SEISMIC HAZARD ZONE REPORT 131

SEISMIC HAZARD ZONE REPORT FOR THE CLIFTON COURT FOREBAY 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 Clifton Court Forebay 7.5-Minute Quadrangle, Contra Costa County, California. The topographic quadrangle map, which covers approximately 152 square kilometers (~59 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 encompassed area includes a small fraction of the unincorporated census-designated place of Byron, Contra Costa County and State of California land.

This Seismic Hazard Zone Report describes the development of the Seismic Hazard Zone for the Clifton Court Forebay 7.5-Minute Quadrangle. 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 29 square kilometers (11 square miles) of land in the Clifton Court Forebay Quadrangle has been designated as EZRI for liquefaction, encompassing most of the delta-alluvial plain and the upland alluvial valley bottoms. The borehole logs of test holes drilled in areas adjacent to the Clifton Court Forebay Quadrangle 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 Clifton Court Forebay Quadrangle is 0.06 square kilometer (0.02 square miles). These zones are located on the side slopes of areas mapped as artificial fill around the California Aqueduct in the southwestern corner of the map area.

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 Clifton Court Forebay Quadrangle 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, provides 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 Clifton Court Forebay Quadrangle. Sections 3 and 4 summarize the analyses and criteria used to delineate liquefaction and earthquake-induced landslide hazard zones, respectively, in the Clifton Court Forebay Quadrangle.

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 Clifton Court Forebay Quadrangle include those associated with soft clay deformation, non-liquefaction-related settlement, ridge-top spreading, and shattered ridges. In addition, this report does not address the potential for ground failure related to precipitation-induced landslides, including debris flows.

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/.

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.

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

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

CLIFTON COURT FOREBAY 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 Clifton Court Forebay Quadrangle and then discuss the collection, processing, and analyses of primary geologic and engineering geologic data that were used to delineate EZRI.

GEOGRAPHY

Location

The Clifton Court Forebay Quadrangle covers an area of approximately 153 square kilometers (59 square miles) of land in Contra Costa, Alameda, and San Joaquin Counties, California. The center of the quadrangle is about 61 kilometers (38 miles) east of the City of Oakland and about 85 kilometers (53 miles) south of the City of Sacramento. The portion of the Clifton Court Forebay Quadrangle evaluated for this report includes approximately 46 square kilometers (18 square miles) in the northwestern quarter of the quadrangle that lies within Contra Costa County. This evaluated area encompasses a small fraction of the unincorporated census-designated place of Byron, Contra Costa County and State of California land.

The map area is situated on the southern edge of the Sacramento-San Joaquin Delta within the western portion of the Great Valley Geomorphic Province. Topography of the southwestern quarter of the map area is characterized by low, gently rolling hills, whereas the remaining three-quarters of the map area is dominated by the relatively flat Sacramento-San Joaquin Delta-alluvial plain. Elevations in the map area generally increase towards the southwest and range from 3 meters (10 feet) below sea level on Coney Island along Old River in the eastern part of the map area to 67 meters (220 feet) in the southwestern corner of the map area near the California Aqueduct.

One leveed tract and three leveed islands are located in the map area, including Byron Tract, Coney Island, Widdows Island, and Eucalyptus Island. These tracts and islands are separated from each other by delta waterways, such as rivers, sloughs, and canals. Waterways within the quadrangle include Old River, Brushy Creek, Frisk Creek, and Italian Slough. Old River largely trends north-south across the entire length of the Clifton Court Forebay Quadrangle and defines the eastern boundary of the study area. Brushy and Frisk Creeks begin in the foothills of the Diablo range southwest of the map area and drain towards the delta-alluvial plain to the east, eventually entering the Sacramento-San Joaquin Delta. Frisk Creek drains into the northwestern part of the study area, while Brushy Creek drains into Italian Slough, which is a man-made branch off Old River.

The most notable geographic feature within the study area is the Clifton Court Forebay, a reservoir created in 1969 by inundating a delta tract as part of the California State Water Project. The Clifton Court Forebay serves as the intake point for the California Aqueduct and feeds the Delta-Mendota Canal, both of which traverse the southwestern part of the study area from northeast to southwest. The California Aqueduct and Delta-Mendota Canals are man-made water conveyance systems that divert water from the Sacramento-San Joaquin Delta to southern California and the Central Valley, respectively, for agricultural, industrial, and municipal uses. To the north and east of the Clifton Court Forebay, a number of unnamed small man-made canals and waterways dissect Byron Tract and Coney Island, providing water for local agricultural purposes.

Land Use

Most of the Clifton Court Forebay Quadrangle is located within the Sacramento-San Joaquin River Delta. The Sacramento-San Joaquin Delta is the largest estuarine system on the west coast of North America and receives runoff from about 40 percent of the land area of California and 50 percent of California's total stream flow (Ingebritsen and others, 2000). In the early 1800's, most of the Clifton Court Forebay Quadrangle consisted of marshy wetlands, channels, and delta islands with low natural levees flanking marshy interiors that flooded intermittently with the seasons and tides. Beginning in the 1870's large scale efforts were undertaken to reclaim parts of the delta for agricultural purposes. The first levees in the delta were completed in 1870 (Thompson, 2006) and the modern-day levee and drainage systems surrounding the Byron Tract and Coney, Widdows, and Eucalyptus Islands were largely completed by 1930 (Ingebritsen and others, 2000).

Since the reclamation of Byron Tract, Coney Island, Widdows Island, and Eucalyptus Island, land use in the map area historically was dominated by agriculture. However, in 1968 the community of Discovery Bay was developed 1 mile north of the Clifton Court Forebay Quadrangle boundary. Discovery Bay, once rural unincorporated land, was developed mainly as homes, golf courses, and shopping centers. Since 2000, the population of Discovery Bay has nearly doubled in size and development of rural, unincorporated areas within the map area is expected to occur in the coming years. More than three-quarters of the study area remains undeveloped, consisting primarily of orchards and agriculture, and recreational area.

The primary transportation route in the study area is Byron Highway, which trends northwest-southeast across southern part of the quadrangle and connects the town of Discovery Bay with the cities of Stockton and Brentwood. The Union Pacific Railroad runs northwest-southeast through the southwestern part of the map area, connecting the City of Tracy south of the map area with the communities of Byron and Brentwood in the north. Camino Diablo, Herdlyn Road, Armstrong Road, Bethany Lane, Clifton Court Road, and Holey Road are major east-west trending rural roads that connect the Byron Highway with ranches and rural residences in the map area. Byron Hot Springs Road and Bruns Road are the only north-south trending roads in the study area, connecting the Byron Highway to Vasco Road and Bethany Reservoir, respectively. A network of small, private roads provide access to crops, pumping stations, and levees on Byron Tract and Coney Island. Access to undeveloped areas within the quadrangle is primarily by paved county roads and paved and unpaved private roads in the northern half of the quadrangle.

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 Clifton Court Forebay Quadrangle, digital topography in the form of a lidar-derived digital elevation model was 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 elevations at a 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 ground water elevations to derive a "depth to water" map. In alluvial areas, the depth value obtained was 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 mapping used in the evaluation of these materials for the Clifton Court Forebay Quadrangle is the CGS 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 Atwater (1982) and Helley and Graymer (1997). The Quaternary geologic unit nomenclature used by CGS for mapping in the San Francisco Bay Region was adopted from Knudsen and others (2000).

