SEISMIC HAZARD ZONE REPORT 125

PRELIMINARY

SEISMIC HAZARD ZONE REPORT FOR THE ANTIOCH NORTH 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

2018

DEPARTMENT OF CONSERVATION
California Geological Survey

STATE OF CALIFORNIA
EDMUND G. BROWN, JR.
GOVERNOR

THE RESOURCES AGENCY
JOHN LAIRD
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
DAVID BUNN
DIRECTOR

CALIFORNIA GEOLOGICAL SURVEY
JOHN G. PARRISH, PH.D.
STATE GEOLOGIST

CALIFORNIA GEOLOGICAL SURVEY
JOHN G. PARRISH, PH.D., *STATE GEOLOGIST*

Copyright © 2018 by the California Department of Conservation. All rights reserved. No part of this publication may be reproduced without written consent of the Department of Conservation.

The Department of Conservation makes no warrantees as to the suitability of this product for any particular purpose.

Release and Revision History: Seismic Hazard Zone Map and Evaluation Report of the Antioch North Quadrangle, SHZR 125	
October 4, 2018	Preliminary Map Release

TABLE OF CONTENTS

EXECUTIVE SUMMARY ..... **iv**

INTRODUCTION ..... **v**

The California Seismic Hazards Mapping Program v
Methodology and Organization of this Report v
Scope and Limitations vi
Accessing Earthquake Zones of Required Investigation Maps, Reports, and GIS Data vii

SECTION 1: GEOGRAPHY, GEOLOGY AND ENGINEERING GEOLOGY **1**

Purpose of this Section 1

GEOGRAPHY **1**

Location 1
Land Use 2
Digital Terrain Data 2

GEOLOGY **3**

Bedrock Units 3
Quaternary Sedimentary Deposits 3
Old Quaternary Units *4*
Young Quaternary Units *5*
Geologic Structure 6
Existing Landslides 6

ENGINEERING GEOLOGY **7**

Historic-High Groundwater Mapping 7
Hydrographic Setting *7*
Groundwater Basins *8*
Groundwater Levels *8*
Geologic Material Testing 9
Liquefaction Hazard Zoning: In-Situ Penetration Resistance *9*
Landslide Hazard Zoning: Laboratory Shear Strength *10*

REFERENCES **10**

SECTION 2: GROUND MOTION ASSESSMENT **13**

Purpose of this Section 13

PROBABILISTIC SEISMIC HAZARD ANALYSIS MODEL **13**

APPLICATION TO LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENT **15**

REFERENCES **16**

SECTION 3: EVALUATION OF LIQUEFACTION HAZARD 19

Purpose of this Section 19

ZONING TECHNIQUES 19

Liquefaction Susceptibility 19
Ground Motion for Liquefaction Hazard Assessment 20
Liquefaction Analysis 21
Liquefaction Zoning Criteria 21
Delineation of Liquefaction Hazard Zones 22
Areas of Past Liquefaction 22
Artificial Fills 22
Areas with Sufficient Existing Geotechnical Data 23
Areas with Insufficient Existing Geotechnical Data 23

ACKNOWLEDGMENTS 23

REFERENCES 24

SECTION 4: EVALUATION OF EARTHQUAKE-INDUCED LANDSLIDE HAZARD 26

Purpose of this Section 26

NO EARTHQUAKE-INDUCED LANDSLIDES ZONED 26

TABLES

Table 1.1. Quaternary units mapped in the Contra Costa County potion of the Antioch North 7.5-Minute Quadrangle. 4

Table 1.2. State of California watershed boundary designations in the Contra Costa County portion of the Antioch North 7.5-Minute Quadrangle. 7

Table 2.1. Summary of ground motion parameters used for liquefaction analyses. 15

Table 3.1. Liquefaction susceptibility of Quaternary units in the Contra Costa portion of the Antioch North 7.5-Minute Quadrangle. 20

PLATES

Plate 1.1. Quaternary geologic materials map and locations of boreholes used in evaluating liquefaction hazard, Contra Costa County portion of the Antioch North 7.5-Minute Quadrangle, California.

Plate 1.2 Depth to historic-high groundwater levels in Quaternary alluvial deposits and groundwater data points, Contra Costa County portion of the Antioch North 7.5-Minute Quadrangle, California.

Plate 1.3 Geologic materials and landslide inventory map with locations of shear test samples used in evaluating landslide hazard, Contra Costa County portion of the Antioch North 7.5-Minute Quadrangle, California.

Plate 2.1 Map of V_{S30} groups and corresponding geologic units extracted from the state-wide V_{S30} map developed by Wills and others (2015). Qi, intertidal mud; af/Qi, artificial fill over intertidal mud; Qal1, Quaternary (Holocene) alluvium in areas of low slopes (< 0:5%); Qal2, Quaternary (Holocene) alluvium in areas of moderate slopes (0.5%–2.0%); Qal3, Quaternary (Holocene) alluvium in areas of steep slopes (>2%); Qoa, Quaternary (Pleistocene) alluvium; Qs, Quaternary (Pleistocene) sand deposits; Tsh, tertiary shale and siltstone units; Tss, tertiary sandstone units; Tv, tertiary volcanic units; KJf, Cretaceous-Jurassic Franciscan complex rocks.

Plate 2.2 Pseudo-PGA for liquefaction hazard mapping analysis, Antioch North 7.5-Minute Quadrangle and surrounding area, California.

Plate 2.3 Probabilistic peak ground acceleration for landslide hazard mapping analysis, Antioch North 7.5-Minute Quadrangle and surrounding area, California.

Plate 2.4. Modal magnitude for landslide hazard mapping analysis, Antioch North 7.5-Minute Quadrangle and surrounding area, California.

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the map of *Seismic Hazard Zones* (a subset of *Earthquake Zones of Required Investigation* (EZRI) along with Earthquake Fault Zones) for the Contra Costa portion of the Antioch North 7.5-Minute Quadrangle (study area). The topographic quadrangle map, which covers approximately 31.5 square kilometers (12 square miles) at a scale of 1:24,000 (41.7 mm = 1,000 meters; 1 inch = 2,000 feet), displays EZRI boundaries for liquefaction and earthquake-induced landslides. The study area includes part of the City of Antioch, City of Pittsburg, and unincorporated areas of Contra Costa County.

This Seismic Hazard Zone Report describes the development of the Seismic Hazard Zones for the Contra Costa County portion of the Antioch North 7.5-Minute Quadrangle (study area). Ground motion calculations used by California Geological Survey (CGS) exclusively for regional zonation assessments are currently based on the probabilistic seismic hazard analysis (PSHA) model developed by USGS for the 2014 *Update of the United States National Seismic Hazard Maps* (NSHMs).

The zonation process for liquefaction hazard includes an evaluation of ground motions, highest historical groundwater, Quaternary geologic mapping, and geotechnical data. Approximately 25 square kilometers (10 square miles) of land in the study area has been designated as EZRI for liquefaction. These zones are mainly located in lowlands adjacent to the San Joaquin River and New York Slough, within Browns and Winter Island. Additionally, liquefaction encompass major stream valleys such as Kirker Creek, West Antioch Creek, East Antioch Creek, Los Medanos Wasteway, Markley Canyon, and other smaller unnamed stream valleys. Minor drainages that ultimately outlet into Suisun Bay are also zoned.

Within the study area, there are no EZRI for earthquake-induced landslides. However, the potential for landslides may exist locally, particularly along streambanks, margins of drainage channels, and similar settings where steep banks or slopes occur.

City, county, and state agencies are required by the California Seismic Hazards Mapping Act to use the Seismic Hazard Zone maps in their land-use planning and permitting processes. They must withhold building permits for sites being developed within EZRI 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 of real property within these zones to disclose that fact at the time such property is sold.

INTRODUCTION

The California Seismic Hazards Mapping Program

The Seismic Hazards Mapping Act of 1990 (the Act) (Public Resources Code, Division 2, Chapter 7.8) directs the State Geologist to prepare maps that delineate Seismic Hazard Zones for liquefaction, earthquake-induced landslides, tsunami inundation, and other ground failures. These are a subset of Earthquake Zones of Required Investigation (EZRI), which also include Earthquake Fault Zones. The California Geological Survey (CGS) prepares EZRI following guidelines prepared by the California State Mining and Geology Board (SMGB). For liquefaction and landslide hazard zone delineation, the SMGB established the Seismic Hazard Mapping Act Advisory Committee to develop guidelines and criteria for the preparation of seismic hazard zones in the state. The committee's recommendations are published in CGS Special Publication 118, which is available on online at: http://www.conservation.ca.gov/cgs/publications/sp118.

The purpose of the Act is to reduce the threat to public safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. City, county, 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. State-of-the-practice evaluation and mitigation of seismic hazards are conducted under guidelines published in CGS Special Publication 117A, which are available online at: http://www.conservation.ca.gov/cgs/publications/sp117a.

Following the release of the Special Publication 117A Guidelines, local government agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction and earthquake-induced landslide hazards. These agencies convened two independent committees, one for liquefaction and one for landslides, to provide more detailed procedures for implementing the Special Publication 117A Guidelines. The reports produced by these committees were published under the auspices of the Southern California Earthquake Center (SCEC) and are available online at: http://www-scec.usc.edu/resources/catalog/hazardmitigation.html.

Methodology and Organization of this Report

Delineating liquefaction and earthquake-induced landslide hazard zones requires the collection, compilation, and analysis of multiple types of digital data. These data include geologic maps, groundwater measurements, geotechnical data, elevation (terrain) maps, and probabilistic ground shaking estimates. The data are processed into a series of geographic information system (GIS) layers using commercially available and open-source software, which are used as input for the delineation of hazard zones.

Earthquake Zones of Required Investigation (EZRI) for liquefaction and earthquake-induced landslides share many input datasets. Section 1 of this report describes the geographic, geologic, and hydrologic characteristics of the Contra Costa County portion of the Antioch North

Quadrangle (study area) and laboratory tests used to categorize geologic materials within the quadrangle according to their susceptibility to liquefaction and/or landslide failure. Section 2 describes the development of the earthquake ground motion parameters used in the liquefaction and landslide hazard analyses, presents map plates of the spatial distribution of key ground motion parameters, and summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential in the Antioch North Quadrangle. Sections 3 and 4 summarize the analyses and criteria used to delineate liquefaction and earthquake-induced landslide hazard zones, respectively, in the study area.

Scope and Limitations

Seismic Hazard Zones for liquefaction and earthquake-induced landslides are intended to prompt more detailed, site-specific geotechnical investigations. Due to scale and other limitations inherent in these zones, they should not be used as a substitute for site-specific geologic or geotechnical investigations required under Chapters 7.5 and 7.8 of Division 2 of the California Public Resources Code. Site-specific geologic/geotechnical investigations are the best way to determine if these hazards could affect structures or facilities at a project site.

The zones described in this report identify areas where the potential for ground failure related to liquefaction and earthquake-induced landslides is relatively high. Some liquefaction and landslide occurrences may occur outside the delineated zones in future earthquakes, but the majority of the occurrences should be within zoned areas. Conversely, not all of the area within a hazard zone will experience damaging ground failure in future earthquakes. The analyses used to delineate liquefaction and earthquake-induced landslide zones cannot predict the amount or direction of liquefaction- or landslide-related ground displacements, or the amount of damage to structures or facilities that may result from such displacements. Because of this limitation, it is possible that run-out areas during future earthquakes could extend beyond zone boundaries.

Other earthquake-induced ground failures that are not specifically addressed in the analyses conducted for the study area include those associated with soft clay deformation, non-liquefaction-related settlement, ridge-top spreading, and shattered ridges.

Although data used in this evaluation was selected using rigorous criteria, 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.

Accessing Earthquake Zones of Required Investigation Maps, Reports, and GIS Data

CGS EZRI, including Seismic Hazard Zones and Earthquake Fault Zones, their related reports and GIS data, are available for download and/or online viewing on the CGS Information Warehouse: http://maps.conservation.ca.gov/cgs/informationwarehouse/.

Alternatively, EZRI are available as an interactive web map service (WMS) here: https://spatialservices.conservation.ca.gov/arcgis/rest/services/CGS_Earthquake_Hazard_Zones.

