SEISMIC HAZARD ZONE REPORT 016

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

1998

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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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 Burbank 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 62 square miles at a scale of 1 inch = 2,000 feet.

The Burbank Quadrangle is about 9 miles northwest of Los Angeles City Hall. The City of Burbank and Universal City are entirely within the quadrangle and much of the City of Glendale extends along the entire eastern border. The remainder of the quadrangle contains City of Los Angeles communities, including North Hollywood, Toluca Lake, Sun Valley, and Tujunga. Most of the intensive development within the quadrangle is on the San Fernando Valley floor or within the Tujunga Valley in the extreme northeastern corner. Several freeways cross this heavily urbanized region, including the Golden State (I-5), the Ventura (State Highway 134), the Hollywood (State Highway 170) and the Foothill (I-210). The Burbank-Glendale-Pasadena Airport is also located within the quadrangle. South of the Los Angeles River, the easternmost part of the Santa Monica Mountains is included within Griffith Park, which straddles the southern boundary of the quadrangle. The Verdugo Mountains rise above the cities of Burbank and Glendale and extend cross the northeastern third of the map area.

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 Burbank Quadrangle the liquefaction zone covers about 15 square miles of the San Fernando Valley floor up to about three miles north of the Los Angeles River. Small areas of liquefaction zone also occur in Sun Valley and in the Verdugo Wash area of Glendale. About 22 percent of the quadrangle is in an earthquake-induced landslide zone due primarily to steep slopes in the Verdugo Mountains and weak rocks in the Santa Monica Mountains.

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 Burbank 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

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

By
Christopher J. Wills

California Department of Conservation
Division of Mines and Geology

PURPOSE

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

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Burbank 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 Burbank 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 Burbank 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 Burbank Quadrangle covers an area of about 62 square miles in west-central Los Angeles County. The City of Burbank lies completely within the quadrangle, near its center, which is about 9 miles northwest of Los Angeles City Hall. Much of the City of Glendale extends along the entire eastern border of the quadrangle across the Verdugo Mountains. Universal City, which covers about one square mile, also lies entirely within the map area near the southwestern corner. The remainder of the quadrangle is covered by communities that are parts of the City of Los Angeles, including North Hollywood, Toluca Lake, Sun Valley, and Tujunga.

Most of the intensive development within the quadrangle is situated on the San Fernando Valley floor or within the Tujunga Valley in the extreme northeastern corner. Several freeways cross this heavily urbanized region, including the Golden State (I-5), the

Ventura (State Highway 134), the Hollywood (State Highway 170) and the Foothill (I-210). The Burbank-Glendale-Pasadena Airport is located within the western part of the quadrangle. South of the Los Angeles River, the easternmost part of the Santa Monica Mountains is included within Griffith Park of the City of Los Angeles, which straddles the southern boundary of the quadrangle. The Verdugo Mountains rise above the cities of Burbank and Glendale and extend cross the northeastern third of the map area.

The San Fernando Valley is an east-trending structural trough within the Transverse Ranges of southern California. The San Gabriel Mountains, and their southern outlier the Verdugo Mountains, which bound the valley on the northeast, are composed of plutonic and metamorphic rocks that are being elevated along thrust faults over the valley from the north. As the mountains have risen and been deformed, the San Fernando Valley has subsided and filled with sediment.

The eastern portion of the valley, including most of the Burbank Quadrangle, has received sediment from Pacoima and Tujunga washes. These washes are associated with large river systems that have their sources in the steep, rugged San Gabriel Mountains, which are comprised of crystalline bedrock. The rivers have deposited a broad alluvial fan composed of sand, silt, and gravel that blankets most of the Burbank Quadrangle. The remainder of the San Fernando Valley is covered by smaller alluvial fans that have been deposited by local streams. Streams from the Verdugo Mountains have deposited alluvial fans composed of sand and silty sand similar to the larger Tujunga fan. Small streams that drain the Santa Monica Mountains are so much smaller than the Tujunga fan that they do not form recognizable deposits beyond the narrow canyons in the Santa Monica Mountains.

GEOLOGY

Surficial Geology

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

In preparing the Quaternary geologic map for the San Fernando Valley, geologic maps prepared by Tinsley and others (1985), Yerkes (1996), and Dibblee (1991a; 1991b) were referred to. We began with the map of Yerkes (1996) as a digital file in the DMG Geographic Information System. The Quaternary geology shown on the map of Yerkes (1996) was compiled from Tinsley and others (1985). For this study, we did not review or revise the mapping of bedrock units by Yerkes (1996), except at the contacts between bedrock and Quaternary units. Within the Quaternary units, mapping by Hitchcock (and for this study) was used to refine and substantially revise the mapping of Tinsley and others (1985). For this map (Plate 1.1), geologic units were defined based on geomorphic expression of Quaternary units (interpreted from aerial photographs and early-edition topographic maps) and subsurface characteristics of those units (based on borehole data). The nomenclature of the Southern California Areal Mapping Project (SCAMP) (Morton and Kennedy, 1989) was applied to all Quaternary units (Table 1.1).

	Alluvial Fan Deposits	**Alluvial Valley Deposits**	**Age**
Active	Qf- active fan	Qa- active depositional basin	
	Qw- active wash		
Young	Qyf2	Qyt	Holocene?
	Qyf1		
Old	Qof1		Pleistocene?

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

The Quaternary geologic map (Plate 1.1) shows that the part of the San Fernando Valley within the Burbank Quadrangle is largely covered by an alluvial fan that extends from north of the quadrangle to the Los Angeles River. The major sources of the sediment that make up this fan have been the river systems that culminate in Tujunga and Pacoima washes, both of which receive sediment from large regions in the San Gabriel Mountains. These river systems begin in high, rugged mountains composed of crystalline rocks. Periodic torrential rainfall and associated flooding characterize the drainage regimes of these washes. Sedimentation in the study area has resulted primarily in deposits of sand, silt, and gravel, the composition of which reflects the crystalline rocks in the source areas. The major alluvial fan, here referred to as the Pacoima-Tujunga fan, has its head on the San Fernando and Sunland quadrangles, north of the present study area. The Los Angeles River, which flows from west to east across the southern part of the Burbank Quadrangle, has contributed very little sediment to the basin.

The Pacoima/Tujunga alluvial fan can be subdivided based on relative ages of different surfaces. In the Burbank Quadrangle, young alluvium (Qyf2) and two generations of active wash deposits (historic and pre-historic) can be distinguished on the Pacoima/Tujunga fan (Plate 1.1). These units are dominantly composed of sand and silty sand with some gravel.

ENGINEERING GEOLOGY

The geologic units described above were primarily mapped from their surface expression, especially geomorphology as shown on aerial photos and old topographic maps. The geomorphic mapping was compared with the subsurface properties described in over 250 borehole logs in the study area. Subsurface data used for this study include the database compiled by John Tinsley for previous studies (Tinsley and Fumal, 1985; Tinsley and others, 1985), a database of shear wave velocity measurements originally compiled by Walter Silva (Wills and Silva, 1998), and additional data collected for this study. Subsurface data were collected for this study at Caltrans, the California Department of Water Resources, CDMG files of seismic reports for hospital and school sites, the Regional Water Quality Control Board and from Law Crandall, Inc., Leighton and Associates, Inc, and Woodward-Clyde Consultants. In general, the data gathered for geotechnical studies appear to be complete and consistent. Data from environmental geology reports filed with the Water Quality Control Board are well distributed areally and provide reliable information on water levels. Geotechnical data, particularly SPT blow counts, from environmental studies are sometimes less reliable however, due to non-standard equipment and incomplete reporting of procedures. Water-well logs from the Department of Water Resources tend to have very sketchy lithologic descriptions and, surprisingly, unreliable reports of water levels. Apparently, water-well drillers may note the level of "productive water," ignoring shallower perched water or water in less permeable layers.