Digital geologic maps covering the Clifton Court Forebay Quadrangle 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 study 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). These investigators believe that the individual stratigraphic assemblages originated in separate depositional basins or in different parts of large basins that were later juxtaposed by large offsets on strike-slip and dip-slip faults during Tertiary time. Stratigraphic Assemblage VI underlies the Clifton Court Forebay Quadrangle.

In the Clifton Court Forebay Quadrangle, the oldest rocks exposed in the fault-bounded assemblage belong the slightly deformed Mesozoic Great Valley Sequence (Graymer and others, 1994). The Great Valley Sequence, as exposed in the quadrangle, consists of interbedded sandstone and shale originally deposited on the ocean floor by turbidity currents and subsequently folded, faulted and uplift (Graymer and others, 1994). An angular unconformity forms the boundary between underlying Cretaceous Great Valley Sequence units and overlying Tertiary marine strata (Graymer and others, 1994).

Mesozoic and Tertiary rocks outcrop in the Clifton Court Forebay where they have not been buried beneath Quaternary sediments (Plate 1.1). These rocks are expressed in narrow linear outcrops that strike parallel to and form linear ridges. They typically dip to the north or northeast and become younger to the northeast. Both Mesozoic and Tertiary rocks have been subjected to extensive grading and development in the southwestern part of the map area in the vicinity of the California Aqueduct. The following is a summary of bedrock map units exposed in the Clifton Court Forebay Quadrangle based on Dawson (2010).

Mesozoic Units

Mesozoic rock units cover about 49% of the uplands in the southwest corner of the map area and consist of Late Cretaceous Great Valley Sequence rocks, divided into the following units, from southwest to northeast and oldest to youngest: Unit D (**Kd**); Unit D, interbeds (**Kds**); and Unit E, Lower Member (**Kel**). In the map area, units **Kd** and **Kel** form low rolling hills, whereas unit **Kds** typically forms gentle side slopes and valley bottoms. Generally, the Mesozoic units form a greater proportion of steeper slopes than the Tertiary units.

Unit **Kd** of the Great Valley Sequence occurs as thick packages (up to 10 meters) of medium to coarse grained, light gray, clean sandstone with 1 to 2 meters of interbedded siltstone and mudstone. In places, the clean sandstone is interbedded with fine to medium grained wacke with mudstone rip-up clasts. The shale member of Unit D of the Great Valley Sequence, **Kds**, occurs in two distinct layers, one being a brown to gray, micaceous mudstone and brown micaceous siltstone and the other a dark gray-brown to dark gray, massive, foraminifera-rich, siliceous mudstone. Conformably overlying unit **Kd** to the north is Great Valley Sequence Unit E, Lower Member (**Kel**). Unit **Kel** is a light gray to gray brown, foraminifera-bearing siltstone and mudstone.

Tertiary Units

Tertiary rocks cover the remaining 51% of the hills in the map area and consist entirely of the Pliocene Tehama Formation (**Pth**). The Pliocene Tehama Formation (**Pth**) occurs as low relief hills and is mapped along the west-central quadrangle boundary and on both sides of the California Aqueduct in the southwestern part of the map area. This unit is a poorly consolidated, non-marine, gray to maroon siltstone, quartz arenite sandstone, tuff, and weakly indurated pebble to cobble conglomerate.

Quaternary Sedimentary Deposits

Approximately 34 square kilometers (13 square miles) of the Clifton Court Forebay Quadrangle is covered by Quaternary sediments, of which approximately 12 square kilometers (5 square miles) are Pleistocene in age and 22 square kilometers (9 square miles) are Holocene in age. In total, 8 different Quaternary units are mapped in the Clifton Court Forebay Quadrangle (Plate 1.1). These sedimentary units are summarized in Table 1.1 and discussed below. The liquefaction susceptibility evaluation and development of the Seismic Hazard Zone Map for the quadrangle was based on the distribution of these deposits at a scale of 1:24,000 (Plate 1.1); analyses of associated geotechnical data are discussed under the Engineering Geology heading of this section. Structural features such as faults are not presented on the plate.

Old Quaternary Units

Nearly 26 percent of the map area is covered by Older Quaternary (latest Pleistocene) alluvial sediments. Only one Pleistocene sedimentary unit is exposed in the Clifton Court Forebay Quadrangle; latest Pleistocene alluvial fan deposits (**Qpf**). The unnamed latest Pleistocene alluvial fan unit (**Qpf**) consists of sand, gravel, silt, and clay. This unit is related to modern drainages and forms broad, gently sloping fans and terraces exposed in the western half of the map area on the delta-alluvial plain between the uplands and the Clifton Court Forebay and the Sacramento-San Joaquin Delta (Plate 1.1). Deposits of **Qpf** are distinguished from younger alluvial units by higher topographic position, greater degree of dissection, and stronger soil profile development.

Young Quaternary Units

Young Quaternary (Holocene) alluvial sediments cover approximately 48 percent of the Contra Costa County portion of the Clifton Court Forebay Quadrangle. These deposits are subdivided into seven distinct units: undifferentiated alluvium (**Qha**); stream channel (**Qhc**); alluvial fan, fine facies (**Qhff**); floodplain (**Qhfp**); and artificial fill (**ac**, **af** and **alf**).

Holocene undifferentiated alluvial deposits (**Qha**) are mapped in the southwest corner of the map area. These materials were eroded from surrounding hills, then transported and deposited into the inter-ridge valley bottoms of Bushy Creek tributaries and unnamed drainages and on the delta-alluvial plain. Unit **Qha** consists of intercalated sand, silt, and gravel, with little to no dissection. Late Holocene to modern stream channel deposits (**Qhc**) consist of unconsolidated sand and gravel recently transported within active channels. These deposits are mapped primarily in the southwestern part of the map area along tributaries of Bushy Creek as well as other unnamed drawings in the map area.

The Holocene alluvial fan, fine facies deposits (**Qhff**) are mapped as distal alluvial fan deposits and flood plain overbank deposits laid down in very gently sloping portions of the alluvial plain and consists primarily of clay and silt, with interbedded lobes of coarser alluvium (sand and occasional gravel). These alluvial fan deposits were deposited by streams emanating from Marsh Creek, Kellogg Creek, Busy Creek, Frisk Creek and several unnamed drainages onto the Sacramento-San Joaquin delta-alluvial plain and flatland surrounding the community of Byron. These deposits extend across the delta-alluvial plain in the northwestern part of the quadrangle.

Floodplain deposits (**Qhfp**) are mapped along the banks of Old River and the Clifton Court Forebay in the central part of the Quadrangle and are younger than and lap onto the Holocene alluvial fan, fine facies deposits (**Qhff**). These deposits include abandoned oxbows, channels and interdistributary basins, flood basins and basin rims, distal alluvial fans, and low natural levees adjacent to Old River. Floodplain deposits generally slope downstream at low gradients parallel to the Old River and consist of sandy to silty clay with lenses of silt, sand, and pebbles.

Late Holocene artificial fill (**af**), artificial channels (**ac**), and artificial levee fill (**alf**) are deposits of sand, gravel, silt, and clay resulting from human activity and are mapped across the study area in and around the canals and rivers in the vicinity of the Sacramento-San Joaquin Delta and Clifton Court Forebay. These units include engineered and non-engineered fill and are chiefly related to residential, industrial, commercial, and water conveyance system development projects. The most significant source of artificial fill in the map area is associated with California Department of Water Resources operated facilities in the southwestern part of the map area, mainly the California Aqueduct and Clifton Court Forebay. Although significant areas with fills have been mapped, not all fills are represented in the study area.

