SEISMIC HAZARD ZONE REPORT 135

SEISMIC HAZARD ZONE REPORT FOR THE VINE HILL 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

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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) which include Earthquake Fault Zones) for the Vine Hill 7.5-Minute Quadrangle, Contra Costa County, California. The Contra Costa County portion of the topographic quadrangle map, which covers approximately 58 square kilometers (22 square miles) at a scale of 1:24,000 (41.7 mm = 1,000 meters; 1 inch = 2,000 feet), displays the boundaries of the EZRI for liquefaction and earthquake-induced landslides. The mapped area includes primarily unincorporated Contra Costa County, including the communities of Mococo, Mountain View, Vine Hill, Maltby, Port Chicago, and Monsanto, and parts of the Cities of Martinez and Concord.

This Seismic Hazard Zone Report describes the development of the Seismic Hazard Zone for the map area. The process of zonation for liquefaction hazard involves evaluation of earthquake loading, Quaternary geologic maps, groundwater level records, and subsurface geotechnical data. The process of zonation for earthquake-induced landslide hazard incorporates evaluation of earthquake loading, existing landslides, slope gradient, rock strength, and geologic structure. Ground motion calculations used by CGS exclusively for regional zonation assessments are currently based on the probabilistic seismic hazard analysis (PSHA) model developed by the United States Geological Survey (USGS) for the 2018 *Update of the United States National Seismic Hazard Maps*.

About 43 square kilometers (16.5 square miles) of land in the map area has been designated as EZRI for liquefaction, encompassing most of the Clayton Valley and Ygnacio Valley, and major drainages such as Pacheco, Walnut, Payton, Vine Hill, Grayson, Mt. Diablo and Seal Creek, and waterways such as Hastings, Payton, and Belloma sloughs. Some alluvial deposits on the Pittsburg Plain in the northeastern part of the map area are also zoned. The borehole logs of test holes drilled in these areas indicate the widespread presence of near-surface soil layers composed of saturated, loose sandy sediments. Geotechnical tests indicate that these soils have a moderate to high likelihood of liquefying, given that the region is subject to strong ground motion.

The amount of area designated as EZRI for earthquake-induced landslides within the map area is approximately 2 square kilometers (0.8 square miles). These zones are mostly found on the moderate to steep slopes of Los Medanos Hills, located in the eastern part of the map area. Additional zones are found along the hills and ridges adjacent to Highway 680.

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 health and safety 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 initial release of Special Publication 117 in 1997, local government agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction and landslide hazards. These agencies convened two independent committees, one for liquefaction and one for landslides, to provide more detailed procedures for implementing Special Publication 117 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. Special Publication 117 was revised in 2008 as Special Publication 117A.

Methodology and Organization of this Report

Delineating liquefaction and landslide hazard zones requires the collection, compilation, and analysis of multiple types of digital data. These data include geologic maps, ground water measurements, subsurface and laboratory geotechnical tests, elevation (terrain) maps, and probabilistic ground motion 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 map 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 shaking parameters used in the liquefaction and landslide hazard analyses and summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential in the map area. Sections 3 and 4 summarize the analyses and criteria used to delineate liquefaction and earthquake-induced landslide hazard zones, respectively, in the map 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. Liquefaction and landslides 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 map 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 a web map service (WMS) and feature service here: https://gis.conservation.ca.gov/server/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/.

Information on how to purchase EZRI maps and reports is available online at: http://www.conservation.ca.gov/cgs/publications.

Information regarding the Seismic Hazard Zonation Program is available on the CGS website: http://www.conservation.ca.gov/cgs/shp.

SECTION 1: GEOGRAPHY GEOLOGY AND ENGINEERING GEOLOGY

of the

VINE HILL 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

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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 Vine Hill Quadrangle, Contra Costa County, and then discuss the collection, processing, and analyses of primary geologic and engineering geologic data that were used to delineate EZRI.

GEOGRAPHY

Location

The map area covers approximately 58 square kilometers (22 square miles) in north-central Contra Costa County, California. The center of the map area is about 31 kilometers (12 miles) northeast of the City of Oakland and about 80 kilometers (50 miles) southwest of the City of Sacramento. The City of Martinez is located within the western part of the map area, occupying approximately 8 square kilometers (3 square miles) of land. The City of Concord is located within the southeastern part of the map area, occupying approximately 8 square kilometers (3 square miles) of the map area. The Concord Naval Weapons Station covers 3 square kilometers (1 square mile) of land in the southeast corner of the map area. The remainder of the map area consists of unincorporated census-designated communities of Mococo, Mountain View, Vine Hill, Maltby, Port Chicago, and Monsanto, and Contra Costa County and State of California land.

The map area is located south of the Sacramento-San Joaquin Delta. The map area is mostly located to the west of the Los Medanos Hills, part of the Diablo Range in the Coast Ranges Geomorphic Province (Schemmann and others, 2007; Weber-Band and others, 1997). The northeastern limits of the Los Medanos Hills are in the eastern part of the map area. Elevations in the map area generally increase towards the southwest and east and range from sea level along the southern shores of Suisun Bay and Carquinez Strait to 193 meters (634 feet) in the Los Medanos Hills in the eastern extent of the map area.

Approximately three-quarters of the central part of the map area consists of flatlands, typically marshes and alluvial plains. Topography in the northeastern part of the map area is characterized by northwest-southeast trending, gentle to moderately steep, rounded ridges of the Los Medanos Hills, part of the Diablo Range of the Coast Ranges Geomorphic Province. The western part of the map area is characterized by northwest-southeast trending, gentle to moderately steep, rounded ridges separated by narrow valleys in the vicinity of Vine Hill.

In the map area, the drainages of Payton Creek, Vine Hill-Pacheco Creek, Grayson-Walnut Creek, and Mt. Diablo-Seal Creek flow north to northwest towards Suisun Bay.

The Contra Costa Canal traverses the eastern part of the map area feeding into Mallard Reservoir, it then traverses the southern part of the map area before ultimately terminating into Martinez Reservoir. Water from the Contra Costa Canal originates from Rock Slough in the Sacramento-San Joaquin Delta (CCWD, 2009). This canal provides water for agricultural, industrial, and municipal uses in the Bay Area.

Land Use

Land use in the map area was historically dominated by agriculture in flatland areas and ranching in the surrounding low-lying hills. In the western part of the map area, the oil refinery began in the early 1900s and continue to present. In the eastern portion of the map area, the Concord Naval Weapons Station opened in 1942 and remained operational until 2005 when the Defense Base Realignment and Closure Commission announced that the Inland Area of the base was approved for closure (USEPA, 2005). In the last several decades, urban development substantially increased in the cities, with the addition of light industrial, shopping centers and new homes. Additionally, many of the unincorporated communities have grown significantly, with development largely occurring in the southwest. Substantial areas of undeveloped land remain in the map area, primarily along the shoreline of Suisun Bay, Carquinez Strait, and in the uplands of the eastern part of the map area.

The primary automotive transportation routes in the map area are California State Route 4 and 242, in the southeast part of the map area, and Interstate 680, in the western part of the map area. The southern end of the Benicia-Martinez Bridge is also located within the map area. Railway routes within the map area include the Burlington Northern Santa Fe, Union Pacific, and Bay Area Rapid Transit (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 map area, digital topography in the form of a lidar-derived digital elevation model was obtained from Contra Costa County (https://gis.cccounty.us/Downloads/). These lidar data were collected in 2010 and present elevations at a point spacing of 3 meters, with 1-meter horizontal accuracy and 15-centimeter RMSE vertical accuracy.

For liquefaction hazard analyses, surface elevations derived from the Contra Costa County DEM are differenced with historical-high ground water elevations to derive a "depth to water" map. In alluvial areas, the depth value obtained is combined with geologic data from boreholes and used in liquefaction calculations.

For earthquake-induced landslide hazard analyses, slope gradient and slope aspect are calculated using the slope applications built into commercially available GIS software. Both parameters are

calculated using a third-order, finite difference, center-weighted algorithm based on Horn (1981), as documented in Burrough and McDonnell (1998). The slope gradient is combined with the geologic material strength map to calculate yield acceleration, a measure of susceptibility to earthquake slope failure as described in Section 4 of this report.

GEOLOGY

The primary source of geologic information used in the evaluation of liquefaction and earthquake-induced landslide hazards in the Vine Hill Quadrangle, Contra Costa County, is the CGS unpublished preliminary geologic map digital database of the Stockton 30' x 60' Quadrangle (Dawson, 2010). This geologic map was compiled from geologic mapping by Witter and others (2006), Knudsen and others (2000), Knudsen and Lettis (1997), Graymer and others (1994 and 1996), and Bartow (1985). Other geologic maps and reports reviewed in this investigation include Nilsen and others (1975) and Dibblee (1981).

Digital geologic maps covering the map area and adjacent areas were combined to form a single 1:24,000-scale geologic materials map. 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. Landslide deposits were deleted from the geologic map so that the distribution of bedrock formations and the newly created landslide inventory would exist on separate layers for the hazard analysis. 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. The distribution of Quaternary and bedrock 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 map unit names and descriptions of geologic units exposed in the map area are taken primarily from Dawson (2010). The Quaternary geologic unit nomenclature used by CGS for mapping in the San Francisco Bay Region was adopted from Knudsen and others (2000).