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

Data from previous databases and additional borehole logs were entered into the DMG Geographic Information System (GIS) database. Locations of all exploratory boreholes considered in this investigation are shown on Plate 1.2. Construction of cross sections

from the borehole logs, using the GIS, enabled the correlation of soil types from one borehole to another and outlining of areas of similar soils.

In most cases, the subsurface data allow mapping of different alluvial fans. Different generations of alluvium on the same fan, which are very apparent from the geomorphology, are not distinguishable from the subsurface data.

Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are necessarily generalized but give the characteristics of the unit most commonly encountered.

Older alluvium (Qof1)

Older alluvium Qof1 is mapped in a part of the Tujunga Valley based on the mapping of Crook and others (1987), who describe this unit (Qal_3f on their map) as unconsolidated fine to medium sand and gravel. No subsurface data was gathered for this unit, which lies in an area of relatively deep ground water near the drainage divide between the Tujunga Wash and Verdugo Wash.

Younger alluvium (Qyf2, Qf, Qw)

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

Younger alluvium of the Pacoima/Tujunga fan consists of sand and silty sand with lesser quantities of silt and gravel. In the younger fan deposits and the modern wash, a braided channel pattern is apparent on pre-development aerial photographs. Braided channels lead to lenticular bedding which usually cannot be correlated between wells. Most sand and silty sand layers are loose to medium dense (SPT field N values typically range between 5 and 15), but very loose sands with SPT blow counts as low as 1 were recorded in some boreholes. The sand becomes denser with depth, with typical SPT field N values that range from 15 to 30 below 20 feet.

Young alluvial fans from the Verdugo Mountains

The fans of many small streams originating in the Verdugo Mountains have merged to form a continuous alluvial apron on the northeast side of the San Fernando Valley. Generally, these small fans have their apices at the mountain front and extend to the Pacoima-Tujunga fan on the southwest. These fans are composed of sand and silty sand. Generally the near surface deposits have loose to medium dense consistency.

Young alluvium of the Santa Monica Mountains

Alluvium from streams originating in the Santa Monica Mountains is found in the stream valleys. The Pacoima-Tujunga fan from the opposite side of the valley is so much larger that it has overwhelmed any alluvial fans from the Santa Monica Mountains.

Artificial fill (af)

Artificial fill on the Burbank Quadrangle consists of engineered fill for freeways and waste landfills. The freeway fills are shown on the map of Yerkes (1996) and were not modified. The waste landfills occupy old gravel pits on the northwestern part of the quadrangle. The boundaries of these landfills were remapped, based on maps from the Upper Los Angeles River Watermaster (Blevins, 1995). Because the engineered fills are too thin to affect the liquefaction hazard and the waste landfills are in an area of deep ground water, no effort was made of determine their subsurface characteristics.

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.

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

The Report of Referee shows that ground water reached its highest levels in 1944, before excessive pumping caused drawdowns throughout the basin. Management of the ground-water resources led to stabilizing of ground-water elevations in the 1960's and, in some cases, rise of ground-water elevations in the 1970's and 1980's to levels approaching those of 1944. Wells monitored by the Upper Los Angeles River Watermaster (Blevins, 1995) show that in most of the eastern San Fernando Valley, water levels have not recovered to the levels of the 1940's. In the southeastern part of the Burbank Quadrangle, however, water levels are up to 10 feet higher than the 1940’s levels.

In order to consider the historically highest ground-water level in liquefaction analysis, the 1944 ground-water elevation contours (California State Water Rights Board 1962, Plate 29) were digitized. A three-dimensional model was created from the digitized contours giving a ground-water elevation at any point on a grid. The ground-water

elevation values in this grid were then subtracted from the surface elevation values from the USGS Digital Elevation Model (DEM) for the Burbank Quadrangle. The difference between the surface elevation and the ground-water elevation is the ground-water depth. Subtracting the ground-water depth grid from the DEM results in a grid of ground-water depth values at any point where the grids overlapped.

The resulting grid of ground-water depth values shows several artifacts of the differences between the sources of ground-water elevation data and surface elevation data. The ground-water elevations were interpreted from relatively few measurements in water wells. The USGS DEM is a much more detailed depiction of surface elevation; it also shows man-made features such as excavations or fills that have changed the surface elevations. Most of these surface changes occurred after the ground-water levels were measured in 1944. The ground-water depth contours were smoothed and obvious artifacts removed to create the final ground-water depth map (Plate 1.2).

In general, the final ground-water depth map shows shallow ground water along the Los Angeles River in the southern portion of the San Fernando Valley. This area was recognized as an area of shallow ground water in the Report of Referee (1962).

The 1944 ground-water depths were checked against the water levels measured in boreholes compiled for this study. Measured ground-water levels from the 1970's, 1980's and early 1990's tend to be 10 to 20 feet deeper than the 1944 water level, but show the same pattern of shallow ground water near the Los Angeles River and deeper ground water to the north. In the Glendale and Burbank areas, water levels recorded in the Los Angeles River Watermaster's report (Blevins, 1944) are up to 10 feet higher than the 1944 levels. Water levels shown on borehole logs collected for this study also show that ground water has risen up to 10 feet above the 1944 levels. The final map of depth to ground water (Plate 1.2) reflects the 1944 water levels over most of the quadrangle with an adjustment in the Burbank and Glendale areas to reflect this recent rise in ground water.

Ground water is also relatively shallow in all canyons in the Santa Monica Mountains where records were examined. In general, it appears that relatively shallow and impermeable bedrock underlying the canyon alluvium helps to maintain a shallow water table.

PART II

LIQUEFACTION POTENTIAL

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

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

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

LIQUEFACTION SUSCEPTIBILITY

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

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

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. A qualitative susceptible soil inventory is outlined below and s Old alluvium (Qof1)

Old alluvium on the Burbank Quadrangle consists of unit Qof1 in the Tujunga Valley. This material is described from surface mapping as unconsolidated fine to medium sand and gravel, but no subsurface data were gathered for this unit. Because of low ground water, liquefaction susceptibility of this unit is thought to be low.

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

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

Artifical fill (af)

Artificial fill on the Burbank Quadrangle consists of engineered fill for freeways and waste landfills. The engineered fill is generally too thin to affect liquefaction susceptibility. The waste landfills are located in the northwestern part of the quadrangle, an area of deep ground water. They have low liquefaction susceptibility due to the deep ground water.

Geologic Map Unit	Material Type	Consistency	Liquefaction Susceptibility
Qw, stream channels	Sandy, silty sand	Loose-moderately dense	High
Qf, active alluvial fans	Silty sand, sand, minor clay	Loose-moderately dense	High
Qyf2, younger alluvial fans	Silty sand, sand, minor clay	Loose-moderately dense	High
Qyf1, young alluvial fan	Silty sand, sand, minor clay	Loose-moderately dense	High
Qof1, older alluvial fan	Sand & gravel	Dense	Low

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

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 Burbank Quadrangle, peak accelerations of 0.51 g to 0.74 g, resulting from an earthquake of magnitude 6.4 to 7.0 were used for liquefaction analyses. The PGA and magnitude values were derived from maps prepared by Petersen and others (1996); Cramer and Petersen, 1996), respectively. See the ground motion portion (Section 3) of this report for further details.