Table 1.1. Quaternary units mapped in the Clifton Court Forebay Quadrangle.

Map Unit	Environment of Deposition	Age
ac	Artificial Stream Channel	Historical
af	Artificial Fill	Historical
alf	Artificial Levee Fill	Historical
Qhfp	Floodplain	Holocene
Qhc	Stream Channel	Holocene
Qha	Undifferentiated Alluvium	Holocene
Qhff	Distal Alluvial Fan	Holocene
Qpf	Alluvial Fan	Latest Pleistocene

Geologic Structure

The structural framework of the Clifton Court Forebay Quadrangle is governed by the series of sub-parallel, gently northwest-striking faults ranging in age from Mesozoic to present time that shaped the Diablo Range (Wentworth and others, 1999). 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 4 million years into the Mount Diablo Anticline (Schemmann and others, 2007). Bedrock units on the northeast flank of the Mount Diablo anticline are exposed in the southwestern part of the map area, where they dip gently towards the northeast and below the remainder of the map area, buried by tens to hundreds of meters of alluvial and deltaic deposits (LHSC, 2012).

Two faults are mapped within the Clifton Court Forebay Quadrangle. The Quaternary West Tracy Thrust Fault is a northwest-southeast trending, west-dipping reverse fault that extends from south of the City of Tracy to the town of Byron. This fault bisects the Clifton Court Forebay in the central part of the map area. There is no documented surface trace of the West Tracy Thrust fault, but it is inferred in alluvial deposits based primarily on analyses of borehole and seismic reflection data (Wagner et al., 1991; Sterling, 1992; URS, 2007). Just outside the western boundary of the Clifton Court Forebay Quadrangle, the West Tracy Thrust Fault intersects the pre-Quaternary north-south trending Midland Fault Zone near the community of Byron.

An unnamed, northeast-southwest trending fault is mapped crossing bedrock in the southwest corner of the quadrangle (Bryant and Cluett, 2002; Dawson, 2010; Graymer and others, 1994). This fault is apparently pre-Quaternary in age and is well constrained where in bedrock and inferred in alluvium. No active faults are mapped in the Clifton Court Forebay Quadrangle by the California Geological Survey under the Alquist-Priolo Earthquake Fault Zoning Act.

Existing Landslides

As a part of the landslide hazard zoning process, CGS typically prepares an inventory of existing landslides for the map area and includes them in the final landslide hazard zone. However, a landslide inventory had not been completed for the area covered by the Clifton Court Forebay Quadrangle prior to the delineation of landslide hazard zones. Thus, no existing landslides have been included in the landslide hazard zones for the Clifton Court Forebay Quadrangle.

ENGINEERING GEOLOGY

Historic-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 1.2 depicts contours reflecting the historic-high depth to groundwater surface within the Clifton Court Forebay Quadrangle.

Groundwater Basins

A majority of the study area is located within the northwestern-most part of the California Department of Water Resources (CDWR) designated San Joaquin Valley Groundwater Basin, Tracy Subbasin (Groundwater Subbasin Number 5-22.15). The remainder of the map area is located within the Tracy Subbasin's associated highland area known as the Tracy Highlands, see Plate 1.2. For this study, groundwater mapping was performed for the valley and flatland regions of the Tracy Subbasin that is subject to liquefaction zonation in order to estimate depths to saturated materials.

Water-bearing units in the northwestern Tracy Subbasin include continental deposits of Late Tertiary to Quaternary age flood-basin deposits, and Pleistocene to Holocene alluvium (CDWR, 2003). These alluvial deposits generally contain no extensive confining units and consist of thick packages of sand and gravel with thin, discontinuous beds of clay and silt (LHSC, 1999; 2007; 2012). Groundwater levels in these deposits are influenced in part by natural groundwater recharge resulting from direct precipitation and annual runoff in creeks and streams (CDWR, 2003; USGS, 2015). However, groundwater levels in the Clifton Court Forebay Quadrangle are also strongly influenced by tides, variable rates of pumping (freshwater exports), and other artificial sources of groundwater recharge such as canal seepage, irrigation return flows, urban landscaping runoff, and agricultural tail water. In general, groundwater flow in the map area is towards the east-northeast, flowing from alluvial valleys in the foothills of Mount Diablo, across the delta-alluvial plain towards the San Joaquin River Delta. However, freshwater pumping operations can cause the normally tidally averaged flow in Old River and other adjacent delta channels to change course and flow towards Clifton Court Forebay and Banks Pumping Plant in the southwestern part of the map area (Arthur and others, 1996; Monsen and others, 2007).

Groundwater Data

Groundwater conditions in the Clifton Court Forebay Quadrangle were evaluated using depth to groundwater levels noted in online groundwater databases, groundwater monitoring reports, and water well drilling logs. Water level data were collected from the State Water Resources Control Board (SWRCB), California Department of Water Resources (CDWR), the United States Geological Survey (USGS), and local water districts and agencies.

Water level data evaluated in this study represents more than 170 groundwater measurements (Plate 1.2) collected from the early 1970’s through the present, with most records representing conditions of the past twenty years. Review of hydrographs of wells in the Tracy Subbasin indicate that, except for seasonal variation resulting from recharge and pumping, most water levels in wells in the Tracy Subbasin have remained relatively stable over at least the last 10 years (USGS, 2020; CDWR, 2003; 2020 a&b; CWRCB, 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 historic-high groundwater elevation surface map for the alluvial valleys and flatlands of the northern-most part of the Tracy Subbasin and the Tracy Highlands 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, reservoirs, and delta channels. The depth to groundwater contours depicted on Plate 1.2 do not represent present-day conditions, as usually presented on typical groundwater contour maps, but rather the historic-high depths to groundwater in the Clifton Court Forebay Quadrangle.

Groundwater Levels

Historic-high groundwater depths in the Clifton Court Forebay Quadrangle vary from 0 feet in the low-lying eastern half of the map area along the delta channels and Clifton Court Forebay, to greater than 40 feet below ground surface in the southwestern part of the map area where ground surface elevation is highest. Historic-high groundwater levels below the surface of the Pleistocene and Holocene alluvial fan deposits range between 0 and 30 feet deep, where the greatest depths are typically found near to the apex of alluvial fans and gradually shallow away from the foothills and towards the Sacramento-San Joaquin Delta in the east-northeast. Some of the older alluvial deposits (**Qpf**) have been dissected by active stream channels where shallow groundwater conditions, within 10 feet of the ground surface, were noted.

Prior to delta land reclamation, the delta islands and tracts in the map area flooded intermittently with the seasons and tides. Levees constructed in the late 1800’s now protect these low-lying areas from intermittent flooding. However, reclamation and agriculture have led to subsidence of the land surface in the delta part of the study area. The primary cause of this land subsidence is decomposition of organic carbon in the peat deposits of the delta mud and peat below the surficial unit (**Qhfp**). Islands that were originally near sea level are now well below sea level, and large areas of many islands, such as Coney Island, are now up to 10 feet below sea level. The land surface profile of many islands in the delta is somewhat saucer-shaped, because subsidence is greater in the thick peat soils near their interior than in the more mineral-rich soils near their perimeter (Ingebritsen, 2000). Because of low ground surface elevation, numerous pump stations are used to prevent flooding of the delta reclaimed land through pumping drainage returns (seepage through levees, precipitation, unconsumed irrigation water, and surface-water withdrawals) off the land into adjacent channels (Ingebritsen, 2000).

