SEISMIC HAZARD ZONE REPORT 088

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

2003

DEPARTMENT OF CONSERVATION
California Geological Survey

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Southern California Regional Office
888 South Figueroa Street, Suite 475
Los Angeles, CA 90017
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801 K Street, MS 14-31
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Bay Area Regional Office
345 Middlefield Road, MS 520
Menlo Park, CA 94025
(650) 688-6327

List of Revisions – Condor Peak SHZR 088	
5/31/05	BPS address correction, web link updates
10/10/05	Bay Area Regional Office and Southern California Regional Office addresses updated

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Condor Peak 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 16 square miles at a scale of 1 inch = 2,000 feet.

The Condor Peak Quadrangle is a few miles east of the communities of Sunland and Tujunga and 15 to 20 miles north of the Los Angeles Civic Center in central Los Angeles County. Most of the quadrangle lies within the Angeles National Forest and is unincorporated Los Angeles County land. Only about 15 square miles of the southwestern quarter and a square mile surrounding Hidden Springs along the eastern boundary of the quadrangle have been evaluated. Small portions of the cities of Los Angeles, Glendale, and Pasadena extend into the southwestern quarter. The quadrangle is characterized by steep, rugged, deeply dissected terrain typical of the western San Gabriel Mountains. The drainage from the mountains follows Big Tujunga Canyon across the southwestern quarter. Elevations within the southwestern quarter range from 1,740 feet at the western boundary to 5,074 feet on top of Mt. Lukens, which is 1.3 miles from the canyon bottom. Access to the region is limited to Big Tujunga Canyon Road and a few unpaved Forest Service roads.

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 percent probability of exceedance in 50 years.

In the Condor Peak Quadrangle the liquefaction zone is restricted to the bottoms of Big Tujunga Canyon and Mill Creek Canyon near Hidden Springs. Although the study area is underlain by crystalline bedrock, the rocks are highly jointed and fractured and most of the terrain is very steep. Landslides and large rock slides are widespread and abundant. These conditions contribute to an earthquake-induced landslide zone that covers about 74 percent of the area evaluated within the quadrangle.

How to view or obtain the map

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

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

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

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

INTRODUCTION

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

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

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

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

SECTION 1
LIQUEFACTION EVALUATION REPORT

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

By
Elise Mattison, Janis L. Hernandez, and Allan G. Barrows

California Department of Conservation
California Geological Survey

PURPOSE

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

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

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

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

BACKGROUND

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

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

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

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

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Condor Peak Quadrangle mainly consist of canyons. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. 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 Condor Peak Quadrangle covers about 62 square miles in central Los Angeles County two to four miles east of the communities of Sunland and Tujunga and 15 to 20 miles north of the Los Angeles Civic Center. Nearly the entire quadrangle lies within the Angeles National Forest and consists of unincorporated Los Angeles County land. Only about 15 square miles of the southwestern quarter and approximately one square mile surrounding Hidden Springs along the eastern boundary of the quadrangle have been evaluated for zoning purposes. This land is under the jurisdiction of the cities of Los Angeles, Glendale, and Pasadena or is privately owned within the national forest.

Land within the quadrangle is steep, rugged, deeply dissected terrain typical of the western San Gabriel Mountains. Big Tujunga Creek flows west from Big Tujunga Dam, which is about a mile south of the center of the quadrangle. In the southwestern quarter of the quadrangle, drainage from the mountains flows into Big Tujunga Canyon. Elevations within this quarter of the quadrangle range from 1,740 feet at the western boundary to 5,074 feet on Mt. Lukens, which is 1.3 miles south of the bottom of Big Tujunga Canyon. Access to the region is via Big Tujunga Canyon Road from the west and Angeles Crest Highway (State Highway 2) from the south. The mountainous areas are accessed by a few unpaved Forest Service roads.

GEOLOGY

Bedrock and Surficial Geology

Late Quaternary alluvial and fluvial sedimentary deposits and artificial fill generally are susceptible to liquefaction. CGS evaluated the areal distribution of these types of deposits in the Condor Peak Quadrangle using a digital version of a portion of the geological map of the San Gabriel Fault Zone and vicinity by Weber (1982, Plate 1B; map segment D), provided by SCAMP, the Southern California Areal Mapping Project (Morton and Kennedy, 1989). Other geologic references reviewed for this project include those by Oakeshott (1958) and Crook and others (1987, Plate 2.1). CGS geologists modified the digital geologic map by deleting landslide deposits and revising contacts between bedrock and surficial units to better conform to the topographic contours of the U.S. Geological Survey 7.5-minute quadrangle. Additionally, they modified the digital geologic map to reflect the more recent mapping in the area and include interpretations of observations made during the landslide inventory prepared from aerial photographs and field reconnaissance (Plate 1.1). In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units.

Quaternary deposits cover about one square mile of the study area, or 2 percent of the Condor Peak Quadrangle. The remainder of the study area is mostly crystalline basement rock (Plate 1.1). Less than half of the Quaternary deposits in the study area are mapped as Holocene units.

Weber (1982) mapped artificial fill (af) in Big Tujunga Canyon between the mouths of Breakneck and Fusier canyons, and along Tujunga Canyon Road at Vogel Flats. The lower reaches of Maple Canyon, less than a mile south of Big Tujunga Dam, have since been filled and terraced. There is terraced fill also in Big Tujunga Canyon at the mouth of Maple Canyon and down and across Big Tujunga Creek. Los Angeles County placed engineered fill slopes and concrete/shotcrete channel linings along Tujunga Creek, below the dam. Periodically, the county removes debris that accumulates behind the dam during cleanout operations and places it in a small, unnamed canyon north of Maple

Canyon (Manolito LaSao, Los Angeles County Materials Engineering Division, oral communication, 2002).

Younger alluvium (Qal) includes modern stream channel and overbank river and floodplain deposits of loose to medium dense sand, silty sand, and minor clay. Commonly, the active channel deposits include gravelly sand, with scattered to concentrated boulders. It also includes colluvium or slope wash where the deposits are large enough to map at 1:24,000 scale. Younger alluvium was mapped in Big Tujunga Canyon, and in the eastern part of the study area, along Tujunga and Mill creeks.

Weber (1982) mapped slightly older alluvium (Qalo) at several places along Big Tujunga Canyon. It forms gently sloping surfaces at Wildwood, La Paloma Flat, and elsewhere bordering the modern creek channel. Qalo is mostly fine to coarse sand and gravel with some clay, weakly consolidated, and light brown. Weber (1982, Plate 2) described it as "dissected and perhaps slightly uplifted." In some places these deposits probably consist of a "terrace deposit" overlain by material that accumulated from slope wash and other surficial processes in the steep canyon.

The Quaternary unit covering the largest area is older alluvium (Qoa as mapped by Weber, 1982), which consists of very poorly consolidated sand and gravel and, locally, includes terrace deposits and remnants of older fan deposits. In roadcuts, Qoa is a light brown to tan crudely stratified fine to coarse gravel with some silt and sand. Where observable in roadcuts the deposits are as much as several tens of feet thick. These deposits are isolated and elevated above the modern drainage course in Big Tujunga Canyon and are evidence of previous stream activity in the canyon. Weber (1982) inferred relatively young surface fault rupture along strands of the San Gabriel Fault where deposits of Qoa appear to have been displaced.

Bedrock exposed in the Condor Peak Quadrangle is a complex mixture of Precambrian to Mesozoic granitic and gneissic crystalline units. Large landslide deposits are scattered across the area, especially on the northeastern slopes of Mt. Lukens (Morton and Streitz, 1969). See the earthquake-induced landslide portion (Section 2) of this report for further details.