Quantitative Liquefaction Analysis

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

Of the nearly 270 borehole logs compiled for this study (Plate 1.2), only 77 had blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction

analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

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

LIQUEFACTION ZONES

Criteria for Zoning

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

1. Areas known to have experienced liquefaction during historical earthquakes

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

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

4. Areas where existing geotechnical data are insufficient

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

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

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

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

Application of SMGB criteria to liquefaction zoning in the Burbank Quadrangle is summarized below.

Areas of Past Liquefaction

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

Artificial Fills

In the Burbank Quadrangle, two kinds of artificial fill are large enough to show at the scale of mapping, engineered fill for freeways, and waste landfills. The engineered fills are generally too thin to have an impact on liquefaction hazard and so were not investigated. Areas of waste landfill were remapped based on the report of the Upper Los Angeles River Watermaster (Blevins, 1995) but no attempt was made to determine their engineering properties because all are in areas of deep ground water.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data were evaluated for zoning based on the liquefaction potential determined by the Seed-Idriss Simplified Procedure. Younger alluvial deposits (Qyf1, Qyf2, Qyt Qw) of the main Pacoima/Tujunga fan have generally high liquefaction susceptibility. Ground water becomes deeper to the north, however, so the northern portions of these units have not had recorded ground water within 40 feet of the surface. All younger alluvium where ground water has been less than 40 feet from the surface are included in a liquefaction zone.

Areas with Insufficient Existing Geotechnical Data

Old alluvium on the Burbank Quadrangle consists of sand and silty sand of unit Qof1. This material is described from surface mapping as unconsolidated fine to medium sand and gravel, but no subsurface data were gathered for this unit. Because of relatively deep ground water, this unit was not included in a liquefaction hazard zone.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

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

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PURPOSE

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

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Burbank 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 Burbank 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 Burbank 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 Burbank 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 Burbank Quadrangle covers an area of about 62 square miles in west-central Los Angeles County. The City of Burbank lies completely within the quadrangle, near its center, which is about 9 miles northwest of Los Angeles City Hall. Much of the City of Glendale extends along the entire eastern border of the quadrangle across the Verdugo Mountains. Universal City, which covers about one square mile, also lies entirely within the map area near the southwestern corner. The remainder of the quadrangle is covered

by communities that are parts of the City of Los Angeles, including North Hollywood, Toluca Lake, Sun Valley, and Tujunga.

Most of the intensive development within the quadrangle is situated on the San Fernando Valley floor or within the Tujunga Valley in the extreme northeastern corner. Hillside residential development began after World War II and continues at the present time with several mass-grading projects. Several freeways cross this heavily urbanized region, including the Golden State (I-5), the Ventura (State Highway 134), the Hollywood (State Highway 170) and the Foothill (I-210). The Burbank-Glendale-Pasadena Airport is located within the western part of the quadrangle. South of the Los Angeles River, the easternmost part of the Santa Monica Mountains is included within Griffith Park of the City of Los Angeles, which straddles the southern boundary of the quadrangle. The Verdugo Mountains rise above the cities of Burbank and Glendale and extend cross the northeastern third of the map area.

The San Fernando Valley is an east-trending structural trough within the Transverse Ranges of southern California. The San Gabriel Mountains, and their southern outlier the Verdugo Mountains, which bound the valley on the northeast, are composed of plutonic and metamorphic rocks that are being elevated along thrust faults over the valley from the north. As the mountains have risen and been deformed, the San Fernando Valley has subsided and filled with sediment.

The eastern portion of the valley, including most of the Burbank Quadrangle, has received sediment from Pacoima and Tujunga washes. These washes are associated with large river systems that have their sources in the steep, rugged San Gabriel Mountains, which are comprised of crystalline bedrock. The rivers have deposited a broad alluvial fan composed of sand, silt, and gravel that blankets most of the Burbank Quadrangle. The remainder of the San Fernando Valley is covered by smaller alluvial fans that have been deposited by local streams. Streams from the Verdugo Mountains have deposited alluvial fans composed of sand and silty sand similar to the larger Tujunga fan. Small streams that drain the Santa Monica Mountains are so much smaller than the Tujunga fan that they do not form recognizable deposits beyond the narrow canyons in the Santa Monica Mountains.

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 Burbank 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 terrain data to reflect areas that have recently undergone large-scale grading, graded areas in the hilly portions of the Burbank Quadrangle, essentially the Verdugo Mountains, were identified. Terrain data for these areas were obtained from an

airborne interferometric radar (TOPSAR) DEM flown and processed in August 1994 by NASA's Jet Propulsion Laboratory (JPL), and processed by Calgis, Inc. (GeoSAR Consortium, 1995; 1996). The terrain data were also smoothed and filtered prior to analysis. Plate 2.1 shows those areas where the topography is updated to 1994 grading conditions.

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

GEOLOGY

Bedrock and Surficial Geology

A recently compiled U.S. Geological Survey (USGS) geologic map was obtained in digital form (Yerkes, 1996) for the Burbank Quadrangle. This map was compared with other geologic maps of the area by Weber and others (1980), Dibblee (1991a; 1991b) 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.

The San Gabriel Mountains in the northeast corner of the quadrangle, and their southern outlier the Verdugo Mountains, are blocks of plutonic and metamorphic rocks that are being thrust over the San Fernando Valley from the north. The crystalline bedrock forms very steep slopes, which are prone to severe erosion and debris flows. Erosion of these actively rising mountain ranges supplies the sediment that has filled the San Fernando Valley.

Bedrock geology in the crystalline bedrock of the Verdugo and San Gabriel Mountains shown by Yerkes (1996) was simplified to just one unit called dgn (diorite and gneiss). Though other workers differentiate areas underlain by Mesozoic diorite from gneiss in the area, no significant differences in material strength or landslide density were found between these units. The simplified bedrock geology of Yerkes (1996) was used for our study.

Cretaceous granitic rocks (gr) are also exposed in the eastern Santa Monica Mountains, where they are overlain unconformably by shallow-marine clastic sedimentary rocks and volcanics of the middle Miocene Topanga Group and deep-marine biogenic and clastic rocks of the upper Miocene Modelo Formation. The Topanga Group consists of interbedded conglomerate, massive sandstone, concretionary shale and siltstone, and basalt flows (Ttc, Tts, and Tb). The Modelo Formation is composed of interbedded clay shale, siltstone, and sandstone (Tm).