Due to historical records of flooding on the delta islands and tracts and water level measurements indicating groundwater has been between 0 and 6 feet below ground surface for more than 50 years, low lying areas in the eastern and northern parts of the quadrangle have been assigned historic-high groundwater levels of 0 feet below ground surface.

Sufficient borehole and water measurement data are lacking in the upland alluvial valleys of the Bushy Creek tributaries in the southwestern part of the map area. Because of this, the historic-high groundwater level could not be well constrained. The deposits in the upland alluvial valleys are typically thin, consist of sand, gravel, clay, and tend to trap and accumulate heavy runoff and near-surface groundwater. 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

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, 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 weight 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 $(N_1)_{60}$. Geotechnical borehole logs provided information on lithologic and engineering characteristics of Quaternary deposits within the study area.

For liquefaction hazard zoning in the Clifton Court Forebay Quadrangle, borehole logs from previous CGS Seismic Hazard Zoning projects were collected and reviewed; including more than 701 borehole logs from the Brentwood, Antioch North, Antioch South, Honker Bay, and Byron Hot Springs quadrangles. These boreholes are located in mapped Quaternary units that extend into the Clifton Court Forebay Quadrangle and provide sufficed coverage to adequately assess geologic material properties. An additional 71 borehole logs drilled in the map area for a previous CGS Sacramento-San Joaquin Delta area liquefaction study were also evaluated (Real and Knudsen, 2010) during the course of this study.

Of the 772 geotechnical borehole logs evaluated in this study, 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

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. Shear-strength data for the units identified on the Clifton Court Forebay geologic materials map were obtained from the California Department of Water Resources. The locations of rock and soil samples taken for shear testing within the Clifton Court Forebay Quadrangle are shown on Plate 1.1. Shear tests from neighboring quadrangles (Brentwood, Antioch South, Antioch North, and Clayton) were used to augment data for the geologic formations for which little or no shear test information was available within the Clifton Court Forebay Quadrangle (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). The locations of rock and soil samples taken for laboratory shear testing and GSI field measurements within the Clifton Court Forebay Quadrangle are shown on Plate 1.1.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped based on average angle of internal friction (average phi) and lithologic character. Average (mean or 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.

Table 1.2. Summary of the shear strength statistics for the Clifton Court Forebay Quadrangle.

	Formation Name	Number of Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Kd	10	31 / 30	31		31
GROUP 2	Pth Qpf	37 10	29 / 28 28 / 27	29 / 28		29
GROUP 3	Qh* Af*	21 2	26 / 27 24 / 24	26 / 25	Kel, Kds	26

*Unit af includes af, ac, alf; Qh includes Qha, Qhff, Qhc, Qhfp. Formation abbreviations from Dawson (2010)

Table 1.3 Summary of shear strength groups for the Clifton Court Forebay Quadrangle

GROUP 1	GROUP 2	GROUP 3
Kd	Pth Qpf	Qh af Kel Kds

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APPENDIX A: Sources of Rock Strength Data

SOURCE	NUMBER OF TESTS SELECTED
California Department of Water Resources	**14**
Antioch South Quadrangle	**28**
Brentwood Quadrangle	**21**
Honker Bay Quadrangle	**9**
Antioch North Quadrangle	**6**
Byron Hot Springs Quadrangle	**2**
Total Number of Shear Tests	**80**

SECTION 2: GROUND MOTION ASSESSMENT

for the

CLIFTON COURT FOREBAY 7.5-MINUTE QUADRANGLE, RIVERSIDE 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 Clifton Court Forebay Quadrangle. 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 (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 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-average shear-wave velocity in the upper 30 m 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 (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 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. 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 Clifton Court Forebay 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 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 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. Ground motion generally increases from the northeast corner to the southwest corner as distance to the Greenville and Calaveras fault zones decreases. Multiple fault sources control shaking hazards, including the Greenville, Great Valley, and Calaveras faults zones with increasing hazard contribution from the Mount Diablo Thrust fault toward in northeast part of the quadrangle. Other sources that contribute to shaking hazards include the Las Positas fault, Hayward fault, Concord fault, San Andreas fault zone, and background (gridded) seismicity. Modal magnitudes (Plate 2.4) reflects the magnitudes of earthquakes that the Greenville, Great Valley, and Calaveras fault zones are capable of producing. Ground motion distribution is controlled by proximity to these faults and is affected by subsurface geology. 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 analysis.

PGA (g)	Pseudo-PGA (g)	Modal Magnitude	V_{S30} (m/s)
0.24 to 0.38	0.21 to 0.32	6.28 to 6.91	176 to 503

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SECTION 3: EVALUATION OF LIQUEFACTION HAZARD

in the

CLIFTON COURT FOREBAY 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

by

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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 Clifton Court Forebay Quadrangle.

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). 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 ground water are summarized in Table 3.1.

Table 3.1. Liquefaction Susceptibility of Quaternary Units in the Clifton Court Forebay Quadrangle.

Geologic Map Unit	Age	Sediment/Material Type	Consistency	Susceptible?*
ac, af, alf	Late Holocene	Sand, silt, gravel, concrete	Loose to dense	Yes
Qhfp	Holocene	Clay, silt, sand, pebbles	Loose to dense	Yes
Qhc	Holocene	Sand, gravel, cobbles, clay, silt	Loose	Yes
Qha	Holocene	Sand, gravel, silt	Loose to medium dense	Yes
Qhff	Holocene	Silt, clay, sand, gravel	Loose to medium Dense	Yes
Qpf	Latest Pleistocene	Gravel, sand, silt, Clay	Loose to very dense	Not likely below a depth of 20 feet

*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 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

Upon completion of the liquefaction hazard evaluation within the Clifton Court Forebay Quadrangle, CGS applied the above criteria to its findings in order to delineate Seismic Hazard Zones for liquefaction. Based on the evaluation, about 29 square kilometers (11 square miles) of the quadrangle are included in the Seismic Hazard Zone for liquefaction. The zones encompass most of the delta-alluvial plain and the upland alluvial valley bottoms in the southwestern part of the map area.

Areas of Past Liquefaction

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

Artificial Fills

Non-engineered fill placements are often composed of uncompacted, silty or sandy material and, therefore, are generally considered to have a high potential for liquefaction when saturated. Many of the levees in the Sacramento-San Joaquin Delta region consist of non-engineered fill, which are underlain by peat. No data on the shear strength properties of the levees along Old River were collected during the course of this study. As such, it was assumed that these levees consist of non-engineered fill.

Artificial fill areas in the southwestern part of the Clifton Court Forebay Quadrangle large enough to show at the scale of project mapping (1:24,000) are associated with the California Aqueduct, which is designed, operated, and maintained by the California Department of Water

Resources (DWR). These fills are treated as engineered fills, consistent with the construction practices of DWR, and are considered to have a low potential for liquefaction.