Structural Geology

Regional faulting is the primary structural feature of the southwestern quarter of the Condor Peak Quadrangle. The main strand of a cluster of northwest-trending faults that belong to the San Gabriel Fault Zone lies along the northern side of Big Tujunga Canyon. Big Tujunga Canyon Road winds back and forth across the fault in several places. East of the Big Tujunga (Forest Ranger) Station the San Gabriel Fault strikes more easterly and continues for more than 30 miles through the center of the San Gabriel Mountains. Also near the Ranger Station, a prominent southeasterly striking fault diverges from the main San Gabriel Fault and follows, in part, the canyon of Vasquez Creek. This fault, called the Vasquez Creek Fault by Miller (1934) and shown as such on the State Fault Map (Jennings, 1994), has also been called the Sierra Madre Fault by many workers in the past (for example, Jennings and Strand, 1969). The Vasquez Creek Fault is generally

interpreted as a "cross" fault between the San Gabriel Fault Zone and the Sierra Madre Fault Zone north-dipping reverse faults that bounds the base of the San Gabriel Mountains to the south in Altadena and La Canada (Crook and others, 1987). Weber (1982) mapped a western strand of this fault zone that he called the Tujunga segment of the San Gabriel Fault. It has also been reported as the south branch of the San Gabriel Fault (Smith, 1978).

Although the San Gabriel Fault in this quadrangle does not meet the criteria required for inclusion in an Official Earthquake Fault Zone prepared by CGS, the San Gabriel Fault is considered to be a major potential seismic source (Cramer and Petersen, 1996; Petersen and others, 1996). Evidence of Holocene surface rupture that is sufficient for zoning, such as that found in the Sunland Quadrangle to the west (DOC, 1979), has not been found in the Condor Peak Quadrangle.

GROUND-WATER CONDITIONS

Depth to ground water is fundamental to liquefaction hazard studies. Liquefaction of subsurface sediments can result in structure-damaging ground failure at the surface through differential settlement or lateral spreading. Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less, where saturation reduces the effective normal stress (Youd, 1973). Natural processes and human activities cause large fluctuations in ground-water levels over time, so it is impossible to specify what conditions will exist when ground shaking occurs. To address this uncertainty, CGS develops ground-water maps that show depths to historically shallow levels recorded from water wells and boreholes. The resultant maps differ considerably from conventional ground-water maps that are based on measurements collected during a single season or year.

For purposes of seismic hazard zoning in the Condor Peak study area, depth to shallow ground water in alluviated canyon environments is the elevation difference between the measured or estimated high water surface and the upper limit of adjacent liquefiable Quaternary deposits. Plate 1.2 shows a range of depth to historically shallow ground water within the canyons because the map scale disallows detailed contour lines.

PART II

LIQUEFACTION POTENTIAL

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

mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

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

LIQUEFACTION SUSCEPTIBILITY

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

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

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 percent probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in CGS's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Condor Peak study area, CGS has calculated PGAs of 0.56 to 0.59 g, resulting from an earthquake of magnitude 7.0. The PGA and magnitude values are based on de-

aggregation of the probabilistic hazard at the 10 percent in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion portion (Section 3) of this report for further details.

LIQUEFACTION ZONES

Criteria for Zoning

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

1. Areas known to have experienced liquefaction during historical earthquakes

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

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

4. Areas where existing geotechnical data are insufficient

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

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10 percent 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 percent 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 percent 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 Condor Peak Quadrangle is summarized below.

Areas of Past Liquefaction

No documentation of historic or paleoseismic liquefaction in the Condor Peak Quadrangle was found during this study.

Artificial Fills

In the Condor Peak study area, most artificial fill areas large enough to show at the scale of mapping (1:24,000) are considered to be properly engineered, and therefore not zoned for liquefaction. The smallest volume of fill, above Vogel Flats, is above the hypothetical ground-water table and is, therefore, excluded from the zone.

Areas with Sufficient Existing Geotechnical Data

Geotechnical logs of boreholes in the Condor Peak study area were not found during the data collection phase of this study.

Areas with Insufficient Existing Geotechnical Data

Younger alluvium (Qal) and slightly older alluvium (Qalo) in the Condor Peak study area are designated zones of required investigation for liquefaction where considered saturated. Liquefaction zonation is based on above criterion 4a for Qal and 4b for Qalo.

ACKNOWLEDGMENTS

The authors would like to thank Robert Larson and Manolito LaSao from the Los Angeles County Materials Engineering Division who provided assistance and information about Big Tujunga Dam. Also, at CGS, Terilee McGuire and Bob Moscovitz provided GIS support, and Barbara Wanish and Ross Martin prepared the final liquefaction hazard zone maps and graphic displays for this report.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

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

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

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Condor Peak 7.5-Minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking), complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://www.conservation.ca.gov/CGS/index.htm

BACKGROUND

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

METHODS SUMMARY

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

- Digital terrain data were used to provide an up-to-date representation of slope

gradient and slope aspect in the study area

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

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

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

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

SCOPE AND LIMITATIONS

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

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Condor Peak 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 Condor Peak 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 Condor Peak Quadrangle covers an area of about 62 square miles in central Los Angeles County about two to four miles east of the communities of Sunland and Tujunga and 15 to 20 miles north of the Los Angeles Civic Center. Nearly the entire quadrangle lies within the Angeles National Forest and consists of unincorporated Los Angeles County land. Only about 15 square miles of the southwestern quarter and approximately one square mile surrounding Hidden Springs along the eastern boundary of the quadrangle have been evaluated for zoning purposes. These areas are either under the jurisdiction of the cities of Los Angeles, Glendale, and Pasadena or privately owned within the national forest.

Land within the quadrangle is steep, rugged, deeply dissected terrain typical of the western San Gabriel Mountains. The drainage from this mountainous region travels toward Big Tujunga Canyon, into Big Tujunga Creek, which then flows westward across the southwestern quarter of the quadrangle. Elevations within this quarter of the quadrangle range from 1,740 feet at the western boundary to 5,074 feet on top of Mt. Lukens, which is 1.3 miles from the canyon bottom. Access to the region is via Big Tujunga Canyon Road from the west and Angeles Crest Highway (State Highway 2) from the south, which intersects with the Angeles Forest Highway. The steep mountainous areas are accessed by a few unpaved Forest Service roads.

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 in the form of a digital topographic map. Within the Condor Peak Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, prepared from the 7.5-minute quadrangle topographic contours based on 1957 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy. New topography within some recently filled areas in the southern part of the quadrangle was evaluated in the field and changes were incorporated into the final landslide hazard zone map.

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

GEOLOGY

Bedrock and Surficial Geology

The primary source of bedrock geologic mapping used in this slope stability evaluation was obtained from the Southern California Areal Mapping Project [SCAMP] (Morton and Kennedy, 1989). SCAMP provided us with a digital version of the Condor Peak portion of the preliminary geologic map of the San Gabriel Fault Zone (Weber, 1982, Plate 1B; map segment D). This map was also used as the Quaternary surficial geologic map for the Condor Peak Quadrangle.

CGS geologists modified the digital geologic map in the following ways. Landslide deposits were deleted from the map so that the distribution of bedrock formations and a newly created landslide inventory would exist on separate layers for the hazard analysis. Contacts between bedrock and surficial units were revised to better conform to the topographic contours of the U.S. Geological Survey 7.5-minute quadrangle. Air-photo interpretation, digital orthophoto review, and field reconnaissance was performed to assist in adjusting contacts between bedrock and surficial geologic units, and to review geologic unit lithology and geologic structure. In the field, observations were made of exposures, aspects of weathering and the general surface expression of the geologic units. The relation of the various geologic units to the development and abundance of landslides was also noted.