Quaternary deposits cover the floor and margins of the San Fernando Valley and extend southward up into the canyons in the mountains. These units were re-mapped for

liquefaction hazards zoning (see Section 1 above). They generally consist of younger alluvial-fan deposits of Holocene age (Qf, Qw, Qyf1, and Qyf2). Landslides (Qls) are found throughout bedrock areas of the Burbank Quadrangle, although they occur primarily in the crystalline bedrock terrain. Modern man-made (artificial) fills (af) were also mapped in some areas. A more detailed discussion of the Quaternary deposits in the Burbank Quadrangle can be found in Section 1.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Burbank Quadrangle was prepared (Treiman, 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 and 1953) were the primary source for landslide interpretation. Also consulted during the mapping process were previous maps and reports that contain geologic and landslide data (Dibblee, 1991a, 1991b; Harp and Jibson, 1995; Hoots, 1930; Los Angeles Dept. of Public Works, 1963; and Weber and others, 1979). 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.). All landslides on the digital geologic map (Yerkes, 1996) were verified or re-mapped during preparation of the inventory map. To keep the landslide inventory of consistent quality, all landslides originally depicted on the digitized geologic map were deleted, and only those included in the DMG inventory were incorporated into the hazard-evaluation process. 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 Burbank Quadrangle geologic map were obtained from from the City of Los Angeles, Department of Public Works (see Appendix A). The locations of rock and soil samples taken for shear testing 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. No shear tests were available for Qao, Qay1, Qf, Qof1, Tb, and Ttc (fine grained) and these geologic units were added to existing groups on the basis of lithologic and stratigraphic similarities. 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.

Adverse Bedding Conditions

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

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

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

BURBANK QUADRANGLE SHEAR STRENGTH GROUPS							
	Formation Name	**Number of Tests**	**Mean/Median Phi**	**Mean/Median Group Phi (deg)**	**Group Mean/Median C (psf)**	**No Data: Similar Lithology**	**Phi Values Used in Stability Analysis**
GROUP 1	gr Ttc(fbc) dgn	10 24 17	37.3/37 36.2/36.5 34.1/34	35.7/36	576/550	Tb	35.7
GROUP 2	Qw Tm(fbc) Tts(fbc) Qyf1,2	42 25 46 44	32.7/33 32/34 31/32 29.8/31	31.3/32	321/250	Qao Qay1 Qf Qof1	31.3
GROUP 3	Tts(abc)	13	27.6/28.4	27.6/28.4	527/600	Ttc(abc)	27.6
GROUP 4	Tm(abc)	5	23.1/23	23.1/23	431/400		23.1
GROUP 5	Qls	—	—	—	—	—	15

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength

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

SHEAR STRENGTH GROUPS FOR THE BURBANK QUADRANGLE				
Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
dgn gr Tb Ttc(fbc)	Af afc Qao Qay1 Qf Qof1 Qw Qyf1,2 Tm(fbc) Tts(fbc)	Ttc(abc) Tts(abc)	Tm(abc)	Qls

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

Modal Magnitude:	6.5 to 7.0
Modal Distance:	3.8 to 7.5 km
PGA:	0.53 to 0.77 g

The strong-motion record selected for the slope stability analysis in the Burbank Quadrangle was the Channel 3 (north horizontal component) University of Southern California Station #14 recording from the magnitude 6.7 Northridge earthquake (Trifunac and others, 1994). This record had a source to recording site distance of 8.5 km and a PGA of 0.69 g. The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

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

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 0.129 and 0.232 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Burbank Quadrangle.

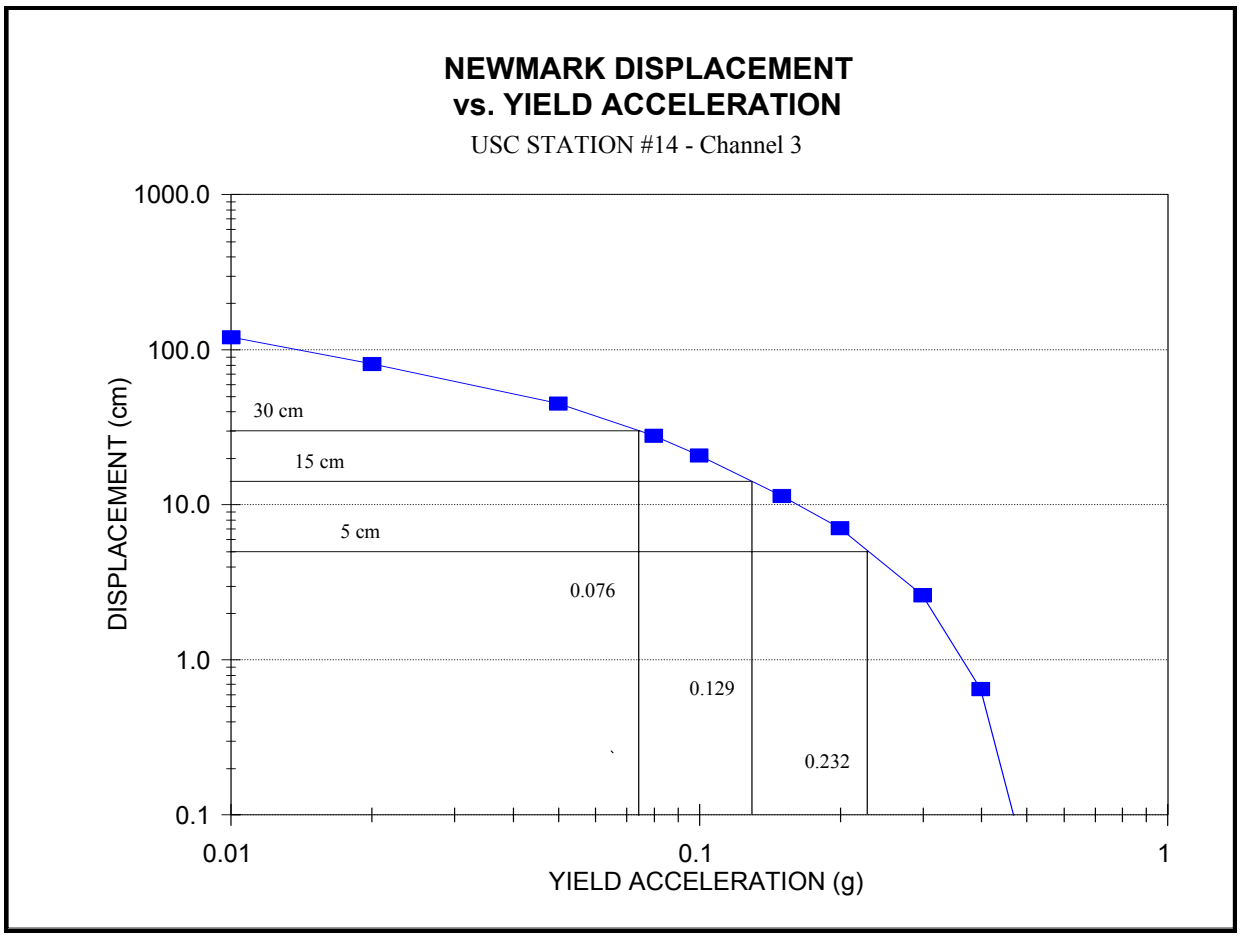

Figure 2.1. Yield acceleration vs. Newmark displacement for the USC Station # 14 strong-motion record From the 17 January 1994 Northridge, California Earthquake.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.076g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)

2. If the calculated yield acceleration fell between 0.076g and 0.129g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)

3. If the calculated yield acceleration fell between 0.129g and 0.232g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)

4. If the calculated yield acceleration was greater than 0.232g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

BURBANK QUADRANGLE HAZARD POTENTIAL MATRIX											
		SLOPE CATEGORY (% SLOPE)									
Geologic Material Group	Mean Phi	I 0-14	II 14-19	III 19-28	IV 28-30	V 30-36	VI 36-44	VII 44-53	VIII 53-58	IX 58-65	X >65
1	35.7	VL	VL	VL	VL	VL	VL	L	L	M	M
2	31.3	VL	VL	VL	VL	VL	L	M	H	H	H
3	27.6	VL	VL	VL	L	L	M	H	H	H	H
4	23.1	VL	VL	L	L	M	H	H	H	H	H
5	15	L	M	H	H	H	H	H	H	H	H

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

No earthquake-triggered landslides had been identified in the Burbank Quadrangle prior to the Northridge earthquake. The Northridge earthquake caused a number of relatively small, shallow slope failures in the Burbank Quadrangle (Harp and Jibson, 1995). Landslides attributed to the Northridge earthquake covered approximately 8.4 acres of land in the quadrangle. Of the area covered by these Northridge earthquake landslides, 89% falls within the area of the hazard zone based on a computer comparison of the zone map and the Harp and Jibson (1995) inventory.

