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

1998

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Division of Mines and Geology

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SEISMIC HAZARD ZONE REPORT 025

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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 Glendora 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 24 square miles at a scale of 1 inch = 2,000 feet. The seismic hazard zone map has been trimmed back so that it only covers part of the south half of the quadrangle. The northern boundary of the zone map is located one to two miles north of the Angeles National Forest boundary along the San Gabriel Mountain front.

About 6 square miles of the densely populated San Gabriel Valley, which includes parts of the cities of Glendora, San Dimas, and La Verne is located in the southwestern corner of the Glendora Quadrangle. The rest of the land in the quadrangle is in the San Gabriel Mountains within the Angeles National Forest except for 7 or 8 square miles of private land along the mountain front. Access is primarily via the Foothill Freeway (I-210), Foothill Boulevard and San Gabriel Canyon Road (State Highway 39). The San Gabriel Mountains rise very abruptly above the valley to elevations of about 3500 feet near the center of the quadrangle. Along the western side of the Glendora Quadrangle, the San Gabriel River flows through San Gabriel Canyon, in which is located Morris Reservoir and San Gabriel Reservoir. Other major drainages on the Glendora Quadrangle are Little Dalton Canyon and Big Dalton Canyon and San Dimas Canyon. Residential and commercial development is concentrated in the gently sloping valley area. Hillside residential development, which began before World War II, has continued with small residential developments along the mountain front and mass-grading projects on the lower hills in the eastern part of the quadrangle.

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

In the Glendora Quadrangle the liquefaction zone is essentially restricted to the bottoms of three of the larger canyons. Steep slopes characterize the San Gabriel Mountains and, accordingly, an earthquake-induced landslide zone covers about 75 percent of the mountainous terrain in the zoned 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://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf).

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

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

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

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

SECTION 1
LIQUEFACTION EVALUATION REPORT

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

By
Ralph C. Loyd and 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 Glendora 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 Glendora 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 Glendora Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. 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 Glendora Quadrangle covers an area of about 62 square miles in eastern Los Angeles County. About 6 square miles in the southwestern quarter of the quadrangle is in the densely populated San Gabriel Valley. The remainder of the land in the quadrangle lies within the San Gabriel Mountains. Except for 7 or 8 square miles of private land along the mountain front, the rest of the mountainous terrain lies within Angeles National Forest. Parts of the cities of Glendora, San Dimas, and La Verne lie within the valley part of the quadrangle. Primary transportation routes in the quadrangle area are east-west in the San Gabriel Valley. These include the Foothill Freeway (I-210) and major thoroughfares such as Foothill Boulevard. A major access route into the San Gabriel Mountains, San Gabriel Canyon Road (State Highway 39) leads northward from Azusa on the adjacent Azusa Quadrangle and across the western part on the Glendora Quadrangle. A secondary route into the mountains, Glendora Ridge Road begins in Little

Dalton Canyon, north of Glendora, climbs out of the canyon to the west, then follows the ridge to the north and east.

The San Gabriel Mountains rise very abruptly from the valley and reach elevations of about 3500 feet near the center of the quadrangle along the ridge followed by Glendora Ridge Road. The mountains are composed of a complex assemblage of Precambrian through Cretaceous igneous and metamorphic rocks that have been thrust to the south over the adjacent basins. Slopes in the crystalline bedrock are "exceptionally steep and insecure" (Muir, 1877), which, along with periodic torrential rains, leads to periodic debris flows and floods in the valley.

Streams draining the San Gabriel Mountains have deposited alluvial fans in the valley. The San Gabriel River, the largest stream in the mountains, drains a watershed of over 200 square miles. Along the western side of the Glendora Quadrangle, the San Gabriel River flows through a deep canyon, San Gabriel Canyon, now occupied by Morris Reservoir and San Gabriel Reservoir. North of San Gabriel Reservoir, the river splits into a west-flowing branch on the east and an east-flowing branch, called the West Fork, that drains an area in the adjacent Azusa Quadrangle. Other major drainages on the Glendora Quadrangle are Little Dalton canyon and Big Dalton Canyon, which end in Glendora, and San Dimas Canyon, which drains southward to the La Verne and San Dimas areas at the southeastern corner of the quadrangle. Of these drainages, only Big Dalton Canyon and Little Dalton Canyon, and the smaller nearby canyons have deposited substantial alluvial deposits in the Glendora Quadrangle. The resulting alluvial fans form the surface upon which the City of Glendora sits.

GEOLOGY

Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. In preparing the Quaternary geologic map for the Glendora Quadrangle, geologic maps prepared by Nourse and others (1998), Crook and others (1987), and McCalpin (unpublished) were referred to. We began with the maps of McCalpin (unpublished), and Nourse and others (1998) as files in the DMG Geographic Information System. Nourse and others (1998) mapped the mountainous areas of the quadrangle showing the bedrock geology in great detail. McCalpin mapped the Quaternary units, primarily using geomorphic expression and soil surveys to map and determine the ages of various Quaternary geologic units. He also incorporated the mapping of Crook and others (1987), especially for areas of artificial fill, which McCalpin had not mapped originally (McCalpin, personal communication, 1998). McCalpin's mapping also used the SCAMP nomenclature for geologic units (Morton and Kennedy, 1989). Nourse and others (1998) mapping of bedrock also showed the geologic boundaries between the bedrock and Quaternary units with more detail than McCalpin. The completed map of Quaternary geology uses primarily boundaries between the geologic units as mapped by Nourse and others (1998) in the mountainous areas and McCalpin in the valley, with unit designations modified

somewhat from McCalpin based on Crook and others (1987). The Quaternary geologic map of the Glendora Quadrangle is reproduced as Plate 1.1.

The Quaternary geologic map (Plate 1.1) shows that the valley areas of the Glendora Quadrangle are covered by alluvial fans of various ages, including remnants of very old fans along the front of the San Gabriel Mountains, older alluvial surfaces, and young alluvial fans. The sources of the sediment that makes up the other young fans have been the small drainages, usually with only a few square miles of watershed, in the San Gabriel Mountains. The largest drainage in the area, in Big Dalton and Little Dalton canyons, has deposited a young alluvial fan beginning just south of the mountain front. The alluvial fans are composed primarily of sand, silt, and gravel, the compositions of which reflect the crystalline rocks of the San Gabriel Mountains. San Dimas Canyon, which is equivalent in size to Big and Little Dalton canyons, reaches the mountain front at the southern edge of the quadrangle, so sediments from this drainage area were deposited on the adjacent San Dimas Quadrangle. On the Glendora Quadrangle, the alluvial units have been subdivided into very old alluvium (Qvof), four generations of older alluvium (Qoa1 – Qoa4), four generations of young alluvium (Qya1- Qya4) and active wash and fan deposits (Table 1.1).

	Alluvial Fan Deposits	**Alluvial Valley Deposits**	Age
Active	Qf- active fan	Qa	
	Qw- active wash		
Young	Qyf4	Qya4	Holocene
	Qyf3	Qya3	
	Qyf2		
	Qyf, Qyf1	Qya, Qya1	
		Qoa3	
	Qof2	Qoa2	
Old	Qof, Qof1	Qoa, Qoa1	Pleistocene?
Very old	Qvof		Pleistocene

Some unit names include the "characteristic grain size" (e.g. Qyf2a, Qofg), b: boulder gravel, g: gravel, a: arenaceous (sand), s: silty, c: clayey.

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

ENGINEERING GEOLOGY

No borehole logs were collected for the Glendora Quadrangle study because adequate hydrologic data (see Ground Water section) showed that almost all of the alluvial valley

area covered by the quadrangle has been characterized by deep ground water levels throughout historical time. Since such areas do not contain soils susceptible to liquefaction, soil analyses is not required. Also, no borehole logs were located for the few canyon outlet areas identified as having historical shallow ground water levels. Zoning of areas lacking adequate subsurface data is accomplished using criteria adopted by the State Mining and Geology Board (see Criteria For Zoning section).

