OPEN-FILE REPORT 2000-012

SEISMIC HAZARD EVALUATION OF THE BLACK STAR CANYON 7.5-MINUTE QUADRANGLE, ORANGE COUNTY, CALIFORNIA

2000

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Division of Mines and Geology

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CONTENTS

PREFACE vii

INTRODUCTION 1

SECTION 1 LIQUEFACTION EVALUATION REPORT Liquefaction Zones in the Black Star Canyon 7.5-Minute Quadrangle, Orange County, California 2

PURPOSE 2

Background 3

Scope and Limitations 3

PART I 4

STUDY AREA LOCATION AND PHYSIOGRAPHY 4

GEOLOGIC CONDITIONS 5

GROUND-WATER CONDITIONS 7

PART II 8

EVALUATING LIQUEFACTION POTENTIAL 8

LIQUEFACTION OPPORTUNITY 8

LIQUEFACTION SUSCEPTIBILITY 9

LIQUEFACTION ZONES 11

ACKNOWLEDGMENTS 12

REFERENCES 13

SECTION 2 EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT Earthquake-Induced Landslide Zones in the Black Star Canyon 7.5-Minute Quadrangle, Orange County, California 16

PURPOSE 16

Background 17

Scope and Limitations 17

PART I 18

STUDY AREA LOCATION AND PHYSIOGRAPHY 18

GEOLOGIC CONDITIONS 18

PART II 23

EARTHQUAKE-INDUCED LANDSLIDE GROUND SHAKING OPPORTUNITY 23

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL 25

EARTHQUAKE-INDUCED LANDSLIDE ZONE 27

ACKNOWLEDGMENTS 28

REFERENCES 28

AIR PHOTOS 30

APPENDIX A 31

SECTION 3 GROUND SHAKING EVALUATION REPORT Potential Ground Shaking in the Black Star Canyon 7.5-Minute Quadrangle, Orange County, California 32

PURPOSE 32

EARTHQUAKE HAZARD MODEL 33

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS 37

USE AND LIMITATIONS 37

REFERENCES 40

ILLUSTRATIONS

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station #14 Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake. 25

Figure 3.1. Black Star Canyon 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Firm rock conditions. 34

Figure 3.2. Black Star Canyon 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Soft rock conditions. 35

Figure 3.3. Black Star Canyon 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Alluvium conditions.....36

Figure 3.4. Black Star Canyon 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration—Predominant earthquake. 38

Table 1.1 Quaternary stratigraphic nomenclature used in the Black Star Canyon Quadrangle. .7

Table 1.2 General geotechnical characteristics and liquefaction susceptibility of Quaternary sedimentary units. 10

Table 2.1. Summary of the Shear Strength Statistics for the Black Star Canyon Quadrangle. ..22

Table 2.2. Summary of the Shear Strength Groups for the Black Star Canyon Quadrangle. 23

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Black Star Canyon Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone 27

Plate 1.1. Quaternary geologic map of the Black Star Canyon Quadrangle

Plate 1.2. Historically highest ground-water contours and borehole log data locations, Black Star Canyon Quadrangle

Plate 2.1. Landslide inventory, shear test sample locations, and areas of significant grading, Black Star Canyon Quadrangle

PREFACE

With the increasing public concern about the potential for destructive earthquakes in northern and southern California, the State Legislature passed the Seismic Hazards Mapping Act in 1990. The purpose of the Act is to protect the public from the effects of strong ground shaking, liquefaction, landslides or other ground failure, and other hazards caused by earthquakes. The program and actions mandated by the Seismic Hazards Mapping Act closely resemble those of the Alquist-Priolo Earthquake Fault Zoning Act (which addresses only surface fault-rupture hazards) and are outlined below:

1. **The State Geologist** is required to delineate the various "seismic hazard zones."

2. **Cities and Counties**, or other local permitting authorities, must regulate certain development "projects" within the zones. They must withhold the 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.

3. **The State Mining and Geology Board (SMGB)** provides additional regulations, policies, and criteria to guide cities and counties in their implementation of the law. The SMGB also provides criteria for preparation of the Seismic Hazard Zone Maps (Web site http://www.consrv.ca.gov/dmg/shezp/zoneguid/) and for evaluating and mitigating seismic hazards.

4. **Sellers (and their agents)** of real property within a mapped hazard zone must disclose at the time of sale that the property lies within such a zone.

As stated above, the Act directs the State Geologist, through the Division of Mines and Geology (DMG) to delineate seismic hazard zones. Delineation of seismic hazard zones is conducted under criteria established by the Seismic Hazards Mapping Act Advisory Committee and its Working Groups and adopted by the California SMGB.

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

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

Seismic Hazard Evaluation Reports, released as Open-File Reports (OFR), 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 Open-File Reports are available

for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. Copies of the reports may be purchased at the Sacramento, Los Angeles, and San Francisco offices. In addition, the Sacramento office offers prepaid mail order sales for all DMG OFRs. **NOTE: The Open-File Reports are not available through BPS Reprographic Services.**

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Seismic Hazard Evaluation Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, 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 (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

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

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

This Seismic Hazard Evaluation Report summarizes the development of the hazard zone map for each area. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historic high-water-table 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 evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Black Star Canyon 7.5-minute Quadrangle (scale 1:24,000).

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Black Star Canyon 7.5-Minute Quadrangle, Orange County, California

By
Richard B. Greenwood

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, 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 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 (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Black Star Canyon 7.5-minute Quadrangle (scale 1:24,000). This section and Section 2 addressing earthquake-induced landslides, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazards zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Liquefaction-induced ground failure has historically 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 sediments within the upper 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 opportunity 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 Black Star Canyon Quadrangle.

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils is generally confined to areas covered by Quaternary sedimentary deposits. Such areas consist mainly of alluviated valleys, floodplains, and canyon regions. The evaluation is based on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth data, most of which are gathered from a variety of sources. The quality of the data used varies. Although selection of data used in this evaluation was rigorous, 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 and thickness of liquefiable sediments, depth to ground water, rate of drainage, slope gradient, proximity to free-face conditions, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to determine 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 potential, opportunity, susceptibility, and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Black Star Canyon Quadrangle covers an area of about 62 square miles at the northern end of the Santa Ana Mountains. Most of the quadrangle is in Orange County except for about five square miles of unevaluated terrain in the northeastern corner that lies in Riverside County. The mapped area includes portions of the cities of Anaheim, Orange, and Yorba Linda, as well as unincorporated portions of Orange County. The Santa Ana River and Santiago Creek drain the northern and central portions of the quadrangle. These two drainage systems are separated by the eastern part of the Peralta Hills, a west-trending projection of the Santa Ana Mountains that includes the Anaheim Hills community within the City of Anaheim. Southeast of Santiago Creek is an upland area of unincorporated Orange County that includes a prominent monocline of Puente Formation, locally named Loma Ridge. Elevations in the Black Star Canyon Quadrangle range from about 380 feet at the mouth of Santa Ana Canyon, near the northwestern corner of the quadrangle, to 3,045 feet at Sierra Peak in the Santa Ana Mountains, on the county line in the northeastern portion of the quadrangle.

The southwestern quarter of the quadrangle, where relief is moderate, consists of rolling hills underlain by Miocene sedimentary rocks. Elevations here range from 440 feet to 1332 feet. The present and ancestral drainages of Santiago Creek generally define an erosional separation between areas underlain by sedimentary rocks of contrasting ages. Resistant Mesozoic metavolcanic and metasedimentary rocks underlie the higher elevations of the Santa Ana Mountains in the eastern part of the quadrangle. The foothill section of the Santa Ana Mountains has been sculpted by erosion into a maze of canyons and tributary gullies—including Black Star Canyon, a tributary of Santiago Creek that has been referred to locally as the “Grand Canyon of the Santa Ana Mountains.”

The Black Star Quadrangle is nearly bisected by the north-south Orange County Eastern Transportation Corridor (State Route 241). The northern border of the study area is accessible from the Riverside Freeway (State Route 91), which follows the southern bank of the Santa Ana River, through Santa Ana Canyon.

Dense commercial development covers the floor of the Santa Ana River valley. Residential development in recent years has taken place mainly along the lower slopes and ridgetops in the northwestern part of the Black Star Canyon Quadrangle, west of the Eastern Transportation Corridor. Most residential development in the upland areas consists of major projects that required substantial grading and drainage modification prior to construction.