Geologic and Geotechnical Analysis

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

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

1. Geologic Strength Group 5 is included for all slope gradient categories. (Note: Geologic Strength Group 5 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 4 is included for all slopes steeper than 19 percent.

3. Geologic Strength Group 3 is included for all slopes steeper than 28 percent.

4. Geologic Strength Group 2 is included for all slopes steeper than 36 percent.

5. Geologic Strength Group 1 is included for all slopes greater than 44 percent.

This results in 22 percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the Burbank 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 the City of Los Angeles, Department of Building and Safety, with the assistance of Nicky Girmay. 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. Assistance in the application of the radar DEM was provided by Rick Wilson and Tim McCrink.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Los Angeles, Department of Building and Safety	267

SECTION 3
GROUND SHAKING EVALUATION REPORT

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

By

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

PURPOSE

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

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

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

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

EARTHQUAKE HAZARD MODEL

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

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

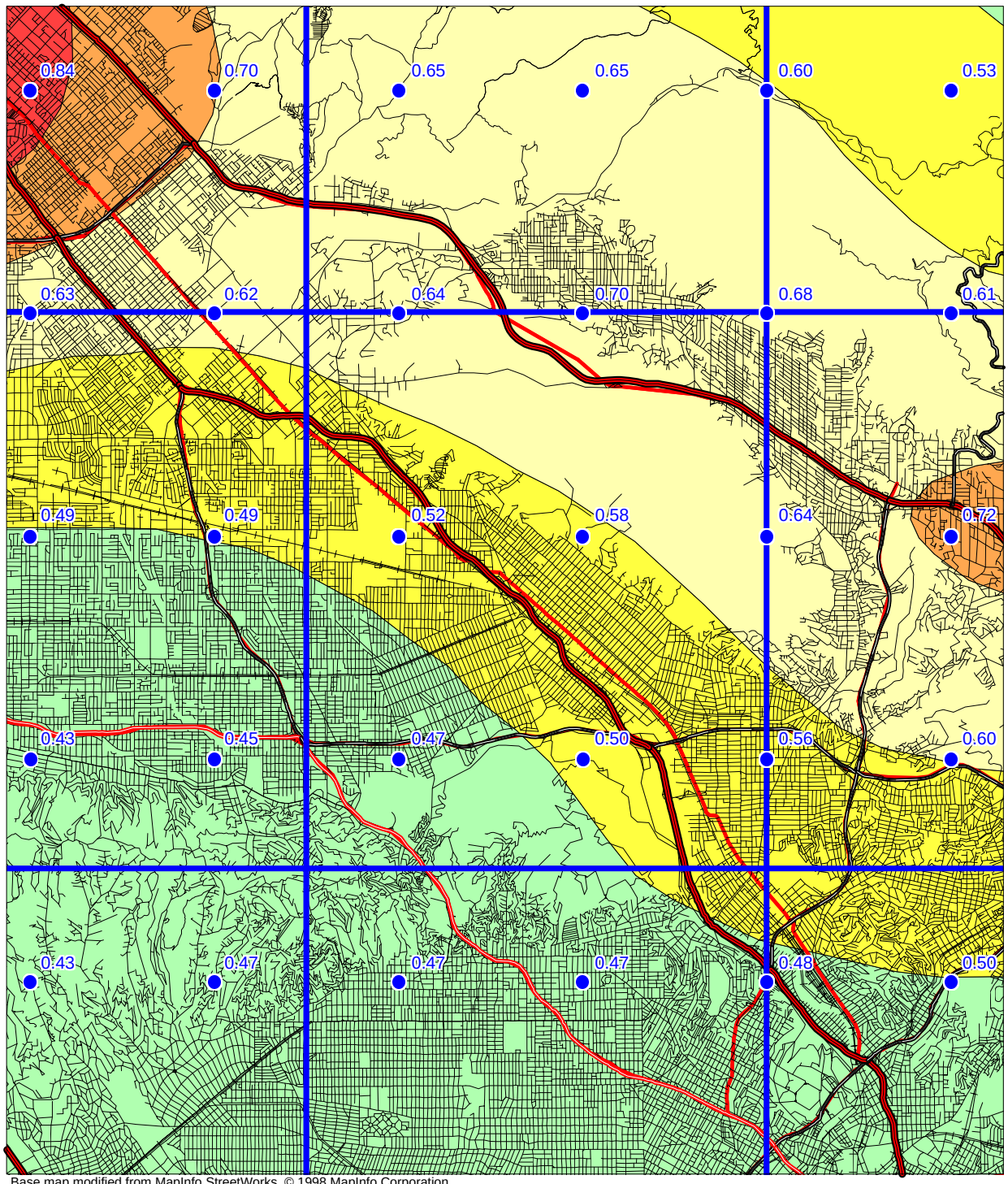
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