EZRI are also available on a statewide parcel base, which can be useful for initial Natural Hazards Disclosure determinations, by using the California Earthquake Hazards Zone Application (EQ Zapp): https://maps.conservation.ca.gov/cgs/EQZApp/app/.

EZRI maps and reports are also available for purchase at the CGS Sacramento office at the address presented below, or online at: http://www.conservation.ca.gov/cgs/publications/shop.

Publications and Information Office
801 K Street, MS 14-34
Sacramento, CA 95814-3531
(916) 445-5716

Information regarding the Seismic Hazard Zonation Program with links to the Seismic Hazards Mapping Act and the Alquist-Priolo Earthquake Fault Zoning Act are available on the CGS website: http://www.conservation.ca.gov/cgs/shp.

SECTION 1: GEOGRAPHY, GEOLOGY AND ENGINEERING GEOLOGY

of the

ANTIOCH NORTH 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

by

Ante N. Mlinarevic
P.G. 8352, C.E.G 2552

DEPARTMENT OF CONSERVATION
CALIFORNIA GEOLOGICAL SURVEY

Purpose of this Section

Preparing Earthquake Zones of Required Investigation (EZRI) for liquefaction and earthquake-induced landslides requires many input datasets and complex analyses. The purpose of Section 1 of the Seismic Hazard Zone Report is to describe the overall geologic and geographic setting of the Contra Costa County portion of the Antioch North Quadrangle (study area) and then discuss the collection, processing, and analyses of primary geologic and engineering geologic data that were used to delineate EZRI.

GEOGRAPHY

Location

The study area covers an area of approximately 31 square kilometers (12 square miles) in eastern Contra Costa County, California. The center of the study area is about 46 kilometers (29 miles) northeast of the City of Oakland and about 70 kilometers (43 miles) south-southwest of the City of Sacramento. The study area includes the northern portion of City of Antioch, the northeastern portion of the City of Pittsburg, and lesser unincorporated areas of Contra Costa County. Unincorporated areas include

The study area is located on the western margins of the Sacramento-San Joaquin Delta, and along the southern banks of the San Joaquin River and shores of Suisun Bay. Within Suisun Bay, Browns and Winter Island are divided by Middle Slough and separated from the mainland by New York Slough. The study area is situated on the Pittsburg-Antioch alluvial plain, and is positioned northeast of Los Medanos Hills - part of the Diablo Range in the Coast Ranges Geomorphic Province (Schemmann, Unruh and Moores, 2007; Weber-Band, 1997). Elevation in the study area gradually increase from sea level to over 36 meters (120 feet), near the Contra Costa Canal in the southwest portion of the study area. The topography consists of mild sloping alluvial plains emanating from the foothills of the Diablo Range, south of the study area

Water flows north-northeast in the drainages of Kirker Creek, Markley Canyon, West Antioch Creek, and several unnamed streams, while water flows north-northeast in the drainages of East Antioch Creek flow northwest. All drainages outlet into the San Joaquin River, and ultimately into Suisun Bay.

Portions of the Contra Costa Canal (Main Canal segment) and Mokelumne Aqueduct traverse the southwestern part of the study area, and flow east to west. These man-made water conveyance systems provide water for agricultural, industrial, and municipal uses in the Bay Area. The Contra Costa Canal was built in 1948 and diverts Sacramento-San Joaquin Delta water from Rock Slough in the east to Martinez in the west (CCWD, 2009). Water in the Mokelumne aqueduct is sourced from the Mokelumne River and provides water to the eastern Bay Area.

Land Use

Land use in the study area was historically dominated by agriculture, mining, and urban development. In the 1850's, coal was discovered in the Los Medanos hills south of Antioch, and mining developed as a substantial industry from the early 1860's through the early 1900's. In the 1920's, demand shifted from coal to sand and mining for sand and continued until 1949 when the mines closed.

In the last several decades, urban development substantially increased in Antioch and Pittsburg, with light industrial, shopping centers and home construction. Since 1990, the growth of the cities has nearly doubled with development largely concentrated towards the south and east. Substantial areas of undeveloped, agricultural land, primarily grazing, remains on the valley floor and in the Los Medanos Hills southeast of the study area.

The primary automotive transportation route in the study area is California State Route 4, located in the southwestern part of the study area, which connects the cities of Antioch and Pittsburg. Additionally, State Highway 160, located in the eastern part of the study area, connects Contra Costa County with Sacramento County to the north via the Antioch Bridge. Railway routes included in the study area include the Atchison-Topeka and Santa Fe, Southern Pacific, and BART railways.

Digital Terrain Data

A digital representation of the earth's surface is a key component in delineating liquefaction and earthquake-induced landslide hazards. Within the study area, digital topography in the form of a Digital Elevation Model (DEM) obtained from Contra Costa County (http://www.co.contra-costa.ca.us/4475/Maps-and-Data). This terrain data was collected in 2010 and presents point spacing of 3 meters and elevations at 1-meter horizontal accuracy and 15-cm RMSE vertical accuracy.

For liquefaction hazard analyses, surface elevations derived from the Contra Costa County DEM are differenced with historic-high groundwater elevations to derive a "depth to water" map. In alluvial areas, the depth value obtained was analyzed, along with geologic data from boreholes and used in liquefaction evaluation.

GEOLOGY

The primary sources of geologic information used in the evaluation of liquefaction and earthquake-induced landslide hazards in the Contra Costa County portion of the Antioch North 7.5-Minute Quadrangle (study area) are the 1:24,000-scale geologic mapping by Knudsen and others (2000), Helley and Graymer (1997), Atwater (1982), and Nilsen (1975). Unpublished 1:100,000-scale geologic mapping by Dawson (2010) was also used.

Digital geologic maps covering the study area and adjacent areas were combined to form a single, 1:24,000-scale, geologic materials map. California Geological Survey (CGS) staff used DEMs, aerial photos, online imagery, and limited field reconnaissance to modify the Quaternary/bedrock boundary, confirm the location of geologic contacts, map recently modified ground surfaces, observe properties of near-surface deposits, and characterize the surface expression of individual geologic units. No landslide deposits were located within the study area. Young alluvial valleys were added or modified by CGS geologists in some areas to refine the map and ensure continuity of geologic mapping with adjacent quadrangles. Linear structural features such as folds, faults, and anticlines that did not form a geologic boundary were removed. Young alluvial valleys were added or modified by CGS geologists in some areas to refine the map and ensure continuity of geologic mapping with adjacent quadrangles. The distribution of Quaternary deposits on the final geologic materials map was used in combination with other data, to evaluate liquefaction and landslide susceptibility and develop the Seismic Hazard Zone Map.

The following Quaternary geologic unit nomenclature used by CGS for mapping in the San Francisco Bay Region was adopted from Knudsen and others (2000).

Bedrock Units

There are no known bedrock units exposed within the study area.

Quaternary Sedimentary Deposits

Within the study area approximately 32 km^2 (12 mi^2) are covered by Quaternary sediments, of which approximately 20 km^2 (8 mi^2) are latest Pleistocene to Holocene age (Plate 1.1). These sedimentary units are summarized in Table 1.1 and discussed below. The following is a summary of Quaternary sedimentary deposits exposed in the study area is based on Dawson (2010); Knudsen and others (2000); Helley and Graymer (1997); Atwater (1982); and Nilsen (1975).

Table 1.1. Quaternary units mapped in the Contra Costa County potion of the Antioch North 7.5-Minute Quadrangle.

CGS Map Units	Dawson, 2010 (1:100,000)	Knudsen and others, 2000 (1:24,000)	Helley and Graymer, 1997 (1:24,000)	Atwater, 1982 (1:24.000)	Nilsen, 1975 (1:24,000)	Environmental Deposition	Age
Qpf	*Qf Qpf Qoa*	*Qf Qpf Qoa*	*Qpaf*	*Qoa Qia*	*Qt*	Old Fan, Alluvium deposits, Terraced deposits	Pleistocene
Qds	*Qds*	*Qds*	*Qds*	*Qm2e Qoe Qe?*	*Qs*	Dune Sand; Windblown sand deposit	Latest Pleistocene to Holocene
Qhf	*Qhf Qha Qhl*	*Qhf Qha Qhl*	*Qhaf, Qhb Qhl*	*Qya Qia*	*Qal*	Alluvial Fan Deposits	Holocene
Qhbm	*Qhbm Qhdm*	*Qhbm Qhdm*	*Qhbm Qhpm*	*Qpm*	*Qm Qsl*	Bay Mud, Marshland and Slough deposits	Holocene to Modern
Qhsc	*Qhc*	*Qhc*	*Qhsc*		*Qal*	Alluvial Deposits - Undifferentiated	Holocene to Modern
af	*ac afbm alf*	*ac afbm alf*	*af alf Qhasc*		*Qaf Qsl*	Artificial Fill, Artificail Fill over Bay Mud, Artifical Levee Fill, Slough deposit, Artifical dam fill, Artifical Stream Channel	Modern

Old Quaternary Units

The oldest geologic unit exposed in the study area are Pleistocene alluvial fan deposits (**Qpf**), poorly-sorted to well-sorted deposits containing unconsolidated mixtures of gravel, sand, silt, and clay, with particle size typically decreasing downstream, away from the alluvial fan apex. These typically stream-deposited sediments emanated from Los Medanos Hills onto Pittsburg-Antioch alluvial plain, and include terraced, debris flow and braided stream deposits. **Qpf** deposits are thickest adjacent to the paleo-stream channel and typically thin away from the channel axis. The deposits in the study area are spatially terraced in narrow bedrock canyons and incised along the broad gentle-sloping fans on valley floors. Deposits of **Qpf** overlie bedrock in the study area.

Young Quaternary Units

Latest Pleistocene to Holocene dune sand deposits (**Qds**) typically form a mantle on the valley floor of varying thickness with many small hills. These very well-sorted deposits of loosely consolidated to weakly cemented, fine to medium grained sands are conformably interlayered with Holocene alluvial fan deposits (**Qhf**), and unconformably overlie Pleistocene alluvial fan deposits (**Qpf**) or bedrock in the study area.

Holocene alluvial fan deposits (**Qhf**) typically form in narrow bedrock canyons, incised within older alluvium deposits, and situated over older alluvial fan deposits on Pittsburg-Antioch valley floors. These poorly-sorted to well-sorted deposits contain unconsolidated mixtures of sand, silt, and clay, and gravel, with particle size typically fining downstream, away from Los Medanos Hills. **Qhf** typically consist of stream-deposited or redeposited, and include debris flow, terraced, levee, and flat-floored basin deposits. **Qhf** deposits are thickest adjacent to the stream channel and typically thin away from the channel axis. Deposits of **Qhf** are conformably interlayered with Holocene dune sand deposits (**Qds**), and unconformably overlie Pleistocene alluvial fan deposits (**Qpf**) in the study area.

Holocene bay mud deposits (**Qhbm**) typically form in estuarian, tidal marsh, mud flat, or bay bottoms environments, and locally modified with diked for farming, salt evaporators, or other purposes. These well-sorted deposits contain unconsolidated mixtures of silt, clay, and fine sand, with local deposits containing organic plant matter and shells. **Qhbm** typically consist of tidal wetland sediments include peat and peaty mud deposits with sand lenses at or near sea level. **Qhbm** deposits typically thicken towards Suisun Bay and the San Joaquina River, and generally uniform on Browns and Winter Island. Deposits of bare or conformably interlayered with overlie Holocene alluvial fan and dune sand deposits (**Qhf** and **Qds**), and unconformably overlie Pleistocene alluvial fan deposits (**Qpf**) in the study area

Holocene channel deposits (**Qhc**) typically form in narrow bedrock canyons, incised within alluvium deposits, and situated over older alluvial fan deposits on valley floors. These poorly-sorted to well-sorted deposits contain unconsolidated mixtures of sand, gravel, and cobble, with minor silt and clay. The particle size distribution of these deposits typically fining downstream, away from Los Medanos Hills. These typically stream-deposited or redeposited sediments are frequently reworked. **Qhc** deposits are thickest adjacent to the stream axis and thins towards the boundaries. Deposits of **Qhc** unconformably overlie Holocene alluvial fan, dune sand, and bay mud deposits (**Qhf**, **Qds**, and **Qhbm**), and Pleistocene alluvial fan deposits (**Qpf**), in the study area.