GEOLOGIC CONDITIONS

Surface Geology

The geologic map for the Black Star Canyon Quadrangle was digitized by the Southern California Areal Mapping Project [SCAMP](1995) from DMG 1:12,000-scale mapping by Miller and Tan (1983) and Tan (1992). Quaternary unit designations were compiled by the Southern California Areal Mapping Project (1995) from Miller and Tan (1983) and Tan (1992) and received "spot field review" during the course of this investigation. Schoellhamer and others (1981) also described the geologic units in the northern Santa Ana Mountains. Regional maps by Morton and Miller (1981) and by Greenwood and Morton (1990) cover this area too. The Quaternary geologic map of the Black Star Canyon Quadrangle is reproduced as Plate 1.1.

Quaternary deposits of older alluvium flank the lower slopes of the hills and lie beneath the basin area in the west half of the quadrangle. The deposits along the Santa Ana River and Santiago Creek include late Pleistocene (?) to Holocene floodplain and stream terrace deposits (Qvofsa, Qvofga, Qvofa, Qofa, Qyfsa, Qyfga, Qyfa, Qf1, Qp, Qycsa, Qyag, Qyaa). These deposits consist of unconsolidated to poorly consolidated mixtures of sand, silt, and gravel. The only units mapped in this quadrangle as artificial fill (af) are earth-filled embankment dams and highway-related engineered fills.

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

Subsurface Geology and Geotechnical Characteristics

Information on subsurface properties was obtained from more than 34 borehole logs in the study area. Subsurface data used for this study include the database compiled by Sprotte and others (1980) for ground response studies, with additional water well logs from the California Department of Water Resources and the Orange County Water District, and geotechnical logs from larger geotechnical firms. Geotechnical data, particularly SPT blow counts, from environmental studies are sometimes less reliable, however, due to the use of non-standard equipment and incomplete reporting of procedures.

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

Older, elevated terrace deposits (Qvofsa ,Qvofga)

Late Pleistocene (?) terrace deposits in the Black Star Canyon Quadrangle occur along the margins of Santiago Creek and the Santa Ana River. The terrace sand and gravels and silty-sands are isolated on slopes or found at the base of slopes where ground water is deep, so no extensive effort was made to collect subsurface data.

Old fan deposits (Qofa)

Isolated occurrences of Late Pleistocene (?) older fan deposits were mapped by Miller and Tan (1983) near the head of Baker Canyon. These older, elevated alluvial deposits are likely to be equivalent to the older terrace deposits. They are inferred to consist of dense to very dense sand and gravel with interbedded sand and silty sand.

Lacustrine (lake and pond) deposits (Qp)

Lacustrine deposits in the Black Star Canyon Quadrangle occur behind major engineered dams (Santiago Dam) and local embankment dams. They generally consist of soft, wet, silt to silty sand deposits.

Colluvium deposits (Qycsa)

Deposits of colluvium in the Black Star Canyon Quadrangle occur along the base of slopes, adjacent to drainages and at the heads of drainages. They generally consist of soft, wet, sand to silty-sand deposits.

Younger (and active) fan deposits (Qyfsa, Qyfga, Qyfa, Qf1)

Younger fan deposits that occur within the drainage courses of the Santa Ana River, Santiago Creek, and adjacent associated drainage courses and upland creeks. They generally consist of wet, loose, gravelly sands, sands, and silty-sands.

Active alluvial deposits (Qyag, Qyaa)

Miller and Tan (1983) identified younger (active) alluvial (wash) deposits within the higher reaches of creeks that are tributary to Santiago Creek. They generally consist of wet, loose, gravelly sands and sands.

Geologic Map Unit	Material Type	Consistency	Age
Qyag, Qyaa, active alluvial deposits	gravelly-sand and sand	Loose	Holocene
Qyfsa, Qyfga, Qf1 Younger fan deposits	Gravelly-sand, sand, silty-sand	Loose	Holocene
Qycsa colluvium deposits	sand, silty-sand	Soft	Holocene
Qp lacustrine deposits	Silt, silty-sand	Soft	Holocene
Qofsa old fan deposits	sand & gravel, sand, silty-sand	Dense-very dense	Late Pleistocene (?)
Qvofsa, Qvofga older elevated terrace deposits	sand & gravel, silty-sand	Dense-very dense	Late Pleistocene (?)

Table 1.1. Quaternary stratigraphic nomenclature used in the Black Star Canyon Quadrangle.

GROUND-WATER CONDITIONS

Liquefaction hazard mapping focuses on areas historically characterized by ground-water depths of 40 feet or less. Accordingly, ground-water conditions were investigated in the Black Star Canyon Quadrangle to evaluate the depth to saturated sediments. Saturated conditions reduce the normal effective stress acting on loose, near-surface sandy deposits, thereby increasing the likelihood of liquefaction (Youd, 1973). Ground-water depth data were obtained from geotechnical boreholes, water-well logs, and environmental monitoring wells. The evaluation was based on first-encountered water levels encountered in the boreholes and selected water wells. The depths to first-encountered water, free of piezometric influences, were plotted onto a map of the project area showing depths to historically shallowest ground water (Plate 1.2). Such a map differs from most ground-water maps, which show the actual water table at a particular time, in that this map depicts a hypothetical ground-water table. This map was digitized and used for the liquefaction analysis.

The geotechnical boreholes indicate perennial high ground water in the Santiago Creek and Santa Ana River drainages and in the upper portions of the tributary drainages in the Santa Ana Mountains. Sediments in these drainages are assumed to be saturated during periods of high precipitation. The Orange County Water District maintains subsurface inflow in the Santa Ana River Canyon, in accordance with ground-water basin-management practices. The Serrano Water District monitors subsurface inflow into Santiago Creek.

PART II

EVALUATING LIQUEFACTION POTENTIAL

Liquefaction occurs in water-saturated sediments during moderate to great earthquakes. Liquefied sediments are characterized by a loss of strength and may fail, causing damage to buildings, bridges, and other such structures. A number of 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 susceptibility units, and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce liquefaction potential. Liquefaction susceptibility is a function of the capacity of sediments to resist liquefaction and liquefaction opportunity is a function of the seismic ground shaking intensity. The application of the Seed Simplified Procedure (Seed and Idriss, 1971) for evaluating liquefaction potential allows a quantitative characterization of susceptibility of geologic units. Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for mapping liquefaction hazards in the Los Angeles region. The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985), combining geotechnical data analyses, and geologic and hydrologic mapping, but follows criteria adopted by the California State Mining and Geology Board (in press).

LIQUEFACTION OPPORTUNITY

According to the criteria adopted by the California State Mining and Geology Board (in press), liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. 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. The earthquake magnitude is the magnitude that contributes most to the acceleration.

For the Black Star Canyon Quadrangle, a peak acceleration of 0.42 g resulting from an earthquake of magnitude 6.8 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) and Cramer and Petersen (1996). See the ground motion portion (Section 3) of this report for further details.

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of soils to loss of strength when subjected to ground shaking. Primarily, physical properties and conditions of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance. These properties and conditions are correlated with geologic age and environment of deposition. With increasing age of a deposit, relative density may increase through cementation of the particles or the increase in thickness of the overburden sediments. Grain size characteristics of a soil also influence susceptibility to liquefaction. Sands are more susceptible than silts or gravels, although silts of low plasticity are treated as liquefiable in this investigation. Cohesive soils are generally 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 lower liquefaction susceptibility generally result in higher penetration resistances to the soil sampler. Different blow count corrections are used for silty sand and nonplastic silt than for clean sand (Seed and others, 1985). Therefore, blow count or cone penetrometer values are a useful indicator 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 (more likely to liquefy). Soils that lack resistance (susceptible soils) are typically saturated, loose sandy sediments. Soils resistant to liquefaction include all soil types that are dry or sufficiently dense.

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil-property and soil-condition factors such as type, age, texture, color, and consistency, along with historic depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, findings can be related to the map units. DMG's qualitative susceptible soil inventory is summarized on Table 1.2.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and others, 1985; National Research Council, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (SPT) results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The factor of safety (FS) relative to liquefaction is: FS=CRR/CSR. FS, therefore, is a quantitative measure of liquefaction

potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site related structures. For a regional assessment DMG normally has a range of FS that results from the liquefaction analyses. The DMG liquefaction analysis program calculates an FS at each sample that has blow counts. The lowest FS in each borehole is used for that location. These FS vary in reliability according to the quality of the geotechnical data. These FS, as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which then directly translate to Zones of Required Investigation**.**

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Susceptible to Liquefaction?*
Qyaa,Qyag	Gravelly-sand, sand	Active stream channels	Loose	Yes
Qyfsa, Qyfga, Qyfa, Qf1	Gravelly-sand, sand, silty-sand	Younger and active alluvial fans	Loose	Yes
Qycsa	Sand, silty-sand	Colluvial deposits	Soft	Yes
Qp	Silt, silty-sand	Lacustrine deposits	Soft	Yes
Qofa	Sand and gravel, sand, silty-sand	Old fan deposits	Dense to very dense	Not likely
Qvofsa, Qvofga	Sand and gravel, sand, silty-sand	Older alluvial fans	Dense to very dense	Not likely

* When saturated.

