SEISMIC HAZARD ZONE REPORT 017

SEISMIC HAZARD ZONE REPORT FOR THE SUNLAND 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

1998

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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

SEISMIC HAZARD ZONE REPORT FOR THE SUNLAND 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

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ILLUSTRATIONS

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Sunland 7.5-minute Quadrangle, Los Angeles County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 25 square miles at a scale of 1 inch = 2,000 feet. Only part of the southern half of the quadrangle was evaluated. National forest land in the northern half was not evaluated.

The Sunland Quadrangle is in western Los Angeles County. The community of Sunland, which is about 14 miles north-northwest of the Los Angeles Civic Center, and the adjacent community of Tujunga, both parts of the City of Los Angeles, are located primarily within the Tujunga Valley in the southern part of the quadrangle. On the north, the San Gabriel Mountains cover about four-fifths of the quadrangle. Except for a small fringe of unincorporated Los Angles County land along the mountain front most of the land in the mountains lies within the Angeles National Forest. South of Tujunga Valley, the northwestern end of the Verdugo Mountains extends into the southern edge of the quadrangle. Development has mostly occurred on the valley floor, although homes and small ranches are also scattered on the adjacent slopes.

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 Sunland Quadrangle liquefaction occurred in the 1994 Northridge earthquake in the sediments behind Hansen Dam, where sand boils, fissures, and minor lateral spreading features developed. The liquefaction zone coincides with Tujunga Valley, Big Tugunga and Little Tujunga canyon bottoms and about a square mile in western Sunland. The 1971 San Fernando earthquake triggered widespread rockfalls, soil falls, debris slides, avalanches, and slumps in the foothills. Although most of the failures were shallow, the largest landslide triggered by the San Fernando earthquake, a reactivated slump in Schwartz Canyon, also occurred within the Sunland Quadrangle. The 1994 Northridge earthquake triggered small, shallow slope failures in the quadrangle. The combination of steep slopes in the San Gabriel Mountains and weak rocks in the foothills contributes to an earthquake-induced landslide zone that covers about 22 percent of the evaluated portion of the quadrangle.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the 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://www.consrv.ca.gov/dmg/pubs/sp/117/).

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 Sunland 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Sunland 7.5-Minute Quadrangle, Los Angeles County, California

By
Christopher J. Wills

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

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. . The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the Sunland 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 within the Sunland Quadrangle consist mainly of 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 Sunland Quadrangle covers an area of about 62 square miles in western Los Angeles County. The community of Sunland, which is about 14 miles north-northwest of the Los Angeles Civic Center, and the adjacent community of Tujunga, both parts of the City of Los Angeles, are located primarily within Tujunga Valley in the southern part of the quadrangle. North of the valley, the San Gabriel Mountains cover about four-fifths of the quadrangle. Except for a small fringe of unincorporated Los Angles County land along the mountain front most of the land in the mountains lies within the Angeles National Forest. South of Tujunga Valley, the northwestern end of the Verdugo Mountains extends into the southern edge of the quadrangle. Canyons within the mountains extend south to the San Fernando Valley.

The San Fernando Valley is an east-trending structural trough within the Transverse Ranges of southern California. The San Gabriel Mountains that bound it to the northeast are composed of plutonic and metamorphic rocks that are being thrust over the valley from the north. As the range has been elevated and deformed, the San Fernando Valley has subsided and filled with sediment.

The northern portion of the San Fernando Valley in the Sunland Quadrangle has received sediment from drainage systems originating in the San Gabriel Mountains. The larger systems, Little Tujunga and Big Tujunga washes, are large river systems that have their sources in the steep, rugged San Gabriel Mountains. Each of these drainage systems has a drainage basin of tens of square miles within the mountains and can carry a large volume of sediment. The alluvial fans deposited by these drainage systems have their apexes are outside of the Sunland Quadrangle in the southern San Fernando Quadrangle and cover most of the Van Nuys and Burbank quadrangles to the south. Composition of these deposits is dependent on the source areas of the drainages. Drainages with source areas in the San Gabriel Mountains primarily have granitic or other plutonic rocks in their drainage basins. The deposits of these streams, consequently are composed of sandy alluvium.

GEOLOGY

Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. Late Quaternary geologic units in the San Fernando Valley area were completely re-mapped for this study and a concurrent study by engineering geologist Chris Hitchcock of William Lettis and Associates (Hitchcock and Wills, 1998; 2000). Lettis and Associates received a grant from the National Science Foundation (NSF) to study the activity of the Northridge Hills uplift. As part of the research for this study, Hitchcock mapped Quaternary surficial units by interpreting their geomorphic expression on aerial photographs and topographic maps. The primary source for this work was 1938 aerial photographs taken by the U.S. Department of Agriculture (USDA). His interpretations were checked and extended for this study using 1952 U.S.D.A. aerial photos, 1920's topographic maps and subsurface data. The resulting map (Hitchcock and Wills, 2000) represents a cooperative effort to depict the Quaternary geology of the San Fernando Valley combining surficial geomorphic mapping and information about subsurface soils engineering properties. The portions of this map that cover the Sunland Quadrangle are reproduced as Plate 1.1.

In preparing the Quaternary geologic map for the Sunland Quadrangle, geologic maps prepared by Barrows and others, (1975), Crook and others (1987), Oakeshott (1958), Tinsley and others (1985), Dibblee (1991) and Yerkes (1996) were referred to. We began with the map of Yerkes (1996) as a digital files in the DMG Geographic Information System (GIS). The Quaternary geology shown on the map of Yerkes (1996) was compiled from Tinsley and others (1985) and Oakeshott (1958). For the liquefaction portion of this study, we did not review or revise the mapping of bedrock units by Yerkes

(1996), except for the contacts between bedrock and Quaternary units. However, changes to the bedrock geology were made for the landslide portion of this study, and the changes are described in the landslide portion (Section 2) of this evaluation report. Within the San Fernando Valley mapping of Quaternary units by Hitchcock (and for this study) was used to refine and substantially revise this mapping. For this map (Plate 1.1), geologic units were defined based on geomorphic expression of Quaternary units (interpreted from aerial photographs and historic topographic maps) and subsurface characteristics of those units (based on borehole data). In the Tujunga Valley portion of the Sunland Quadrangle, Quaternary mapping by Crook and others (1987) was compiled for this map. The nomenclature of the Southern California Areal Mapping Project (SCAMP) (Morton and Kennedy, 1989) was applied to all Quaternary units (Table 1.1).

	Alluvial Fan Deposits	Alluvial Valley Deposits	Age
Active	Qf- active fan ????? Qw- active wash		Holocene?
Young	Qyf2 Qyf1	Qyt	
Old	Qof1		Pleistocene?
Very old	Qvof1	Qvoa*	Pleistocene

*May have been alluvial fan, depositional form not preserved

Table 1.1. Units of the Southern California Areal Mapping Project (SCAMP) Nomenclature Used in the San Fernando Valley.

The Quaternary geologic map (Plates 1.1 and 1.2) shows that the oldest alluvial units in the Sunland Quadrangle are found on the south flank of the San Gabriel Mountains. The Saugus Formation, a Pleistocene alluvial unit, is exposed in the core of a syncline north of the Sierra Madre Fault and south of a series of thrust faults that place crystalline basement rocks over Tertiary sedimentary rock.

Overlying Saugus Formation along the front of the San Gabriel Mountains are very old alluvial deposits (Qvoa, Qvof1, and Qab). These deposits are uplifted, deformed, commonly have red (mature) soils and are typically dense to very dense. Qvoa consists of intensely deformed older alluvium along the San Fernando segment of the Sierra Madre fault zone. Its age in relation to the other units is not known. Qvof1 exists as remnants of alluvial surfaces on tops of ridges between Pacoima Wash and Big Tujunga Canyon. Qab is mixed alluvial and colluvial material deformed along the Sierra Madre Fault Zone.

Older alluvium (Qof1) consists of remnants of alluvial fans now uplifted as terraces along the edge of Tujunga Wash. Older alluvial fans are also found in the uplifted area between Pacoima and Big Tujunga Canyons. These deposits are composed of sand, silt, and gravel and commonly form recognizable alluvial fans. The fan surfaces are no longer active because continuing deformation has either lifted them out of the area of deposition or because they have been buried by later alluvium. The younger alluvial fans can be subdivided into young (Qyf1 and Qyf2) and active (Qf, Qw) fan deposits on the basis of geomorphology. Young alluvial fans are described below.

Younger alluvial fans of Big Tujunga and Little Tujunga Canyons

Tujunga Wash has a drainage basin of about 90 square miles in rugged mountainous terrain that includes peaks up to 5000 feet in altitude. It is divided into two main branches, Little Tujunga Canyon to the west and Big Tujunga Canyon to the east. These two streams merge in the Tujunga Valley, where they form a broad wash. Deposits in the wash are composed of sandy gravel with boulders. The Tujunga Wash ends at Hansen Dam Flood Control Basin, built where the wash had cut through the northwestern end of the Verdugo Mountains. Hansen Dam marks the apex of the main Tujunga Wash portion of the Pacoima-Tujunga fan, which spreads south from the Sunland Quadrangle.