Late Holocene artificial fills (**af**) typically are found in areas of recent highway and railway embankments, along the developed bay margin, and areas developed along channels or lakes. These fills are engineered and non-engineered deposits resulting from reworking of soils due to human activity. Although areas with significant fills have been mapped, not all fills are represented in the study area. The thickness of fills varies and are mostly undetermined based on lack of grading information. Local grading details including survey documentation of overexcavation and finish surface grade are beyond the limit of this study. Deposits of fill unconformably overlie Holocene alluvial fan, dune sand, and bay mud, and channel deposits (**Qhf**, **Qds**, **Qhbm**, **Qhc**), and unconformably overlie Pleistocene alluvial fan deposits (**Qpf**), in the study area.

Geologic Structure

The structural framework of the study area is governed by the geologic processes that created Mount Diablo. This area falls within in a tectonically active region associated with movement of the Mendocino Triple Junction along the boundary of the Pacific and North American plates. The Mendocino Triple Junction passed the latitude of Mount Diablo about 10 million years ago, generating a change from a convergent to a strike slip plate boundary margin. The two plates are currently moving past each other in a right lateral sense at the rate of about 4.8 centimeters per year (Petersen and others, 1996).

In the San Francisco Bay area presently accommodated by shearing that is distributed across a broad, complex belt marked by major northwest-trending faults, including the San Andreas, Hayward, and Calaveras, along with parallel secondary faults such as the Greenville, Green Valley, and San Ramon-Concord. Differential strike-slip movement among these faults locally generates thrust faulting, folding, and related structures throughout this tectonic belt. Movement on these faults has resulted in the current transpressional tectonic regime, characterized by horizontal northeast-southwest maximum compression, that has uplifted Mount Diablo and folded the surrounding rocks over the last 4 million years into the Mount Diablo Anticline and associated Los Medanos Hills Thrust system (Schemmann and others, 2007; Weber-Band and others, 1997; Unruh and Sundermann, 2006).

The study area is located entirely within the Pittsburg-Antioch alluvial plain, consisting of Quaternary sedimentary units positioned unconformably over the northeast flank of the Los Medanos Hills, which consist of a complex of northeast dipping faults that elevate the Los Medanos Hills (Weber-Band and others, 1997; Unruh and Sundermann, 2006).

The study area contains a minor portion of the Pittsburg fault, and the Antioch fault projects towards the study area (Bryant and others, 2006; Jennings and Bryant, 2010). A portion of the northwest-southeast trending Pittsburg fault is mapped along the western edge study area, between California State Route 4 and New York Slough. The fault is Quaternary aged (<2.6 my), part of the Pittsburg-Kirby fault zone, and moderately constrained in Pleistocene alluvial fan (**Qpf**) deposits. The north-south trending Antioch fault, also referred to as the Davis fault by (Bryant and others, 2006), projects towards the study area, but is mapped just outside the limits of the study area (Jennings and Bryant, 2010). The Antioch fault is Quaternary aged (<2.6 my), concealed by Holocene alluvial fan (**Qhf**) deposits along East Antioch Creek, and well-constrained where in bedrock (Jennings and Bryant, 2010). No active faults are designated as Earthquake Zones of Required Investigation in the study area by the California Geological Survey, under the Alquist-Priolo Earthquake Fault Zoning Act.

Existing Landslides

There are no known existing landslides within the study area.

ENGINEERING GEOLOGY

Historic-High Groundwater Mapping

Natural hydrologic processes and human activities cause groundwater levels to fluctuate over time, and it is impossible to predict the depths to saturated soils during future earthquakes. One method to address time-variable depth to saturated soils is to establish a high groundwater level based on historical groundwater data. In areas where groundwater is currently near the surface (within 50 feet) or could return to near-surface levels within a land-use planning interval of 50 years, CGS constructs regional contour maps depicting highest historical depth to groundwater surface. Plate 1.2 depicts contours reflecting the historic-high depth to groundwater surface within the Contra Costa County portion of the Antioch North 7.5-Minute Quadrangle (study area).

Hydrographic Setting

Various parameters such as tides, precipitation, evaporation, watershed area, surface runoff, basin infiltration, and human activity influence the hydrologic setting in the study area. The margins of San Joaquin River New York Sough define the base potentiometric groundwater surface for the groundwater basin in the study area. The regions general climate is considered Mediterranean, with annual precipitation ranging from 11 to 18 inches (CDWR, 2003). Precipitation is the primary source of water to the groundwater basin. Precipitation and evaporation is consolidated by the topographic relief in each watershed. Within the various watersheds, the concentration of surface runoff and its infiltration into the basin alter the potentiometric surface to define the groundwater surface. Human activity has further artificially modified the hydrographic setting through development, grading, and pumping.

A majority of the study area is within the San Joaquin Delta Hydrologic Unit (HU) of the San Joaquin Hydrologic Basin Planning Area (HBPA) and a smaller portion of the study area is within the Suisun HU of the San Francisco HBPA, as defined by the California State Water Resources Control Board and (CIWMC, 2004). The San Joaquin Delta HU is not divided any further, and the Suisun HU is divided in to the Concord, Suisun Bay, and Suisun Bay - in Delta Hydraulic Areas (HAs). The Hydrologic Subareas include the Pittsburg - in Delta, and other undefined areas, see Table 1.2 for a breakdown of these watershed boundaries.

Table 1.2. State of California watershed boundary designations in the Contra Costa County portion of the Antioch North 7.5-Minute Quadrangle.

Hydrologic Basin Planning Area (HBPA)	Hydrologic Unit (HU)	Hydrologic Area (HA)	Hydrologic Subarea (HSA)
San Francisco Bay	Suisun	Concord	Pittsburg - in Delta
		Suisun Bay - in Delta	undefined
San Joaquin	San Joaquin Delta	undefined	undefined

These HAs and HSAs are used to locally identify the contributions of precipitation, surface water, and groundwater inflows into the watershed within the specific portions of the groundwater basin. The historic-high depth to groundwater contour surface is typically depressed along Hydraulic Subareas (HSAs), as the boundaries represent areas of divergent surface water (USGS, 2013).

Groundwater Basins

The California Department of Water Resources (DWR) groundwater basins within the study area includes the San Joaquin Valley - Tracy Groundwater Basin (5-022.15), and a portion of the Pittsburg Plain Groundwater Basin (2-004) (CDWR, 2003). The specific groundwater basin boundaries used for this study are more detailed and defined by the best available Quaternary geologic maps, which delineate consolidated and unconsolidated sedimentary deposits in the flatlands and narrow valleys. Plate 1.2 depicts the specific basin boundaries in the study area that characterize actual or historic shallow groundwater.

In the study area, near-surface unconfined groundwater basin materials consist of Pleistocene to recent age highly lenticular alluvial deposits (CDWR, 2003). Confined aquifers have not been delineated in the study area. Natural groundwater recharge in this study area is generally from precipitation, and streambed percolation from Kirker Creek, Markley Canyon, West Antioch Creek, East Antioch Creek, and several unnamed streams. Artificial sources of groundwater recharge may include urban landscape irrigation, agricultural irrigation, septic tanks, and other agricultural or recreational water impoundments. Additionally, artificial recharge related to water impoundments such as Lake Alhambra, locally raise groundwater levels downstream and upstream of the reservoir due to seepage.

Groundwater Levels

Groundwater levels in the study area were evaluated using depth to groundwater well records compiled from the Department of Water Resources (CDWR), California Water Resources Control Board (CWRCB), California Department of Transportation (CDOT), and local water districts and agencies. The groundwater well or borehole records consisted of available online data from geographic information systems, water well drilling logs, basin management plans, and groundwater monitoring reports.

Groundwater level data in this study represents more than 11,250 collected measurements from monitoring wells and borehole logs. Most of the groundwater level data is from CWRCB GeoTracker and GeoTracker GAMA websites, which contain primarily groundwater and environmental monitoring well measurements spanning a relatively narrow range of years, 2001 to 2018 (CWRCB, 2018). Some of the groundwater level data is from CDWR and CDOT, which contain groundwater monitoring well measurements and as-encountered groundwater measurements from borehole logs spanning a wider range of years, 1960 to 2017 (CDWR, 2018; CDOT, 2018). Groundwater levels have remained stable over the period of record except for static water level drops and subsequent recovery associated with the 1976 - 1977 and 1987 - 1992 drought periods (CDWR, 2003).

Groundwater data from all available records were spatially and temporally evaluated in a geographic information system (GIS). CGS created a historic-high groundwater elevation surface for the groundwater basin of the study area based on available groundwater level data

and data from previous groundwater basin studies. The highest historical groundwater elevation surface was compared with the existing ground-surface elevation (DEM), and consideration was given to active creeks, recharge ponds, detention basins, water impoundments, and reservoirs. The depth to groundwater contours depicted on Plate 1.2 do not represent present-day conditions or conditions at any specific date in time, as usually presented on typical groundwater contour maps, but rather the historic-high depth to groundwater for the basin. Water depth data from boreholes known to penetrate confined aquifers or screened in weathered and/or fractured rock units were not utilized in this study.

Historic-high groundwater elevation gradients within the groundwater basin are generally consistent with topographic gradients, which flow towards the north-northeast. It is important to note that the initiation or expansion of large-scale artificial recharge programs could significantly affect future groundwater levels. When alerted of such programs, CGS will evaluate their impact relative to liquefaction potential and revise official Seismic Hazard Zone maps, if necessary.

Geologic Material Testing

Liquefaction Hazard Zoning: In-Situ Penetration Resistance

Of particular value in liquefaction evaluations are logs that report the results of downhole standard penetration tests in alluvial materials. The Standard Penetration Test (SPT) provides a standardized measure of the penetration resistance of geologic deposits and is used as an index of soil density. For this reason, SPT results are a critical component of the Seed-Idriss Simplified Procedure (Seed and Idriss, 1982), a method used by CGS and the geotechnical community to quantitatively analyze liquefaction potential of sandy and silty material. SPT is an in-field test based on counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials (ASTM) in test method D1586 (ASTM, 2018). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differs from that specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts, if reliable conversions can be made. The actual and converted SPT blow counts are normalized to a common-reference, effective-overburden pressure of 1 atmosphere (approximately 1 ton per square foot) and a hammer efficiency of 60 percent using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$. Geotechnical borehole logs provided information on lithologic and engineering characteristics of Quaternary deposits within the study area.

For liquefaction hazard zoning in the study area, borehole logs were collected from the files of the City of Antioch, City of Pittsburg, and California Department of Transportation (CDOT). Data from a total of 243 borehole logs were entered into the CGS geotechnical GIS database and analyzed.

Of the 243 geotechnical borehole logs analyzed in this study (Plate 1.3), most included blow-count data from SPTs or from penetration tests that allow reasonable blow count conversions to SPT-equivalent values. Few of the borehole logs collected, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal analysis using the Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction

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

Landslide Hazard Zoning: Laboratory Shear Strength

Geologic classification and materials testing for earthquake-induced landslide hazard zoning was not evaluated due to the gentle sloping nature of the study area.

REFERENCES

American Society for Testing and Materials (ASTM), 2018, *in* Annual Book of ASTM Standards: https://www.astm.org/Standard/standards-and-publications.html

Atwater, B.F., 1982, Geologic maps of the Sacramento-San Joaquin Delta, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1401, scale 1:24,000, https://pubs.er.usgs.gov/publication/mf1401.

Bryant, W.A., and Cluett, S.E., Hart, E.W., Lundberg M.J., Treiman, J.A, compilers, 2006, Quaternary fault and fold database of the United States, accessed June 2018, from USGS web site: https://earthquake.usgs.gov/hazards/qfaults.

California Department of Water Resources (CDWR), 2018, Groundwater Level Data, Water Data Library, http://www.water.ca.gov/waterdatalibrary (June 2018).

California Department of Water Resources (CDWR), 2003, California's Groundwater, Bulletin 118, updated February 27, 2004, http://www.water.ca.gov/groundwater/bulletin118/update2003.cfm.

California Department of Water Resources (CDWR), 2018, California Statewide Groundwater Elevation Monitoring (CASGEM) Program, https://water.ca.gov/Programs/Groundwater-Management/Groundwater-Elevation-Monitoring--CASGEM, (June 2018).