Bedrock Units

The bedrock geology of Contra Costa County has been divided by Graymer and others (1994) into six individual stratigraphic assemblages (I – VI), each lying within a discrete, fault-bounded block. The concept of individual fault-bounded stratigraphic assemblages in the San Francisco Bay Area was introduced by Jones and Curtis (1991) and then defined further by Graymer and others (1994). Stratigraphic Assemblage IV and VI underlie the map area (Graymer and others, 1994).

In central Contra Costa County, the oldest rocks exposed in the fault-bounded assemblage belong to the Franciscan Complex and the overlying Cretaceous Great Valley Sequence (Graymer and others, 1994). Franciscan Complex rock units are not exposed in the map area. However, the Great Valley Sequence exposed in the map area consists of a thick sequence of interbedded sandstone and shale originally deposited on the ocean floor by turbidity currents that was subsequently folded, faulted and uplift (Graymer and others, 1994). An angular unconformity

forms the boundary between underlying Cretaceous Great Valley Sequence units and Cenozoic marine strata (Graymer and others, 1994).

The following is a summary of bedrock map units exposed in the map area based on Dawson (2010).

Mesozoic Units

The oldest Mesozoic rock units in the map area are the undivided Cretaceous Great Valley sequence units **Ku** and **Kus** exposed west of Pacheco Creek. These units are comprised of sandstone, siltstone, and shale, with **Ku** also including minor conglomerate.

Cenozoic Units

The Tertiary units in the map area rest unconformably on Cretaceous rocks and are mapped on the ridges and highlands in the area. The Tertiary units in the southwest part of the map area consist of the Vine Hill Sandstone (**Tvh**, **Tvhu**, and **Tvhl**, Paleocene), Las Juntas Shale (**Tlju** and **Tljl**, Paleocene and Eocene), Muir Sandstone (**Tmr**, **Tmru**, and **Tmrl**, Eocene), Escobar Sandstone (**Tes**, **Tehs**, and **Teh** Eocene), San Ramon Sandstone (**Tsr**, Oligocene and/or Miocene), Sobrante Sandstone (**Ts,** Miocene), and Briones Sandstone (**Tbr,** Miocene). The Tertiary units in the eastern part of the map area consist of the Markley Formation (**Tmkl,** Eocene), Cierbo Sandstone (**Tc**, Miocene), Lawlor Tuff (**Tl**, Pliocene), and Tulare Formation (**Ttu**, Pliocene).

Quaternary Sedimentary Deposits

Approximately 45 square kilometers (17.5 square miles) of the Vine Hill Quadrangle in Contra Costa County is covered by Quaternary sediments and historical artificial materials. In total, nine different units are mapped in the Vine Hill Quadrangle (Plate 1.1). They are divided into groups based on age, origin, and composition (Table 1.1). The liquefaction susceptibility evaluation and development of the Seismic Hazard Zone Map for the quadrangle is based on the distribution of these deposits at 1:24,000-scale (Plate 1.1).

Pleistocene to Holocene alluvial sediments

Alluvial sediments in the map area are mapped along stream channels and adjoining flood prone areas in and at the mouth of valleys of the Diablo Range. These deposits include undifferentiated alluvium (**Qoa**, Pleistocene, **Qpa**, late Pleistocene; **Qha**, Holocene), alluvial fans (**Qpf**, late Pleistocene; **Qhf**, Holocene), and stream channel deposits (**Qhc**, Holocene). Alluvial sediments generally consist of poorly to moderately sorted, poorly to well bedded, loose to dense sand, gravel, silt, and clay. Pleistocene age is indicated by depth of stream incision, stronger soil development and lack of historical flooding evidence.

Holocene bay mud deposits

Bay mud deposits (**Qhbm**) consist of estuarine sediments and are located at the mouths of tidally influenced coastal streams where freshwater mixes with seawater and between the modern shoreline and the historical limits of tidal marshes and mudflats. These sediments primarily consist of silt and clay with interbedded organic-rich layers and occasionally well sorted sand and/or gravel. **Qhbm** thicken northward towards Suisun Bay and Carquinez Strait.

Historical artificial fills

Late Holocene artificial fill (**af**) are mixtures of clays, silts, sands, and gravels, resulting from human activity and are mapped throughout the map area. These units include engineered and non-engineered fill and are related to residential, industrial, commercial, and water conveyance system development projects. Although areas with fills have been mapped, not all fills are represented in the map area.

Table 1.1 Quaternary units mapped in the Vine Hill Quadrangle, Contra Costa County.

Map Unit	Environment of Deposition	Age
af	Artificial Fill	Historical
Qhc	Stream Channel	Holocene
Qha	Undifferentiated Alluvium	Holocene
Qhf	Alluvial Fan	Holocene
Qhbm	Bay Mud, Marshland and Slough	Holocene
Qpf	Alluvial Fan	Latest Pleistocene
Qpa	Undifferentiated Alluvium	Latest Pleistocene
Qoa	Undifferentiated Alluvium	Pleistocene

Geologic Structure

The structural framework of the map 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 transform 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, about three-fourths of this relative movement is accommodated by shearing distributed across a broad, complex belt marked by major northwest-trending faults, including the San Andreas, Hayward, and Calaveras, along with many parallel secondary faults such as the Greenville, Green Valley, and Concord faults. In the current transpressional tectonic regime, characterized by a horizontal northeast-southwest maximum compression direction, differential strike-slip movement along these faults locally generates thrust faulting and folding. This has resulted in the uplift of Mount Diablo and folded the surrounding rocks over the last four million years into the Mount Diablo Anticline (Schemmann and others, 2007) and associated Los Medanos Hills Thrust system (Weber-Band and others, 1997; Unruh and Sundermann, 2006).

The map area is located on the northern flank of Mount Diablo. Tertiary strata, exposed in the eastern and southwestern uplands, ridges, and hills, generally strike northwest and are moderately to steeply dipping. The local geologic structure consists of a gently northeast-dipping anticline in the eastern part of the map area and a gently dipping syncline in the southwest part of the map area.

The northern segment of the Concord fault trends north-northwest and parallels Pacheco Creek and Walnut Creek. This fault bisects the central portion of the map area, extending from Suisun Bay, southeast along Pacheco Creek, to the mouth of Walnut Creek. The Concord fault is Holocene (<11,700 years) and generally well-defined, delineated by geomorphic features indicative of right-lateral strike-slip faulting (Bryant, 1992; and Wills and Hart, 1992). The Concord fault is considered active and mapped under the Alquist-Priolo Earthquake Fault Zoning Act.

There are two northwest trending well-constrained late Quaternary faults in the Los Medanos Hills within the map area (Jennings and Bryant, 2010). One of the faults is located near the base of the hills, north of Diablo Creek, and the other is in the higher elevations within the central part of the Los Medanos Hills. These faults are not considered active (>11,700 years) and are not mapped under the Alquist-Priolo Earthquake Fault Zoning Act.

Existing Landslides

As a part of the geologic data compilation, an inventory of existing landslides in the map area was prepared through field reconnaissance and review of previously published landslide mapping, but primarily from geomorphic analyses of lidar-derived topography and Google Earth Pro imagery. The lidar dataset consists of bare earth DEM derived hillshade, contour, slope, and other derivative layers. This data was acquired by Contra Costa County in 2010 and meets QL2 accuracy with 4 points per meter pulse density. All landslides in this inventory were digitized in an ArcGIS environment at a resolution of no larger than 1:2,000.

For each landslide included on the map, several characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable, or questionable) and properties, such as activity, thickness, and associated geologic unit(s). The completed landslide map was digitized, and the attributes were entered into a database. Landslides rated as definite or probable are carried into the landslide zones as described in Section 4. A small-scale version of this landslide inventory is included on Plate 1.2.

A total of 28 landslides were identified in the landslide inventory, covering less than 1% of the uplands of the map area, or approximately 0.6 square kilometers (0.2 square miles). There is one record of a historical landslide in the map area. All other landslides in the inventory are classified as dormant-young, dormant-mature, or dormant-old/relict and consist of 22 rock slides, two earth flows, two debris slides, one debris flow, and one debris fan. As the dip of strata generally exceeds the slope inclination, dip-slope landslides are not common. Rather, a primary controlling factor seems to be the differing geologic units and steepness of slopes. Landslides appear to be mostly located in the Los Medanos Hills in the eastern portion of map area, where slopes are steeper with higher relief. Additionally, there does not appear to be a clustering of landslides near faults mapped in the Quaternary fault and fold database for the United States (USGS, 2023) or in Graymer and others, (1994), suggesting faulting has not played a significant role in slope failures in this area.

Because it is not within the scope of the Seismic Hazards Mapping Act to review and monitor grading practices to ensure past slope failures have been properly mitigated, all documented slope failures, whether surface expression currently exists, are included in the landslide inventory.

ENGINEERING GEOLOGY

Historical-High Groundwater Mapping

Liquefaction occurs only in saturated soil conditions, and the susceptibility of a soil to liquefaction varies with the depth to groundwater. Natural hydrologic processes and human activities can cause groundwater levels to fluctuate over time. Therefore, it is impossible to predict depths to saturated soils during future earthquakes. One method of addressing time-variable depth to saturated soils is to establish a high groundwater level based on historical groundwater data. In areas where groundwater is either currently near surface or could return to near-surface levels within a land-use planning interval of 50 years, CGS constructs regional contour maps that depict highest historical depths to groundwater surface. Plate 1.3 depicts contours reflecting the historical-high depth to groundwater surface within the Contra Costa County portion of the Vine Hill Quadrangle .

