APPENDIX E

GEOTECHNICAL REPORT

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GEOLOGICAL, GEOTECHNICAL, AND HYDROGEOLOGICAL REVIEW
PORTUGUESE BEND LANDSLIDE REMEDIATION PROJECT
RANCHO PALOS VERDES, CALIFORNIA

by
Haley & Aldrich, Inc.
San Diego, California

for
Chambers Group, Inc.
Santa Ana, California

File No. 0135399-001
January 2023

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18 January 2023
File No. 0135399-001

Chambers Group, Inc.
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Santa Ana, California 92707

Attention: Mr. Michael McEntee, President

Subject: Geological, Geotechnical, and Hydrogeological Review
Portuguese Bend Landslide Remediation Project
Rancho Palos Verdes, California

Ladies and Gentlemen:

As requested, Haley & Aldrich, Inc., (Haley & Aldrich) conducted a geological, geotechnical, and hydrogeological review of the proposed Portuguese Bend Landslide Remediation Project in Rancho Palos Verdes, California.

Our review was conducted on behalf of the Chambers Group, Inc., in accordance with our proposal dated 15 July 2020, our change order dated 8 July 2022, and your subsequent Task Order #8 dated 23 July 2022 under our contract dated 24 September 2014. This final document addresses the City of Rancho Palos Verdes comments you provided in your 7 December 2022 email. Please contact us if you have any additional questions or comments.

Sincerely yours,
HALEY & ALDRICH, INC.

Robert K. Scott

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Senior Associate Hydrogeologist

Catherine H. Ellis

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Senior Associate, Geotechnical Engineer

Enclosures

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GEOLOGICAL, GEOTECHNICAL, AND HYDROGEOLOGICAL REVIEW
PORTUGUESE BEND LANDSLIDE REMEDIATION PROJECT
RANCHO PALOS VERDES, CALIFORNIA

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CHAMBERS GROUP, INC.
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1. Project Background

As requested, Haley & Aldrich, Inc., (Haley & Aldrich) conducted a geological, geotechnical, and hydrogeological review of the proposed Portuguese Bend Landslide Remediation Project in Rancho Palos Verdes, California (Site). Our review was conducted on behalf of the Chambers Group, Inc., (Chambers) in accordance with our proposal dated 15 July 2020, our change order dated 8 July 2022, and your subsequent Task Order #8 dated 23 July 2022 under our contract dated 24 September 2014.

Our understanding is based on the draft Environmental Impact Report (EIR) currently under development (Chambers, 2022). The Portuguese Bend Landslide (PBL), a component of the City's ancient Landslide Complex, is an ancient landslide mass that shows possible signs of movement as far back as 120,000 to 800,000 years ago (DBSA, 2018). In more recent times, the landslide was reactivated during the 1950s when Los Angeles County was constructing an extension to Crenshaw Boulevard down the south side of the Palos Verdes Hills to an intersection with Palos Verdes Drive South. A small landslide occurred in 1956 during the road construction, and approximately 160,000 cubic yards of material was removed and placed at the head of the PBL (DBSA, 2018). At the time of the Crenshaw Road extension project, the homes were on septic waste systems, and there were no storm drains to manage surface water flow. Both factors contributed to groundwater recharge in the PBL area at this time. The increased pore water pressure that resulted from elevated groundwater levels was considered a significant factor to landslide movement in the PBL area (Daniel B. Stephens & Associates, Inc. [DBSA], 2018).

Since the reactivation of the PBL in 1956, it has moved at various rates and is one of the largest continuously active landslides in the United States. Horizontal displacement of over 8.5 feet per year has been measured within the eastern and seaward subslides (DBSA, 2018). The continued land movement has resulted in significant damage to homes, moving some of them by hundreds of feet onto other properties. It has also resulted in damage to utilities and roadways, including Palos Verdes Drive South, a major transportation route, and to a sanitary sewer trunk line serving the Palos Verdes Peninsula (Peninsula).

Sudden and major land movement, which has occurred previously in nearby landslides, has the potential to close Palos Verdes Drive South because of roadway failure. This potential closure would bifurcate the City of Rancho Palos Verdes (City), eliminating a major connector and result in a 15-mile detour. This would impede wildfire evacuations since Palos Verdes Drive South is one of only a few evacuation routes for the entire high-risk Peninsula. Equally critical would be the potential interruption of the sanitary sewer transmission trunk line. This could require tens of thousands of residents to relocate and result in business closures while repairs are being made. A rupture of the sewer trunk line and uncontrolled discharge of untreated sewage also poses a threat to the sensitive Pacific Ocean shoreline ecosystem, including the Abalone Cove Ecological Reserve.

The City and its citizens are seeking to minimize landslide movement to preserve infrastructures and open lands; preserve natural vegetation and recreational facilities within the Palos Verdes Nature Preserve; reduce soil erosion losses; and reduce health and safety concerns related to the integrity of the surrounding road system, sewer system, and other infrastructure. The City initiated an EIR to meet these objectives by evaluating environmentally sensitive engineering solutions and measures to reduce movement of the PBL to protect the public.

Our review is based on the documents provided for the preparation of the EIR as well as readily available, publicly published references. The documents provided are listed in the References in the last section of this document.

2. Geologic and Geotechnical Review

The PBL is a section of a much larger ancient landslide complex on the south side of the Palos Verdes Hills, one that had been previously dormant for possibly millenniums. In the PBL segment of the ancient landslide, it was first noticed to be moving in the summer of 1956. This south-trending seaward movement is ongoing today. Merriam (1960) recognized that from the summer of 1956 to September 1959, the PBL moved 260 acres of land as much as 68 measurable feet.

Movement of the PBL was triggered by roadwork by Los Angeles County road crews who were constructing an extension of Crenshaw Boulevard from Crest Road, through Portuguese Bend, to Palos Verdes Drive South, as previously noted. Approximately 160,000 cubic yards of soil, which had been excavated for the road, had been relocated on the head of the ancient landslide. In August 1956, the PBL broke a water line that caused flooding and subsequent significant land movement. Many homes began to move downslope, and roads on the PBL had to be rerouted. Many residents left their homes as a result of this landslide. Approximately 100 homes were damaged, while more than 50 were totaled. The Portuguese Bend club house, restaurant, and pool were destroyed. (Maureen Megowan Real Estate, webpage date and reference of data unknown; Geophile.net, Palos Verdes fieldtrip #3). A map of the City of Rancho Palos Verdes and Site is shown on Figure 1 by Geo-Logic Associates ([Geo-Logic], 2019) in Appendix A.

The following sections describe the general geologic setting and hazards of the PBL and surrounding areas.

2.1 GEOLOGIC SETTING

The Site is located within the Southwestern structural block of the Los Angeles Basin portion of the Peninsular Range Geomorphic Province of California, where it is merging with the Transverse Range Geomorphic Province of California to the north. Geologic structures, as they relate to the Palos Verdes Hills and the PBL area, including faulting and folding, are discussed in the following sections.

2.1.1 Regional Geology

The Site is located in the geologic structure of the Palos Verdes anticlinorium (geographically, the Palos Verdes Hills). The Palos Verdes Hills are located south of the Southwestern block of the Los Angeles Basin in the Peninsular Range Geomorphic Province of California. The Los Angeles Basin is one of over twenty Neogene basins found throughout western California today (Behl, 2007). The Palos Verdes Hills consist mostly of Miocene marine sedimentary rock of the Monterey Formation with some middle Miocene basalts and Pliocene-Pleistocene marine and terrace sediments. The Monterey Formation and its volcanic equivalents drape unconformably over the Mesozoic metamorphic basement in this portion of the Los Angeles Basin.

The Monterey Formation or its comparable sedimentary rocks accumulated in the Los Angeles Basin from ~17-5 million years ago ([Ma]; Behl, 2007). During that time, a depositional center was forming in response to a complex combination of conditions which included tectonic “restructuring” along with localized subsidence, high eustatic sea-level, strengthening of coastal upwelling, and the establishment of the modern thermohaline circulation (Ingle, 1981ab; Barron, 1986; Behl, 1999).

The Palos Verdes anticlinorium today, at its highest point, is around 1,473 feet above sea level at the San Pedro Hills of the Palos Verdes Uplift. Tectonic uplift of the hills occurred since the latest Miocene based on a tectonic reorganization of the southern California region (Wright, 1991; Ingersoll and Rumelhart, 1999). In the Palos Verdes Hills, the Monterey Formation, with a basal blue-schist breccia or conglomerate (in places mapped as San Onofre Breccia), was deposited directly onto uplifted Mesozoic Catalina Schist. The Palos Verdes Hills were initially located on the deeper, offshore edge of a shallower, northwest-trending "schist ridge" that acted as a sill or peninsula bounding the Los Angeles Basin (Yerkes et al., 1965; Wright, 1991; Bohannon and Geist, 1998), and subsequently tectonically uplifted the Los Angeles Basin into a bathymetric high. Wright (1991) interprets the relatively fine nature of Monterey Formation sediments in the Palos Verdes area compared with Puente facies, to the east of the Hills and on the eastern side of the Palos Verdes Fault, in the subsurface of the central Los Angeles Basin as evidence for slow uplift of the submarine ridge beginning as early as the late middle Miocene, with accelerated uplift and bathymetric shoaling of the Palos Verdes Hills occurring after the mid-Pliocene (~3 Ma; Nardin and Henyey, 1978; Behl, 2012).

Past studies show the Palo Verde Hills' tectonic uplift by dating remnants of marine terraces, chiefly over the past ~400,000 years (Bryant, 1982; Ponti, 1989; Orme, 1998; Shlemon, 2004). The Palos Verdes Hills have 13 mappable marine terraces, with the oldest and highest marine terrace possibly as old as 1.4 Ma (Woodring et al., 1946; Bryant, 1982). While the average uplift rate of the Palos Verdes Peninsula is ~0.3mm/year, the relative elevations of the younger marine terraces (80 and 125 thousand years ago [ka]) suggest that the rate of uplift varies across the doubly plunging anticline and may have accelerated during the latest Quaternary, reaching rates as high as ~0.7mm/year (Orme, 1998).