ENGINEERING GEOLOGY

The geologic units described above and listed in Table 1.2 were primarily mapped from their surface expression, especially geomorphology, as displayed on aerial photos and old topographic maps. The geomorphic mapping was compared with the subsurface properties described in about 50 borehole logs in the study area. Subsurface data used for this study include the database compiled by John Tinsley for previous studies (Tinsley and Fumal, 1985; Tinsley and others, 1985), a database of shear wave velocity measurements originally compiled by Walter Silva (Wills and Silva, 1998), and additional data collected for this study. Subsurface data were collected for this study at Caltrans, the California Department of Water Resources, the Regional Water Quality Control Board. In general, the data gathered for geotechnical studies appear to be complete and consistent. Data from environmental geology reports filed with the Water Quality Control Board are well distributed areally and provide reliable information on water levels. Geotechnical data, particularly SPT blow counts, from environmental studies are sometimes less reliable however, due to 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 $(N_1)_{60}$.

Geologic Map Unit	Material Type	Consistency	Liquefaction Susceptibility
Qw, stream channels	sand, gravelly sand	loose-moderately dense	High
Qf, active alluvial fans	silty sand, sand	loose-moderately dense	High
Qyf2, younger alluvial fans	silty sand, sand, minor clay	loose-moderately dense	High
Qyf1, young alluvial fan	silty sand, sand, minor clay	loose-moderately dense	High
Qof1, older alluvial fan	sand & gravel	Moderately dense	Low
Qvoa, Qvof1, very old alluvium	clay-silty sand	dense-very dense	Low

Table 1.2. General Geotechnical Characteristics and Liquefaction Susceptibility of Younger Quaternary Units.

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 outlining of areas of similar soils.

Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are generalized but give the most commonly encountered characteristics of the unit (see Table 1.2).

Saugus Formation (Qs, Qsu)

The Pleistocene Saugus Formation is an alluvial unit that may not always be distinguished from younger overlying alluvium in borehole logs. We were not able to find logs of boreholes on the Sunland Quadrangle where Saugus Formation was encountered. On other quadrangles, it is described as "sandstone." In some locations, dense or very dense sand may be Saugus Formation but also could be old or very old alluvium.

Very old alluvium (Qvoa, Qvof1)

Very old alluvium, mapped along the Sierra Madre Fault, is also not represented in our subsurface data for the Sunland Quadrangle. At the surface this material is sand and gravelly sand.

Older alluvium (Qof1)

Older alluvium is distinguished from younger alluvium by being uplifted and usually incised by younger drainages and by having relatively even tonal patterns on pre-development aerial photographs. In contrast, younger alluvium typically has a braided stream tonal pattern even where those stream channels have no geomorphic expression. Qof1 consists of remnants of small alluvial fans in the Tujunga Valley and uplifted surfaces in the upper Little Tujunga Canyon and adjacent areas. Older alluvium usually occupies uplifted areas at the mountain front, because relatively little large-scale development has occurred here, this material is also not represented in our subsurface data for the Sunland Quadrangle.

Younger alluvium (Qyf1, Qyf2, Qw)

Within an alluvial fan, the different generations of younger alluvium can be distinguished by their geomorphic relationships. In the subsurface, it is not possible to distinguish among the generations on an alluvial fan. There may simply be too little difference in age among these units, which probably range from mid-Holocene to historic, for any differences in density or cementation to have formed.

Big Tujunga and Little Tujunga Canyons

The alluvium of Big Tujunga and Little Tujunga canyons is found mainly in channel deposits in the mountains and in the Tujunga Wash. The wash deposits are composed of sand, gravelly sand and silty sand, with some layers of gravel. SPT blow counts show that this material is loose to very dense, although some of the higher blow counts may be due to impact on large clasts in gravelly layers.

Artificial fill (af)

In the Sunland Quadrangle artificial fills large enough to show at the scale of mapping include the Hansen Dam, and engineered fill for freeways. These units were compiled from the digital map of Yerkes (1996).

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 Sunland 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. 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.

The San Fernando Valley ground-water basin is a major source of domestic water for the City of Los Angeles and, as a result, has been extensively studied. The legal rights to water in the ground within the San Fernando Valley were the subject of a lawsuit by the City of Los Angeles against the City of San Fernando and other operators of water wells in the basin. The "Report of Referee" (California State Water Rights Board, 1962) contains information on the geology, soils and ground-water levels of the San Fernando Valley.

The Report of Referee shows that ground water reached its highest levels in 1944, before excessive pumping caused drawdowns throughout the basin. Management of the ground-water resources led to stabilizing of ground-water elevations in the 1960's and, in some cases, rise of ground-water elevations in the 1970's and 1980's to levels approaching those of 1944 (Blevins, 1995).

In order to consider the historically highest ground-water level in liquefaction analysis, the 1944 ground-water elevation contours (California State Water Rights Board 1962, Plate 29) were digitized. A three-dimensional model was created from the digitized contours giving a ground-water elevation at any point on a grid. The ground-water elevation values in this grid were then subtracted from the surface elevation values from the USGS Digital Elevation Model (DEM) for the Sunland Quadrangle. The difference between the surface elevation and the ground-water elevation is the ground-water depth. Subtracting the ground-water depth grid from the DEM results in a grid of ground-water depth values at any point where the grids overlapped.

The resulting grid of ground-water depth values showed several artifacts of the differences between the sources of ground-water elevation data and surface elevation data. The ground-water elevations were interpreted from relatively few measurements in water wells. The USGS DEM is a much more detailed depiction of surface elevation, it also shows man made features such as excavations or fills that have changed the surface elevations. Most of these surface changes occurred after the ground-water levels were measured in 1944. The ground-water depth contours were smoothed and obvious artifacts removed to create a ground-water depth map. Ground-water levels from borehole data collected for this study were compared with the depths on the combined map. Borehole data led to some refinements of the final ground-water depth contours (Plate 1.2).

The ground-water depth map shows areas of shallow ground water north Hansen Dam and in the western Tujunga. Ground water is also relatively shallow in all canyons in the San Gabriel Mountains according to records that we have obtained. In general, it appears that relatively shallow and impermeable bedrock underlying the canyon alluvium helps to maintain a shallow water table.

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. A qualitative susceptible soil inventory is outlined below and summarized in Table 1.2.

Very old alluvium (Qvoa, Qvof1)

Very old alluvium consists is found as uplifted remnants along the front of the San Gabriel Mountains, in an area of deep ground water. On adjacent quadrangles this material is dense to very dense. Liquefaction susceptibility of this unit is low.

Old alluvium (Qof1)

Old alluvium also is generally found as raised terraces in the San Gabriel Mountains. On adjacent quadrangles this material is dense to very dense. This deposit has low liquefaction susceptibility over most of its area due to deep ground water.

Young alluvium (Qyf1, Qyf2, Qf, Qw, Qa)

Younger alluvium on the Sunland Quadrangle consists of sand with sand, silt and clay. Most boreholes in these units contain loose to moderately dense sand or silty sand. Where ground water is within 40 feet of the surface, liquefaction susceptibility of these units is high.

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 Sunland Quadrangle, peak accelerations of 0.75 g to 0.79 g resulting from an earthquake of magnitude 6.7 to 7.0 were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion 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 57 geotechnical borehole logs reviewed in this study (Plate 1.2), 5 include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

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

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 Sunland Quadrangle is summarized below.

Areas of Past Liquefaction

Liquefaction occurred in the 1994 Northridge earthquake in the sediments behind Hansen Dam (locality 1, plate 1.2). Sand boils, fissures, and minor lateral spreading features occurred in an area about 300 by 1000 feet (Moehle, 1994). The exact location of this liquefaction is not shown in the volume by Moehle (1994), this liquefaction could have been on the San Fernando Quadrangle or the Sunland Quadrangle, or both. Settlements of up to one foot and lateral spreading of up to three feet were reported. It is not reported if the liquefaction occurred in the recent deposits behind the dam, in the underlying Holocene wash deposits, or both.

Artificial Fills

In the Sunland Quadrangle artificial fills large enough to show at the scale of mapping include the Hansen Dam, and engineered fill for freeways. These engineered fills are generally too thin to have an impact on liquefaction hazard and so were not investigated.

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. Younger alluvial deposits (Qyf1, Qyf2, Qf, Qw) of the alluvial fans are composed of sand and silty sand. Most wells have layers of loose to moderately dense sand or silty sand. Those sand layers generally have a factor of safety against liquefaction of less than one in the anticipated earthquake shaking. All younger alluvial fan deposits and stream channel deposits where ground water has been less than 40 feet from the surface have been included in the liquefaction zones.

Areas with Insufficient Existing Geotechnical Data

Very old alluvium and older alluvium in the Sunland Quadrangle are generally found in uplifted areas that have deep ground water. Because of the projected deep ground water and assumed dense consistency of these materials, these geologic units have not been included in liquefaction zones in this area.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Sunland 7.5-Minute Quadrangle, Los Angeles 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 Sunland 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 Sunland 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 Sunland 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 Sunland 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 Sunland Quadrangle covers an area of about 62 square miles in western Los Angeles County. The community of Sunland, which is about 14 miles north-northwest of the Los Angeles Civic Center, and the adjacent community of Tujunga, both parts of the City of Los Angeles, are located primarily within the Tujunga Valley in the southern part of the quadrangle. North of the valley, the San Gabriel Mountains cover about four-fifths of the quadrangle. Except for a small fringe of unincorporated Los Angles County land along the mountain front most of the land in the mountains lies within the Angeles National Forest. South of Tujunga Valley, the northwestern end of the Verdugo Mountains extends into the southern edge of the quadrangle. Canyons within the mountains extend south to the San Fernando Valley.

