Final Report
Los Angeles County Public Beach Facilities Sea-Level Rise Vulnerability Assessment

Made possible by
Climate Ready Grant No. 13-085
from the California Coastal Conservancy

April 19, 2016

Los Angeles County Public Beach

Sea-Level Rise Vulnerability Assessment

Prepared for the Los Angeles County Department of Beaches and Harbors

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Prepared by Noble Consultants-G.E.C., Inc.

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Introduction

In accordance with California State Coastal Conservancy Agreement No. 13-085, this report presents the results of a review of the Los Angeles County public beach facilities to assess their vulnerability to future sea-level rise. The Los Angeles County shoreline is a unique urban setting that is one of the most valuable coastal resources for the State. Its regional beaches, many of which have been artificially enhanced and stabilized over the past century, provide recreation and enjoyment for millions of visitors annually. Their significant recreational draw also provides an important source of income to the local economy. The purpose of the study is to assess the potential threat that the public beach assets may face in the future and suggest possible management strategies that can be considered to preserve and maintain the existing public beach system for as long as possible. This study focuses on beaches owned and/or operated by the Los Angeles County Department of Beaches and Harbors.

Sea level is rising due to the effects of global warming. Presently, no one knows with certainty how fast and how high the increase will be. By the end of this century, estimates of global sea level rise range from 1 to 6.6 feet. This broad forecast makes it difficult to plan for the long term as the threat potential associated with the two extremes will vary significantly. To initiate a process of proactive preparedness, this report is intended to present an overview of the existing Los Angeles County public beach setting, assess the potential threat that future sea-level rise may pose to the public beach recreation assets, and introduce appropriate strategies that may be considered to begin a dialog on how best to address the issue.

The Los Angeles County Shoreline

The Los Angeles County Department of Beaches and Harbors operates and maintains 19 public beach facilities between Malibu and San Pedro. **Figure 1** shows their locations. To provide public access, safety, and an enjoyable recreational experience, the County has built an infrastructure of improvements at each beach that include parking lots, restroom buildings, concessions, lifeguard stations, and other amenities to serve the County’s metropolitan population as well as non-residents and tourists. The beach facilities are distributed within three shoreline regions that are generally distinguished from one another by their differences in physical morphology, land development, and population density.

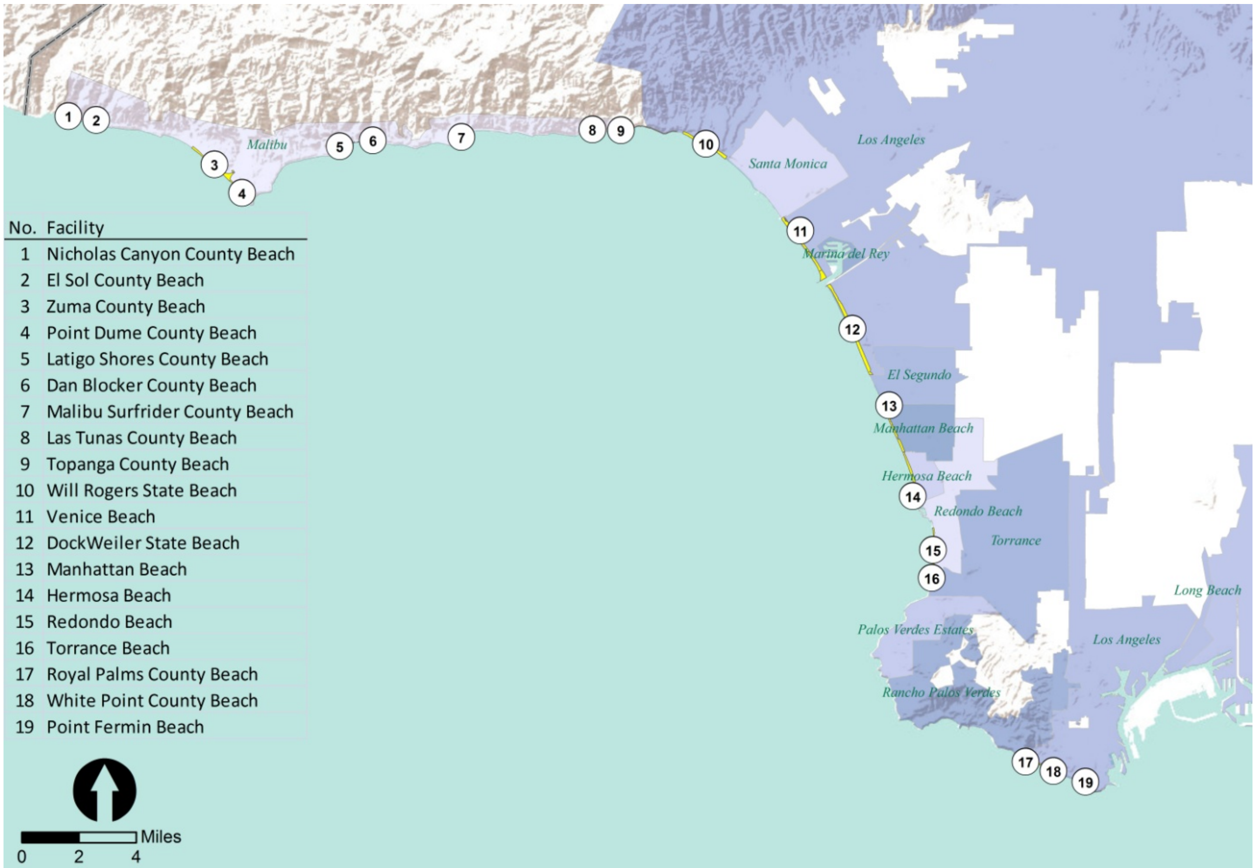

Figure 1. Los Angeles County Public Beach Facilities Source: Los Angeles County, 2016 [1]

Malibu Region

The Malibu Region extends from the Los Angeles/Ventura County Line to Topanga Canyon. The east-west shoreline alignment consists of a succession of narrow crescent beaches bordered by resistant rocky headlands. The beaches are mostly the result of their proximity to the mouths of streams and the sand retention features of downcoast bedrock exposures or boulder forms at the stream mouths[2].

Most of this coastline is backed by cliffs or mountainous coast. However, wider stretches of sandy beach exist at Zuma Beach, and along the Malibu Colony sand spit. East of Malibu Creek,

1 Los Angeles County, 2016. Beach facilities maps, prepared by the Department of Beaches and Harbor, Planning Division, March 2016.

2 Thompson, W.C., 1988. "Report on the effectiveness of the groins on Las Tunas Beach, " prepared for the Office of the Attorney General, California Department of Justice, April 1988.

Figure 2. Malibu coastline looking from Pt. Dume west to Zuma County Beach. Source: Perry, 2012. [3]

the beaches gradually diminish in width to narrow to non-existent conditions between Los Flores and Topanga Canyon. An aberrant wide beach occurs at the mouth of Topanga Canyon Creek mouth, but the shoreline immediately reverts again to a more narrow strand littered with boulders, gravel, cobble, and other debris.

The County maintained beaches within this region include Nicholas Canyon, Zuma, Point Dume, Dan Blocker, Malibu Surfrider, and Topanga Beaches.

Santa Monica Bay Region

The Santa Monica Bay region extends from Santa Ynez Canyon (Sunset Boulevard) to Malaga Cove. The topography varies from cliffed backshore at the Santa Monica and Redondo Beach/ Torrance flanks to the low lying broad expanse of the Los Angeles Basin within the central section. The shoreline is one of the most densely populated areas in the State. The beaches have also been significantly enhanced by man. Starting in the 1930s, over 35 million cubic yards of sand has been placed to widen the beaches. The sand nourishment coupled with the construction of numerous retention structures including the Santa Monica and Venice breakwaters, Marina del Rey and King harbors, and groin fields has transformed the Santa Monica Bay region from historically narrow to artificially wide beaches that provides some of the most important economic areas and shoreline recreation anywhere.

[3] Perry, Bruce, 2012. Department of Geological Sciences, CSU Long Beach, http://geology.cnsm.ad.csulb.edu/people/bperry/AerialPhotosSoCal/AerialPhotographyIndexMapPage.htm.

The beaches that the County maintains within this region include Will Rogers and Dockweiler State Beaches, Venice Beach, Redondo Beach, and Torrance Beach.

Figure 3. Santa Monica Bay Beaches. This aerial photograph shows Venice Beach looking north to Santa Monica. The wide sandy beaches are relics from historical beach nourishments and the effects of sediment retention structures. Source: Perry, 2012.

Palos Verdes Peninsula Region

The Palos Verdes Peninsula Region is approximately 16 miles long and extends from Malaga Cove to San Pedro. The peninsula's rolling hills are fronted by a shoreline that consists of narrow rocky, gravelly pocket beaches backed by seacliffs that are up to 150 feet high. Sediment contribution to the rocky shoreline is nominal and primarily comes from seacliff erosion, active landslides, and small local streams. The shoreline within this cell has experienced little or no changes over time except at two landside areas where local advances in the shoreline have occurred since the 1950s. The County operates and maintains Royal Palms and White Point beach parks at the southern end of the peninsula near San Pedro.

Figure 4. Palos Verdes Peninsula. Source: Perry, 2012.

Public Beach Assets

Table 1 summarizes the inventory of County beach facility assets by region. Each beach facility (the physical land footprint of the shoreline park) is supported by an infrastructure (the assets within each facility) that consists of parking lots, restroom buildings, concessions, lifeguard safety stations, maintenance yards, utilities, and other recreational amenities. Together they comprise the essential improvements that are needed to support and promote safe public beach recreation opportunities for the Los Angeles County metropolitan area.

The Malibu restroom assets were recently upgraded with advanced technology sewage treatment units that replaced outdated septic and leach field systems. The improvements represent a significant investment by the County to improve ground water quality. However, the new technology is sensitive to salt water intrusion and more vulnerable to damage from wave runup and inundation flooding.

Table 1. Summary of Los Angeles County Public Beach Facility Assets

Region	Facility	Concession	Lifeguard Bldg.	Maintenance Yard	Parking Lot	Restroom	Utilities	Other (see note)	Total	Note
		Asset Type								
Malibu	Nicholas Canyon County Beach				1	1		1	3	Access road
	El Sol County Beach							1	1	Access road with parking
	Zuma County Beach	2	2	1	12	9			26	
	Point Dume County Beach		2		1	3		1	7	Access road
	Dan Blocker County Beach				1	1			2	
	Malibu Surfrider County Beach		1		1	1			3	
	Topanga County Beach		1		2	1		1	5	Access road
Santa Monica Bay	Will Rogers State Beach	2	1	1	6	6			16	
	Venice Beach		1	1	3	1			6	
	Dockweiler State Beach	2	3	1	6	10	3	3	28	Parking lot buildings
	Manhattan County Beach	1	4	1		5			11	
	Hermosa Beach									
	Redondo County Beach		3	1		7			11	
	Torrance County Beach	1	1		1	2			5	
Palos Verdes Peninsula	Royal Palms County Beach				1	1		1	3	Access road
	White Point County Beach				1	1			2	
		8	19	6	36	49			129	

Note: Of the 129 total assets, 23 share space within 11 buildings. The total number of individual assets for purposes of this study is 121 as summarized in Appendix A. Source: County of Los Angeles, 2016.

The County also maintains 11 public beach accessways in Malibu shown in **Figure 5**. The structures generally consist of on grade or pile supported stairs and/or ramps to provide pedestrian access to the shoreline. The County Department of Public Works and other municipal agencies maintain a significant paved pedestrian and bicycle path that extends from Torrance County to Will Rogers State Beach.

Sea Level Rise

The vulnerability of Los Angeles County's beach facilities will depend upon the magnitude of future sea level rise. As greenhouse gas emissions continue to impact the global climate, the warming of the atmosphere and oceans is projected to accelerate melting of glaciers and polar ice sheets, release more water into the oceans, and cause sea water to expand. The cumulative effect of these physical processes will result in ocean levels higher than today. Predictions of the magnitude and rate of rise are continually evolving as the science and understanding of the phenomenon becomes better understood and the ability to more accurately simulate the process with numerical models improves.

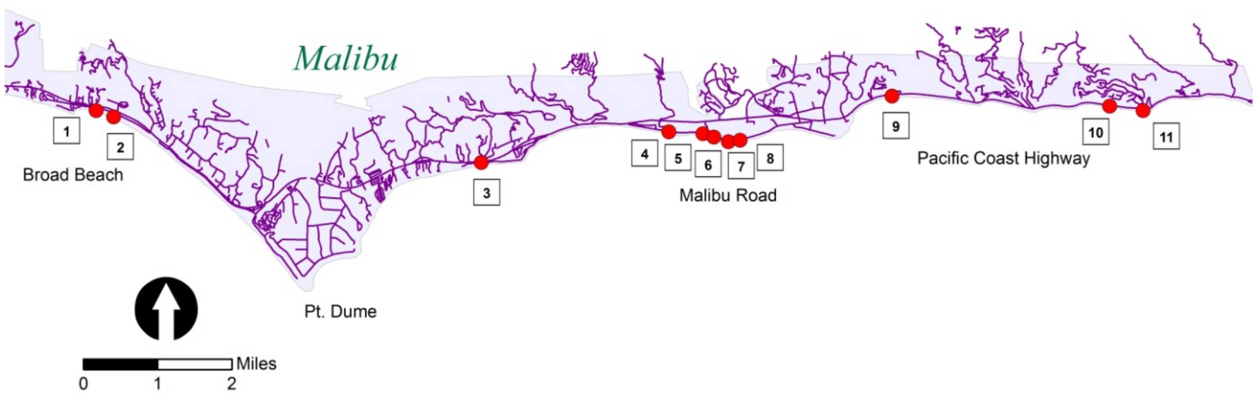

Figure 5. Location of County Maintained Public Beach Accessways

Source: Los Angeles County Dept of Beaches and Harbors

In the past 25 years, numerous studies have been published on the topic resulting in a confusing number of forecasts that don't all agree with one another. Three studies have recently emerged as the most relevant to the California coast. The National Oceanic and Atmospheric Administration's (NOAA) Climate Program Office summarized its assessment of future sea-level rise in their 2012 report.[4] NOAA indicates that by 2100, global mean sea level is estimated to rise anywhere between 8 inches and 6.6 feet. The wide range in their forecast is because of the inability to confidently predict the future climate and how it will correlate to polar ice sheet losses and the other contributing sea-level rise components.

The National Research Council (NRC) published its sea-level rise assessment for the U.S. West Coast in 2012.[5] The recommendations are largely based upon prior research published by others who forecast future sea level rise by modeling six different global warming scenario groups previously established by the Intergovernmental Panel on Climate Change (IPCC). Their predictions rely upon statistical models that use semi-empirical relationships between past and predicted future global temperature changes. The NRC forecast of sea-level rise by 2100 ranges from about 1.4 to 5.5 feet. In 2013, the State of California's Coastal and Ocean Working Group of the California Climate Action Team[6] (CO-CAT) recommended that the sea-level projections estimated by the NRC be adopted. Their specific guidelines are reproduced in **Table 2**.

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[4] Parris, A. et al, 2012. Global sea level rise scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

[5] Committee on sea level rise in California, Oregon, and Washington, 2012. Sea-level rise for the coasts of California, Oregon, and Washington: past, present, and future, National Research Council, Board on Earth Sciences and Resources and Oceans Studies Board, 2012.

[6] Coastal and Ocean Working Group of the California Climate Action Team, 2013. State of California sea-level rise guidance document, March 2013 update.

Table 2. NRC Sea-Level Rise Projection from Year 2000

	South of Cape Mendocino	
Time Period	Low Estimate	High Estimate
2000 to 2030	0.13 feet	0.98 feet
2000 to 2050	0.39 feet	2.00 feet
2000 to 2100	1.38 feet	5.48 feet

Source: Coastal and Ocean Working Group of the California Climate Action Team, 2013

Finally, the IPCC published its 5th Assessment on Climate Change report in late 2013. The sea-level rise study[7] that was commissioned as part of that effort, represents a departure from prior studies. The 5th Assessment's estimates of ice sheet loss, thermal expansion, and land water storage components were computed with the benefit of an improved physical understanding of the process models that were used. The working group's findings significantly lowered previous forecasts of sea-level rise to a range of between approximately 1.4 to 3.2 feet by 2100. Houston[8] has indicated that the 2013 IPCC study represents the most current and credible estimate of global sea level rise available that should be cited.

Figure 6 summarizes the current range of sea-level rise forecasts. The figure illustrates the dilemma that confronts planners and decision makers who are charged with management of Los Angeles County's shoreline and its public beach facilities. The lack of certainty in how high sea level will rise and when it will occur makes it difficult to adopt implementation plans now for the future. This suggests that an adaptive management strategy may be the most appropriate path forward to address how best to maintain existing facilities and respond to future conditions as certainty becomes more focused.

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7 Church, J. et al, 2013. Climate Change 2013, the physical basis, Working Group I contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Chapter 13, Sea level change.

8 Houston, J., 2016. "Do not undercut the Intergovernmental Panel on climate change," Shore & Beach, Vol. 84, No. 1, American Shore & Beach Preservation Association, Winter 2016.

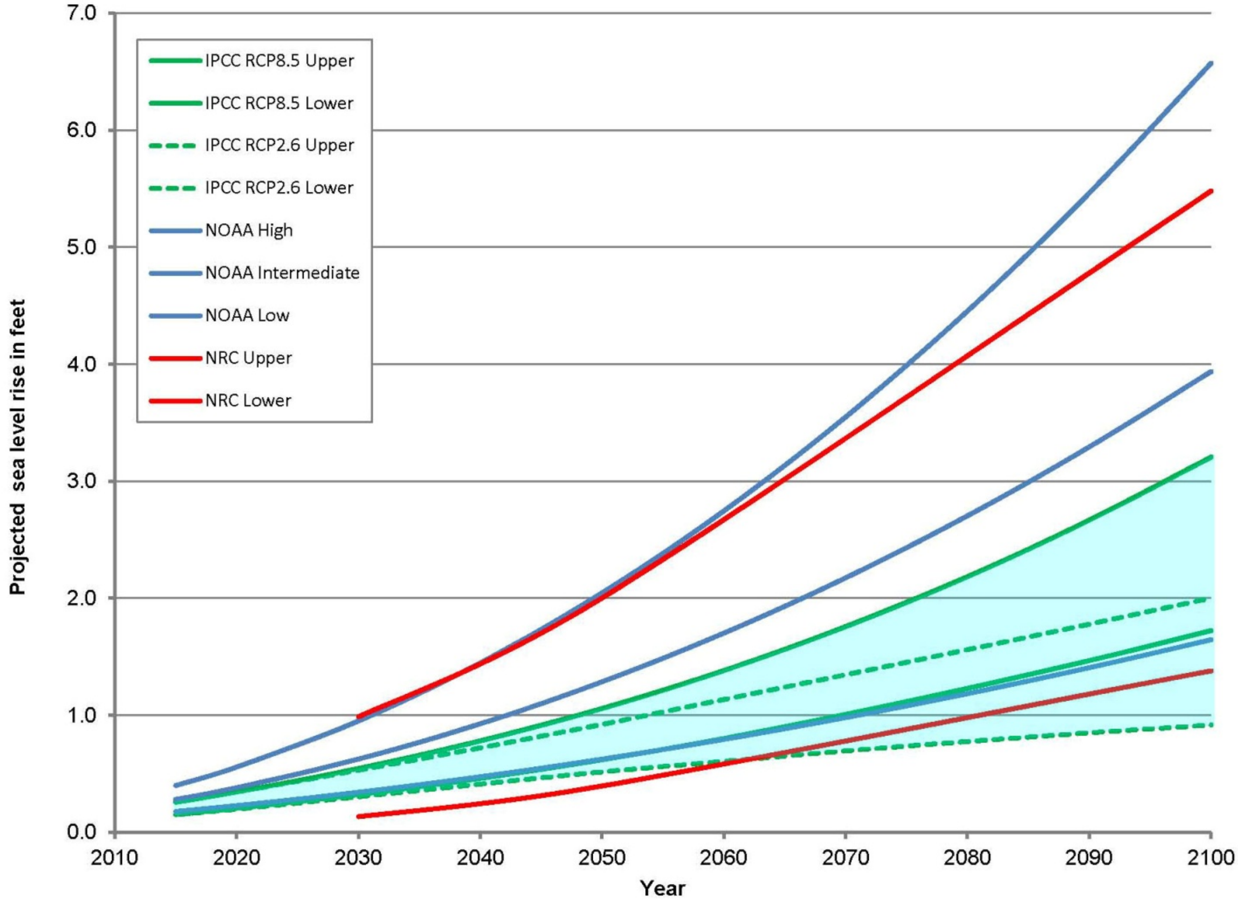

Figure 6. Current estimates of sea-level rise. The figure shows the variable range of future sea rise forecasts as predicted by NOAA, the State of California and NRC, and the IPCC. The blue lines represent the low, intermediate, and upper estimates by NOAA in 2012. The red lines show the probable range as predicted by the State's 2012 NRC sponsored study. The light blue band, represents the most recent forecast range published by the IPCC in 2013 using an improved understanding of the science involved and advanced numerical modeling techniques.