2.1.2 Local Geology

Miocene sediments make up most of the bedrock material on the Palos Verdes Hills. The bedrock consists mostly of the lower, middle, and upper Altamira Shale, the Valmonte Diatomite, and the Malaga Mudstone of the Monterey Formation. The Site is located on the Upper Altamira Shale member of the Monterey Formation. The geologic map is shown on Figure 3 by Geo-Logic (2019) in Appendix A. This part of the Altamira Shale weathers white and has thin beds of siliceous and phosphatic shale with interbeds of limestone, dolostone, siltstone and diatomaceous material. In the vicinity of Portuguese Bend, Upper Altamira Shale sediments have been disturbed by landslide movement and mechanical grading.

The Altamira Shale (Behl, 2007) is estimated to have been deposited between ~20 to 10 ma during an eruption of volcanism that consisted of thick layers of volcanic tuff. The tuff, when exposed to water, weathers into layers of bentonite clay that is the base of the PBL plane. San Onofre Breccia and the Catalina Schist are found at depth below the landslide, are not exposed at the surface, and are major contributors to the landsliding areas. Therefore, these formations are not discussed in any detail in this report. Landslides and marine terraces are discussed in detail within the following sections.

2.1.3 Ancient and Active Landslide Complexes

The Ancient Landslide Complex in the Palos Verdes Hills was best classified as a complex landslide (Eckel, 1958), since it consists of numerous independent merging slides of various forms (Merriam, 1960). The Ancient Landslide Complex first started to move ~37 ka. This landslide stopped moving and stabilized before historic times. The present movement at the lower end is a slow earthflow by which crushed, altered landslide material produced by older sliding has undergone slow, plastic flow down a low gradient to the south or toward the ocean. Movement farther upslope from the coastal bluffs is characterized by the shifting of very large blocks that are dislocated in relation to one another and are moderately cracked and deformed. Uppermost zones show limited rotational movement as block slumps.

Given the anthropogenic processes on the Ancient Landslide Complex, such as private sewage disposal systems, landscape irrigations, and the unfinished grading of the extension of Crenshaw Boulevard from Crest Road to Palos Verdes Drive South, the PBL segment of the Ancient Landslide reactivated. The PBL started to creep in 1956 and is still creeping today. The mechanisms of the PBL are discussed in the Geologic Hazards section below.

2.2 GEOLOGIC HAZARDS

The primary geologic hazards in California are:

- Seismic hazards related to earthquakes, including ground rupture, liquefaction, strong motion, and tsunami;
- Landslides of all kinds, including seismically triggered landslides, debris flows, mud flows, and rock falls;
- Mineral hazards such as asbestos, radon, and mercury; and
- Volcanic hazards, such as ash fall, lava flows, lahars, pyroclastic flows, toxic gases, and volcanic landslides.

A discussion of the geologic hazards relative to the Site is presented below.

2.2.1 Earthquake Faults

The PBL is located within the seismically active area of southern California, where there is the potential for the Site to experience strong ground shaking from local and regional faults. Within the Palos Verdes Hills, faulting is very common, though the identified faults do not display evidence of Holocene movement or being active at this time. Many of the faults located in the Palos Verdes Hills are normal faults associated with large graben structures and could be associated with landsliding. The Cabrillo Fault, found in the eastern and trending to the central part of the Palo Verdes Hills, is a splay of the Palos Verdes Fault and has not been found to have any Holocene displacement at this time, therefore it is not discussed in the following sections.

During a fault search using the 2008 National Seismic Hazard Maps - Source Parameters, the latitude and longitude of approximately the center of the landslide was determined to be N 33.740255 and W 118.361896, from Google Earth Pro.

Using the Working Group on California Earthquake Probabilities (1995), we prepared Table 1 to show a list of all known active faults and their distance within a 25-mile radius of the subject Site. The Table indicates fault distance from the Site, name of the fault, slip rate, dip of fault, rupture depth of the top and bottom of the fault in kilometers, maximum calculated magnitude, and the length.

2.2.2 Seismic Setting and Fault Rupture Hazard

The closest identified Holocene fault near the Site is the Palos Verdes Fault, which is located about 3.7 miles north of the Site so surface fault rupture would not be an issue in the PBL area. This Fault has a right lateral strike-slip movement offshore and changes to a likely thrust movement onshore where it wraps around the hills to the north. The Palos Verdes Fault can generate an earthquake with a maximum magnitude of M=7.7, which could cause an earthquake with the greatest magnitude in the vicinity of the Palos Verdes Hills. Since the Palos Verdes Fault is closest to the proximity of the Site and would have the greatest earthquake magnitude, a maximum probable earthquake on the Palos Verdes Fault could cause extensive damage and slope failures within the PBL from strong motion during a maximum probable earthquake.

The other fault closest to the Project having displaced during the Holocene is the Newport-Inglewood Fault Zone, which is located approximately 10.3 miles to the northeast. This Fault could have a probable earthquake of M=7.5, which is considered a very powerful earthquake and could cause massive amounts of damage and slope failures within the Palos Verdes Hills. Because of the Fault's distance from the landslide, there is a limited potential for surface fault rupture from this Fault on the PBL, though there could be slope failures on the Palo Verdes Hills from strong motion during a maximum probable earthquake.

The Los Angeles Basin is known for its blind thrust faults, which are thrust fault that do not break the earth's surface, and earthquakes from these faults. The potential of large earthquakes with no surface ground rupture from the blind thrust faults is high in the Los Angeles Basin. During earthquakes such as the 1994 Northridge Earthquake, uplift can occur (United States Geological Survey [USGS, 2008]). Moderate shaking from an earthquake on one of the closer LA Basin blind thrusts could possibly be detected throughout the Hills, cause low to moderate damage to buildings and infrastructure, and could cause creep on the PBL to increase or reoccur.

Nothing is known about the physical properties of the Palos Verdes Hill Fault except what was modeled by Ward, 1994, so this Fault is being mentioned but not expressed as being an earthquake fault. If the Palos Verdes Hills Fault does exist, it is unclear whether it meets the criteria for an active fault. The other faults mentioned in the following pages are known Holocene faults, and strong motion from a considerable earthquake throughout the Palos Verdes Hills and at the PBL Site could cause possible considerable damage.

2.2.3 Slope Stability/Landslides

The Site is within an a mapped and widely known area for landslides, which the State of California has zoned as required investigation. When in a zone of investigation, it is probable that the slope or landslide can fail during a moderate to large earthquake, per the California Geological Survey, so geotechnical practitioners are required by the State of California to perform a slope stability investigation.

One of the features of the Palos Verdes bentonite is the ease and rapidity with which colloidal gels are formed when water content is increased, a characteristic known as highly thixotropic. Specifically, change in water content has a great effect on the properties of the Palos Verdes bentonite. Doubling the moisture content decreases the unconfined shear strength by more than 10 times (Kerr, 1967).

Sea bluff erosion and retreat is another geologic condition that could accelerate instability of the PBL by reducing the mass of rock (natural buttress) at its toe. Since the landslide rock and soil, at the toe, is crushed and loose from landslide slippage along the slide plane, it is readily susceptible to the coastal bluff erosion retreat process. As the landslide thrusts out toward the beach, wave action can over steepen and undercut the toe of the bluff, forming steep overhangs that result in continuous rockfalls. These rockfalls regenerate a beach protection zone that results in reducing the rate of wave action erosion. Additionally, artesian springs or groundwater sapping at the landslide toe can cause erosion and result in a steep overhang that can eventually fall onto the beach, as does the factor of wave action. Artesian groundwater conditions are discussed in the Hydrogeology section of this document.

The PBL is a hazard to buildings and infrastructure since it is creeping and experiencing movement. The sea bluff erosion can present additional hazard from rockfalls as the landslide creeps toward the ocean. Loose rocks and wave action could increase the falling rock hazard.

2.2.4 Liquefaction

Liquefaction involves sudden loss in strength of a saturated, cohesionless soil (predominantly sand) caused by the buildup of pore water pressure during cyclic loading, such as that produced by an earthquake. This increase in pore water pressure can temporarily transform the soil into a fluid mass, resulting in vertical settlement and can also cause lateral ground deformations. Typically, liquefaction occurs in areas where there are loose sands and the depth to groundwater is less than 50 feet from the surface. Seismic shaking can also cause soil compaction and ground settlement without liquefaction occurring, including settlement of dry sands above the water table.

The beach sands at the toe of the landslide are saturated with ocean water based on sea level and the uprun by the wave action. Although the sands contain gravels and cobbles., the sands between the coarser-grained material could liquefy. If the beach sands liquefy during a seismic event, the coastal bluffs along the landslide toe could become unstable. The onshore portion of the Site includes landslide materials that consist of a mixture of clay, silt, sand, gravel, and cobbles with boulders. The liquefaction potential on the onshore portion of the landslide is unknown at this time. Within the areas of shallow groundwater with saturated sand deposits, the liquefaction potential could increase in the landslide mass if the saturated sands are in the upper 50 feet. The potential of the PBL experiencing liquefaction would be localized to the sandy deposits if it did develop.

2.2.5 Tsunami Hazard

2.2.5.1 Seismic Generated Tsunami

The Site is on the eastern portion of the Pacific Ocean known as the Ring of Fire or the Circum-Pacific Belt. Very large offshore earthquakes and volcanic eruptions, associated with subduction zone thrusting, have been known to occur along the rim of the Ring of Fire. When certain types of earthquakes of large magnitudes occur within this region, there may be a tsunami potential throughout the Pacific Ocean. During a seismic event, if there is complete rupture of the fault and the rupture reaches the seafloor with particularly large vertical displacements, as with the 2011 Tohoku earthquake (Ide et al., 2011), the displacement of the sea floor would likely be generating a tsunami as it did along mainland Japan as experienced during the offshore Tohoku earthquake. The greater the displacement in a short period of time, the larger the tsunami. Other factors that would control the size of the tsunami wave would be distance or how sheltered the area is from the open sea. These factors could decrease the intensity of a tsunami (USGS, 1985).