The San Fernando Valley is an east-trending structural trough within the Transverse Ranges of southern California. The San Gabriel Mountains that bound it to the northeast are composed of plutonic and metamorphic rocks that are being thrust over the valley from the north. As the range has been elevated and deformed, the San Fernando Valley has subsided and filled with sediment.

The northern portion of the San Fernando Valley in the Sunland Quadrangle has received sediment from drainage systems originating in the San Gabriel Mountains. The larger systems, Little Tujunga and Big Tujunga washes, are large river systems that have their sources in the steep, rugged San Gabriel Mountains. Each of these drainage systems has a drainage basin of tens of square miles within the mountains and can carry a large volume of sediment. The alluvial fans deposited by these drainage systems have their apexes are outside of the Sunland Quadrangle in the southern San Fernando Quadrangle and cover most of the Van Nuys and Burbank quadrangles to the south. Composition of these deposits is dependent on the source areas of the drainages. Drainages with source areas in the San Gabriel Mountains primarily have granitic or other plutonic rocks in their drainage basins. The deposits of these streams consequently are composed of sandy alluvium.

The Seismic Hazard Zone Map for this quadrangle has been trimmed back so that it covers essentially only the south half of the Sunland 7.5-minute Quadrangle. The northern boundary of the zone map is located 1.5 to 2.5 miles north of the Angeles National Forest Boundary along the San Gabriel Mountain front. The land excluded from the zone map is almost entirely National Forest land with only a few scattered inholdings of private property.

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 Sunland 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 1966 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

To update the topographic base map, areas that have undergone large-scale grading as a part of residential development or freeway construction in the hilly portions of the Sunland Quadrangle, along the base of the San Gabriel Mountains and at the north end of the Verdugo Mountains were identified on aerial photography flown in the spring of 1994 (see Plate 2.1). Terrain data for these areas were obtained from an airborne interferometric radar (TOPSAR) DEM flown and processed in August 1994 by NASA's

Jet Propulsion Laboratory (JPL), and reprocessed by Calgis, Inc. (GeoSAR Consortium, 1995 and 1996). These terrain data were also smoothed prior to analysis.

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 Sunland Quadrangle, a recently compiled geologic map was obtained from the U.S. Geological Survey (USGS) in digital form (Yerkes, 1996). Other geologic maps reviewed for this project include: Oakeshott (1958), Barrows and others, (1975), Weber (1982), Crook and others (1987) and Dibblee (1991). The digital geologic map was modified to reflect the most recent mapping in the area and to include interpretations of observations made during the aerial photograph landslide inventory and field reconnaissance. Modifications to the geologic map included remapping most of the contacts between the bedrock and Quaternary units. In the field, observations were also made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of slope failures was noted.

The uplands of the Sunland Quadrangle are underlain by Precambrian to Mesozoic igneous and metamorphic rocks that are faulted against or overlain by Paleocene to Pleistocene sedimentary and volcanic rocks, and Holocene alluvium. The northwest-striking San Gabriel Fault crosses the northern half of the quadrangle and separates contrasting geologic terranes. This fault generally, but not entirely, separates the Precambrian metamorphic rocks exposed northeast of the fault from the younger igneous, metamorphic and sedimentary rocks exposed southwest of the fault. The oldest rocks in the Sunland Quadrangle are Precambrian Mendenhall Gneiss (pCm) and anorthosite complex rocks (an) exposed north of the San Gabriel Fault. The Mendenhall Gneiss consists of blue quartz-plagioclase gneiss intruded by rocks of the anorthosite complex that are composed of medium to very coarse-grained, pale gray to white plagioclase and, in the gabbroic phases, pyroxene that weathers to a dark grayish green. The anorthosite complex includes abundant varieties of gabbroic rocks (gb), especially norite and inclusion of ilmenite-magnetite gabbro (gbm).

An assortment of pre-Cenozoic igneous and metamorphic rocks are exposed south of the San Gabriel Fault. The oldest of these rocks is the pre-Triassic? Placerita Formation (pm), which consists of biotite-quartz-feldspar gneiss, meta-quartzite, biotite schist-gneiss, and small bodies of marble, limestone, and dolomite. Mesozoic diorite gneiss (dgn) is the next youngest unit consisting of dark gneiss, meta-diorite, hornblende diorite and local amphibole schist. The youngest of the Mesozoic rocks is the granodiorite (gd) unit, which is comprised of medium- to coarse-grained granitic rocks that range from quartz diorite to granite that is locally gneissic near contacts with the older rocks. The igneous and metamorphic rocks, which form the basement rocks in the study area, are exposed along the north half of the western, northern, the entire eastern and about the central third of the southern boundaries of the study area, and outcrop over more than three-fourths of the upland terrain in the Sunland Quadrangle.

Sedimentary rocks that rest upon the basement south of the San Gabriel Fault are identified in the southwestern quarter and the western half of the southeastern quarter of the quadrangle. These rocks form generally northwest-trending bands that underlie the foothills north of the San Fernando Fault and the northwestern end of the Verdugo Mountains. The oldest of this sequence of sedimentary rocks is the Paleocene Martinez Formation (Tmz) of Yerkes (1996) and Oakeshott (1958), and mapped as the Santa Susana Formation by Dibblee (1991). It consists of marine sandstone, thin interbeds of black shale and lenticular beds of pebble conglomerate. These rocks are only exposed in slivers along the south side of the San Gabriel Fault.

The middle Miocene Topanga Formation (Tt) is exposed south of Tujunga Valley, south and east of Sunland Boulevard. This formation consists of nonmarine arkose and conglomerate, as well as vesicular basaltic flows and minor breccia (Tb). The Modelo Formation (Tm) rests conformably upon Topanga Formation south of Tujunga Valley, north and west of Sunland Boulevard and lies directly north of the San Fernando Fault. The Modelo consists of upper Miocene diatomaceous to cherty shale, sandstone, and conglomerate. The Pico Formation (Tp), also mapped as Towsley (?) Formation by Dibblee (1991), consists of upper Pliocene sandstone and pebble conglomerate that conformably overlies the Modelo Formation.

The youngest lithified sedimentary unit is the Plio-Pleistocene nonmarine Saugus Formation (Qs). The Saugus Formation has a larger outcrop area in the quadrangle than any other sedimentary unit. The Saugus Formation is exposed in the center of the western half of the quadrangle where it either rests unconformably upon Pico Formation or igneous and metamorphic rocks or is in fault contact with Modelo Formation or igneous and metamorphic rocks. The Saugus Formation consists of nonmarine pebble conglomerate and coarse-grained arkosic sandstone

The late Quaternary geologic units exposed on geomorphic terraces in the uplands and exposed on the uplifted and undeformed portions of the flatlands in the San Fernando Valley area of the Sunland Quadrangle were completely re-mapped for this study. The geomorphic terraces and the uplifted flatlands in the San Fernando Valley area were mapped as a variety of alluvial units including: older and very old alluvium (Qof1, Qoal, Qvoa, Qvof, Qvof1, and Qao), terrace deposits (Qt), and alluvium-breccia deposits (Qab). These allluvial units consist of moderately dense to very dense sand, clayey and silty sand, gravel and clay layers. The undeformed portions of the flatlands in the San Fernando Valley area are underlain by younger alluvium (Qal, Qya1, Qyf1, Qyf2, and Qw), which consists of loose, moderately dense sand, silty sand, gravelly sand and minor clay. A more detailed description of the late Quaternary geologic units is presented in the Liquefaction portion (Section 1) of this report.

Landslide deposits (Qls) are relatively abundant south of the San Gabriel Fault and north of the Tujunga Valley in the west-central portion of the quadrangle were they occur on the sedimentary and igneous rocks of the uplands. Landslides in the sedimentary rocks were identified primarily on the Saugus Formation and Modelo Formation, where they occur individually or as landslide complexes, and range in size from small to large. Landslides in the igneous rocks occur primarily in the granodiorite and form complexes along the Lopez Fault (Dibblee, 1991; Treiman, unpublished) or are otherwise scattered throughout the outcrop area of the basement complex. The landslides in the granodiorite range in size from small to large, with most of the largest single landslides and landslide complexes along the Lopez Fault to the northwest of Little Tujunga Canyon. The scattered landslides in the granodiorite also range in size from small to large, but most are small with fewer large landslides than in the sedimentary rocks.

Modern man-made fill (af), and cut/fill (acf) occur primarily along freeway embankments. A more detailed description of the man-made fill is presented in Section 1 of this report.

Structural Geology

Regional faults are the primary structural features of the Sunland Quadrangle. The northwest-striking San Gabriel Fault is the dominant structure in the northern half of the Sunland Quadrangle. In the southern third of the quadrangle, however, the Lakeview Segment of the San Fernando Fault, which ruptured at the surface during the February 9, 1971 earthquake, defines the southern edge of the mountain front. Faulting along the Lakeview Segment juxtaposes Modelo Formation over coarse, older alluvium-breccia deposits. The fault also crosses the Modelo Formation and the Quaternary (modern) wash deposits at the mouths of Little Tujunga and Big Tujunga canyons. This fault is referred to as the Lakeview Fault Zone on the map by Dibblee (1991) and the Lakeview Segment of the San Fernando Fault on the map by Barrows and others (1975).