Groundwater Basins

Much of the map area is located within the California Department of Water Resources designated Clayton Valley and Ygnacio Valley groundwater basins (CDWR, 2020). The remainder of the map area is located within small portions of the Arroyo Del Hambre Valley and Pittsburg Plain groundwater basins (CDWR, 2020) (Plate 1.3). These groundwater basins are combined, and their boundaries are further modified to better delineate the areas of materials that may be subject to liquefaction within the map area.

Water-bearing units in the groundwater basins primarily consist of recent to older alluvium valley fill deposits. The deposits are generally unconsolidated Quaternary alluvium and semi-consolidated Tertiary-Quaternary deposits consisting of clays, silts, sands, and gravels (CDWR, 2020). Groundwater levels in these deposits are influenced by natural groundwater recharge resulting from percolation and infiltration of precipitation, sheet flow, and concentrated flow in creeks and streams. Artificial sources of groundwater recharge often affect local groundwater levels and result from canal seepage, irrigation return flows, urban landscape irrigation, agricultural irrigation, septic tanks, slow leakage from detention basins, or releases of treated water.

Aquifers in the Clayton Valley, Ygnacio Valley, and Pittsburg Plain groundwater basins are hydrologically connected to Suisun Bay, and the Arroyo Del Hambre Valley groundwater basin is hydrologically connected to the Carquinez Strait (CDWR, 2020). There are limited data regarding the occurrence and movement of groundwater in the basins. However, groundwater gradients within the alluvial flatlands and upland valleys were evaluated as part of this study, and they are generally consistent with natural topography, which slopes to the north towards Suisun Bay and Carquinez Strait.

Groundwater Data

Groundwater conditions in the map area were evaluated using depth to groundwater levels noted in geotechnical boreholes, online groundwater databases, groundwater monitoring reports, and water well drilling logs. Geotechnical borehole logs for this study were acquired from planning departments at the cities of Concord, Walnut Creek, Pittsburg, Antioch, and the California Department of Transportation (CDOT, 2022). Additional water level data were collected from

the State Water Resources Control Board (CWRCB, 2022a; 2022b), California Department of Water Resources (CDWR, 2022a; 2022b), the United States Geological Survey (USGS, 2022b), and local water districts and agencies.

Water level data evaluated in this study include more than 12,000 groundwater measurements (Plate 1.3) collected from the 1980's through the present, with most records representing conditions of the past twenty years. Review of hydrographs of wells in the Clayton Valley and Ygnacio Valley ground basins indicate that groundwater levels have shown a gradual decline over the period of record (CDWR, 2020). Hydrographs from DWR well data in the Pittsburg Plain Groundwater Basin indicate that groundwater levels in this area have remained somewhat stable over the period of record (CDWR, 2020).

Groundwater data from all available records were spatially and temporally evaluated in a GIS database to constrain the estimate of historically shallowest groundwater for the project area. CGS created a historical-high groundwater elevation surface map for the alluvial valleys and flatlands of the Clayton Valley, Ygnacio Valley, Pittsburg Plain, and Arroyo Del Hambre Valley groundwater basins based on available well records and data from previous groundwater studies. Our highest historical groundwater elevation surface was compared with the existing ground-surface elevation, and consideration was given to active creeks, recharge ponds, detention basins, water impoundments, and reservoirs. The depth to groundwater contours depicted on Plate 1.3 do not represent present-day conditions, as usually presented on typical groundwater contour maps, but rather the historical-high depths to groundwater in the map area.

Groundwater Levels

Historical-high groundwater depths in the map area vary from less than 10 feet along streams, reservoirs, and in upland alluvial valleys to greater than 50 feet below older Quaternary deposits in the northwestern part of the map area. Most of the water-bearing materials in the map area are in the northwest-southeast trending Clayton Valley and north-south trending Ygnacio Valley in the central parts of the map area. Historical-high groundwater levels below the surface of the Pleistocene alluvial fan deposits (**Qpf**) and undifferentiated alluvium (**Qpa**) range from less than 10 feet to greater than 30 feet deep, where the greatest depths are typically measured near the apex of alluvial fans and gradually shallow towards the streams and foothills that flank the valley. Historical-high depth to water in the older undifferentiated alluvial deposits (**Qoa**) range from less than 10 feet to greater than 50 feet deep. Active stream channels (**Qhc**) and bay mud deposits (**Qhbm**) typically contain shallow historical-high groundwater conditions, within 10 feet of the ground surface, due to surface water infiltration and tidal influences.

The deposits in the upland alluvial valleys and canyons are more confined, consisting of mixtures of clays, silts, sands, and gravels. As such, these areas were assigned a historical-high groundwater value of less than 10 feet, unless otherwise noted.

Geologic Material Testing

Liquefaction Hazard Zoning: In-Situ Penetration Resistance

Liquefaction evaluations are dependent on boreholes 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, a method used by CGS and the geotechnical community to quantitatively analyze

liquefaction potential of sandy and silty material. The SPT is an in-field test based on counting the number of blows required to drive a standard split-spoon sampler (1.375-inch inside diameter) one foot into the soil. The driving force is provided by dropping a 140-pound hammer 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 2004). 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 $(N_1)_{60}$.

For liquefaction hazard zoning in the map area, borehole logs were collected from the files of the City of Concord, City of Walnut Creek, City of Martinez, and CalTrans (CDOT, 2018). Data from a total of 45 borehole logs were entered into the CGS geotechnical GIS database and analyzed. The geotechnical borehole logs analyzed in this study (Plate 1.1) included blow-count data from SPTs or from penetration tests that allow reasonable blow count conversions to SPT-equivalent values. However, only few of the borehole logs collected include all of the necessary information (e.g. soil density, moisture content, sieve analysis, etc.) required for 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

To evaluate the stability of geologic materials susceptible to landslide failure under earthquake conditions, the bedrock map units described above were ranked and grouped based on their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. A total of five shear-strength tests were obtained from the City of Walnut Creek for the units identified within the map area. The locations of rock and soil samples taken for shear testing within the map area are shown on Plate 1.2. Shear tests from neighboring quadrangles were used to augment data for several geologic formations for which little or no shear test information was available within the map area (see Appendix A at the end of this Section). For geologic units where sufficient shear-strength laboratory data could not be acquired, field measurements of Geologic Strength Index (GSI) (Marinos and others, 2007) were collected and the Hoek-Brown Failure Criterion (Hoek and others, 2002) was used to estimate the overall geologic unit strength.

The non-linear Hoek-Brown Failure Criterion is a rock mass characterization method which uses equations to relate rock mass classification of the Geological Strength Index (GSI) to the angle of internal friction of a rock mass. This method allows strength assessment based on collected data, mainly discontinuity density, discontinuity condition, and geologic material properties (Hoek and others, 2002; Marinos and others, 2007). No GSI field measurements were completed within the limits of the map area; however, measurements from adjacent areas are included.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped based on mean angle of internal friction (mean phi) and lithologic character. Mean and median phi values for each geologic map unit and corresponding strength groups are summarized in Table 1.2. For each geologic strength group (Table 1.3) in the map

area, the mean shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Table 1.2 and Table 1.3, and this map provides a spatial representation of material strength for use in the slope stability analysis.

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

The strength characteristics of existing landslides (**Qls**) should be based on tests of the materials along the landslide slip surface. For the map area, strength parameters applicable to existing landslide planes were not available and are not included in Table 1.2.

Table 1.2. Summary of the shear strength statistics for the Vine Hill Quadrangle, Contra Costa County.

	Formation Name	Number of Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group Cohesion (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Ts Teh Tn Tub Tmr Tlju	1 3 3 1 2 1	34 / 34 34 / 34 32 / 35 35 / 35 38 / 38 37 / 37	34 / 35	1305 / 1358	Tsr, Tehs, Tes, Tmrl, Tmru	35
GROUP 2	Ku Tlj Tbr Tc Ttu Qoa Qpa Qhf	2 3 5 5 6 22 5 17	28 / 28 22 / 28 27 / 29 26 / 29 31 / 30 27 / 28 23 / 29 27 / 29	27 / 29	734 / 550	Kus, Tlj, Tljl, Tl, Tlt, Td, Tdl, Tdu	29
GROUP 3	Qpf Qhbm af	60 14 5	25 / 26 26 / 28 24 / 27	25 / 26	530 / 460		27
GROUP 4	Ka Tmkl Tgvt Tvhu Th Tcs Qha	5 7 3 3 11 2 6	25 / 23 19 / 23 25 / 24 24 / 24 25 / 25 25 / 25 22 / 23	23 / 24	815 / 700	Tmk, Kcs, Tvhl, Tvh, Tcsc	24
GROUP 5	Tnv Tus Tr Qhc	6 4 18 3	14 / 12 18 / 19 19 / 19 15 / 16	16 / 16	1089/ 835	Tush	18

Shear strength data from Contra Costa County are utilized for statistical analyses.

Table 1.3. Summary of shear strength statistics for the Vine Hill Quadrangle, Contra Costa County.

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Ts Tsr Teh Tehs Tes Tlju Tmr Tmrl Tmru	Ku Kus Tl Tljl Tlt Tbr Tc Ttu Qoa Qpa Qhf	Qpf Qhbm af	Tmkl Tvh Tvhl. Tvhu Qha	Qhc

Shear strength data from Contra Costa County are utilized for statistical analyses.