Areas with Sufficient Existing Geotechnical Data

CGS reviewed 772 borehole logs that included penetration and associated geotechnical test data required to quantitatively analyze liquefaction potential of the geologic units in the map area. Of the 772 borehole logs evaluated in this study, 701 are from boreholes drilled in adjacent quadrangles, located within the Sacramento-San Joaquin Delta plain. The remaining 71 boreholes are located on the levees surrounding the Byron Tract and islands in the Clifton Court Forebay Quadrangle. These 71 borehole logs were acquired from URS and used in a 2010 CGS liquefaction hazard study of the Sacramento-San Joaquin Delta area (Real and Knudsen, 2010). As part of this previous investigation, CGS performed a quantitative analysis of the geotechnical boreholes to evaluate liquefaction potential using an earlier version of the CGS 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 results from this previous CGS quantitative borehole analysis were incorporated into this study and evaluated. Collectively, these logs provide the level of subsurface information needed to conduct a regional assessment of liquefaction susceptibility with a reasonable level of certainty.

Much of the surface area of the delta-alluvial plain is covered by Holocene alluvium with a thickness generally greater than 40 feet, which CGS considers to be the maximum depth at which liquefaction can cause damaging ground failure at the surface. Examination of geotechnical boring logs shows that the Sacramento-San Joaquin Delta-alluvial plain deposits consist of discontinuous layers of sand, gravel, silt, clay, and peat. Analyses of blow count values and other soil property measurements reported in the logs indicate that most of the boreholes penetrated one or more layers of material that may liquefy under expected earthquake loading. These deposits include modern stream channel deposits (**Qhc**), Holocene flood plain deposits (**Qhfp**) latest Pleistocene to Holocene alluvial fan, fine facies deposits (**Qhff**), and latest Pleistocene to Holocene undifferentiated alluvium (**Qha**). Due to shallow historic-high groundwater levels in the Clifton Court Forebay Quadrangle, all of these Holocene materials are highly susceptible to liquefaction. Accordingly, all areas where the identified layers of liquefiable material are saturated within 40 feet of the surface are included in the Seismic Hazard Zone.

In general, liquefaction analyses of boreholes in older Quaternary units indicate a low potential for liquefaction. However, in some areas in adjacent quadrangles, borehole logs penetrating older Quaternary alluvium indicated the presence of potentially liquefiable material in the upper 20 feet of some Pleistocene fans (**Qpf**). Accordingly, where unit **Qpf** is mapped in the Clifton Court Forebay Quadrangle, Seismic Hazard Zones were extended into older Quaternary units where saturated at a depth of 20 feet or shallower. The boundary for the Seismic Hazard Zone is defined in part by the contact of young Quaternary deposits with bedrock and/or old Quaternary deposits and extends along the base of the foothills in the southwestern part of the map area and into the upland alluvial valleys.

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. Adequate geotechnical borehole information is lacking for most of the Clifton Court Forebay Quadrangle outside of the levees. All of the Quaternary units mapped in the Clifton Court Forebay Quadrangle extend into adjacent quadrangles with sufficient borehole coverage to adequately assess the liquefaction susceptibility and lithologic character of the units. These units contain varying amounts of loose, granular materials that are saturated because of the presence of near-surface groundwater and proximity to delta channels. 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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SECTION 4: EVALUATION OF EARTHQUAKE-INDUCED LANDSLIDE HAZARD

in the

CLIFTON COURT FOREBAY 7.5-MINUTE QUADRANGLE, RIVERSIDE COUNTY, CALIFORNIA

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CALIFORNIA GEOLOGICAL SURVEY

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 Clifton Court Forebay Quadrangle.

ZONING TECHNIQUES

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method 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 on a GIS 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 Clifton Court Forebay Quadrangle 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 historic earthquake activity.
2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

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

Delineation of Earthquake-Induced Landslide Hazard Zones

Upon completion of the earthquake-induced landslide hazard evaluation within the Clifton Court Forebay Quadrangle, CGS applied the above criteria to its findings to delineate Earthquake Zones of Required Investigation for earthquake-induced landslides. Based on our evaluation, about 0.06 square kilometers (0.02 square miles) of the quadrangle are included in the Seismic Hazard Zone for landslides. These zones are present on the side slopes of moderately steep embankments mapped as artificial fill around the California Aqueduct in the southwestern corner of the map area. Following is a description of the criteria-based factors that governed the construction of the Seismic Hazard Zone Map for the Clifton Court Forebay Quadrangle.

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). As such, CGS typically includes all existing mapped landslides in the landslide hazard zone. However, a landslide inventory had not been completed for the area covered by the Clifton Court Forebay Quadrangle prior to the delineation of landslide hazard zones. Thus, no mapped landslides have been included in the landslide hazard zones for the Clifton Court Forebay Quadrangle.

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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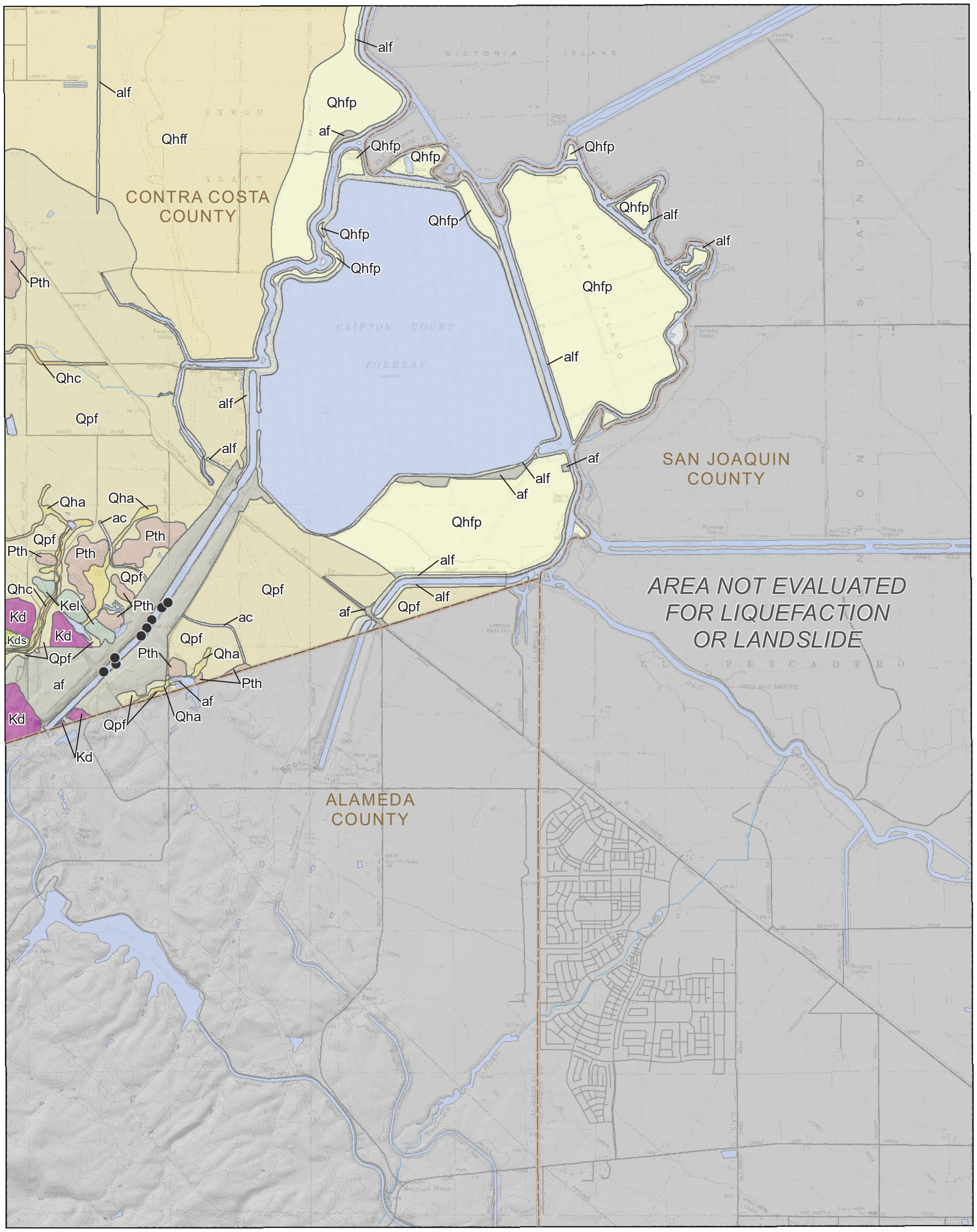
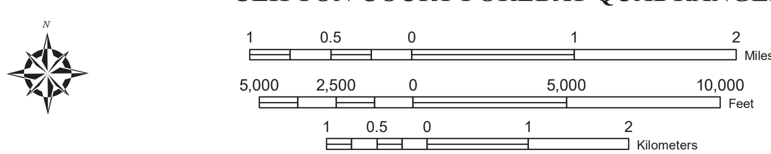