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 Glendora 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 obtained from technical publications, geotechnical boreholes, and water-well logs dating back to the turn-of-the- century, namely 1904 ground-water contour maps (Mendenhall, 1908), 1944 ground-water contour maps (California Department of Water Resources, 1966), shallow ground-water maps included in Leighton and Associates (1990), and ground-water level measurements reported in compiled 1960-1997 geotechnical and water-well borehole logs.

Shallow ground-water conditions (less than 40 feet depth) were identified in several areas within the Glendora Quadrangle (Plate 1.2). All three areas are situated along the northern margin of the San Gabriel Valley where near-surface sediments are frequently saturated by surface and subsurface waters flowing within and from Harrow, Englewild, Little Dalton, Big Dalton, and San Dimas canyons. Upon entering the valley, such water quickly descends to great depths through the porous sand and gravel deposits that dominate the valley sediments deposited along the base of the range front.

PART II

LIQUEFACTION POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some

of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

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

LIQUEFACTION SUSCEPTIBILITY

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

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

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

Map Unit	Age	Environment of Deposition	Primary Textures	General Consistency	Susceptible to Liquefaction?*
Qw	latest Holocene	Active stream channels	sand, gravel, cobbles	very loose to loose	yes
Qf	latest Holocene	Active alluvial fan deposits	sand, silt gravel	very loose to loose	yes
Qa	latest Holocene	Active alluvial basin deposits	sand, silt, clay	very loose to loose	yes
Qyf1-4	Holocene to latest Pleistocene	Younger alluvial fan deposits	gravel, sand, silt	loose to moderately dense	yes
Qya1-4	Holocene to latest Pleistocene	Younger alluvial basin deposits	sand, silt, clay	loose to moderately dense	yes
Qof	late Pleistocene	Older alluvial fan deposits	sand, gravel, silt, clay	dense to very dense	not likely
Qoa	late Pleistocene	Older alluvial basin deposits	sand, silt, clay	dense to very dense	not likely
Qvof	Pleistocene	very old alluvial fan deposits	gravel, sand, silt, clay	dense to very dense	not likely

*** When saturated.**

Table 1.2. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Sedimentary Deposits in the Glendora Quadrangle.

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 Glendora Quadrangle, a peak acceleration of 0.76g resulting from an earthquake of magnitude 7.0 was used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion section (3) of this report for further details.

Quantitative Liquefaction Analysis

No quantitative analysis of 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) was performed in the Glendora Quadrangle because no useful geotechnical borehole logs were available for areas having depths to ground water of 40 feet or less.

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 Glendora Quadrangle is summarized below.

Areas of Past Liquefaction

In the Glendora Quadrangle, no areas of documented historic liquefaction are known. Areas showing evidence of paleoseismic liquefaction have not been reported.

Artificial Fills

No artificial fill is mapped within the Glendora Quadrangle.

Areas with Sufficient Existing Geotechnical Data

No areas within the Glendora Quadrangle were zoned on the basis of existing geotechnical borehole log data.

Areas with Insufficient Existing Geotechnical Data

Areas within the Glendora Quadrangle that are characterized by near-surface, saturated younger Quaternary alluvium all lack geotechnical borehole log data. These areas, all of which are canyon bottoms and outlets (Harrow, Englewild, Big Dalton, Little Dalton, and San Dimas canyons), were zoned according to criteria 4a-c described above.

ACKNOWLEDGMENTS

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Glendora 7.5-Minute Quadrangle, Los Angeles County, California

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Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps 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 Glendora 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 Glendora 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 Glendora 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 Glendora 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 Glendora Quadrangle covers an area of about 62 square miles in eastern Los Angeles County. About 6 square miles in the southwestern quarter of the quadrangle is in the densely populated San Gabriel Valley. The remainder of the land in the quadrangle lies within the San Gabriel Mountains. Except for 7 or 8 square miles of private land along

the mountain front, the rest of the mountainous terrain lies within Angeles National Forest. Parts of the cities of Glendora, San Dimas, and La Verne lie within the valley part of the quadrangle. Primary transportation routes in the quadrangle area are east-west in the San Gabriel Valley. These include the Foothill Freeway (I-210) and major thoroughfares such as Foothill Boulevard. A major access route into the San Gabriel Mountains, San Gabriel Canyon Road (State Highway 39) leads northward from Azusa on the adjacent Azusa Quadrangle and across the western part on the Glendora Quadrangle. A secondary route into the mountains, Glendora Ridge Road begins in Little Dalton Canyon, north of Glendora, climbs out of the canyon to the west, then follows the ridge to the north and east.

The San Gabriel Mountains rise very abruptly from the valley and reach elevations of about 3500 feet near the center of the quadrangle along the ridge followed by Glendora Ridge Road. The mountains are composed of a complex assemblage of Precambrian through Cretaceous igneous and metamorphic rocks that have been thrust to the south over the adjacent basins. Slopes in the crystalline bedrock are "exceptionally steep and insecure" (Muir, 1877), which, along with periodic torrential rains, leads to periodic debris flows and floods in the valley.

Streams draining from the San Gabriel Mountains have deposited alluvial fans in the valley. The San Gabriel River, the largest stream in the mountains, drains a watershed of over 200 square miles. Along the western side of the Glendora Quadrangle, the San Gabriel River flows through a deep canyon, San Gabriel Canyon, now occupied by Morris Reservoir and San Gabriel Reservoir. North of San Gabriel Reservoir, the river splits into a west-flowing branch on the east and an east-flowing branch, called the West Fork, that drains an area in the adjacent Azusa Quadrangle. Other major drainages on the Glendora Quadrangle are Little Dalton canyon and Big Dalton Canyon, which end in Glendora, and San Dimas Canyon, which drains southward to the La Verne and San Dimas areas at the southeastern corner of the quadrangle. Of these drainages, only Big Dalton Canyon and Little Dalton Canyon, and the smaller nearby canyons have deposited substantial alluvial deposits in the Glendora Quadrangle. The resulting alluvial fans form the surface upon which the City of Glendora sits.

Residential and commercial development is concentrated in the gently sloping valley area. Hillside residential development began before World War II with small developments of single homes or cabins along streams at the base of the San Gabriel Mountains. Hillside development has continued with small residential developments along the mountain front and mass grading projects on the lower hills in the eastern part of the quadrangle.

The Seismic Hazard Zone Map for this quadrangle has been trimmed back so that it covers essentially only the south half of the Glendora 7.5-minute Quadrangle. The north boundary of the Zone Map is located one to two miles north of the Angeles National Forest Boundary along the San Gabriel Mountain front. The land excluded from the Zone map is 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 Glendora 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 1964 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 in the hilly portions of the Glendora Quadrangle were identified. Using 1:40,000-scale NAPP photography from the USGS taken in June, 1994, and October 1995 (see Air Photos in References), photogrammetric DEMs covering the graded areas were prepared by the U.S. Bureau of Reclamation with ground control obtained by DMG. The photogrammetric DEMs were then merged into the USGS DEM, replacing the areas of out-dated elevation data.

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

Recently compiled geologic maps were obtained in digital form from the Southern California Areal Mapping Project (SCAMP). These maps include the Quaternary geologic map of McCalpin (unpublished) for the Glendora Quadrangle and the geologic map of Nourse and others (1998). These maps were compared with other geologic maps of the area by Shelton (1955), Streitz (1966), and Crook and others (1987). This mapping was briefly field checked; observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the landslide inventory would exist on separate layers for the hazard analysis.