Vulnerability Assessment

The vulnerability of Los Angeles County's public beach assets to coastal hazards will be defined by their ground elevation, proximity to the edge of the shoreline, and exposure to beach erosion, wave runup, and inundation. Beaches are dynamic and constantly in motion. Over the long term, the shoreline may erode, accrete, or remain relatively stable. Short term cyclical changes will occur seasonally and during storm events. Beaches tend to recede in the winter months and accrete during summer. Storm swell can move significant volumes of sand offshore and alongshore resulting in temporary and sometimes permanent losses to beach width.

The location of the existing County public beach assets with respect to the existing shoreline varies. **Figure 7**shows the range of distances the facilities are presently from the water's edge. **Figure 8** summarizes the range of base elevations of the improvements at each County beach facility.

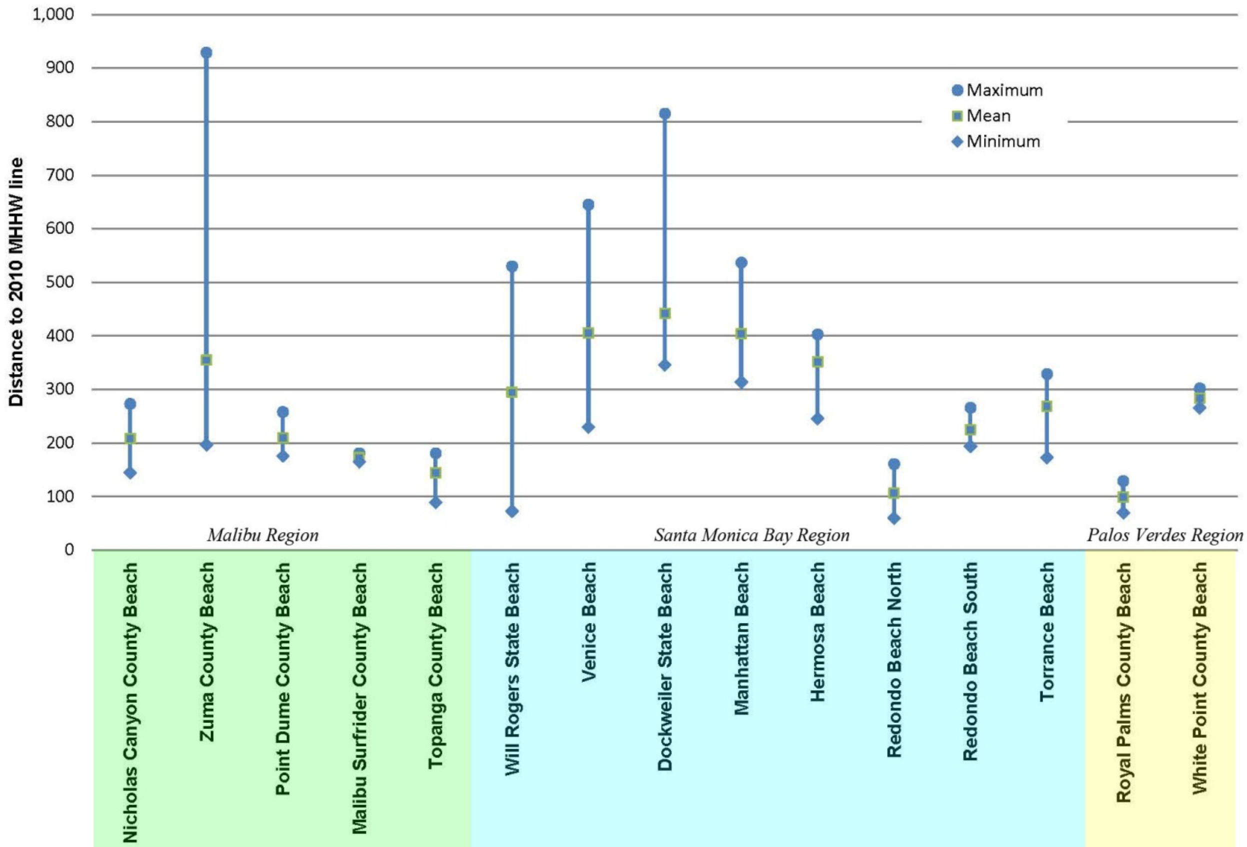

Figure 7 Location of public beach assets relative to the 2010 Mean Higher High Water shoreline position. The graph illustrates the minimum, average, and maximum leading edge distances of assets from the high tide line at each beach facility as measured from 2010 topographic data. In general, beach improvements within the Malibu Region are closer to the water's edge, and improvements within the central Santa Monica Bay Region have a wider beach in front of them

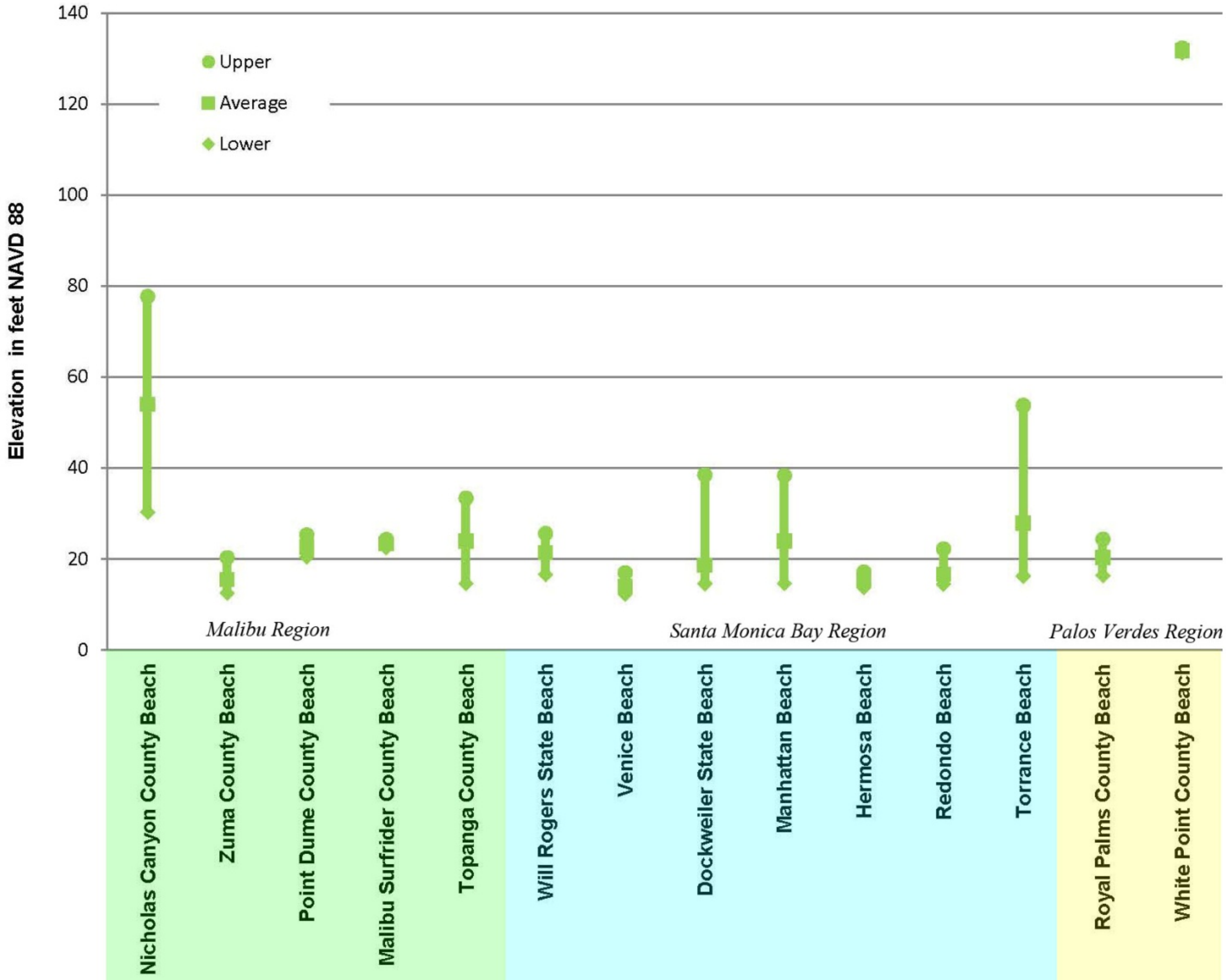

Figure 8. Summary of existing elevations of existing County beach assets relative to NAVD 88 vertical datum. The figure shows the minimum, average, and maximum ground elevation of assets at each facility. The higher elevations reflect improvements that are located on backbeach bluff and cliff areas. Source: Topographic data from Barnard et al, 2010. [9]

In general, **Figures 7** and **8** show that many of the County assets within the Malibu region are on low lying and relatively narrow beaches. The wider beach widths of the central Santa Monica region offset to a degree the fact that many of facility improvements there are at lower elevations. The vulnerability of the assets will then revert to a review of the susceptibility to erosion and coastal flooding over time.

CoSMoS 3.0 Vulnerability Forecast

Forecasting Los Angeles County's future shoreline position is a difficult and complex task because of the number of variables that are involved. The lack of certainty in future sea level

9 Barnard, P.L., and Hoover, D., 2010, A seamless, high-resolution coastal digital elevation model (DEM) for southern California. U.S. Geological Survey Data Series 487

rise, shoreline condition, and frequency of storm attack are unknown. However, assumptions can be made based upon the present understanding of the physical system and use of available numerical modeling tools. The US Geologic Survey (USGS) is in the process of completing a detailed coastal hazards assessment model of the Los Angeles County shoreline as part of their coastal storm modeling system (CoSMoS)[10] study for the California shoreline. The effort consists of integrating a complex suite of sophisticated atmospheric and hydrodynamic computer models to estimate the interaction of future storm events with ocean swell, sea levels, bathymetry, and coastal sediments to forecast short term and long term shoreline changes and inundation from wave runup. The model is intended to forecast the potential vulnerability of the Los Angeles County shoreline to flooding and shoreline erosion.

The preliminary model results available for this study consist of five incremental scenarios of sea-level rise that range from 0 to 6.6 feet (0 to 200 centimeters). Each scenario is assumed to be coincident with a 100-year storm event to review the potential threat to existing development that future beach erosion and storm wave runup may pose. **Figure 9** shows the different CoSMoS scenarios (version 3.0) that have been run thus far and their relationship to the current understanding of future sea-level rise projection. **Appendix A** contains the results of the CoSMoS 3.0 map output overlaid upon Los Angeles County public beach facilities.

[10] Barnard, P. et al, 2015. CoSMoS 3.0: Southern California (in progress), https://walrus.wr.usgs.gov/coastal_processes/cosmos/socal3.0/index.html

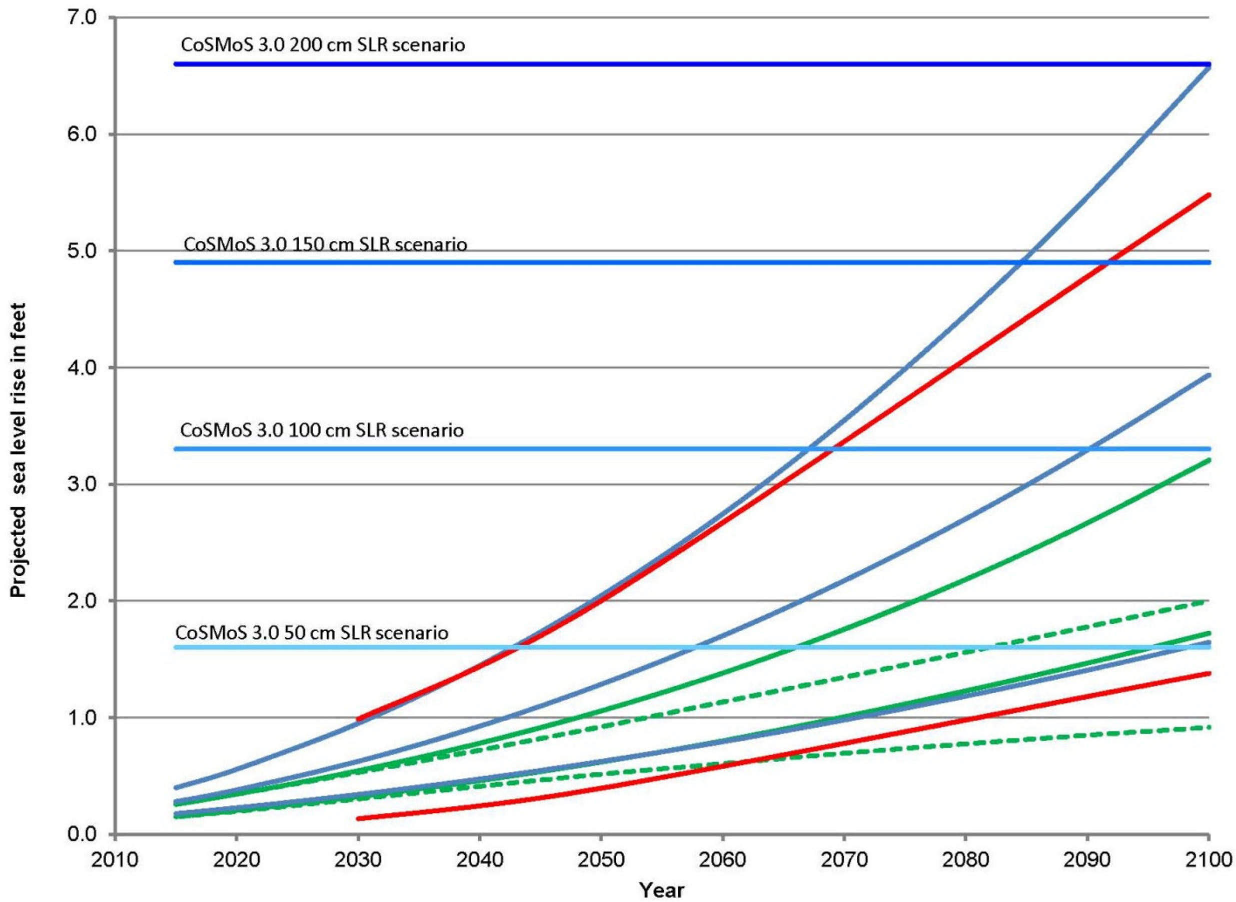

Figure 9. CoSMoS sea level rise scenarios in relation to the current range of future global sea level rise forecasts.

Tables 3 and **4** summarize the potential vulnerability to Los Angeles County public beach assets as forecast by the CoSMoS 3.0 numerical model forecast for the range of sea-level rise scenarios run. **Table 3** indicates the potential long term loss in beach width at the County beaches as a result of sea level rise corresponding to the 100 centimeter and 200 centimeter level (3.3 and 6.6 feet, respectively). As shown in **Figure 6**, these scenarios represent the more severe or upper limits of sea-level rise forecasts by 2100. The CoSMoS simulations generally indicate that the Malibu region beaches may be significantly reduced in width with some facilities losing their entire sandy beach. Facilities between Dockweiler State Beach and Torrance County Beach may be reduced by at least half of their present day width.

Table 3. Potential Percentage of Shoreline Loss due to Sea-Level Rise as Forecast by CoSMoS 3.0

	CoSMoS SLR scenario	
Facility	**100 cm**	**200 cm**
Nicholas Canyon County Beach	50%	100%
Zuma County Beach	25%	50-90%
Point Dume County Beach	20%	90%
Dan Blocker County Beach	100%	100%
Malibu Surfrider County Beach	25%	50%
Topanga County Beach	100%	100%
Will Rogers State Beach West	30%	90%
Will Rogers State Beach East	50%	50-100%
Venice Beach	10-20%	25-50%
Dockweiler State Beach	10%	40%
Manhattan Beach	25%	50%
Hermosa Beach	50%	60%
Redondo Beach	25%	60%
Torrance Beach	25%	60%
Whites Point/ Royal Palms County Beach	100%	100%

Table 4 summaries the potential vulnerability of the public beach assets due to wave runup and inundation as visually extracted from the CoSMoS 3.0 model results. The table lists the percentage of assets that may be impacted for all of the CoSMoS 3.0 sea level rise scenarios. **Table 5** shows the vulnerability breakdown between the Malibu, Santa Monica Bay, and Palos Verdes regions. The data suggests that by the time sea level rise approaches 100 centimeters (3.2 feet), threats to Los Angeles County's existing beach assets will be more significant.