Topographic base map from USGS. Contour interval 20 feet. Roads from www.census.gov. Scale 1:75,000. Map preparation by Janine Bird, CGS.

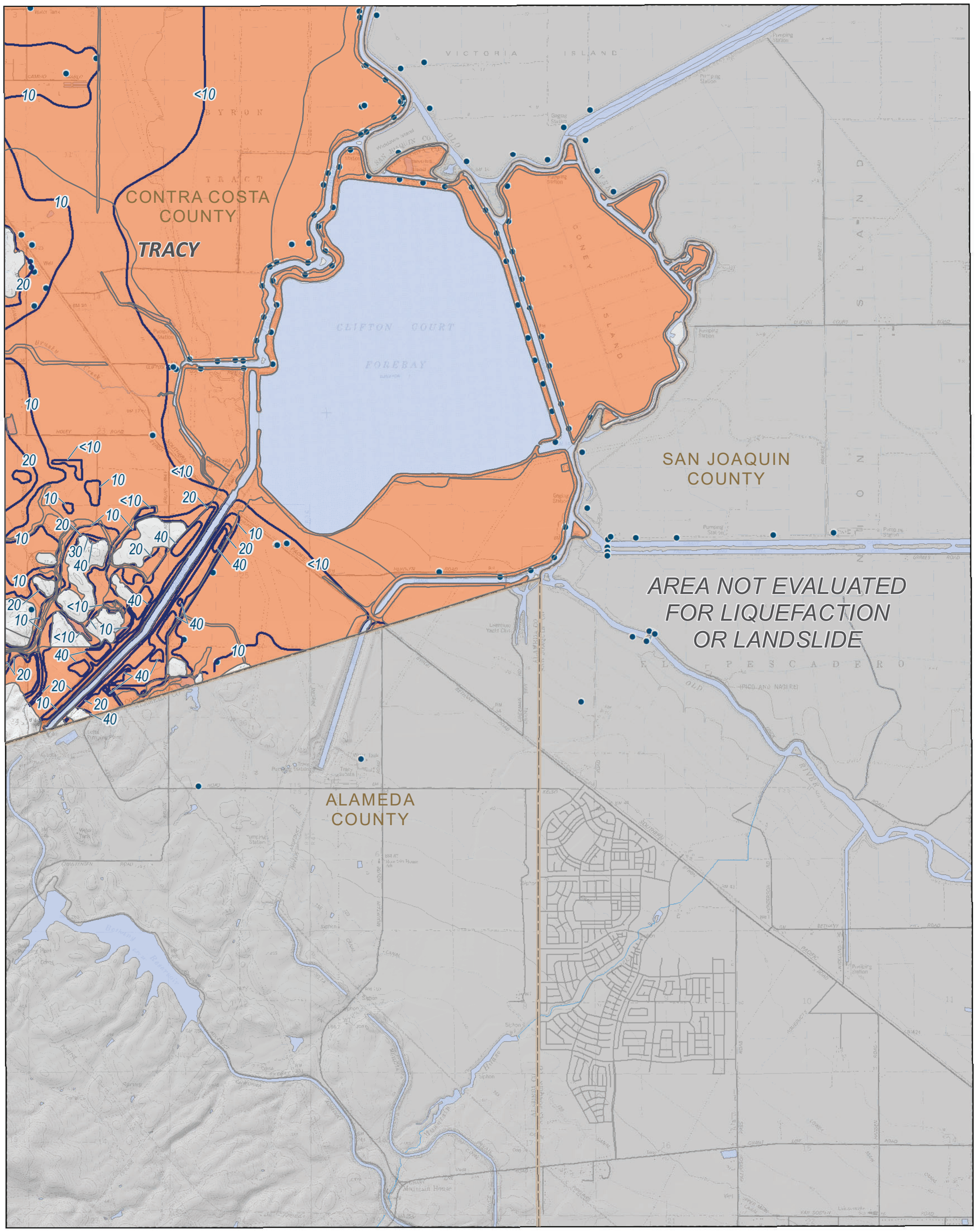
CLIFTON COURT FOREBAY QUADRANGLE



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

● Shear test sample location

Plate 1.1 Geologic materials map with locations of shear test samples used in evaluating landslide hazard, Clifton Court Forebay Quadrangle, California.



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

CLIFTON COURT FOREBAY 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

- Groundwater measurement location
- 10 Depth to historic-high groundwater (in feet)
- Groundwater basin limits

Plate 1.2 Groundwater basins, depth to historic-high groundwater levels, and groundwater data points, Clinton Court Forebay Quadrangle, California.