The San Gabriel Mountains that cover most of the quadrangle are comprised of blocks of plutonic igneous and metamorphic rocks that are being thrust over the San Gabriel Valley from the north. Bedrock geology in the crystalline bedrock of the San Gabriel Mountains shown by McCalpin (unpublished) is simplified to just one unit, herein called Mx (Mesozoic crystalline rocks). More detail is shown in the southern part of the mountains east of Glendora where Miocene age volcanic rocks (Glendora Volcanics) and sedimentary rocks (Puente and Topanga formations) crop out. Nourse and others (1998) mapped the mountainous areas of the quadrangle, showing the bedrock geology in great detail, and also showing the locations of contacts between crystalline rocks and

Quaternary sediments. The map by Nourse and others (1998) separates the crystalline bedrock of the San Gabriel Mountains into units based on age (i.e., Cretaceous, pre-Cambrian, etc.), gross rock type (i.e., granite, granodiorite,etc.), and accessory mineralogy (i.e., pyroxene-biotite granodiorite, hornblende-biotite granodiorite, etc.). This map also shows suites of dikes of various composition. The crystalline bedrock of the San Gabriel Mountains was considered as one strength group for slope stability analyses, and therefore, the detail provided in this map was greater than that required for the evaluation of landslide susceptibility. Consequently, the map was simplified by grouping similar rock types together, and by including small isolated units with the larger surrounding rock units. For instance, granodiorites and quartz diorites of similar ages were grouped together, regardless of differences in accessory mineralogy, and shown as one unit on the final geologic map. If small dikes or inclusions of different rock were present within the granodiorite unit, they were also shown as part of the granodiorite unit. In order to show geologic contacts as accurately as possible, the final geologic map used for this evaluation used the simplified geologic boundaries from the mapping by Nourse and others (1998) in the mountainous areas, and those of McCalpin in the alluvial valley areas.

Major crystalline bedrock units mapped by Nourse and others (1998) in the Glendora Quadrangle include Precambrian granite (pCgr), granodiorite (pCgd), and gneissic rocks (pCgn). These are intruded by Triassic quartz monzonite, quartz diorite, and diorite, and Jurassic granite, designated as TRJgr, TRJgd, and TRJd on the final map. This suite of crystalline rocks is then intruded by Cretaceous granite, granodiorite, monzonite, quartz diorite, and diorite, designated as Kgr and Kgd on the final map. The metamorphic and plutonic rocks are cut by dikes and sills of late Jurassic or Cretaceous granite and Tertiary rhyolitic and mafic rock. However, as explained above, these dikes were not shown on the final geologic map. There are a few areas of undifferentiated bedrock shown on the final geologic map as "bedrock complex" (bc) or "metasedimentary" (ms) rock units.

In the northern part of the quadrangle, zones of weakened, sheared rock are associated with the Vincent Thrust fault, or the more recent San Gabriel fault. Mylonitized gneiss (KTmy) is associated with the Vincent Thrust, and sheared rock units (shear zone) are discontinuously located along the San Gabriel fault.

Volcanic and sedimentary rocks of Miocene age overlie the metamorphic and intrusive rocks in the southern part of the quadrangle are. These include various units of the Glendora Volcanics, the Topanga Formation, and the Puente Formation. The Glendora Volcanics are a heterogeneous mixture of brecciated andesite flows (Tga), fine-grained andesite (Tgf), basalt (Tgb), tuff-breccia (Tgt), and undifferentiated volcanics (Tgv). The Topanga Formation (Tt) consists of bedded fine-grained marine sandstone and siltstone, with occasional interbeds of weak claystone. The Puente Formation (Tp) consists of bedded marine sandstone and diatomaceous shale, with local areas of interbedded, landslide-prone bentonite-clay shale.

Surficial units in the mountainous areas include colluvium (Qc), talus, and stream deposits in the canyons. Stream deposits are typically sand and gravel in the active

channel (Qw), and raised terraces (Qt) capped by young alluvium (Qyf2) and older alluvium (Qoa1) above the modern channel level.

The valley areas of the Glendora Quadrangle are covered by alluvial fans of various ages (Qyf3a, Qyf3g, Qyf4a, Qyf4b, Qyf4g, Qof, Qofa, Qofs, Qof2a, Qof2g, including remnants of very old fans along the front of the San Gabriel Mountains (Qvofg), older alluvial surfaces (Qo, Qoa, Qoag, Qoa2g, Qoa3g), and younger fans (Qyf, Qyfa, Qyfg) and alluvial surfaces (Qaa, Qal, Qya, Qyaa, Qyab, Qyag, Qya1g, Qya3b, Qya3g, Qya4g). Other Quaternary units in the valley areas include colluvial deposits (Qycc, Qycg), active channel deposits (Qw, Qwa, Qwb, Qwg), and areas of artificial fill (Qaf, af). A more detailed discussion of the Quaternary deposits in the Glendora Quadrangle can be found in Section 1.

Structural Geology

Structural geologic information, including bedding and foliation attitudes (strike and dip) and fold axes, provided on geologic maps by Morton (1973) and Shelton (1955), along with field checking of rock units, were used to determine which rock units might display adverse bedding conditions. The crystalline rocks of the San Gabriel Mountains are massive to moderately foliated, with no obvious pattern of change in slope stability conditions related to changes in foliation attitude. Therefore, dip slope analysis was not performed on crystalline bedrock of the San Gabriel Mountains. Likewise, rock units of the Glendora Volcanics are not suited to dip slope analysis, because the structure is generally chaotic, owing to the heterogeneous nature of original emplacement, and to subsequent faulting and landsliding in the area adjacent to the Sierra Madre fault zone along the San Gabriel Mountain front. The two bedded marine units present in the quadrangle, the Topanga and the Puente Formations, did display alternating weak and strong layers, with lateral continuity of layering, that warranted dip slope analysis.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Glendora Quadrangle was prepared (Treiman, 1998, unpublished) by combining field observations, analysis of aerial photos, and interpretation of landforms on current and older topographic maps. Aerial photos (see Air Photos in References) taken by the U.S. Department of Agriculture (1952/53) were the primary source for landslide interpretation. Also consulted during the mapping process were previous maps and reports that contain geologic and landslide data (Morton and Streitz, 1969; Streitz 1966; Crook and others, 1987). The completed hand-drawn landslide map was scanned and digitized by the Southern California Areal Mapping Project (SCAMP) at U.C. Riverside. 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 geologic map were obtained from the Los Angeles County Public Works Department and the City of Glendora (see Appendix A).

Shear strength information was scarce or entirely lacking for some rock units in the Glendora Quadrangle. Where appropriate, strength data from adjacent quadrangles were used to characterize the shear strength of rock units within the quadrangle. The use of the data was considered appropriate where the rock units were similar in lithology, and were located within one half mile of the Glendora Quadrangle. Four shear strength tests from the Mount Baldy Quadrangle, and two from the San Dimas Quadrangle were used to supplement data from the Glendora Quadrangle.

The locations of rock and soil samples taken for shear testing within the Glendora Quadrangle, and those used to provide supplemental data from the adjacent San Dimas and Mount Baldy Quadrangles, are shown on Plate 2.1

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 have undergone repeated tectonic movement and compression, resulting in a pervasive fracturing, which imparts a common strength characteristic to all the rock units, which dominates other characteristics related to age and mineralogy. Based on shear test results obtained for Glendora and nearby quadrangles, and on phi values for similar rock types published in rock mechanics text books (Franklin and Dusseault, 1989; Hoek and Bray, 1981; and Jumikis, 1983), all the crystalline rocks of the San Gabriel Mountains were grouped into one strength group, designated "gr", for the landslide evaluation for the Glendora Quadrangle.

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.

In the Glendora Quadrangle, only the Topanga and the Puente formations were analyzed for dip slope conditions. These 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 Topanga and Puente formations are included in Table 2.1.

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.