The type of shoreline affects the intensity of a tsunami. Along coasts consisting of elevated sea bluffs, the runup would be more intense with more copious amounts of bluff erosion and damage than with a tsunami of the same intensity inundating an estuary or low-lying coastal region where flooding may be the main factor. Numerical models modified from Houston, 1980, suggest that during a statistical 500- or 100-year tsunami along the Palos Verdes Hills southern coast, the runup wave would vary from 5 feet to 4 feet, respectively, above the current sea-level.

Hence, an oblique right lateral earthquake on the Palos Verdes Fault would be unlikely to cause a large tsunami. With this in mind, for a seismic event on the offshore portion of the Palos Verdes Fault, maximum magnitude and onshore ground motion should both be lower than for rare ruptures from any unknown offshore California thrust faults. Such movement could still generate a tsunami that has the potential to undermine the base of the coastal bluffs.

2.2.5.2 Landslide Generated Tsunami

Submarine landslides are the second most frequent tsunami source worldwide. However, their complex and diverse nature of origin combined with their infrequent event records, make predictive modelling challenging. More research needs to be conducted to determine how these modeling methods, combined with the probabilistic context, can be used to improve landslide tsunami hazard analysis in the future. In the San Pedro Bay, offshore to the south of the Site, the submarine landslides potential is high. At this time, the possibility of a submarine landslide-induced tsunami could be a secondary effect of a large onshore or offshore earthquake in the general vicinity.

2.2.6 Subsidence

The National Oceanographic and Atmospheric Administration (1998) defines subsidence as “the sinking of the ground from underground material movement is most often caused by the removal of water, oil, natural gas, or mineral resources out of the ground by pumping, fracking, or mining activities.” Subsidence can also be triggered by natural events such as earthquakes, soil compaction, glacial isostatic adjustment, erosion, sinkhole formation, and adding water to fine soils deposited by wind (loess deposits). Subsidence can occur on a wide scale: very large areas like whole states or provinces, or very small areas like the corner of your yard. In the Chesapeake Bay area, for example, land subsidence may be caused by a combination of sediment loading (when rivers deposit sediment in an area that then sinks under the additional weight) and sediment compaction after groundwater is removed.

Subsidence could occur on the PBL during a large earthquake when loose, fractured and or porous materials consolidate from moderate to large earth shaking resulting in the formation of small depressions. The withdraw of water during the dewatering of the landslide or adding artificial fill in areas where the soils are unconsolidated can be another source of potential subsidence on the landslide. Also, movement of different landslide blocks along the slide plane can cause rises and basins (hummocky topography). With continued landslide movement, the rises can continue to go up and the basins go down or even the reverse. The areas of subsidence on the PBL may be small and isolated, and although minor, could be a continuous problem with different amounts of movement.

Mobile clay along the slide plane of the PBL consists essentially of bentonite or montmorillonite and is thought to be extruded from the slip planes as they emerge below the sea level in the San Pedro Bay south where the landslide toes out below the ocean (Kerr, 1967). Removal of this clay from possible oversaturation makes the clay flow like liquid from beneath portions of the slide area and is likely responsible for subsidence east of Portuguese Canyon. Subsidence from clay extrusion from the PBL area could be a problem and needs to be checked periodically to see if the loss of clay along the slide plane is continuing or if has stopped. The instrumentation plan, including inclinometers, should incorporate monitoring for movement of the clays.

2.2.7 Flood Hazard

A flood is any relatively high streamflow overtopping the natural or artificial banks in any reach of a stream that can inundate an area. Statistically per region, zones are categorized into 500- and 100-year floodplains. A 500-year Floodplain is an area of minimal flood hazard. A 100-year Floodplain is an area with a 1% annual chance of flooding. Within developed countries, flooding has been controlled and reduced by flood control devices such as storm drains, channelization, construction of levees, and other engineered infrastructure. With these engineered solutions, there is a reduction of inundation from storm flooding as long as the measures are maintained, and the flooding is not greater than the capacity of the device.

The Site does not fall within a 100- or a 500-year Federal Emergency Management Agency flood zone.

2.2.8 Volcanic Eruptions

California is known for its catastrophic earthquakes and wildfires, but there are other natural hazards in the state. The state also has a dozen restive volcanoes that stretch nearly from one end of the state to the other. California is host to every type of volcano that can cause various types of volcanic hazards. The specific hazards to people and property depend on which volcano type erupts, the style (effusive or explosive), the volume of lava, the location of the vent, the eruption duration, and local hydrologic (water) conditions. The severity of volcanic eruption hazards generally declines with distance from the volcano vent or volcanic field. Although there are abundant Tertiary or older volcanic rock deposits throughout the mountainous and hilly areas of the Los Angeles region, including the PBL area, volcanic activity ceased during the Miocene. The Site is not in a volcanic hazard zone and so the potential of a volcanic eruption is low.

2.3 GEOTECHNICAL HAZARDS

Primary geotechnical hazards in the area include soil collapse, soil expansion, erosion, and groundwater. A discussion on soil collapse and soil expansion are presented below. Erosion and groundwater are discussed in the Hydrogeology section.

2.3.1 Soil Collapse

Collapsible soils are soil structures subject to a large and sudden reduction in volume upon wetting, and are often found in young alluvial deposits within arid or semi-arid environments. Collapsible soil structures contain granular particles with voids supported by a matrix of clay or silt particles or by carbonate cementation. Hydration of the matrix can result in a loss of support, resulting in densification and collapse of the soil structure. The resulting settlement can be severe enough to distress structures or improvements bearing on this soil. Based on the geologic conditions at the Site, including lack of arid or semi-arid conditions, the collapse potential for near-surface Site soils is negligible.

2.3.2 Soil Expansion

Expansive surface soils contain clay particles that experience high volume changes following exposure to seasonal or man-made fluctuations in moisture content. The volume changes from these soils can negatively impact foundations and other improvements if mitigation methods are not implemented. The bentonite clays in the PBL are subject to significant volumetric changes with changes in moisture content. However, since there are no structures planned, impacts from movement associated with the presence of expansive soil will be negligible, assuming that earthwork will include proper moisture conditioning of the clays where encountered.

2.3.3 Earthwork

Earthwork poses a challenge for landslide remediation and repairs. Potential concerns include instability during construction as well as integrating the edges and boundary of the repair into the undisturbed conditions.

Earthwork includes the excavation and movement of soil during the execution of a project. For a landslide repair, attention must be given to the timing and the location of the removal of soil or cuts. Although not anticipated, removal of material could result in undermining the toe of the landslide. Removal of the toe reduces the stability of the slide mass and can generate slide movement, sometimes instantaneously or over time. Placement of new material, whether as a temporary stockpile or as a permanent fill, can place additional load on the landslide. The additional fill becomes a driving force that increases the risk of a slide. The movement can happen instantaneously or gradually over time.

Proper control of water during construction, including landslide repairs, utility installation, and surface and stormwater management systems, is important. Excess water can decrease the stability of landslides and generate failures during construction. Proper control of water must be maintained to avoid excess water impacting the project landslides. Free water should not be allowed to run across the Site. Utility pipes should be maintained, protected, or carefully removed during construction to avoid uncontrolled flow. When developed, the proposed construction plans should incorporate requirements for controlling water during construction.

The boundaries of the proposed remedial measures will need to be considered by the Project Geotechnical Engineer and Geologist to confirm that the measures are well tied into the undisturbed conditions. If not considered or addressed, the landslide mitigation repairs may begin to unravel or cause localized failures. This may result in propagation of the existing landslide failures. The project plans will need to include details on integrating project boundaries, specifically at and near the limits of work.

A California Certified Engineering Geologist should be engaged with the Project during its execution to observe for conditions that could lead to construction instability.

3. Hydrogeology Review

3.1 REGIONAL HYDROGEOLOGY

The following regional geology discussion is summarized from DWR, 2003. The PBL is located within the West Coast Subbasin (Groundwater Basin No. 4-11.03) of the Coastal Plain of the Los Angeles County Groundwater Basin (Basin); it is bordered to the north, northwest and east by the West Coast Sub Basin, and to the southwest by the Pacific Ocean. It is bounded on the north by the Ballona Escarpment, an abandoned erosional channel from the Los Angeles River. On the east it is bounded by the Newport-Inglewood fault zone, and on the south and west by the Pacific Ocean and consolidated rocks of the Palos Verdes Hills. The water-bearing deposits of the West Coast Sub Basin (Sub Basin) include the unconsolidated and semi-consolidated marine and alluvial sediments of Holocene, Pleistocene, and Pliocene ages. Discharge of groundwater from the subbasin occurs primarily by pumping extractions.

Principal aquifers of the Sub Basin include the Semi-perched, Bellflower, Gaspur, Gardena, Gage, Lynwood, Silverado, and an unnamed deep aquifer. The Semi-perched aquifer is unconfined; the water in underlying aquifers is confined throughout most of the Sub Basin, however, the Gage and Gardena aquifers are unconfined where water levels have dropped below the Bellflower aquiclude. The Silverado aquifer, underlying most of the West Coast Sub Basin, is the most productive aquifer in the Sub Basin; it yields 80-90 percent of the groundwater extracted annually. Specific yield values range from 1 percent to 26 percent, with a Sub Basin average of 13 percent.