Bedrock of the Condor Peak Quadrangle consists of Precambrian to Mesozoic igneous and metamorphic granitic and gneissic crystalline bedrock units. The fault-dominated structural framework breaks up the area into many slivers and blocks. This has influenced the nomenclature of the rock units and many workers infer that there has been large-scale strike-slip displacement along the San Gabriel Fault. Miller (1934), Oakeshott (1958), Ehlig (1975), and Powell and others (1983) have described the rocks.

Mesozoic granitic rocks that range in composition from granite to quartz diorite (Oakeshott, 1958) crop out in the southwestern part of the study area. The most common types are light-colored, granodioritic or monzogranitic rocks that are fine to coarse grained, massive to locally foliated, and abundantly sheared and fractured. Weber (1982) chose to designate the rocks in this vicinity as mixtures of granitic and metamorphic rocks (map unit grt + m) due to the widespread scattering of dark metamorphic inclusions in the granitic rocks.

Elongate bands of Precambrian dark gray, biotite-quartz-feldspar gneiss of meta-igneous and/or metasedimentary origin (map unit ms) are exposed east of the Mt. Lukens area. Oakeshott (1958) named similar rocks Mendenhall Gneiss to the west in the Sunland Quadrangle. These rocks and interlayered light-colored granitic rocks (map unit grs) are

well exposed along Angeles Crest Highway (State Highway 2) in the southeastern corner of the evaluated area.

Well exposed along most of Big Tujunga Canyon Road within the study area is a great variety of highly sheared, crushed and jointed mixtures of greenish-gray dioritic gneiss (map unit m) and pinkish intrusive granitic (map unit grs) rocks. Strands of the northwest-trending San Gabriel Fault zone are readily visible in roadcuts as thick grayish-green to bleached clayey gouge seams.

Quaternary alluvial deposits and massive landslide/rockslide breccia deposits that rest upon the bedrock were mapped by Weber (1979; 1982, Plate 2, Explanation of Map Units). The landslide/rock breccia deposits are discussed in the Landslide Inventory section below. Quaternary older alluvial deposits (Qoa) consist of very poorly consolidated sand and gravel, and locally include terrace deposits and remnants of older fan deposits. Where exposed in roadcuts, Qoa is a light brown to tan, crudely stratified, fine to coarse gravel with some silt and sand, and several tens of feet thick. These deposits are isolated and elevated above the modern drainage course in Big Tujunga Canyon and are evidence of geologically young to historic stream activity. Weber (1982) inferred relatively young surface fault rupture along strands of the San Gabriel Fault where deposits of Qoa appear to have been displaced.

Slightly older alluvium (Qalo) occurs at several places along Big Tujunga Canyon where it forms gently sloping surfaces at Wildwood, La Paloma Flat, and elsewhere bordering the modern creek channel. Qalo consists mostly of fine to coarse sand and gravel, is weakly consolidated, and is light brown with some clay. It is described as “dissected and perhaps slightly uplifted” (Weber, 1982). In some places these deposits probably consist of a “terrace deposit” overlain by material that accumulated from slope wash and other surficial processes in the steep canyons.

Younger alluvium (Qal) includes modern stream channel and overbank deposits of loose to medium dense sand, silty sand and minor clay. Commonly, the active channel deposits include gravelly sand, with scattered to concentrated boulders. It also includes colluvium or slope wash where the deposits are large enough to map at 1:24,000 scale. Some areas of artificial fill (af), were mapped in and around Big Tujunga Dam in the southern part of the quadrangle. Some engineered fill slopes and concrete/shotcrete lined channel materials were placed along Tujunga Creek below the dam. The fill slopes have been placed for erosion protection and to stabilize excess soil stockpiles from the dam construction and cleanout operations (M. La Sao, personal communication, 2002).

Structural Geology

Regional faulting is the primary structural feature of the southwestern quarter of the Condor Peak Quadrangle. The main strand of a cluster of northwest-trending faults that belong to the San Gabriel Fault Zone lies along the northern side of Big Tujunga Canyon. Big Tujunga Canyon Road winds back and forth across the fault in several places. East of the Big Tujunga [Forest Ranger] Station, the San Gabriel Fault strikes more easterly and continues for more than 30 miles through the center of the San Gabriel Mountains.

Also near the Ranger Station, a prominent southeasterly striking fault diverges from the main San Gabriel Fault and follows, in part, the canyon of Vasquez Creek. This fault, called the Vasquez Creek Fault by Miller (1934), and shown as such on the State Fault Map (Jennings, 1994), has also been called the Sierra Madre Fault by many workers in the past (for example, Jennings and Strand, 1969). The Vasquez Creek Fault is generally interpreted as a "cross" fault between the San Gabriel Fault Zone and the Sierra Madre Fault Zone, which lies south of the Condor Peak Quadrangle. Weber (1982) mapped a western strand of the Vasquez Creek Fault that he called the Tujunga segment of the San Gabriel Fault. It has also been reported as the south branch of the San Gabriel fault (Smith, 1978).

Although the San Gabriel Fault in this quadrangle does not meet the criteria required for inclusion in the Official Earthquake Fault Zone prepared by CGS, the San Gabriel Fault is considered to be a major potential seismic source (Cramer and Petersen, 1996; Petersen and others, 1996). Evidence of Holocene surface rupture that is required for zoning has not been found in the Condor Peak Quadrangle.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Condor Peak Quadrangle within the study area was prepared. Methods included field reconnaissance, analysis of stereo-paired aerial photographs and digital orthophotos, and a review of previously published (Morton and Streitz, 1969; Weber, 1982) and unpublished (Hart, 2001) landslide mapping. Landslides were mapped at a scale of 1:24,000. Large landslide deposits are scattered across the area, especially on the northeastern slopes of Mt. Lukens (Morton and Streitz, 1969). Weber (1982, Plate 1B) also mapped many landslides using arrow symbols to designate them on the map.

Two types of landslide deposits occur within the Condor Peak Quadrangle: 1) older landslide breccia deposits and 2) large rock slide deposits.

The older landslide breccia deposits range from masses of nearly intact fractured rock, to a coarse disordered breccia of angular blocks. These deposits are readily identifiable where roadcuts expose massive to crudely stratified, well-consolidated accumulations of angular blocks, ranging from pebbles to boulders, composed of igneous and metamorphic rocks. The breccia probably originated as massive or composite rockfalls, talus slides, and debris slides. In many places, such as Grizzly Flat, in the central portion of the study area, Weber (1982, Plate 2) did not differentiate between the breccia deposits and older alluvium, and the area was mapped as a combination of the two units.

Some of the largest and most common landslides are deep rock slides, most of which display locally benched or hummocky topography, but poorly defined boundaries. Most notable is the large landslide complex west and northwest of Big Tujunga Dam, near White Oak Canyon. This slide complex has a large bench with a possible closed depression feature on hill "3228," suggesting some Holocene movement (McCalpin and Hart, 1999). Morton and Streitz (1969) and Weber (1979) also mapped elements of this slide.

Several large rock slides on the northeast side of Mt. Lukens appear to extend to the ridge crest, as suggested by linear sags, sidehill benches and uphill-facing scarps. These sag features have been mapped by McCalpin and Hart (1999), who consider them to be indicative of earthquake-induced ridge-top spreading, and to be related to adjacent landslides. Additionally, these features were identified in the fault evaluation report of the San Gabriel Fault (Smith, 1978) which describes these features along the ridge top as lateral spreading-type features. Paleoseismic trenching at three sites within the greater San Gabriel Mountains, where well-developed ridge-top sags occur, reveals stratigraphic evidence for 2-4 paleoseismic events at each site during Holocene time (McCalpin and Hart, 1999).

