated Orange County land and large areas of parkland, including Crystal Cove State Park, Laguna Coast Wilderness Park, and a part of the Aliso/Wood Canyons Regional Park. The quadrangle is dominated by hilly, locally rugged, terrain of the San Joaquin Hills that is dissected by numerous canyons. Within one-half mile of the coastline, from Corona Del Mar to downtown Laguna Beach, the gently southwest-sloping marine terrace surface has been heavily urbanized. Development has also spread into the San Joaquin Hills at Newport Beach, up the steep hillsides that face the ocean at Laguna Beach, and in Laguna Canyon. Elevations range from sea level to 1,164 feet. Access is provided by Pacific Coast Highway (State Highway 1), Laguna Canyon Road (State Highway 133) along the eastern boundary, and the San Joaquin Hills Transportation Corridor (toll road) in the northern 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 Laguna Beach Quadrangle the liquefaction zone is restricted to the bottoms of canyons and the beach. The combination of dissected hills and weak rocks has produced widespread and abundant landslides in the Laguna Beach Quadrangle. These conditions contribute to an earthquake-induced landslide zone that covers about 43% of the onshore part 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.consrv.ca.gov/dmg/shezp/

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

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

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

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp.

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 Laguna Beach 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Laguna Beach 7.5-Minute Quadrangle, Orange County, California

By
Richard B. Greenwood

California Department of Conservation
Division of Mines and Geology

PURPOSE

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

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

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in 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 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 Laguna Beach 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 onshore portion of the Laguna Beach Quadrangle covers an area of about 34 square miles in coastal Orange County. Nearly the entire City of Laguna Beach and portions of the cities of Corona Del Mar, Newport Beach, and Irvine lie within the map area. The remainder of the quadrangle consists of undeveloped, unincorporated Orange County land and large areas of parkland, including Crystal Cove State Park, Laguna Coast Wilderness Park, and a part of the Aliso/Wood Canyons Regional Park.

Topographically, the Laguna Beach Quadrangle is dominated by the hilly, locally rugged terrain of the San Joaquin Hills that is dissected by numerous canyons, many of which drain southwestward to the ocean. Within one-half mile of the coastline, from Corona Del Mar to downtown Laguna Beach, the gently southwest-sloping marine terrace surface has been heavily urbanized. Development has also spread into the northwesternmost San Joaquin Hills at Newport Beach and the steep hillsides that face the ocean above Laguna Beach, as well as along the bottom of Laguna Canyon. Elevations range from sea level to a maximum of 1,164 feet at Signal Peak in the north-central part of the quadrangle. The top of Temple Hill in Laguna Beach, less than two miles from the ocean is 1,036 feet above sea level.

Access to places within the quadrangle is provided by Pacific Coast Highway (State Highway 1) along the coast and by Laguna Canyon Road (State Highway 133) along the eastern boundary of the quadrangle. The San Joaquin Hills Transportation Corridor (toll road) crosses the northern part of the quadrangle. East of Newport Beach local roads include San Joaquin Hills Drive, Newport Coast Drive, and Pelican Hill Road.

GEOLOGY

Regional Geology

The Laguna Beach Quadrangle encompasses the coastal portion of northwestern flank of the Peninsular Ranges of southern California. The quadrangle covers much of the San Joaquin Hills and overlaps the southwestern fringe of the Los Angeles Basin. Prominent localities within the San Joaquin Hills include 716-foot Pelican Hill, near Newport Beach, and 1036-foot Temple Hill, which overlooks the City of Laguna Beach. The upland areas are underlain by a thick sequence of marine and nonmarine Tertiary sedimentary rocks. The lower Tertiary rocks (Paleocene to Oligocene) are located east of the Shady Canyon fault, whereas the upper Tertiary rocks (Miocene and younger) are only exposed west of the fault. Numerous NNW-NNE trending diabase dikes intrude the central and the eastern portions of the quadrangle. Along the coast are Pleistocene wave-cut marine platforms, which are covered by marine deposits. Subsequent erosion of the bordering hilly areas generated a nonmarine colluvial cover that veneers some of these terraces. Alluvium and slope wash deposits occur within the major drainages in some areas.

Surficial Geology

A geologic map for the Laguna Beach Quadrangle was compiled and digitized by the Southern California Areal Mapping Project (SCAMP, 1995) from original mapping by Yerkes and others (1965). It was extensively modified in accordance with the 1:12,000-scale mapping of Tan and Edginton (1976), as compiled by Greenwood and Morton (1990). Pleistocene marine terrace deposits were updated using recent mapping of Kern (unpublished). The revised geologic map that was used in this study of liquefaction susceptibility is included as Plate 1.1.

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. The oldest Quaternary geologic unit mapped in the Laguna Beach Quadrangle consists of mid to upper Pleistocene terrace deposits (Qtm). Most of these deposits are marine sand and silty sand exposed in isolated ridgetop occurrences, approximately two miles inland from the present coastline.

Late Pleistocene marine sediments (Qvom, and Qvom+aa) are found in the westernmost part of the San Joaquin Hills. These deposits are composed of medium- to coarse-grained sand (Qvom+aa) and silty sand with fine to coarse-grained sand.

Younger alluvium (Qyaa) is exposed in the bottoms of deeply incised coastal creek and river valleys. It generally consists of coarse sand and gravel with interbedded silt and fine- to medium-grained sand.

Modern beach deposits (Qm), which consist of well-sorted, medium- to coarse-grained sand, form discontinuous beaches in the Laguna Beach Quadrangle.

ENGINEERING GEOLOGY

The geologic units described above were primarily mapped from their surface expression. The subsurface properties are described in over 59 borehole logs in the study area. Subsurface data used for this study include the database compiled by Sprotte and others (1980) and additional data collected for this study. Subsurface data were collected for this study at Caltrans, DMG files of seismic reports for hospital and school sites, the Orange County Health Care Agency, and Leighton and Associates Geotechnical Services. In general, the data gathered for geotechnical studies appear to be complete and consistent. Geotechnical data, particularly SPT blow counts, from environmental studies may sometimes be less reliable, however, due to the use of non-standard equipment and incomplete reporting of procedures.

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 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 $(N_1)_{60}$.

Data from previous databases and additional borehole logs were entered into the DMG GIS database. Locations of all exploratory boreholes considered in this investigation are shown on Plate 1.2. Construction of cross sections from the borehole logs, using the GIS, enabled the correlation of soil types from one borehole to another and the outlining of areas of similar soils.

Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are necessarily generalized, but give the most commonly encountered characteristics of the units (see Table 1.1).

Oldest marine terrace deposits (Qtm) and older marine terrace deposits (Qvoma and Qvoma+aa)

Oldest marine terrace deposits (Qtm) occur as isolated, discontinuous, ridge-top coverings, predominantly in the central and southern Laguna Beach Quadrangle,

approximately one to two miles inland from the coast. The terrace surfaces typically consist of a veneer of dense to very dense sands and silty sands so no extensive effort was made to collect subsurface data.

Older marine terrace deposits (Qvoma and Qvoma+aa) comprise the near-surface materials that make up much of the land underlying the cities of Corona Del Mar and Newport Beach in the northwestern part of the Laguna Beach Quadrangle. The deposits generally consist of dense to very dense sand and silty sand. Relatively looser and damp or wet fine sands and silty sands were observed in sea cliffs.