Folding and associated faulting have formed the dominant northwest-trending structural features in the West Coast Sub Basin . The major structural feature in the area is the Newport-Inglewood fault zone, which forms the eastern boundary of the Sub Basin. The fault zone is a partial barrier to groundwater movement in the area, and is marked by thinning, folding, and offsetting of the aquifers. Southeast of Signal Hill, the Cherry Hill, and Reservoir Hill faults of this fault zone act as barriers to groundwater movement in each of the aquifers. The Avalon-Compton fault acts as a barrier below the Lynwood aquifer and the Rosecrans and Dominguez anticlines appear to act as partial barriers to groundwater movement.

Natural recharge of the West Coast Sub Basin is largely limited to underflow from the Central Basin through and over the Newport-Inglewood fault zone . Water spreads in the Central Basin as artificial recharge percolates into aquifers there, and some flows across the Newport-Inglewood fault to supplement the groundwater supply in the West Coast Sub Basin. Seawater intrusion occurs in some aquifers that are exposed to the ocean. Injection wells in the West Coast Basin Barrier create a north-south trending mound of fresh water from the Los Angeles International Airport on the north to the Palos Verdes Hills in the south. Injection wells also form a protective groundwater mound at the Dominguez Gap Barrier near Wilmington . Minor groundwater replenishment to the uppermost aquifers of the West Coast Sub Basin occurs through infiltration of surface inflow from both the Los Angeles and San Gabriel Rivers. Other minor sources of aquifer recharge through surface water infiltration include return irrigation water from fields and lawns, industrial waters, and other applied surface waters.

3.2 PORTUGUESE BEND LANDSLIDE (LOCAL) HYDROGEOLOGY

Groundwater flow at the PBL is approximately defined to the north by the topographic crest of the hill near Crest Road, which is the approximate location of the surface water and groundwater flow divide. Surface water and groundwater that occurs north of Crest Road generally flows inland toward the Pacific Coast Highway; surface water and groundwater that occurs south of Crest Road generally flows southward, through the PBL, and toward the Pacific Ocean. Surface water that falls or flows south of Crest Road may infiltrate and percolate into the PBL as groundwater. This is the water that has the potential to impact the stability of the PBL (DBSA, 2018). Previous studies of the PBL have concluded that groundwater movement (how groundwater flows through the aquifers) is a significant factor contributing to PBL instability. Groundwater at the PBL generally occurs in two water-bearing zones, a shallow and a deep zone.

3.2.1 Shallow Groundwater Zone

According to Leighton and Associates (1998), the shallow zone in the Portuguese Bend Landslide is unconfined and present at depths ranging from approximately 5 to 110 feet below ground surface (bgs). Figure 8 by Geo-Logic (2019) shows a contoured piezometric surface of the water table based on interpolation of groundwater elevations measured in wells at the Portuguese Bend Landslide. In general, the shallowest occurrences of groundwater have been observed in the Landward subslide, above the heads of the East-Central and West-Central subslides. Shallow groundwater typically flows above the bentonite clay layers (shear zones) that form the main slip or rupture zones (failure surfaces). The shallow groundwater zone receives recharge preferentially through local fractures, canyon bottoms, and infiltration of stormwater where canyons discharge onto alluvial fans, head slopes, sag ponds, and hummocky areas of the landslide area (DBSA, 2018). Douglas (2013) reported that water levels in wells pumping from the shallow groundwater zone respond quickly (days to weeks) to major rain events.

The horizontal hydraulic gradient of the unconfined groundwater of the shallow groundwater zone trends north to south and has a magnitude of approximately 0.10 foot of vertical head loss per horizontal foot (Leighton and Associates, 1998), and it mimics the general Site topographic gradient. Typical horizontal groundwater hydraulic gradients in aquifers range from 0.01 to 0.00001; by comparison, the gradient at the Portuguese Bend Landslide is therefore unusually high. High horizontal hydraulic gradients can be indicative of low-permeability conditions, areas of intensive groundwater recharge, high topographic relief, faults, and other structural controls, and/or groundwater extraction. Under homogeneous conditions, the direction of groundwater flow is generally parallel to the direction of the hydraulic gradient, in this case north to south (DBSA, 2018).

3.2.2 Deep Groundwater Zone

Deep groundwater originates in the upper part of the (Portuguese Canyon) drainage basin, is present below the landslide failure surfaces (rupture zones), and occurs under confined conditions under pressure (DBSA, 2018). Douglas (2013) reported that wells drilled deep enough often encounter pressurized groundwater zones below the basal rupture surface of the landslide. The deepest occurrences of groundwater have been observed north of the active landslide area and underlying the north-south trending topographic ridge.

The occurrence of groundwater in the deep groundwater zone beneath the rupture zone is less understood compared to shallow groundwater zone, and additional characterization would be needed for a clear understanding of the effect that deep groundwater has on the Portuguese Bend Landslide stability (DBSA, 2018). Nested piezometers completed at four locations on the Portuguese Bend Landslide indicate that groundwater occurs below the slide plane (Ehlig and Yen, 1997). Vertical hydraulic head measurements indicate that a downward vertical gradient occurs within the landslide mass and an even greater downward vertical gradient exists across the slide plane (Ehlig and Yen, 1997); the presence of these downward vertical gradients at the lower end of the hillslope was potentially attributed to increased groundwater recharge rates along the topographic surface of the landslide, including the presence of extensional ground fractures.

3.2.3 Artesian Groundwater Conditions

The following discussion of artesian groundwater conditions at the PBL was summarized from, “Geotechnical Evaluation Report, Portuguese Bend Landslide Complex Mitigation Measures, Rancho Palos Verdes, California,” prepared in 2019 for the City of Rancho Palos Verdes, California (Geo-Logic, 2019). Structurally, the Peninsula is a double plunging dome structure that is elongated in the northwest-southeast direction with smaller anticlinal and synclinal fold axes superimposed over the main structure; this results in bedding planes which predominantly plunge in the downslope direction. The presence of low strength, bentonite bedding planes dipping downslope has resulted in numerous landslides; however, this structure also can act as a barrier to groundwater flow given the low conductivity characteristics of the bentonite clay. Water percolating into bedrock that is stratigraphically below the bentonite clay beds may be trapped stratigraphically below the slide plane resulting in an artesian or confined groundwater condition. The Valley View Graben that overlies the ancient landslide complex and includes the active PBL is a closed depression that may have formed from movement of the ancient landslide complex. Given that the Valley View Graben appears to be formed by extension, it may expose bedrock stratigraphically below the Portuguese Tuff; this condition of the Valley View Graben may be a conduit for groundwater infiltration below the Portuguese Tuff, resulting in artesian groundwater conditions beneath the PBL, and potentially a significant contributor to instability.

Quantitative information regarding artesian conditions is generally unknown or unavailable at this time; where data exist, standpipe piezometers and/or wells in the area often cross over the Portuguese Tuff, yielding a hybrid piezometric pressure condition. According to Ehlig and Yen, 1997, a well that was constructed and screened at the toe of the Klondike Canyon landslide was reported to be artesian; the interpretation was given that slope stability analyses pertaining to the Seaward subslide need to consider confined groundwater conditions beneath the slide plane. They also generally concluded that groundwater occurrence beneath the PBL rupture plane was consistent with groundwater recharge occurring at the upper end of the hill slope and subsequent deeper migration beneath the slide plane toward the ocean. The artesian piezometric surface elevation was assumed based on the one measurement in the northeasterly portion of the PBL reported by them. Based on this measurement, the artesian piezometric surface was assumed to be 10 feet above the hydrostatic groundwater table across the PBL footprint. Figure 9 by Geo-logic (2019) in Appendix A shows an interpretation of groundwater information at the Site; it shows the anticipated height of the hydrostatic groundwater above the basal rupture surface.

3.2.4 Evidence of Artesian Groundwater Conditions

Geo-Logic (2019), compiled the following list of available reports that documented or noted the occurrence of artesian pressure within and in the vicinity of the PPL:

- Ehlig (1992) – "only one boring" within the PBL footprint "has encountered artesian pressure" within the easterly portion of the seaward subslide, "about 200 feet inland from the beach in 1957;" the source of the water is possibly attributable to infiltration from upgradient septic systems; "in 1981, artesian water was encountered 700 feet further east at the toe of the Klondike Canyon landslide;" "artesian pressure may occur locally near the beach but there is no evidence of artesian pressure affecting movement of the slide";
- Ehlig and Yen (1997) – of three piezometer installations within the northeasterly portion of the PBL Complex, measurements from two suggest that upward flow across the basal rupture surface is "negligible," while the remaining location showed approximately 10 feet of artesian pressure head above the corresponding hydrostatic condition;
- Leighton (2000) – the relatively fast rate of movement of the seaward subslide is "in part due to the episodic excess pore water pressure below the rupture surface" and "in part due to the continual wave erosion of the toe of the active landslide" (i.e., apparently, artesian pressure is more significant in the southerly portion of the PBL than elsewhere, but it is not necessarily the only or the most important factor affecting stability);
- Hill et al. (2007), citing Ehlig / BYA (1997) – restates that Ehlig / BYA (1997) investigated the potential for flow across the basal rupture surface by installing three multi-stage pneumatic piezometers; two instruments in the northern portion of the landslide measured a higher piezometric level above the rupture surface than below, suggesting negligible downward flow across the surface; the remaining piezometer measured approximately ten feet of hydraulic head beneath the rupture surface and none above;
- Douglas (2013) – makes several mentions of artesian, pressurized, and/or confined flow below the PBL basal rupture surface as an important contributing factor to the ongoing instability and displacement but does not provide evidence to support such claims;
- RPV (2019) – one groundwater extraction well, of seven installed, located in the northeasterly portion of the PBL encountered artesian groundwater conditions at a depth of approximately 400 feet bgs (i.e., at a level significantly below the basal rupture surface); water reportedly flowed from the well for approximately six days, and, afterward, remained at approximately the level of the surrounding ground surface.