Additional landslide types observed within the Condor Peak study area include shallow rock and debris slides and falls with associated scars. Due to the steep slopes and generally hard bedrock materials these shallow slope failures are extremely abundant in the mapped area. Harp and Jibson (1995) mapped approximately ten minor landslides, mostly along road cuts, that they believe were triggered by the 1994 Northridge earthquake. Many of the smaller landslides, including those mapped by Harp and Jibson (1995), were not included in the landslide inventory because of the difficulty in identifying and accurately locating small features at 1:24,000 scale.

For each landslide included on the inventory 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 landslide zoning as described later in this report. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed landslide inventory 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, they first must be ranked based on their overall shear strength. We typically obtain shear strength data for the rock units identified on the geologic map from geotechnical reports prepared by consultants on file with local government permitting departments. Due to the undeveloped nature of the study area, no such data were available.

For the Condor Peak Quadrangle, shear test values used to estimate rock strength were obtained by taking into consideration data from the adjacent Pasadena, Sunland, and Mount Wilson quadrangles. The geologic units were placed into three groups: crystalline rocks, older and younger alluvial deposits and fill materials, and landslide deposits. The groups are based upon average angle of internal friction (average ϕ) and lithologic character of similar geologic materials in the adjacent quadrangles.

As is typical of crystalline rocks elsewhere, the basement rocks of the San Gabriel Mountains, as a group, have engineering characteristics different from other rock units. Because no shear tests were available for them from within the quadrangle, some assumptions had to be made about the choice of phi value for this 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. Paradoxically, they are pervasively fractured yet 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 were consolidated into one group, basement complex, and this group was designated as the highest strength group. A phi value of 38 degrees was chosen to represent the group. This is the mean/median value derived from tests of basement rocks used in the adjacent Pasadena Quadrangle (Wilson and Wills, 1998, Table 2.1). It is also consistent with phi values published in rock mechanics and engineering geology textbooks (Franklin and Dusseault, 1989; Hoek and Bray, 1981; and Jumikis, 1983).

The results of the grouping of geologic materials in the Condor Peak Quadrangle are in Tables 2.1 and 2.2.

Existing Landslides

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

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used. As previously discussed, no shear strength data were available for landslide slip surface materials within the Condor Peak Quadrangle study area, and the value presented in Table 2.1 reflects the strength of similar materials in adjacent quadrangles.

CONDOR PEAK QUADRANGLE SHEAR STRENGTH STATISTICS

	Formation Name	Number of Tests	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Basement complex (crystalline rocks)	0	38	500	m, ms, grs, grt	38
GROUP 2	Older and Younger Alluvial Units and fill	0	32	250	Qoa, Qalo, Qal, af	32
GROUP 3	Qls	0	15	400	Qls	15

Note: Due to the lack of shear strength information in the Condor Peak Quadrangle, all values used in the stability analyses were referenced from data from the adjacent Pasadena, Sunland, and Mount Wilson quadrangles.

Table 2.1. Summary of the Shear Strength Statistics for the Condor Peak Quadrangle.

SHEAR STRENGTH GROUPS FOR THE CONDOR PEAK QUADRANGLE

GROUP 1	GROUP 2	GROUP 3
ms	Qoa	Qls
m	Qalo	
grs	Qal	
grt	af	

Table 2.2. Summary of the Shear Strength Groups for the Condor Peak Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

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

Modal Magnitude:	7.0 to 7.2
Modal Distance:	2.5 km to 6.4 km
PGA:	0.54 g to 0.76 g

The strong-motion record selected for the slope stability analysis in the Condor Peak Quadrangle was the Corralitos record from the 1989 magnitude 6.9 (M_w) Loma Prieta earthquake (Shakal and others, 1989). This record had a source to recording site distance of 5.1 km and a peak ground acceleration (PGA) of 0.64. Although the magnitude from the Corralitos record does not fall within the range of the probabilistic parameters, this record was considered to be sufficiently conservative to be used in the stability analyses. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

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

estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.09, 0.13, and 0.23 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Condor Peak Quadrangle.

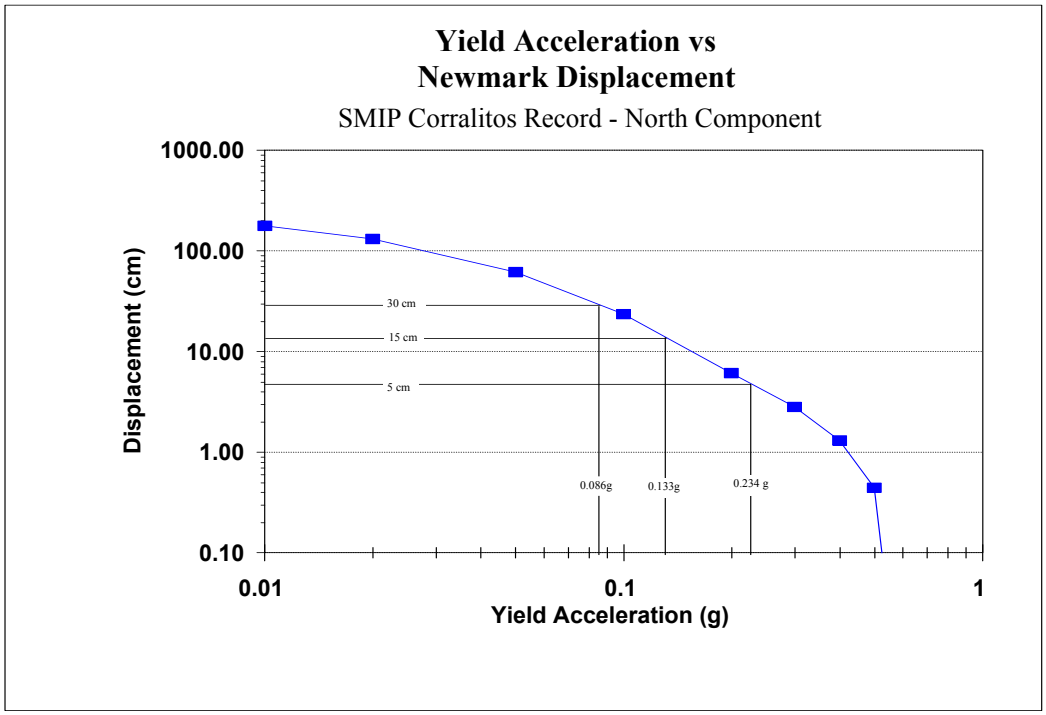

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the 1989 Loma Prieta Earthquake Corralitos Record. Record from California Strong Motion Instrumentation Program (CSMIP) Station 57007.

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 0.09g, 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 0.09g 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 0.23g, 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 0.23g, 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.

CONDOR PEAK QUADRANGLE HAZARD POTENTIAL MATRIX				
Geologic Material Strength Group (Average Phi)	HAZARD POTENTIAL (Percent Slope)			
	Very Low	Low	Moderate	High
1 (38)	0 to 52%	52 to 62%	62 to 69%	>69%
2 (32)	0 to 37%	37 to 47%	47 to 52%	>52%
3 (15)	0 to 4%	4 to 13%	13 to 18%	>18%

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Condor Peak Quadrangle. Values in the table show the range of slope gradient (expressed as percent slope) corresponding to calculated Newmark displacement ranges from the design earthquake for each material strength group.