Table 4. Potential Percentage of Public Beach Assets Impacts by Future Sea-Level Rise

		CoSMoS 3.0 SLR Scenario with 100 yr storm				
Facility	**Total Assets**	**0 cm**	**50 cm**	**100 cm**	**150 cm**	**200 cm**
Nicholas Canyon County Beach	4	25%	50%	50%	50%	50%
El Sol County Beach	0					
Zuma County Beach	27	0%	33%	67%	93%	100%
Point Dume County Beach	4	0%	0%	0%	0%	25%
Latigo Shores County Beach	0					
Dan Blocker County Beach	2	0%	0%	0%	0%	0%
Malibu Surfrider County Beach	3	0%	33%	67%	67%	100%
Las Tunas County Beach	0					
Topanga County Beach	3	67%	67%	67%	67%	67%
Will Rogers State Beach	17	18%	24%	24%	35%	47%
Venice Beach	6	50%	83%	100%	100%	100%
Dockweiler State Beach	27	0%	19%	56%	81%	85%
Manhattan Beach	7	0%	0%	0%	43%	86%
Hermosa Beach	5	0%	0%	20%	60%	100%
Redondo Beach	8	0%	0%	13%	88%	88%
Torrance Beach	4	0%	0%	25%	25%	25%
Royal Palms County Beach	2	50%	50%	100%	100%	100%
White Point County Beach	2	0%	0%	0%	0%	0%
Point Fermin Beach	0					

Table 5. Summary of Potential Impacts to Los Angeles County's Public Beach Facilities per CoSMoS 3.0 Sea-Level Rise Scenarios

		CoSMoS 3.0 SLR Scenario with 100 yr storm				
Region	**Total Assets**	**0 cm**	**50 cm**	**100 cm**	**150 cm**	**200 cm**
All regions	121	10	29	54	81	93
Percent impacted		8%	24%	45%	67%	77%
Malibu	43	3	14	24	31	35
Percent impacted		7%	33%	56%	72%	81%
Santa Monica Bay	74	7	15	30	50	58
Percent impacted		9%	20%	41%	68%	78%
Palos Verdes	4	1	1	2	2	2
Percent impacted		25%	25%	50%	50%	50%

Traditional Beach Erosion and Wave Runup Hazard Analysis

Vulnerability to the County's public beach assets was also reviewed via a simplified assessment of shoreline erosion and wave runup. The Los Angeles County beaches regularly experience erosion, flooding, and significant storm events. Future sea level rise will exacerbate these natural forces. Based on the differences in physical setting, wave exposure, locations of the County's public beach assets, and data availability, thirteen representative beach facilities were selected for an erosion and flooding analysis performed for this study. The representative beaches analyzed, from west to east and north to south, were Nicholas Canyon Beach, Zuma Beach, Point Dume Beach, Malibu Surfrider Beach, Topanga Beach, Will Rogers State Beach, Venice Beach, Dockweiler State Beach, Manhattan Beach, Hermosa Beach, Redondo Beach, and Torrance Beach. The analysis that was performed is summarized in the following sections. The analysis was performed assuming the high estimate of sea-level rise as summarized in **Table 2** and **Figure 6** (NRC Upper curve).

The County's beaches will change over time in response to coastal storm frequency and intensity, nearshore currents, and gradual rise in sea level. In general, the total change in beach width at any time will be a function of several response variables: the long-term recession in response to future sea level rise, the long-term evolution caused by the alongshore variation of alongshore sediment transport rate, the seasonal variation in response to the annual changes in wave climate and resultant cross-shore sediment transport, and temporary losses induced by short term winter storm events. The analysis performed for this study assumes that the magnitude of the long-term beach evolution caused by the variation of alongshore sediment transport rate is significantly less than the seasonal beach variation and the storm-induced beach erosion. This component was neglected in this evaluation in order to simplify the analysis.

Beach Recession in Response to Sea Level Rise

The beach recession in response to sea-level rise was estimated using the Bruun Rule (1962)[11] . The theory has been widely applied by the engineering and scientific communities to provide a first approximation of the potential shoreline retreat caused by rising ocean levels. Assuming all sand removed from the upper portion of the beach profile is deposited offshore as sea level rises, the Bruun Rule (1962) provides a relationship to estimate shoreline retreat as a function of sea level rise and beach profile characteristics.

The Bruun Rule reads

$$R = S\frac{W_*}{(h_* + B)}$$

[11] Bruun, P. (1962), "Sea-level rise as a cause of shore erosion," Journal of Waterways and Harbors Division, Vol. 88 (1-3), 117-130.

where R is the shoreline/beach recession distance, S is the sea level rise, W_* is the horizontal dimension of the active zone of the beach profile, h_* is the depth of closure, and B is berm height above the sea level. Using this formula, long term beach loss was estimated for the County's thirteen beach facilities analyzed in this study. The representative beach profile characteristics (W_*, h_*, and B) at these beaches were determined based on the beach profiles that were formulated in the U.S. Army Corps of Engineers' Coast of California Storm and Tidal Waves Study for the Los Angeles County Shoreline (CCSTWS)[12].

Seasonal Beach Variation

Typically, beaches (and dunes) undergo a seasonal transformation from a "summer" beach to a "winter" beach. As storms and wave heights (along with a general change in wave and wind direction) increase during the fall and winter months, the berm erodes in a process where the beach sand is pulled offshore and deposited in offshore sandbars. In the late spring and early summer months, more gentle sea and swell waves prevail that causes the sand to slowly return and beach widths to recover.

The seasonal beach variation was estimated based on monthly beach width surveys conducted by the County at four of its beaches. The data consists of Redondo Beach since 2000, Zuma Beach since 2010, and Venice Beach and Manhattan Beach from 2011. Statistical analysis was conducted for the surveyed beach width data to determine the 10-, 50- and 90-percent narrower beach widths. The difference between the 10-percent narrower beach width and the median (50%) beach width was used to represent the seasonal beach erosion distance. It is noted that the beach width surveys were only available for four out of the thirteen beaches reviewed in this report. The seasonal erosion distances for the other nine beaches were assigned values from the existing database based upon similarity of beach characteristics and judgment.

Storm-Induced Beach Erosion

One large coastal storm, wave swell event, or cluster of storms can cause significant beach erosion that can be temporary or permanent. Storm erosion follows a similar but more rapid pattern than seasonal erosion. The most impacting episodes usually occur in the fall, winter, or early spring months when the "seasonal" beach profile is already relatively depleted of sand or more narrow in width. Changes seen at the beach are similar to the seasonal changes, with extensive loss of the berm. Storm recovery also follows a similar process of the seasonal beach, with offshore sandbars providing protection, and slow, gradual build up of the berm in response to the more benign post-storm wave climate. Complete recovery can be rapid, or take months or years.

The storm-induced beach erosion distance was estimated based on the positions of the Mean Higher High Water line at the beginning and at the end of the severe January 18-25, 2010 El Nino storm, which were computed by the USGS study team during CoSMoS 1.0 model

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[12] U.S. Army Corps of Engineers, 2010. Coast of California Storm and Tidal Waves Study, Los Angeles Region. Prepared by the Los Angeles District, November 2010.

simulations of the Southern California coast[13]. The difference between the pre-storm and post-storm MHHW shorelines was used to represent the storm-induced beach erosion distance for this study.

Total Beach Recession

The total beach recession distance was calculated by summing up the above three components: beach recession in response to long term sea-level rise, seasonal beach erosion, and storm-induced erosion. The more extreme projection for sea-level rise published by the State was used in this analysis (see **Table 2**.). It is noted that some County facilities are backed by bluffs, embankments, or other structures that will be more resistant to erosion than the sandy beach. Therefore, the beach erosion is assumed to stop at these landward barriers. Estimates of the component and total beach recession distances are summarized in **Table 6** for the thirteen beaches in 2010, 2040, and 2100, respectively. The analysis indicates that beach recession distances vary significantly for different beaches as a result of the different beach profile characteristics and other variables involved.

Coastal Flood Inundation Analysis

Wave Runup on the Edge of Beach

The 100-year wave runup on the beach was determined using the "system response analyses" approach that is recommended by FEMA[14]. This response approach uses the wave conditions along with simultaneously measured water levels to determine site specific wave runup for a variety of storms. The wave runups for these storm events are then statistically evaluated to determine the 1% annual chance (or the 100-year) wave runup elevation.

The wave runup on the beach was computed using the following equation that is recommended in US Army's Coastal Engineering Manual [15]:

$$\frac{R_{2\%}}{H_0} = 1.86\xi_0^{0.71}$$

where $R_{2\%}$ is the 2% wave runup that is defined as the runup exceeded by 2 percent of the runup crests, H_0 is the significant deep-water wave height, and ξ_0 is the Iribarren number, or the surf similarity parameter that is defined as

13 http://walrus.wr.usgs.gov/coastal_processes/cosmos/socal1.0/index.html

14 Federal Emergency Management Agency (FEMA), 2005. Final Draft Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States. Final Draft Prepared November 2004, Section D.4.5 Revised January 2005.

15 U.S. Army Corps of Engineers (USACE), 2003. *Coastal Engineering Manual*. Engineering Manual 1110-2-1100, USACE, Washington, D.C. (in Part II).

$$\xi_0 = \tan\beta\left(\frac{H_0}{L_0}\right)^{-1/2}$$

in which $tan\beta$ is the averaged beach slope from the wave breaking point to the wave runup limit, and L_0 is the deep-water wave length that is

$$L_0 = gT^2/2\pi$$

where g is the gravitational acceleration and T is the peak wave period.

In this analysis, the 2% wave runup elevations were computed for every three hours for the 36-year period between 1970 through 2005 for the thirteen beaches. The 3-hourly nearshore wave condition at the representative locations of these thirteen beaches, which was computed in the CCSTWS for this 36 years period, was used in the wave runup calculation. The hourly water level data that was simultaneously measured by the National Oceanic and Atmospheric Administration (NOAA) gauge at Los Angeles Outer Harbor (NOAA ID: 9410660)[16] was used as the still water levels at these thirteen beaches. The representative beach profiles used in the wave runup calculations were determined based on the beach profiles that were formulated in the CCSTWS[12].

Based on the 3-hourly wave runup elevations, the annual maximum wave runup elevations were determined for the 36 years between 1970 and 2005. A statistical analysis was then conducted for these 36-year annual maximum wave runup elevations to determine 1% annual chance (or, 100-year) runup elevations. The computed 100-year wave runup elevations are shown in **Table 7** for the existing condition. The impact of the future sea-level rise was considered by elevating the measured hourly water level data by the projected sea-level rise. The wave runup elevations for 2040 and 2100, after including the sea-level rise impact, are also listed in **Table 7**.

Overtopping Water Propagation Distance on Beach

When the wave runup exceeds the berm elevation of a beach, overtopping water will further propagate inland over the beach. However, to date no theory or reliable methods have been formulated to predict how far the overtopping water will travel over the relatively flat sections of beach. As a first approximation of this inundation extent due overtopping waves, Cox and Machemehl[17] proposed a simplified formula to correlate the water travel distance to the wave's overtopping height above the berm. Based on this relation, propagation distances were estimated, and the results are listed in **Table 7**.

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16 National Ocean Service, Los Angele Outer Harbor Tide Gage, 9410660, http://tidesandcurrents.noaa.gov/stationhome.html?id=9410660

17 Cox, J. C., and Machemehl, J. (1986), "Overload Bore Propagation Due to An Overtopping Wave," *J. of Waterway, Port, Coastal and Ocean Engineering*, 112 (1), pp. 161-163.

Coastal Erosion and Flood Vulnerability Assessment of County's Assets

Based on the computed results of the beach erosion and wave runup analysis, the +5-foot NAVD88 elevation water lines and potential landward extent of the coastal flood inundation were derived for the thirteen beaches that were studied. The results are shown in **Figures 11 through 13** for 2010, 2040, and 2100, respectively. The locations of the County's assets are shown schematically in these figures for comparison. It is noted that the additional long and short term erosion landward of areas protected by bluffs or hard structures was not included in the analysis. The side slopes of these more armored areas are much steeper than the berm of the beach, and flooding was assumed not to pass bluff or hard structure barriers. Where inundation was estimated to reach existing bluff toes and armored sections, a red arrow is used in these figures to indicate slower bluff erosion, structure damage, or reduced inland flooding.

The percent of beach berm that is estimated to be left after erosion is listed in **Table 8**. The number of County's assets potentially exposed to future erosion hazard is summarized in **Table 9**. The number of County's assets that may be vulnerable to inundation is listed in **Table 10**.

West Beaches

For the high estimate of sea-level rise scenario, the beach erosion and wave runup analysis suggests that Nicholas Canyon Beach may be completely eroded by 2040 if no shoreline measure is implemented. Malibu Surfrider Beach, Topanga Beach, and Will Rogers State Beach will only have approximately 50% of beach or less left in 2040. These four beaches are forecast to be completely eroded by 2100. The analysis results suggest that Zuma Beach and Point Dume Beach will have more than 50% of beach left in 2040, and more than 30% of beach remaining in 2100.

For the 2040 high sea-level rise projection, the County's assets located on the beach may be more vulnerable to erosion hazard at Topanga Beach, and Will Rogers State Beach. In 2100, the assets will be vulnerable to erosion hazard at Malibu Surfrider Beach, Topanga Beach, and Will Rogers State Beach. If no protection measures are implemented, the assets will be vulnerable to inundation damage at Zuma Beach, Point Dume Beach, Malibu Surfrider Beach, Topanga Beach and Will Rogers State Beach under the existing condition, in 2040, and in 2100.

South Beaches

The north portion of Redondo Beach and Torrance Beach are estimated to have less than 50% of beach left by 2040. These two beaches may be completely eroded by 2100. Venice Beach, Dockweiler State Beach, Manhattan Beach, Hermosa Beach, and the south segment of Redondo Beach may have more than 50% of beach left in 2040. By 2010, approximately 30% or more of the beach will remain for Venice Beach, Dockweiler State Beach, and Hermosa Beach.

The County's assets on or in the landward of the north segment of Redondo County Beach will be vulnerable to erosion hazard under the existing condition. By 2100, some of the County's assets will be vulnerable to erosion hazard for most south beaches. Under the existing condition, some assets will be flooded for most south beaches, in 2040, and in 2100, unless preventive action is taken.

The above vulnerability estimates represent an extreme scenario that consists of the high estimate of sea level rise coincident with a severe storm event. Impacts to facilities and assets are significantly dependent upon the actual rate of sea-level rise that will occur and the intensity of storm occurrence. If the IPCC’s most recent projections prove to be correct, the potential shoreline erosion and inundation impacts discussed above may be delayed for decades and possibly not be relevant until the next century. This sensitivity to the analysis is what makes continued monitoring of climate change’s impact on the oceans so important.

Table 6. Beach Recession Components

Sites	2010 Pre-storm beach width (ft)	Beach recession response to SLR (ft)		Seasonal Erosion (ft) ②	Storm-induced Erosion (ft) ③	Total beach recession distance = ①a or ①b+②+③ (ft)		
		2040 ①a	2100 ①b			2010	2040	2100
Nicholas Canyon County Beach	100	52	206	31	54	85	100*	100*
Zuma County Beach	390	24	95	31	58	89	113	184
Point Dume County Beach	260	26	105	31	37	68	94	173
Malibu Surfrider County Beach	240	62	248	31	21	52	114	240*
Topanga County Beach	190	51	205	31	50	81	132	190*
Will Rogers State Beach	250	53	213	50	69	119	172	250*
Venice Beach	650	53	213	50	91	141	194	354
Dockweiler State Beach	590	50	198	50	106	156	206	354
Manhattan Beach	420	50	198	32	129	161	211	359
Hermosa Beach	470	49	195	32	108	140	189	335
Redondo Beach (North)	140	28	110	15	67	82	110	140*
Redondo Beach (South)	230	35	140	15	88	82	110	192
Torrance Beach	250	52	206	32	54	120	155	250*

Note: * denotes the beach is completely eroded, and further erosion of backshore bluff may occur.

Table 7. Wave Runup and Resulting Bore Propagation Distance on the Beach

Sites	Berm edge elevation (ft, NAVD88)	2% runup at berm edge (ft, NAVD88)			Overtopping height (ft)			Bore propagation distance (ft)		
		2010	2040	2100	2010	2040	2100	2010	2040	2100
Nicholas Canyon County Beach	+10.4	+23.8	+25.9	+32.5	13.4	15.5	22.1	104	112	133
Zuma County Beach	+10.9	+23.0	+24.5	+29.9	12.1	13.6	19.0	99	105	124
Point Dume County Beach	+12.1	+26.4	+28.0	+32.9	14.3	15.9	20.8	107	113	129
Malibu Surfrider County Beach	+10.3	+16.7	+20.0	+28.7	6.4	9.7	18.4	72	88	122
Topanga County Beach	+10.9	+20.0	+22.7	+29.7	9.1	11.8	18.8	86	97	123
Will Rogers State Beach	+11.9	+23.9	+26.1	+31.7	12.0	14.2	19.8	98	107	126
Venice Beach	+10.6	+21.6	+23.1	+28.5	11.0	12.5	17.9	94	100	120
Dockweiler State Beach	+11.4	+26.3	+28.3	+34.2	14.9	16.9	22.8	110	117	135
Manhattan Beach	+13.3	+22.6	+24.2	+29.4	9.3	10.9	16.1	87	94	114
Hermosa Beach	+13.1	+23.1	+24.7	+30.6	10.0	11.6	17.5	90	97	119
Redondo Beach (North)	+15.1	+18.9	+21.3	+28.3	3.8	6.2	13.2	28	35	52
Redondo Beach (South)	+13.7	+29.5	+32.6	+36.8	15.8	18.9	23.1	75	82	91
Torrance Beach	+11.5	+29.5	+31.0	+34.8	18.0	19.5	23.3	120	125	137

Table 8. Beach Recession Distance and Percentage of Remaining Beach

Sites	2010 Pre-storm beach width (ft)	Recession Distance (ft)			Percent of beach remaining		
		2010	2040	2100	2010	2040	2100
Nicholas Canyon County Beach	100	85	100*	100*	15%	0%	0%
Zuma County Beach	390	89	113	184	77%	71%	53%
Point Dume County Beach	260	68	94	173	74%	64%	34%
Malibu Surfrider County Beach	240	52	114	240*	78%	53%	0%
Topanga County Beach	190	81	132	190*	57%	31%	0%
Will Rogers State Beach	250	119	172	250*	52%	31%	0%
Venice Beach	650	141	194	354	78%	70%	46%
Dockweiler State Beach	590	156	206	354	74%	65%	40%
Manhattan Beach	420	161	211	359	62%	50%	15%
Hermosa Beach	470	140	189	335	70%	60%	29%
Redondo Beach (North)	140	82	110	140*	42%	22%	0%
Redondo Beach (South)	230	82	110	192	64%	52%	17%
Torrance Beach	250	120	155	250*	52%	38%	0%

Note: * denotes the beach is completely eroded, and further erosion of backshore bluff may occur.