Table 1. 2. General geotechnical characteristics and liquefaction susceptibility of Quaternary sedimentary units.

Of the 34 geotechnical borehole logs used in this study (Plate 1.2), 5 include blow-count data from SPT's or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2 1/2-inch inside diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (soil density, moisture content, sieve analysis, etc) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values or using average test values of similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

The areas underlain by late Quaternary geologic units were included in liquefaction zones using the criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (in press). Under those criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historic earthquakes.

2. All areas of uncompacted fills 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 historic 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 (between 11,000 years and 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 historic high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria for liquefaction zoning in the Black Star Canyon Quadrangle is summarized below.

Areas of Past Liquefaction

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

Artificial Fills

In the Black Star Canyon Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for river levees and elevated freeways. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata. Areas of major reservoirs, such as Santiago Reservoir, were not zoned for liquefaction, in accordance with program directives.

Areas with Sufficient Existing Geotechnical Data

The study area does not contain sufficient areal distribution or density of boreholes, nor is the quality of data collected in this investigation from the existing boreholes sufficient to adequately evaluate the liquefaction susceptibility.

Areas with Insufficient Existing Geotechnical Data

Geologic conditions were adequately identified and characterized by representative surface geologic mapping, at a scale that is appropriate for this regional hazard analysis, and by logs from available subsurface boreholes and wells. The areas were placed within Zones of Required Investigations because such soils generally reflect conditions named in the SMGB criteria items 4a-c.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Black Star Canyon 7.5-Minute Quadrangle, Orange 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, 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 (1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Black Star Canyon 7.5-minute Quadrangle (scale 1:24,000). This section and Section 1 addressing liquefaction, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Landslides triggered by earthquakes have historically been a major cause of earthquake damage. Landslides triggered by the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes were responsible for destroying or damaging numerous homes and other structures, blocking major transportation corridors, and damaging various types of life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, in loose soils, and on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, most notably in hilly areas already developed or currently undergoing development. In addition, the opportunity 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, which includes the Black Star Canyon Quadrangle.

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 primarily from a variety of outside sources; thus the quality of the data is variable. Although the selection of data used in this evaluation was rigorous, 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. Earthquake-generated ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. 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 Black Star Canyon Quadrangle, for more information on the delineation of liquefaction zones.

Information developed in the study is presented in two parts: physiographic, and geologic conditions in PART I, and ground shaking opportunity, landslide hazard potential and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Black Star Canyon Quadrangle covers an area of about 62 square miles in eastern Orange and western Riverside counties. Approximately five square miles in the northeastern corner of the quadrangle is within western Riverside County and was not included in our analysis. The entire quadrangle lies within the northwest-trending Santa Ana Mountains where elevations ranging from 300 feet in the northwest to 3700 feet in the east. Santa Ana Canyon, incised into the mountains by the westward-flowing Santa Ana River, forms the northern boundary of the area. The Cleveland National Forest extends into the eastern third of the quadrangle. Portions of the cities of Anaheim and Yorba Linda, where mass grading and development has occurred, lie within the northwestern quarter of the quadrangle. The area is accessible from the south by the Orange County Eastern Transportation Corridor (State Routes 241 and 261) and Santiago Canyon Road (along Santiago Creek), and from the northeast and northwest by the Riverside Freeway (State Highway 91). Highway 241 runs almost the length of the western half of the quadrangle separating populated areas to the west from largely unpopulated areas to the east. Undeveloped areas to the east contain brushy chaparral vegetation and relatively steep terrain.

GEOLOGIC CONDITIONS

Surface and Bedrock Geology

The geologic map for the Black Star Canyon Quadrangle was digitized by the Southern California Areal Mapping Project [SCAMP](1995) from DMG 1:12,000-scale mapping by Miller and Tan (1983) and Tan (1992). Geology for the Cleveland National Forest section in the southeastern portion of the quadrangle was taken from Schoellhamer and others (1981). The digital geologic map was modified during this project to reflect field observations and the most recent mapping in the area. In the field, 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 slope failures was noted.

The oldest geologic units, exposed in the eastern part of the area, are Middle to Late Jurassic Bedford Canyon Formation (labeled on geologic map as Jbc) and Late Jurassic-Cretaceous Santiago Peak Volcanics (Jsp, KJsp, Kvsp) (Morton and others, 1976). The Jbc consists of a slightly metamorphosed sedimentary sequence of siltstone and mudstone interbedded with sandstone and conglomerate. The Santiago Peak Volcanics consist of mildly metamorphosed andesitic flows, tuffs, and agglomerates.

Unconformably overlying the basement rocks is a highly varied sequence of nonmarine and marine sedimentary units that range in age from Late Cretaceous to Holocene. The basal unit exposed just to the west of the basement rocks is the Late Cretaceous Trabuco

Formation (Ktr), which consists of nonmarine boulder fanglomerate. Overlying the Ktr is a Late Cretaceous, well-bedded marine unit called the Ladd Formation (Kl), which consists of several members: the Baker Canyon Conglomerate (Klb, Klbc), the Holz Shale (Klh, Klhs), and the Holz Sandstone/Conglomerate (Klhsc). The Ladd Formation crops out in the eastern and central portions of the quadrangle.

Overlying the Ladd Formation are Late Cretaceous marine members of the Williams Formation that are exposed throughout the central portion of the quadrangle. The older member is the Schulz Ranch Member (Kws, Kwsr), which consists of siltstone beds that grade upward into conglomeratic sandstone beds. The younger member is the Pleasants Sandstone Member (Kwp, Kwps), which consists of fine-grained silty sandstone layers interbedded with concretionary fine-grained sandstone/siltstone units.

The oldest Tertiary rocks, which were deposited on a major unconformity, are Paleocene Silverado Formation (Tsi) and Eocene-Oligocene Santiago Formation (Tsa). The Tsi is composed of basal nonmarine sandstone and conglomerate with siltstone interbeds that grade upward into marine interbedded sandstone and siltstone. The Tsa is composed of basal marine silty sandstone that grades upward into brackish-nonmarine massive pebbly sandstone. These formations exist throughout much of the southern and eastern portions of the quadrangle.

The Miocene Sespe and Vaqueros formations (Ts and Tv, respectively) overlie the Santiago Formation. Because these two formations have a complex interfingering relationship in the area, they are difficult to separate in the field and are sometimes shown combined on the geologic map (Tvs where this occurs). The Sespe Formation is a poorly bedded, nonmarine coarse to conglomeratic sandstone unit, whereas the Vaqueros Formation is a marine interbedded siltstone, mudstone, and shale unit. These formations crop out in the southern and central portions of the quadrangle, west of the Santiago Formation.

The Miocene Topanga Formation (Tt) and the four members of the Miocene Puente Formation, the La Vida (Tpl), Soquel (Tps), Yorba (Tpy), and Sycamore Canyon (Tpsc) members, were deposited on the Sespe and Vaqueros formations. The Topanga Formation is composed predominantly of marine sandstone beds with occasional tuffaceous sandstone and siltstone interbeds. The La Vida Member is composed of laminated siltstone with thin interbeds of feldspathic sandstone. The Soquel Member consists mainly of coarse-grained to pebbly feldspathic sandstone beds. The Yorba Member consists of thinly bedded siltstone and fine-grained sandstone beds. The Sycamore Canyon Member is composed of interbedded sandstone, siltstone, and conglomerate layers. These formations crop out in the western half of the quadrangle.

Quaternary deposits include late Pleistocene to Holocene floodplain and stream terrace deposits (Qvofsa, Qvofga, Qvofa, Qofa, Qoa, Qco, Qsa, Qyofsa, Qyfsa, Qyfga, Qyfa, Qf1, Qp, Qycsa, Qyag, Qyaa, and Qc). These deposits consist of unconsolidated to poorly consolidated, non-marine mixtures of sand, silt, and gravel. The only items mapped in this quadrangle as artificial fill (af) are earth-filled dam embankments and

highway-related engineered fills. A more detailed description of the Quaternary units is given in Section 1 of this report.

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, they first must be ranked based on their overall 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 California Department of Transportation, the Silverado Construction Company, the City of Anaheim, and Environmental Impact Reports and Hospital Review Project files at DMG (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 mapped geologic unit, and subdivided for fine-grained and coarse-grained lithologies if appropriate. Geologic units were grouped on the basis of average angle of internal friction (average f) and lithologic character. For the Black Star Canyon Quadrangle, shear test values and statistical results from adjacent quadrangles were used to help match formations without geotechnical information with the appropriate strength group.