Numerous shorter faults that trend northwest-southeast or north-south are scattered throughout the uplands. Fault names used in the following discussion are taken from Dibblee (1991), and Barrows and others (1975). The De Mille Fault and Watt Fault are local strands of the San Gabriel Fault and are just south of that fault. Near the western margin of the quadrangle and just south of the San Gabriel Fault, the Buck Canyon Fault trends generally east-west and forms the contact between the Saugus Formation and the granodiorite. Farther to the southeast, an unnamed fault that trends southwest-northeast is just northwest of Kagel Canyon. The Lopez Fault is exposed just northwest of Little Tujunga Canyon where it forms the contact between the Saugus Formation and the granodiorite and diorite-gneiss. The fault forms a backward “L”, with the southern portion of the fault trending west-northwest and the northern portion trending north-northeast. South of Yerba Buena Ridge, the Sunland Fault trends in an arcuate, open to the north-northeast, pattern from Little Tujunga Canyon on the west to Big Tujunga Canyon to the east.

In the igneous and metamorphic basement rocks north of the San Gabriel Fault the foliation strikes generally about northwest-southeast, parallel to the San Gabriel Fault and locally northeast-southwest. Dips of the foliation in the Mendenhall Gneiss, anorthosite complex and gabbroic rocks range between 20 and 70 degrees, generally to the southwest, but locally to the northwest or northeast. In the granodiorite south of the San Gabriel Fault the foliation strikes generally about northwest-southeast, parallel to the San Gabriel Fault with typically vertical dips, but locally, dips greater than 50 degrees are inclined toward the northeast, towards the San Gabriel Fault. Foliations in the diorite gneiss and Placerita Formation are less well defined, but generally strike about northwest-southeast, and dip typically northward 75 degrees to vertical. Bedding in the sedimentary rocks typically strikes northwest-southeast, parallel to the San Gabriel Fault, although locally, especially near the other faults, bedding strikes northeast or is overturned. Dips here are between 10 and 70 degrees.

A number of folds have been mapped in the western half of the Sunland Quadrangle. Just south of the San Gabriel Fault, a short parallel anticline and syncline trending southwest-northeast and a short syncline trending northwest-southeast were mapped in the Saugus Formation. Dips on the limbs of the folds are between 5 and 30 degrees, but locally as high as 50 degrees. The Merrick Syncline lies between the San Fernando Fault and the Lakeview Segment of the San Fernando Fault, in the Saugus Formation. The axial trace of the syncline trends northwest-southeast. The syncline is asymmetric with dips between 25 and 70 degrees to the north on the southern limb, and between 50 degrees to the south to an overturned 75 degrees to the northeast on the northern limb. Exposed in the hills south of Tujunga Valley are an alternating set of two anticlines and two synclines that trend nearly east-west. Dips of the folded Modelo Formation strata are typically between 5 and 20 degrees but locally are up to 30 degrees.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Sunland Quadrangle was prepared by using interpretation of stereo-paired aerial photographs of the study area and limited field reconnaissance (Treiman, unpublished). All areas containing landslides identified in the previous work of: Oakeshott (1958); Morton and Streitz (1969); Morton\ (1975); Weber (1982); and Dibblee (1991) where re-evaluated during the aerial photograph interpretation conducted for this investigation. Some of the landslides identified in the previous work were not included in the landslide inventory because in our reevaluation, it was concluded the feature was not a landslide. Many additional landslides were identified, and the boundaries of many of the landslides identified in the previous work were modified. Additionally, all landslides shown on the digital geologic map (Yerkes, 1996) were verified, re-mapped or removed during preparation of the inventory maps. 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.

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 Sunland Quadrangle geologic map were obtained from the City of Los Angeles, Department of Public Works (see Appendix A). Due to land-ownership patterns within the quadrangle, residential and commercial development has taken place primarily on the gently sloping alluvial areas of the San Fernando Valley, and on the hills at the north end of the Verdugo Mountains. Consequently, shear strength information was scarce or entirely lacking for many rock units in the San Gabriel Mountain portion of the quadrangle. Where appropriate, strength data from rock units in adjacent quadrangles were used to characterize the shear strength of rock units within the Sunland Quadrangle. The use of the data was considered appropriate where the rock units were similar in lithology, in fairly close proximity (within a few miles of the Sunland Quadrangle), and where generally along the same strike as the rock units within the Sunland Quadrangle. One shear test report from the Burbank Quadrangle just south of the Sunland Quadrangle, and 4 shear test reports from the San Fernando Quadrangle were used to help characterize the Topanga Formation in the Sunland Quadrangle.

The locations of rock and soil samples taken for shear testing, within the Sunland Quadrangle and immediately south in the Burbank Quadrangle, are shown on Plate 2.1. The four samples taken in the San Fernando Quadrangle are shown in the evaluation report for that 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. 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.

The crystalline rocks of the San Gabriel Mountains, as a group, have engineering characteristics different from other rock units in the quadrangle, yet very few shear test results were available for them from the quadrangle, or from adjacent quadrangles. Thus some assumptions had to be made about the choice of phi value for the rock group, based on field observations and comparisons with other rock units. The ancient crystalline bedrock in the western San Gabriel Mountains is pervasively fractured. This pervasive fracturing is the dominant physical characteristic of all the crystalline rocks, and it appears to dominate the engineering behavior of the rocks, regardless of their mineralogy, age, or metamorphic history. Although they are pervasively fractured, the rocks support some of the steepest slopes in the quadrangle, and are, therefore, likely to be some of the strongest rocks in the quadrangle. For the purpose of slope stability analysis, all the crystalline rocks of the San Gabriel Mountains and Verdugo Mountains were consolidated into one group (Kgr), and this group was designated as the highest strength group. A phi value of 38 degrees was chosen to represent the group, based on phi values published in rock mechanics and engineering geology text books (Franklin and Dusseault, 1989; Hoek and Bray, 1981; and Jumikis, 1983) and comparison with shear test results for the group. The value of 38 degrees was in the middle of the range of the few shear test results that were collected from the quadrangle and the surrounding area.

Existing landslides (Qls) were assigned a phi of 14 for stability analysis calculations for this quadrangle. None of the geotechnical reports reviewed for the quadrangle contained any direct shear tests run on actual slide plane material, but there were a few such test results for nearby quadrangles. The phi values for slide plane material actually tested had a wide range, and 14 was near the low end of this range. In those geotechnical reports that provided slope stability calculations, conservative assumed phi values were generally chosen, and 14 was again on the low end of the range of values used.

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

SUNLAND QUADRANGLE SHEAR STRENGTH STATISTICS

	Formation Name	Number of Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Kgr*	0				Kgr*	38
GROUP 2	Tm-fbc	20	33.9/35	34.6/34	362/300	Td, Tcs-fbc	35
	Qa*	24	33.5/33			Tmc1-fbc, Tvz-fbc	
	Ttc-fbc	18	33.8/33			Tb	
	Tp-fbc	5	33.6/35				
GROUP 3	Tm-abc	17	27.8/29	29.6/30	348/255	Tmc2-fbc	30
	Tp-abc	6	28.2/27				
GROUP 4	Ttc-abc	7	24.7/25	24.7/26	757/490	Tcs-abc, Tmc1-abc	26
GROUP 5	Qls	0		14	400	Qls*	14**

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse grained material strength
Kgr* = pre-Tertiary crystalline units
Qa* = af (fill) and Quaternary units
* = subunits of these formations have been combined
** = lowest calculated phi vaule was accepted as representative phi value for landslides

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

SHEAR STRENGTH GROUPS FOR THE SUNLAND QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
An	Tm-fbc	Tm-abc	Ttc-abc	Qls
dgn	Ttc-fbc	Tp-abc	Tmz	
gb	Tp-fbc	Qs-abc		
gbm	Tb			
gd	Qs-fbc			
pCm	af & acf			
pm	Qab			
	Qal			
	Qao			
	Qao1			
	Qof1			
	Qt			
	Qvoa			
	Qvof & Qvof1			
	Qw			

Table 2.2. Summary of the Shear Strength Groups for the Sunland 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 Sunland 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 7.6
Modal Distance:	2.6 to 16.6 km
PGA:	0.55 to 0.77 g

The strong-motion record selected for the slope stability analysis in the Sunland Quadrangle was the Channel 3 (north horizontal component) Pacoima-Kagel Canyon Fire Station recording from the magnitude 6.7 Northridge earthquake (Shakal and others, 1994). This record had a source to recording site distance of 2.6 km and a PGA of 0.44 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 0.074, 0.13 and 0.21g. 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 Sunland Quadrangle.