California Department of Water Resources (CDWR), 2018, Groundwater Level Data, Water Data Library, http://www.water.ca.gov/waterdatalibrary (June 2018).

California Geological Survey (CGS), 2008, Guidelines for evaluating and mitigating seismic hazards in California: California Geological Survey Special Publication 117a, 98 p., originally published 1992, available on-line at: http://www.conservation.ca.gov/cgs/publications/sp117a

California Geological Survey (CGS), 2004, Recommended criteria for delineating seismic hazard zones in California: California Geological Survey Special Publication 118, 12 p., originally published 1992, available on-line at: http://www.conservation.ca.gov/cgs/publications/sp118

California Interagency Watershed Mapping Committee (CIWMC), 2004, California Interagency Watershed Map (Calwater 2.2.1), originally published 1999, https://catalog.data.gov/dataset/calwater-2-233fac.

California Water Resources Control Board (CWRCB), 2018, California Protection Agency, GeoTracker database, http://geotracker.waterboards.ca.gov (June 2018).

California Water Resources Control Board (CWRCB), 2018, California Protection Agency, GeoTracker Groundwater Ambient Monitoring & Assessment (GAMA) database, http://geotracker.waterboards.ca.gov/gama (June 2018).

Contra Costa Water District (CCWD), 2009, Los Vaqueros Reservoir Expansion Project – Draft EIS/EIR, https://www.ccwater.com/DocumentCenter/View/3257/20-Background.

Dawson, T., 2010, Preliminary Geologic Map of the Stockton 30'x 60' Quadrangle, California; California Geological Survey, unpublished.

Helley, E.J., Graymer, R. W., 1997, Quaternary geology of Alameda County, and parts of Contra Costa, Santa Clara, San Mateo, San Francisco, Stanislaus, and San Joaquin Counties, California: A digital database: U. S. Geological Survey Open-File Report 97-97, 13 pp., https://pubs.usgs.gov/of/1997/0097/

Horn, B.K.P., 1981, Hill shading and the reflectance map: Proceedings of the IEEE, v. 69, no. 1, p.14-47.

Jennings C.W., Bryant, W.A., 2010, Fault activity map of California, prepared in recognition of the California Geological Survey's 150th Anniversary, original compilations 1977 and 1994, http://maps.conservation.ca.gov/cgs/fam/

Knudsen, K.L., Sowers, J.M., Witter, R.C., Wentworth, C.M., and Helley, E.J., 2000, Description of mapping of quaternary deposits and liquefaction susceptibility, nine-county San Francisco Bay region, California: U.S. Geological Survey Open-File Report 00-444, https://pubs.usgs.gov/of/2006/1037/.

Nilsen, T., 1975, Preliminary Photointerpretation Map of Landslide and other surficial Deposits of Part of the Antioch North 7 ½' Quadrangle, Contra Costa, California, U.S. Geologic Survey Open File Report 75-0277, Map No. 2, https://pubs.er.usgs.gov/publication/ofr75277.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Chao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A., and D.P. Schwartz. 1996. Probabilistic seismic hazard assessment for the State of California. (Also U.S. Geological Survey Open-File Report 96-706). This report was coauthored and published by both the DMG and USGS, https://pubs.er.usgs.gov/publication/ofr96706.

RMC Water and Environment, 2016, City of Pittsburg 2015 Urban Water Management Plan Final Draft, prepared for City Council, June 2016, http://www.ci.pittsburg.ca.us/Modules/ShowDocument.aspx?documentid=8283.
Schemmann, K., Unruh, J.R., and Moores, E.M., 2007, Kinematics of Franciscan Complex exhumation: New insights from the geology of Mount Diablo, California: Geological Society of America Bulletin, v. 120; no. 5/6; p. 543–555.

Seed, H.B., and Idriss, I.M., 1982, Ground motions and soil liquefaction during earthquakes: Monograph Series, Earthquake Engineering Research Institute, Berkeley, California, 134 p.

Seed, H.B., Tokimatsu, K., Harder, L.F., and Chung, R.M., 1985, Influence of SPT procedures in soil liquefaction resistance evaluations: Journal of Geotechnical Engineering, ASCE, v. 111, no. 12, p. 1,425-1,445.

Sims, J.D., Nilsen, T.H., 1972, Preliminary Photointerpretation Map of Landslide and Other Surficial Deposits of Parts of the Pittsburg Rio Vista 15-Minute Quadrangle, Contra Costa and Solano Counties, California, U.S. Geologic Survey Miscellaneous Field Studies Map MF-322, Sheet 1 of 2, https://pubs.er.usgs.gov/publication/mf322.

Sims, J.D., Fox, K.F., Jr., Barton, J.A., Helley, E.J., 1973, Preliminary Geologic Map of Solano County and Parts of Napa, Contra Costa, Marin, and Yolo Counties, California, U.S. Geologic Survey Miscellaneous Field Studies Map MF-484, Sheet 5 of 5, https://pubs.er.usgs.gov/publication/mf484.

Tetra Tech, 2018, Contra Costa County Hazard Mitigation Plan, Volume 1 – Planning-Area-Wide-Elements and prepared for Contra Costa County, Project No.103S4848, January 2018. http://www.co.contra-costa.ca.us/6416/Current-Local-Hazard-Mitigation-Plan.

Tetra Tech, 2011, Draft: Contra Costa County Hazard Mitigation Plan, Volume 2 – Planning Partners Annexes, prepared for Contra Costa County, Project No. 135-23736-08-090, May 2011, http://www.co.contra-costa.ca.us/6416/Current-Local-Hazard-Mitigation-Plan.

Unruh, J.R., Dumitru, T.A. and Sawyer, T.L., 2007, Coupling of early Tertiary extension in the Great Valley forearc basin with blueschist exhumation in the underlying Franciscan accretionary wedge at Mount Diablo, California: Geological Society of America Bulletin, v. 119; no. 11/12; p. 1347–1367. https://doi.org/10.1130/B26057.1

Unruh, J.R., Sundermann, S., 2006, Digital Compilation of Thrust and Reverse Faults Data for the Northern California Map Database: Collaborative Research with William Lettis & associates, Inc., and the U.S. Geological Survey: Final Technical Report: National Earthquake Hazards Reduction Program, Award Number 05QGR005424, 24 p.: http://www.deltarevision.com/2006_docs/2006thrust_final_report.pdf

Weber-Band, J., Williams, P.L., Jones, D.L., Johnson, P., McEvilly, T.V., 1997, Active Tectonic Deformation at the Eastern Margin of the California Coast Ranges Results of the BASIX and CALCRUST Programs: U. S. Geological Survey Open-File Report 97-691, 17 pp.: https://pubs.er.usgs.gov/publication/ofr97691

West Yost and Associates, City of Antioch 2015 Urban Water Management Plan, prepared for the City of Antioch, Project No. 622-12-15-03, May 2015, https://www.antiochca.gov/fc/environment/UWMP-2015.pdf.

U.S. Geological Survey, 2001, National Water Information System data available on the World Wide Web (Water Data for the Nation): http://waterdata.usgs.gov/nwis/ (June 2018).

U.S. Geological Survey, 2013, Federal Standards and Procedures for the National Watershed Boundary Dataset (WBD), Techniques and Methods 11–A3, https://pubs.usgs.gov/tm/11/a3.

SECTION 2: GROUND MOTION ASSESSMENT

for the

ANTIOCH NORTH 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

using the

2014 NATIONAL SEISMIC HAZARD MODEL

by

Rui Chen
P.G. 8598

DEPARTMENT OF CONSERVATION
CALIFORNIA GEOLOGICAL SURVEY

Purpose of this Section

This section of the Seismic Hazard Zone Report presents an assessment of shaking hazards from earthquakes in the Contra Costa County potion of the Antioch North 7.5-Minute Quadrangle (study area). It includes an explanation of the probabilistic seismic hazard analysis model from which ground motion parameters are derived, and how these parameters are used to delineate liquefaction and earthquake-induced landslide hazard zones in the study area.

PROBABILISTIC SEISMIC HAZARD ANALYSIS MODEL

Probabilistic ground motions are calculated using the United States Geological Survey (USGS) probabilistic seismic hazard analysis (PSHA) model for the 2014 Update of the National Seismic Hazard Maps (NSHM) (Petersen and others, 2014; 2015). This model replaces ground-motion models of Petersen and others (2008), Frankel and others (2002), Cao and others (2003) and Petersen and others (1996) used in previous official Seismic Hazard Zone maps. Like previous models, the 2014 USGS PSHA model utilizes the best available science, models and data; and is the product of an extensive effort to obtain consensus within the scientific and engineering communities regarding earthquake sources and ground motions. In California, two earthquake source models control ground motion hazards, namely version three of the Uniform California Earthquake Rupture Forecast Model (UCERF3) (Field and others, 2013; 2014) and the Cascadia Subduction Zone model (Frankel and others, 2014). For shallow crustal earthquakes, ground motions are calculated using the Next Generation Attenuation Relations for Western U.S. (NGA-West2) developed from a Pacific Earthquake Engineering Research Center ground motion research project (Bozorgnia and others, 2014). The NGA-West2 includes five ground motion prediction equations (GMPEs): Abrahamson and others (2014), Boore and others (2014), Campbell and Bozorgnia (2014), Chiou and Youngs (2014), and Idriss (2014). For subduction zone earthquakes and earthquakes of other deep sources, GMPEs developed specifically for such sources are used, including the Atkinson and Boore (2003) global model, Zhao and others (2006), Atkinson and Macias (2009), and BC Hydro (Addo and others, 2012).

In PSHA, ground motion hazards from potential earthquakes of all magnitudes and distances on all potential seismic sources are integrated. GMPEs are used to calculate the shaking level from each earthquake based on earthquake magnitude, rupture distance, type of fault rupture (strike-slip, reverse, normal, or subduction), and other parameters such as time-average shear-wave velocity in the upper 30 m beneath a site (V_{S30}). In previous applications, a uniform firm-rock site condition was assumed in PSHA calculation and, in a separate post-PSHA step, National Earthquake Hazard Reduction Program (NEHRP) amplification factors were applied to adjust all sites to a uniform alluvial soil condition to approximately account for the effect of site condition on ground motion amplitude. In the current application, site effect is directly incorporated in PSHA via GMPE scaling. Specifically, V_{S30} is built into GMPEs as one of the repressors and, therefore, it is an input parameter in the PSHA calculation. V_{S30} value at each grid point is assigned based on a geology- and topography-based V_{S30} map for California developed by Wills and others (2015). The statewide V_{S30} map consists of fifteen V_{S30} groups with group mean V_{S30} values ranging from 176 m/s to 733 m/s. It is to be noted that these values are not determined from site-specific velocity data. Some group values have considerable uncertainties as indicated by a coefficient of variation ranging from 11% in Quaternary (Pleistocene) sand deposits to 55% in crystalline rocks.

For zoning purpose, ground motions are calculated at each grid point of a 0.005-degree grid (approximately 500-m spacing) that adequately covers the entire quadrangle. V_{S30} map and grid points in the Antioch North 7.5-minute Quadrangle are depicted in Plate 2.1. For site investigation, it is strongly recommended that V_{S30} be determined from site-specific shear wave velocity profile data.

PSHA provides more comprehensive characterizations of ground motion hazards compared to traditional scenario-based analysis by integrating hazards from all earthquakes above a certain magnitude threshold. However, many applications of seismic hazard analyses, including liquefaction and induced landslide hazard mapping analyses, still rely on scenario earthquakes or some aspects of scenario earthquakes. Deaggregation enables identification of the most significant scenario or scenarios in terms of magnitude and distance pair. Deaggregation is often performed for a particular site, a chosen ground motion parameter (such as peak ground acceleration or PGA), and a predefined exceedance probability level (i.e., hazard level). As in previous regulatory zone maps, the ground motion hazard level for liquefaction and landslide hazard zoning is 10% exceedance probability in 50 years or 475-year return period.

Probabilistic ground motion calculation and hazard deaggregation are performed using a new USGS hazard codebase, nshmp-haz version 1.1.6, a Java library developed in support of the USGS NSHM project. The Java code library is hosted in GitHub and is publicly available at: https://github.com/usgs/nshmp-haz. This codebase also supports the USGS web-based site-specific ground motions calculator, the Unified Hazard Tool, https://earthquake.usgs.gov/hazards/interactive/. The source model used for the published 2014 NSHMs is adopted in its entirety. The 2014 source model is also hosted in GitHub and is publically available at: https://github.com/usgs/nshmp-model-cous-2014/.