Table 9. Number and Percentage of County's Assets Vulnerable to Erosion Hazard

Sites	Total	No of eroded assets			Percent of eroded assets		
		2010	2040	2100	2010	2040	2100
Nicholas Canyon County Beach	2	0	0	0	0%	0%	0%
Zuma County Beach	26	0	0	0	0%	0%	0%
Point Dume County Beach	4	0	0	0	0%	0%	0%
Malibu Surfrider County Beach	2	0	0	2	0%	0%	100%
Topanga County Beach	2	0	1	1	0%	50%	50%
Will Rogers State Beach	18	1	1	8	6%	6%	44%
Venice Beach	7	0	0	4	0%	0%	57%
Dockweiler State Beach	15	0	0	2	0%	0%	13%
Manhattan Beach	7	0	0	2	0%	0%	29%
Hermosa Beach	5	0	0	1	0%	0%	20%
Redondo Beach (North)	3	1	2	2	33%	67%	67%
Redondo Beach (South)	6	0	0	0	0%	0%	0%
Torrance Beach	4	0	0	1	0%	0%	25%

Table 10. Number and Percentage of County's Assets Vulnerable to Coastal Flood Hazard

Sites	Total	No of flooded assets			Percent of flooded assets		
		2010	2040	2100	2010	2040	2100
Nicholas Canyon County Beach	2	0	0	0	0%	0%	0%
Zuma County Beach	26	5	8	17	19%	31%	65%
Point Dume County Beach	4	3	4	4	75%	100%	100%
Malibu Surfrider County Beach	2	1	2	2	50%	100%	100%
Topanga County Beach	2	1	1	1	50%	50%	50%
Will Rogers State Beach	18	8	8	8	44%	44%	44%
Venice Beach	7	2	4	5	29%	57%	71%
Dockweiler State Beach	15	0	4	14	0%	27%	93%
Manhattan Beach	7	2	4	4	29%	57%	57%
Hermosa Beach	5	1	4	5	20%	80%	100%
Redondo Beach (North)	3	2	2	2	67%	67%	67%
Redondo Beach (South)	6	2	4	4	33%	67%	67%
Torrance Beach	4	1	1	1	25%	25%	25%

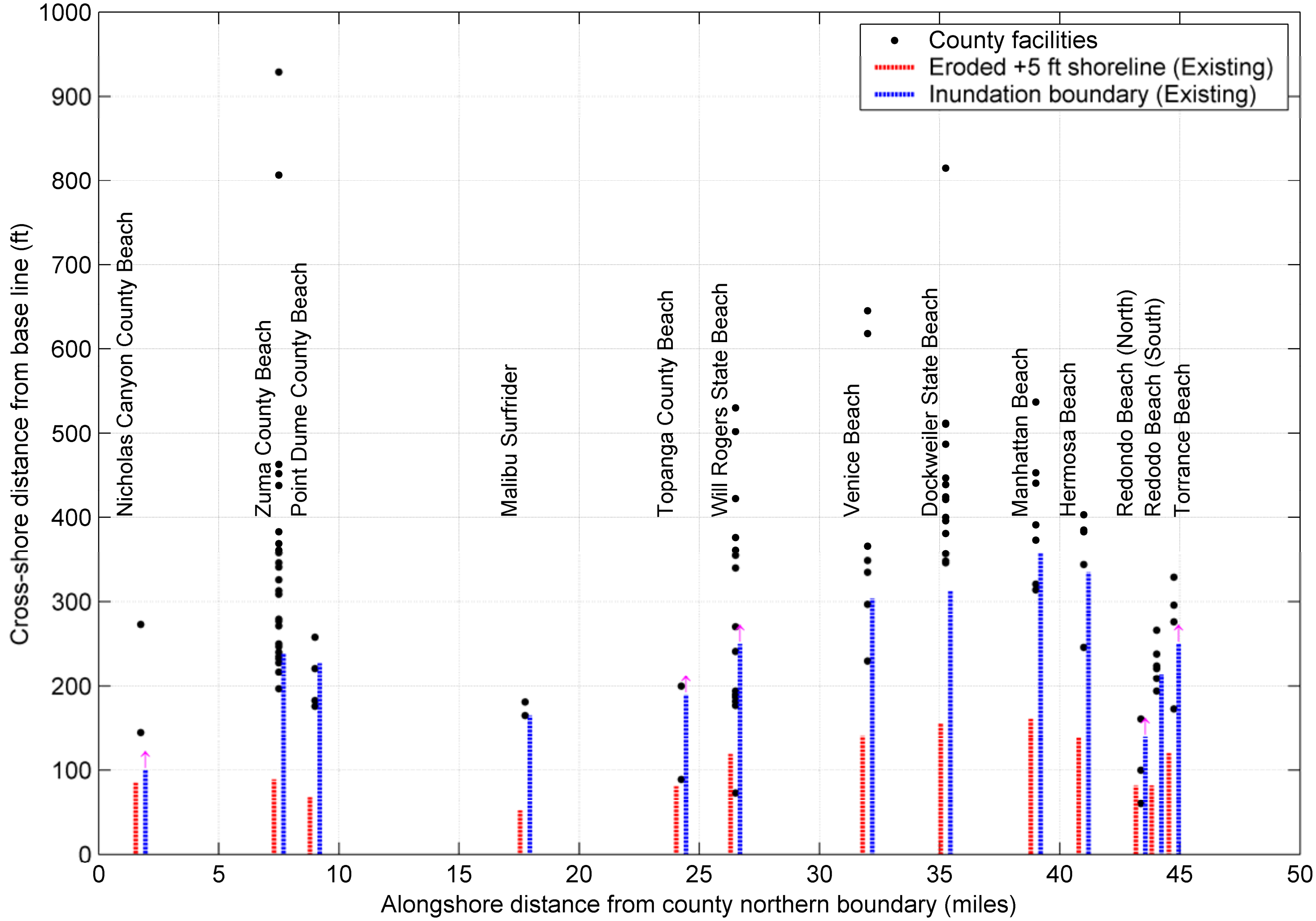


Figure 10. Beach Erosion and Coastal Flood Inundation Extents (Existing Condition)

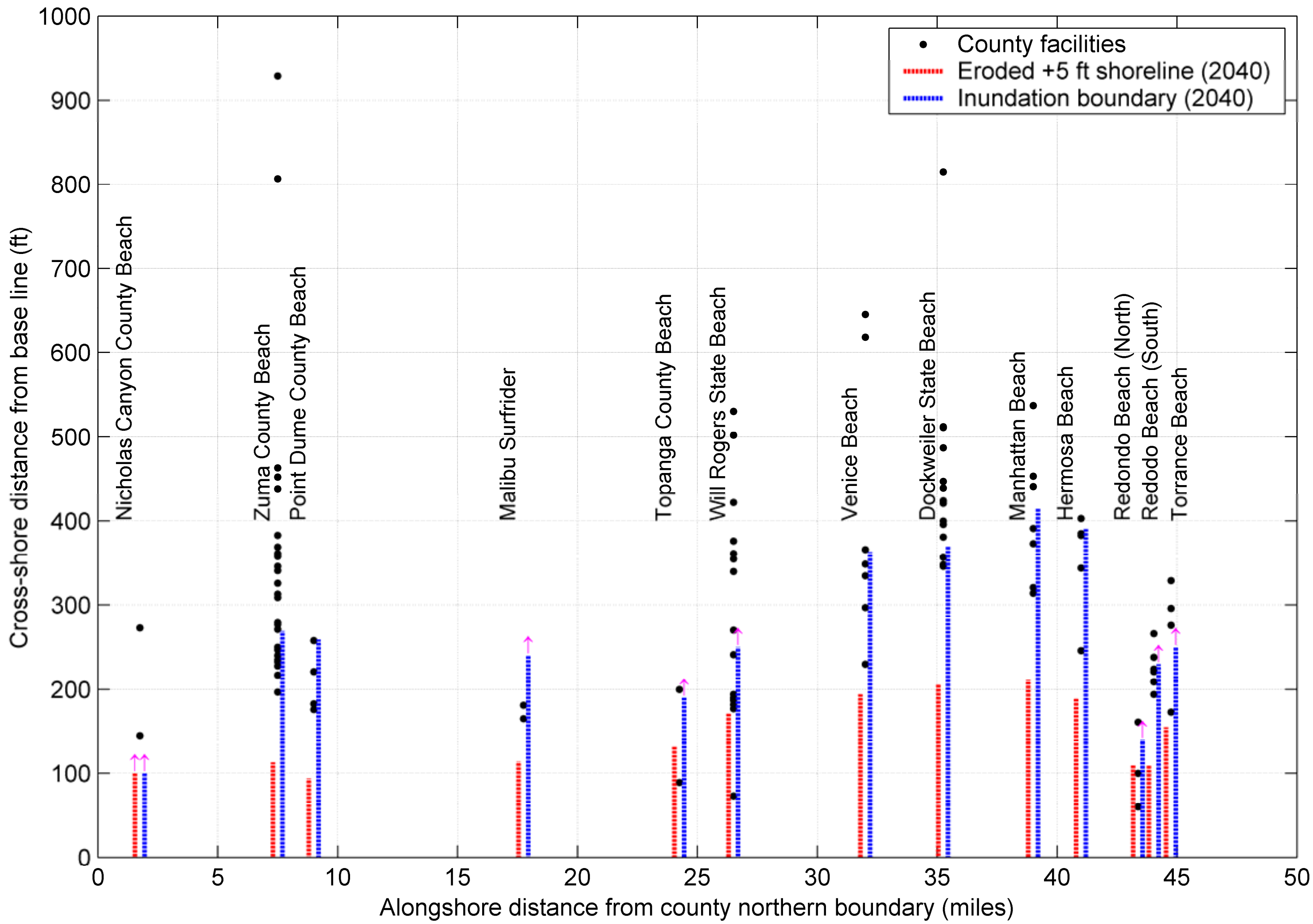


Figure 11. Beach Erosion and Coastal Flood Inundation Extents (2040)

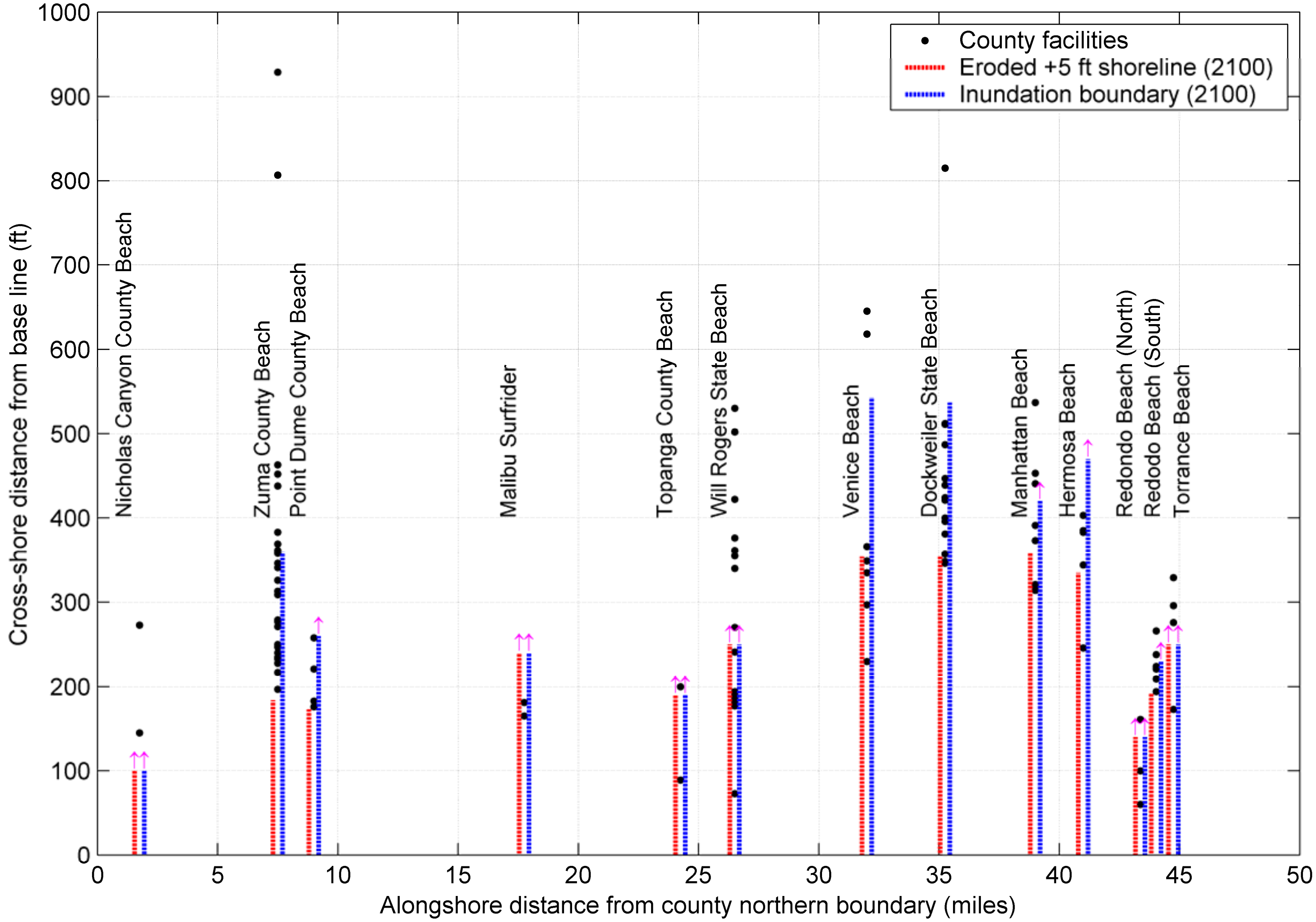


Figure 12. Beach Erosion and Coastal Flood Inundation Extents (2100)

Public Beach Asset Management Strategy

The Los Angeles County shoreline is an important recreational asset that must be maintained. **Figure 13** shows the current demand for beach recreation at Los Angeles County's public beach facilities. In 2014, over 65 million visitors came to the beach. In response to this demand, the County's Department of Beaches and Harbors provides and maintains a significant capital investment of facilities and infrastructure that is necessary to provide a safe and enjoyable recreation experience. With the County's population expected to double by 2100, demand for beach recreation is anticipated to similarly increase. Therefore the challenge for the future will be how can the County best continue to maintain and provide adequate public beach facilities despite the fact that they may become increasingly more vulnerable to future sea-level rise. As shorelines recede and facilities become more exposed to erosion and flood hazards, it is likely that the public will still demand that the important recreational asset that they have come to expect and enjoy remain available for access and use.

Vulnerability of the Los Angeles County public beach facilities will depend upon the magnitude and rate of future sea-level rise. If the extreme projections occur, the erosion and inundation assessment suggests that some or all of the Malibu beaches may significantly erode or disappear. If true, this will invariably add more stress to the Santa Monica Bay beaches as the remaining sections of urbanized strand will be called upon to address all of the shoreline recreation demand for the entire Los Angeles County metropolitan area. The Santa Monica Bay beaches were artificially enhanced and stabilized in the mid 20th century. This shoreline infrastructure provides the key foundation for a future recreation asset that will be called upon to serve the public well into the future.

For at least the next ten to twenty years, the sea-level rise projections indicate that ocean levels will remain relatively static. This implies that winter high tides, coastal storms, and episodic beach erosion events will continue to define the vulnerability of public beaches for some time into the future. Thereafter, only time and monitoring will reveal which scenario is to be expected. This suggests a transitional planning period when the sea-level rate of increase will be better known and the ocean level's critical tipping point can be better forecast. By the year 2100, the more extreme projections of sea-level rise and the finding of this study indicate that accumulated shoreline response and inundation potential may result in more severe exposure to hazards and a third benchmark for plan implementation. Given this scenario, it is recommended that the County adopt an adaptive management strategy that consists of the following elements.

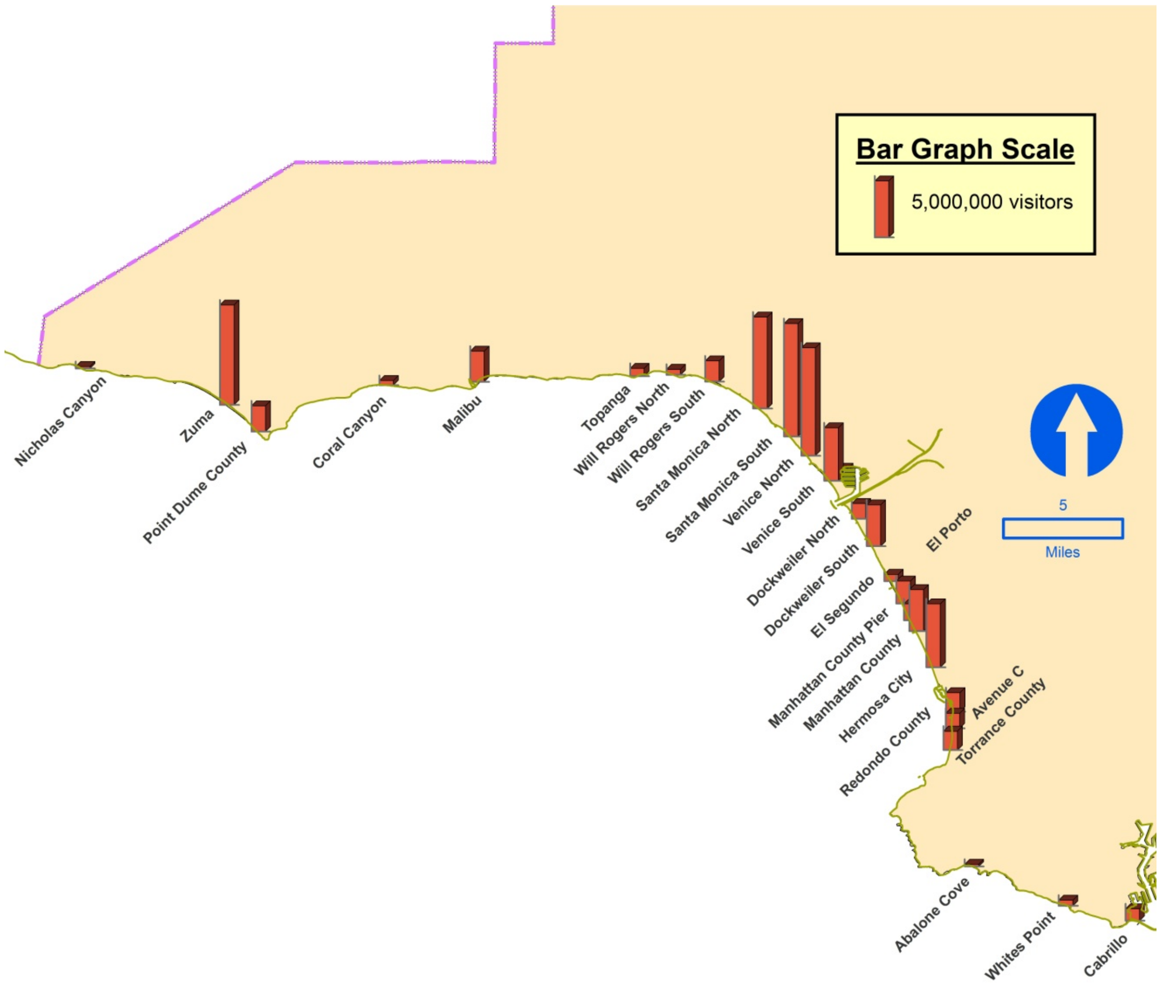


Figure 13. Annual beach attendance for Los Angeles County public beaches for 2013/2014.

The data, collected by County lifeguards, indicates that the beaches experience over 65 million visitors annually. The greatest demand is at Zuma County Beach and from Santa Monica to Torrance. The County's population is projected to double to nearly 20 million by 2100 indicating that demand for beach recreation will only increase. Source: Los Angeles County Department of Beaches and Harbors, 2016.