Existing landslides (Qls) were assigned a phi of 14 degrees 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 degrees 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 degrees was again on the low end of the range of values used. The results of the grouping of geologic materials in the Glendora Quadrangle are in Table 2.1 and Table 2.2

GLENDORA QUADRANGLE
SHEAR STRENGTH GROUPS

	Formation Name	Number Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP A	gr*	12	38.5/37.5	38.5/37.5	156/178		38
GROUP B	Tgv*	16	33.5/35	33.7/34	294/300	Tp-fbc	34
	Qa*	46	33.7/34.5				
	Tt-fbc	4	34.3/33.5				
GROUP C		0		27	500	Tp-abc,Tt-abc, Ktmy/shear zone	27
GROUP D	Qls	0		14	400		14**

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength
gr* = stands for all pre-Tertiary crystalline units
Tgv* = includes Tga, Tgb, Tgf, Tgt, Tgv - Glendora Volcanics
Qa* = stands for af (fill) and all Quaternary units
** = phi value was assumed to be representative for existing landslides

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

SHEAR STRENGTH GROUPS FOR THE GLENDORA QUADRANGLE

GROUP A	GROUP B	GROUP C	GROUP D
pCgr	Tga	Tt-abc	Qls
pCgd	Tgb	Tp-abc	
pCgn	Tgf	Ktmy/shear zone	
TRJgr	Tgt		
TRJgd	Tgv		
TRJd	Tt-fbc		
Kgr	Tp-fbc		
Kgd	af & Qaf		
bc	Qyf,Qyfa, Qyfg		
ms	Qyf2, Qyf3a, Qyf3g		
	Qyf4a, Qyf4b, Qyf4g		
	Qof, Qofa, Qofs		
	Qof2a, Qof2g		
	Qvofg		
	Qaa, Qal, Qya		

Table 2.2. Summary of the Shear Strength Groups for the Glendora 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 Glendora 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:	7.0 to 7.4
Modal Distance:	2.5 to 7.0 km
PGA:	0.63 to 0.74 g

The strong-motion record selected 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 peak ground acceleration PGA of 0.44 g. The parameters associated with this record are lower than those shown above from the probabilistic ground motion maps. However, it was felt that the selected record better represented the expected ground motion at the southerly, more populated portion of the quadrangle. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

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

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.074, 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 Glendora Quadrangle.

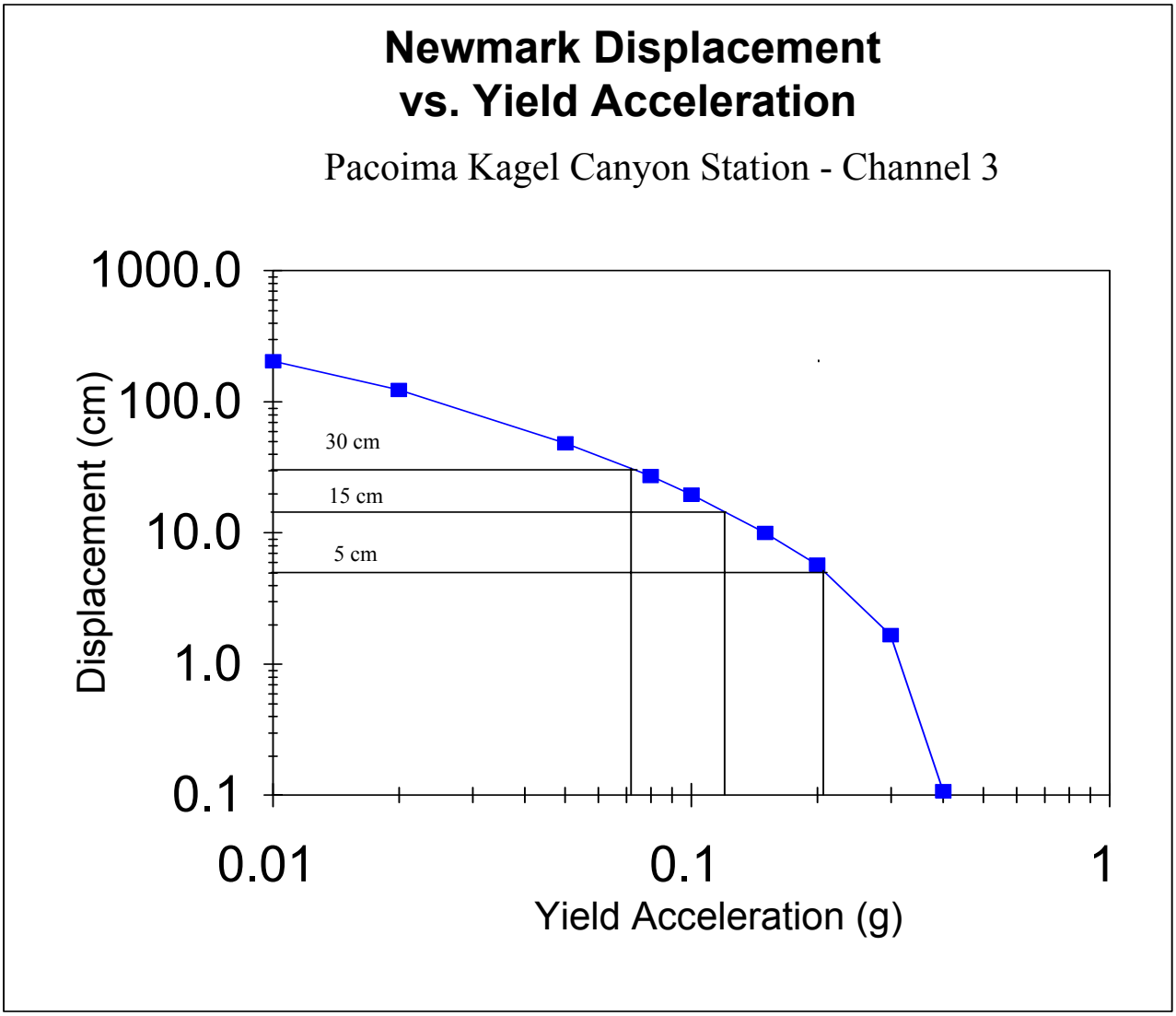

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Pacoima-Kagel Canyon Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake. Record from California Strong Motion Instrumentation Program (CSMIP) Station 24088.

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.

GLENDORA QUADRANGLE
HAZARD POTENTIAL MATRIX

Geologic Material Group	MEAN PHI	SLOPE CATEGORY I 0 - 18%	II 18 - 29%	III 29 - 37%	IV 37 - 44%	V 44 - 52%	VI 52 - 54%	VII 54 - 59%	VIII 59 - 63%	IX 63 - 69%	X > 69%
1	38	VL	VL	VL	VL	VL	VL	L	L	M	H
2	34	VL	VL	VL	VL	L	M	M	H	H	H
3	27	VL	VL	L	M	H	H	H	H	H	H
4	14	L-M	H	H	H	H	H	H	H	H	H

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

Minor rockfalls from steep roadcuts along the Glendora Ridge Road were triggered by the 5.5ML Upland earthquake of February 28. 1990. They were especially common in the vicinity of Horse Canyon Saddle near the center of the quadrangle (Allan Barrows, personal communication, 1998)

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 4 is included for all slope gradient categories. (Note: Geologic Strength Group 4 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 3 is included for all slopes steeper than 29 percent.

3. Geologic Strength Group 2 is included for all slopes steeper than 44 percent.

4. Geologic Strength Group 1 is included for all slopes steeper than 54 percent.

This results in approximately 75 percent of the hillside terrain in the zoned part (25 square miles) of the quadrangle lying within the earthquake-induced landslide hazard zone for the Glendora 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. Geologic material strength data were collected at 1) the City of Glendora, Engineering Division of the Department of Public Works with the assistance of Brad Miller and Eve Tate; 2) the Los Angeles County Department of Public Works with the assistance of Robert Larsen, Michael Montgomery, Charles Nestle, and Dave Poplar; 3) the City of LaVerne, Community Development Department with the assistance of Dominic Milano and Darleen Farrell; and 4) the City of San Dimas with the assistance of Krishna Patel, Senior Associate Engineer. Digital terrain data were provided by Randy Jibson of the U.S. Geological Survey, and Monte Lorenz and George Knight of the U.S. Bureau of Reclamation. Technical review of the methodology was provided by Bruce Clark, Randy Jibson, Robert Larson, Scott Lindvall, and J. David Rogers, who are members of the State Mining and Geology Board's Seismic Hazards Mapping Act Advisory Committee Landslides Working Group. At DMG, special thanks to Bob Moskovitz, Teri McGuire, Scott Shepherd and Barbara Wanish for their GIS operations support, and to Barbara Wanish for designing and plotting the graphic displays associated with the hazard zone map and this report.