APPLICATION TO LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENT

The current CGS liquefaction hazard analysis approach requires that PGA be scaled by an earthquake magnitude weighting factor (MWF) to incorporate a magnitude-correlated duration effect (California Geological Survey, 2004; 2008). The MWF-scaled PGA is referred to as pseudo-PGA and is used as Liquefaction Opportunity (see Section 3 of this report). The MWF calculation is straight forward for a scenario earthquake. In PSHA, however, earthquakes of different magnitudes and distances contribute differently to the total hazard at a chosen probabilistic PGA level. The CGS approach to MWF calculation is based on binned magnitude-distance deaggregation. At each location, an MWF is calculated for each magnitude-distance bin and is weighted by the contribution of that magnitude-distance bin to the total hazard. The total MWF is the sum of probabilistic hazard-weighted MWFs from all magnitude-distance bins. This approach provides an improved estimate of liquefaction hazard in a probabilistic sense. All magnitudes contributing to the hazard estimate are used to weight the probabilistic calculation of PGA, effectively causing the cyclic stress ratio liquefaction threshold curves to be scaled probabilistically when computing factor of safety. This procedure ensures that large, distant earthquakes that occur less frequently but contribute *more*, and smaller, more frequent events that contribute *less* to the liquefaction hazard are appropriately accounted for (Real and others, 2000).

The current CGS landslide hazard analysis approach requires the probabilistic PGA and a predominant earthquake magnitude to estimate cumulative Newmark displacement for a given rock strength and slope gradient condition using a regression equation, described more fully in Section 4 of this report. The predominant earthquake magnitude is chosen to be the modal magnitude from deaggregation.

Pseudo-PGA and probabilistic PGA at grid points are depicted in Plates 2.2 and 2.3, respectively. Modal magnitude is depicted in Plate 2.4. The values of PGA and pseudo-PGA generally increase from the northeast corner to the southwest corner of the quadrangle. Shaking hazards in the quadrangle are controlled mainly by the Great Valley fault zone. Other sources that contribute to shaking hazards include the Concord fault, Mount Diablo thrust fault, Los Medanos fault, Clayton fault, Hayward fault, Greenville fault, Calaveras Fault, San Andreas fault, and background (gridded) seismicity. Modal magnitude reflects the magnitudes of earthquakes that the Great Valley fault zone and Concord fault are capable of producing (Plate 2.4). Ground motion distribution is controlled by proximity to these faults and is affected by subsurface geology. In general, expected PGA is higher where there are softer Quaternary sediments (lower V_{S30} values) and lower where there are harder volcanic and crystalline rocks (higher V_{S30} values). The table below summarizes ranges of PGA, pseudo-PGA, modal magnitude, and V_{S30} values expected in the quadrangle.

Table 2.1. Summary of ground motion parameters used for liquefaction analyses.

PGA (g)	Pseudo-PGA (g)	Modal Magnitude	V_{S30} (m/s)
0.34 to 0.58	0.22 to 0.37	6.15 to 6.91	176 to 733

REFERENCES

Abrahamson, N.A., Silva, W.J., and Kamai, R., 2014, Summary of the ASK14 ground motion relation for active crustal regions: Earthquake Spectra, vol. 30, p. 1025–1055.

Addo, K., Abrahamson, N., and Youngs, R. (BC Hydro), 2012, Probabilistic seismic hazard analysis (PSHA) model—Ground motion characterization (GMC) model: Report E658, published by BC Hydro.

Atkinson, G.M., and Boore, D.M., 2003, Empirical ground-motion relations for subduction-zone earthquakes and their application to Cascadia and other regions: Bulletin of the Seismological Society of America, vol. 93, p. 1,703–1,729.

Atkinson, G.M., and Macias, M., 2009, Predicted ground motions for great interface earthquakes in the Cascadia subduction zone: Bulletin of the Seismological Society of America, vol. 99, p. 1,552–1,578.

Boore, D.M., Stewart, J.P., Seyhan, E., and Atkinson, G.M., 2014. NGA-West2 equations for predicting PGA, PGV, and 5% damped PSA for shallow crustal earthquakes: Earthquake Spectra, vol. 30, p. 1057–1085.

Bozorgnia Y., Abrahamson, N.A., Atik, L.A., Dawson T.D., and others, 2014, NGA-West2 Research Project: Earthquake Spectra, vol 30, no. 3, p. 973 –987, DOI: 10.1193/072113EQS209M.

Campbell, K.W., and Bozorgnia, Y., 2014, NGA-West2 ground motion model for the average horizontal components of PGA, PGV, and 5% damped linear acceleration response spectra: Earthquake Spectra, vol. 30, p. 1087–1115.

California Geological Survey, 2008, Guidelines for evaluating and mitigating seismic hazards in California: California Geological Survey Special Publication 117a, 98 p. Available on-line at: http://www.conservation.ca.gov/cgs/publications/sp117a.

California Geological Survey, 2004, Recommended criteria for delineating seismic hazard zones in California: California Geological Survey Special Publication 118, 12 p. Available on-line at: http://www.conservation.ca.gov/cgs/publications/sp118.

Cao, T., Bryant, W.A., Rowshandel, B., Branum, D. and Wills, C.J., 2003, The Revised 2002 California Probabilistic Seismic Hazard Maps. California Geological Survey, Online Report: http://www.conservation.ca.gov/cgs/Documents/PSHA/2002_CA_Hazard_Maps.pdf.

Chiou, B.S.-J., and Youngs, R.R., 2014. Update of the Chiou and Youngs NGA model for the average horizontal component of peak ground motion and response spectra: Earthquake Spectra, vol. 30, p. 1117–1153.

Field, E.H., Biasi, G.P., Bird, P., Dawson, T.E., Felzer, K.R., Jackson, D.D., Johnson, K.M., Jordan, T.H., Madden, C., Michael, A.J., Milner, K.R., Page, M.T., Parsons, T., Powers, P.M., Shaw, B.E., Thatcher,W.R., Weldon, II, R.J., and Zeng, Y., 2013, Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3)—The Time-Independent Model, U.S. Geological Survey Open-File Report 2013–1165, California Geological Survey Special Report 228, and Southern California Earthquake Center Publication 1792, 97 pp., available at http://pubs.usgs.gov/of/2013/1165/.

Field, E.H., Arrowsmith, R.J., Biasi, G.P., Bird, P., Dawson, T.E., Felzer, K.R., Jackson, D.D., Johnson, K.M., Jordan, T.H., Madden, C., Michael, A.J., Milner, K.R., Page, M.T., Parsons, T., Powers, P.M., Shaw, B.E., Thatcher, W.R., Weldon, II, R.J., and Zeng, Y., 2014, Uniform California earthquake rupture forecast, Version 3 (UCERF3) —The time independent model: Bulletin of Seismological Society of America, vol. 104, p. 1122–1180.

Frankel, A.D., Petersen, M.D., Muller, C.S., Haller, K.M., Wheeler, R.L., Layendecker, E.V., Wesson, R.L., Harmsen, S.C., Cramer, C.H., Perkins, D.M., and Rukstales, K.S., 2002, Documentation for the 2002 Update of the National Seismic Hazard Maps: U.S. Geological Survey, Open-File Report 02-420, 33 p.

Frankel, A., Chen, R., Petersen, M., Moschetti, M., and Sherrod, B., 2014, 2014 Update of the Pacific Northwest Portion of the U.S. National Seismic Hazard Maps: Earthquake Spectra, vol. 31, no. S1, p. S131–S148, DOI: 10.1193/111314EQS193M.

Idriss, I. M., 2014, An NGA-West2 empirical model for estimating the horizontal spectral values generated by shallow crustal earthquakes: Earthquake Spectra, vol. 30, p. 1155–1177.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.

Petersen, M.D., Frankel, A.D., Harmsen, S.C., Mueller, C.S., Haller, K.M., Wheeler, R.L., Wesson, R.L., Zeng, Y., Boyd, O.S., Perkins, D.M., Luco, N., Field, E.H., Wills, C.J., and Rukstales, K.S., 2008, Documentation for the 2008 update of the United States National Seismic Hazard Maps: U.S. Geol. Survey Open-File Report 2008-1128, 60p.

Petersen, M.D., Moschetti, M.P., Powers, P.M., Mueller, C.S., Haller, K.M., Frankel, A.D., Zeng, Y., Rezaeian, S., Harmsen, S.C., Boyd, O.S., Field, N., Chen, R., Rukstales, K.S., Luco, N., Wheeler, R.L., Williams, R.A., and Olsen, A.H., 2014, Documentation for the 2014 update of the United States national seismic hazard maps, U.S. Geol. Survey. Open-File Rept. 2014-1091, 243 pp., doi: 10.3133/ofr20141091.

Petersen, M.D., Moschetti, M.P., Powers, P.M., Mueller, C.S., Haller, K.M., Frankel, A.D., Zeng, Y., Rezaeian, S., Harmsen, S.C., Boyd, O.S., Field, N., Chen, R., Rukstales, K.S., Luco, N., Wheeler, R.L., Williams, R.A., and Olsen, A.H., 2015, The 2014 United States national seismic hazard model: Earthquake Spectra, vol. 31, no. S1, p. S1–S30, doi: 10.1193/120814EQS210M.

Real, C.R., Petersen, M.D., McCrink, T.P. and Cramer, C.H., 2000, Seismic Hazard Deaggregation in zoning earthquake-induced ground failures in southern California: Proceedings of the Sixth International Conference on Seismic Zonation, November 12-15, Palm Springs, California, EERI, Oakland, CA.

Wills, C.J., Gutierrez, C.I., Perez, F.G., and Branum, D.M., 2015, A next-generation V_{S30} map for California based on geology and topography: Bulletin of Seismological Society of America, vol. 105, no. 6, p. 3083–3091, doi: 10.1785/0120150105.

Zhao, J.X., Zhang, J., Asano, A., Ohno, Y., Oouchi, T., Takahashi, T., Ogawa, H., Irikura, K., Thio, H.K., Somerville, P.G., Fukushima, Y.A, and Fukushima, Y., 2006, Attenuation relations of strong ground motion in Japan using site classification based on predominant period: Bulletin of the Seismological Society of America, v. 96, p. 898–913.

SECTION 3: EVALUATION OF LIQUEFACTION HAZARD

in the

ANTIOCH NORTH 7.5-MINUTE QUADRANGLE, SANTA CLARA COUNTY, CALIFORNIA

by

Ante N. Mlinarevic
P.G. 8352, C.E.G 2552

DEPARTMENT OF CONSERVATION
CALIFORNIA GEOLOGICAL SURVEY

Purpose of this Section

This Section of the Seismic Hazard Zone Report summarizes the analyses and criteria used to delineate liquefaction hazard zones in the Contra Costa County portion of the Antioch North 7.5-Minute Quadrangle (study area).

ZONING TECHNIQUES

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. When this occurs, 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, whereas liquefaction opportunity is a function of potential seismic ground shaking intensity.

The method applied in this study to evaluate liquefaction potential is similar to that Tinsley and others (1985) used to map liquefaction hazards in the Los Angeles region. These investigators, in turn, applied a combination of the techniques developed by Seed and others (1983) and Youd and Perkins (1978). California Geological Survey's (CGS's) method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates employing criteria adopted by the SMGB (CGS, 2004).

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, density, compaction, cementation, saturation, and depth from the surface govern the degree of

resistance to liquefaction. Some of these properties can be correlated to a deposit'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, however, be vulnerable to strength loss with remolding and represent a hazard that is not specifically addressed in this investigation. Soil characteristics that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. In summary, soils that lack resistance (susceptible soils) typically are saturated, loose, and granular. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

CGS's inventory of areas containing soils susceptible to liquefaction begins with evaluation of historical occurrences of liquefaction, geologic maps, cross-sections, geotechnical test data, geomorphology, and groundwater hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historic-high depths to groundwater, are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on observable characteristics of surficial deposits, liquefaction susceptibility maps are often similar to Quaternary geologic maps, varying depending on local groundwater levels. Generalized correlations between susceptibility, geologic map unit, and depth to groundwater are summarized in Table 3.1.