Younger alluvium (Qyaa)

Younger alluvium in the incised canyons, for this study are called Qyaa, to be consistent with SCAMP nomenclature (Morton and Kennedy, 1989). These deposits consist of soft interbedded sand and gravel and silty sand. They exceed 40 to 50 feet in thickness in Laguna Canyon.

Beach deposits (Qm)

Modern beach deposits are composed of coarse sand and gravelly sand. This deposit is loose to moderately dense. Beach deposits are typically underlain by older Tertiary sedimentary rocks.

Artificial fill (af)

Artificial fill on the Laguna Beach Quadrangle consists of “engineered” fill. Because the engineered fills are too thin to affect the liquefaction hazard, no effort was made to determine their subsurface characteristics.

Geologic Map Unit	Material Type	Consistency	Liquefaction Susceptibility
Qm, beach deposits	Sand, gravelly sand	loose	high
Qyaa, younger alluvium	sand, gravel, silty sand,	loose-moderately dense	high
Qvom, Qvom+aa marine terrace deposits	sand & silty sand	dense-very dense	low
Qtm, older marine terrace deposits	sand & silty sand	dense-very dense	low

Table 1.1. General Geotechnical Characteristics and Liquefaction Susceptibility of Younger Quaternary Units.

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 Laguna Beach 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 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.

PART II

LIQUEFACTION POTENTIAL

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

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

LIQUEFACTION SUSCEPTIBILITY

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

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

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

Older and younger marine terrace deposits (Qtm, Qvom, Qvom+aa)

Older and younger marine terrace deposits are composed of dense to very dense sands and silty sands. Liquefaction susceptibility of these units is low.

Younger alluvium (Qyaa)

Young alluvium in the deeply incised coastal canyons, designated as Qyaa, consist of soft interbedded sand and gravel and silty sand exceeding 40 to 50 feet in thickness in Laguna Canyon. Liquefaction susceptibility of this unit is high.

Beach deposits (Qm)

Beach deposits include loose sand and gravelly sand. Liquefaction susceptibility of this unit is high.

Artificial fill (af)

Artificial fills commonly overlie young alluvial or estuarine deposits. Because the engineered fills are usually too thin to affect the liquefaction hazard, and the underlying estuarine deposits have a high liquefaction susceptibility, they are assumed to have a high susceptibility to liquefaction.

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 Laguna Beach Quadrangle, peak accelerations of 0.35 to 0.40 g resulting from an earthquake of magnitude 6.8 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 further details.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and others, 1985; National Research Council, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (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 factor of safety (FS) relative to liquefaction is: FS=CRR/CSR. 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 related structures. For a regional assessment DMG normally has a range of FS that results from the liquefaction analyses. The DMG liquefaction analysis program calculates an FS at each sample that has blow counts. The lowest FS in each borehole is used for that location. These FS vary in reliability according to the quality of the geotechnical data. These FS as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil are evaluated in order to construct liquefaction potential maps, which then directly translate to Zones of Required Investigation**.**

Of the 59 geotechnical borehole logs reviewed in this study (Plate 1.2), 48 include blow-count data from SPT's or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2 1/2-inch inside diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (soil density, moisture content, sieve analysis, etc) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values or using average test values of similar materials.

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 Laguna Beach Quadrangle is summarized below.

Areas of Past Liquefaction

No areas of past liquefaction occurrences have been documented in the Laguna Beach Quadrangle.

Artificial Fills

In the Laguna Beach Quadrangle artificial fill consists of engineered fill around commercial and residential developments, and along road grades. Engineered fills are generally too thin to have an impact on liquefaction. Areas underlain by engineered fill have not been included in liquefaction hazard zones.

Areas with Sufficient Existing Geotechnical Data

The oldest and older marine terrace deposits (Qtm, Qvoa, Qvoa+aa) exposed in the Laguna Beach Quadrangle generally have a dense consistency and deep ground water was encountered in boreholes in much of the area underlain by these units. Accordingly, these geologic units have not been included in a liquefaction hazard zone. Although looser, wet fine sands and silty sands were observed in sea cliffs, these relatively softer

marine terrace deposits were not zoned as Pleistocene marine terraces are considered to have low susceptibility to liquefaction (Youd and Perkins, 1978).

Younger alluvial deposits (Qyaa) commonly have layers of loose sand and gravel and silty sand. Where these deposits are saturated, they are included in a liquefaction hazard zone

Modern beach deposits are typically loose saturated sand so they are included in liquefaction hazard zones.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Laguna Beach 7.5-Minute Quadrangle, Orange County, California

By
Florante G. Perez, Jack R. McMillan, Rick I. Wilson, and Timothy P. McCrink

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps 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/SHMPsp117.asp).

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Laguna Beach 7.5-minute Quadrangle. This section, along with Section 1 (addressing liquefaction), and Section 3 (addressing earthquake shaking), form a report that is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on

seismic hazard zone mapping in California can be accessed on DMG's Internet web page: http://www.consrv.ca.gov/dmg/shezp/.

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Laguna Beach 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 Laguna Beach 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 Laguna Beach 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 onshore portion of the Laguna Beach Quadrangle covers an area of about 34 square miles in coastal Orange County. Nearly the entire City of Laguna Beach and portions of the cities of Corona Del Mar, Newport Beach, and Irvine lie within the map area. The remainder of the quadrangle consists of undeveloped, unincorporated Orange County

land and large areas of parkland, including Crystal Cove State Park, Laguna Coast Wilderness Park, and a part of the Aliso/Wood Canyons Regional Park.

Topographically, the Laguna Beach Quadrangle is dominated by the hilly, locally rugged terrain of the San Joaquin Hills that is dissected by numerous canyons, many of which drain southwestward to the ocean. Within one half mile of the coastline, from Corona Del Mar to downtown Laguna Beach, the gently southwest-sloping marine terrace surface has been heavily urbanized. Development has also spread into the northwesternmost San Joaquin Hills at Newport Beach and the steep hillsides that face the ocean above Laguna Beach, as well as along the bottom of Laguna Canyon. Elevations range from sea level to a maximum of 1,164 feet at Signal Peak in the north-central part of the quadrangle. The top of Temple Hill in Laguna Beach, less than two miles from the ocean is 1,036 feet above sea level.

Access to places within the quadrangle is provided by Pacific Coast Highway (State Highway 1) along the coast and by Laguna Canyon Road (State Highway 133) along the eastern boundary of the quadrangle. The San Joaquin Hills Transportation Corridor (toll road) crosses the northern part of the quadrangle. East of Newport Beach local roads include San Joaquin Hills Drive, Newport Coast Drive, and Pelican Hill Road.

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 Laguna Beach 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 1978 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

To update the terrain data, areas that have recently undergone large-scale grading in the hilly portions of the Laguna Beach Quadrangle were identified on 1: 40,000-scale aerial photography flown in 1994 and 1995 (NAPP, 1994; see Air Photos in References). Terrain data for these areas were produced by scanning and rectifying diapositives made from the photography. Using this stereo-rectified image, DMG manually digitized the terrain to produce accurate and up-to-date topography for the mass graded area. This corrected terrain data was digitally merged with the USGS DEM. Plate 2.1 shows the area where topography is updated to 1994 grading conditions.