BURBANK 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

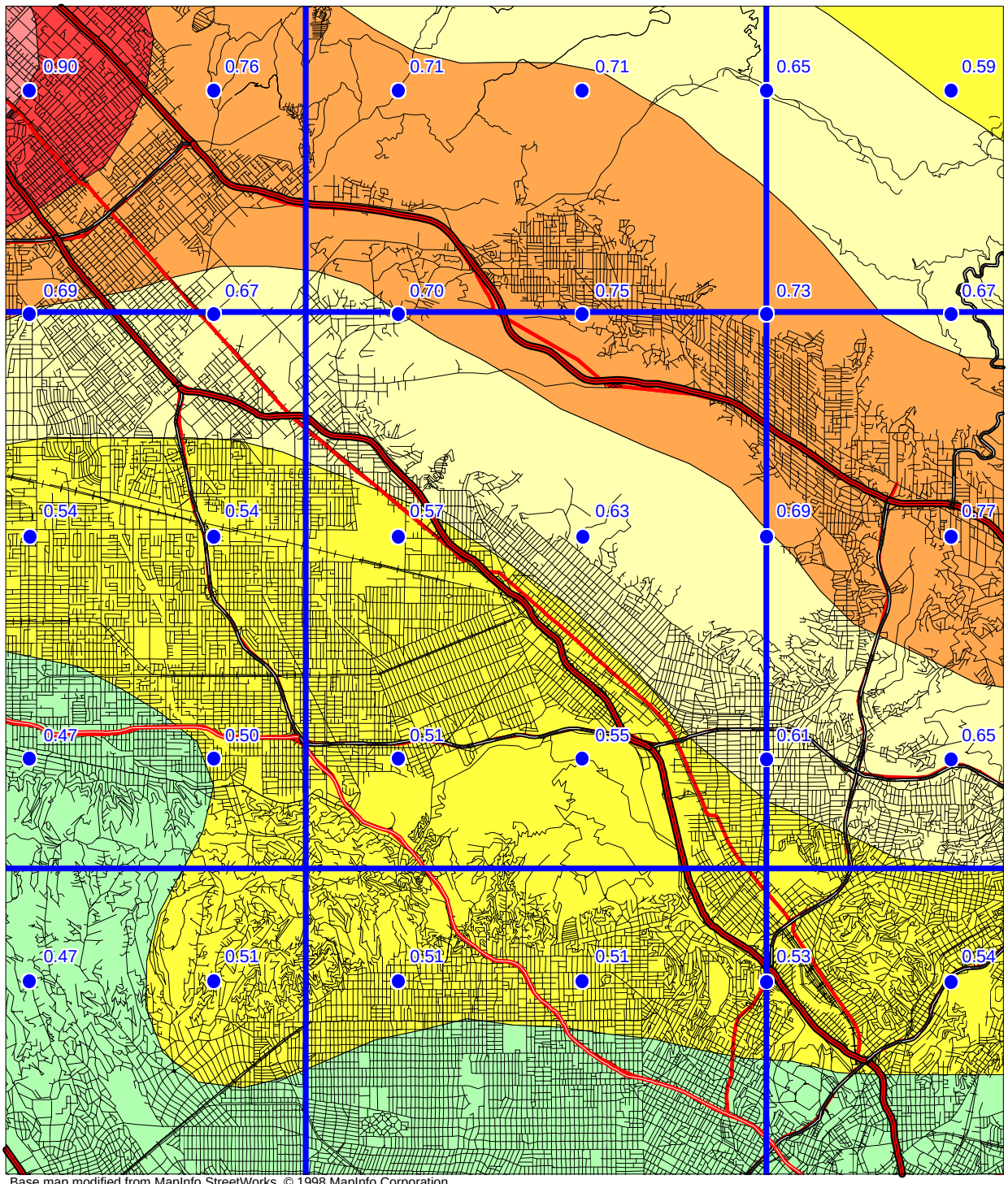
Figure 3.1

BURBANK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

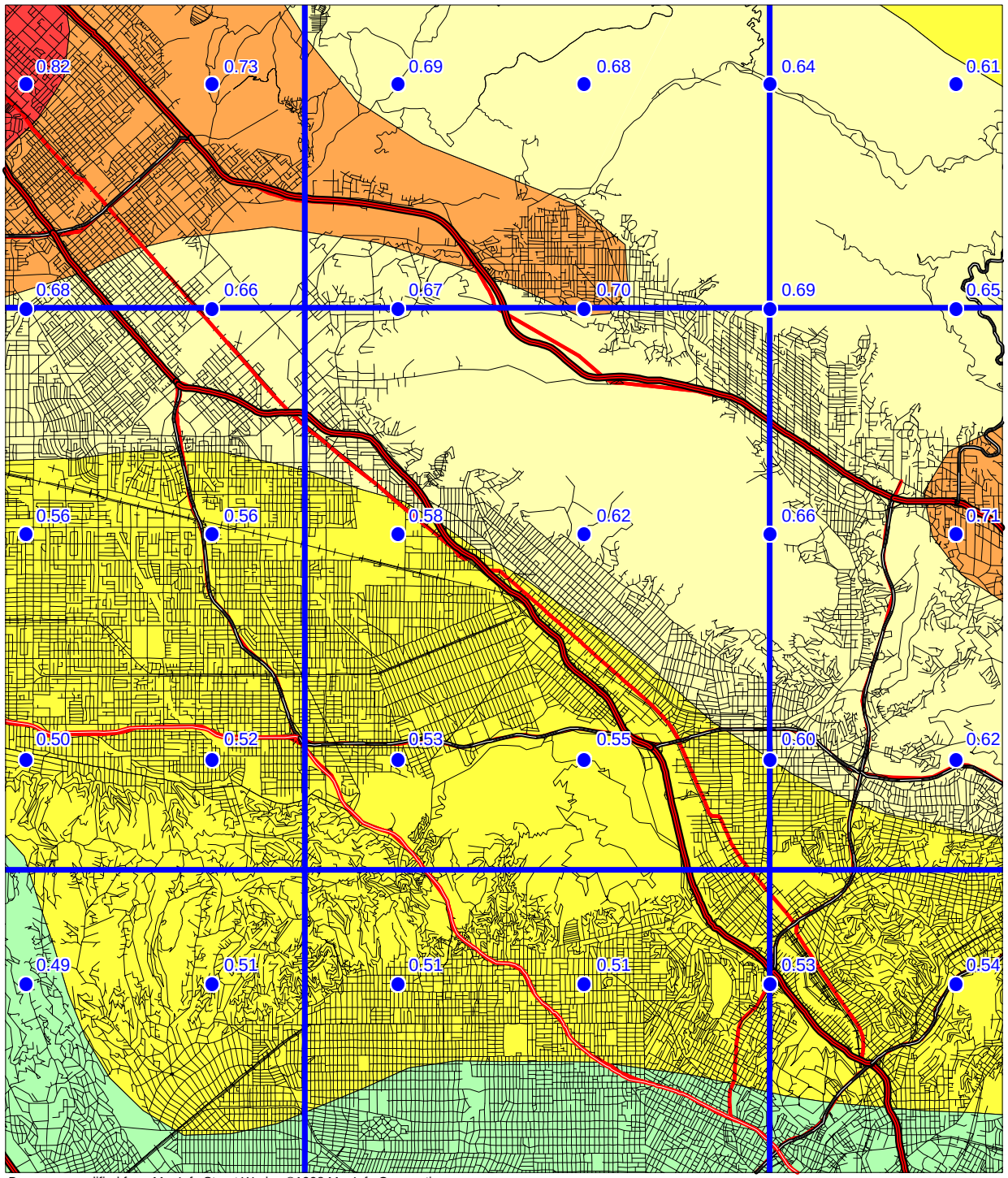
Figure 3.2

BURBANK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



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0 2.5 5
Kilometers

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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.