3.2.5 Groundwater Recharge

A significant contributor to the PBL instability is persistent elevated groundwater pore pressure above and below the basal rupture surface. The groundwater recharge at the PBL is predominantly attributed to the following sources (Geo-Logic, 2019):

- Disrupted and/or poorly defined flow of natural channels, which apparently terminate and/or change slope relatively abruptly near the limits of the PBL. The nearby canyons drain onto the active landslide terrain within the upgradient graben that results from extension when the landslide pulls away from the stable terrain upslope. During periods of heavy rainfall, large quantities of runoff flow onto the landslide from the tributary canyons. Previous field observation indicates that, although the water from these canyons was conveyed across the landslide through a combination of natural and improved drainage courses, significant sections of corrugated metal pipe used for surface drainage are broken and inoperable and that significant quantities of runoff infiltrate and percolate into the ground within and around the periphery of the PBL (DBSA, 2018). Douglas (2013) stated that "In Portuguese and Paint Brush Canyons, the lower reaches of the canyons have been destroyed and 100 percent of the stormwater from these canyon flows directly into the head of the PBL." This water is likely to remain above the landslide slip surface because the low permeability Portuguese Tuff is continuous in the area of the upgradient graben.

- Ponding of water upstream of constructed embankments, including at locations of broken and/or sediment-filled stormwater conveyance structures (e.g., impaired pipe and/or culvert for Portuguese Canyon along Burma Road, ponded water north of Palos Verdes Drive South, apparently undersized and frequently disconnected drainage pipe along Palos Verdes Drive South, etc.). Many of the stormwater conveyances have been damaged as the upslope graben has grown in response to continued movement of the landslide. This water is unlikely to penetrate through the Portuguese Tuff given the relatively low hydraulic conductivity of the bentonite clay.
- Ponding of water at the PBL within closed depressions upstream of slump deposits or constructed embankments. A prominent closed depression at the PBL, adjacent to the north side of Palos Verdes Drive South, is situated directly above relatively low hydraulic conductivity bentonite clay; water impounded in this depression is unlikely to penetrate through the low hydraulic conductivity of the bentonite clay; however, given the proximity of this ponded water directly above the bentonite clay, its presence as a potential source of groundwater recharge at the PBL cannot be dismissed. Figure H-1 in Appendix A depicts the ponded water condition within a closed depression of a landslide (King County, 2016).
- Direct precipitation and infiltration through soils. Infiltration of stormwater into open fractures at the PBL, where surface expressions of cracking have developed because of differential subslide displacement. Existing conditions at Portuguese Bend include desiccation cracks, fractures, and fissures caused by landslide movement that may permit water to migrate beyond the depth of evapotranspiration before the soil reaches its moisture capacity; this limitation may result in an underestimate of groundwater recharge by conventional estimation methods (DBSA, 2018). Water entering open fractures within the landslide terrain is likely to remain above the landslide slip surface given the presence of the relatively low permeability Portuguese Tuff.
- Percolation of water from private residential on-Site wastewater treatment systems (septic systems). The preliminary water budget work performed by DBSA (2018) suggests that there is a substantial amount of recharge into the PBL, particularly in wet years, and that groundwater recharge from septic tanks can be significant in dry to average water years. According to Vonder Linden and Lindvall (1982), there were approximately 156 residential dwellings located on the active PBL when movement was initiated in 1956. This number was reduced to approximately 29 by 1969 and approximately 22 by 1982. The impact of water from residential septic system discharge on pore pressure above the landslide slip surface is unknown, but the impact below the landslide slip surface is likely negligible given the presence of the low hydraulic conductivity Portuguese Tuff.
- Drainage of surface water and stormwater from upgradient locations and subsequent infiltration and percolation at the PBL or into upgradient depressions and grabens. Areas up-gradient of the PBL that are candidate sites for groundwater infiltration include the Valley View Graben. This feature is located east of Crenshaw Boulevard and north of the ancient landslide

complex which includes the PBL (Dibblee, 1999). The Valley View Graben and similar extensional features upslope of the larger, ancient landslide may be allowing for infiltration of surface water, precipitation, and irrigation return from residential watering that infiltrate to bedrock stratigraphically lower than the Portuguese Tuff. The Figure H-2 in Appendix A shows a culvert or water conveyance along the north flank scarp of the PBL that is potentially transporting stormwater and/or surface water drainage from upgradient of the landslide into the PBL.

- Groundwater flow from upgradient locations, termed "underflow." Underflow is generally described as water moving through the sand and gravel under or next to a stream channel. Leighton and Associates (1998) estimated the amount of recharge contributed by irrigation for their project area; because the northern border of their project area was at the upper end of the watershed, it represented a no flow groundwater (and surface water) boundary in their analysis, and as a result, all groundwater flowing south into their proposed project site was the result of groundwater recharge from areas between the north end of the study area (and watershed) and the project site itself (DBSA, 2018). The same is true for the PBL; all groundwater inflow into it results from recharge occurring upslope. Leighton and Associates (1998) estimated that up to 77 acre-feet per year could be entering their project area from upslope irrigation recharge. Extrapolated to the PBL, irrigation return flow represents a significant source of groundwater recharge to the PBL (DBSA, 2018).

3.2.6 Water Wells

Limited documented information is available on the number, construction details, and spatial distribution of the water wells in the PBL. Information previously provided by the City indicates that up to 20 water wells have been constructed and installed within the PBL (DBSA, 2018). Except for four wells installed in 2016, no information could be located that documents the well construction details, last surveyed location, purpose of well (monitoring or dewatering), date of installation, well temporal monitoring data, or the status of the well (DBSA, 2018).

Ehlig and Yen (1997) report that groundwater elevations in the East-Central subslide area are thought to have risen about 50 feet between the slide activation in 1956 and 1968. They attributed the rise in groundwater elevations to an increase in the rate of groundwater recharge within the landslide area caused by the disruption of drainage patterns and the opening of fissures and cracks following the 1956 onset of movement. Water well elevation data presented for four PBL wells with close correlation of groundwater elevation increases to high rainfall months indicate that groundwater recharge is occurring within a month of high rainfall events. In other wells, particularly one located in the East-Central subslide area, the lag between rainfall occurrence and water elevation response was longer, up to 5 months.

3.2.7 Watershed Hydrology

The USGS defines a watershed as an area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, any point along a stream channel or the ocean. The PBL receives both surface water and groundwater from the watersheds of Portuguese Canyon, Ishibashi Canyon, and Paintbrush Canyon. These canyons are generally ephemeral (surface water does not flow throughout the year; rather, these canyons generally have flowing water when and after it rains), and they convey stormwater from the high ground in the watershed toward the Pacific Ocean (DBSA, 2018). Collectively, Portuguese Canyon, Ishibashi Canyon, and Paintbrush Canyon are referred to herein as the PBL Canyons; Klondike Canyon is considered separate from the PBL; however, as described below, water from Klondike Canyon likely flows as underflow across the watershed divide at the lower southwest end of the Klondike Canyon watershed (DBSA, 2018). Klondike Canyon is also an exception in that perennial water is observed flowing in the lower reaches of Klondike Canyon. Figure 5 by DBSA (2018) in Appendix A depicts the combined watershed boundary of the three canyons.

The PBL Canyons are located in what is identified as the "Ocean South South" (sic) drainage area in the Master Plan of Drainage ([MPD]; RBF Consulting, 2015), a part of the Santa Monica Bay Watershed defined by the County of Los Angeles Department of Public Works; the PBL Canyons are directly tributary to the Pacific Ocean (DBSA, 2018). The PBL Canyons have storm drain systems located in their upper reaches that discharge into the canyons that, in turn, drain ultimately into the ocean; the area of the Portuguese Bend watershed that drains into the PBL Canyons is approximately 627 acres (DBSA, 2018).

Over significant reaches of these canyons, notably the portions that direct water to and through the PBL, the drainage systems consist mostly of canyon bottoms that are unimproved open channels (DBSA, 2018). The surface of the ground within much of the PBL is generally hummocky, irregular, and locally fissured given the landslide activity (DBSA, 2018). Previous drainage structures constructed to control and convey stormwater runoff have failed. The MPD (RBF Consulting, 2015) found that the corrugated metal pipe structures were undersized for the calculated flow they would receive; as a result, surface drainage within the landslide is generally poor and difficult to maintain. Infiltration of the runoff conveyed through these canyons is a source of recharge for the groundwater within the landslide (Ehlig and Yen, 1997).

As described by RBF Consulting (2015) in the MPD, Ocean South South has three major canyons: Altamira Canyon, Portuguese Bend Canyon, and Paint Brush Canyon. While a part of the delineated Ocean South South drainage area, surface water from Altamira Canyon does not drain directly into the PBL; however, groundwater that originates from Altamira Canyon infiltration may flow into the PBL area. Portuguese Canyon is located on the westerly side of the PBL and generally forms the boundary of two subslides termed by Ehlig and Yen (1997) as the West-Central and East- Central slides. This boundary, and Portuguese Canyon, is defined by a near vertical fault that extends in a north-south direction along the general alignment of Portuguese Canyon (Ehlig and Yen, 1997). The upper reaches of Portuguese Canyon are steep and convey stormwater quickly to the lower reaches, where water moves more slowly in the low gradient terrain. Smaller in size, Ishibashi Canyon, located east of Portuguese Canyon, drains into Paint Brush Canyon which, in turn, drains into an undeveloped mountain-front alluvial fan area of the PBL; Paint Brush Canyon includes two debris basins in series upstream of the confluence of Ishibashi and Paint Brush Canyons before discharging to the upper end of the PBL, where evidence in the field indicated that stormwater readily infiltrates (DBSA, 2018).