The Present Short Term Management Strategy

The Los Angeles County currently implements an effective, relatively low cost hazards management program to protect beach facilities during each winter season. Public beach assets at Zuma Beach, Venice Beach, Dockweiler State Beach, and Hermosa Beach are protected from storm waves and runup via construction of temporary sand berms to protect restroom facilities, lifeguard headquarters buildings, maintenance yards, public parking lots, and other infrastructure. Sand is scraped from the foreshore using bulldozers to construct the berms of variable lengths that are generally built between 12 to 16 feet high. The berms' cross section consists of a 4:1 slope on the ocean side and a steeper, natural angle of repose on the land side. **Figure 14** shows a typical example of the methodology. The program has been effective to help protect assets during the winter months.

Figure 14. Construction of temporary winter sand berm at Hermosa Beach. The berm protects the lifeguard headquarters building public beach asset. The County's winter berm program is effective as a relatively low cost measure to protect landward facilities from high tides and moderate storm wave runup. The berms are maintained as needed throughout the winter season by the Department of Beaches and Harbors.

Appendix B summarizes an assessment of the County's existing winter sand berm public beach facilities protection program in more detail and how to improve it. When built to crest heights of at least 12 to 16 feet above existing berm level (+23 to +29 feet above Mean Lower Low Water datum) depending on the beach, the temporary berms can provide wave runup protection from a 50-year event. To be most effective, the berms should be built as landward as possible. Considering that at least 100 feet of sandy beach in order to construct the minimum footprint, approximately 200 feet of sandy beach is minimally required to implement the program. If beaches recede significantly in the future, the ability to continue building temporary winter sand berms and the effectiveness of the program will be impaired and alternative strategies may be needed.

The strategy is considered to be an effective plan when sea-level rise remains relatively low. As the ocean level rises, continued implementation of the program may also provide an effective solution to protect assets at those beaches that are presently wide and not yet exposed to storm wave runup or erosion hazards. Therefore, the temporary winter sand berm protection program is considered to applicable now and for some unknown time into the future at Zuma Beach, the wider sections of Will Rogers State Beach, Venice Beach, Dockweiler State Beach, Manhattan Beach, the wider reach of Redondo Beach, and Torrance Beach. It is considered to be one of the most cost effective means to protect Los Angeles County public beach assets. As such it is recommended that the strategy continue to be employed for as long as practical so that the maximum number of the County's public beach infrastructure can be maintained to serve the public demand.

The Future

Los Angeles County is in the process of completing and implementing its Coastal Regional Sediment Management Plan (CRSMP)[18]. The plan addresses the uniquely urbanized coastal environment and recognizes that its sediment resources available to maintain its public beach infrastructure are finite and limited. Consequently, the CRSMP has recommended a suite of policy, management, and capital project activities to preserve and maintain the County's existing public beach system.

As previously mentioned, over 35 million cubic yards of sand has been placed between Will Rogers State Beach and Torrance Beach since the 1920s resulting in increased beach widths of as much as 600 feet. The artificial beaches created by the nourishment were subsequently stabilized via a series of offshore breakwaters and groin fields to allow development of the public beach infrastructure within Santa Monica Bay that exists today. Key to the County's public beach recreation future will be the continued maintenance of this artificial system.

It is well recognized that one of the most effective strategies to promote resilient coasts is to maintain an adequate sandy beach. In addition to their significant recreational asset, beaches provide significant natural buffers that can protect landward improvements from storm erosion and wave runup inundation and damage. The unique shoreline investment that has been made in Santa Monica Bay over the 20th century to widen and stabilize the shoreline represents a long term strategy that should be continued into the future. **Figure 15** shows the locations of significant offshore sand sources that may be used to maintain Santa Monica Bay's public beaches for many years. The offshore deposits should be identified in more detail, better quantified, and reserved by Los Angeles County as a public resource so that the sediment may be utilized as the source sediment in the future when needed to offset beach erosion losses caused by sea level rise.

Beach nourishment strategy is considered to be less practical for most of the Malibu region. In addition to the impracticality of trying to maintain artificial beaches on a traditionally sediment limited section of shoreline, the region's sensitive biological resources will likely inhibit the ability to place the large volumes of sand that may be needed to replenish eroding reaches. The exception may be the wider Zuma Beach, Point Dume Beach, and other facilities in the region where a significant demand for beach recreation exists and will likely increase. Further study will be needed to implement an effective beach nourishment strategy at Malibu beach facilities to preserve the public access and recreation opportunities.

[18] Noble Consultants, 2012. Los Angeles County Coastal Regional Sediment Management Plan, Draft report prepared for the U.S. Army Corps of Engineers and the California Sediment Management Workgroup, December 2012.

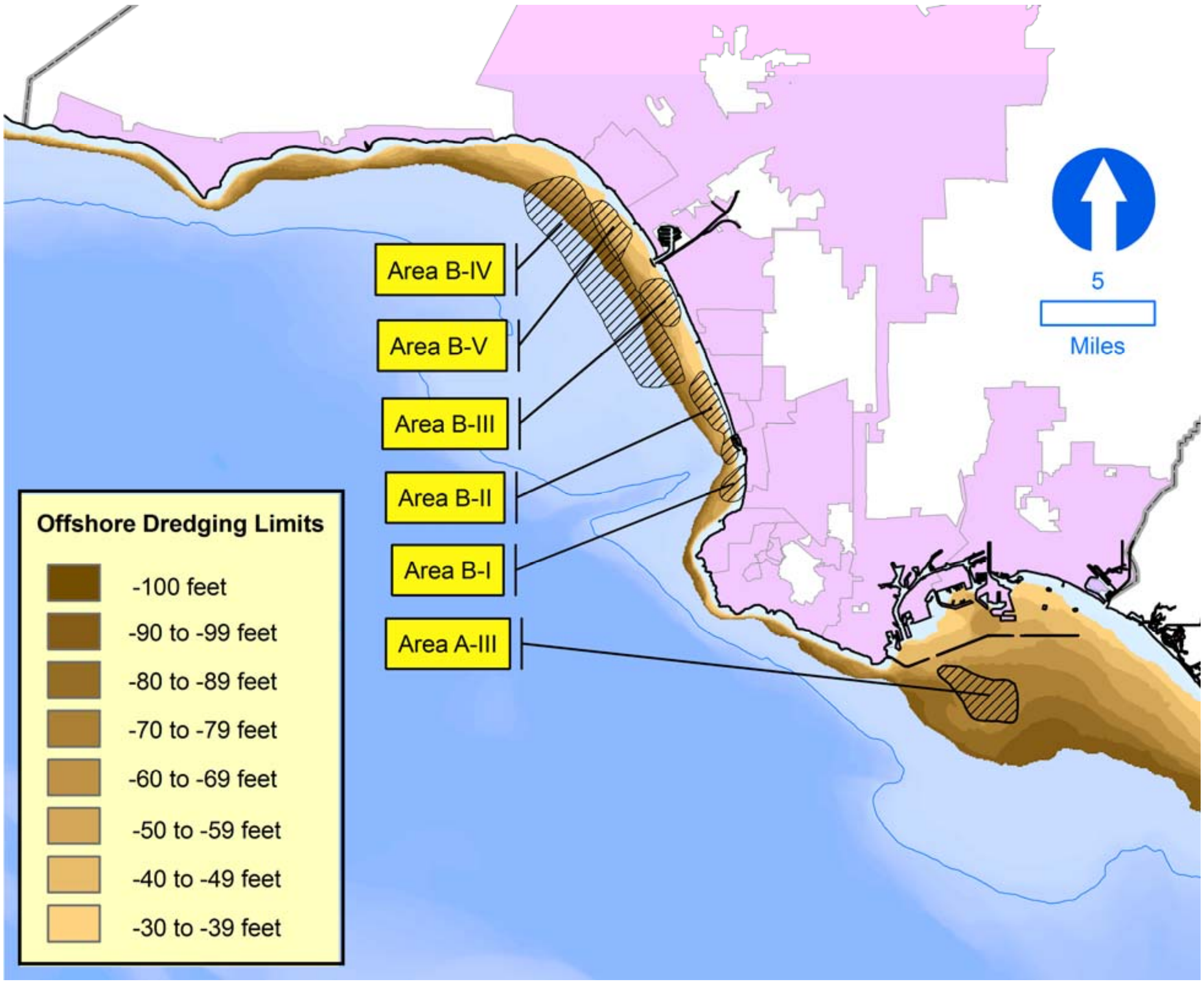


Figure 15. Location of significant offshore sediment deposits adjacent to the Santa Monica Bay region's beaches. The hatched areas are locations believed to contain the largest reserves of beach compatible sand that may be utilized for beach nourishment along the Santa Monica Bay beaches. With careful management, the resource may help to offset the negative effects of sea level rise and preserve the public beach assets. Source: Los Angeles County Coastal Regional Sediment Management Plan, 2012

Long Term Sea Level Rise Management Strategy

Options to deal with future sea level rise at Los Angeles County's public beach facilities are limited. Strategies are limited to the following options:

Retreat — As development and infrastructure become threatened by shoreline erosion and inundation, the assets are removed and re-located further inland. This option has limited opportunities along the Los Angeles County coast primarily because of the unique urban landscape. The constraints of the multiple jurisdictional agencies within the region, private development, and other competing land uses, will not provide sufficient space to re-locate the County's significant facilities footprint. The option has only limited applicability and appeal within the less developed sections of Central and West Malibu.

Elevate — As sea level rises, improvements are raised on fill or pile supported foundations to seek higher ground. The strategy may be appropriate for buildings in some instances, but the option becomes more untenable for the more expansive parking lots and accessways that are critically needed to allow visitors to come to the beach.

Protect — Traditionally, the strategy consists of fortification measures to protect the shoreline from further erosion. However, the option becomes impractical for public beach facilities because protection of the asset can impact the existing beach. In some cases of the extreme projections of sea-level rise scenario, there may be no beach left to provide safe access.

The so called "soft solution" sub-set of this strategy, is placement of suitable sand at the threatened facility. In the form of beach nourishment, the shoreline is replenished with large volumes of sand to maintain adequate width and berm height to keep pace with losses induced by sea-level rise. Construction and maintenance of more landward dune systems represents the other option. Dunes provide a natural buffer against storms and can re-nourish beaches when impacted by high tides and waves. However, sand dunes require a substantial footprint and need a wide offset from the water's edge to be effective and provide adequate space for beach recreation. Within urban coastlines, dune fields can cause significant nuisance issues from windblown sand that migrates landward into unwanted development areas. Dunes can also impair ocean views. Consequently, dune buffers are more practical where sufficiently high backlands already exist to limit landward migration of sand. At least 150 to 200 feet of beach footprint will be needed to accommodate the dune footprint. The only County public beach facility that currently meets these criteria is Dockweiler State Beach.

Long term strategies will require significant capital investment, and more information will be needed before a commitment of public funds can be made. The rate of future sea level rise is currently not known with adequate confidence. Estimates projected by different agencies conflict with one another. Currently, the tendency for planning has been to focus on the extreme forecast which makes the planning process today difficult at best. The most recent estimate of sea level rise prepared by the IPCC is significantly lower than previous forecasts for 2100. The wide range in forecast certainty suggests that the only practical way to deal with the issue will be implementation of tiered action plans that continue to deal with the known present day issues and offer potential solutions to deal with future scenarios. Transitional and long term management strategies can be considered today, periodically revisited, and revised as projections on sea-level rise become more certain. Only then can an appropriate long term action plan and capital investment commitment be practically implemented.

At the two ends of the sea-level rise vulnerability spectrum for Los Angeles County's public beach facilities are their existing coastal hazards exposure and a potential future scenario under the most severe forecast of future sea-level rise. In between lies a transitional period of uncertainty where today's asset management strategy becomes less practical and phasing in of additional adaptive measures will be needed to address the future scenario. Given this planning constraint, the proposed adaptive strategy that may be considered for Los Angeles County's beach facilities at this time is summarized below.

Short Term Period – Sea-level rise less than 1.0 foot.

> Continue to protect public beach recreation assets via the County's existing temporary winter berm protection program as outlined in **Appendix B**. This strategy provides a lowest cost and least impacting methodology to protect low lying public beach assets from winter high tides and moderate storms. The program should be continued and augmented when necessary at Zuma County Beach, Venice Beach, and Dockweiler State Beach where adequate beach widths will accommodate construction and maintenance of the temporary winter sand berms. The program may be introduced at other beach facilities where assets become threatened by wave runup effects.

Transitional Period – Sea-level rise between 1 and 2 feet.

> The vulnerability assessment for the Los Angeles County shoreline suggests that a sea-level rise of about 1.0 to 1.5 feet may be a tipping point for decision making. Prior to that time, traditional short term shoreline management strategies may continue to be implemented as beach widths remain adequate to construct temporary winter berms to protect assets. However, above that elevation range, vulnerability to storms and coastal flooding may tax temporary protective measures and abilities to maintain facilities. That suggests that consideration of selective retreat measures to relocate facilities landward may be required. This may mean acceptance of reduced parking capacity and reliance upon other forms of public transit to allow visitors to access the beach. At this same time, initiation

of beach nourishment planning for the Santa Monica Bay facilities would be appropriate to quantify and locate the offshore sand reserves that can be tapped to replenish beach loss caused by rising sea level and storm wave. More controversial strategies include consideration of sand retention strategies within the Santa Monica Bay urban strand to preserve existing and replenishment resources, maintain beach widths for as long as possible, and protect the necessary public assets that are needed to accommodate the over 65 million visitors that will continue to demand access to the beach annually.

Based upon the wide range of sea level rise projection that currently exists, the Transition Phase may not begin until sometime between 2030 and 2100. Using the IPCC's latest forecast information, the Transition Phase may not occur until the time period between 2045 and 2070 or later. Clearly, the issue should remain on the County's radar for monitoring so that at least 10 years of time is available to plan, review, and implement a consensus strategy for transition to the Long Term policy.

The County's temporary winter sand berm program may be continued at existing locations and initiated at wider sections of Will Rogers State Beach, Manhattan Beach, Redondo Beach, and Torrance Beach to protect additional assets that may become jeopardized in the future during this period.

Long Term Period – Sea-level rise exceeds 2 feet.

Implementation of the County's Coastal Regional Sediment Management Plan will be critical for long term shoreline preservation planning and implementation. Consideration of retreat or re-location of public beach facilities is more appropriate for some facilities within the Malibu region if they become more threatened and susceptible to damage in the distant future. By 2100, if the more extreme forecasts for sea-level rise occur, the narrow and more sediment limited beaches along the Malibu coast may make it impractical to maintain adequate beach widths and protect assets from higher sea levels, beach erosion, and storm waves. This suggests that County resources may be better directed elsewhere to preserve a reduced public beach system for as long as possible.

For the most extreme forecasts of sea-level rise, the artificial Santa Monica Bay beach system can be considered for future nourishment to keep pace with sand losses induced by the effects of long term sea-level rise. The significant sand deposits that are known to exist offshore adjacent to the beaches would provide the compatible sediment source. The material would allow implementation of a more concentrated effort to preserve beaches within the densely populated urban strand between Will Rogers State Beach and Torrance Beach that is tributary to the greater Los Angeles metropolitan inner city region. Similarly, Zuma County Beach and other Malibu facilities may be considered for nourishment because of their importance to the public recreation system. Further study will be needed to assess the feasibility of the periodic replenishment of Malibu region facilities to ensure that the sand can be kept there for reasonable periods of time with no significant impact.

The recommended adaptive management strategy matrix is summarized in **Table 11**. The plan is a compilation of suggested policy implementation, short term action, and longer term plans that may be considered over time.

Sea-level rise less than 1.0 foot	Continue the temporary winter sand berm protection program at Zuma, Venice, Dockeiler State Beach, Hermosa Beach, and other beaches as appropriate. Complete and begin implementation of the County's CRSMP. Obtain a Federal and State funded project authority to help underwrite the significant cost of the County's future beach preservation management plans.
Sea-level rise between 1 and 2 feet	Delineate and quantify the available offshore sand sources in Santa Monica Bay and dedicate them to preservation of the County's public beach system. Maintain and improve the County's system of sediment retention devices in Santa Monica Bay to preserve the existing artificial beach infrastructure in Santa Monica Bay. Continue and initiate implementation of the temporary winter sand berm protection program as warranted at Will Rogers State Beach, Venice Beach, Dockweiler State Beach, Manhattan Beach, Hermosa Beach, Redondo Beach, and Torrance Beach.
Sea-level rise exceeds 2 feet	Re-nourish Zuma, Point Dume, and other appropriate Malibu public beaches. Re-nourish Santa Monica Bay public beach facilities. Build and maintain dune systems within appropriate areas of Dockweiler State Beach. Re-locate facilities as appropriate.

Table 11. Suggested Adaptive Management Strategy for Los Angeles County Public Beach Assets

Region	Malibu									Santa Monica Bay							Palos Verdes		
Potential strategy for existing or future asset on beach	**Nicholas Canyon County Beach**	**El Sol County Beach**	**Zuma County Beach**	**Point Dume County Beach**	**Latigo Shores County Beach**	**Dan Blocker County Beach**	**Malibu Surfrider County Beach**	**Las Tunas County Beach**	**Topanga County Beach**	**Will Rogers State Beach**	**Venice Beach**	**Dockweiler State Beach**	**Manhattan Beach**	**Hermosa Beach**	**Redondo Beach**	**Torrance Beach**	**Royal Palms County Beach**	**White Point County Beach**	**Point Fermin Beach**
Temporary winter berm protection			1							2	1	1	2	1	2	2			
Dune building and maintenance	2											2							
Maintain existing sand retention devices										2	2	2			2				
Beach nourishment			3	3					3	3	3	3	3	3	3	3			
Natural dunes and retreat	3	3			3	3	3	3									3	3	3

Adaptive management strategy key

1	=	Short term period when sea-level rise is less than than 1 foot
2	=	Transitional period when sea-level rise is between 1 and 2 feet
3	=	Long term period when sea-level rise exceeeds 2 feet

There is time to plan for and consider the more difficult long term decisions that may lie ahead. The County should therefore continue to monitor sea-level rise and refine their response plan as appropriate when the forecast becomes better refined in the next 20 to 30 years.