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APPENDIX A
SOURCES OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Glendora, Engineering Div. of Public Works	**41**
Los Angeles County Public Works Department	**37**
Total Number of Shear Tests	**78**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Glendora 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.consrv.ca.gov/dmg/shezp/

EARTHQUAKE HAZARD MODEL

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

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

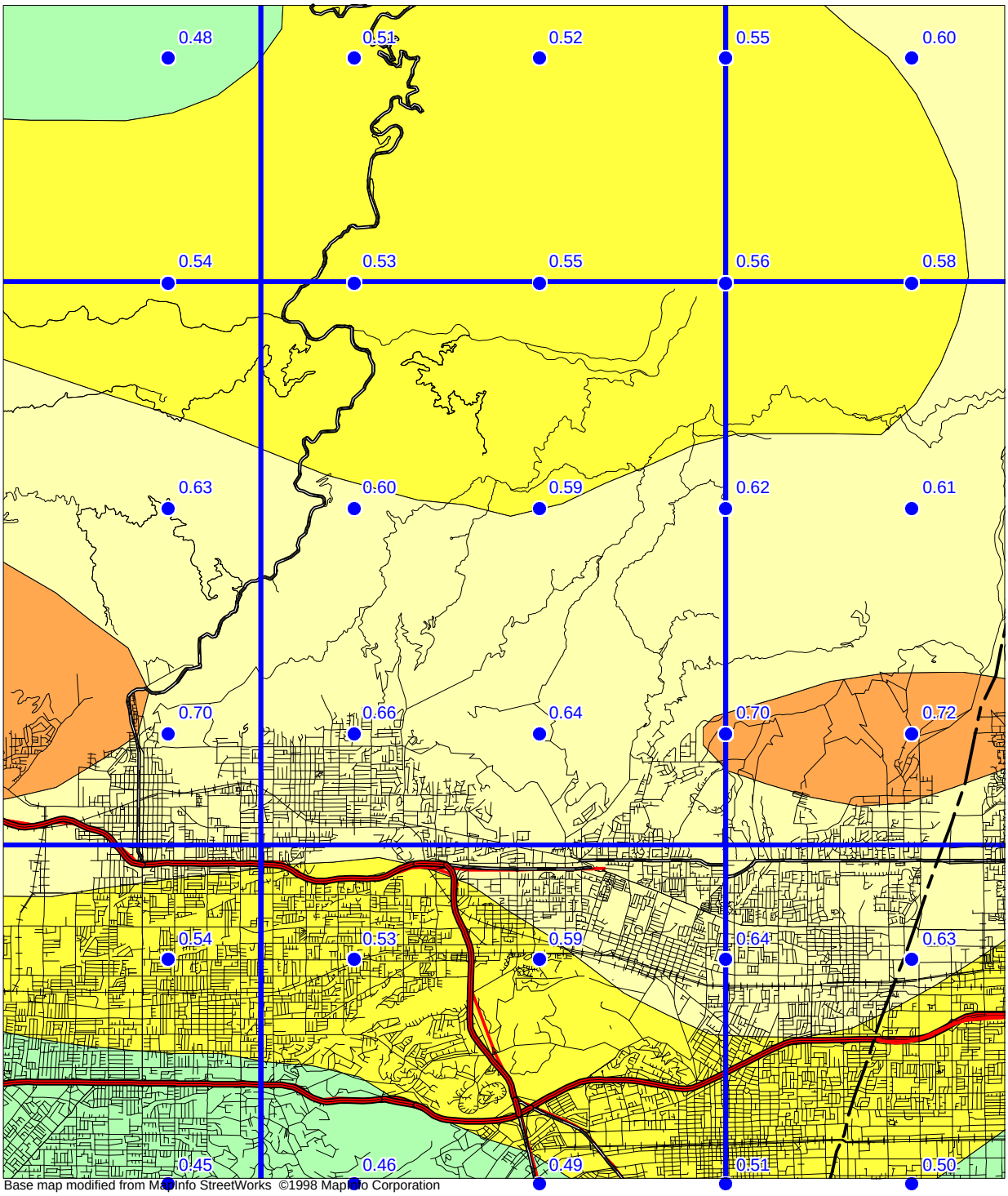
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