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. We felt that a long duration, San Andreas fault-type earthquake could be capable of initiating renewed movement in existing deep-seated landslide deposits. Therefore, as indicated by the mapping criteria, all existing landslides identified in the inventory with a definite or probable confidence of interpretation are included in the earthquake-induced landslide hazard zone.

In the adjacent Sunland Quadrangle, 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). The map of landslides triggered by the San Fernando earthquake prepared by Morton (1975, Plate 3) extends only to the eastern border of the Sunland Quadrangle. However, due to the steep terrain in densely jointed basement rocks just east of the Sunland Quadrangle boundary it is highly likely that rockfalls also occurred in Big Tujunga Canyon in the Condor Peak Quadrangle.

The 1994 Northridge earthquake triggered numerous rockfalls and debris falls in the steep-walled canyons and roadcuts in the San Gabriel Mountains (Harp and Jibson, 1995; Barrows and others, 1995, p.69), especially along Big Tujunga Canyon Road (A.G. Barrows, personal observation, January 18, 1994). These documented earthquake-triggered slope failures are included in the zone of required investigation.

Geologic and Geotechnical Analysis

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

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

1. Geologic Strength Group 3, which for the Condor Peak Quadrangle consists of all definite and probable landslide areas, is always included in the earthquake-induced landslide zone regardless of slope.

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

3. Geologic Strength Group 1 is included for all slopes steeper than 52 percent.

This results in approximately 74 percent of the area mapped in the quadrangle lying within the earthquake-induced landslide hazard zone for the Condor Peak Quadrangle.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Charles Nestle and Greg Johnson from the Los Angeles County Public Works Department provided assistance with geological strength data collection. Robert Larson and Manolito LaSao from the Los Angeles County Materials Engineering Division provided assistance and information about the fill areas near Big Tujunga Dam. Terilee McGuire and Bob Moscovitz provided GIS support. Barbara Wanish, Ross Martin, and Diane Vaughan prepared the final landslide hazard zone maps and the graphic displays for this report.

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SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Condor Peak 7.5-Minute Quadrangle, Los Angeles County, California

By

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California Geological Survey
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PURPOSE

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

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided

herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (DOC, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

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

EARTHQUAKE HAZARD MODEL

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

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10 percent 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.

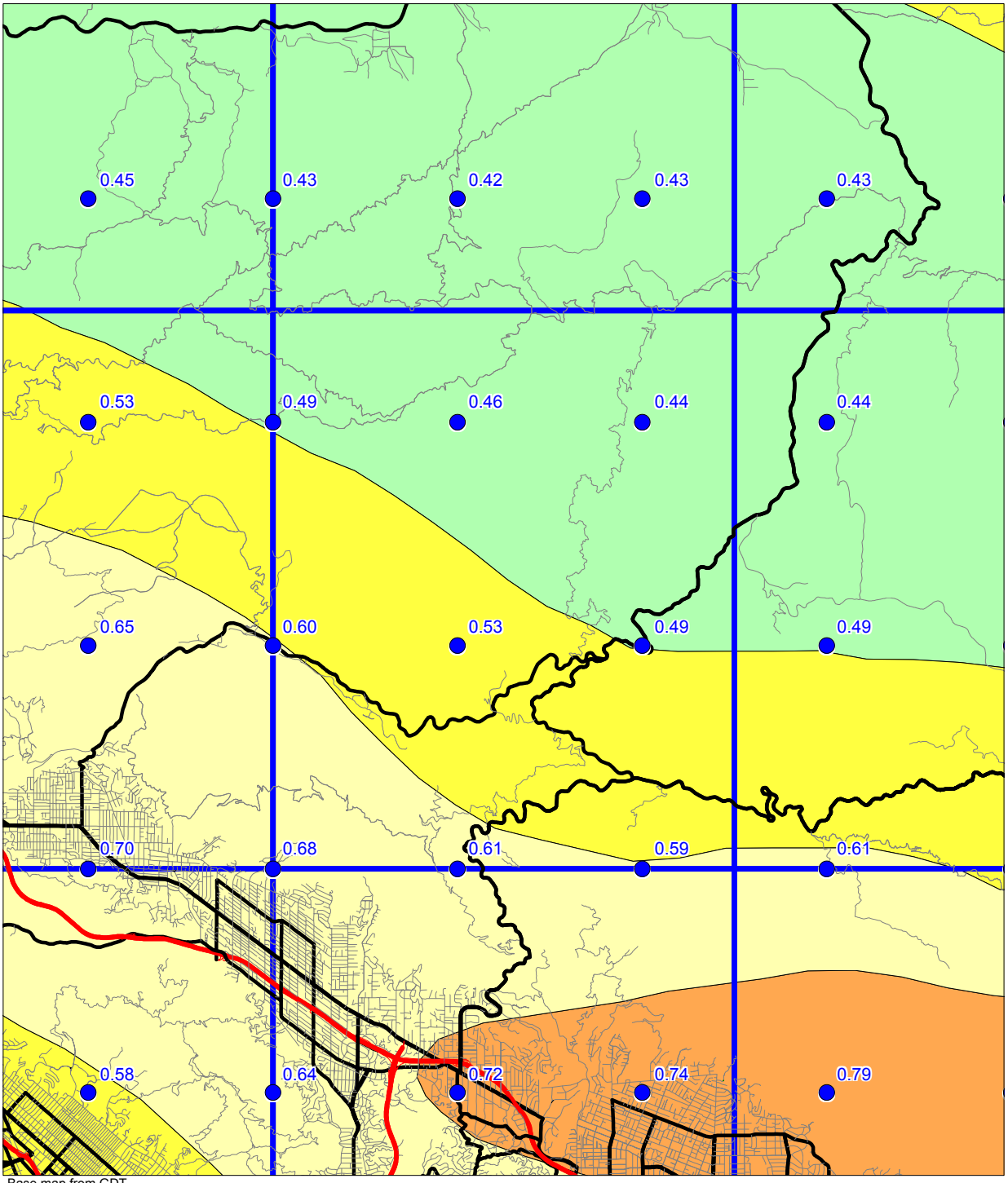
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