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Imagery

Lidar Hillshade derived from the 1.5 m Lidar Digital Terrain Model (2010), source of illumination: 45° sun angle, and 90° and 315° sun azimuths.

APPENDIX A: SOURCES OF ROCK STRENGTH DATA

SOURCE	NUMBER OF LAB TESTS SELECTED	NUMBER OF HOEK-BROWN TESTS COLLECTED
Walnut Creek Quadrangle	84	22
Antioch South Quadrangle	37	91
Brentwood Quadrangle	11	5
Honker Bay Quadrangle	23	31
Antioch North Quadrangle	26	-
Clayton Quadrangle	15	29
Las Trampas Quadrangle	4	-
Briones Valley Quadrangle	2	9
Vine Hill Quadrangle	2	-
Richmond Quadrangle	-	10
Byron Hot Springs Quadrangle	-	3
Benicia Quadrangle	-	3
Total Number of Shear Tests	204	203

SECTION 2: GROUND MOTION ASSESSMENT

for the

VINE HILL 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

using the

2018 NATIONAL SEISMIC HAZARD MODEL

by

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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 Vine Hill Quadrangle, Contra Costa County. 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 zones.

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 2018 Update of the National Seismic Hazard Maps (NSHMs) (Petersen and others, 2020). This model replaces ground-motion models of Petersen and others (2015, 2014, and 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 2018 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 (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 used in the 2018 update of the NSHMs includes four ground motion models (GMMs): Abrahamson and others (2014), Boore and others (2014), Campbell and Bozorgnia (2014), and Chiou and Youngs (2014). For subduction zone earthquakes and earthquakes of other deep sources, GMMs developed specifically for such sources are used, including the 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. GMMs 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-averaged shear-wave velocity in the upper 30 meters beneath a site (V_{S30}). In CGS seismic hazards mapping applications prior to 2017, a uniform firm-rock site condition was assumed in PSHA calculation and, in a separate post-PSHA step, National Earthquake Hazard Reduction Program 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 GMM scaling. Specifically, V_{S30} is built into GMMs as one of the predictor variables and, therefore, it is an input parameter in the PSHA calculation. The V_{S30} value at each location is assigned from 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 landslide zoning purposes, ground motions are calculated at each grid point of a 0.005-degree grid (approximately 500-meter spacing) that adequately covers the entire quadrangle. A V_{S30} map and grid points in the project area are depicted in Plate 2.1. For liquefaction zoning purposes, ground motions are calculated at each boring location. 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 CGS' liquefaction and earthquake-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 earthquake-induced 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 USGS hazard codebase, nshmp-haz version 1.3.0, 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 2018 NSHMs is adopted in its entirety. The 2018 source model is also hosted in GitHub and is publicly available at: https://github.com/usgs/nshm-cous-2018.

APPLICATION TO LIQUEFACTION AND EARTHQUAKE-INDUCED 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 earthquake-induced 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. Ground motion generally increases from the northeast corner to the southwest corner as distance to the Concord fault and Calaveras fault zone decreases and is the highest in the vicinity of the Concord fault. Shaking hazards are controlled predominantly by the Concord fault with increasing contribution from the Calaveras fault toward southwest, except in the northeast corner of the quadrangle where the top contributor is the Great Valley fault zone. Other sources that contribute to shaking hazards include the Greenville fault, Great Valley fault zone, Vine Hill fault, Franklin fault, Hayward fault, Mount Diablo Thrust fault, Los Medanos fault, and background (gridded) seismicity. Modal magnitudes (Plate 2.4) reflect the magnitudes of earthquakes that these controlling fault sources are capable of producing. Ground motion distribution is controlled by proximity to these faults and is affected by subsurface geology. Topographic effects on ground motion are not considered in our analysis at this time. In general, when fault distances are similar, 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 and earthquake-induced landslide analyses.

PGA (g)	Pseudo-PGA (g)	Modal Magnitude	V_{S30} (m/s)
0.46 to 0.62	0.38 to 0.51	6.49	176 to 733

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SECTION 3: EVALUATION OF LIQUEFACTION HAZARD

in the

VINE HILL 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

by

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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 Vine Hill Quadrangle, Contra Cost County.

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 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). CGS's method combines geologic mapping, geotechnical assessment of soils, hydrogeologic and historical groundwater analyses, and probabilistic earthquake ground motions employing criteria adopted by the State Mining and Geology Board (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, 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 historical-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 ground water are summarized in Table 3.1.

Table 3.1. Liquefaction Susceptibility of Quaternary units in the Walnut Creek Quadrangle.

Geologic Map Unit	Age	Sediment/Material Type*	Consistency*	Susceptible?**
af	Late Holocene	Sand, silt, gravel, concrete	Loose to dense	Yes
Qhc	Holocene	Sand, gravel, cobbles, clay, silt	Loose	Yes
Qha	Holocene	Sand, gravel, silt	Loose to medium dense	Yes
Qhf	Holocene	Sand, gravel, silt, clay	Loose to medium dense	Yes
Qhbm	Holocene	Clay, silt, sand, gravel	Loose to dense	Yes
Qpa	Latest Pleistocene	Sand, silt, gravel	Medium dense to dense	Not Likely below a depth of 20 feet
Qpf	Latest Pleistocene	Gravel, sand, silt, clay	Medium dense to dense	Not Likely below a depth of 20 feet
Qoa	Early to Late Pleistocene	Sand, silt, clay, gravel	Medium dense to very dense	Not Likely below a depth of 20 feet

*Based on geomaterials properties from this map area and adjacent quadrangles.

**When saturated

Ground Motion for Liquefaction Opportunity

Ground motion calculations used by CGS for regional liquefaction zonation assessments are based on the probabilistic seismic hazard analysis (PSHA) model developed by the United States Geological Survey (USGS) (Petersen and others, 2020) for the 2018 Update of the National Seismic Hazard Maps (NSHM). 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 weighted, pseudo-PGA ground motion values are used to calculate the seismic load imposed on a soil column, expressed as the cyclic stress ratio (CSR). 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

CGS performs a quantitative analysis of geotechnical data to evaluate liquefaction potential using an in-house developed computer program based on 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 calculations and correction factors used in the program are taken directly from the equations in Youd and others (2001).

The program calculates the liquefaction potential of each non-clay soil layer encountered at a test-drilling site that includes at least one SPT. CGS defines soil layers with a factor of safety (FS) relative to liquefaction hazard of 1.0 or less as potentially liquefiable. The FS is defined as the ratio of cyclic resistance ratio (CRR), which reflects the resistance to liquefaction of the soil layer, to cyclic stress ratio (CSR), which represents the seismic load on the layer. Input parameters for calculation of CRR include SPT results, groundwater level, soil density, grain-size analysis, moisture content, soil type, and sample depth. The CSR is calculated using the pseudo-PGA provided in the ground motion analysis.

The FS is calculated for each layer in the soil column at a given borehole. The minimum FS value of all the layers penetrated by the borehole determines the liquefaction potential for that borehole location. CGS geologists use the results of this analysis, the groundwater analysis, and geologic conditions to determine the final liquefaction hazard zone.

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 historical 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

Upon completion of the liquefaction hazard evaluation within the map area, CGS applied the above criteria to its findings in order to delineate Seismic Hazard Zones for liquefaction. Based on the evaluation, about 43 square kilometers (16.5 square miles) of the map area are included in the Seismic Hazard Zone for liquefaction. The zones encompass much of the Clayton Valley, Ygnacio Valley, Arroyo Del Hambre Valley, Pittsburg Plain, and upland alluvial valleys exposed in the map area.

Following is a description of the criteria-based factors that governed the construction of the Seismic Hazard Zone Map for the map area.

Areas of Past Liquefaction

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

Artificial Fills

Artificial fill areas large enough to show at the scale of project mapping (1:24,000) are mostly associated with the construction of dams, detention basins, and elevated freeways within the map area. In these areas, seismic hazard zonation for liquefaction does not depend on the fill, but on soil properties and groundwater levels in underlying strata.

Areas with Sufficient Existing Geotechnical Data

CGS collected 45 borehole logs that included penetration and associated geotechnical test data required to quantitatively analyze liquefaction potential. Most of the logs evaluated for the map area are from boreholes located within the alluvium of Clayton Valley in the southeast part of the map area. Quaternary units are included in the Seismic Hazard Zone when analysis of blow count values and other soil property measurements indicate that strata identified in the boreholes may liquefy under expected earthquake loading. However, the liquefaction analysis may be

inconclusive based on the limited depth, distribution, and number of available geotechnical data for the analysis.

Areas with Insufficient Existing Geotechnical Data

In areas with insufficient geotechnical data coverage, Quaternary sedimentary deposits were evaluated for seismic hazard zonation based on geologic factors, groundwater levels, and extrapolation of known soil conditions in adjacent areas. These deposits include Holocene-age stream channel (**Qhc**) and bay mud (**Qhbm**), alluvial fans (**Qhf**), and undifferentiated alluvium (**Qha**) that are saturated within 40 feet of the surface. They also include Pleistocene-age alluvial fan (**Qpf)** and undifferentiated alluvium **(Qoa** and **Qpa**) deposits that are saturated within 20 feet of the surface.