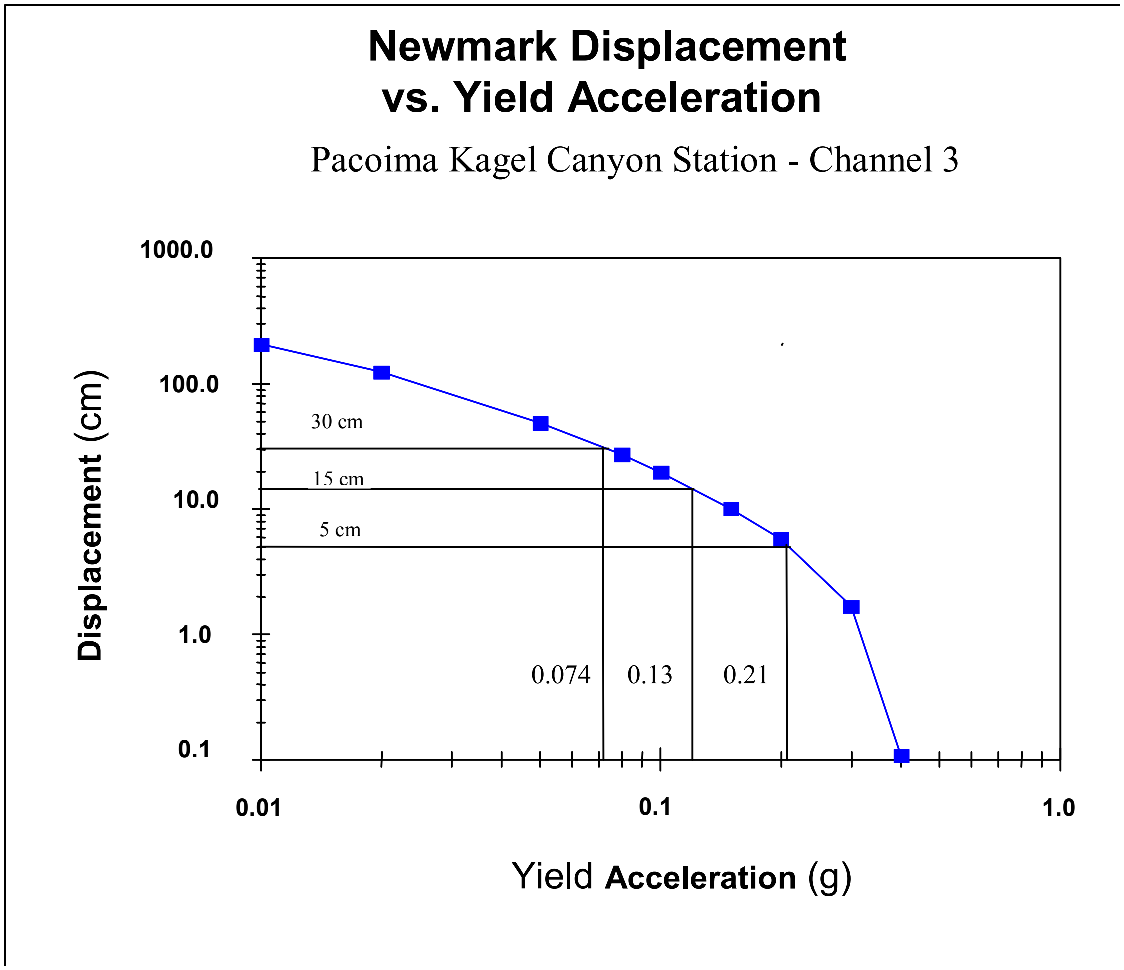

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Pacoima-Kagel Canyon Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake. Record from California Strong Motion Instrumentation Program (CSMIP) Station 24088.

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 0.074g, 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 0.074g and 0.13g, 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 0.13g and 0.21g, 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 0.21g, 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.

SUNLAND QUADRANGLE
HAZARD POTENTIAL MATRIX

SLOPE CATEGORY

Geologic Material Group	Mean Phi	I 0-11%	II 11-18%	III 18-25%	IV 25-34%	V 35-40%	VI 40-44%	VII 44-48%	VIII 48-59%	IX 59-69%	X 69-74%	XI >74%
1	38	VL	VL	VL	VL	VL	VL	VL	VL	L	M	H
2	34	VL	VL	VL	VL	VL	VL	L	M	H	H	H
3	29	VL	VL	VL	VL	L	M	M	H	H	H	H
4	25	VL	VL	VL	L	M	H	H	H	H	H	H
5	14	L	M	H	H	H	H	H	H	H	H	H

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

The February 9, 1971 San Fernando earthquake triggered widespread rockfalls, soil falls, debris slides, avalanches, and slumps in the foothills of the San Gabriel Mountains that rise above the Lakeview segment of the San Fernando Fault (Morton, 1975). Most of the failures were shallow debris or soil falls, although the largest landslide triggered by the San Fernando earthquake, a reactivated slump on the east side of Schwartz Canyon, also occurred within the Sunland Quadrangle (Morton, 1975, plate 3). Along the stretch of the Lakeview segment of the San Fernando Fault between Little Tujunga and Big Tujunga canyons a series on nearly continuous landslides resulted from an unusual mechanism described by Kahle (1975, p. 129). The combination of shaking and oversteepening due to overthrusting of upper plate material upward and southward towards the valley generated the thin soil falls along the fault trace.

The 1994 Northridge earthquake caused a number of relatively small, shallow slope failures in the Sunland Quadrangle (Harp and Jibson, 1995), although they were neither as widely distributed nor as abundant as those triggered by the 1971 event.

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 25 percent.
3. Geologic Strength Group 3 is included for all slopes steeper than 34 percent.
4. Geologic Strength Group 2 is included for all slopes steeper than 44 percent.
5. Geologic Strength Group 1 is included for all slopes greater than 59 percent.

This results in 22 percent of the quadrangle, including National Forest Service land, lying within the earthquake-induced landslide hazard zone for the Sunland Quadrangle.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

(The numbers in parentheses are those tests taken from adjacent quadrangles)

SOURCE	NUMBER OF TESTS SELECTED
City of Los Angeles, Department of Building and Safety	**97 (5)**
Total Number of Shear Tests	**97 (5)**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Sunland 7.5-Minute Quadrangle, Los Angeles 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.

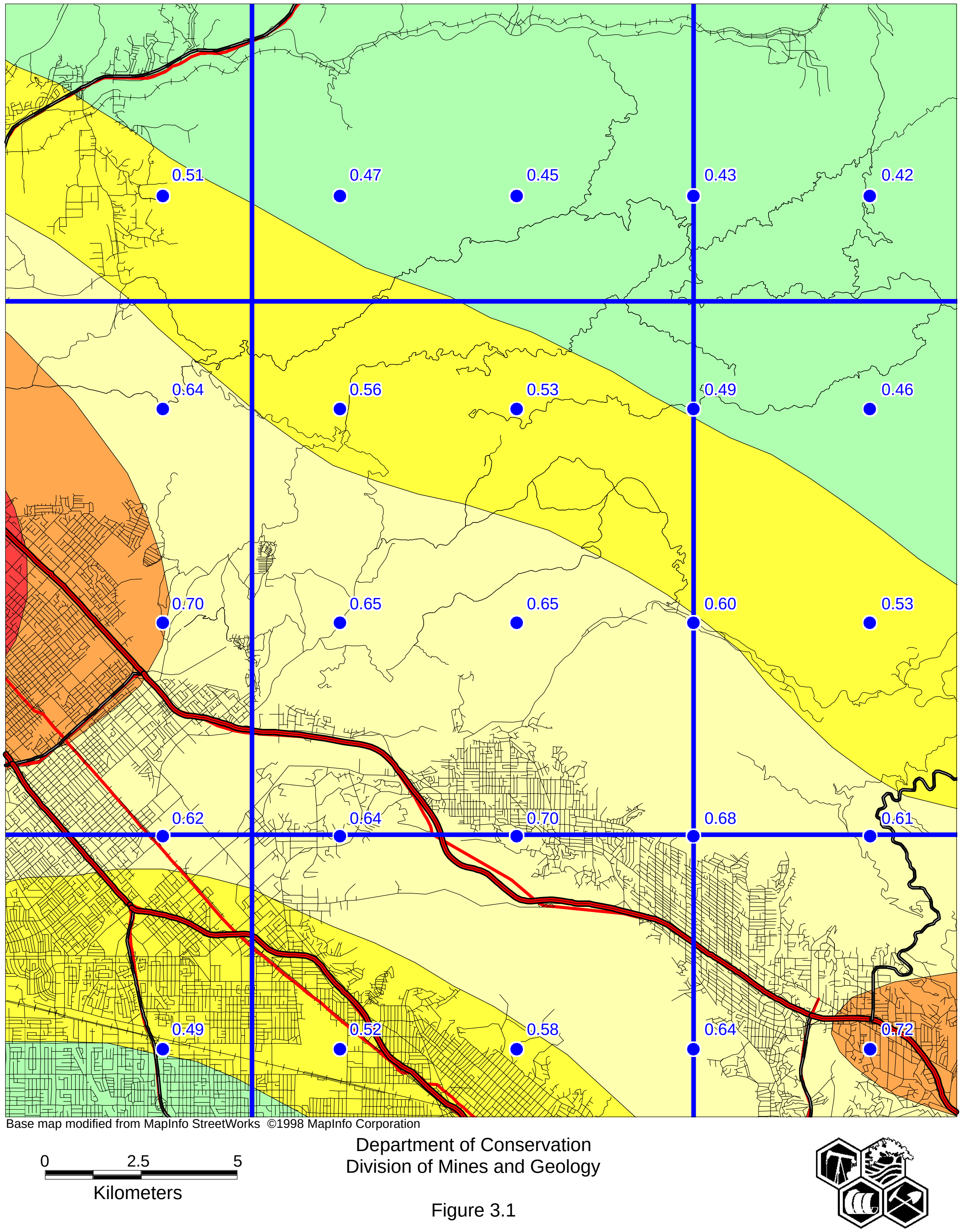
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. 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