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

GEOLOGY

Bedrock and Surficial Geology

For the Laguna Beach Quadrangle, a geologic map was compiled and digitized by the Southern California Areal Mapping Project [SCAMP] (1995) from original mapping by Yerkes and others, (1965), Morton and Miller (1981), and Tan and Edginton (1976). The digital geologic map obtained from SCAMP was modified during the project to reflect field observations and the most recent mapping in the area. In the field, observations were made of exposures of the bedrock units, 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 slope failures was noted.

The Laguna Beach Quadrangle encompasses the coastal portion of northwestern flank of the Peninsular Ranges of southern California. The quadrangle covers much of the San Joaquin Hills and overlaps the southwestern fringe of the Los Angeles Basin. Prominent localities within the San Joaquin Hills include 716-foot Pelican Hill, near Newport Beach, and 1036-foot Temple Hill, which overlooks the City of Laguna Beach. The upland areas are underlain by a thick sequence of marine and nonmarine Tertiary sedimentary rocks. The lower Tertiary rocks (Paleocene to Oligocene) are located east of the Shady Canyon fault, whereas the upper Tertiary rocks (Miocene and younger) are only exposed west of the fault. The central and the eastern portions of the quadrangle are intruded by numerous NNW-NNE trending diabase dikes. Along the coast are Pleistocene wave-cut marine platforms that are covered by marine deposits. Subsequent erosion of the bordering hilly areas generated a nonmarine colluvial cover that veneers some of these terraces. Alluvium and slope wash deposits occur within the major drainages in some areas.

The bedrock geologic units mapped within the Laguna Beach Quadrangle (primarily by Tan and Edginton, 1976) are, from oldest to youngest: Silverado Formation (Tsi), Santiago Formation (Tsa), Sespe Formation (Ts), Vaqueros Formation (Tv), Topanga Formation (Tt), San Onofre Breccia (Tso), Monterey Formation (Tm), Capistrano Formation (Tc), and andesite (Ta) and diabase (Td) dikes.

The oldest geologic unit mapped in the Laguna Beach Quadrangle is the Paleocene Silverado Formation (Tsi) which consists of marine to nonmarine coarse- to medium-grained sandstone and lesser conglomeratic sandstone and claystone. It is exposed within an upthrown block northeast of the Shady Canyon Fault in the northeastern corner of the quadrangle. Also exposed in the same area are rocks of the Santiago Formation (Tsa) of Eocene age, which is composed of medium- to coarse-grained sandstone and interbedded fine-grained sandstone of marine origin. The contact between the Silverado and Santiago formations is thought to be an unconformity, although a gradational relationship has been suggested for some localities (Tan and Edginton, 1976).

Unconformably overlying the older units is the nonmarine Sespe Formation (Ts), which is comprised predominantly of clayey sandstone of various colors, and conglomerate of late Eocene to early Miocene age. Interbedded marine sandstone and siltstone of the

early Miocene Vaqueros Formation overlie the Sespe Formation and are exposed in the central and eastern portions of the quadrangle.

The middle Miocene Topanga Formation, which is conformable and transitional with the underlying Vaqueros Formation, is made up of three distinct members: the Bommer Member (Ttb), the most widely exposed rock unit in the quadrangle and is characterized by thick-bedded resistant coarse-grained sandstone; the Los Trancos Member (Ttlt), composed of thin-bedded siltstone and fine-grained sandstone; and the Paularino Member (Ttp) which has a very limited exposure consisting of tuffaceous sandstone, siltstone, breccia, and flows.

Unconformably overlying these units is the middle Miocene marine and nonmarine San Onofre Breccia (Tso), which is composed of sandstone, siltstone, and conglomerate and characterized by fragments of Catalina Schist breccia. Cropping out in the western portion of the quadrangle, from upper Newport Bay and southward along the coast, are siliceous and tuffaceous shale, siltstone and calcareous sandstone strata of the middle to late Miocene Monterey Formation (Tm). This unit grades upward into the lower part of the Capistrano Formation (Tc) which consists of marine siltstone and fine-grained sand and shale layers. In many places within the quadrangle, middle Miocene diabase dikes, associated with fault zones, intrude the various sedimentary formations, particularly in the central and eastern portions. Late Miocene andesitic intrusions are exposed as stocks and sills along the coast.

The Quaternary units have been generalized in this section they include young alluvium (Qya), young and old Quaternary fan deposits (Qyf, Qof), very old alluvium (Qvo) and marine terraces (Qtm). A detailed discussion of the Quaternary deposits in the Laguna Beach Quadrangle can be found in Section 1.

Structural Geology

The geologic structure of the Laguna Beach Quadrangle is dominated by complex faulting and minor homoclinal folding. The quadrangle is transected by numerous northwest-trending faults including the Pelican Hill, Shady Canyon and southern part of the Laguna Canyon fault zones. North-trending faults, such as the northern portion of the Laguna Canyon fault, and east-trending faults, such as the Temple Hill fault, also transect the quadrangle.

The central portion of the San Joaquin Hills area has been described as a complexly faulted, north- plunging anticline (Vedder, 1970). However, this feature and numerous fault blocks within the quadrangle have bedding attitudes that probably resulted from differential movement and tilting along bounding faults (Tan and Edgington, 1976). The orientation (attitude) of bedding layers within formations does not appear to have as significant an influence on slope stability as do the differences in rock strength between formations. It was, therefore, concluded that the occurrence of adverse bedding (dip slopes) is not as important as material strength when it comes to evaluating the sedimentary rock units for earthquake-induced landslide susceptibility. Accordingly, no

attempt was made to identify adverse bedding conditions in the Laguna Beach Quadrangle.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Laguna Beach Quadrangle was compiled from published regional landslide maps by Tan and Edgington (1976). Then, by combining field observations with analysis of aerial photos (see Air Photos in References) and interpretation of landforms, all landslides on the compiled landslide map were either verified, re-mapped, or deleted during preparation of the landslide inventory map. The most landslide-prone bedrock units in the quadrangle are the Vaqueros Formation, the Los Trancos Member of the Topanga Formation, and the Monterey Formation. The most stable are the San Onofre Breccia, the Silverado Formation, and the Sespe Formation. Most of the landslides inventoried are debris slides with minor block slides and slumps. 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. During final review of the zone maps, using the scanned aerial photography (NAPP, 1994) described in the Digital Terrain Data section above, landslides that are mapped totally within graded areas have been deleted. Landslides with mapped boundaries that extend outside the footprint of the grading are considered intact and capable of failure. A version of this landslide inventory is included with Plate 2.1.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the Laguna Beach Quadrangle geologic map were obtained from the Corridor Design Management Group project files for the San Joaquin Hills Traffic Corridor, the City of Laguna Beach and the City of Newport Beach (see Appendix A). The locations of rock and soil samples taken for shear testing by consultants are shown on Plate 2.1. When available, shear tests from adjacent quadrangles were used to augment data for geologic formations that had little or no shear test information.