GLENDORA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

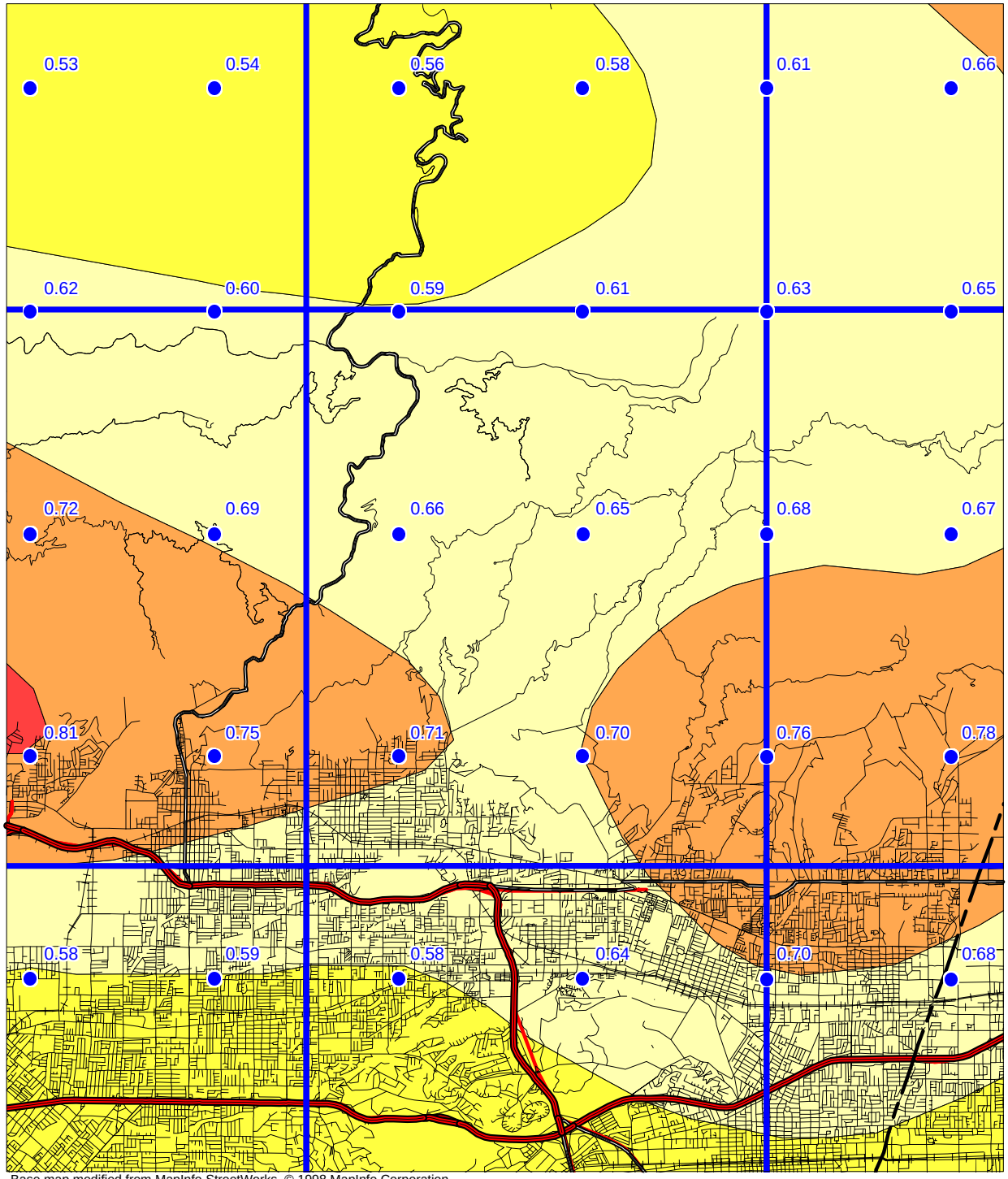
Figure 3.1

GLENDORA 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

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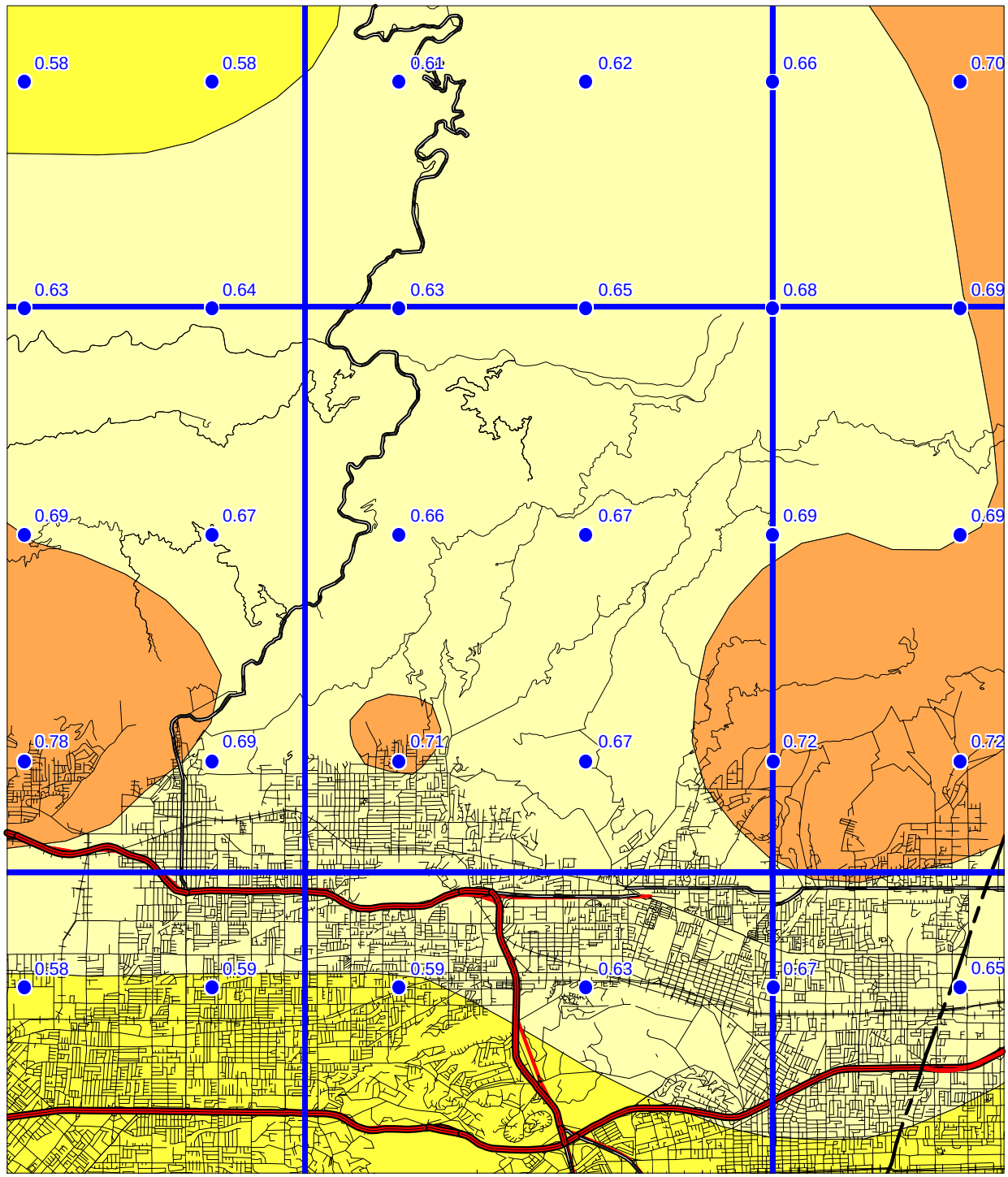
Figure 3.2

GLENDORA 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
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Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the "simplified Seed-Idriss method" of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a "magnitude-weighted" ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

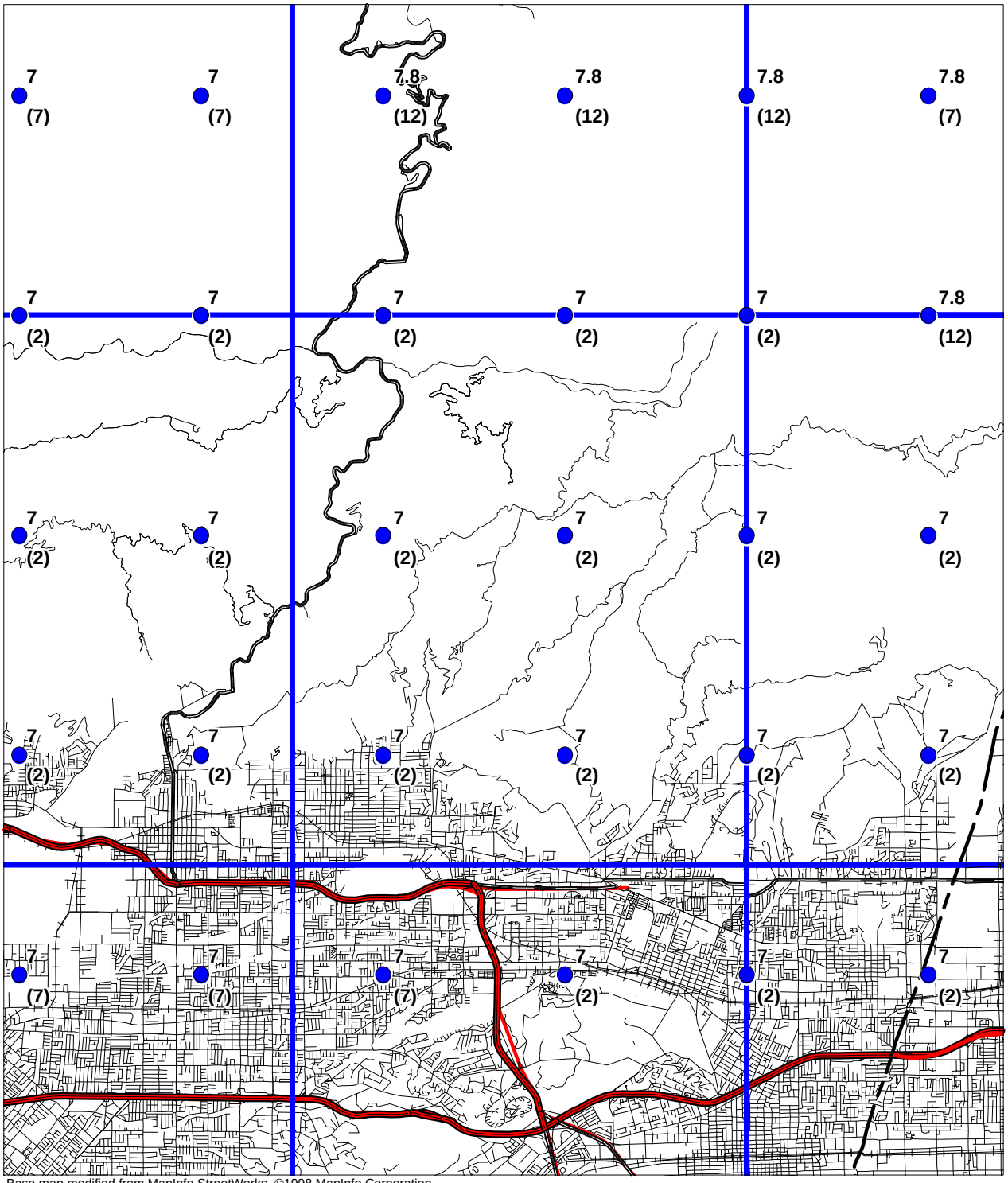
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss' weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