SUNLAND 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Department of Conservation
Division of Mines and Geology

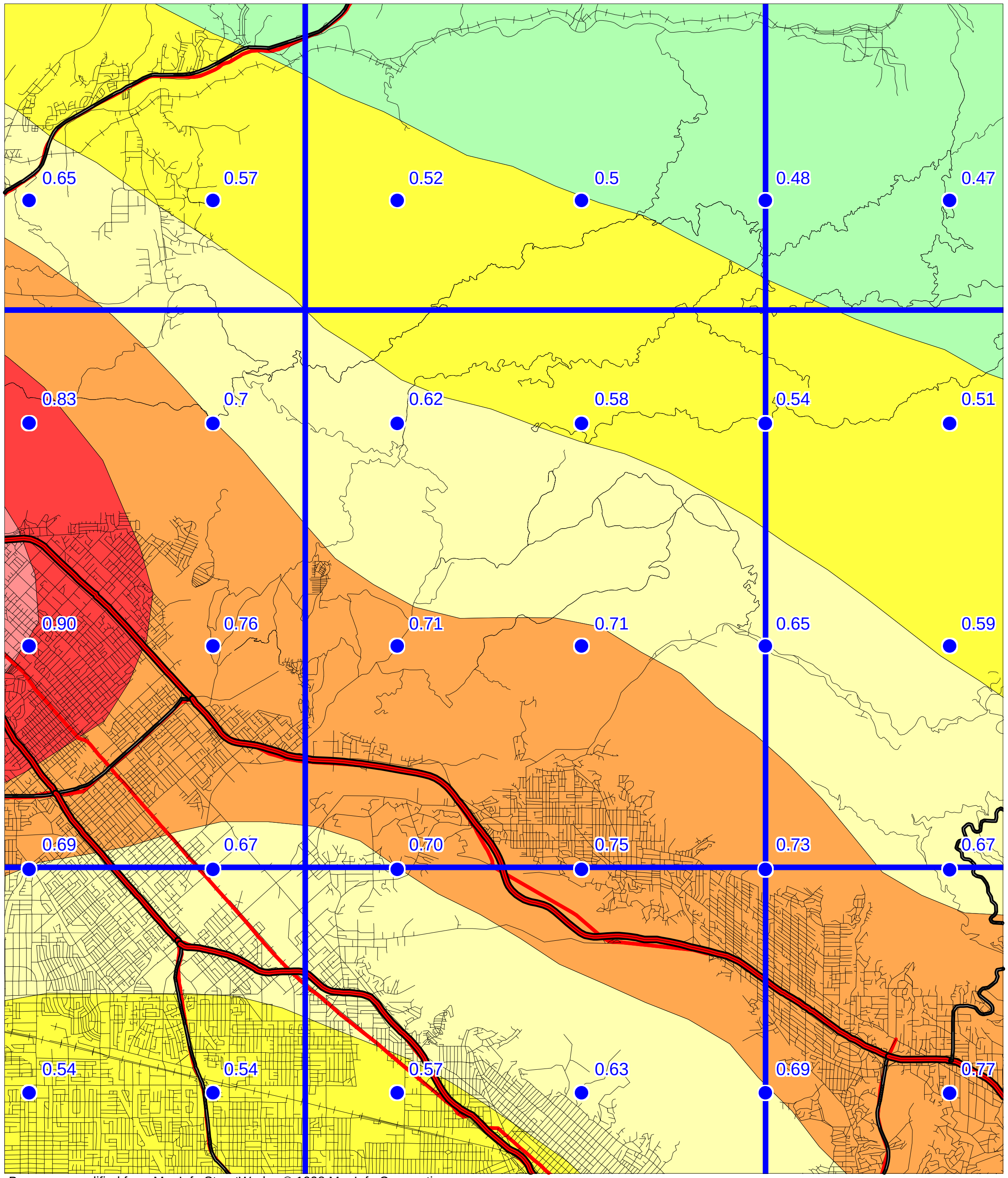
Figure 3.1

SUNLAND 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

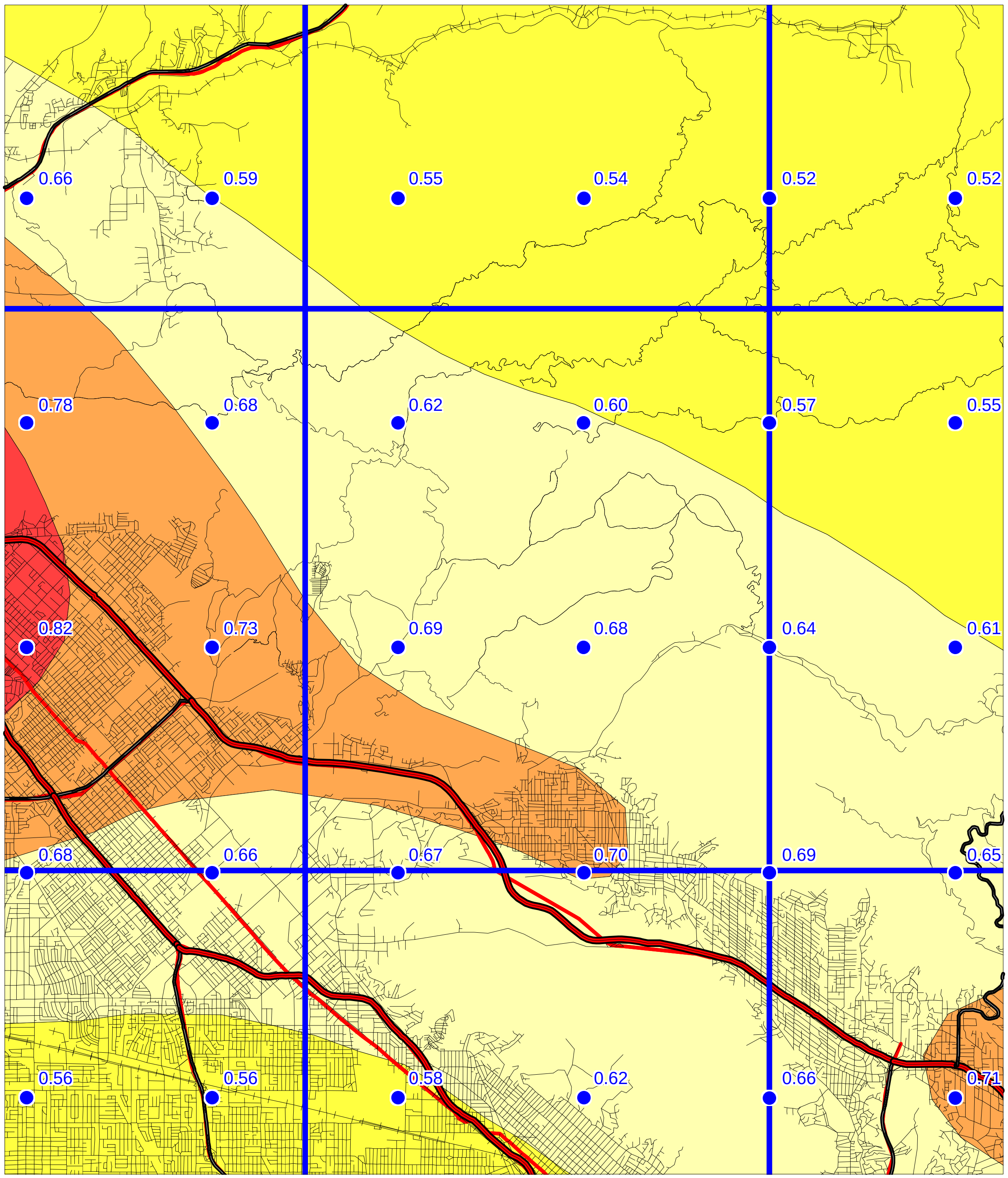
Figure 3.2

SUNLAND 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

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.