Appendix A

CoSMoS 3.0 sea-level rise scenarios for Los Angeles County public beach facilities

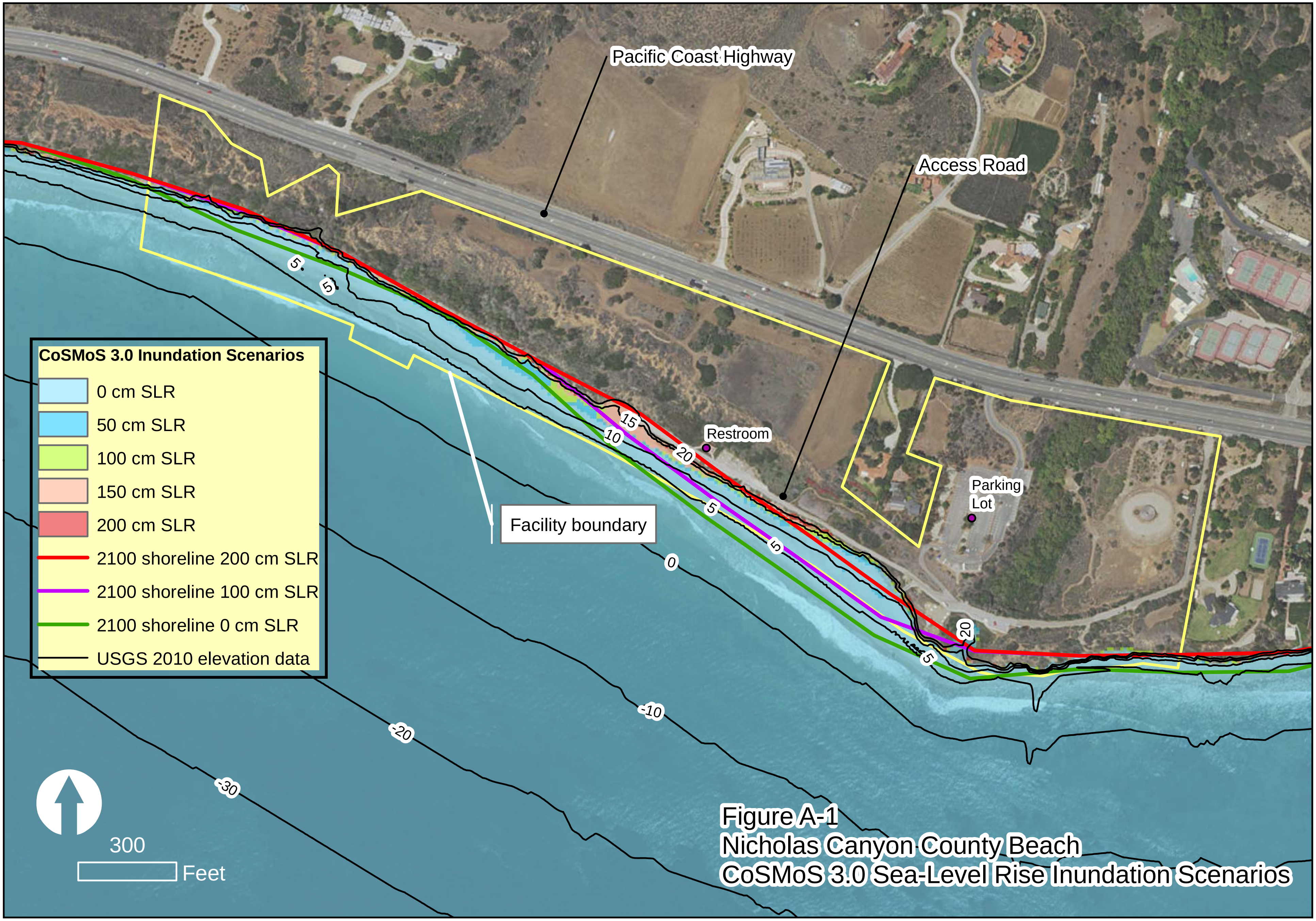


Figure A-1
Nicholas Canyon County Beach
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

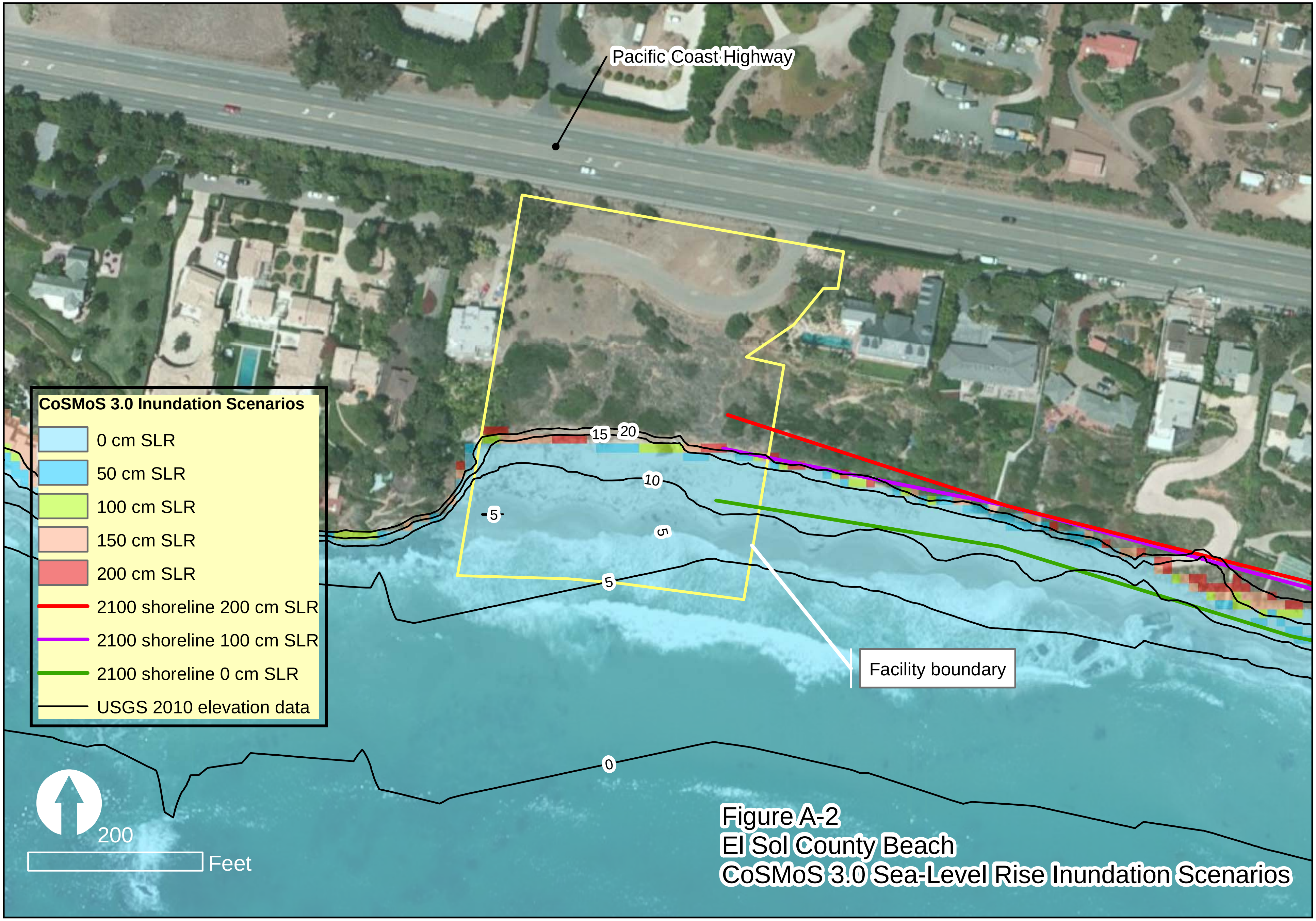


Figure A-2
El Sol County Beach
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

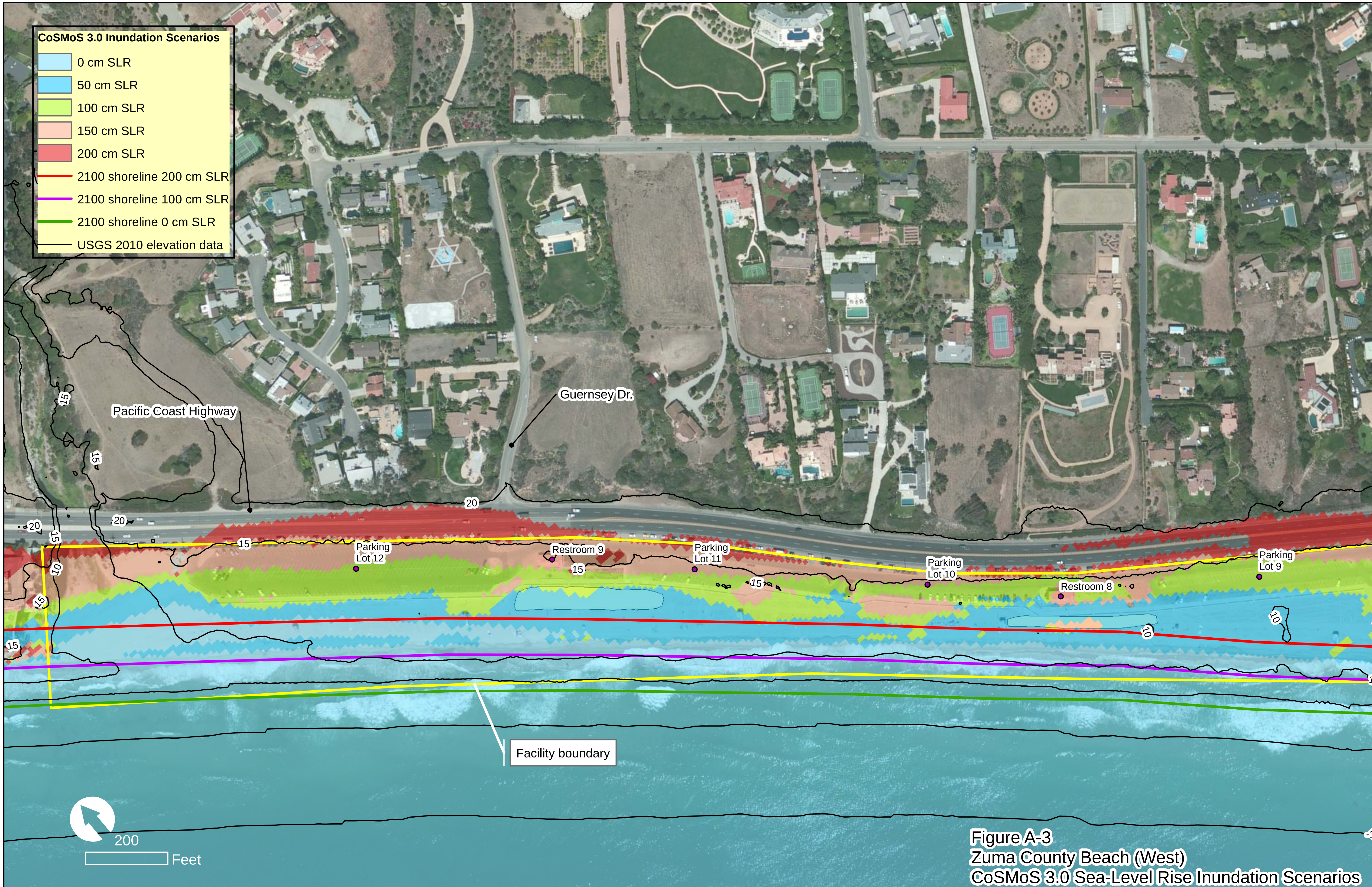


Figure A-3
Zuma County Beach (West)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

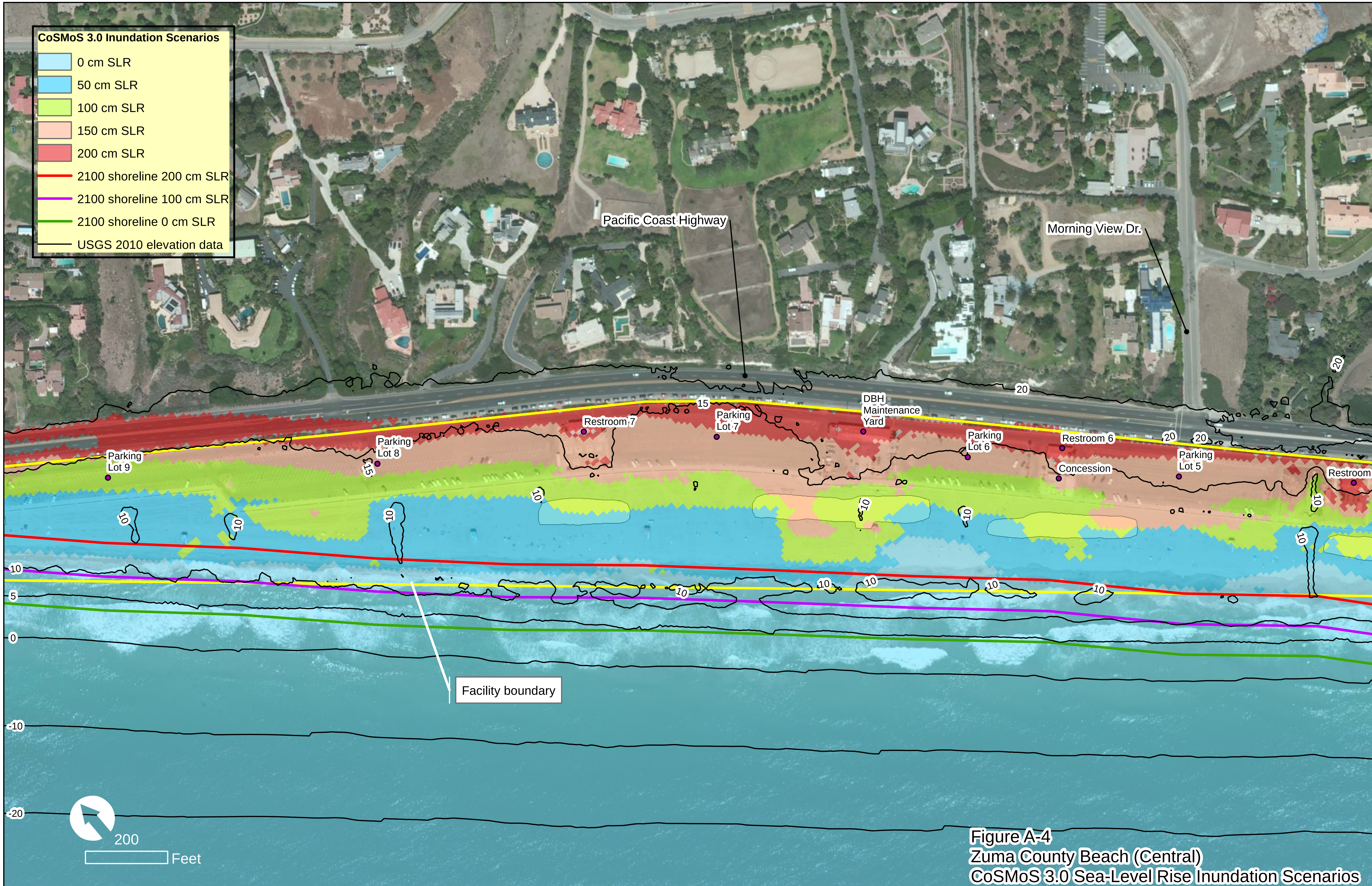


Figure A-4
Zuma County Beach (Central)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

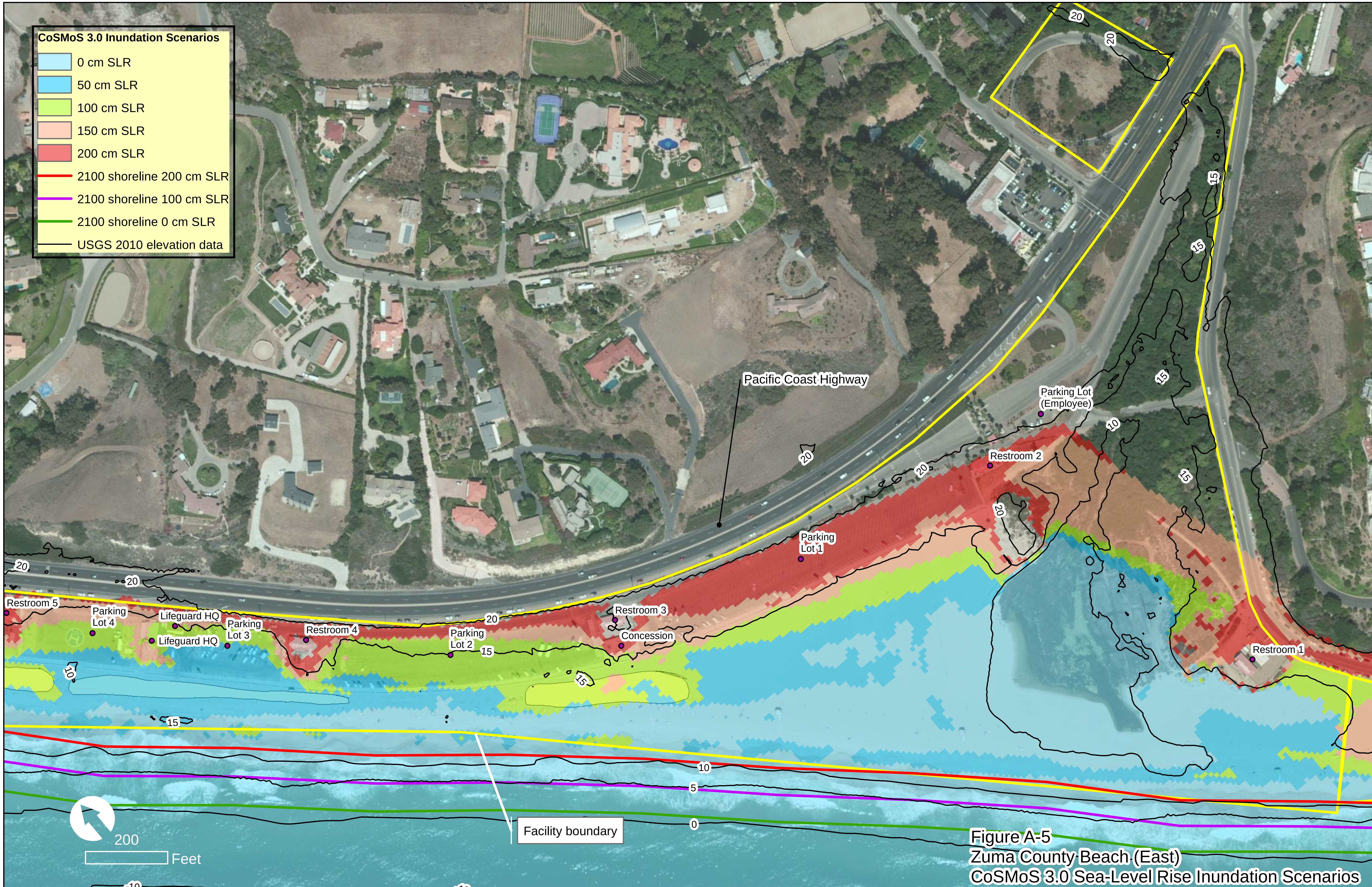


Figure A-5
Zuma County Beach (East)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