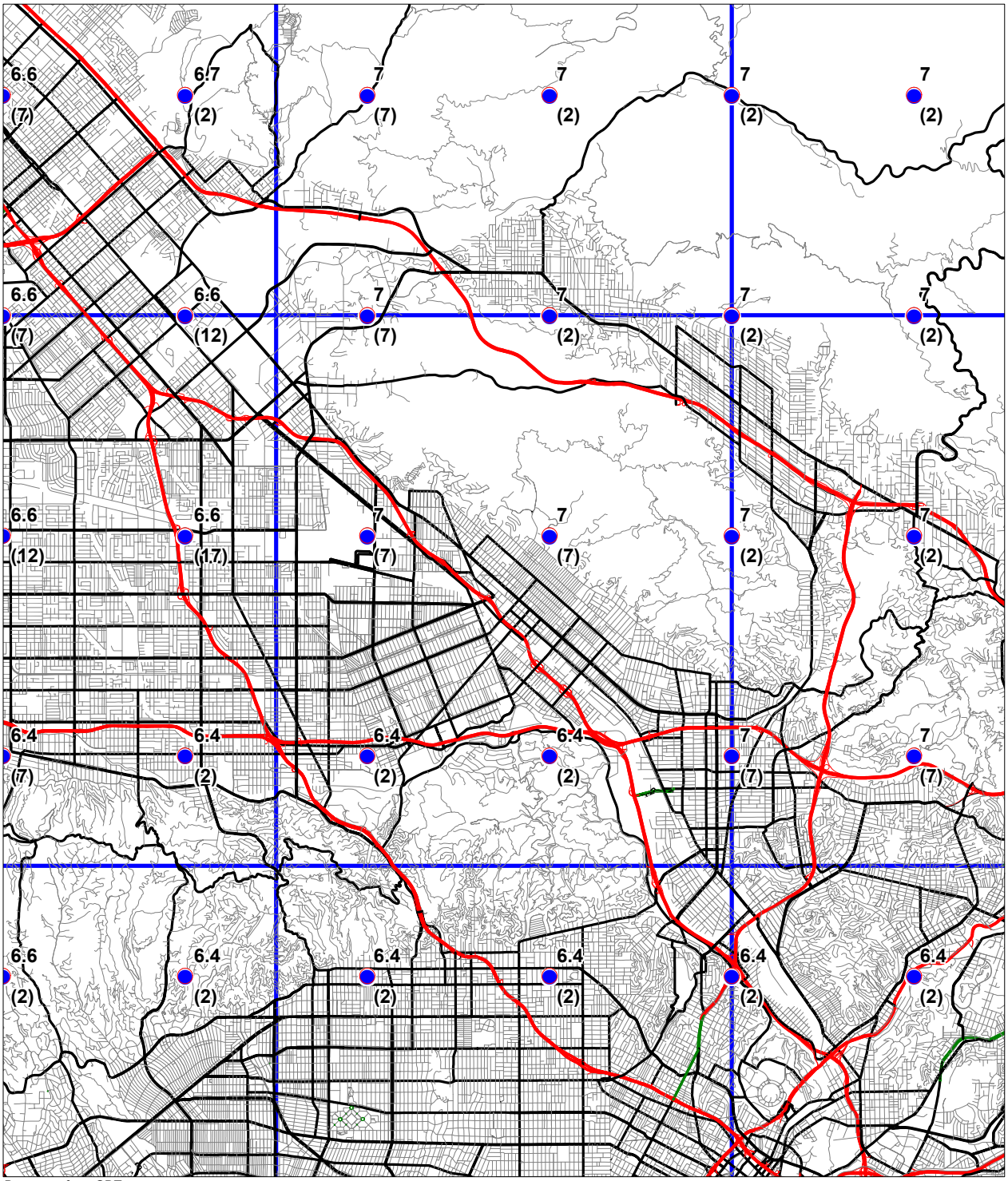
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss' weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

BURBANK 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

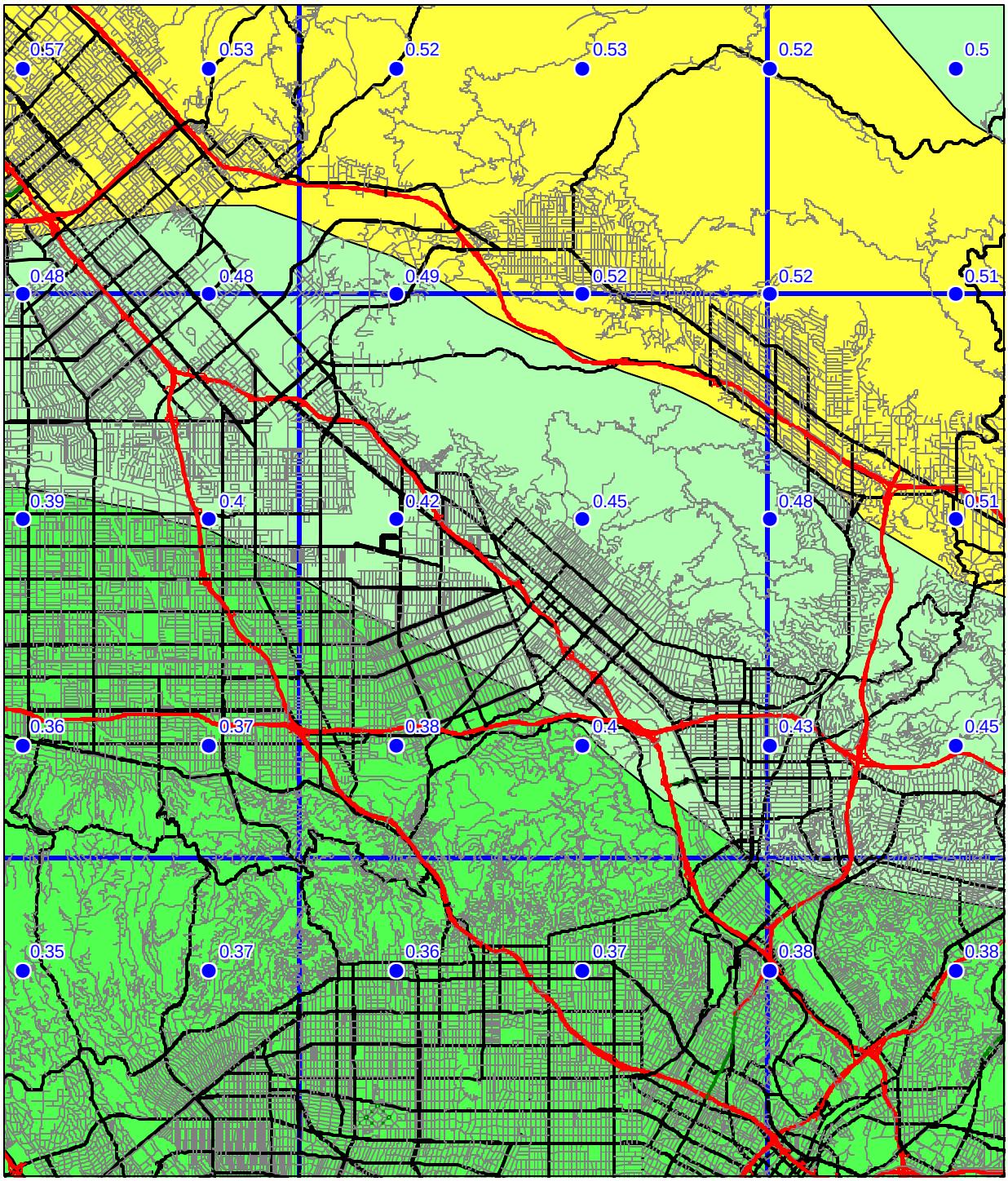
Figure 3.4

BURBANK 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 Burbank Quadrangle.