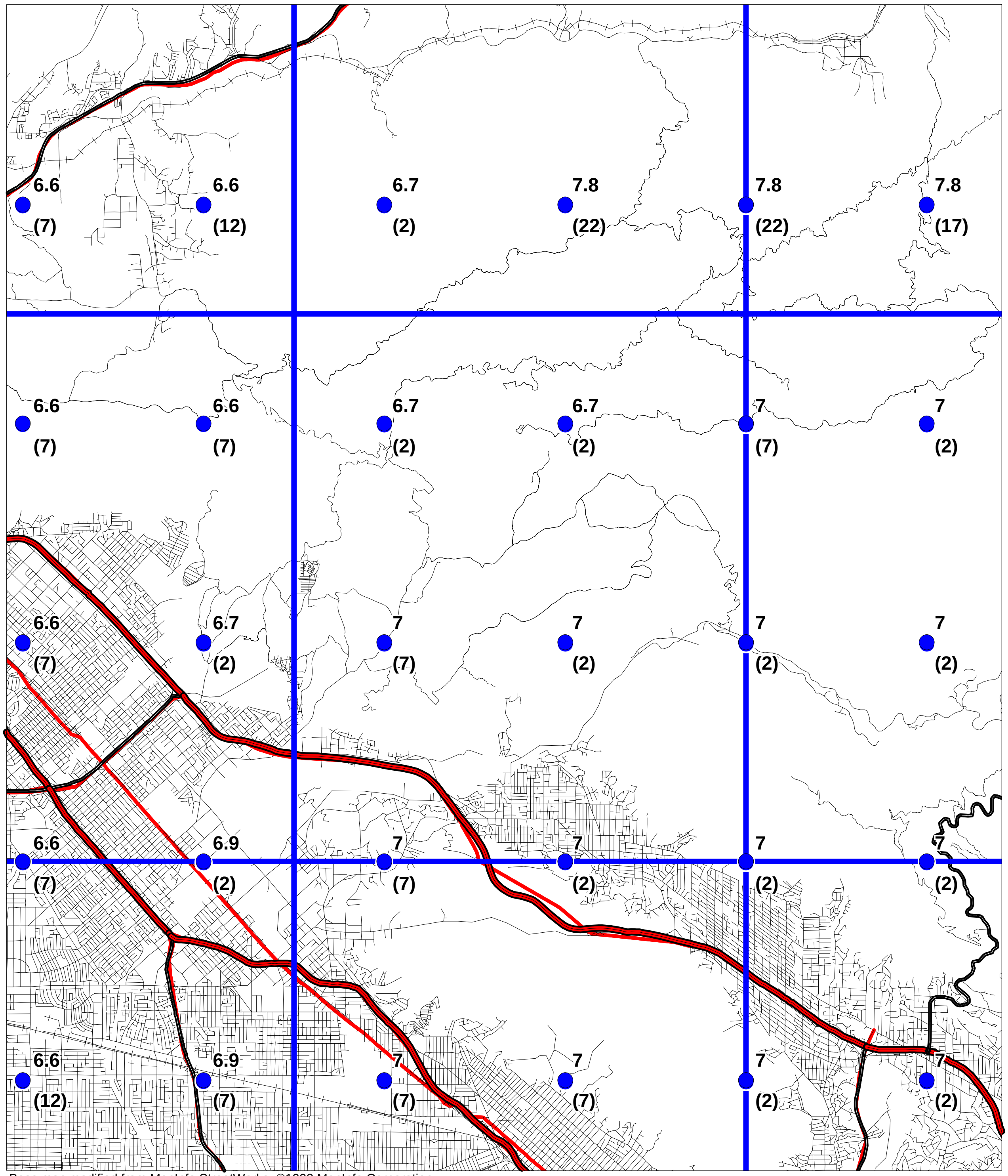
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

SUNLAND 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

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



Department of Conservation
Division of Mines and Geology

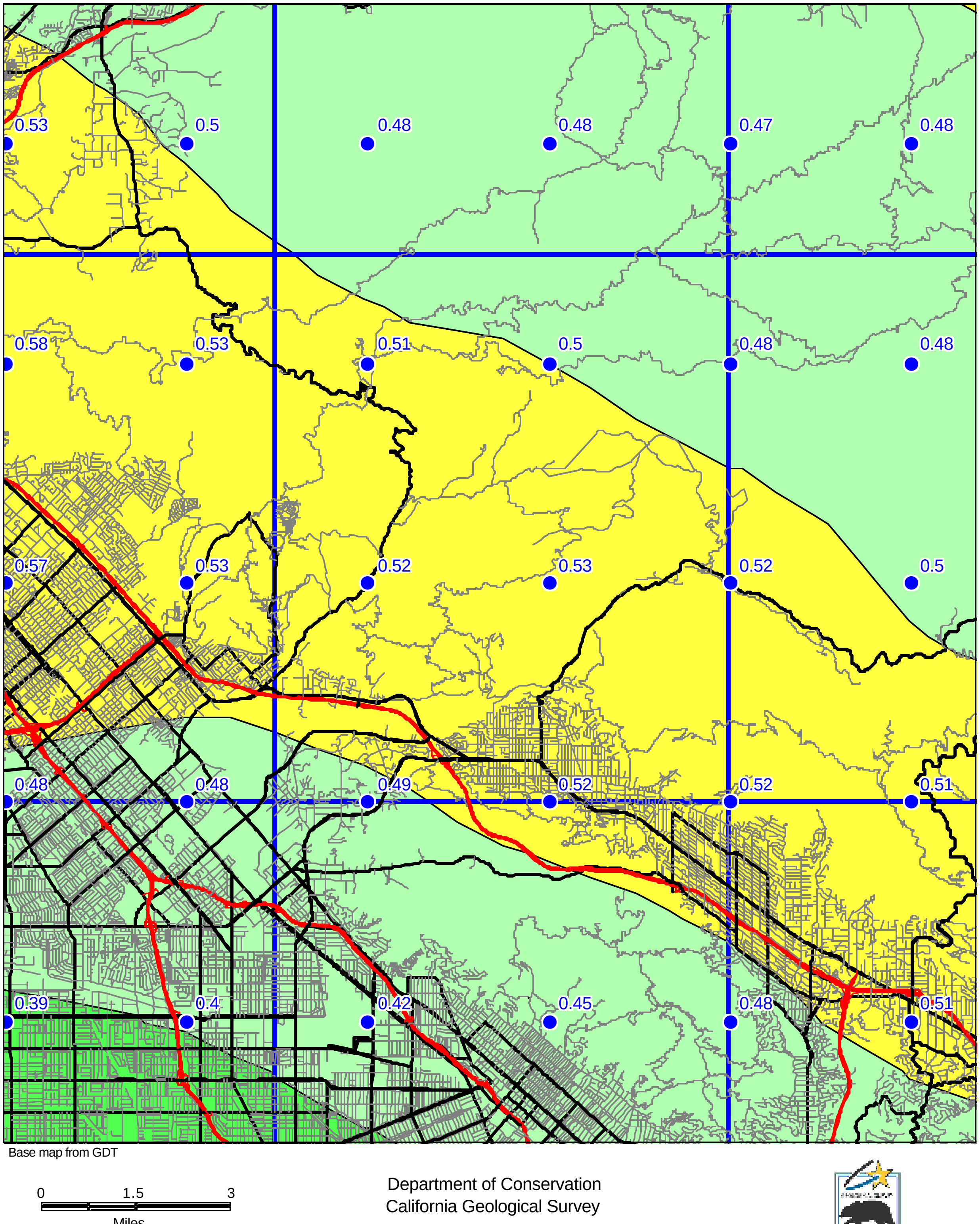
Figure 3.4

SUNLAND 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

LIQUEFACTION OPPORTUNITY



Department of Conservation
California Geological Survey

Figure 3.5

USE AND LIMITATIONS

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

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

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

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

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

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

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

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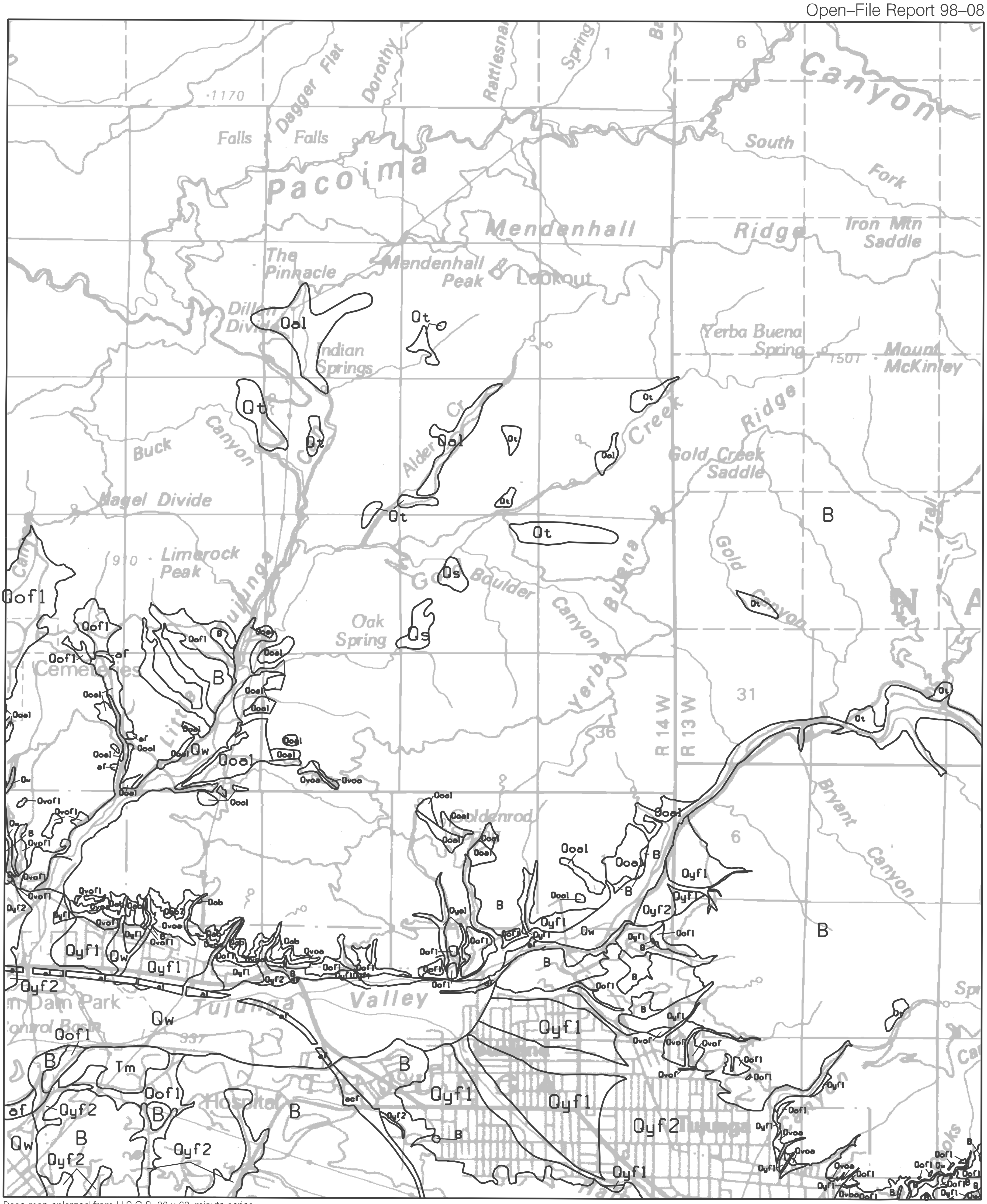