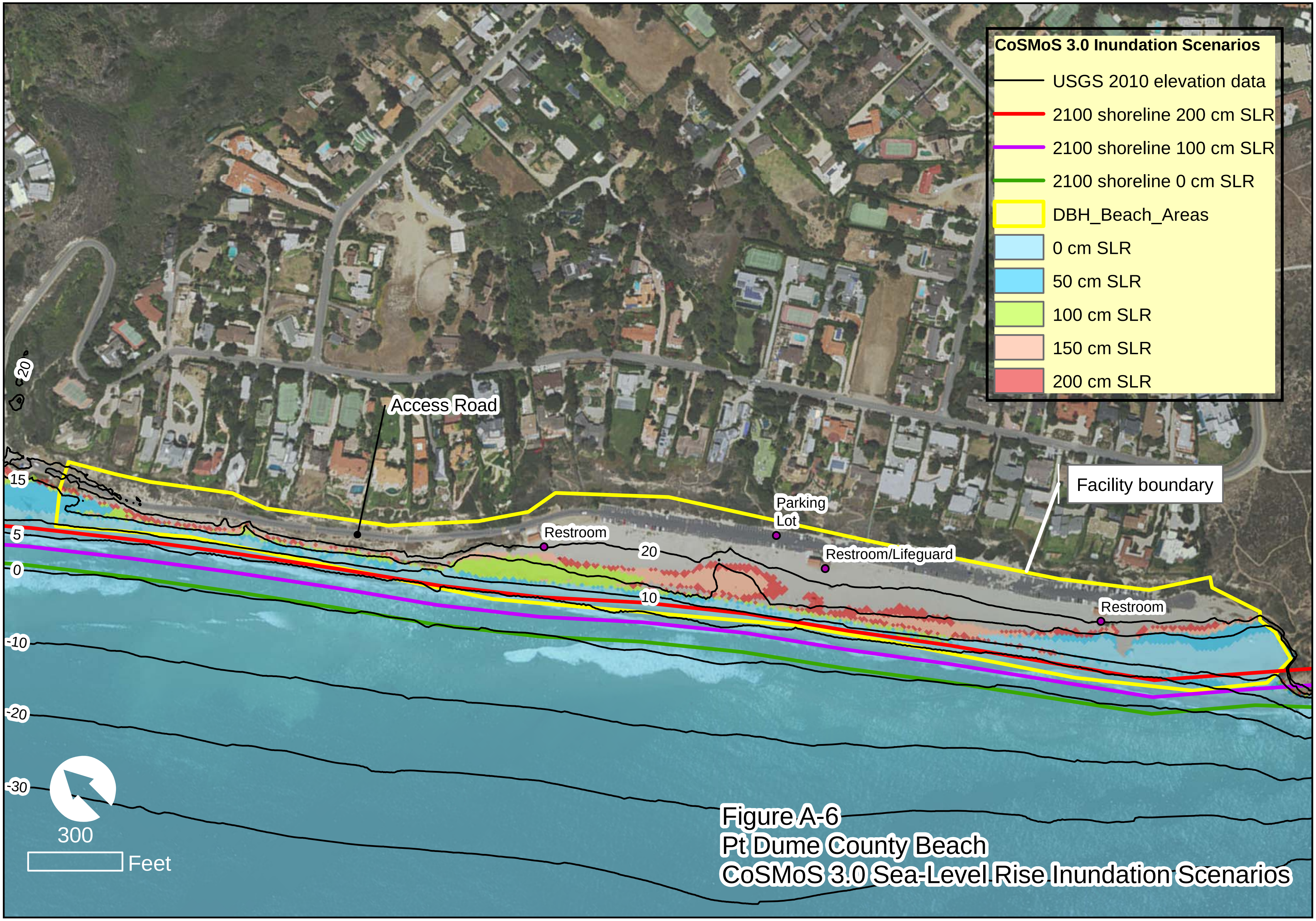


Figure A-6
Pt Dume County Beach
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

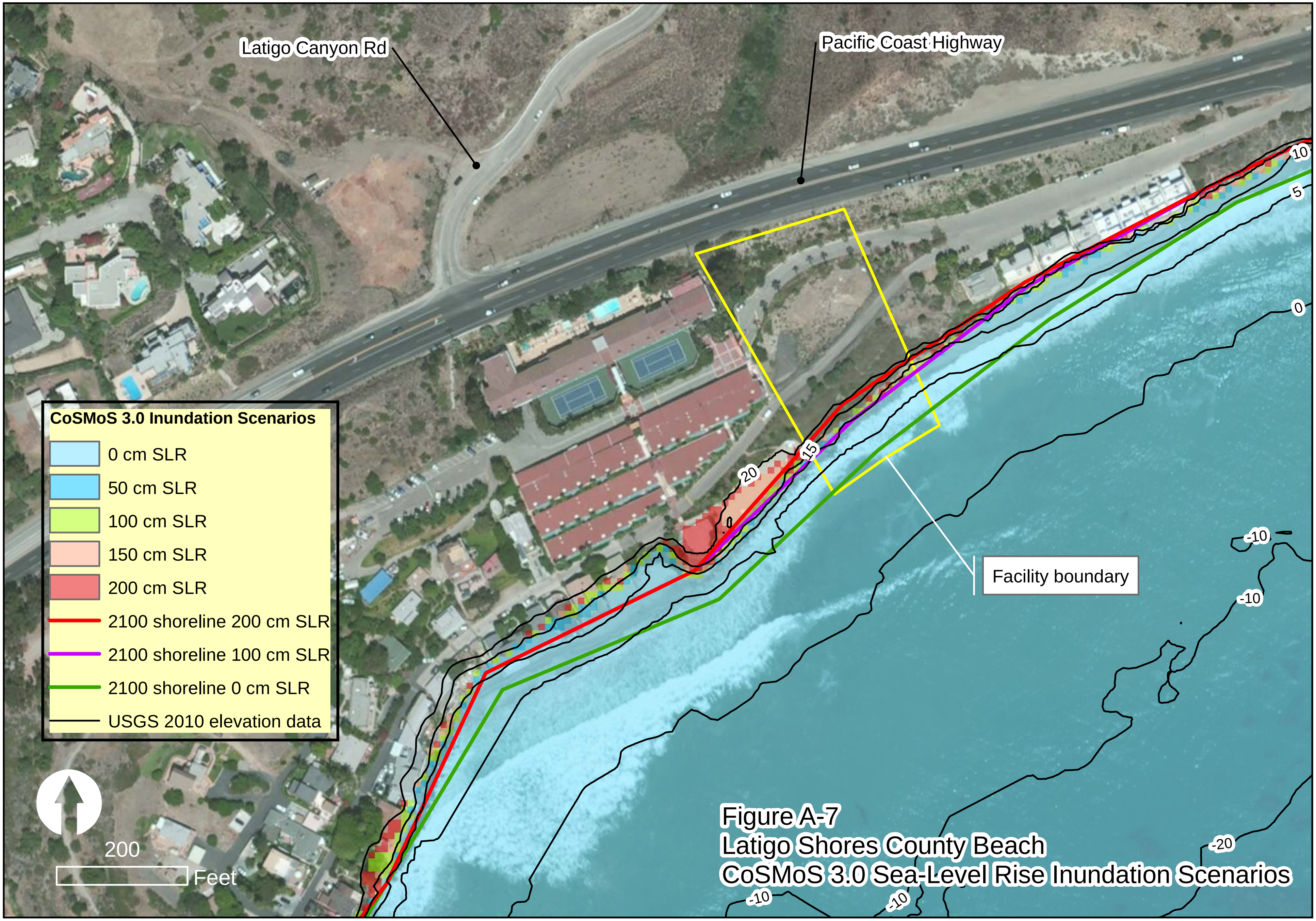


Figure A-7
Latigo Shores County Beach
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

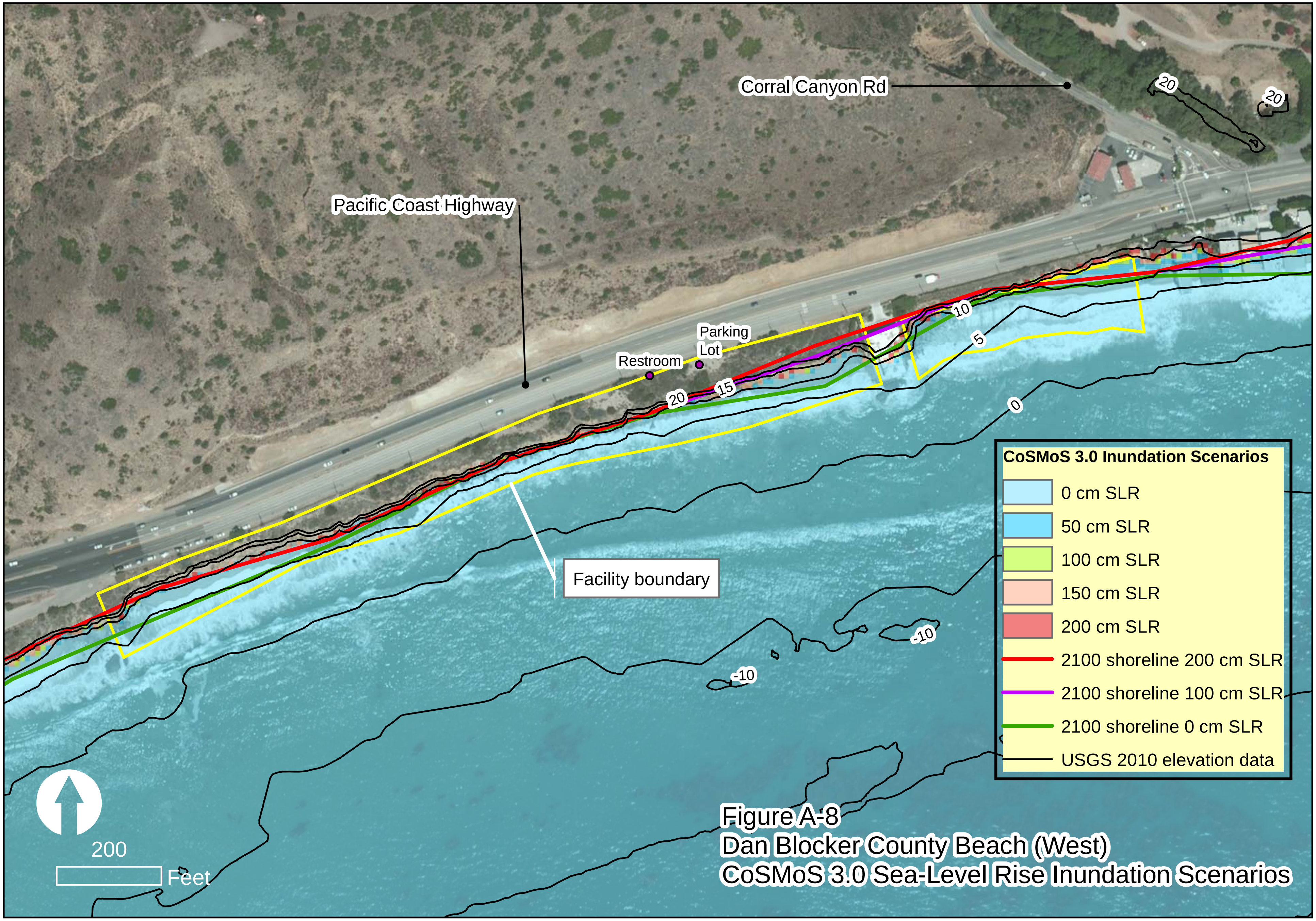
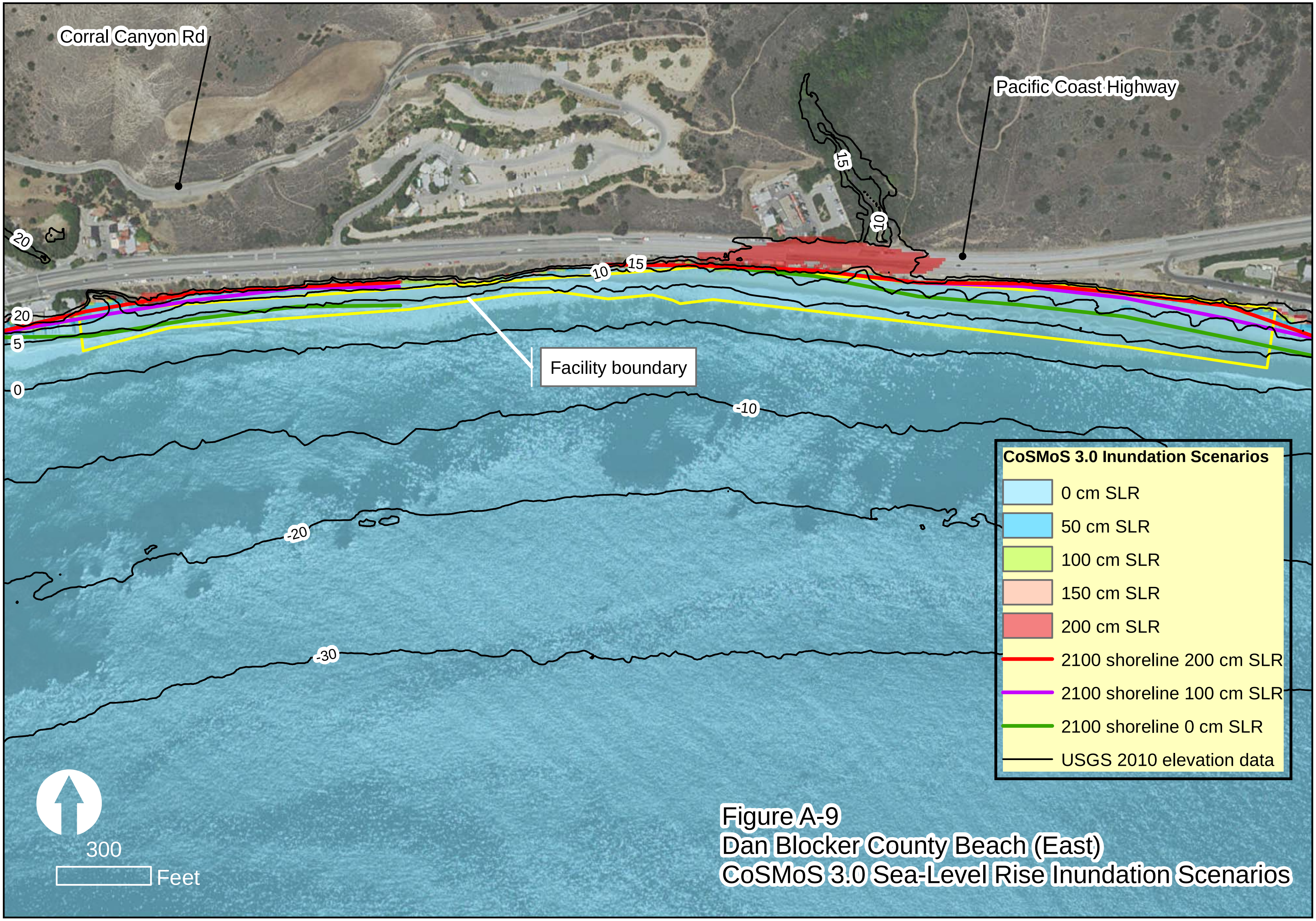


Figure A-8
Dan Blocker County Beach (West)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios



Corral Canyon Rd
Pacific Coast Highway
Facility boundary
20
15
10
15
10
20
5
0
-10
-20
-30
CoSMoS 3.0 Inundation Scenarios
0 cm SLR
50 cm SLR
100 cm SLR
150 cm SLR
200 cm SLR
2100 shoreline 200 cm SLR
2100 shoreline 100 cm SLR
2100 shoreline 0 cm SLR
USGS 2010 elevation data
300
Feet
Figure A-9
Dan Blocker County Beach (East)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

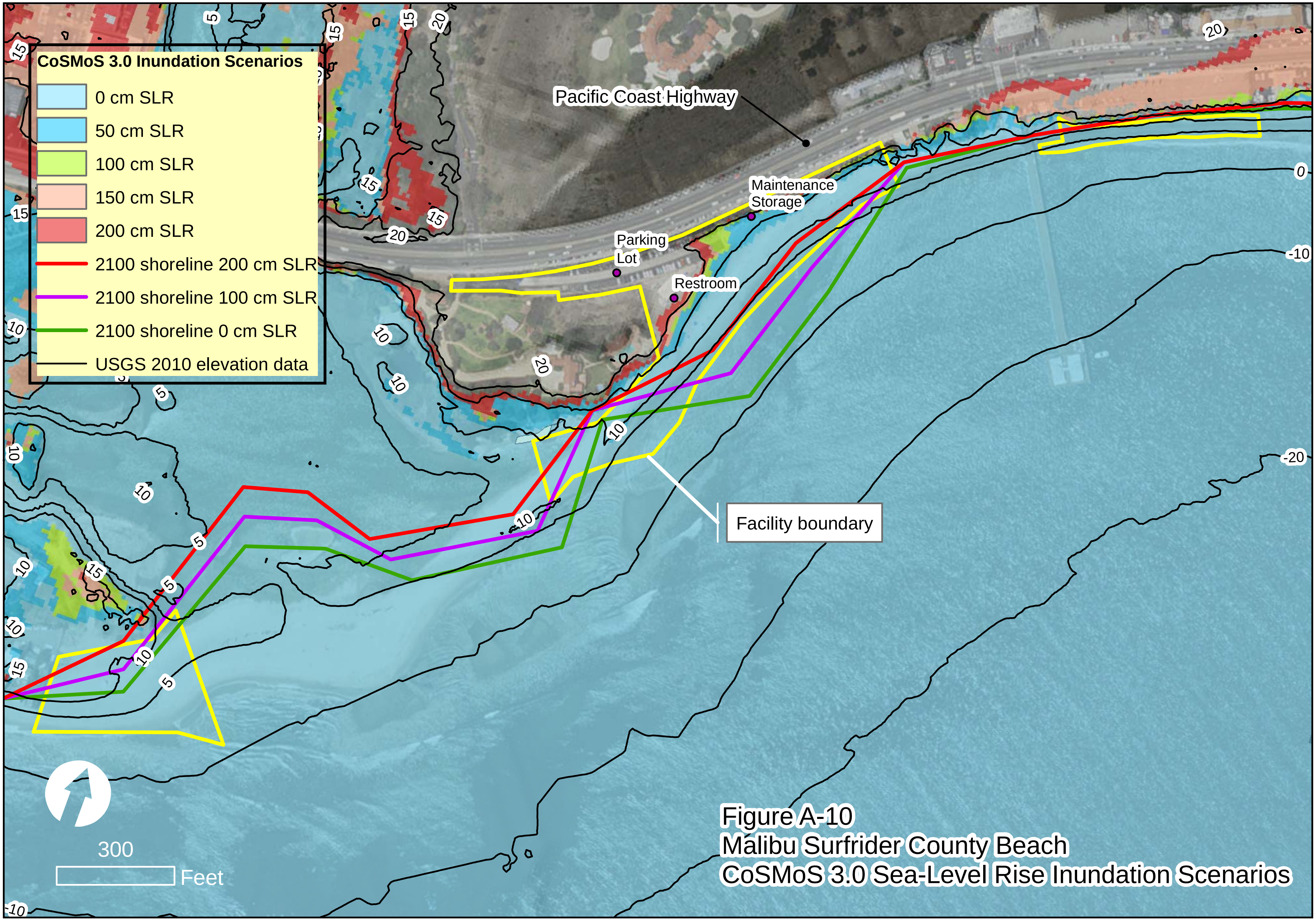
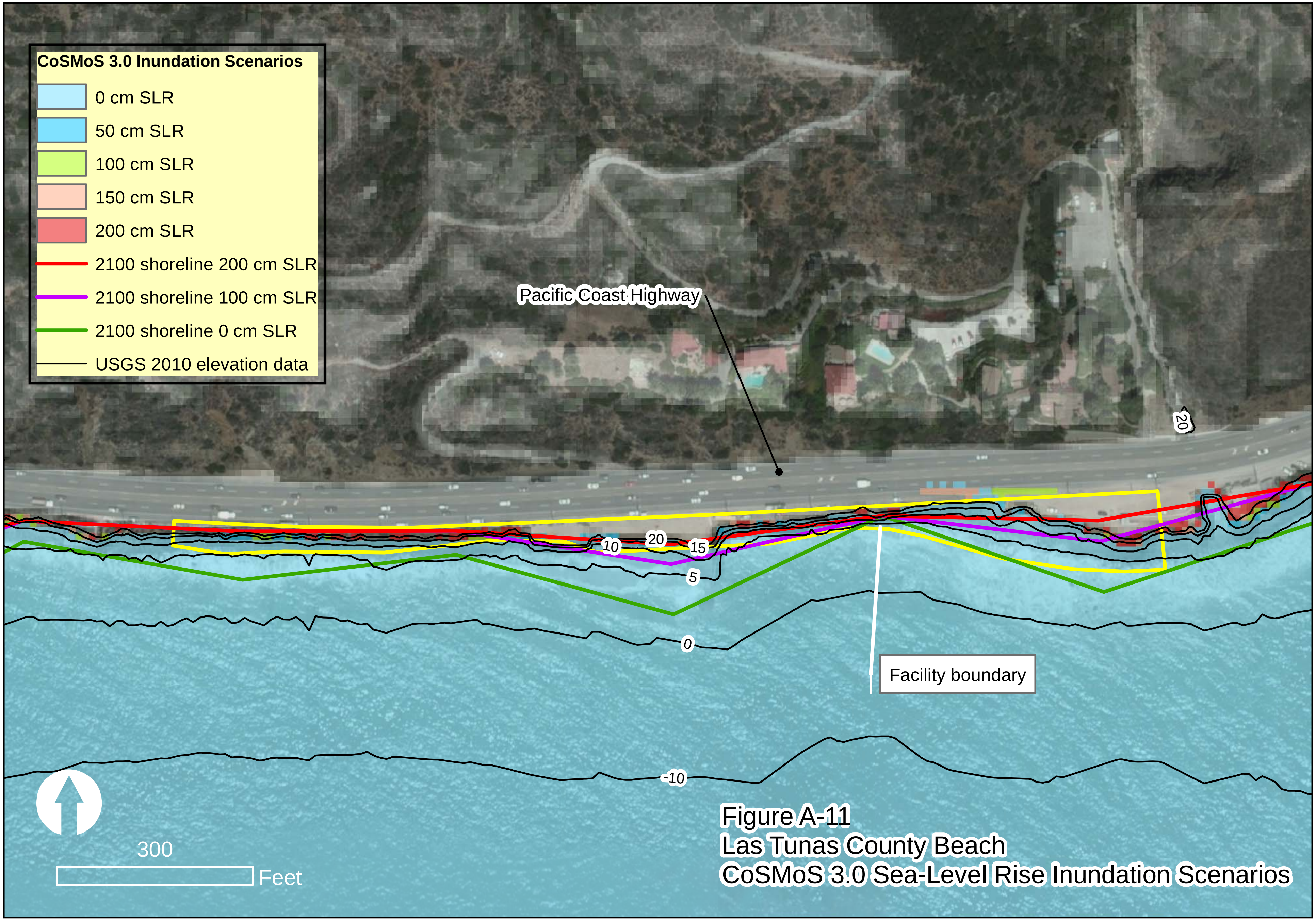