Klondike Canyon is located east of Paintbrush Canyon and the PBL; the area of the Klondike Canyon Watershed is 680 acres and a smaller portion of that area drains into Klondike Canyon itself (DBSA 2018). The southwest margin of the Klondike Canyon Watershed, where Klondike Canyon stormwater empties into the Pacific Ocean, is within the mapped boundary of the PBL. Although it appears likely, based on its location relative to the PBL boundary and the generally low-lying surface terrain, it is unknown whether groundwater is moving from the lower Klondike Canyon Watershed into the PBL Watershed (DBSA, 2018).

There are several swales and storm drains that drain the upper reaches of the watershed into the PBL Canyons and Klondike Canyon where the water is then conveyed to the Pacific Ocean (DBSA, 2018). The upper watershed areas contributing to water flow into the PBL and Klondike Canyon landslides are located within the City of Rolling Hills; of the combined approximately 1,300-acre area of the PBL and Klondike watersheds, approximately 360 acres (28 percent) lies within Rolling Hills, the balance of the watershed areas (940 acres, or 72 percent) lies within the City of Rancho Palos Verdes (DBSA, 2018).

There are currently no known stream gage data based on monitoring of either dry weather or stormwater flow in the canyons that convey water into the PBL and the Klondike Canyon Landslide; these canyons have a bottom generally 10 to 20 feet wide and fall 15 to 20 feet in a 100-foot run (DBSA, 2018). Based on information in the MPD, it is estimated that the 100-year storm runoff for each of the above canyons would be approximately 200 cubic feet per second.

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TABLE

TABLE 1

2008 NATIONAL SEISMIC HAZARD MAPS - SOURCE PARMETERS[1]
PORTUGUESE BEND LANDSLIDE MITIGATION PROJECT
RANCHO PALOS VERDES, CALIFORNIA

Distance in Miles, 25 Mile Radius was Performed	Name	State	Pref Slip Rate (mm/yr)	Dip Dir	Slip Sense	Rapture Top (km)	Rapture Bottom (km) Magnitude Max (M=)[2]	Length
3.70	Palos Verdes Connected	CA	3	V	strike slip	0	10/7.7	285
3.70	Palos Verdes	CA	3	V	strike slip	0	14/7.3	99
10.29	Newport Inglewood Connected alt 1	CA	1.3		strike slip	0	11/7.5	208
10.29	Newport- Inglewood, alt 1	CA	1		strike slip	0	15/7.2	65
11.03	Newport Inglewood Connected alt 2	CA	1.3	V	strike slip	0	11/7.5	208
17.21	Puente Hills (Santa Fe Springs)	CA	0.7	N	thrust	2.8	15/6.7	11
17.61	Puente Hills (LA)	CA	0.7	N	thrust	2.1	157.0	22
20.94	Santa Monica Connected alt 2	CA	2.4		strike slip	0.8	11/7.4	93
21.08	Puente Hills (Coyote Hills)	CA	0.7	N	thrust	2.8	156.9	17
21.24	Santa Monica Connected alt 1	CA	2.6		strike slip	0	16/7.3	79
21.24	Santa Monica, alt 1	CA	1	N	strike slip	0	18/6.6	14
22.00	Malibu Coast, alt 2	CA	0.3	N	strike slip	0	16/7.0	38
22.00	Malibu Coast, alt 1	CA	0.3	N	strike slip	0	8/6.7	38
22.21	Anacapa- Dume, alt 2	CA	3	N	thrust	1.2	12/7.2	65
23.70	Elysian Park (Upper)	CA	1.3	NE	reverse	3	15/6.7	20
23.84	Hollywood	CA	1	N	strike slip	0	17/6.7	17
24.85	San Joaquin Hills	CA	0.5	SW	thrust	2	13/7.1	27

Notes:

[1] Working Group on California Earthquake Probabilities, 1995, Seismic hazards in southern California—Probable earthquakes, 1994 to 2024: Bulletin of the Seismological Society of America, v. 85, no. 2, p. 379-439.

[2] Magnitude Maximum Max (M=) Earthquake Magnitude from Ellsworth and/or Hanks relations.

APPENDIX A
Supporting Figures

NORTH

GRAPHIC SCALE

300' 0' 150' 300' 600' 1200'

LEGEND

- APPROXIMATE LIMITS OF PORTUGUESE BEND LANDSLIDE COMPLEX (BASED ON LEIGHTON, 2000)
- APPROXIMATE LIMITS OF SUBSLIDES OF PORTUGUESE BEND LANDSLIDE COMPLEX (BASED LEIGHTON, 2000)
- APPROXIMATE LIMITS OF NEARBY LANDSLIDES OUTSIDE PORTUGUESE BEND LANDSLIDE COMPLEX LIMITS (BASED ON LEIGHTON, 2000)
- APPROXIMATE LIMITS OF SUBDIVISIONS OF PORTUGUESE BEND LANDSLIDE COMPLEX SUBSLIDES
- APPROXIMATE LIMITS OF SLOPE STABILITY MODEL DOMAIN
- APPROXIMATE LOCATION OF SHORELINE
- A A CROSS SECTION EVALUATED

NOTES:
1. TOPOGRAPHY INLAND OF SHORELINE PROVIDED BY THE CITY OF RANCHOS PALOS VERDES. BATHYMETRY BASED ON USGS (1981).
2. DIMENSIONS, DIRECTIONS, AND LOCATIONS ARE APPROXIMATE.

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A	DATE	ISSUED FOR REVIEW	–	–	–	–

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DRAWN BY: J AMAYA
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CITY OF RANCHO PALOS VERDES
PORTUGUESE BEND LANDSLIDE
RANCHO PALOS VERDES, CALIFORNIA
AERIAL PHOTOGRAPHY WITH LANDSLIDE LIMITS

FIGURE NO. 1

PROJECT NO. DB19.1055

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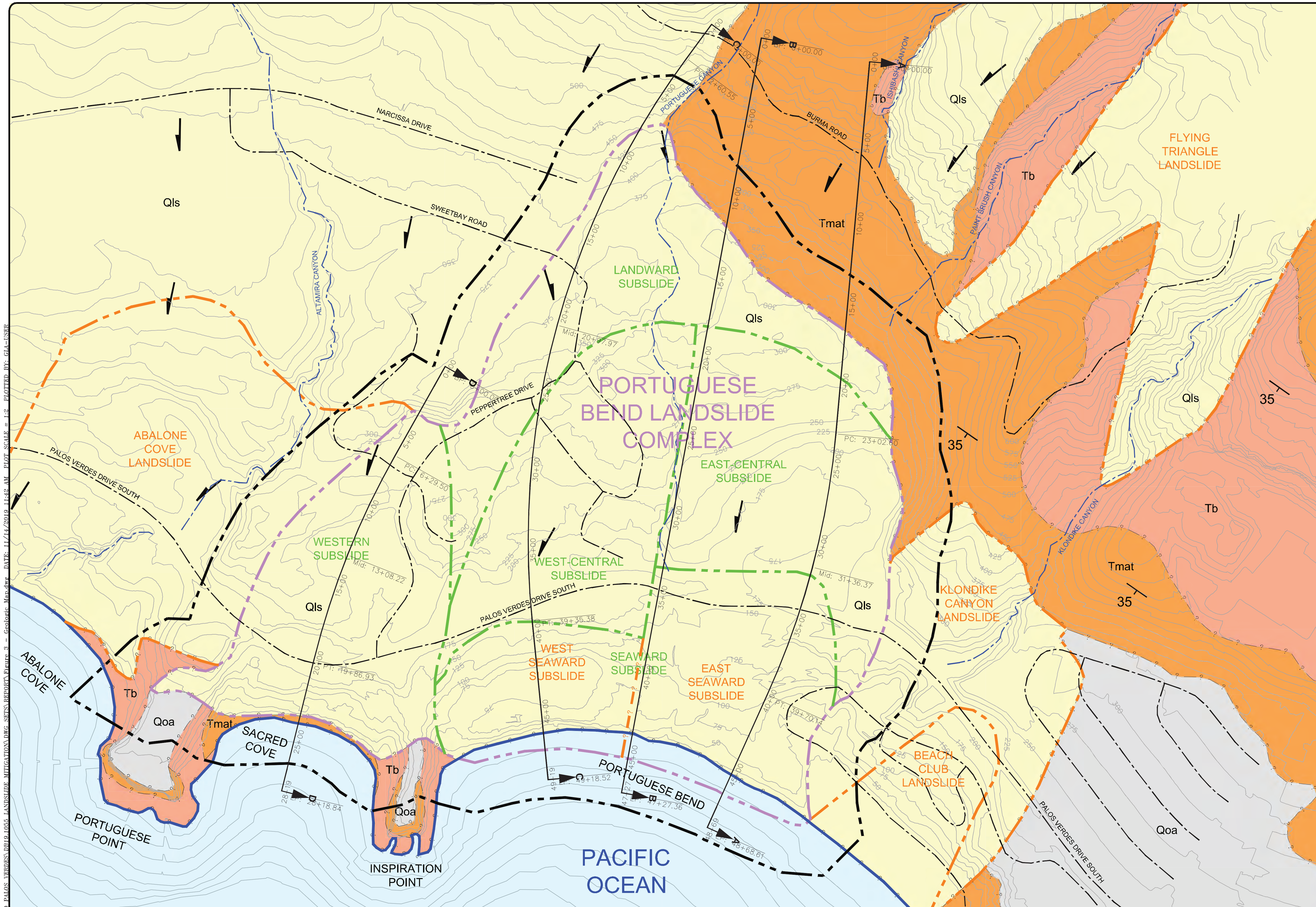

NORTH

GRAPHIC SCALE

300' 0' 150' 300' 600' 1200'

LEGEND

25 FT ELEVATION CONTOUR(1)

APPROXIMATE LIMITS OF PORTUGUESE BEND LANDSLIDE COMPLEX (BASED ON LEIGHTON, 2000)

APPROXIMATE LIMITS OF SUBSLIDES OF PORTUGUESE BEND LANDSLIDE COMPLEX (BASED LEIGHTON, 2000)