Adequate geotechnical borehole information is lacking for upland alluvial valleys in the foothills. The Quaternary units mapped in the upland alluvial valleys typically contain varying amounts of loose, granular materials that are saturated because of the presence of near-surface groundwater following rainfall events and proximity to streams. Those conditions, along with the ground motions expected to occur in the region, combine to form a sufficient basis for including these areas in the Seismic Hazard Zone for liquefaction.

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The authors thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project: Mindy Gentry and Mary Lehman of the City of Concord and Darwin Myers of Contra Costa County. At CGS, Christopher Tran, Edward Southwick, and Austin Reichmuth assisted with geotechnical data collection efforts. Bob Moskovitz and Jonathan Goergen provided database compilation and analysis support. Kate Thomas and Rebecca Vail prepared the final Seismic Hazard Zone Map the graphic displays for this report. Tim Dawson and Erik Frost provided technical review for this report.

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SECTION 4: EVALUATION OF EARTHQUAKE-INDUCED LANDSLIDE HAZARD

in the

VINE HILL 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

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Purpose of this Section

This Section of the Seismic Hazard Zone Report presents the analyses and criteria used to delineate of earthquake-induced landslide hazard zones in the Vine Hill Quadrangle, Contra Costa County.

ZONING TECHNIQUES

To evaluate earthquake-induced landslide hazard potential in the map area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method as originally implemented analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. The double integration of the earthquake acceleration recording to derive displacement considers only accelerations above a threshold value that represents the inertial force required to initiate slope movement (Factor of Safety = 1). This threshold value, called the "yield acceleration," is a function of the strength of the earth materials and the slope gradient, and therefore represents the susceptibility of a given area to earthquake-induced slope failure.

As implemented for the preparation of earthquake-induced landslide zones, susceptibility is derived by combining a geologic map modified to reflect material strength estimates with a slope gradient map. Ground motion parameters are calculated using the United States Geological Survey (USGS) National Seismic Hazard Model, and Newmark displacements are estimated from a regression equation developed by Jibson (2007) that uses susceptibility and ground motion parameters. Displacement thresholds that define earthquake-induced hazard zones are from McCrink and Real (1996) and McCrink (2001).

Earthquake-Induced Landslide Susceptibility

Earthquake-induced landslide susceptibility, defined here as Newmark's yield acceleration (1965), is a function of the Factor of Safety (*FS*) and the slope gradient. To derive a Factor of Safety, an infinite-slope failure model under unsaturated slope conditions was assumed. In

addition, material strength is characterized by the angle of internal friction (Φ) and cohesion is ignored. As a result of these simplifying assumptions, the calculation of FS becomes

$$FS = \frac{\tan \Phi}{\tan \beta}$$

where β is the slope gradient. The yield acceleration (a_y) is then calculated 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 gradient angle (β).

These calculations are conducted in an ArcGIS environment by converting the vector (lines, points and polygons) digital geologic map to a raster (regular spaced grid) material strength map that contains the Φ values assigned to the mapped geologic units (Table 1.3). Preparation of a slope gradient (β) map is discussed in Section 1.

Ground Motion for Landslide Hazard Assessment

Ground motion calculations used by CGS for regional earthquake-induced landslide zonation assessments are currently based on the USGS probabilistic seismic hazard analysis (PSHA) model for the 2018 Update of the National Seismic Hazard Maps (Petersen and others, 2020). The model is set to calculate ground motion hazard in terms of peak horizontal ground acceleration (*PGA*) at a 10 percent in 50 years exceedance probability level. Raster versions of the PSHA *PGA* and Modal Magnitude maps for the Vine Hill Quadrangle, Contra Costa County, were calculated from the statewide model and applied in the Newmark displacement calculations, as described below. A more detailed description of the development of ground motion parameters used in preparation of the Seismic Hazard Zone for earthquake-induced landslides can be found in Section 2 of this report.

Earthquake-Induced Landslide Hazard Potential

Earthquake-induced landslide hazard potential is derived by combining the susceptibility map (a_y) with the ground motion maps (PGA and Modal Magnitude) to estimate the amount of permanent displacement that a modeled slope might experience. The permanent slope displacement is estimated using a regression equation developed by Jibson (2007). That equation is:

$$\log D_N = -2.710 + \log\left[\left(1 - \frac{a_y}{PGA}\right)^{2.335} \left(\frac{a_y}{PGA}\right)^{-1.478}\right] + 0.424\boldsymbol{M} \pm 0.454$$

where D_N is Newmark displacement and ***M*** is magnitude. Jibson's (2007) nomenclature for yield acceleration (a_c) and peak ground acceleration (a_{max}) have been replaced here by a_y and PGA, respectively, to be consistent with the nomenclature used in this report.

The above equation was applied using a_y, *PGA* and Modal Magnitude maps as input, resulting in mean values of Newmark displacement at each grid cell (the standard deviation term at the end

of the equation is ignored). The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001).

Earthquake-Induced Landslide Zoning Criteria

Seismic Hazard Zones for earthquake-induced landslides were delineated using criteria adopted by the California State Mining and Geology Board (CGS, 2004). Under these criteria, these zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historical earthquake activity.
2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Delineation of Earthquake-Induced Landslide Hazard Zones

Upon completion of the earthquake-induced landslide hazard evaluation within the map area, CGS applied the above criteria to its findings to delineate Earthquake Zones of Required Investigation for earthquake-induced landslides. Based on our evaluation, about 2 square kilometers (0.8 square miles) of the map area are included in the Seismic Hazard Zone for landslides. These zones are prominent on the side slopes of many moderate to steep ridges in the map area and generally increase in frequency and size towards the southern and northeastern parts of the Vine Hill Quadrangle. Following is a description of the criteria-based factors that governed the construction of the Seismic Hazard Zone Map for the map area.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing mapped landslides with a definite or probable confidence rating are included within the Seismic Hazard Zone. Mapping and categorization of existing landslides is discussed in further detail in Section 1.

Hazard Potential Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; McCrink, 2001), the Seismic Hazard Zone for earthquake-induced landslides encompass all areas that have calculated Newmark displacements of 5 centimeters or greater.

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The authors thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project: Mindy Gentry and Mary Lehman of the City of Concord and Darwin Myers of Contra Costa County. At CGS, Christopher Tran, Edward Southwick, and Austin Reichmuth assisted with geotechnical data collection efforts. Bob Moskovitz and Jonathan Goergen provided database compilation and analysis support. Kate Thomas and Rebecca Vail prepared the final Seismic Hazard Zone Map the graphic displays for this report. Tim Dawson and Erik Frost provided technical review for this report.

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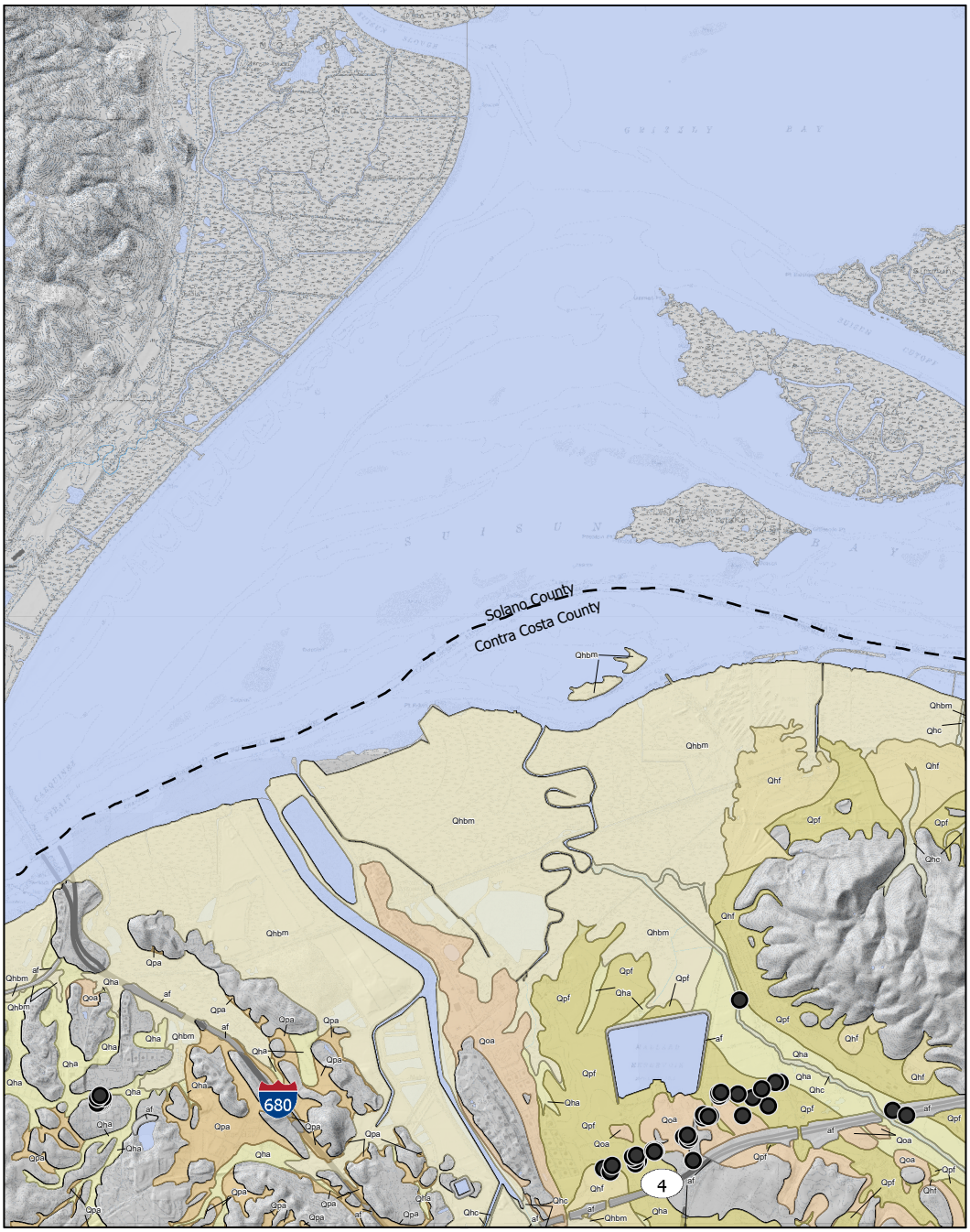


Topographic base map from USGS. Contour interval 20 feet. Scale 1:75,000. See "Geology" in Section 1 of report for descriptions of units.
Pre-Quaternary bedrock units shown without color. Map preparation by Rebecca Vail, CGS.