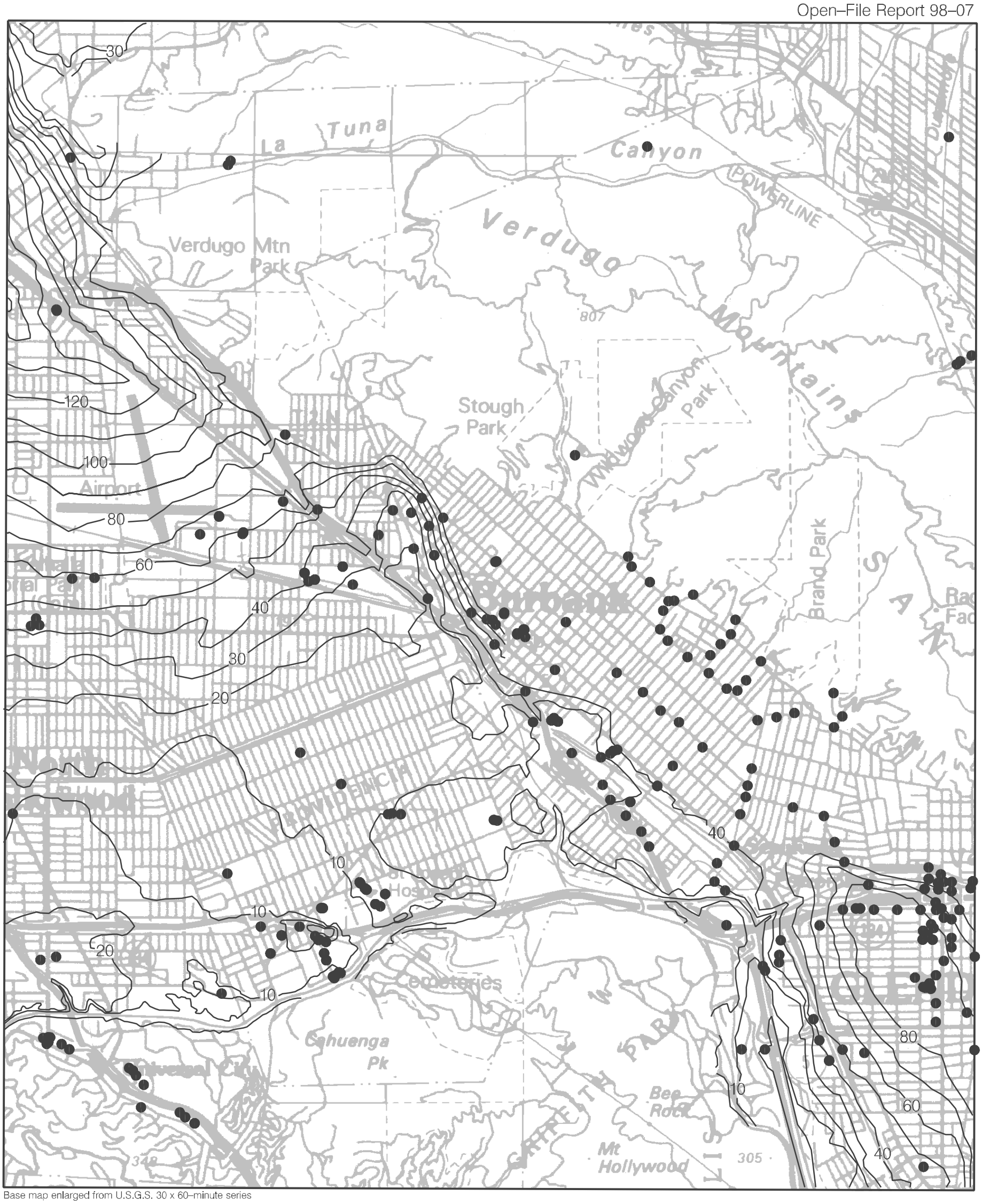
See Geologic Conditions section in report for descriptions of the units.

B = Pre–Quaternary bedrock.

res = reservoir.

ONE MILE

SCALE



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

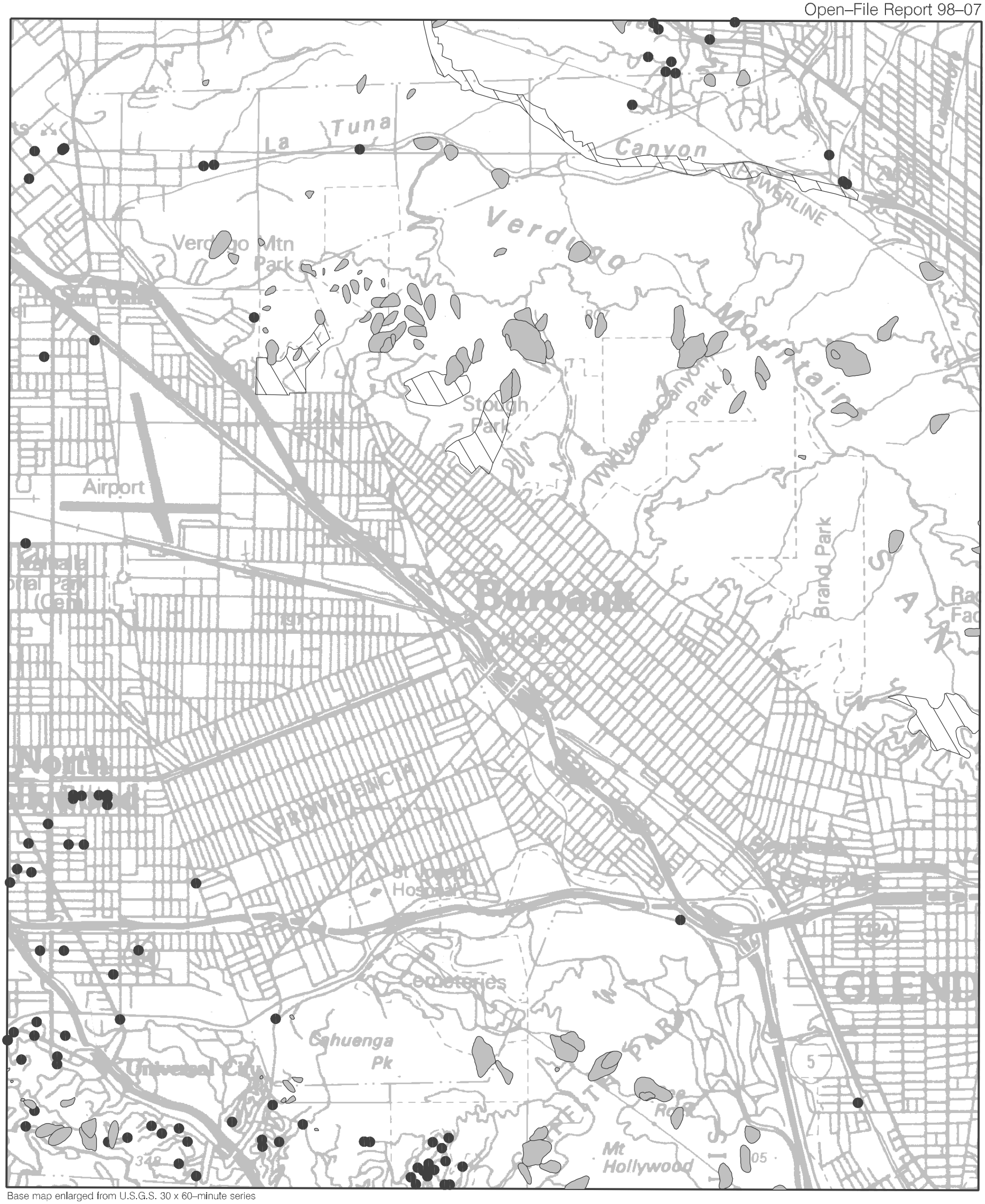
Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Burbank Quadrangle.

● 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, Burbank Quadrangle.

● shear test sample location landslide areas of significant grading

ONE MILE

SCALE