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

geologic map unit and corresponding strength group are summarized in Table 2.1. For most of the geologic strength groups in the map area, a single shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Tables 2.1 and 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

LAGUNA BEACH QUADRANGLE

SHEAR STRENGTH GROUPINGS

	Formation Name	Number Tests	Mean phi value	Group phi Mean/Median (deg.)	Group C Mean/Median (psf)	Similar Lithology; no data	Phi Values Used in Stability Analyses
GROUP 1	Tso-breccia	3	39.7	39.6/40	283/300		39
	Ta	1	39.5				
GROUP 2	Qvo	6	33.2				
	Qof	9	32.4			Tn, Td	
	Qtm	9	30.6	32/32.3	385/300	Tsa, Tsi	32
	Tm-ss	21	34.5				
	Ts	8	34.1				
	Tso-ss	4	32.3				
	Ttb	3	33				
	Af	20	29.8				
GROUP 3	Qya	30	31.2				
	Tc	1	31	30/29.4	430/250	Qyf	30
	Tt	70	29.3				
GROUP 4	Ttlt	18	24.4				
	Tm	25	24.3	24/23.5	495/500	Qm, Tv	24
	Ttp	5	23.2				
GROUP 5	Qls	35	19.1	19.1/16.4	438/230		16

Table 2.1. Summary of the Shear Strength Statistics for the Laguna Beach Quadrangle.

SHEAR STRENGTH GROUPS FOR THE LAGUNA BEACH QUADRANGLE

GROUP 1	GROUP 2		GROUP 3	GROUP 4	GROUP 5
Tso-breccia	Tm-ss	Qvo	af	Qtm	Qls
Ta	Ts	Qof	Qya	Ttlt	
	Tso-ss		Qyf	Tm	
	Ttb		Tc	Ttp	
	Td		Tt	Tv	
	Tsa				
	Tsi				

Table 2.2. Summary of the Shear Strength Groups for the Laguna Beach Quadrangle.

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.

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 Laguna Beach 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:	3.3 to 20.0 km
PGA:	0.30 to 0.38 g

The strong-motion record selected for the slope stability analysis in the Laguna Beach Quadrangle was the Channel 3 (N35°E horizontal component) University of Southern California Station #14 recording from the magnitude 6.7 Northridge Earthquake (Trifunac and others, 1994). This record had a source to recording site distance of 8.5 km and a peak ground acceleration (PGA) of 0.59 g. The selected strong-motion record was not scaled or otherwise modified prior to 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 0.232 g. Because these yield acceleration values are

derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Laguna Beach Quadrangle.

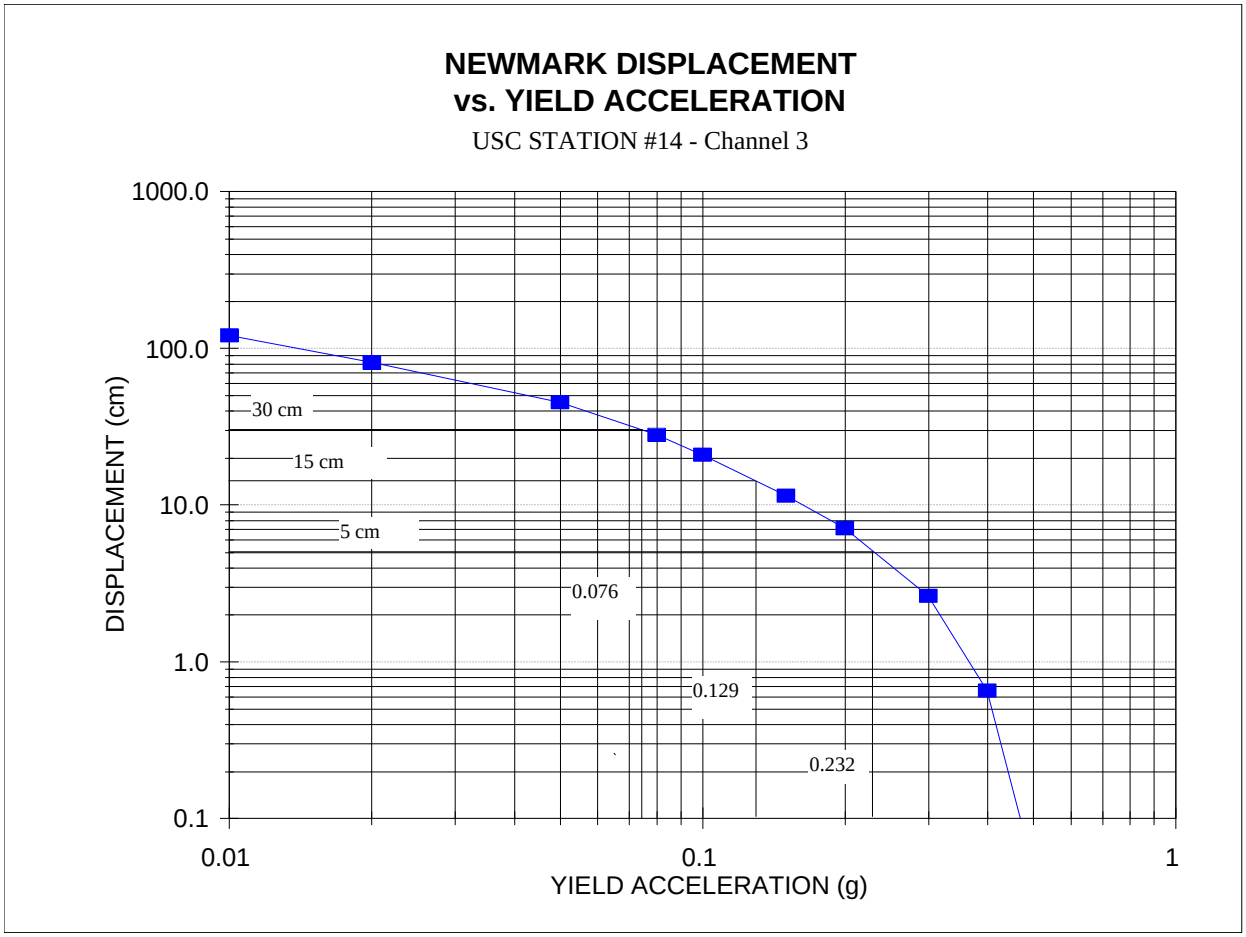

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake.

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.

LAGUNA BEACH QUADRANGLE
HAZARD POTENTIAL MATRIX

Geologic Material Group	MEAN PHI	SLOPE CATEGORY I 0-15 (0-8)	II 16-20 (9-11)	III 21-32 (12-17)	IV 33-37 (18-20)	V 38-47 (21-23)	VI 48-54 (26-28)	VII 55-64 (29-33)	VIII 65-71 (34-36)	IX >71 (>36)
1	39	VL	VL	VL	VL	VL	VL	L	M	H
2	32	VL	VL	VL	VL	L	M	H	H	H
3	30	VL	VL	VL	L	M	H	H	H	H
4	24	VL	VL	L	M	H	H	H	H	H
5	16	L	M	H	H	H	H	H	H	H

(percent)
(degrees)

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Laguna Beach 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 5 is included for all slope gradient categories. (Note: Geologic Strength Group 5 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 4 is included for all slopes steeper than 20 percent.

3. Geologic Strength Group 3 is included for all slopes steeper than 32 percent.

4. Geologic Strength Group 2 is included for all slopes steeper than 37 percent.

5. Geologic Strength Group 1 is included for all slopes greater than 54 percent.

This results in approximately 43 percent (9,700 acres) of the quadrangle lying within the earthquake-induced landslide hazard zone for the Laguna Beach Quadrangle.