To subdivide mapped geologic formations that have both fine-grained and coarse-grained lithologies, we assumed that where stratigraphic bedding dips into a slope (favorable bedding) the coarse-grained material strength dominates, and where bedding dips out of a slope (adverse bedding) the fine-grained material strength dominates. We then used structural information from the geologic map (see “Structural Geology”) and terrain data in the form of slope gradient and aspect, to identify areas with a high potential for containing adverse bedding conditions. These areas, located on the map, were then used to modify the geologic material-strength map to reflect the anticipated lower shear strength for the fine-grained materials.

The results of the grouping of geologic materials in the Black Star Canyon Quadrangle are in Tables 2.1 and 2.2.

BLACK STAR CANYON QUADRANGLE
SHEAR STRENGTH GROUPS

	Formation Name* (rock types)	Number Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No data but Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1	Klb(fbc)	2	39/39	40/39	492/550	Jbc, Jsp, KJsp	40
	Kws(fbc)	2	41/41			Kvsp, Klbc(fbc)	
						Kwsr(fbc)	
GROUP 2	Klh	15	37/36	36/36	565/400	Ktr, Kl	36
	Kwp	6	36/34			Kwps, Klhsc	
	Tsi	14	37/37			Klhs, Ts(fbc)	
	Tsa	11	35/35			Tv(fbc)	
	Tvs(fbc)	54	36/36			Qvofa	
	Tt(fbc)	35	37/38			Qvofga	
	Qyofsa	6	37/38			Qvofsa	
	Qyfsa	9	36/37			Qyfga	
GROUP 3	Kws(abc)	3	30/28	31/30	790/370	Klb(abc)	31
	Tvs(abc)	13	30/34			Klbc(abc)	
	Tps(fbc)	1	31/31			Kwsr(abc)	
	Qc	1	30/30			Ts(abc), Ts(abc)	
	af	7	31/29			Tpl(fbc), Tpy(fbc)	
						Tpsc(fbc), Qoa	
						Qofa, Qco, Qsa	
						Qycsa, Qyaa, Qyag	
						Qyfa, Qf1	
GROUP 4	Tt(abc)	4	26/27	27/24	329/285	Tpl(abc), Tps(abc)	27
	Tpy(abc)	10	28/24			Tpsc(abc), Qp	
GROUP 5	Qls	22	23/23	23/23	288/75		23

*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 Black Star Canyon Quadrangle.

SHEAR STRENGTH GROUPS FOR THE BLACK STAR CANYON QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Jbc, Jsp	Ktr, Kl	Klb(abc)	Tt(abc)	Qls
KJsp, Kvsp	Klh, Klhsc	Klbc(abc)	Tpl(abc)	
Klb(fbc)	Klhs, Kwps, Kwp	Kws(abc)	Tps(abc)	
Klbc(fbc)	Tsi, Tsa	Kwsr(abc)	Tpy(abc)	
Kws(fbc)	Tvs(fbc)	Tvs(abc)	Tpsc(abc)	
Kwsr(fbc)	Ts(fbc)	Ts(abc)	Qp	
	Tv(fbc)	Tv(abc)		
	Tt(fbc)	Tpl(fbc)		
	Qvofa	Tps(fbc)		
	Qvofga	Tpy(fbc)		
	Qvofsa	Tpsc(fbc)		
	Qyofsa	Qoa, Qoaf		
	Qyfsa	Qco, Qsa		
	Qyfga	Qc, Qysca		
		Qyaa, Qyag		
		Qyfa, Qf1, af		

Table 2.1. Summary of the Shear Strength Groups for the Black Star Canyon Quadrangle.

According to statistical protocol, if there are fewer than 30 shear strength tests for a particular formation, the median value, instead of the mean, should be used to represent the formation when forming shear strength groups. There is a disparity between the mean and median value for the rock formations Tvs (abc) and Tpy (abc) that would normally lead to the designation of a new shear strength group, or moving them from one group to another. However, they have been added to their groups based on the similarities to other rock units in those groups. In addition, Group 4 was created at the mean phi angle of 27 degrees instead of median phi angle of 24 degrees because the rocks in this group are stronger than the landslide slip surfaces represented in Group 5 (23 degrees).

Structural Geology

Accompanying the digital geologic map were digital files of associated geologic structural data, including bedding and foliation attitudes (strike and dip) and fold axes. We used the structural geologic information provided with the digital geologic map to categorize areas of common stratigraphic dip direction and magnitude, similar to the method presented by Brabb (1983). The dip direction category was compared to the slope aspect (direction) category and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, and the bedding dip was greater than 25% (4:1 slope), the area

was marked as a potential adverse bedding area. This information was then used to subdivide mapped geologic units into areas where fine-grained and coarse-grained strengths would be used.

Landslide Inventory

The evaluation of earthquake-induced landsliding requires an up-to-date and complete picture of the previous occurrence of landsliding. An inventory of existing landslides in the Black Star Canyon Quadrangle was prepared by reviewing published landslide inventories and combining field observations, analysis of aerial photos, and interpretation of landforms on current and older topographic maps.

Published maps and reports showing or discussing landslides, such as Miller and Tan (1983) and Tan (1992) covering the south and north portions of the quadrangle respectively, were evaluated during the production of the landslide inventory for this study. The aerial photographs are from 1970 and are referenced under Air Photos.

The completed landslide inventory map was digitized and attributes on confidence of interpretation (definite, probable, or questionable) and other properties, such as activity, thickness, and associated geologic unit(s) were entered in a database. A version of this landslide inventory is included with Plate 2.1.

PART II

EARTHQUAKE-INDUCED LANDSLIDE GROUND SHAKING OPPORTUNITY

Design Strong-Motion Record

The Newmark analysis used in delineating the earthquake-induced landslide zones requires the selection of a design earthquake strong-motion record. For the Black Star Canyon Quadrangle, the selection 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; Cramer and Petersen, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.8
Modal Distance:	3 to 15 km
PGA:	0.35 to 0.72g

The strong-motion record selected was the USC Station #14 record (Trifunac and others, 1994) from the 1994 6.7-Mw Northridge earthquake. This record had a source to recording site distance of 8.5 km and a PGA of 0.59g. The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

To develop a relationship between the yield acceleration (a_y; defined as the horizontal ground acceleration required to cause the factor of safety to equal 1.0) and Newmark displacements, the design strong-motion record was integrated twice for a given a_y to find the corresponding displacement, and the process repeated for a range of a_y (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for any combination of geologic material strength and slope angle, as represented by the yield acceleration. We used displacements of 30, 15 and 5 cm as criteria for rating levels of earthquake shaking damage on the basis of the work of Youd (1980), Wilson and Keefer (1983), and the 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 0.232g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant to the Black Star Canyon Quadrangle.