Table 3.1. Liquefaction susceptibility of Quaternary units in the Contra Costa portion of the Antioch North 7.5-Minute Quadrangle.

Geologic Map Unit	Liquefaction Susceptibility*
Qpf	Very Low to Low
Qhf, Qds	Moderate
Qhsc	High to Very High
Qhbm	Moderate to High
af	Variable
*When saturated	

Ground Motion for Liquefaction Hazard Assessment

Ground motion calculations used by CGS for regional liquefaction zonation assessments are based on the probabilistic seismic hazard analysis (PSHA) model developed by USGS (Petersen and others, 2014; 2015) for the 2014 Update of the United States National Seismic Hazard Maps (NSHMs). The model calculates ground motion in terms of peak horizontal ground acceleration (PGA) at a 10 percent in 50 years exceedance probability level. For liquefaction analysis, CGS modifies probabilistic PGA by a scaling factor that is a function of magnitude. Calculation of the scaling factor is based on binned magnitude-distance deaggregation of seismic source contribution to total shaking. The result is a magnitude-weighted, pseudo-PGA that CGS refers

to as Liquefaction Opportunity (LOP). This approach provides an improved estimate of liquefaction hazard in a probabilistic sense, ensuring that the effects of large, infrequent, distant earthquakes, as well as smaller, more frequent, nearby events are appropriately accounted for (Real and others, 2000). These LOP values are then used to calculate cyclic stress ratio (CSR), the seismic load imposed on a soil column at a particular site. A more detailed description of the development of ground shaking opportunity data and parameters used in liquefaction hazard zoning can be found in Section 2 of this report.

Liquefaction Analysis

As mentioned in the Engineering Geology section of this report, borehole logs containing useful geotechnical information were found during the course of this study. However, when borehole logs with adequate geotechnical soil-test data are available, CGS 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; Youd and others, 2001). The procedure first calculates the resistance to liquefaction of each soil layer penetrated at a test-drilling site, expressed in terms of cyclic resistance ratio (CRR). The calculations are based on standard penetration test (SPT) results, groundwater level, soil density, grain-size analysis, moisture content, soil type, and sample depth. The procedure then estimates the factor of safety relative to liquefaction hazard for each of the soil layers logged at the site by dividing their calculated CRR by the pseudo PGA-derived CSR described in the previous section.

CGS uses a factor of safety (FS) of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil layers. The liquefaction analysis program calculates an FS for each geotechnical sample where blow counts were collected. Typically, multiple samples are collected for each borehole. The program then independently calculates an FS for each non-clay layer that includes at least one penetration test, using the minimum $(N_1)_{60}$ value for that layer. The minimum FS value of all the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. In addition to FS, consideration is given to the proximity to stream channels, which accounts in a general way for factors such as sloping ground or free faces that may influence the severity of liquefaction-related ground deformation.

Liquefaction Zoning Criteria

Areas underlain by materials potentially subject to liquefaction during an earthquake are included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (CGS, 2004). 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 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 subsurface data are not sufficient for quantitative evaluation of liquefaction hazard. Within such areas, zones may be delineated by geologic criteria as follows:

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

   b) Areas containing soil deposits of Holocene age (less than 11,700 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.20 g and the anticipated depth to saturated soil is less than 30 feet; or

   c) Areas containing soil deposits of latest Pleistocene age (11,700 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 g and the anticipated depth to saturated soil is less than 20 feet.

Application of the above criteria allows compilation of Earthquake Zones of Required Investigation for liquefaction hazard, which are useful for preliminary evaluations, general land-use planning and delineation of other special study zones (Youd, 1991).

Delineation of Liquefaction Hazard Zones

Following the liquefaction analysis for the study area, CGS applied the liquefaction zoning criteria to the evaluation to determine the liquefaction hazard zones. Based on the evaluation, approximately 25 square kilometers (10 square miles) of the study area are included in the Seismic Hazard Zone for liquefaction. These zones are mainly located in lowlands adjacent to the San Joaquin River and Suisun Bay, within Browns and Winter Island. Additionally, liquefaction encompass major stream valleys such as Kirker Creek, West Antioch Creek, East Antioch Creek, Los Medanos Wasteway, Markley Canyon, and other smaller unnamed stream valleys. Minor drainages that ultimately outlet into Suisun Bay are also zoned.

The following is a detailed description of each of the zoning criteria that governed the construction of the EZRI for liquefaction for the study area.

Areas of Past Liquefaction

Documented observations of historical liquefaction are not recorded for the study area, nor has evidence of paleoseismic liquefaction been reported.

Artificial Fills

Artificial fill in the study area are significant enough to depict at the scale of mapping (1:24,000), and include engineered and non-engineered material. Engineered fills are typically placed on firm and unyielding foundation soils or bedrock determined by field testing and observations. These materials are mechanically moisture conditioned, placed in defined loose-lift thicknesses, and compacted using prescribed methods. Engineered fill typically meet relative compaction requirements as determined by prescribed methods such as American Society for Testing and

Materials (ASTM) methods. Examples of engineered fills in the study area include grading associated with Highway 4 and 160; Atchison-Topeka and Santa Fe, Southern Pacific, and BART railways; and the Contra Costa Canal. Non-engineered fills include materials where documentation regarding placement and compaction are not available and these materials are conservatively assumed to be relatively loose and uncompacted. Examples of non-engineered fills in the study area include hillside grading for residential development and grading associated with facilities located on or adjacent to the San Joaquin River and New York Slough.

Areas with Sufficient Existing Geotechnical Data

Geologic classification and material testing data for over 240 borehole logs are used to quantitatively analyze liquefaction potential in the study area. These boreholes indicate a high potential for liquefaction of young Quaternary sedimentary deposits and indicate a low potential for liquefaction of older Quaternary deposits, which is characteristic of Pleistocene sediments.

Areas with Insufficient Existing Geotechnical Data

Where borehole logs and associated geologic classification and material testing data are not sufficient to quantitively analyze the potential for liquefaction in the study area, more generalized criteria are used. In general, the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 *g* for most of the area, excluding the southeasternmost corner. Based on the consistent levels of ground shaking across the site, the age of the Quaternary sedimentary deposits and historic-high depth to groundwater are used to delineate liquefication zones with insufficient existing geotechnical data.

Areas mapped as Late Pleistocene to modern soils, with the anticipated depth to saturated soil of less than 40 feet, are included in the liquefaction zone. Additionally, Pleistocene soils, with anticipated depth to saturated soil of less than 20 feet, are included in the liquefaction zone.

ACKNOWLEDGMENTS

The authors thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project: Arne Simonsen, Tamara Leach, Lynne Filson, and Harold Jirousky of Antioch City, Stephanie Butler of Brentwood City, Loren Turner of the CalTrans Laboratory, and Kenneth Haseman of California Department of Water Resources arranged access and assisted in retrieving geotechnical data from files maintained by their respective offices. At CGS, Wayne Haydon and Eleanor Spangler provided valuable insights on groundwater mapping. Christopher Tran, Edward Southwick, and Michael Maldonado assisted with geotechnical data collection efforts. Terilee McGuire, Bob Moscovitz, Janine Bird, and Kate Thomas of CGS provided GIS operations and database support. Kate Thomas prepared the final Seismic Hazard Zone Map and Janine Bird prepared the graphic displays for this report. Tim McCrink and Mike Silva provided technical review for this report.

REFERENCES

California Geological Survey (CGS), 2004, Recommended criteria for delineating seismic hazard zones in California: California Geological Survey Special Publication 118, 12 p., originally published 1992, available on-line at: http://www.conservation.ca.gov/cgs/publications/sp118.

National Research Council, 1985, Liquefaction of soils during earthquakes: National Research Council Special Publication, Committee on Earthquake Engineering, National Academy Press, Washington, D.C., 240 p.

Peck R.B., Hanson W.E., and Thornburn T.H., 1953, Foundation Engineering 1953 Edition Hardcover, Publisher, Wiley 410 p.

Petersen, M.D., Moschetti, M.P., Powers, P.M., Mueller, C.S., Haller, K.M., Frankel, A.D., Zeng, Y., Rezaeian, S., Harmsen, S.C., Boyd, O.S., Field, N., Chen, R., Rukstales, K.S., Luco, N., Wheeler, R.L., Williams, R.A., and Olsen, A.H., 2014, Documentation for the 2014 update of the United States national seismic hazard maps, U.S. Geological Survey. Open-File Report 2014-1091, 243 pp., https://pubs.usgs.gov/of/2014/1091/.

Petersen, M.D., Moschetti, M.P., Powers, P.M., Mueller, C.S., Haller, K.M., Frankel, A.D., Zeng, Y., Rezaeian, S., Harmsen, S.C., Boyd, O.S., Field, N., Chen, R., Rukstales, K.S., Luco, N., Wheeler, R.L., Williams, R.A., and Olsen, A.H., 2015, The 2014 United States national seismic hazard model: Earthquake Spectra, vol. 31, no. S1, p. S1–S30, doi: 10.1193/120814EQS210M.

Real, C.R., Petersen, M.D., McCrink, T.P., and Cramer, C.H., 2000, Seismic Hazard Deaggregation in zoning earthquake-induced ground failures in southern California: Proceedings of the Sixth International Conference on Seismic Zonation, November 12-15, Palm Springs, California, Earthquake Engineering Research Institute, Oakland, CA.

Seed, H.B., and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundations Division of American Society of Civil Engineers, v. 97: SM9, p. 1,249-1,273.

Seed, H.B., and Idriss, I.M., 1982, Ground motions and soil liquefaction during earthquakes: Monograph Series, Earthquake Engineering Research Institute, Berkeley, California, 134 p.

Seed, H.B., Idriss, I.M., and Arango, I., 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, v. 109, no. 3, p. 458-482.

Seed, H.B., Tokimatsu, K., Harder, L.F., and Chung, R.M., 1985, Influence of SPT procedures in soil liquefaction resistance evaluations: Journal of Geotechnical Engineering, American Society of Civil Engineers, v. 111, no. 12, p. 1,425-1,445.

Seed, R.B., and Harder, L.F., 1990, SPT-based analysis of cyclic pore pressure generation and undrained residual strength: Proceedings of the H. Bolton Seed Memorial Symposium, v. 2, p. 351-376.

Tinsley, J.C., Youd, T.L., Perkins, D.M., and Chen, A.T.F., 1985, Evaluating liquefaction potential, in Ziony, J.I., editor, Evaluating earthquake hazards in the Los Angeles region — An earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-316, https://pubs.er.usgs.gov/publication/pp1360.

Youd, T.L., 1973, Liquefaction, flow and associated ground failure: U.S. Geological Survey Circular 688, 12 p., https://pubs.er.usgs.gov/publication/cir688.

Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation: Earthquake Engineering Research Institute, Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 111-138.

Youd, T.L., and Idriss, I.M., 1997, editors, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research Technical Report NCEER-97-0022, 276 p.

Youd, T.L., Idriss, I.M., Andrus, R.D., Arango, I., Castro, G., Christian, J.T., Dobry, R., Finn, W.D.L., Harder, L.F. Jr., Hynes, M.E., Ishihara, K., Koester, J.P., Liao, S.S.C., Marcusson, W.F., Martin, G.R., Mitchell, J.K., Moriwaki, Y., Power, M.S., Robertson, P.K., Seed, R.B., and Stokoe, K.H., 2001, Liquefaction resistance of soils; Summary report from the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils: Journal of Geotechnical and Geoenvironmental Engineering, October 2001, p. 817-833.

Youd, T.L., and Perkins, D.M., 1978, Mapping liquefaction-induced ground failure potential: Journal of Geotechnical Engineering, v. 104, p. 433-446.