APPROXIMATE LIMITS OF NEARBY LANDSLIDES OUTSIDE PORTUGUESE BEND LANDSLIDE COMPLEX LIMITS (BASED ON LEIGHTON, 2000)

APPROXIMATE LIMITS OF SUBDIVISIONS OF PORTUGUESE BEND LANDSLIDE COMPLEX SUBSLIDES

APPROXIMATE LIMITS OF SLOPE STABILITY MODEL DOMAIN

APPROXIMATE LOCATION OF SHORELINE

A A CROSS-SECTION EVALUATED

SURFICIAL GEOLOGY (BASED ON DIBBLE, 1999, WITH MODIFICATION BASED ON LANDSLIDE LIMITS BY LEIGHTON, 2000)

Qls: Landslide debris

Qoa: Older surficial sediments

Tb: Basalt

Tmat: Monterey formation

35 BEDDING ATTITUDE

DIRECTION OF MOVEMENT

NOTES:
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CITY OF RANCHO PALOS VERDES
PORTUGUESE BEND LANDSLIDE
RANCHO PALOS VERDES, CALIFORNIA
GEOLOGIC MAP

FIGURE NO. 3
PROJECT NO. DB19.1055

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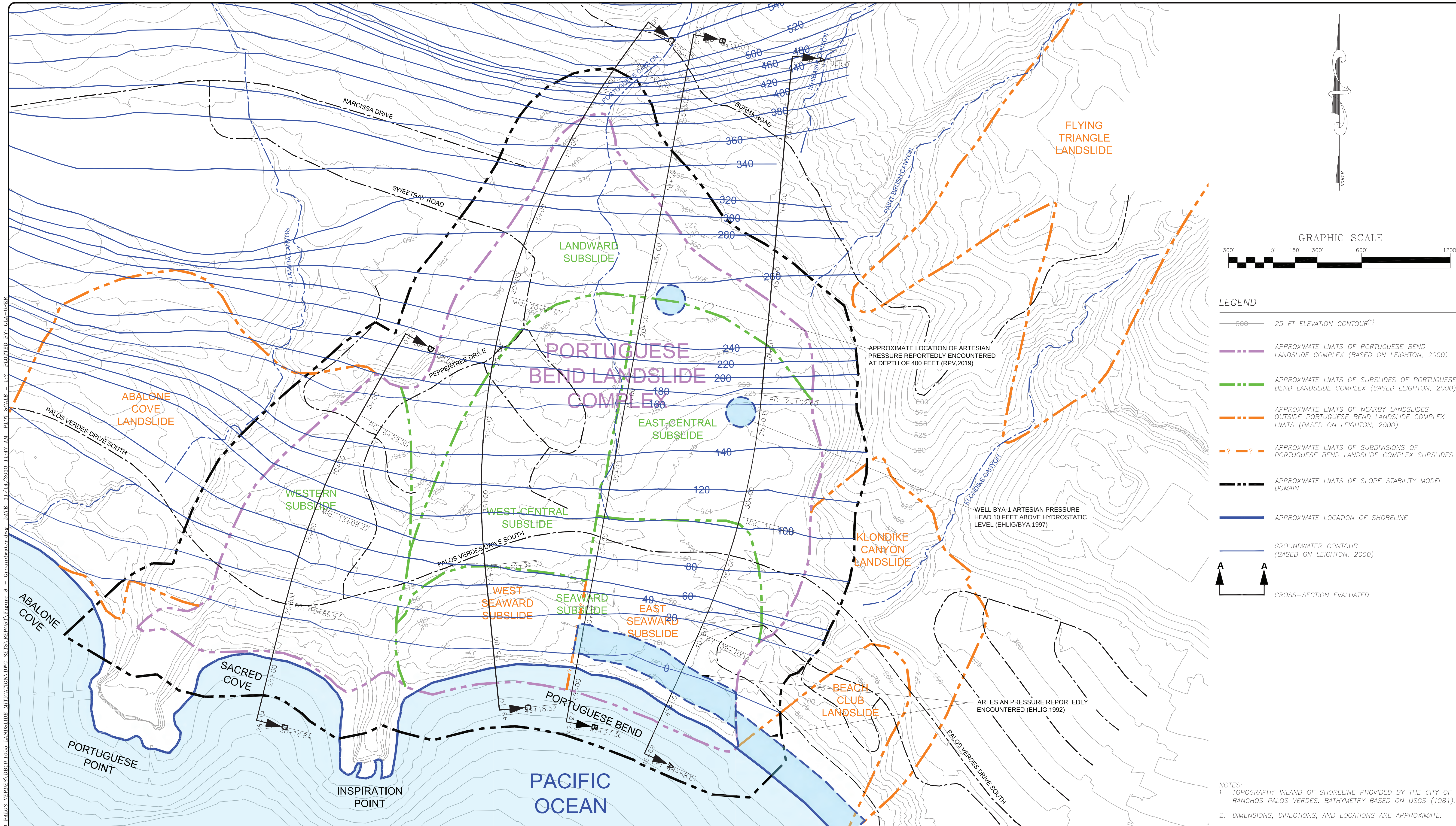

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CITY OF RANCHO PALOS VERDES
PORTUGUESE BEND LANDSLIDE
RANCHO PALOS VERDES, CALIFORNIA
GROUNDWATER CONTOUR MAP

FIGURE NO. 8
PROJECT NO. DB19.1055

LOCATION: P:\SITES\RANCHO PALOS VERDES\DB19.1055 LANDSLIDE MITIGATION\DWG SETS\REPORT\Figure 8 - Groundwater.dwg DATE: 11/14/2019 11:47 AM PLOT SCALE = 1:3 PLOTTED BY: GLA-USER

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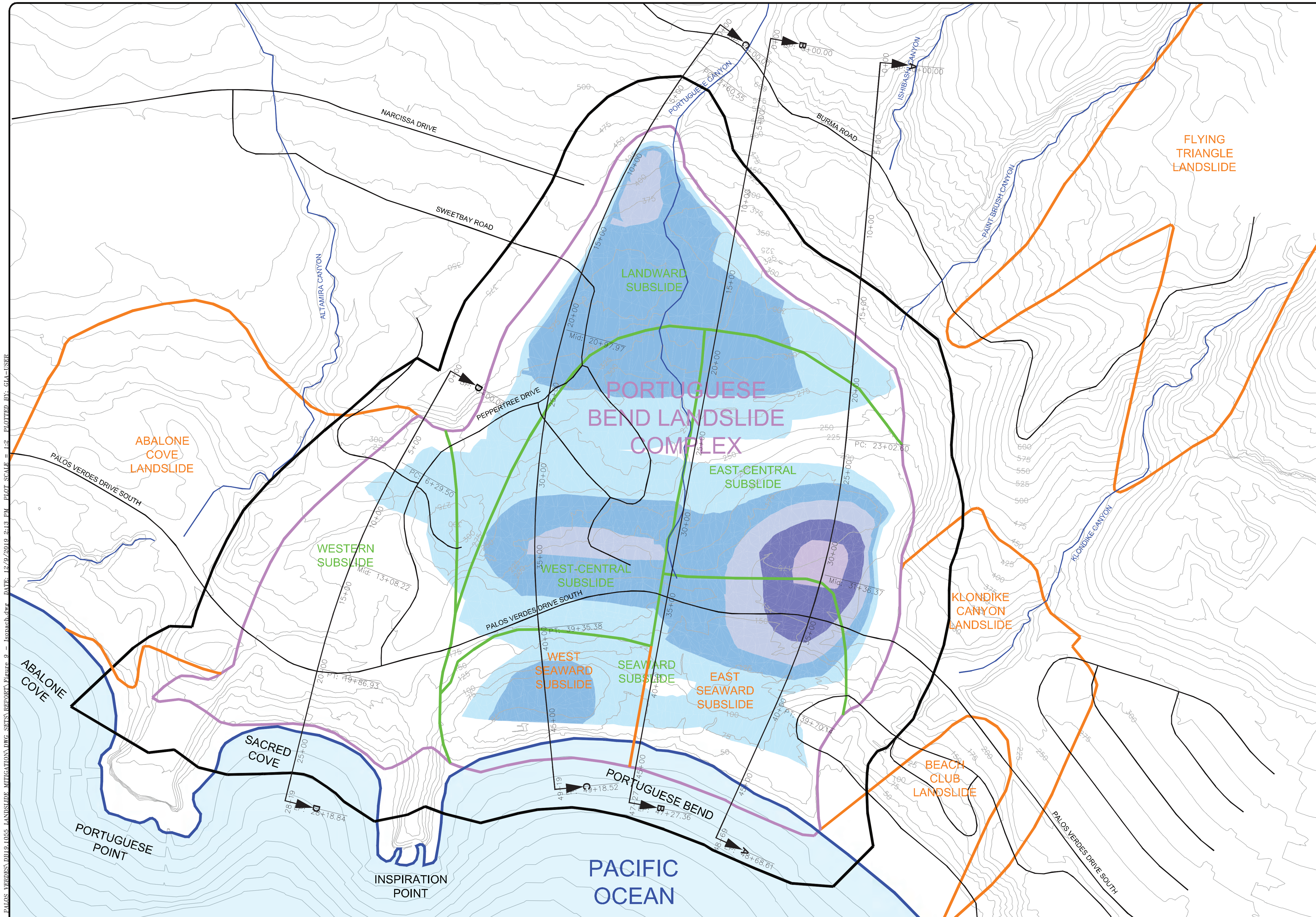

GRAPHIC SCALE

300' 0' 150' 300' 600' 1200'

LEGEND

600	25 FT ELEVATION CONTOUR(1)
	APPROXIMATE LIMITS OF PORTUGUESE BEND LANDSLIDE COMPLEX (BASED ON LEIGHTON, 2000)
	APPROXIMATE LIMITS OF SUBSLIDES OF PORTUGUESE BEND LANDSLIDE COMPLEX (BASED LEIGHTON, 2000)
	APPROXIMATE LIMITS OF NEARBY LANDSLIDES OUTSIDE PORTUGUESE BEND LANDSLIDE COMPLEX LIMITS (BASED ON LEIGHTON, 2000)
? ?	APPROXIMATE LIMITS OF SUBDIVISIONS OF PORTUGUESE BEND LANDSLIDE COMPLEX SUBSLIDES
	APPROXIMATE LIMITS OF SLOPE STABILITY MODEL DOMAIN
	APPROXIMATE LOCATION OF SHORELINE
A A	CROSS-SECTION EVALUATED

HEIGHT OF HYDROSTATIC GROUNDWATER TABLE ABOVE BASAL RUPTURE SURFACE

NUMBER	MINIMUM HEIGHT (FEET)	MAXIMUM HEIGHT (FEET)	COLOR
1	0	25	
2	25	50	
3	50	75	
4	75	100	
5	100	115	

NOTES:
1. TOPOGRAPHY INLAND OF SHORELINE PROVIDED BY THE CITY OF RANCHOS PALOS VERDES. BATHYMETRY BASED ON USGS (1981).
2. DIMENSIONS, DIRECTIONS, AND LOCATIONS ARE APPROXIMATE.