ACKNOWLEDGMENTS

The authors thank staff from the City of Laguna Beach, the Orange County Public Health Department, Environmental Health Division, and the Orange County Public Works Department, Construction and Design Divisions for their assistance in obtaining

geotechnical information used in the preparation of this report. Technical review of the methodology was provided by Bruce Clark, Randy Jibson, Robert Larson, Scott Lindvall, and J. David Rogers, who are members of the State Mining and Geology Board's Seismic Hazards Mapping Act Advisory Committee Landslides Working Group. Dr. Mushtaq Hassain and Dr. Riad Munjy of the Geomatrics Engineering Program in the School of Engineering and Computer Science at California State University, Fresno, assisted in the soft-copy photogrammetry production. At DMG, special thanks to Bob Moskovitz, Teri McGuire, Scott Shepherd and Barbara Wanish for their Geographic Information System operations support, to Barbara Wanish and John Schlosser for assistance with digitizing terrain in graded areas, to Joy Arthur for designing and plotting the graphic displays associated with the earthquake-induced landslide zone map, and to Lisa Chisholm for preparing the landslide attribute tables for input into this report.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Laguna Beach, Office of the City Engineer	**182**
City of Newport Beach, Building Department	**83**
Corridor Design Management Group, San Joaquin Hills Traffic Corridor-Various Contractors	**77**
Total Number of Shear Tests	**342**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Laguna Beach 7.5-Minute Quadrangle, Orange County, California

By

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

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

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp).

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

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

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

EARTHQUAKE HAZARD MODEL

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

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

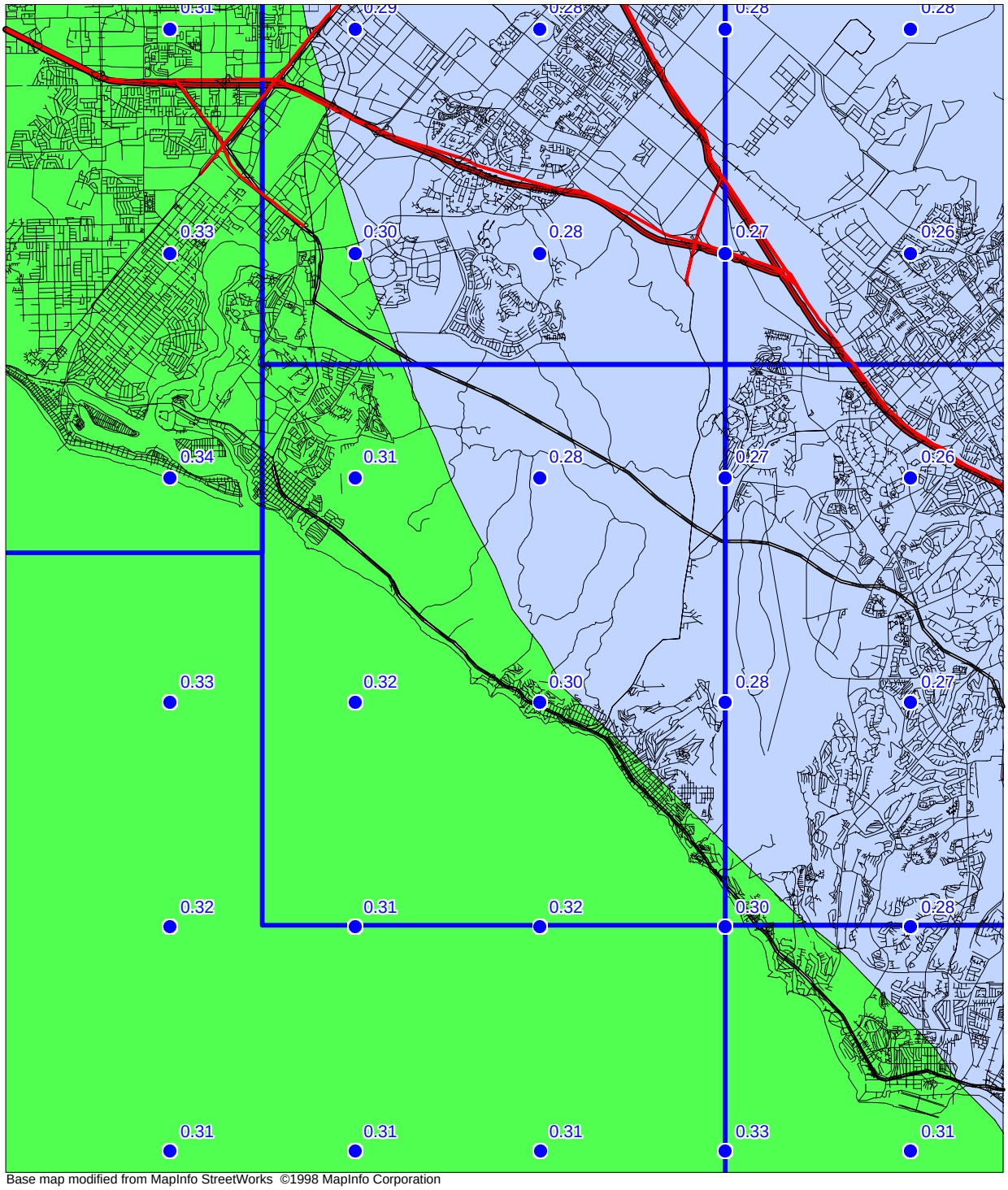
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