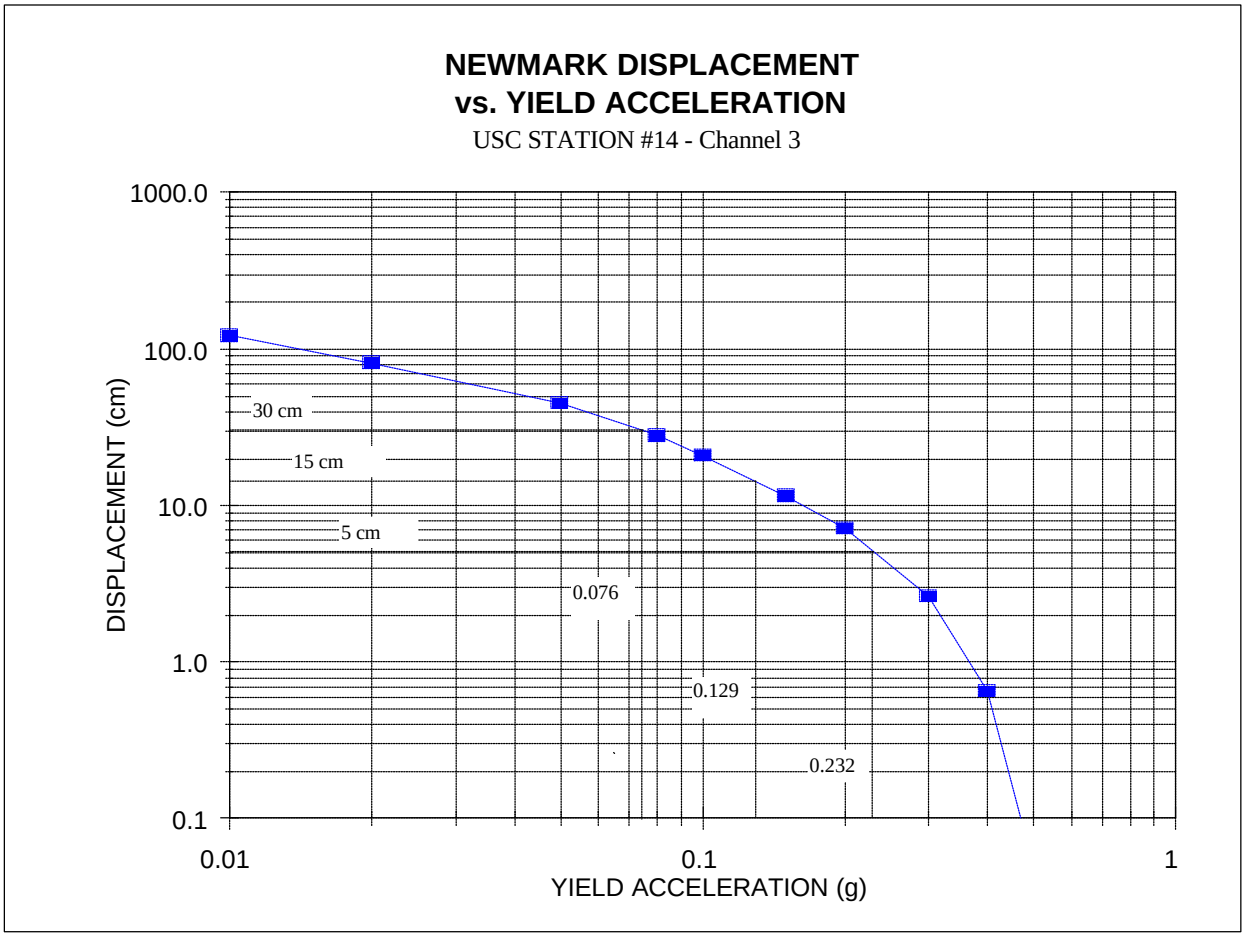

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station #14 Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. To calculate slope gradient for the terrain within the Black Star Canyon Quadrangle, a digital elevation model (DEM) was obtained from an airborne interferometric radar platform flown in 1998, with a estimated vertical accuracy of approximately 2 meters (Intermap Corporation, 1999). An interferometric radar DEM is prone to creating false topography where tall building, metal structures, or trees are present. Due to the low lying chaparral vegetation and relatively small residential construction types present, this type of DEM is appropriate for use in the Black Star Canyon Quadrangle. Nevertheless, the final hazard zone map was checked for potential errors of this sort and corrected.

A slope map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). This DEM was also used to make a slope-aspect map. The slope map was used first in conjunction with the aspect map and geologic structural data to identify areas of potential adverse bedding conditions, and then again with the geologic strength map in the preparation of the earthquake-induced landslide hazard potential map.

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 acceleration calculated by Newmark's equations represents the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. The acceleration values were compared with the ground shaking opportunity, defined by Figure 2.1, to determine the earthquake-induced landslide hazard potential. Based on the susceptibility criteria described above, if the calculated yield acceleration was less than 0.076g, expected displacements could be greater than 30 cm, and a HIGH (H on Table 2.3) hazard potential was assigned. Likewise, if the calculated a_y fell between 0.076 and 0.129g a MODERATE (M on Table 2.3) potential was assigned, between 0.13 and 0.232 a LOW (L on Table 2.3) potential was assigned, and if a_y were greater than 0.232g a VERY LOW (VL on Table 2.3) potential was assigned.

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.

BLACK STAR CANYON QUADRANGLE

HAZARD POTENTIAL MATRIX

GEOLOGIC MATERIAL GROUP	MEAN PHI	SLOPE CATEGORY (% SLOPE) I 0 to 26%	II 27 to 35%	III 36 to 41%	IV 42 to 48%	V 49 to 57%	VI 58 to 64%	VII 65 to 69%	VIII 70 to 74%	IX 75% <
1	40	VL	VL	VL	VL	VL	L	L	M	H
2	36	VL	VL	VL	VL	L	M	H	H	H
3	31	VL	VL	L	L	H	H	H	H	H
4	27	VL	L	M	H	H	H	H	H	H
5	24	L	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Black Star Canyon Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone.

EARTHQUAKE-INDUCED LANDSLIDE ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (1996). Under those criteria, earthquake-induced landslide zones are areas meeting one or both of the following:

1. Areas identified as having experienced landslide movement in the past (including all mappable landslide deposits and source areas), and, where possible, areas known to have experienced earthquake-induced landsliding during historic earthquakes.

2. Areas where geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

Existing Landslides

Studies of the types of landslides caused by earthquakes (Keefer, 1984) show that re-activation of the whole mass of deep-seated landslide deposits is rare. However, it has been observed that the steep scarps and toe areas of existing landslides, which formed as a result of previous landslide movement, are particularly susceptible to earthquake-

induced slope failure. In addition, because they have been disrupted during landslide movement, landslide deposits are inferred to be weaker than coherent, undisturbed, adjacent source rocks. Finally, we felt that a long duration, San Andreas fault-type earthquake could be capable of initiating renewed movement in existing deep-seated landslide deposits. Therefore, all existing landslides identified in the inventory with a definite or probable confidence of interpretation were included in the hazard zone.

Geologic and Geotechnical Analysis

On the basis of a DMG pilot study (McCrink and Real, 1996) the earthquake-induced landslide zone includes all areas determined to lie within the High, Moderate and Low levels of hazard potential. Therefore, as shown in Table 2.3, geologic strength group 5 is always included in the zone (mapped landslides); strength group 4 above 26%; strength group 3 above 35%; strength group 2 above 48%; and strength group 1, the strongest rock types, were zoned for slope gradients above 57%. This results in roughly 44% of the land in the quadrangle lying within the earthquake-induced landslide hazard zone.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. The personnel at the City of Anaheim, and Jim Gunrag and Mike Mundavian of the Corridor Design Management Group provided access to their files for shear strength data. Keith Butz of Silverado Construction Company supplied topographic data for the Eastern Transportation Corridor area. Dean Montgomery, George Knight, and Monte Lorenz of the U.S. Bureau of Reclamation supplied topographic data for areas of mass grading in the quadrangle. Russ Miller and Siang Tan of the Division of Mines and Geology (CDMG) did much of the detailed geologic mapping in this area. Russ Miller and Richard Greenwood (CDMG) provided invaluable field insights on the regional geology, structure, and identification of rock formations.

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AIR PHOTOS

E.L. Pearsons & Associates, July/August 1970, flights 22-30 (frames 1-9, 25-34, 23-27, 22-35, 21-34, 22-30, 22-28, 26-29, 29-30 respectively), black and white, vertical, approximate scale 1:14,000, (partial acquisition from Robert J. Lung & Associates).

APPENDIX A

SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
California Department of Transportation	147
Silverado Construction Company	34
CDMG EIR Review Files	26
City of Anaheim	8
Total number of tests used	215

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Black Star Canyon 7.5-Minute Quadrangle, Orange County, California

By

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

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, 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 (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

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 State Mining and Geology Board, 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 seismogenic sources as published in 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.