VINE HILL QUADRANGLE

N

1 0.5 0 1 2 Miles

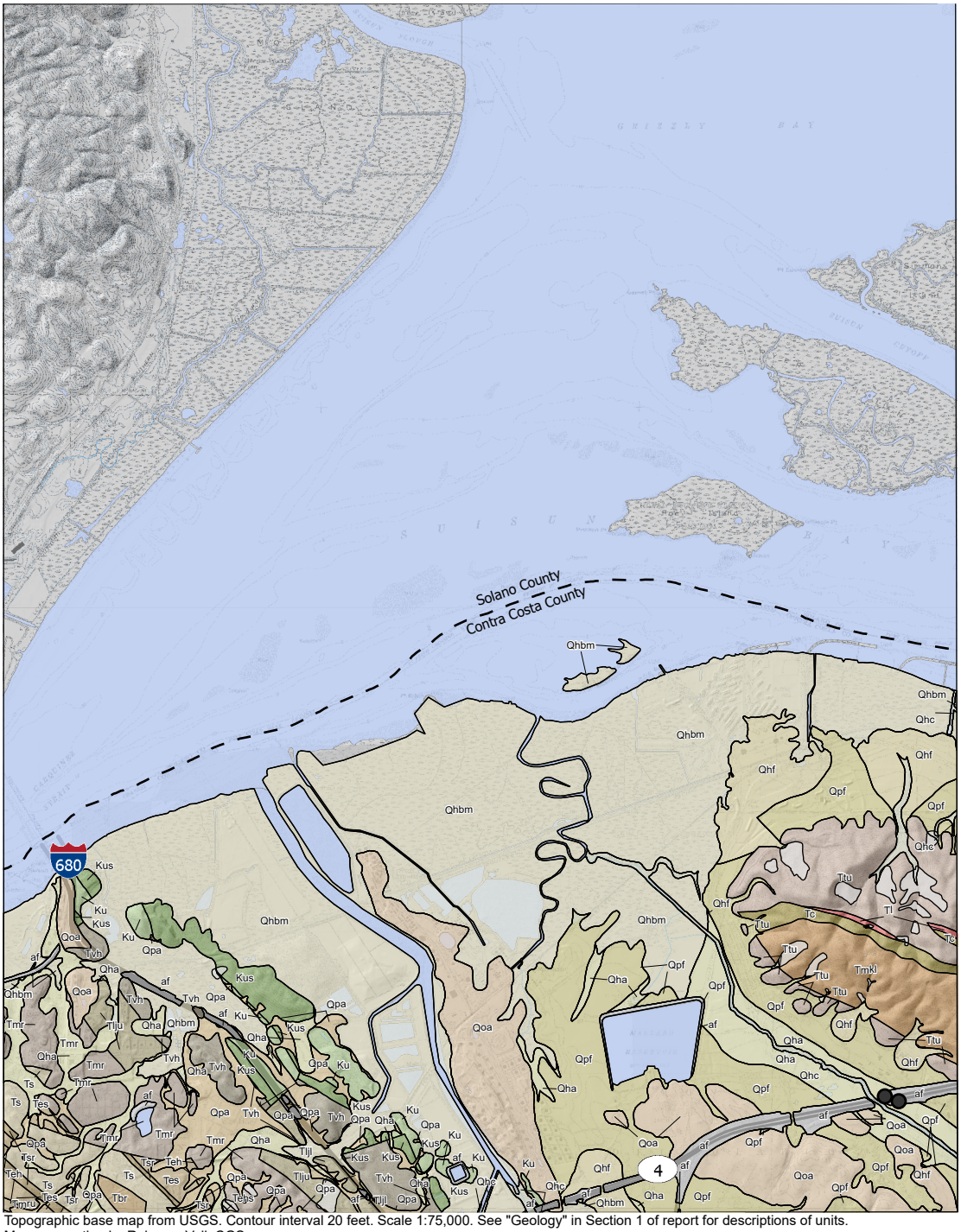
5,000 2,500 0 5,000 10,000 Feet

1 0.5 0 1 2 Kilometers

● Geotechnical boring used in liquefaction evaluation

County Boundary

Plate 1.1 Quaternary geologic materials map and locations of boreholes used in evaluating liquefaction hazard, Vine Hill Quadrangle, Contra Costa County, California.



Topographic base map from USGS. Contour interval 20 feet. Scale 1:75,000. See "Geology" in Section 1 of report for descriptions of units.
Map preparation by Rebecca Vail, CGS.

VINE HILL QUADRANGLE

N

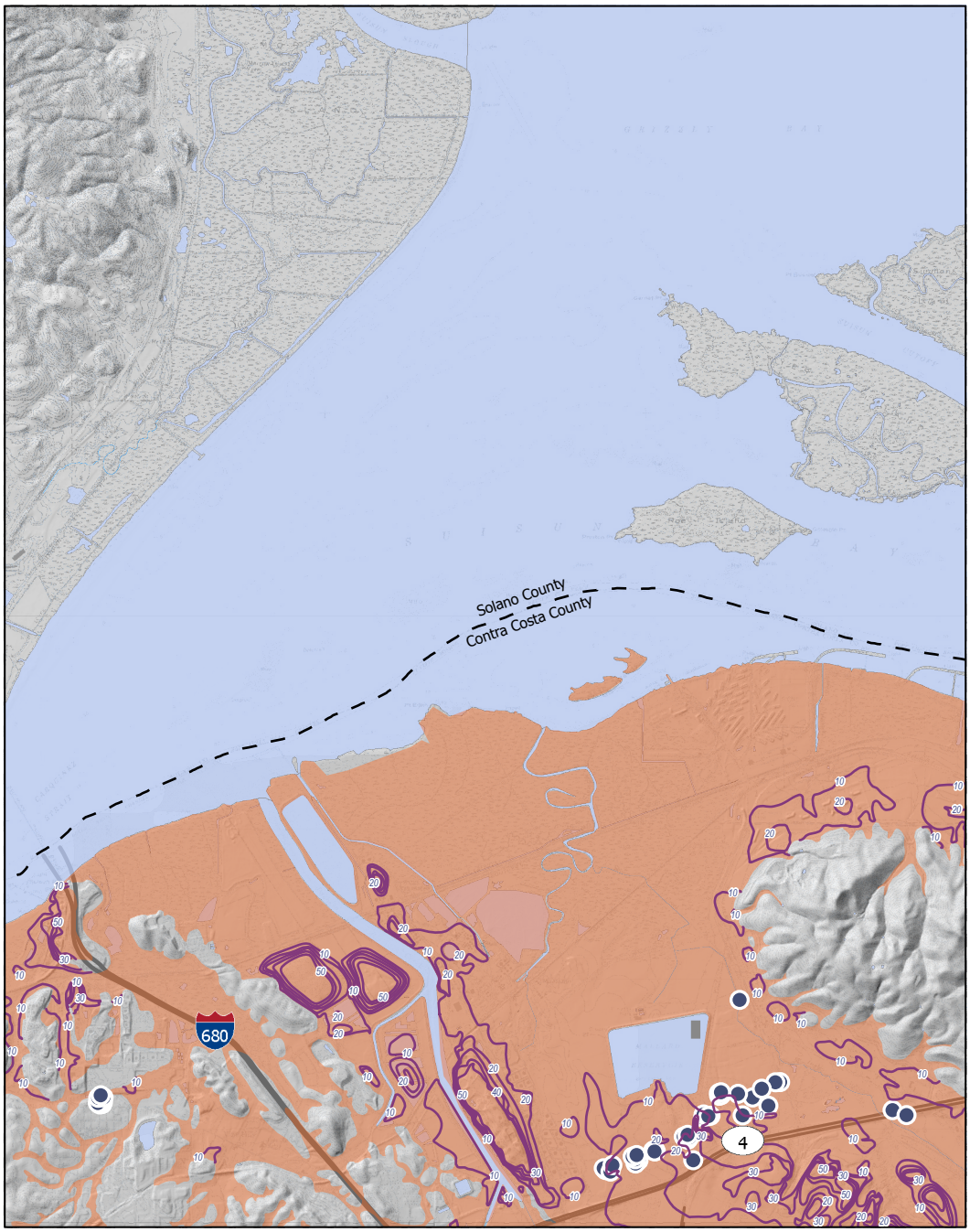
1 0.5 0 1 2 Miles

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

1 0.5 0 1 2 Kilometers

- Shear test sample location
- Landslide
- County Boundary

Plate 1.2 Geologic materials and landslide inventory map with locations of shear test samples used in evaluating landslide hazard, Vine Hill Quadrangle, Contra Costa County, California.