GLENDORA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

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



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

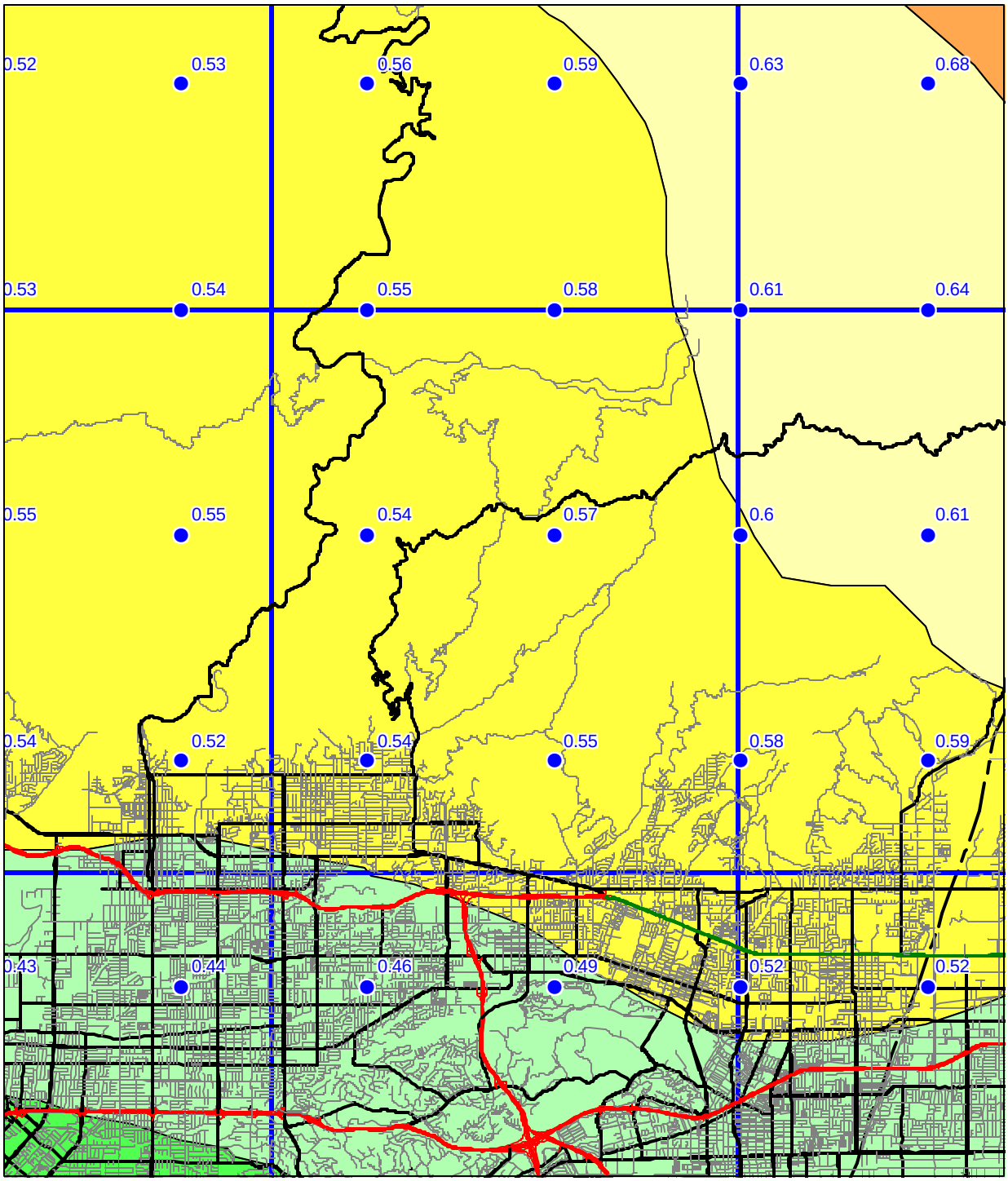
Figure 3.4

GLENDORA 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% 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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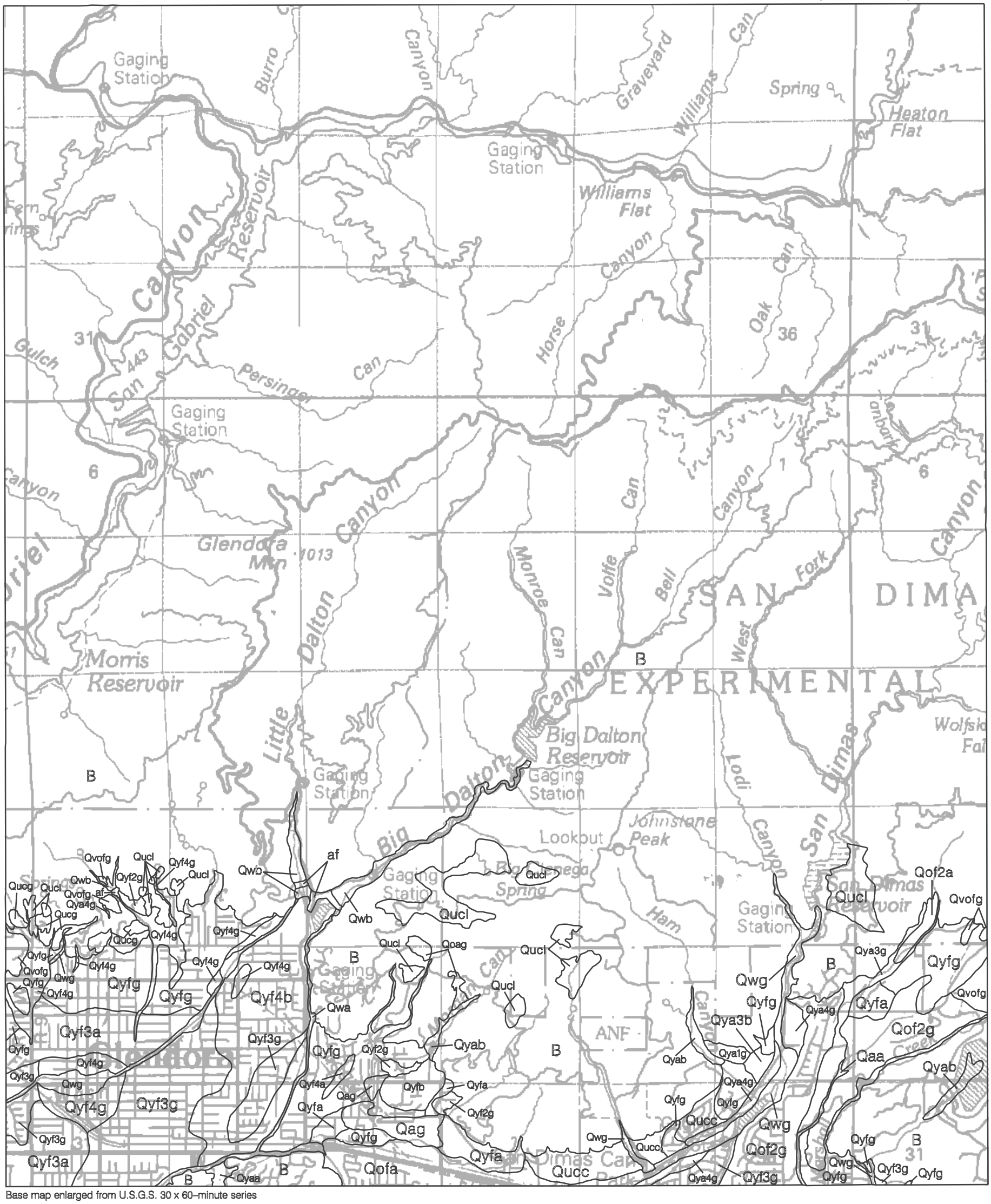