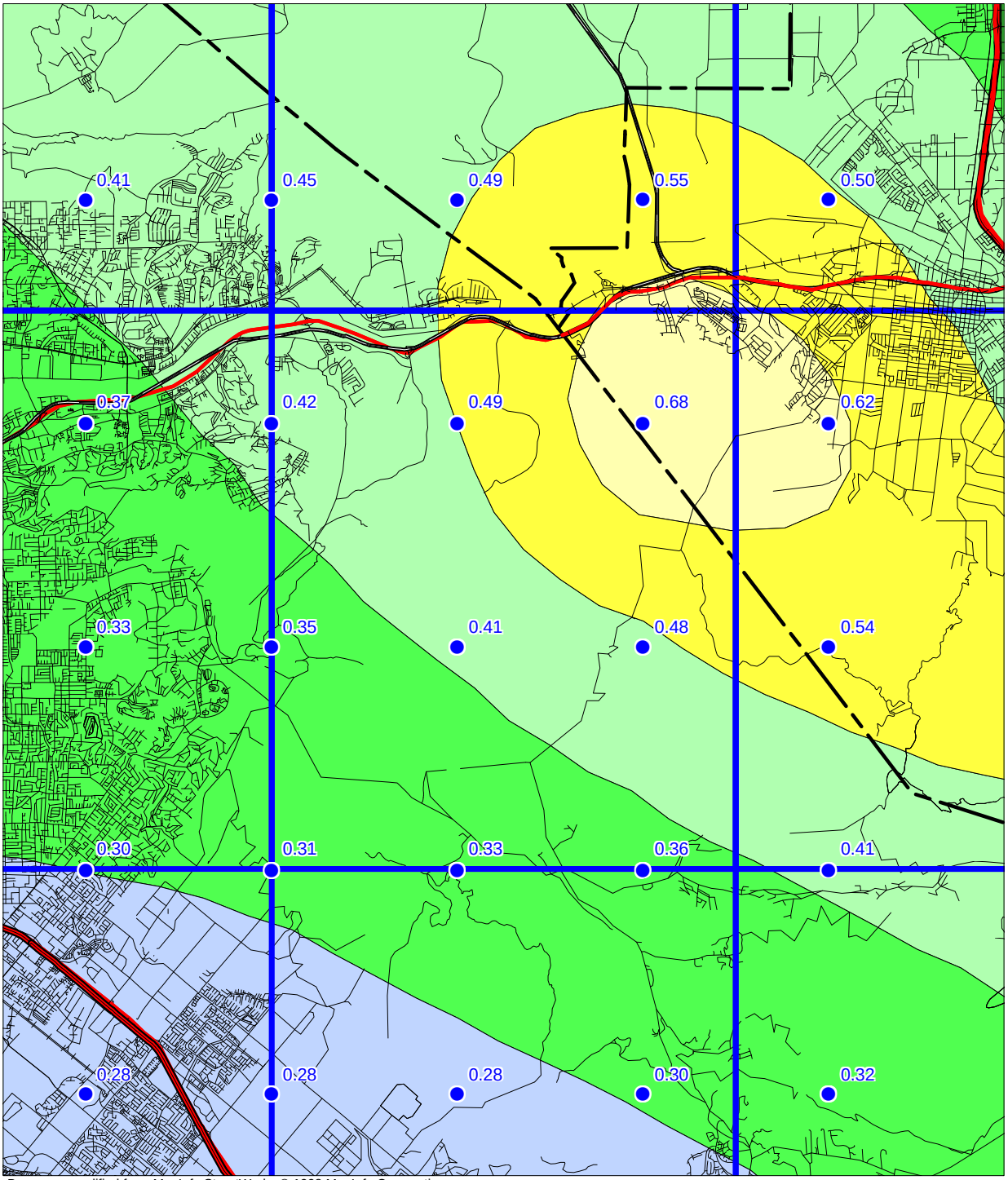
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

BLACK STAR CANYON 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 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