CONDOR PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

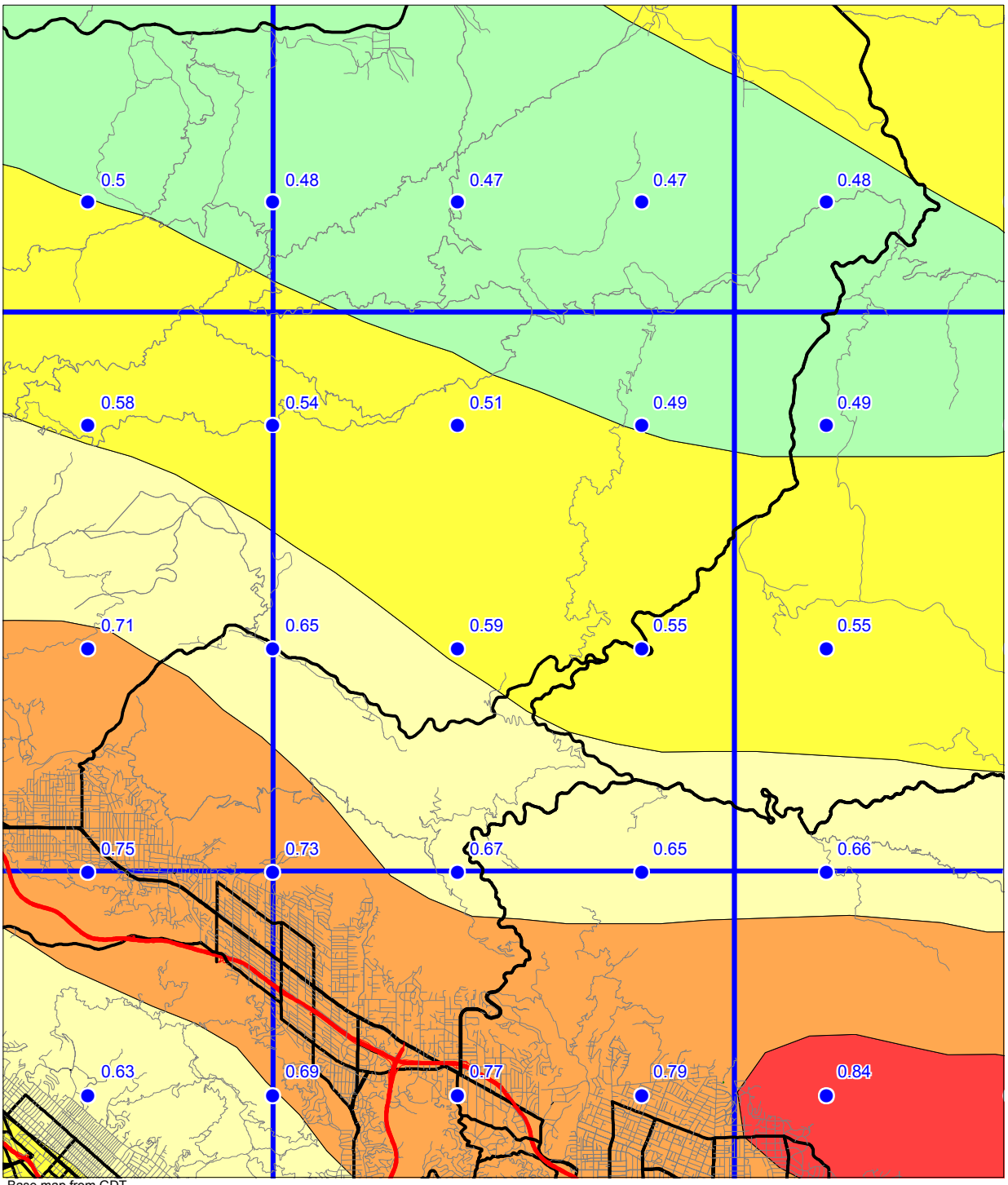
Figure 3.1

CONDOR PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

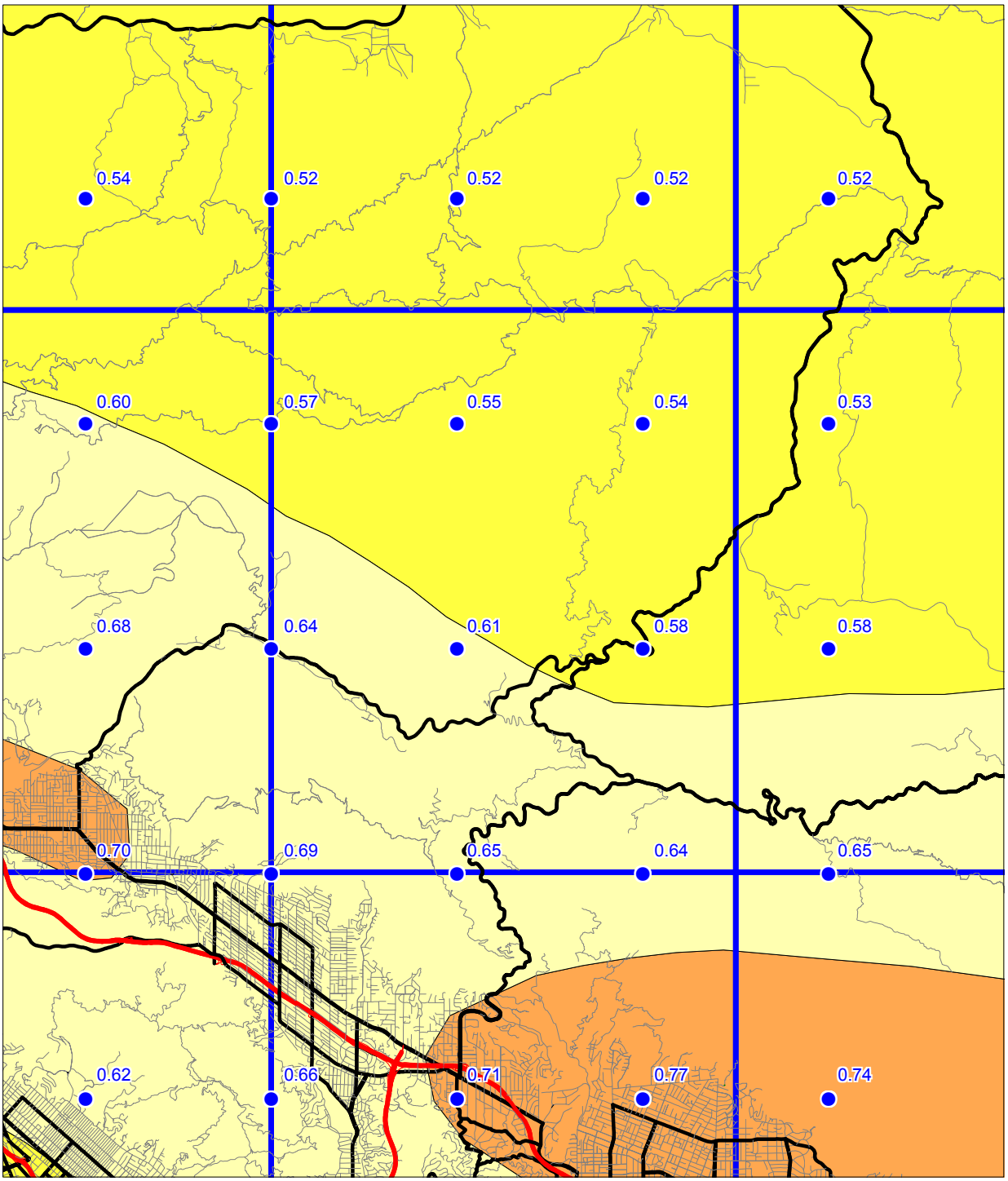
Figure 3.2

CONDOR PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

Figure 3.3

adjacent 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 percent 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.