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CITY OF RANCHO PALOS VERDES
PORTUGUESE BEND LANDSLIDE
RANCHO PALOS VERDES, CALIFORNIA
ISPOPACH MAP
ACTIVE BASAL RUPTURE VS GROUNDWATER

FIGURE NO. 9
PROJECT NO. DB19.1055

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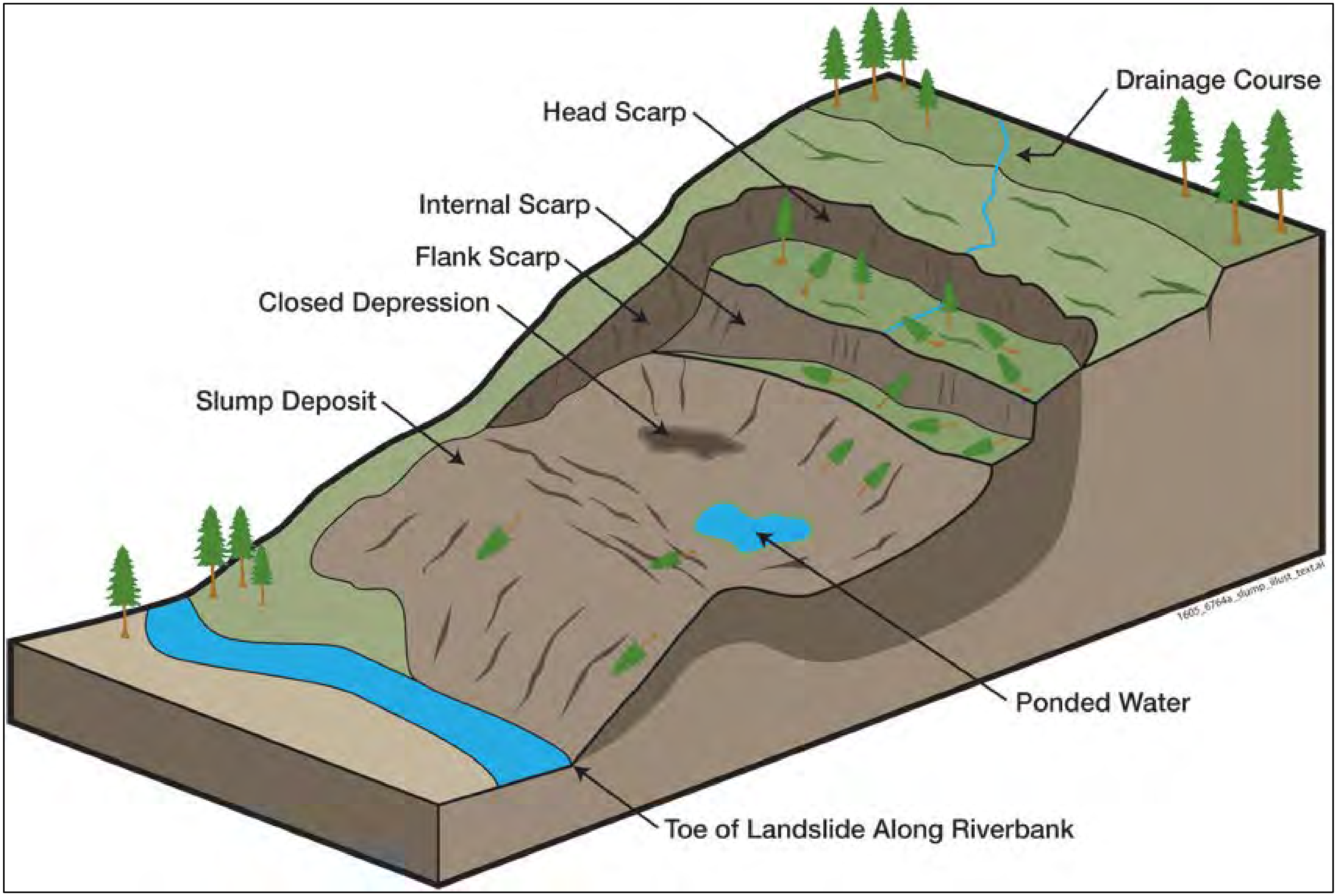
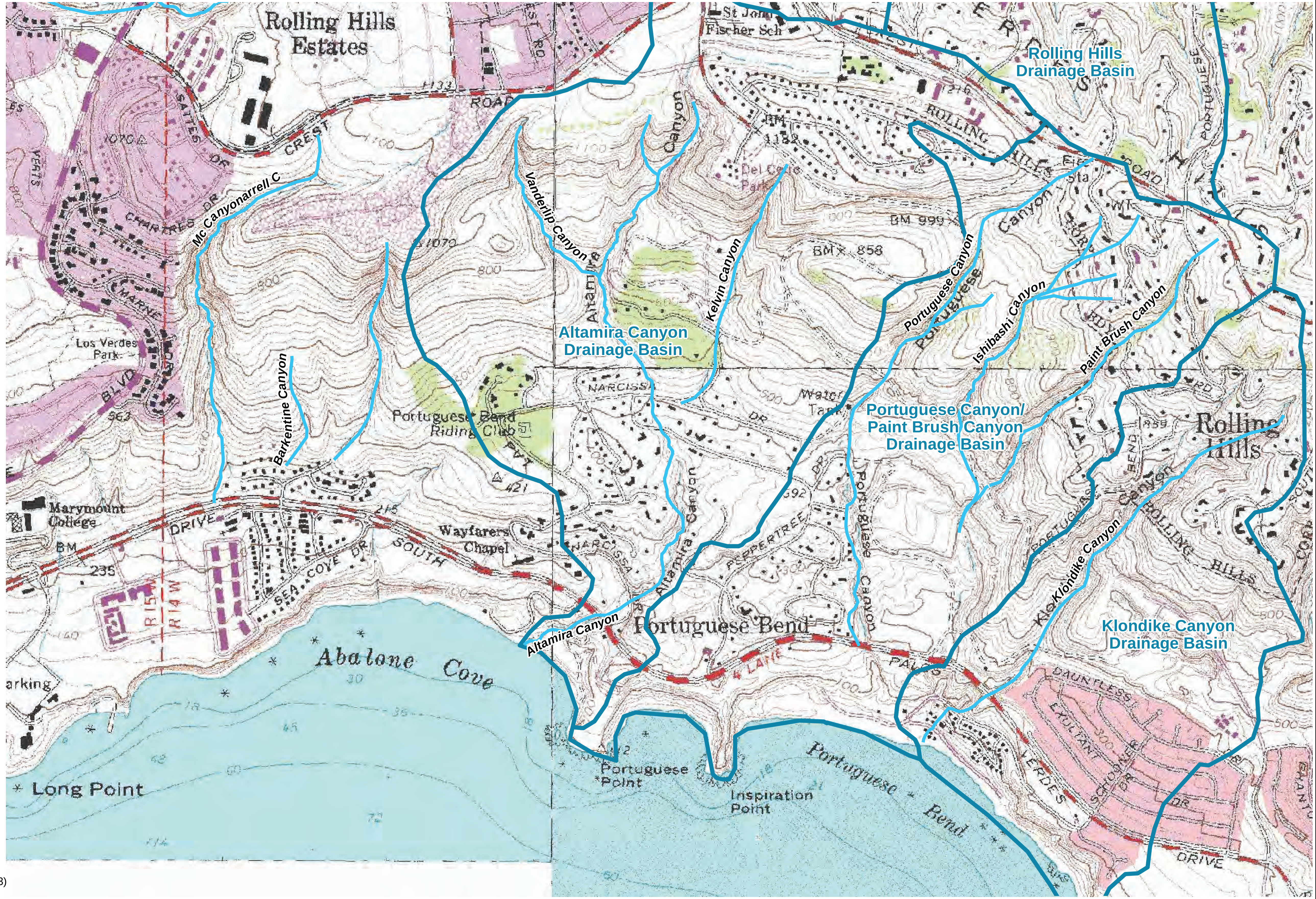


Figure H-1: Generalized landslide diagram; depicts the ponded water condition within a closed depression of a landslide (King County, 2016).

Figure H-2: Culvert or water conveyance along the north flank scarp draining into the Portuguese Bend Landslide.



N

0 600 1,200 Feet

Explanation

- Watershed
- Major canyon

Source: Adapted from Douglas (2013)

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Daniel B. Stephens & Associates, Inc.
11/17/2017 JN DB17.1171

CITY OF RANCHO PALOS VERDES
Watersheds

Figure 5

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