Topographic base map from USGS. Contour interval 10 feet. Scale 1:75,000. Map preparation by Rebecca Vail, CGS.

VINE HILL QUADRANGLE

N

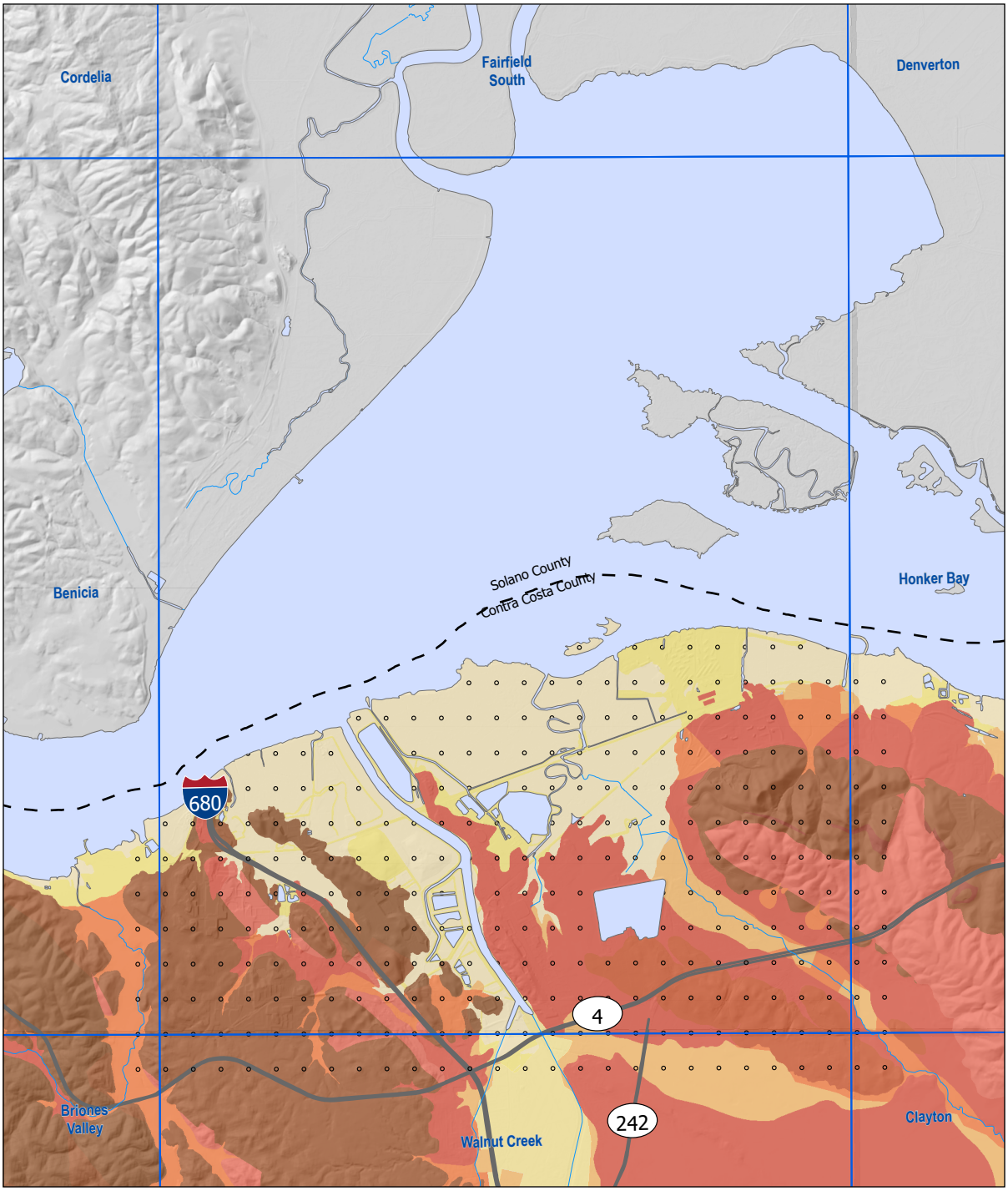
1 0.5 0 1 2 Miles

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

1 0.5 0 1 2 Kilometers

- Groundwater measurement location
- Depth to historical-high groundwater (feet)
- Groundwater basin limits
- County Boundary

Plate 1.3 Groundwater basins, depth to historical-high groundwater levels, and groundwater data points, Vine Hill Quadrangle, Contra Costa County, California.



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

VINE HILL QUADRANGLE

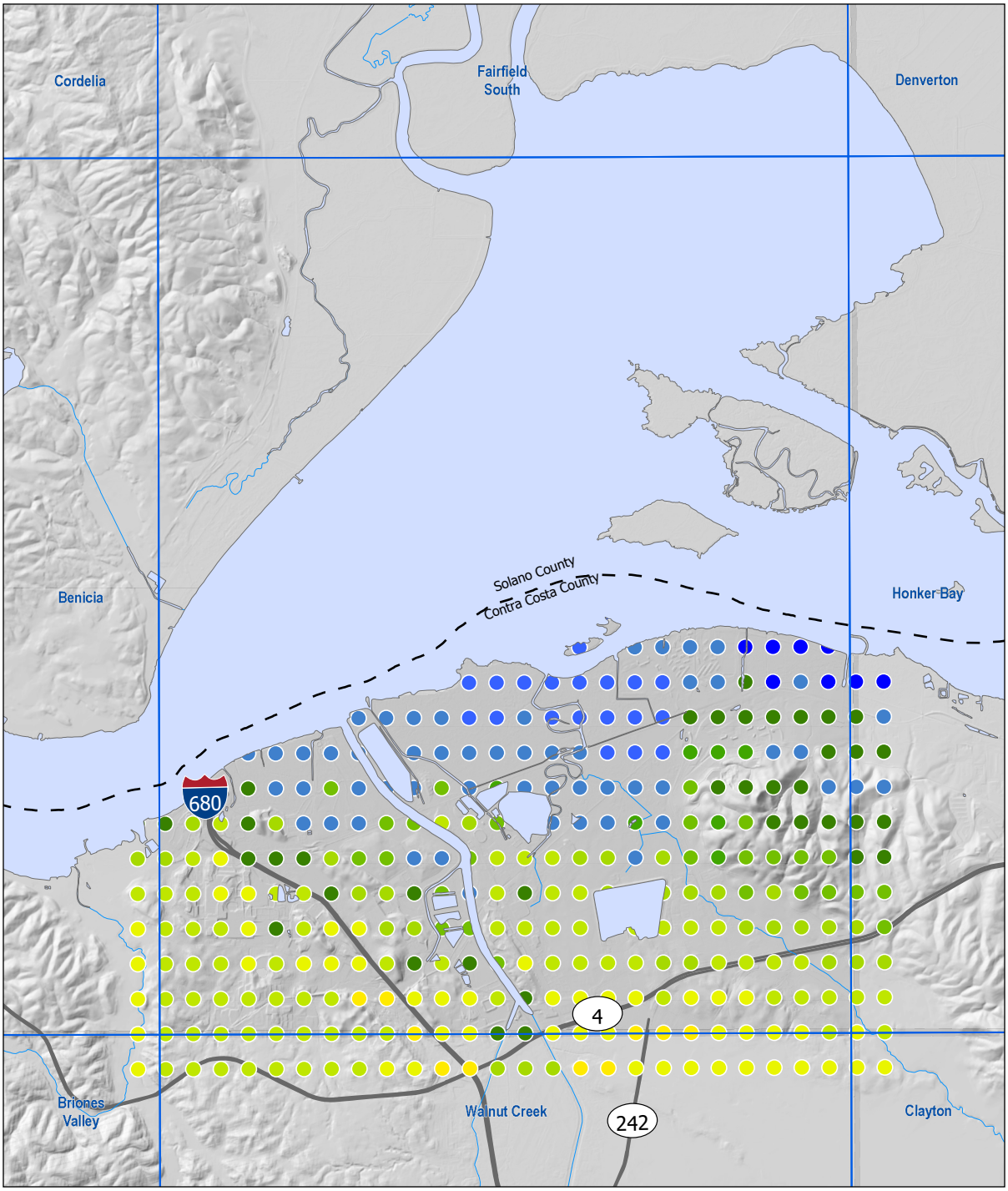
1 0.5 0 1 2 Miles
5,000 2,500 0 5,000 10,000 Feet
1 0.5 0 1 2 Kilometers

N

Shear wave velocity of upper 30 meters

- 733 (KJf)
- 710 (crystalline)
- 572 (serpentine)
- 519 (Tv)
- 503 (Kss)
- 468 (Tss)
- 444 (QT)
- 387 (Qoa)
- 385 (Tsh)
- 352 (Qal3)
- 308 (Qs)
- 294 (Qal2)
- 228 (Qal1)
- 226 (af/Qi)
- 176 (Qi)
- water
- County Boundary

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), Vine Hill Quadrangle, Contra Costa County, California, and surrounding areas.