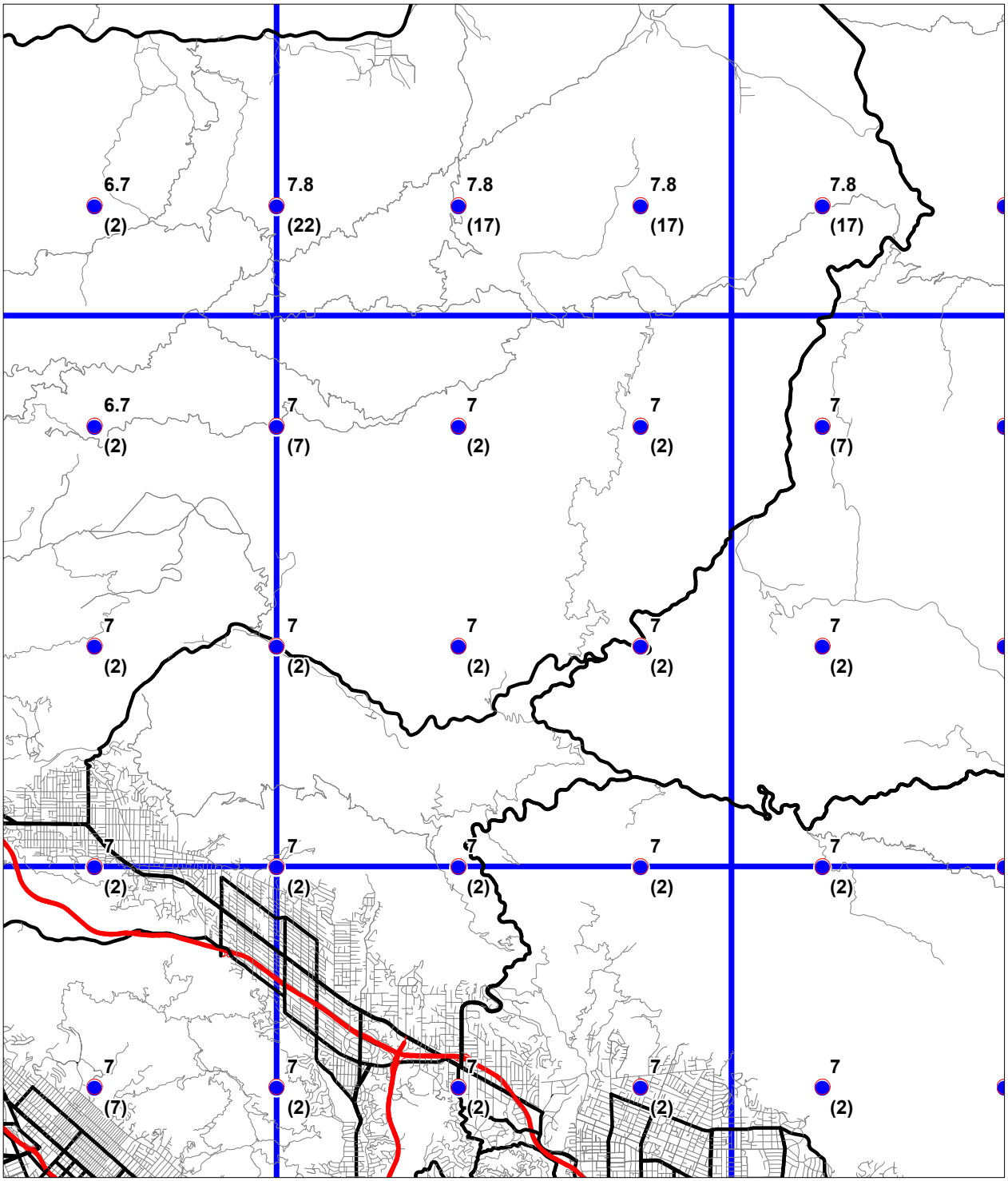
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss' weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