Figure 3.1

BLACK STAR CANYON 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS

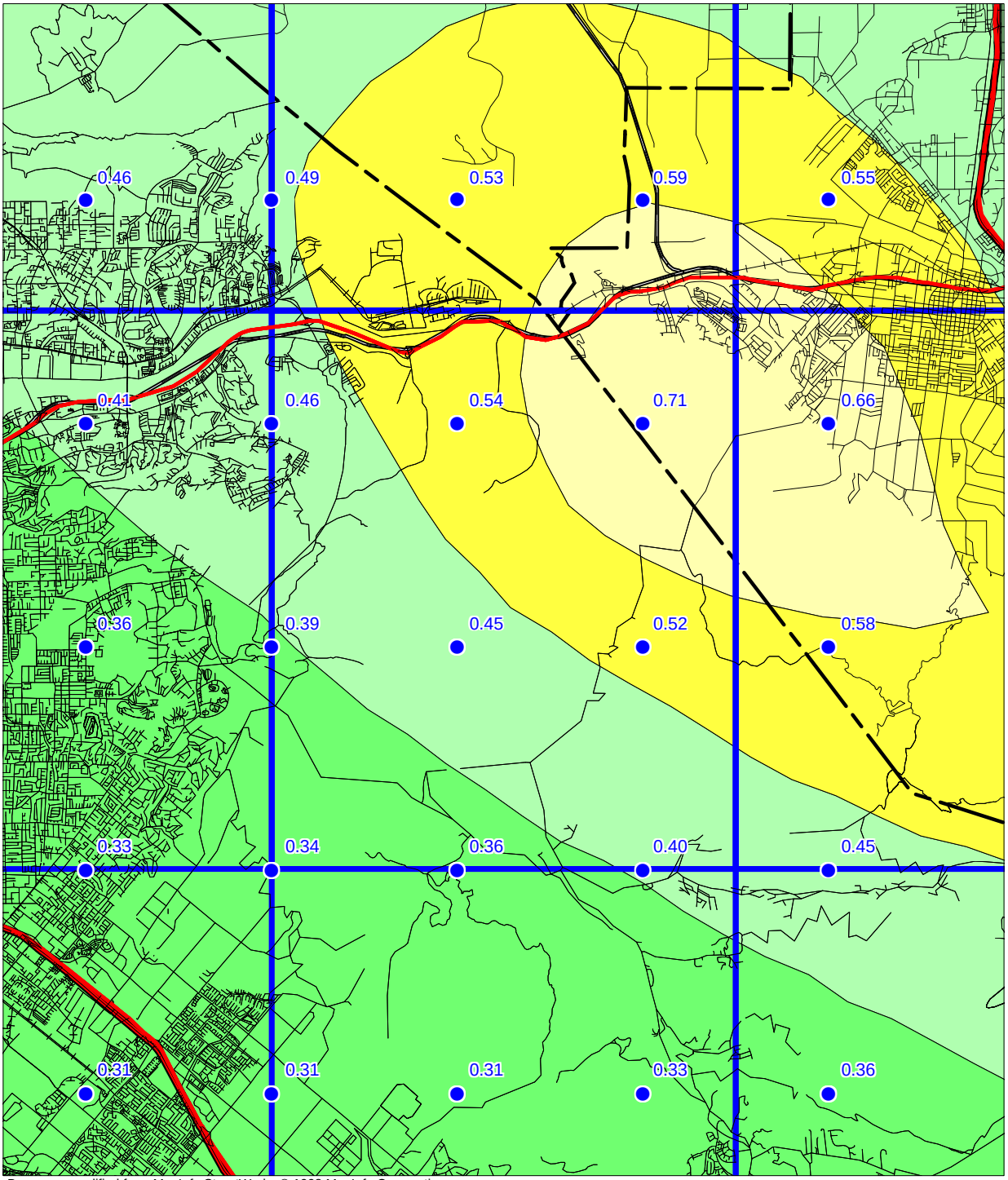


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Figure 3.2

BLACK STAR CANYON 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS

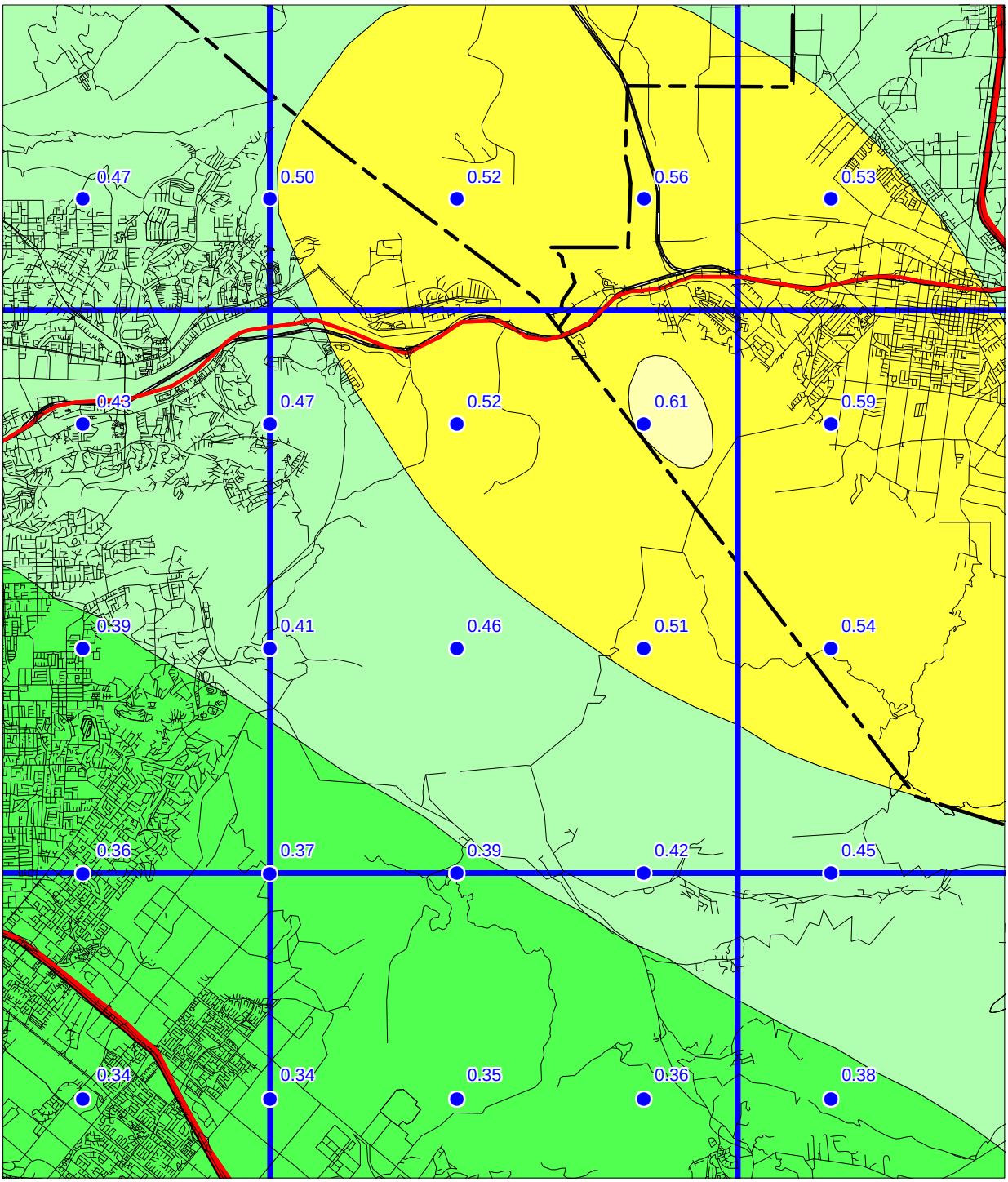

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Figure 3.3

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

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

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

USE AND LIMITATIONS

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

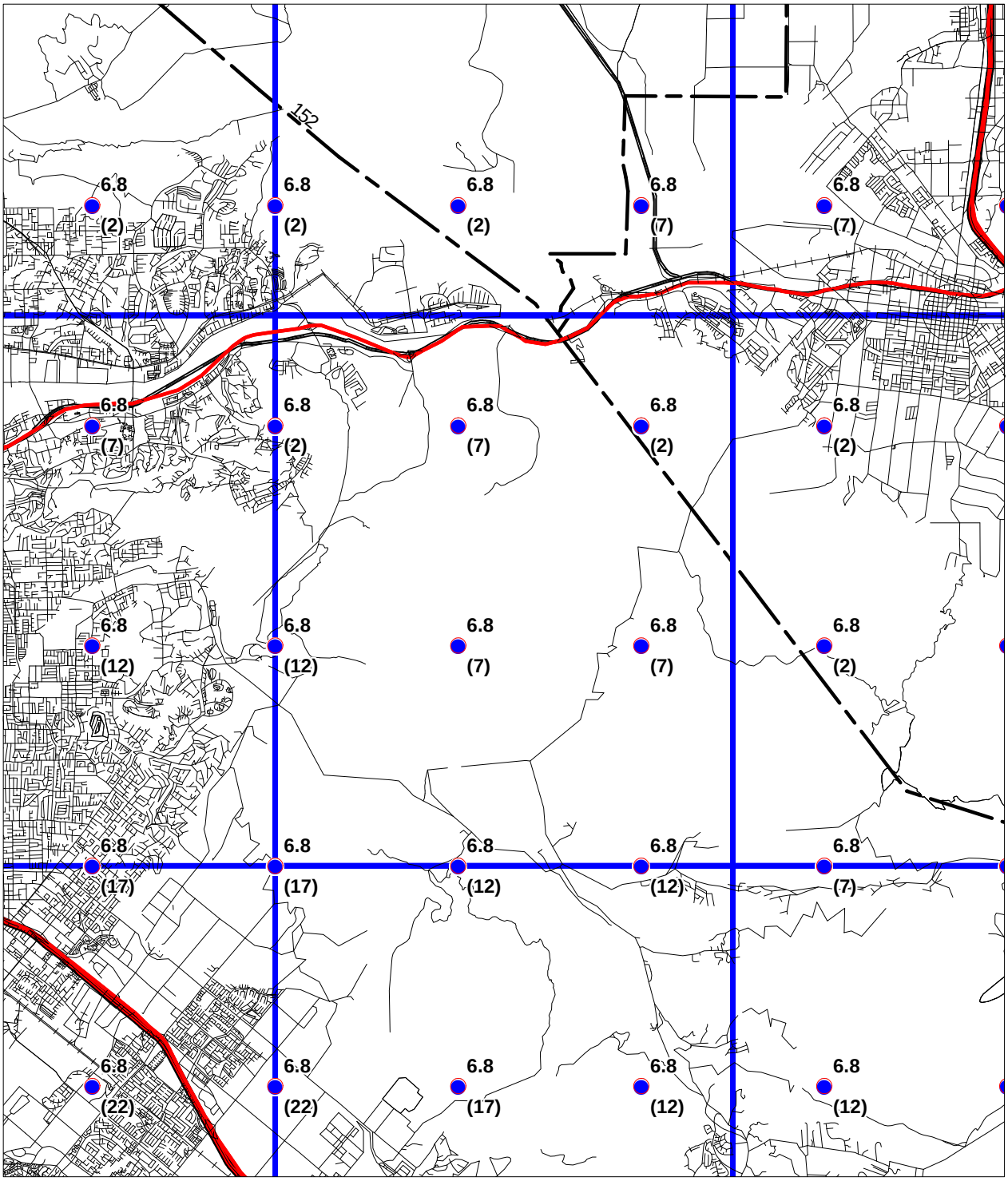
1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated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

BLACK STAR CANYON 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 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