LAGUNA BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

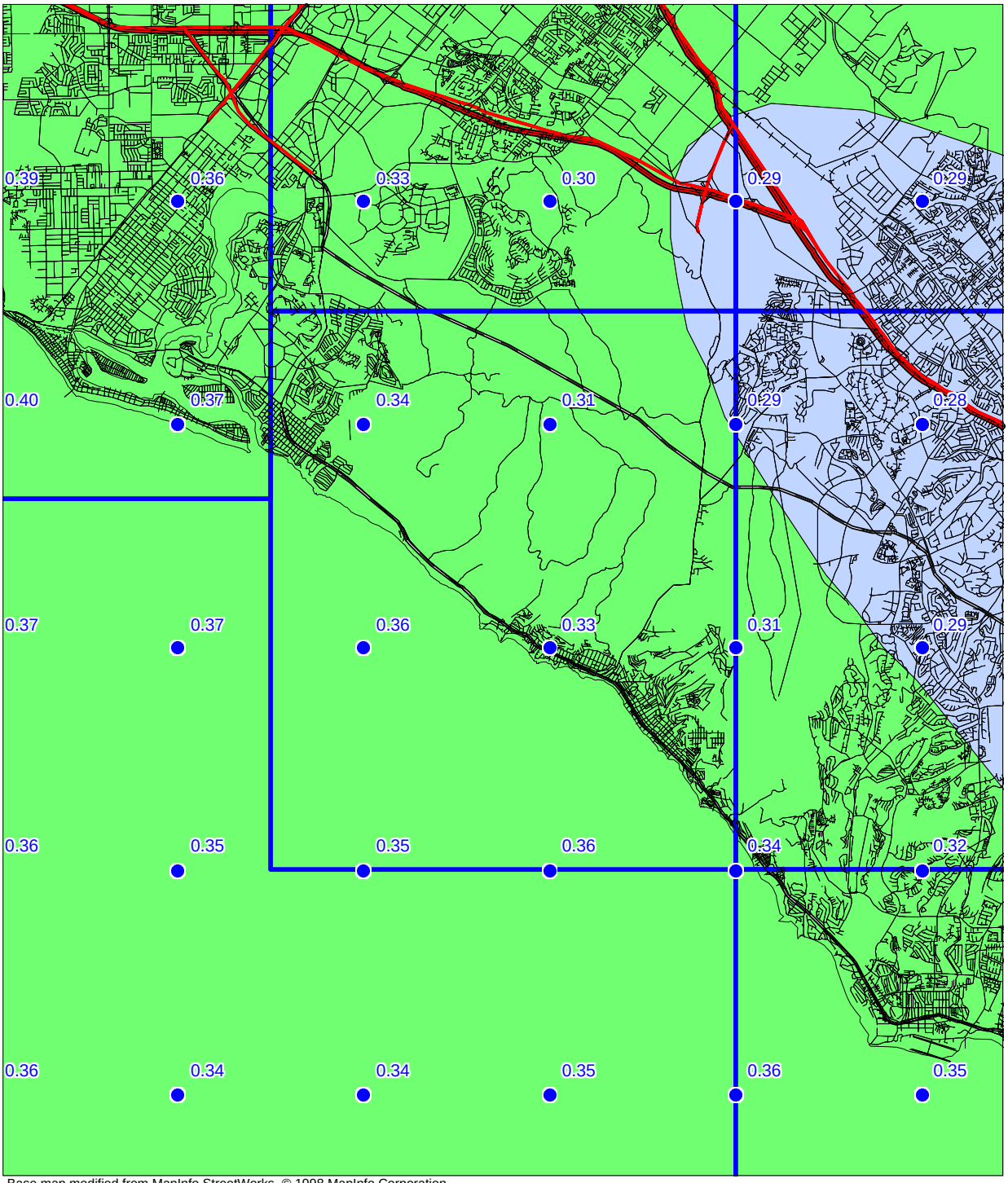
Figure 3.1

LAGUNA BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

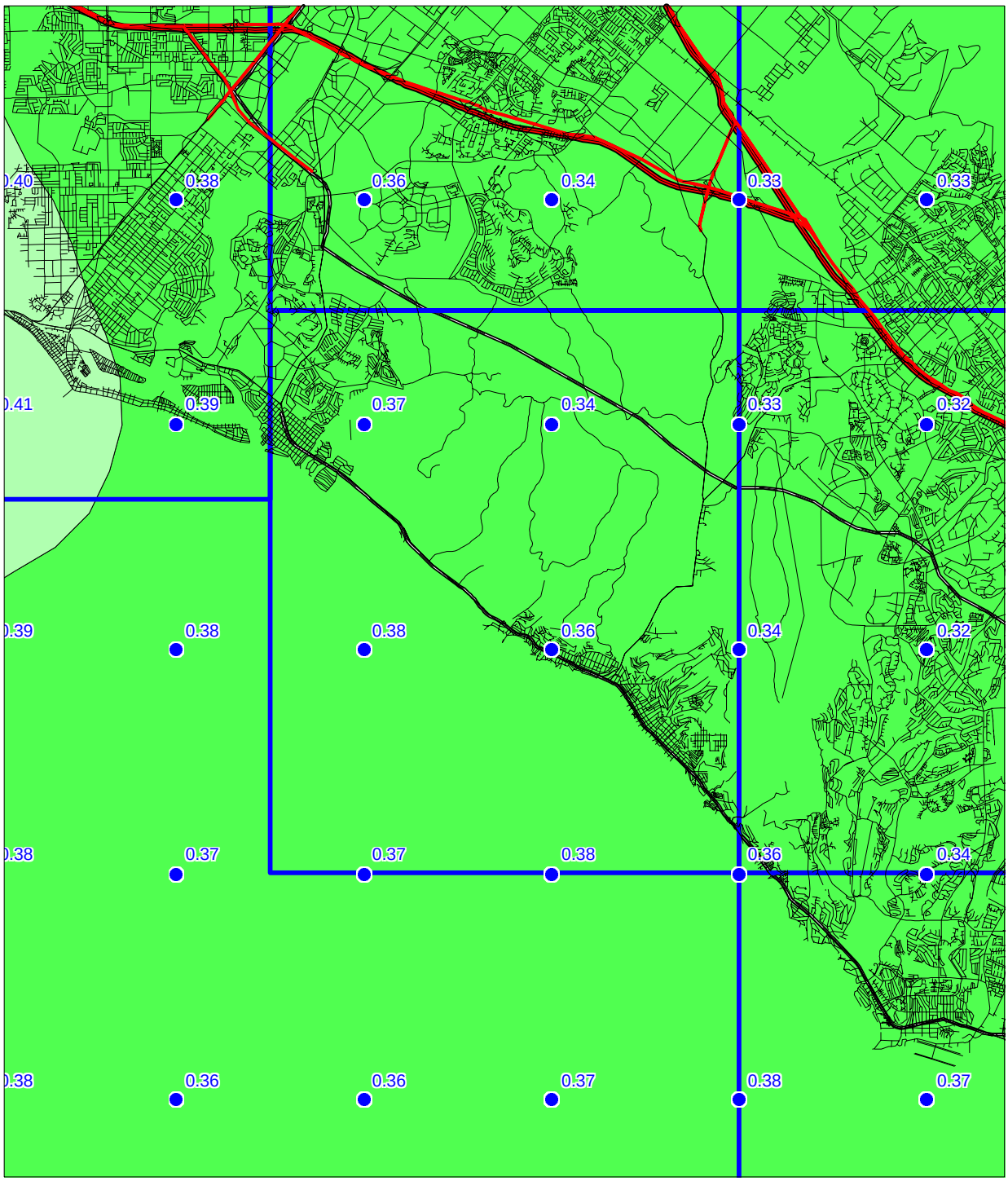
Figure 3.2

LAGUNA BEACH 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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0 2.5 5
Kilometers

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.

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.