CONDOR PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

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



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

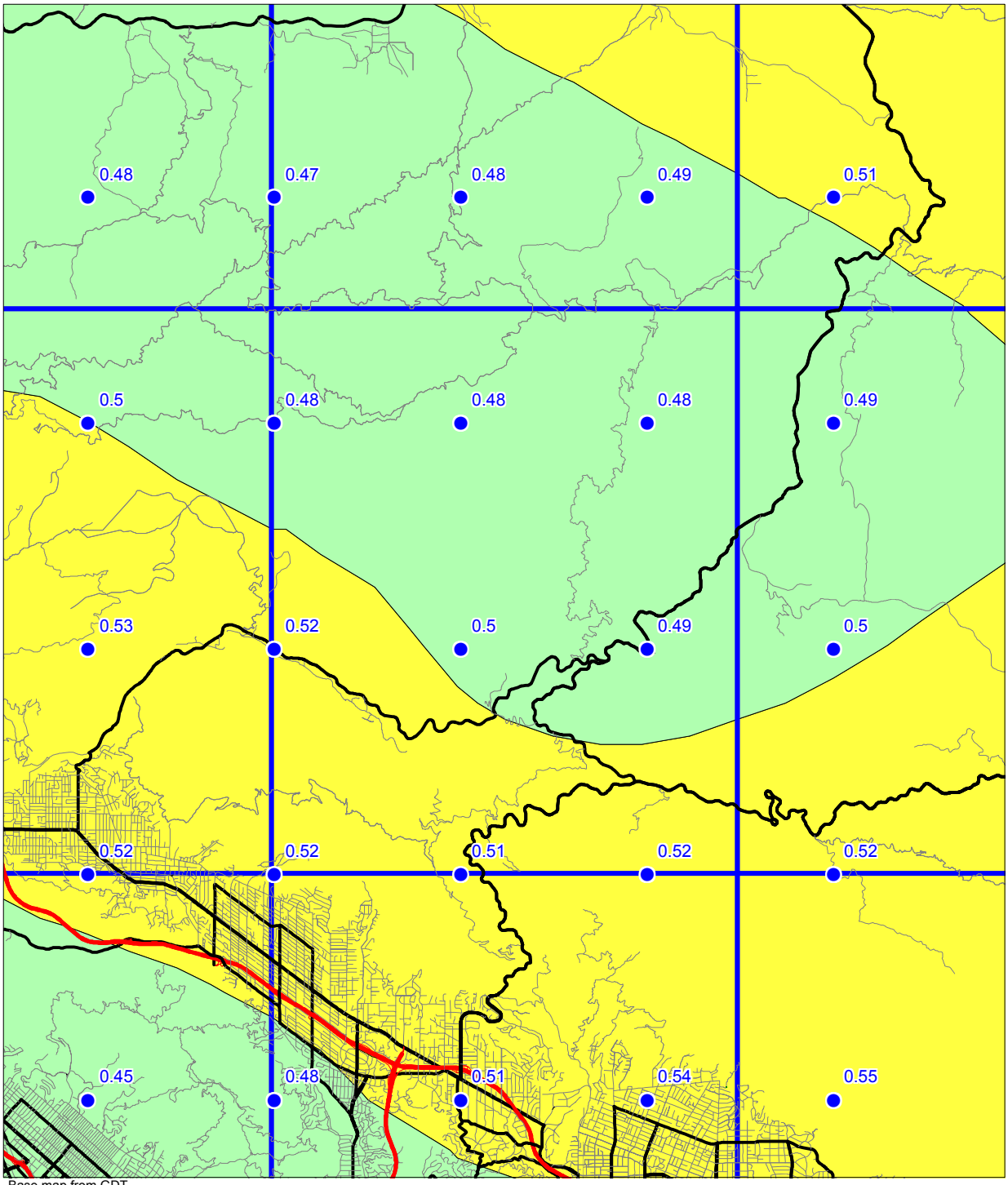
Figure 3.4

CONDOR PEAK 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



Base map from GDT

0 1.5 3
Miles

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 percent 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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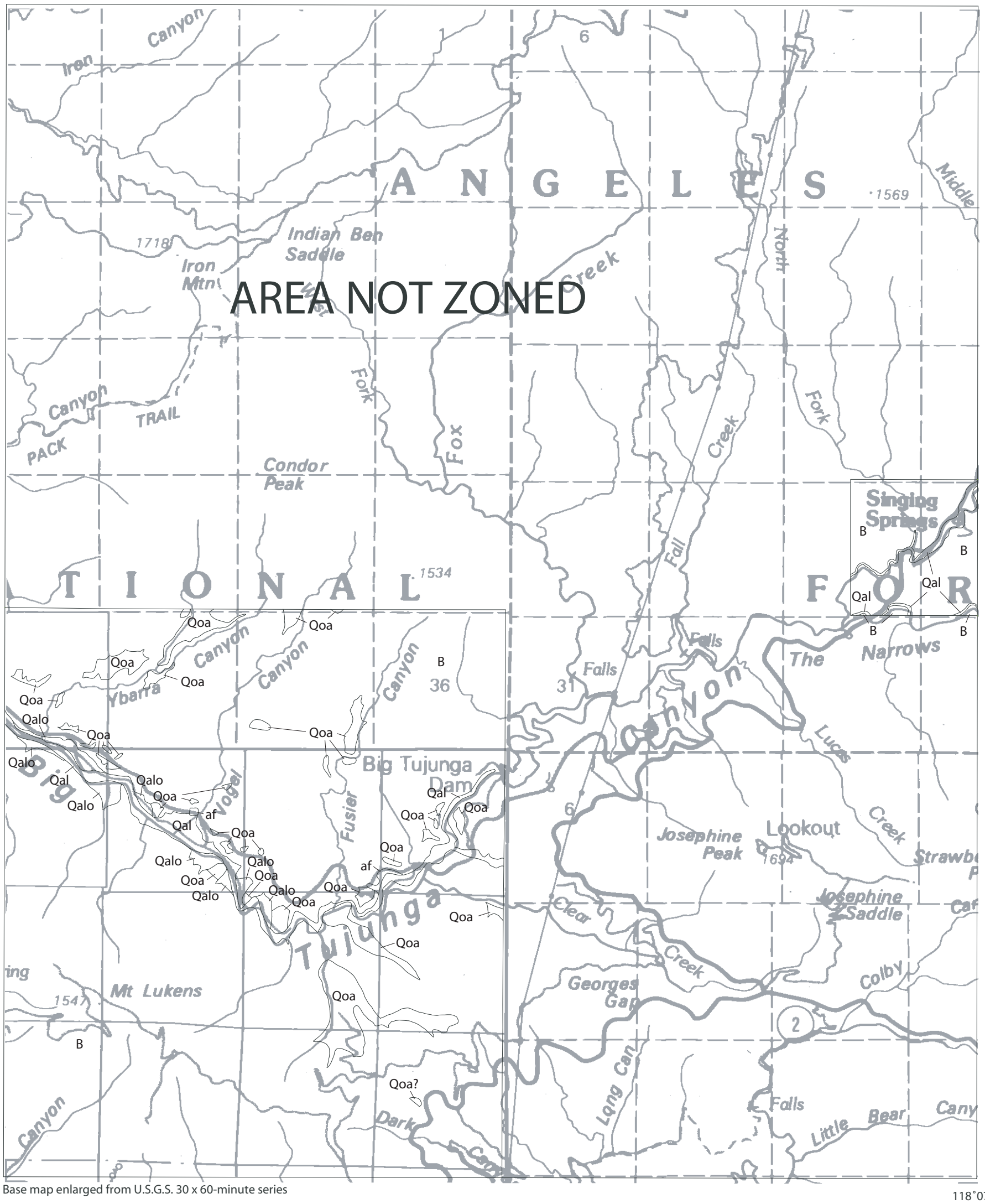


Base map enlarged from U.S.G.S. 30 x 60-minute series

CONDOR PEAK QUADRANGLE

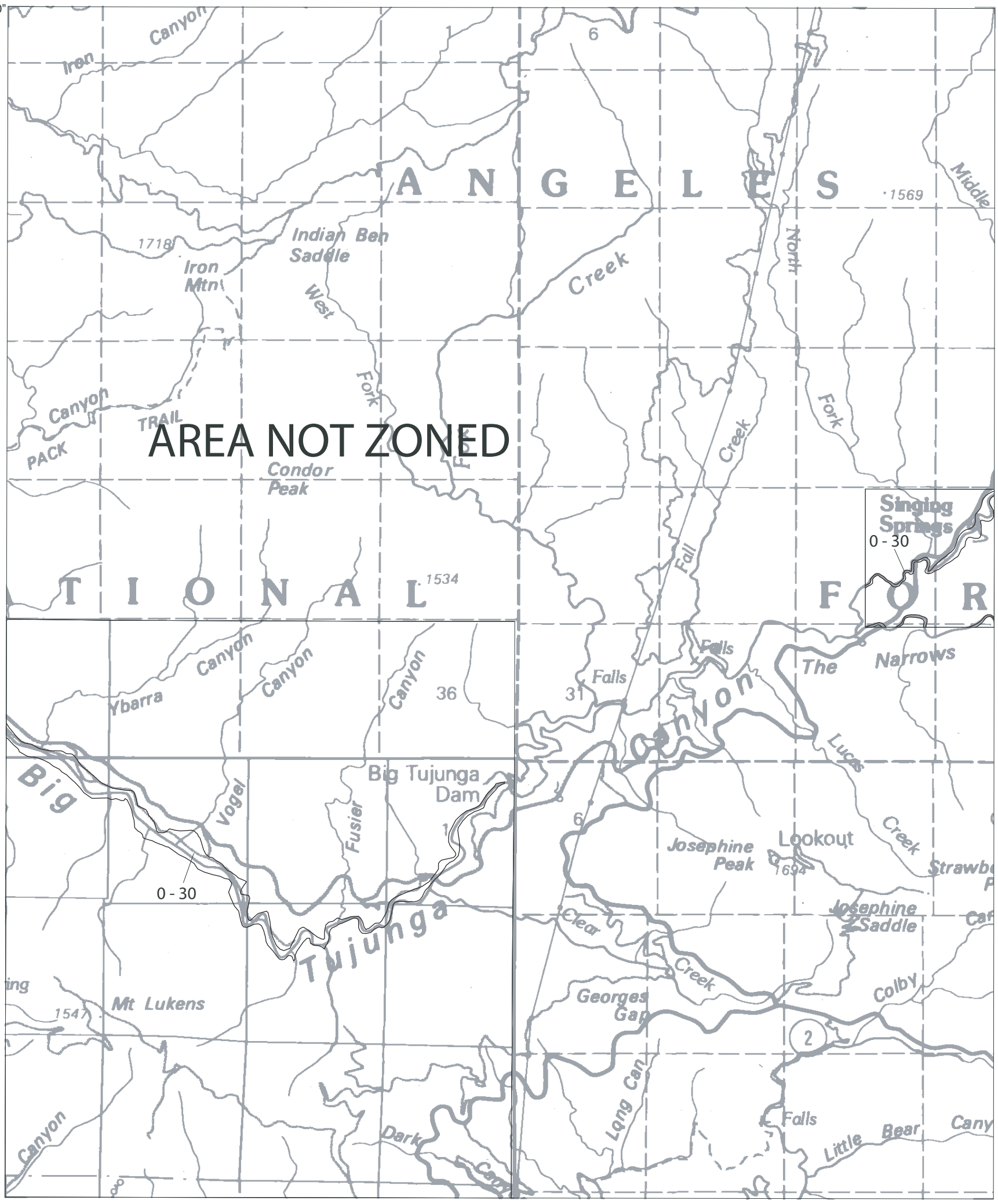
SCALE

N

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

Plate 1.1 Quaternary Geologic Map of the Condor Peak 7.5-Minute Quadrangle, California

Modified from Weber, 1982.



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

CONDOR PEAK QUADRANGLE

SCALE

N

Depth to ground water, in feet

0 - 30

Plate 1.2 Depth to historically shallowest ground water, Condor Peak 7.5-Minute Quadrangle, California

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

CONDOR PEAK QUADRANGLE

SCALE

1 .5 0 1 MILE

1000 0 2000 4000 6000 FEET

1 .5 0 1 KILOMETER

N

Landslide

Plate 2.1 Landslide inventory, Condor Peak 7.5-Minute Quadrangle, California.