Base map enlarged from U.S.G.S. 30 x 60–minute series

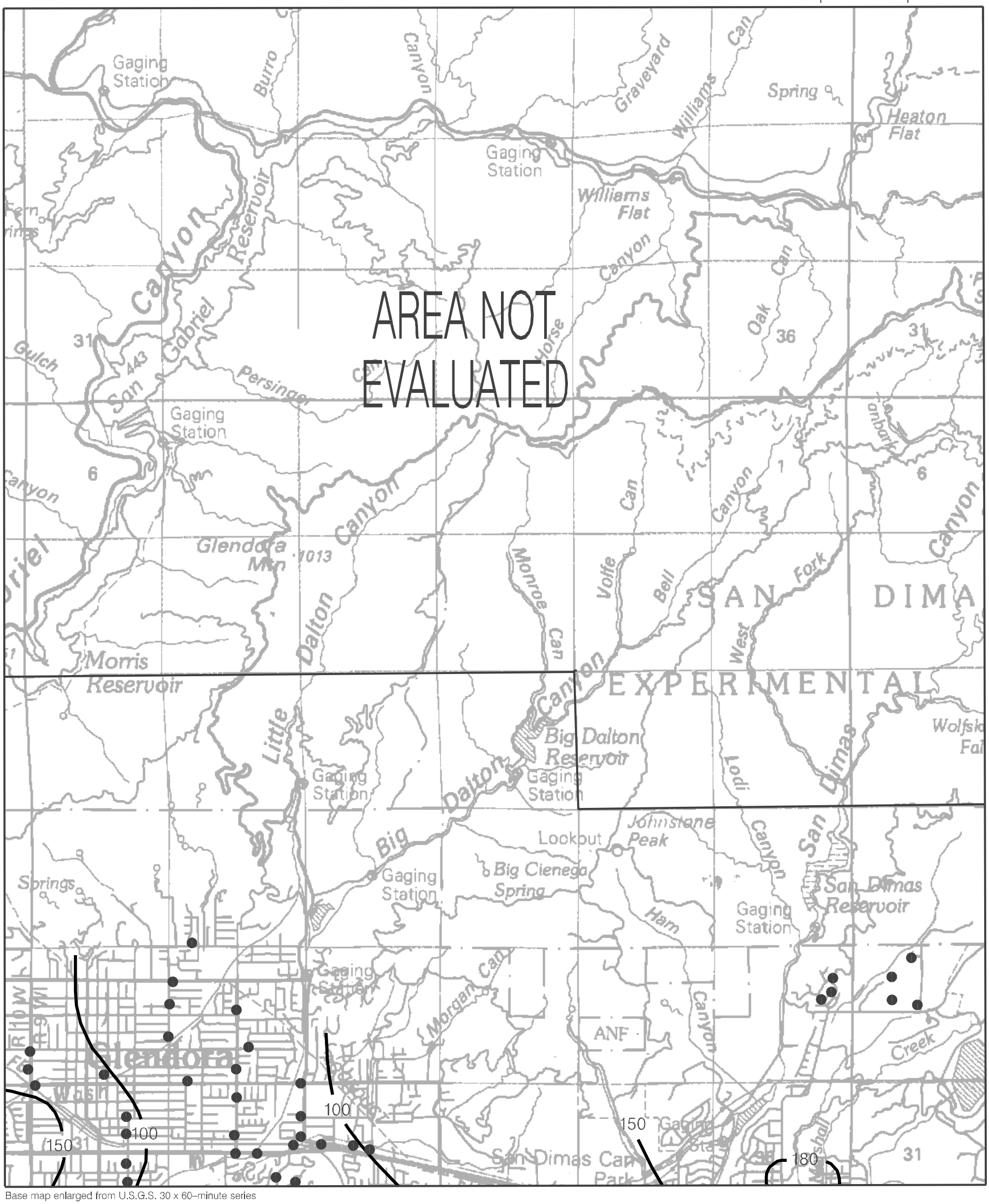
Plate 1.1 Quaternary Geologic Map of the Glendora Quadrangle.

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

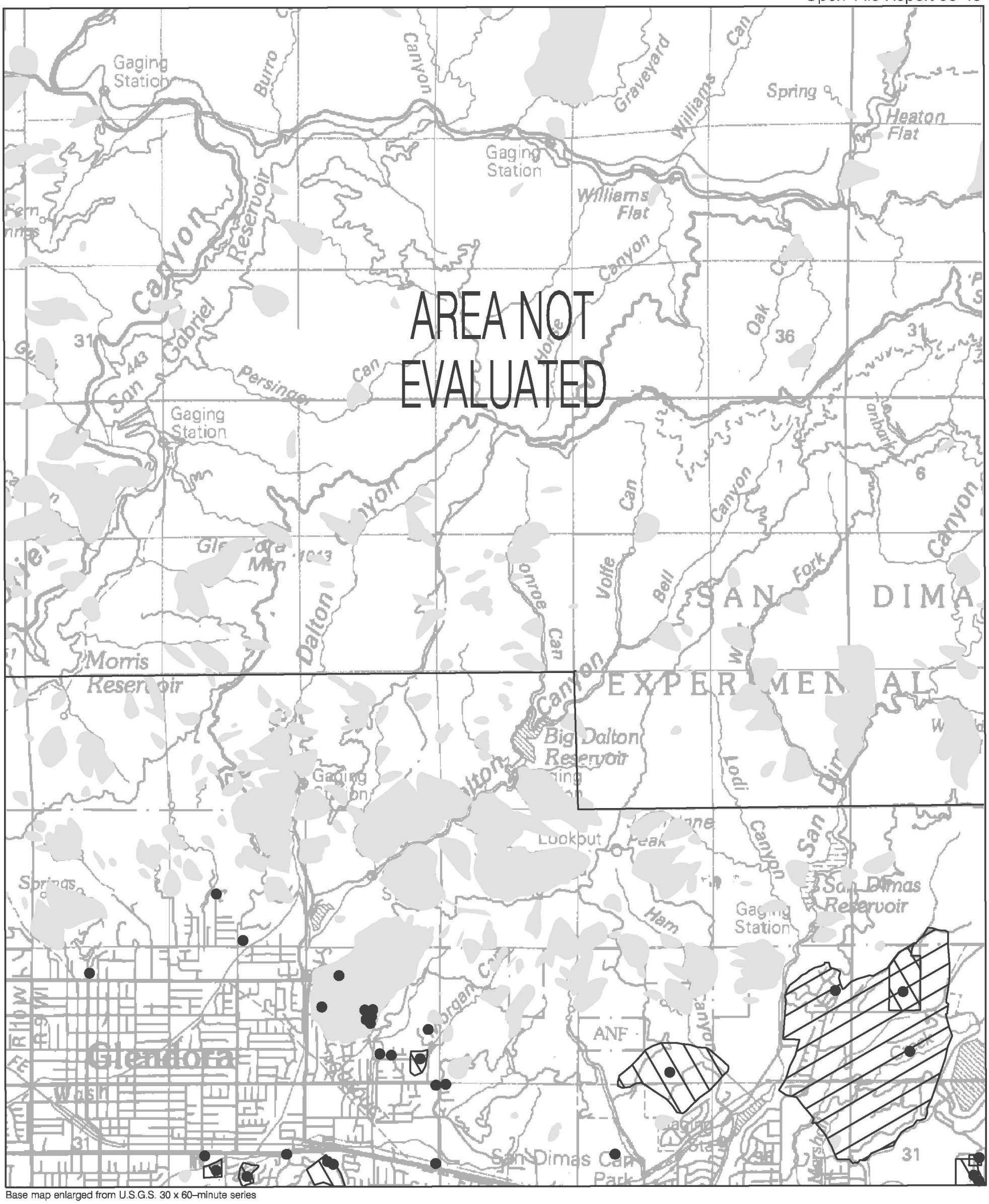
Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Glendora Quadrangle.

● Borehole Site

30 Depth to ground water in feet

ONE MILE

SCALE



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

Plate 2.1 Landslide inventory, Shear Test Sample Locations, and Areas of Significant Grading, Glendora Quadrangle.

● shear test sample location landslide areas of significant grading tract report with multiple borings

ONE MILE
SCALE