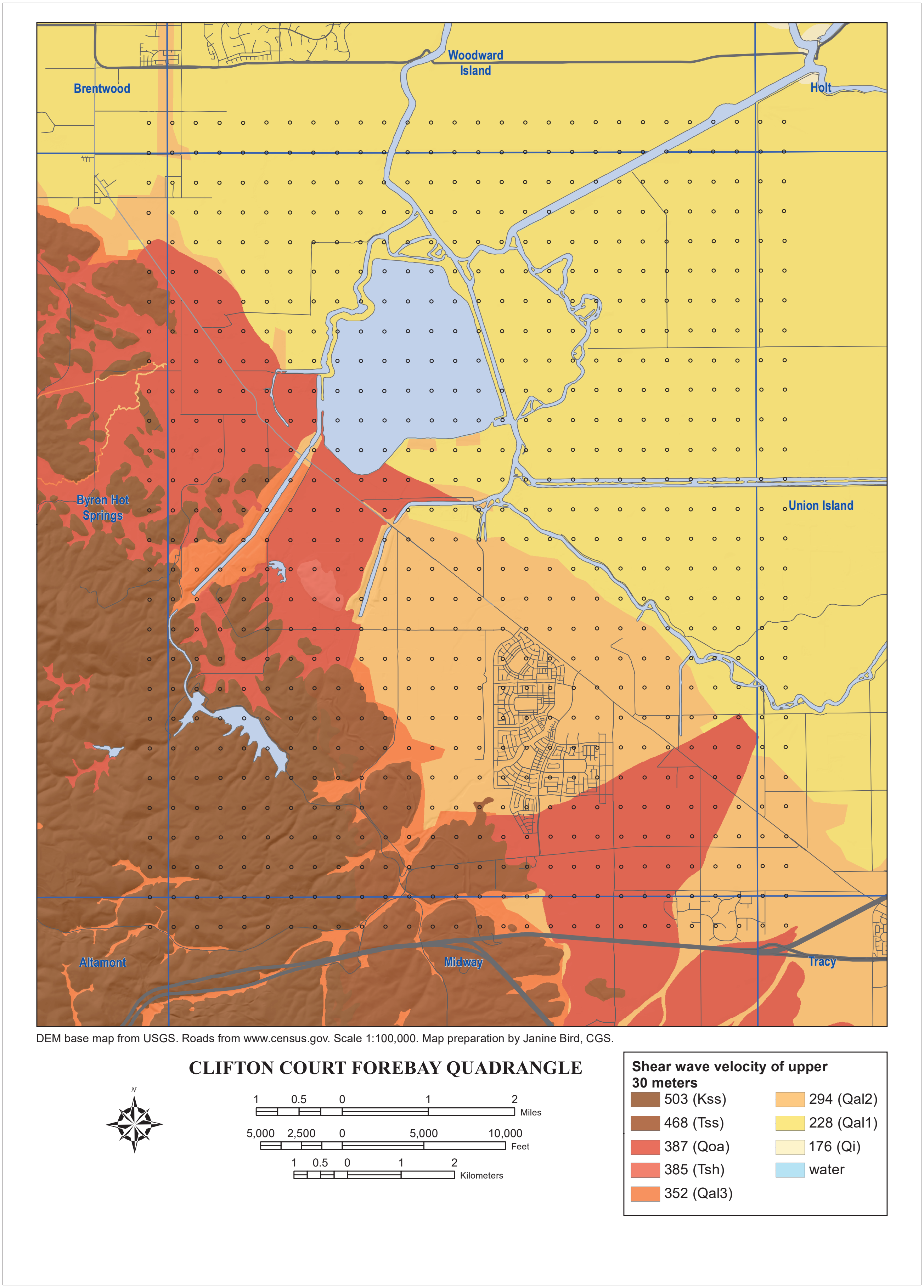


Plate 2.1 Map of V_{S30} groups and corresponding geologic units extracted from the state-wide V_{S30} map developed by Wills and others (2015), Clifton Court Forebay Quadrangle and surrounding area, California.

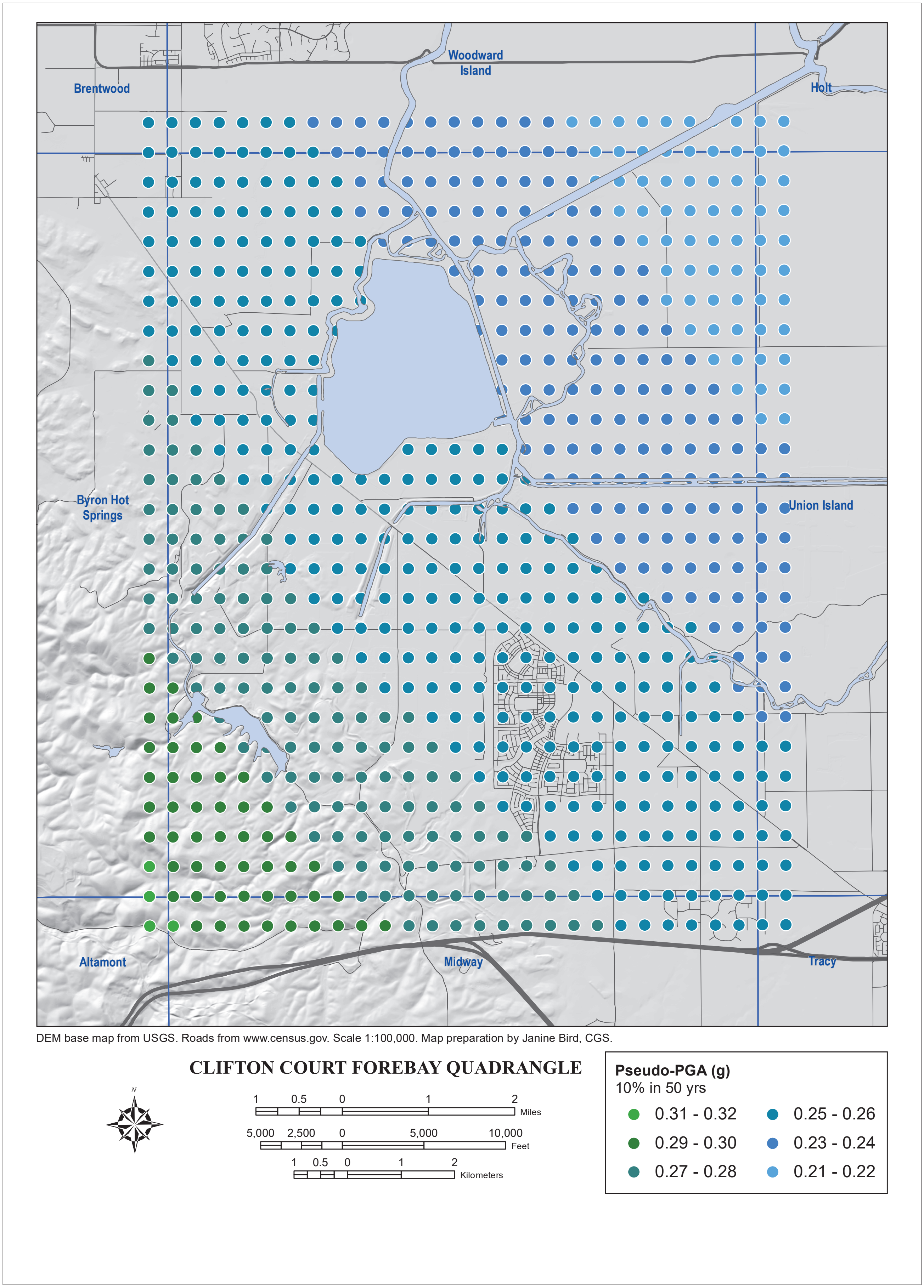
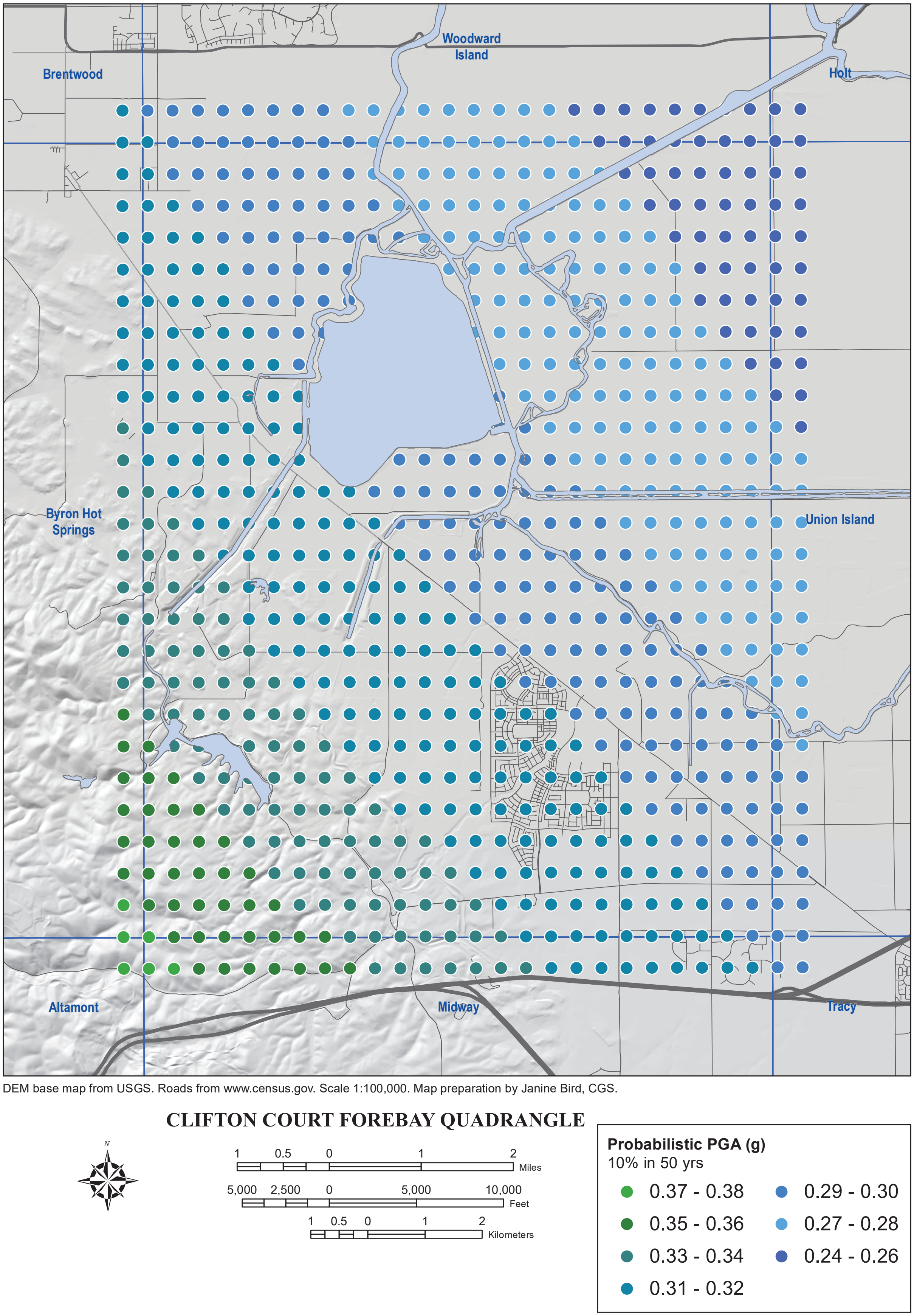