Figure 3.4

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

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

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

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not previously been 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 (California State Mining and Geology Board, 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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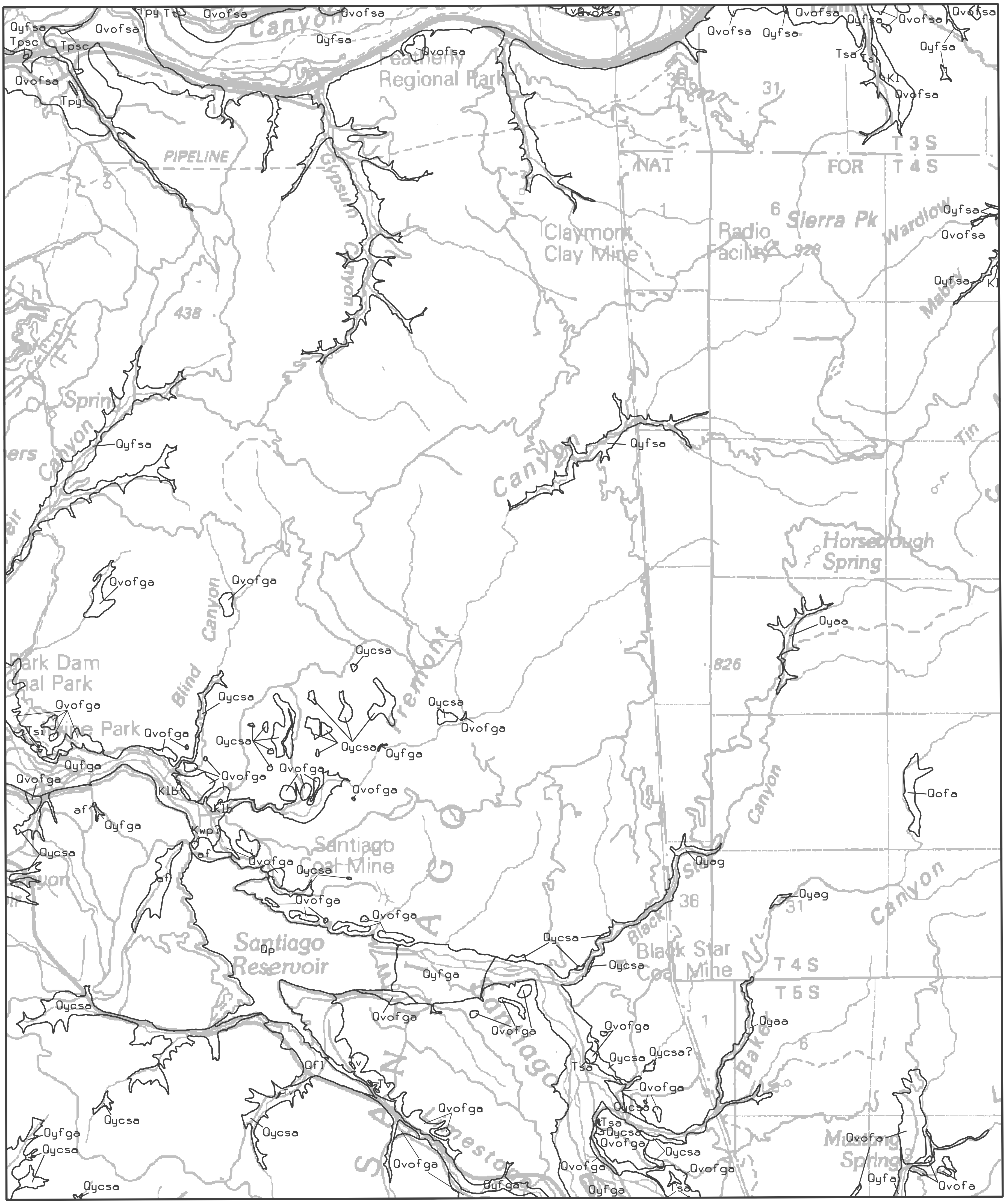
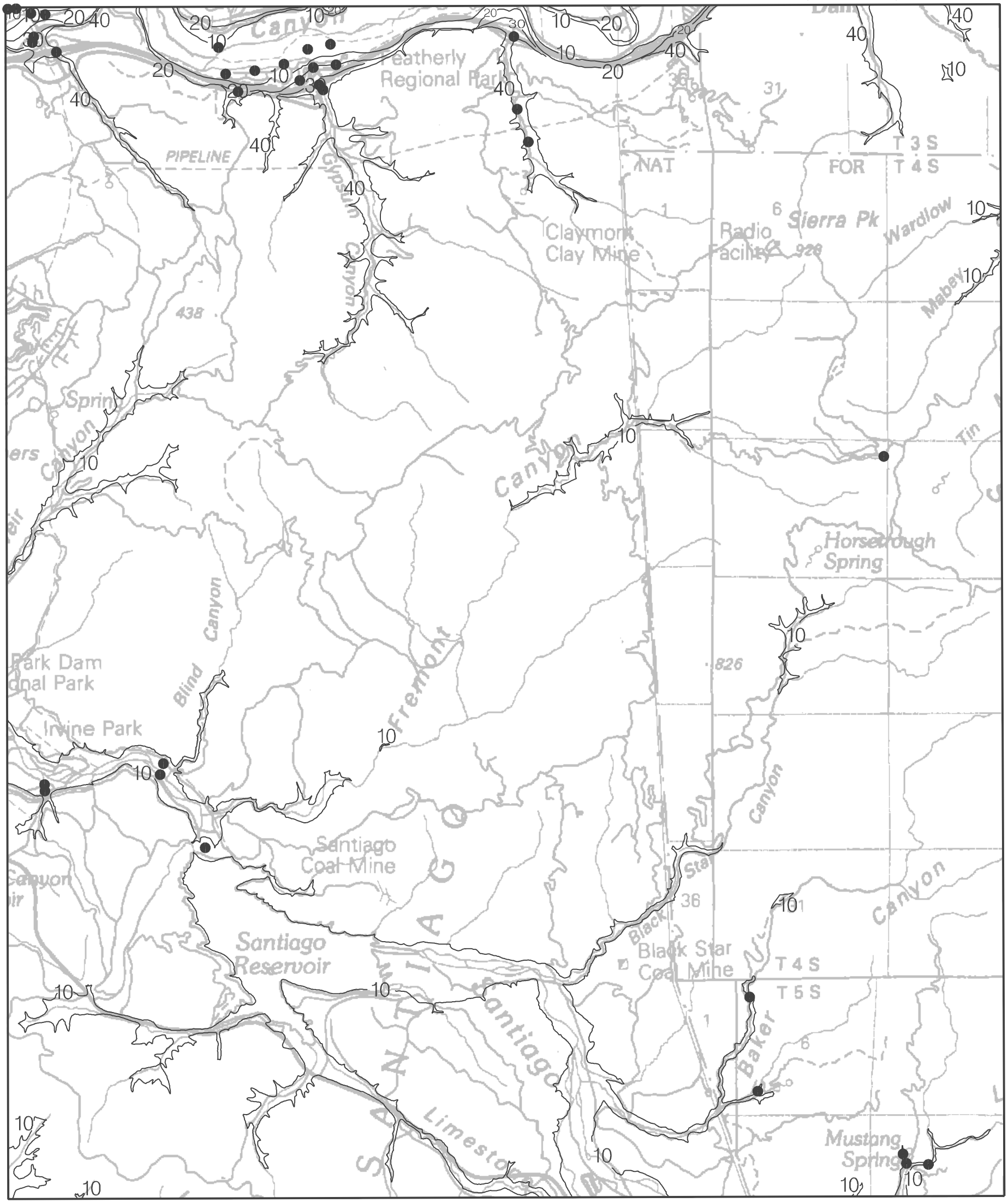


Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 1.1 Quaternary Geologic Map of the Black Star Canyon Quadrangle.
See Geologic Conditions section in report for descriptions of the units.

ONE MILE

SCALE



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

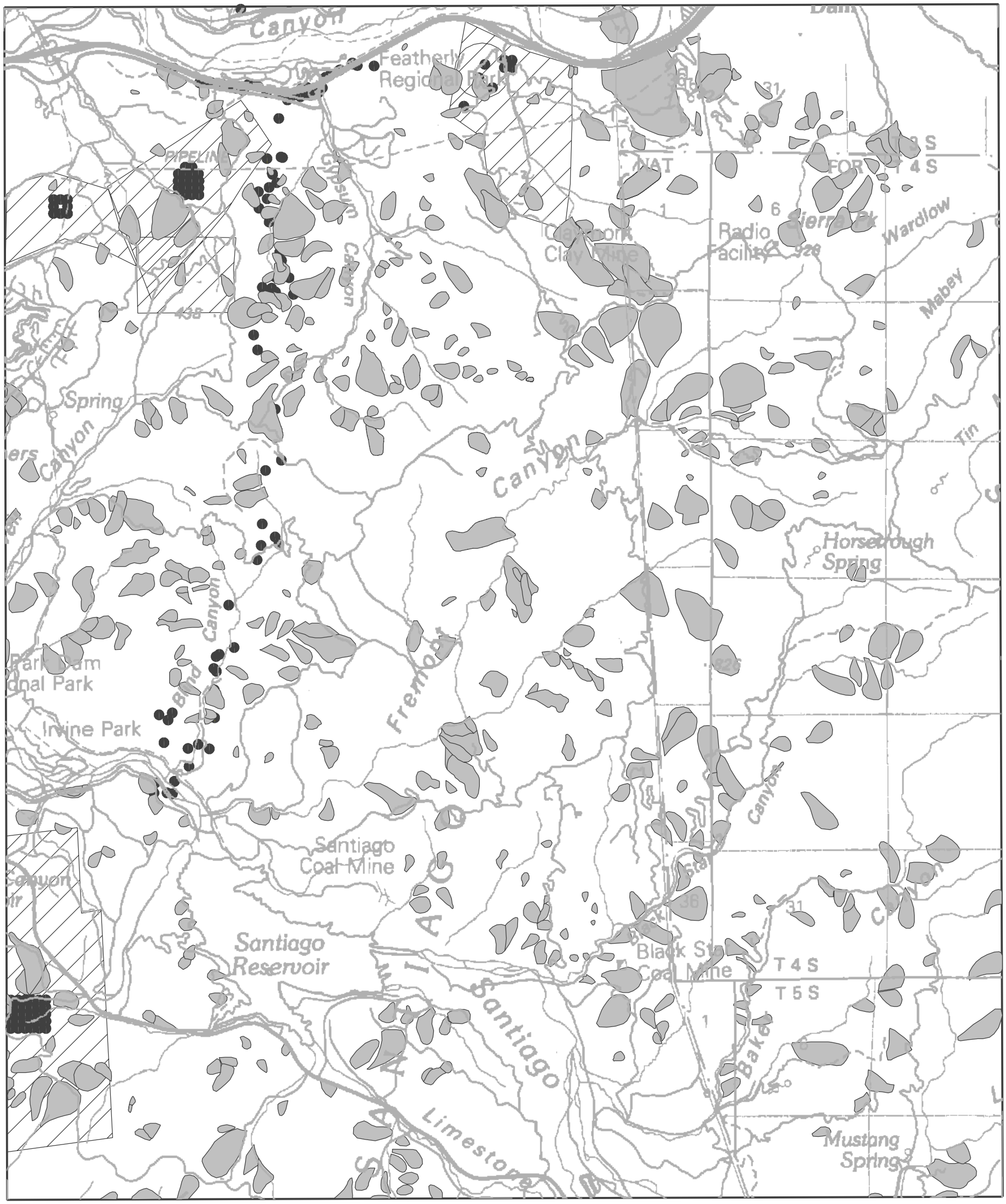
Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Black Star Canyon Quadrangle.

● 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, Black Star Canyon Quadrangle.

● shear test sample location landslide tract report with multiple borings

ONE MILE

SCALE