SECTION 4: EVALUATION OF EARTHQUAKE-INDUCED LANDSLIDE HAZARD

in the

ANTIOCH NORTH 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

by

Ante N. Mlinarevic
P.G. 8352, C.E.G 2552

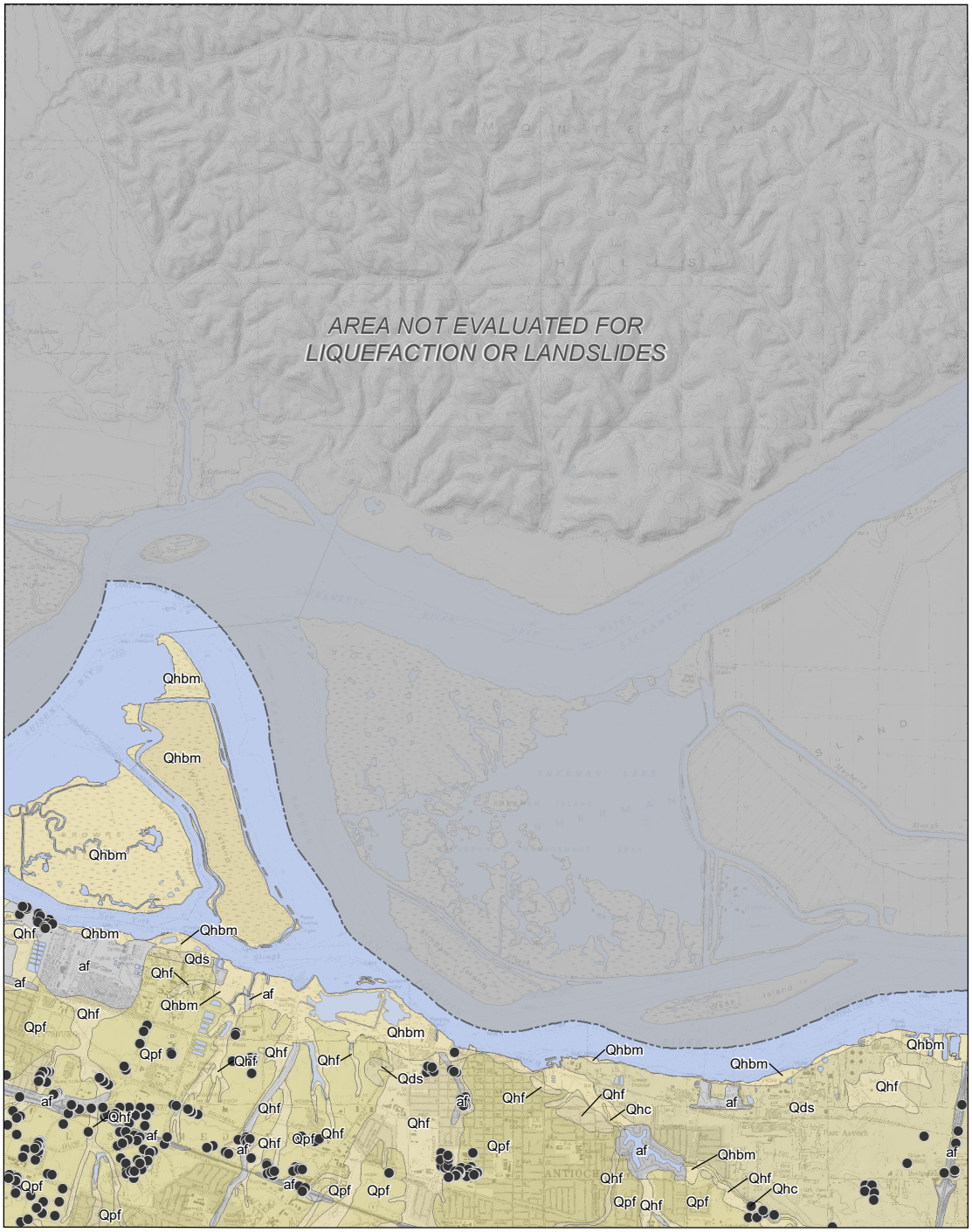
DEPARTMENT OF CONSERVATION
CALIFORNIA GEOLOGICAL SURVEY

Purpose of this Section

This Section of the Seismic Hazard Zone Report summarizes the analyses and criteria used to delineate earthquake-induced landslide hazard zones in Contra Costa County portion of the Antioch North 7.5-Minute Quadrangle (study area).

NO EARTHQUAKE-INDUCED LANDSLIDES ZONED

Within the study area, no Earthquake Zones of Required Investigation (EZRI) for earthquake-induced landslides are mapped. The lack of significant steep slopes is the primary reason for the absence of these zones. However, the potential for landslides may exist locally, particularly along stream banks, margins of drainage channels, and similar settings where steep banks or slopes occur. Such occurrences are of limited lateral extent or are too small and discontinuous to be depicted at 1:24,000 scale (the scale of Seismic Hazard Zone Maps). Within the liquefaction zones, some geologic settings may be susceptible to lateral spreading (a condition wherein low-angle landsliding is associated with liquefaction). Also, earthquake-induced landslide hazards can be created during excavation and grading unless appropriate techniques are used.



Topographic base map from USGS. Contour interval 20 feet. Scale 1:75,000. Map preparation by Janine Bird, CGS.

ANTIOCH NORTH QUADRANGLE

N

1 0.5 0 1 2 Miles

5,000 2,500 0 5,000 10,000 Feet

1 0.5 0 1 2 Kilometers

See "Geology" in Section 1 of report for descriptions of units.
Pre-Quaternary bedrock units shown without color.

● Geotechnical boring used in liquefaction evaluation

Plate 1.1 Quaternary geologic materials map and locations of boreholes used in evaluating liquefaction hazard, Antioch North Quadrangle, California.

Topographic base map from USGS. Contour interval 20 feet. Scale 1:75,000. Map preparation by Janine Bird, CGS.

ANTIOCH NORTH QUADRANGLE

N

1 0.5 0 1 2 Miles

5,000 2,500 0 5,000 10,000 Feet

1 0.5 0 1 2 Kilometers

See "Geology" in Section 1 of report for descriptions of units.

Groundwater measurement location

10 Depth to groundwater (in feet)

Plate 1.2 Depth to historic-high groundwater levels in Quaternary alluvial deposits and ground water data points, Antioch North Quadrangle, California.

Topographic base map from USGS. Contour interval 20 feet. Scale 1:75,000. Map preparation by Janine Bird, CGS.

ANTIOCH NORTH QUADRANGLE

N

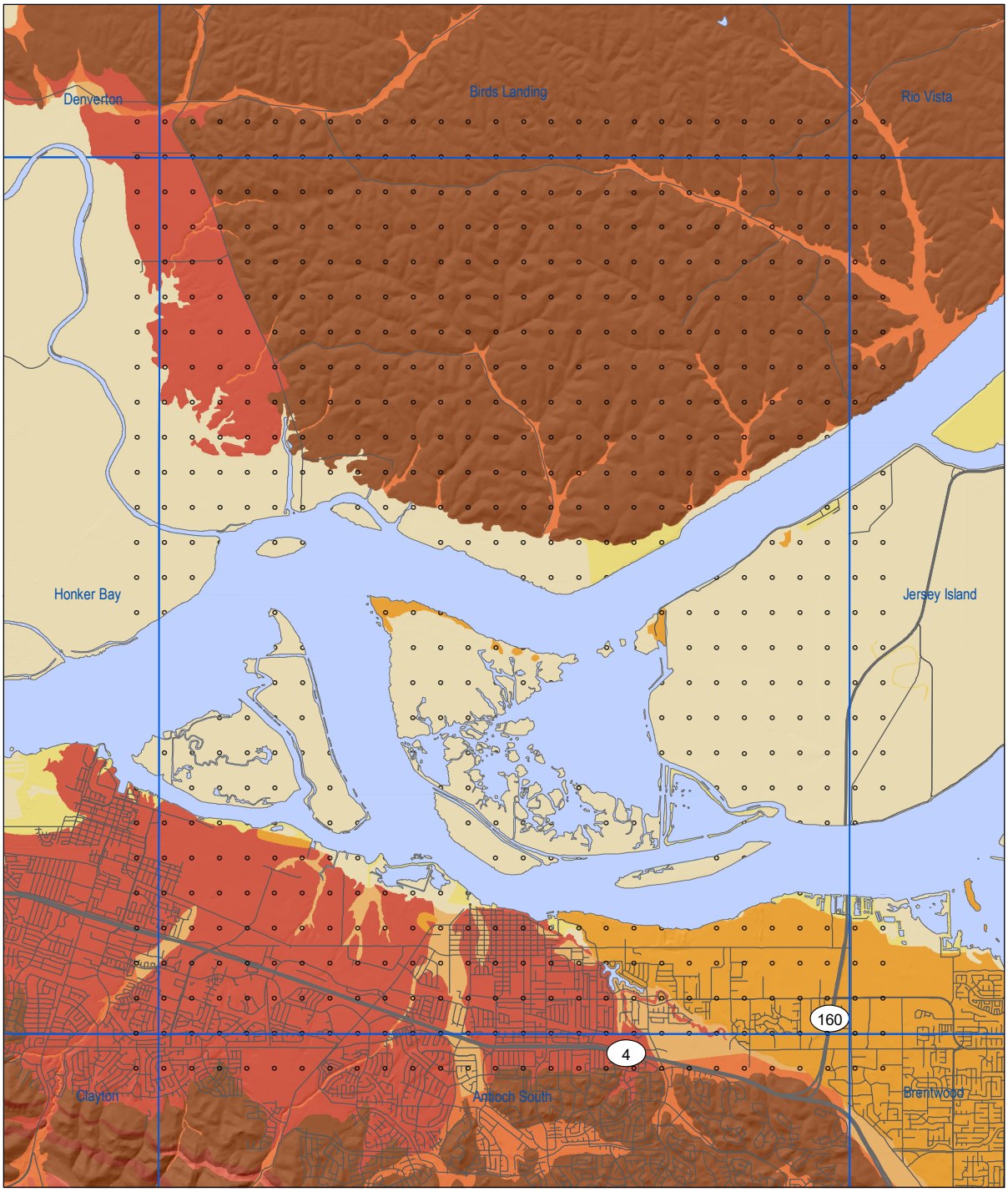
1 0.5 0 1 2 Miles

5,000 2,500 0 5,000 10,000 Feet

1 0.5 0 1 2 Kilometers

See "Geology" in Section 1 of report for descriptions of units.

Plate 1.3 Geologic materials map, Antioch North Quadrangle, California.



DEM base map from USGS. Roads from www.census.gov. Scale 1:100,000. Map preparation by Janine Bird, CGS.