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

VINE HILL QUADRANGLE

N

1 0.5 0 1 2 Miles

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

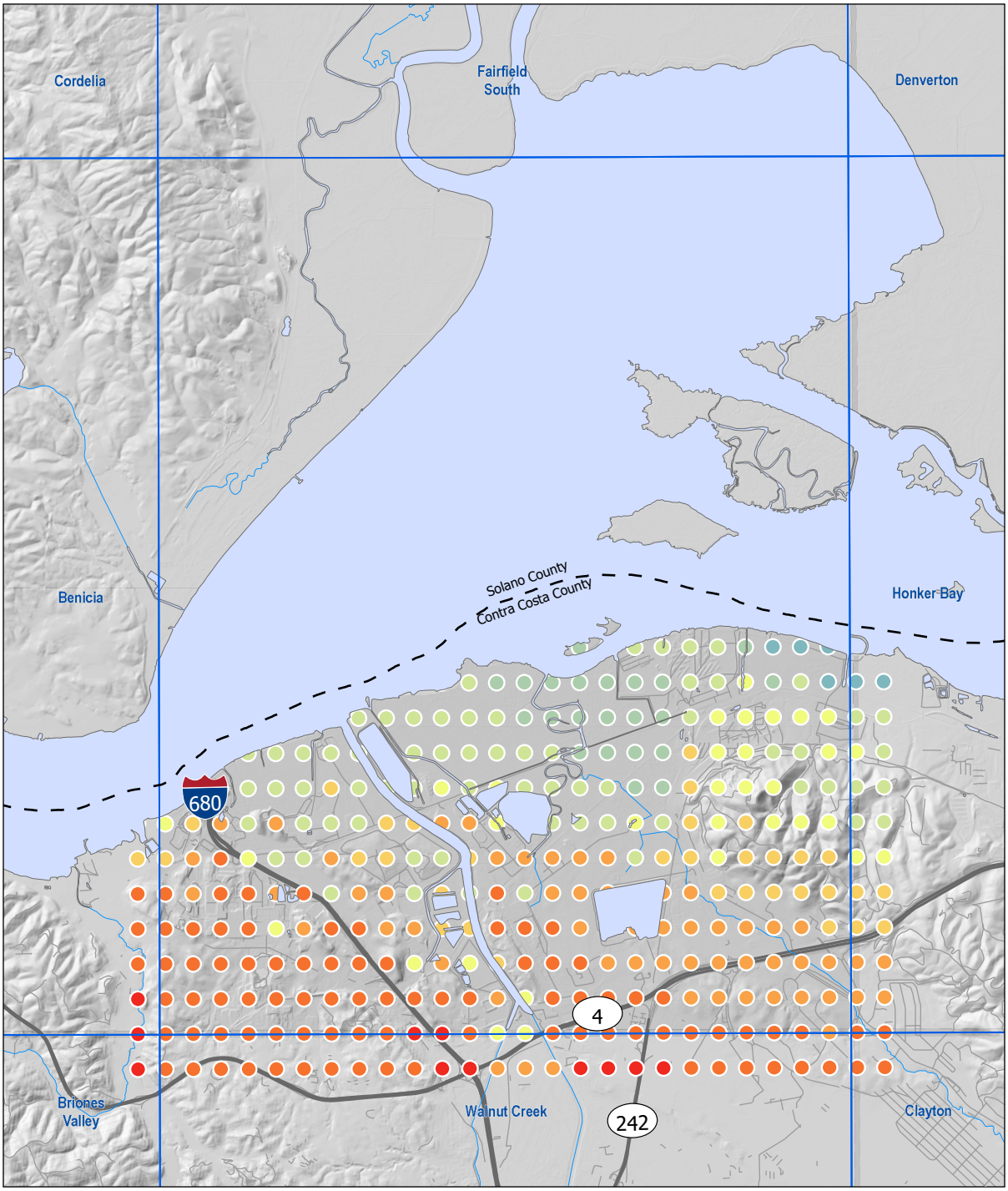
1 0.5 0 1 2 Kilometers

Pseudo-PGA (g)
10% in 50 yrs

0.51 - 0.51	0.44 - 0.44
0.49 - 0.50	0.43 - 0.43
0.48 - 0.48	0.42 - 0.42
0.47 - 0.47	0.40 - 0.41
0.45 - 0.46	0.38 - 0.39

County Boundary

Plate 2.2 Pseudo-PGA for liquefaction hazard mapping analysis, Vine Hill Quadrangle, Contra Costa County, California, and surrounding areas.



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

VINE HILL QUADRANGLE

N

1 0.5 0 1 2 Miles

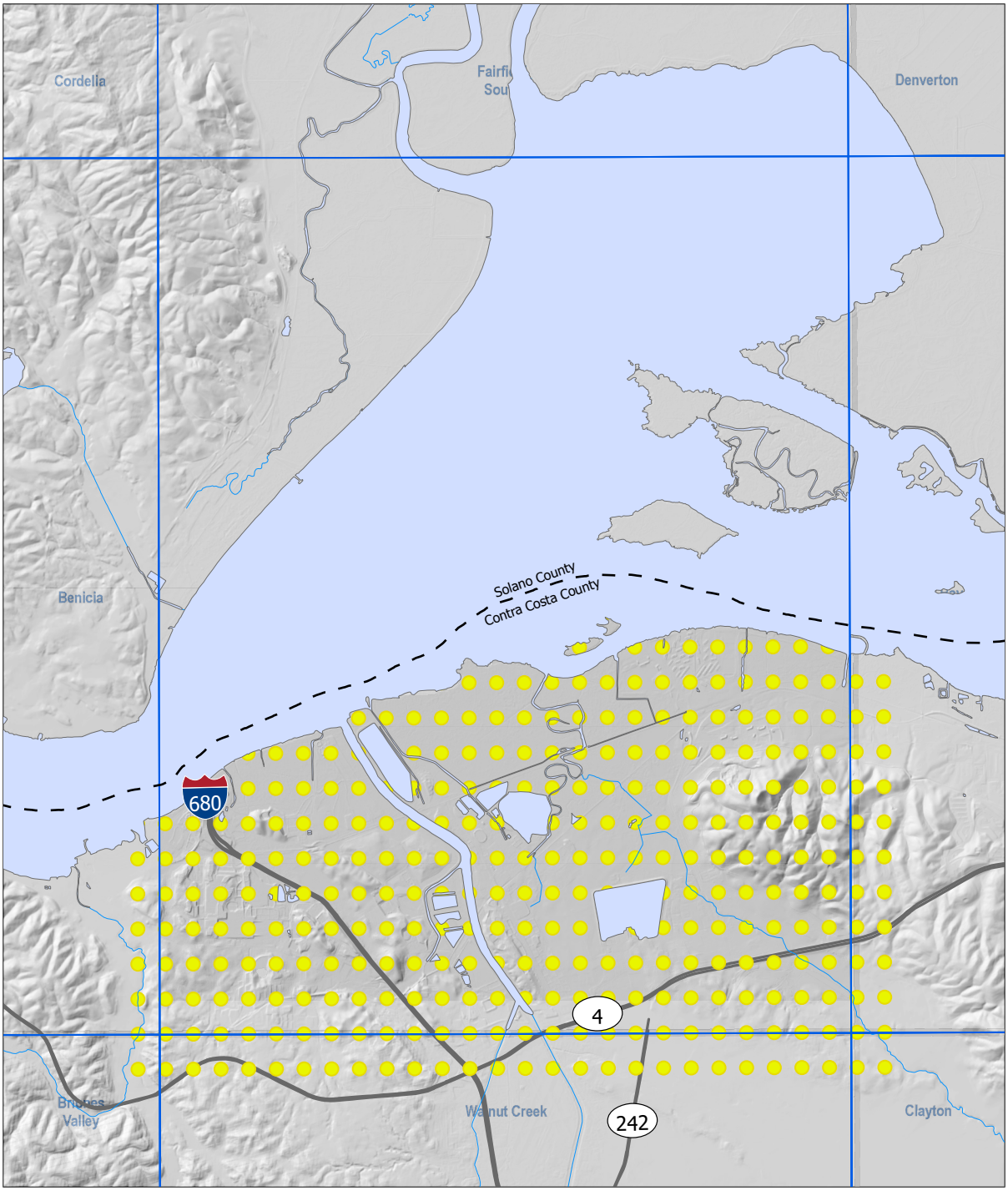
5,000 2,500 0 5,000 10,000 Feet

1 0.5 0 1 2 Kilometers

Probabilistic PGA (g)
10% in 50 yrs

- 0.60 - 0.62
- 0.58 - 0.60
- 0.56 - 0.58
- 0.54 - 0.56
- 0.52 - 0.54
- 0.50 - 0.52
- 0.48 - 0.50
- 0.46 - 0.48
- County Boundary

Plate 2.3 Probabilistic peak ground acceleration for landslide hazard mapping analysis, Vine Hill Quadrangle, Contra Costa County, California, and surrounding areas.



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

VINE HILL 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
6.49
County Boundary

Plate 2.4 Modal magnitude for landslide hazard mapping analysis, Vine Hill Quadrangle, Contra Costa County, California, and surrounding areas.

AUTHORSHIP CREDITS

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Project Manager – Brian Olson, Senior Engineering Geologist



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