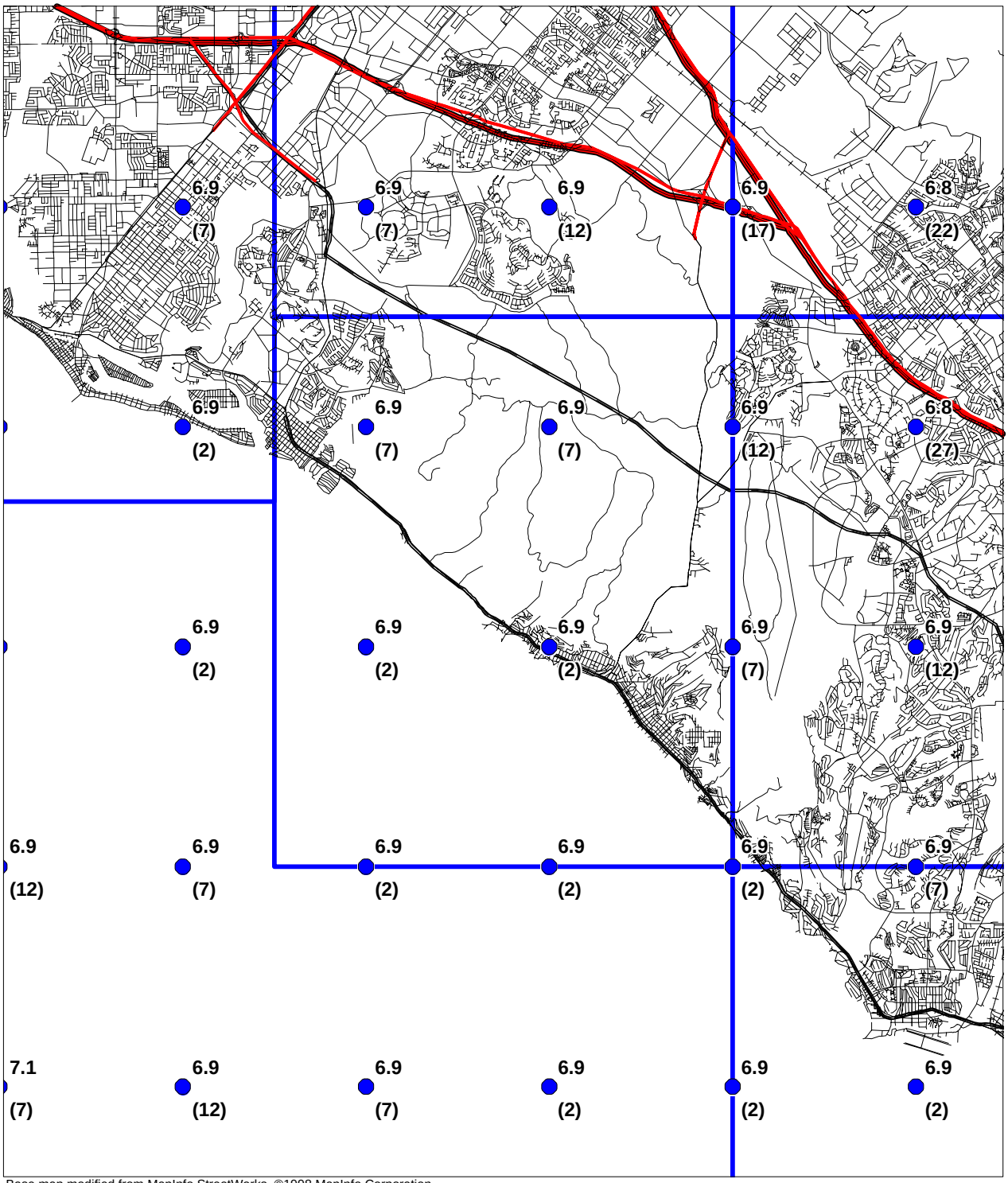
1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated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

LAGUNA BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

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



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology
Figure 3.4

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

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

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

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

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

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

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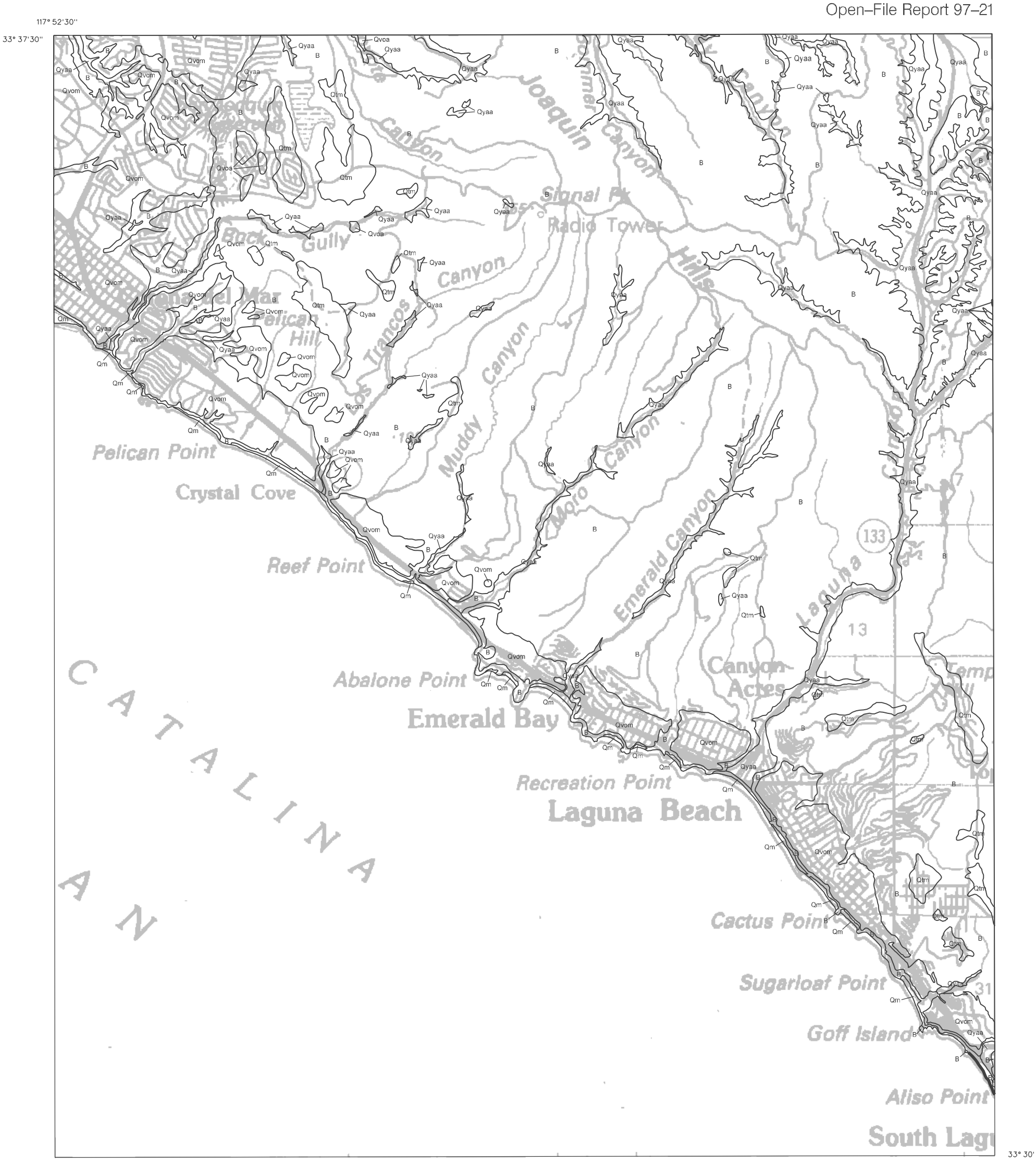
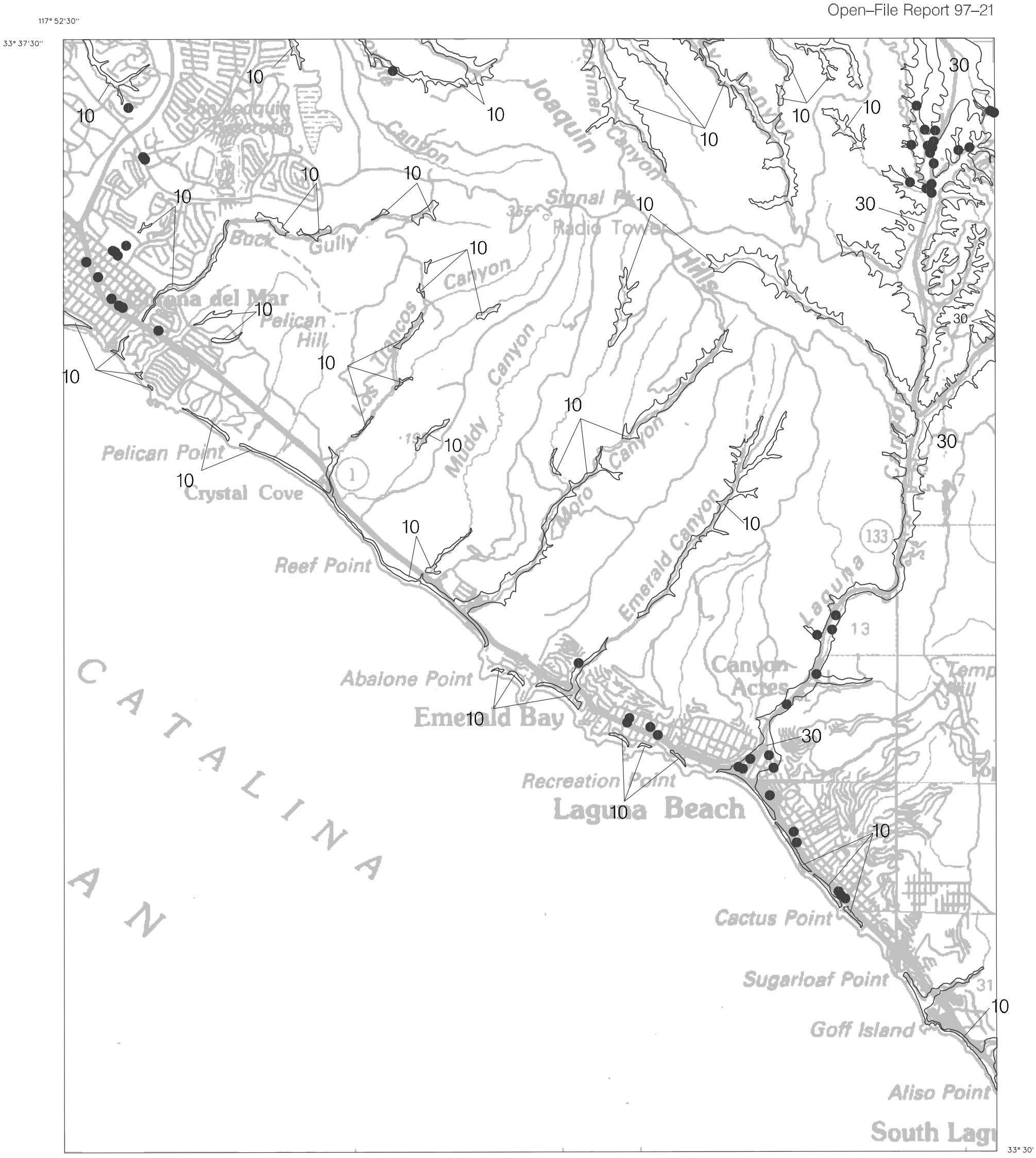