Plate 2.2 Pseudo-PGA for liquefaction hazard mapping analysis, Clifton Court Forebay Quadrangle and surrounding area, California.



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

Plate 2.3 Probabilistic peak ground acceleration for landslide hazard mapping analysis, Clifton Court Forebay Quadrangle and surrounding area, California.

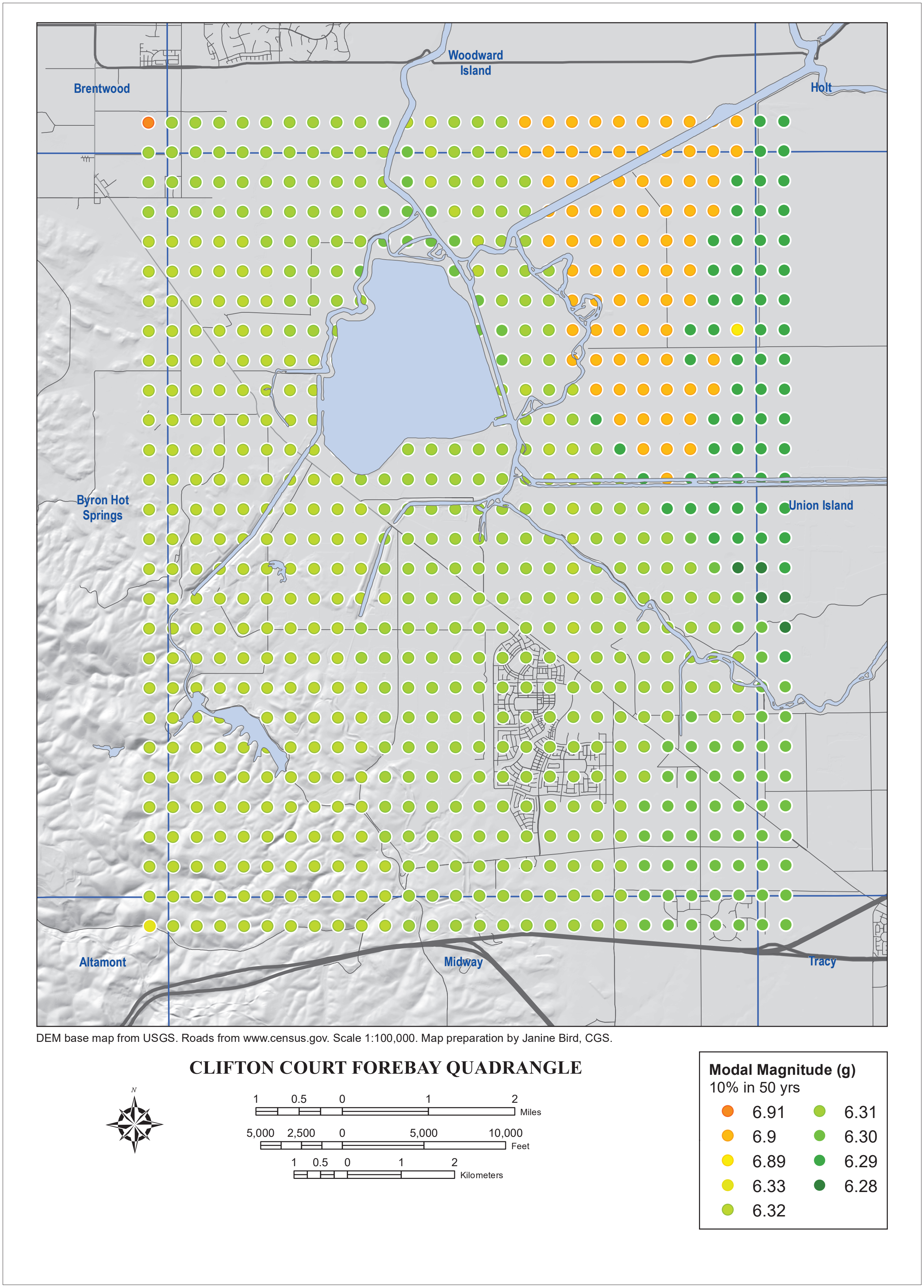


Plate 2.4 Modal magnitude for landslide hazard mapping analysis, Clifton Court Forebay Quadrangle and surrounding area, California.