Base map enlarged from U.S.G.S. 30 x 60–minute series

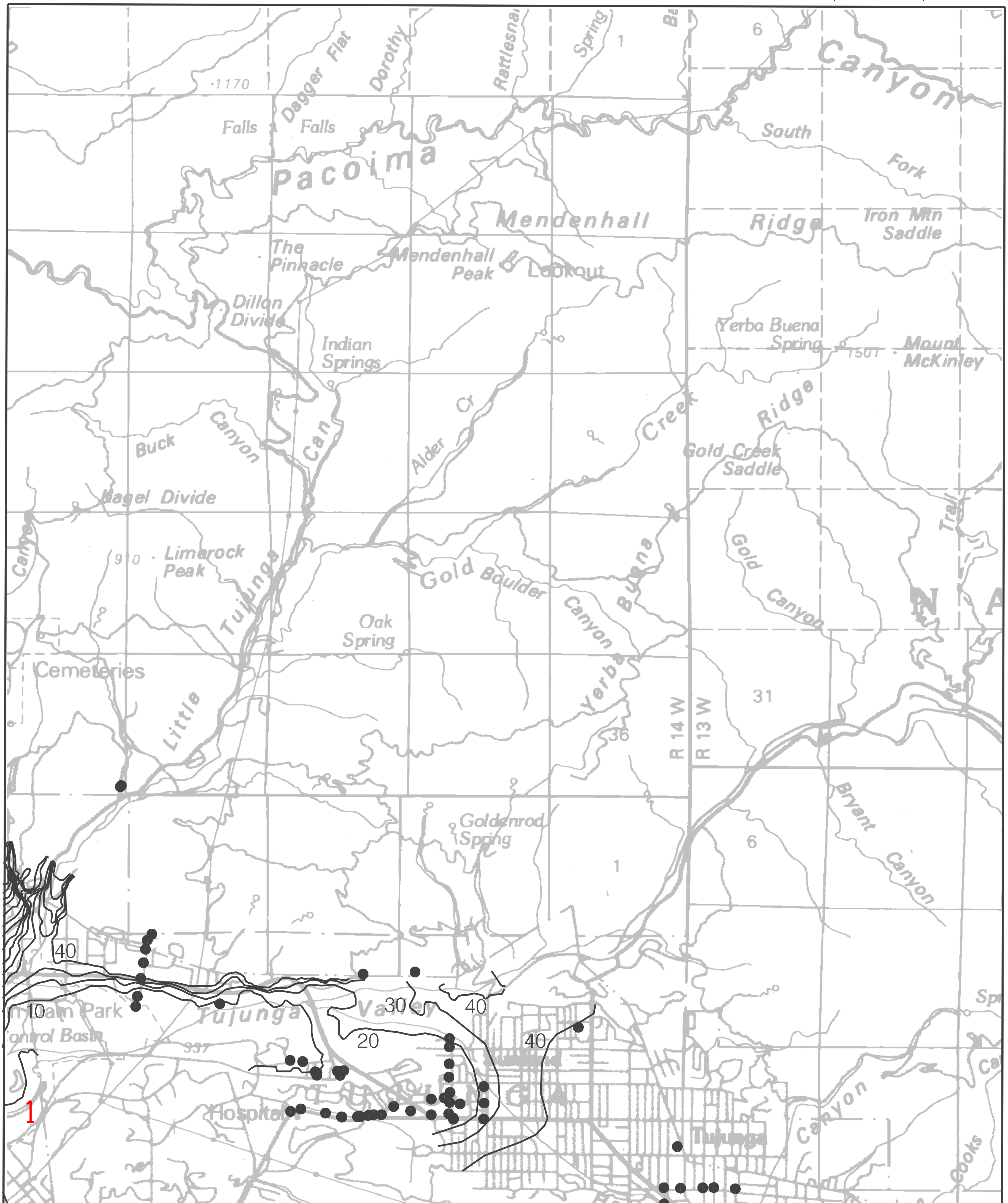
Plate 1.1 Quaternary Geologic Map of the Sunland Quadrangle.

See Geologic Conditions section in report for descriptions of the units.

B = Pre–Quaternary bedrock.

ONE MILE

SCALE



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, Sunland Quadrangle.

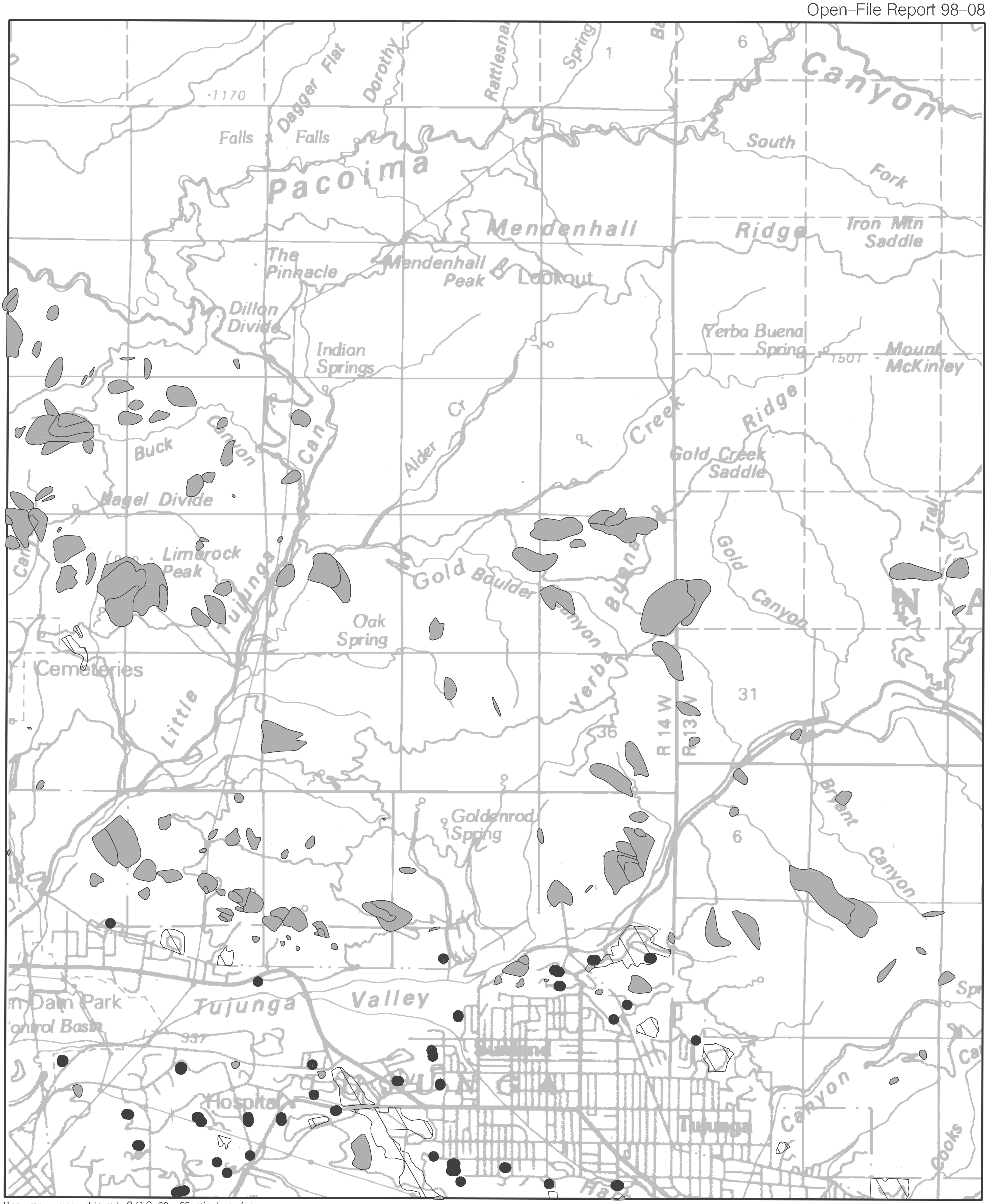
● Borehole Site

⁓ 30 ⁓ Depth to ground water in feet

1 Site of historical earthquake–generated liquefaction. See "Areas of Past Liquefaction" discussion in text.

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, Sunland Quadrangle.

● shear test sample location — landslide — areas of significant grading

ONE MILE

SCALE