ANTIOCH NORTH QUADRANGLE

N

1 0.5 0 1 2 Miles

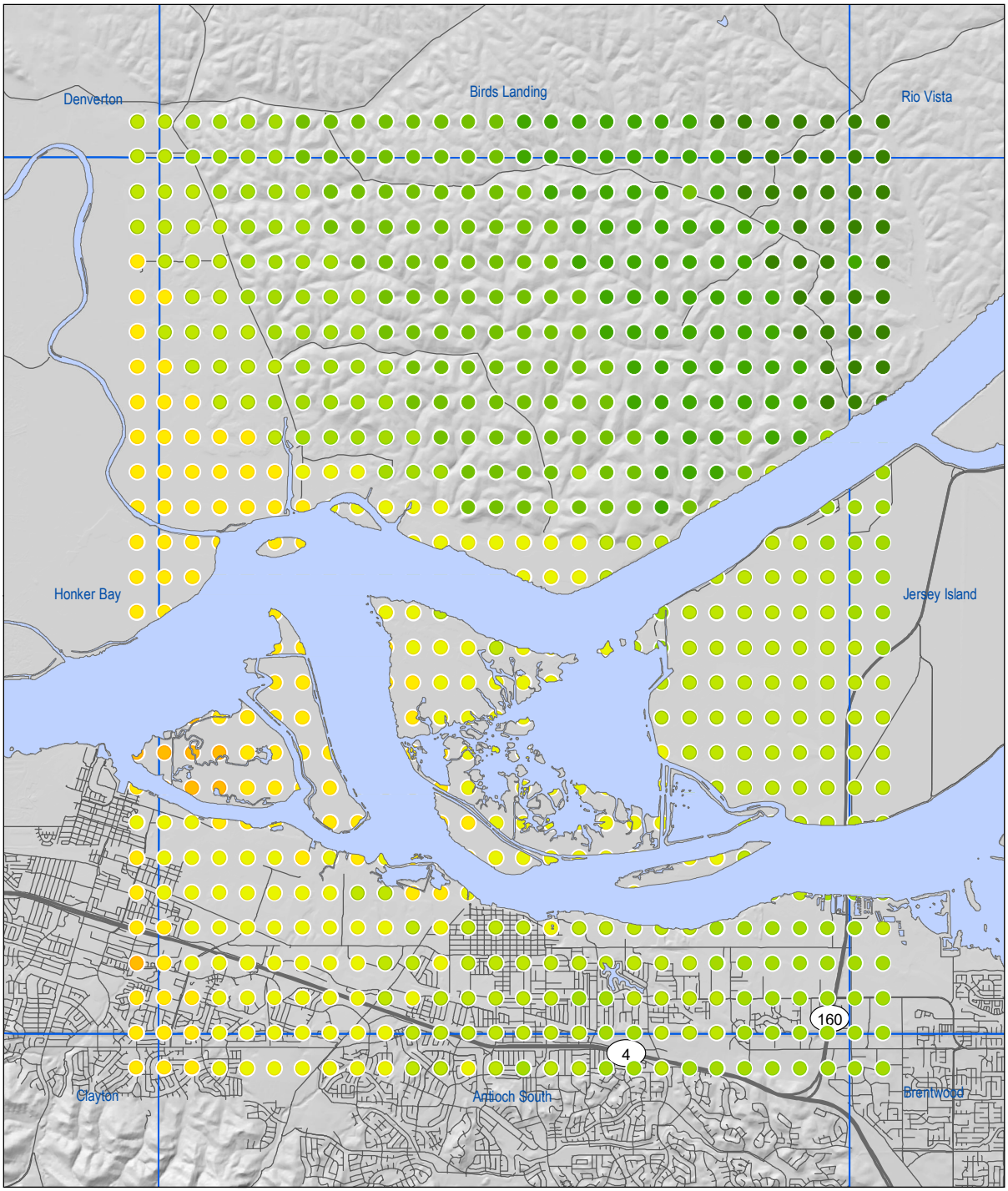
5,000 2,500 0 5,000 10,000 Feet

1 0.5 0 1 2 Kilometers

Shear wave velocity of upper 30 meters

733 (KJf)	308 (Qs)
519 (Tv)	294 (Qal2)
468 (Tss)	228 (Qal1)
387 (Qoa)	226 (af/Qi)
385 (Tsh)	176 (Qi)
352 (Qal3)	water

Plate 2.1 Map of Vs30 groups and corresponding geologic units extracted from the state-wide Vs30 map developed by Wills and others (2015), Antioch North Quadrangle and surrounding area, California.



DEM base map from USGS. Roads from www.census.gov. Scale 1:100,000. Map preparation by Janine Bird, CGS.

ANTIOCH NORTH QUADRANGLE

N

1 0.5 0 1 2 Miles

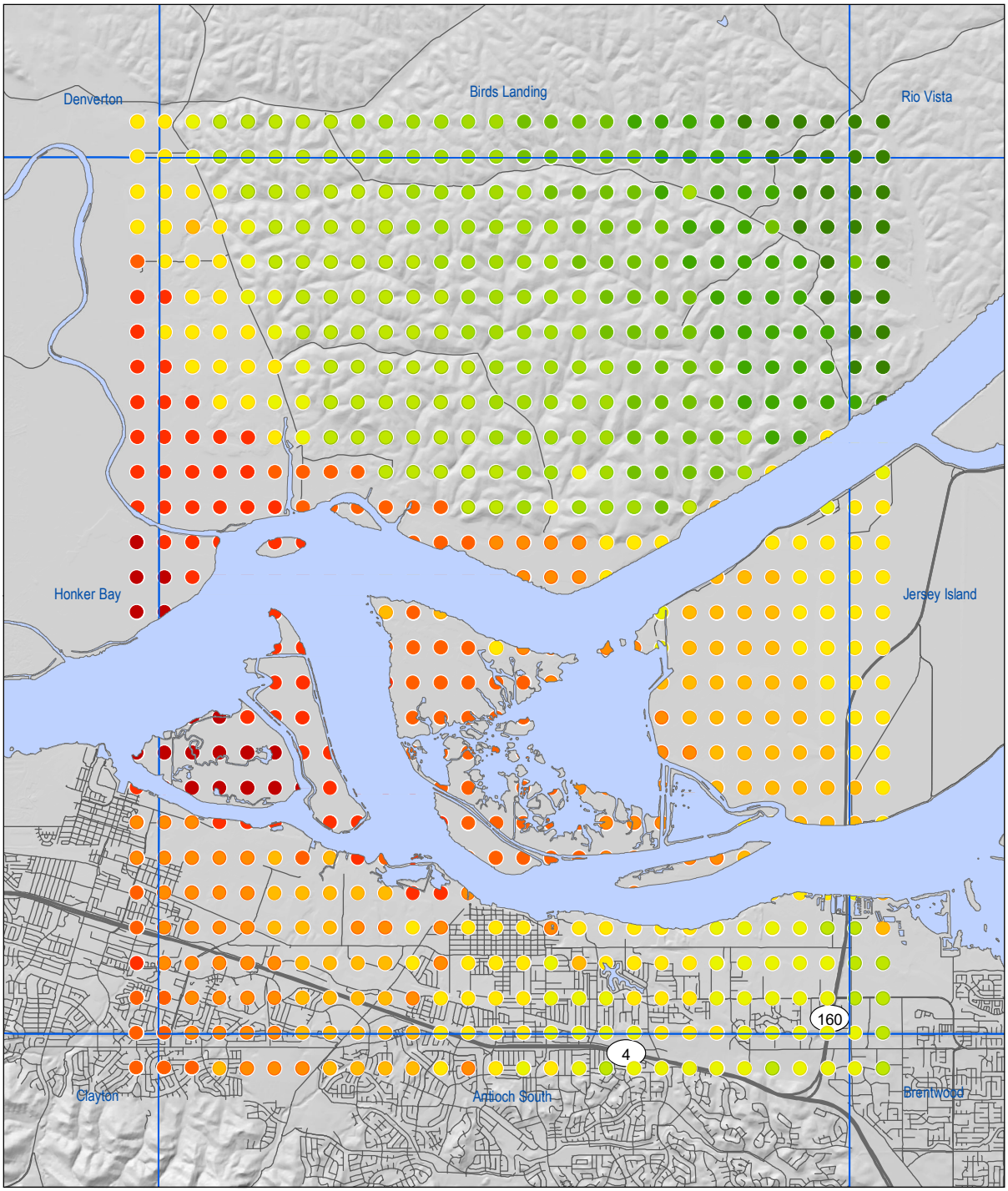
5,000 2,500 0 5,000 10,000 Feet

1 0.5 0 1 2 Kilometers

Pseudo-PGA (g)
10% in 50 yrs

- 0.36 - 0.37
- 0.34 - 0.36
- 0.32 - 0.34
- 0.30 - 0.32
- 0.28 - 0.30
- 0.26 - 0.28
- 0.24 - 0.26
- 0.22 - 0.24

Plate 2.2 Pseudo-PGA for liquefaction hazard mapping analysis, Antioch North Quadrangle and surrounding area, California.



DEM base map from USGS. Roads from www.census.gov. Scale 1:100,000. Map preparation by Janine Bird, CGS.

ANTIOCH NORTH QUADRANGLE

N

1 0.5 0 1 2 Miles

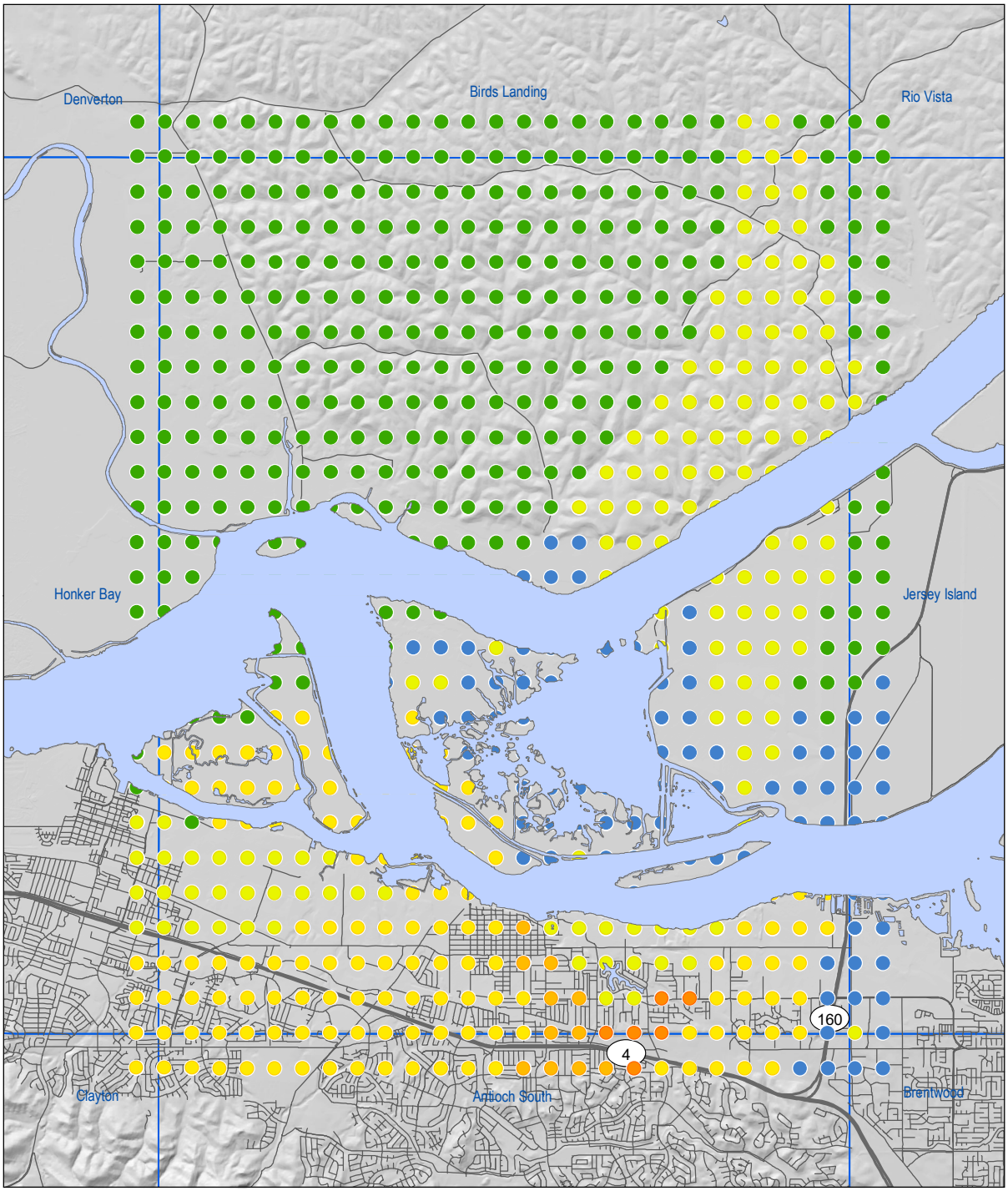
5,000 2,500 0 5,000 10,000 Feet

1 0.5 0 1 2 Kilometers

Probabilistic PGA (g)
10% in 50 yrs

- 0.57 - 0.58
- 0.55 - 0.56
- 0.53 - 0.54
- 0.51 - 0.52
- 0.49 - 0.50
- 0.47 - 0.48
- 0.45 - 0.46
- 0.43 - 0.44
- 0.41 - 0.42
- 0.39 - 0.40
- 0.37 - 0.38
- 0.34 - 0.36

Plate 2.3 Probabilistic peak ground acceleration for landslide hazard mapping analysis, Antioch North Quadrangle and surrounding area, California.



DEM base map from USGS. Roads from www.census.gov. Scale 1:100,000. Map preparation by Janine Bird, CGS.

ANTIOCH NORTH QUADRANGLE

N

1 0.5 0 1 2 Miles

5,000 2,500 0 5,000 10,000 Feet

1 0.5 0 1 2 Kilometers

Modal Magnitude (g)
10% in 50 yrs

- 6.91
- 6.51
- 6.50
- 6.49
- 6.16
- 6.15

Plate 2.4 Modal magnitude for landslide hazard mapping analysis, Antioch North Quadrangle and surrounding area, California.