Base map enlarged from U.S.G.S. 30 x 60–minute series

See Geologic Conditions section in report for descriptions of the units.
B = Pre–Quaternary bedrock.
res = reservoir.

ONE MILE
SCALE

Plate 1.1 Quaternary Geologic Map of the Laguna Beach 7.5–minute Quadrangle, California.



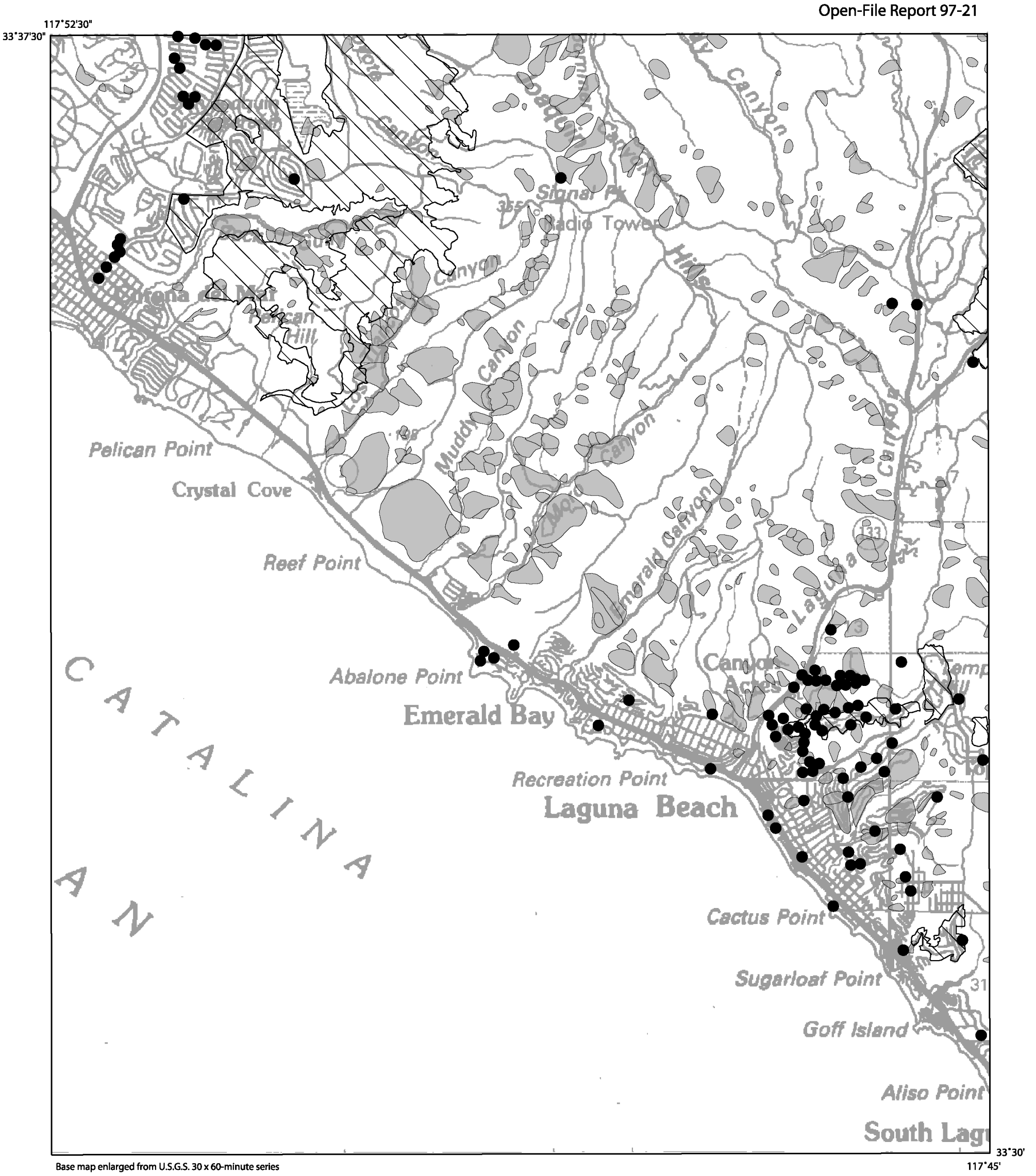
Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Laguna Beach 7.5–minute Quadrangle, California.

● Borehole Site

30 Depth to ground water in feet

ONE MILE
SCALE



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

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

● Shear test sample location

Landslide

Area of significant grading

1 MILE

SCALE