Figure A-10
Malibu Surfrider County Beach
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios


CoSMoS 3.0 Inundation Scenarios
0 cm SLR
50 cm SLR
100 cm SLR
150 cm SLR
200 cm SLR
2100 shoreline 200 cm SLR
2100 shoreline 100 cm SLR
2100 shoreline 0 cm SLR
USGS 2010 elevation data
Pacific Coast Highway
Facility boundary
20
10
20
15
5
0
-10
300
Feet
Figure A-11
Las Tunas County Beach
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

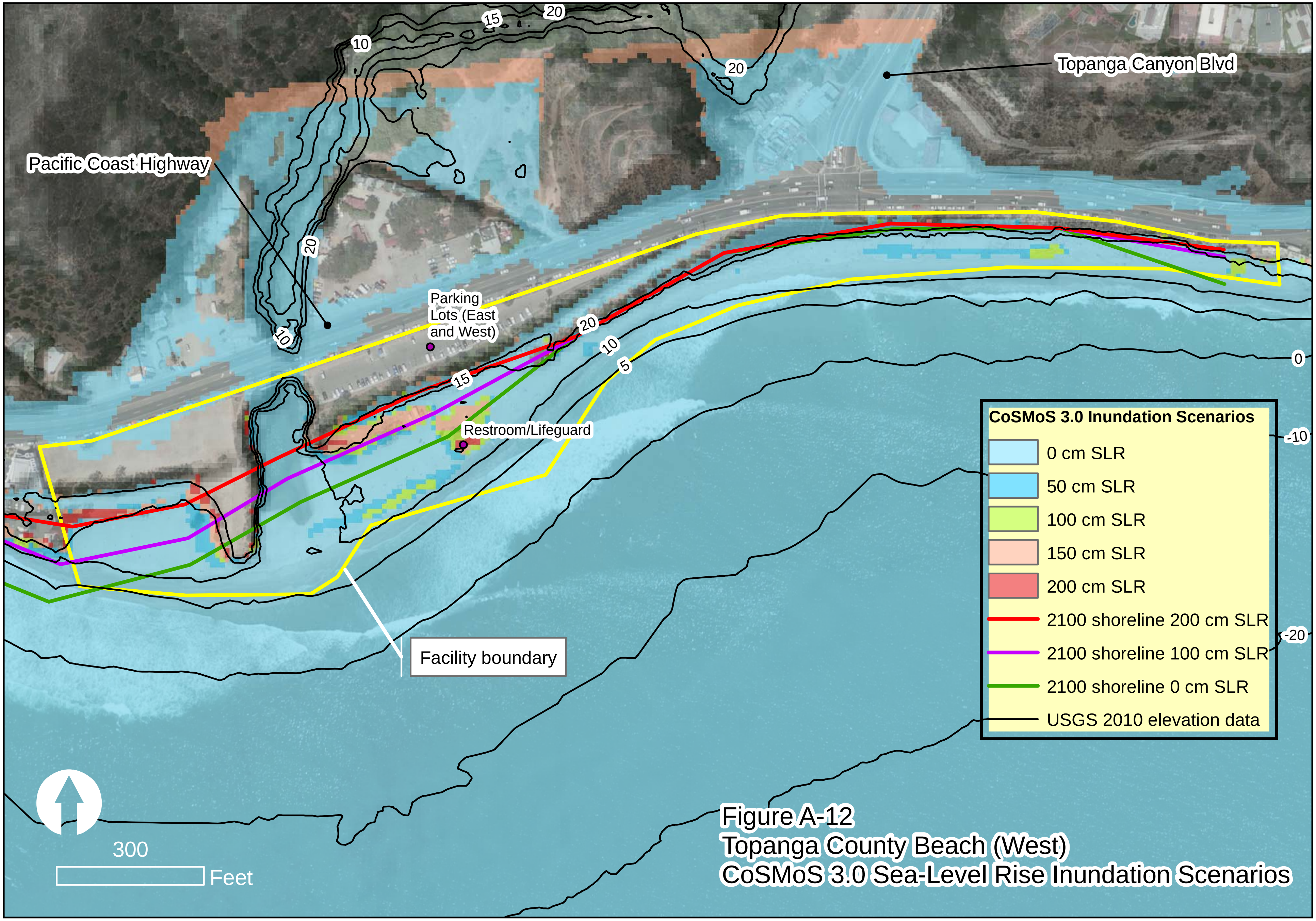


Figure A-12
Topanga County Beach (West)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

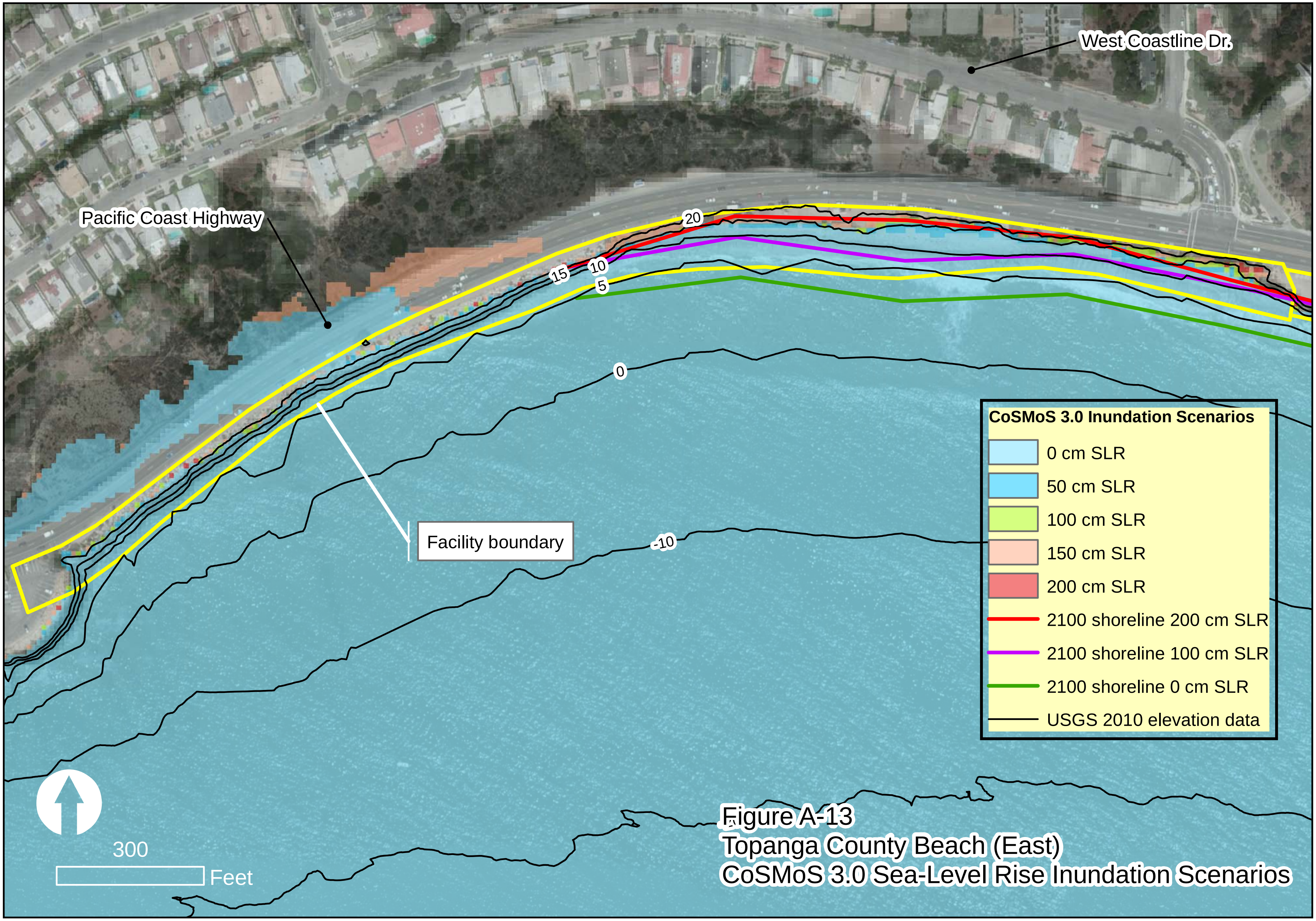


Figure A-13
Topanga County Beach (East)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

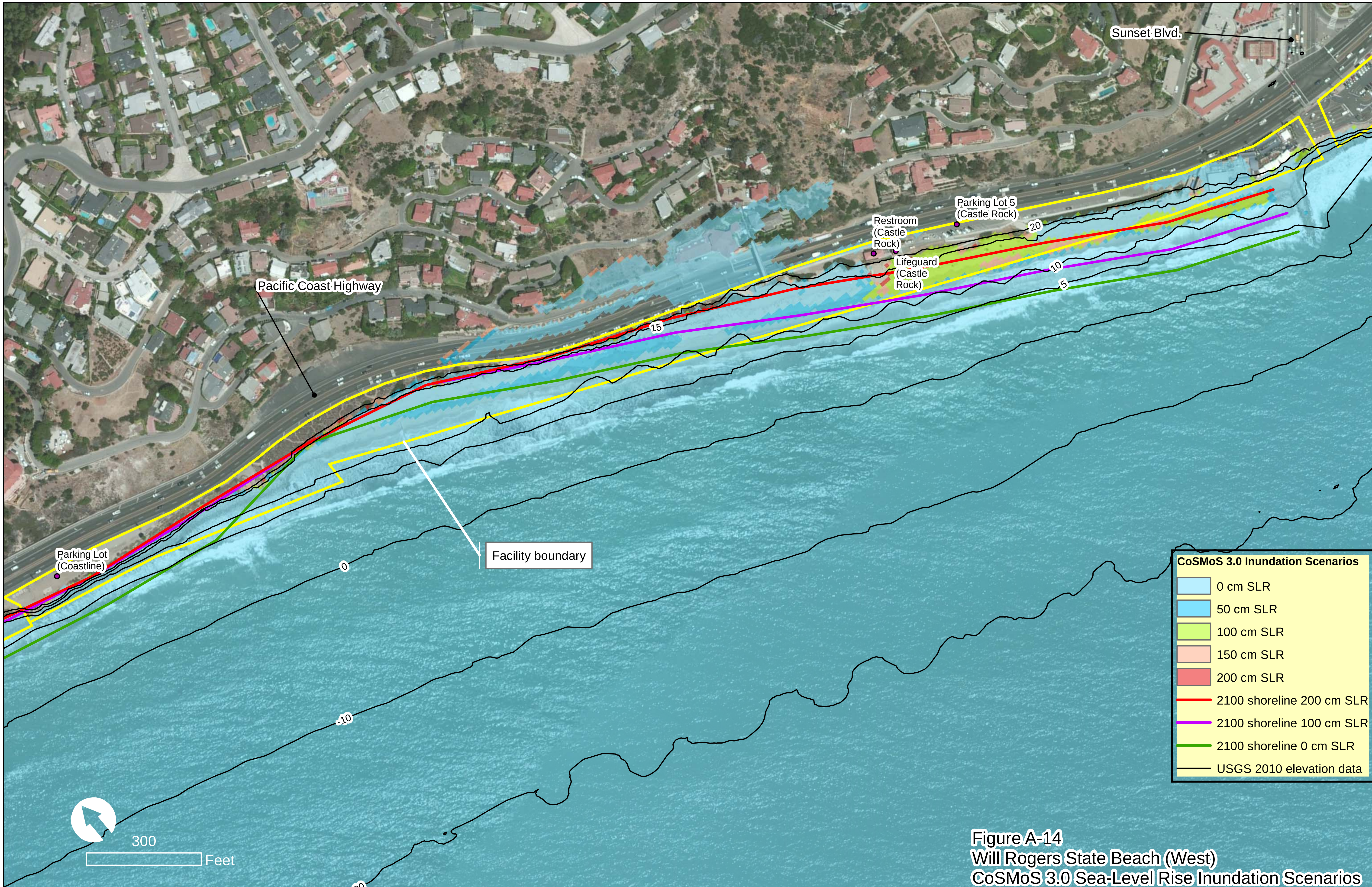


Figure A-14
Will Rogers State Beach (West)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

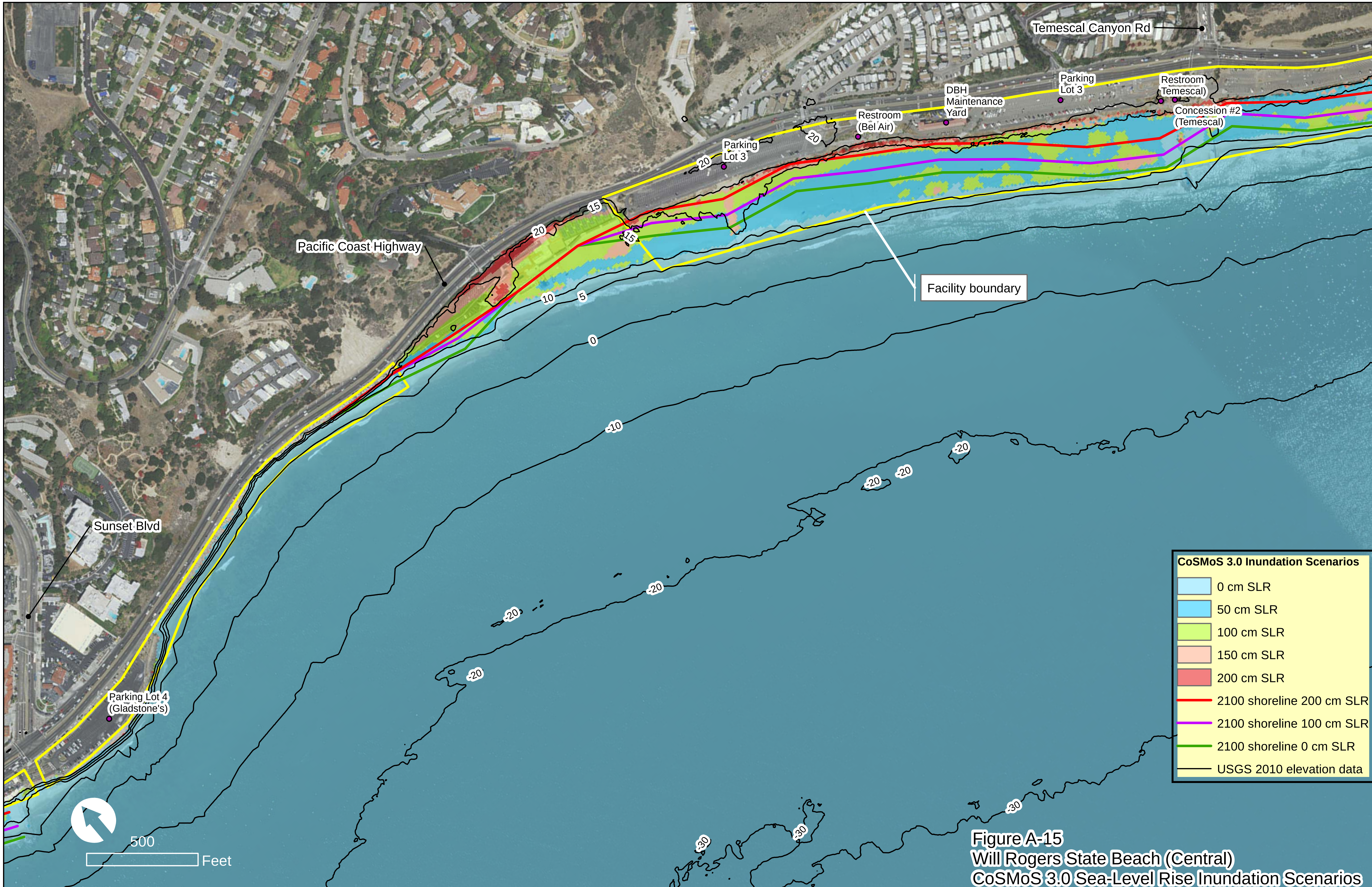


Figure A-15
Will Rogers State Beach (Central)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

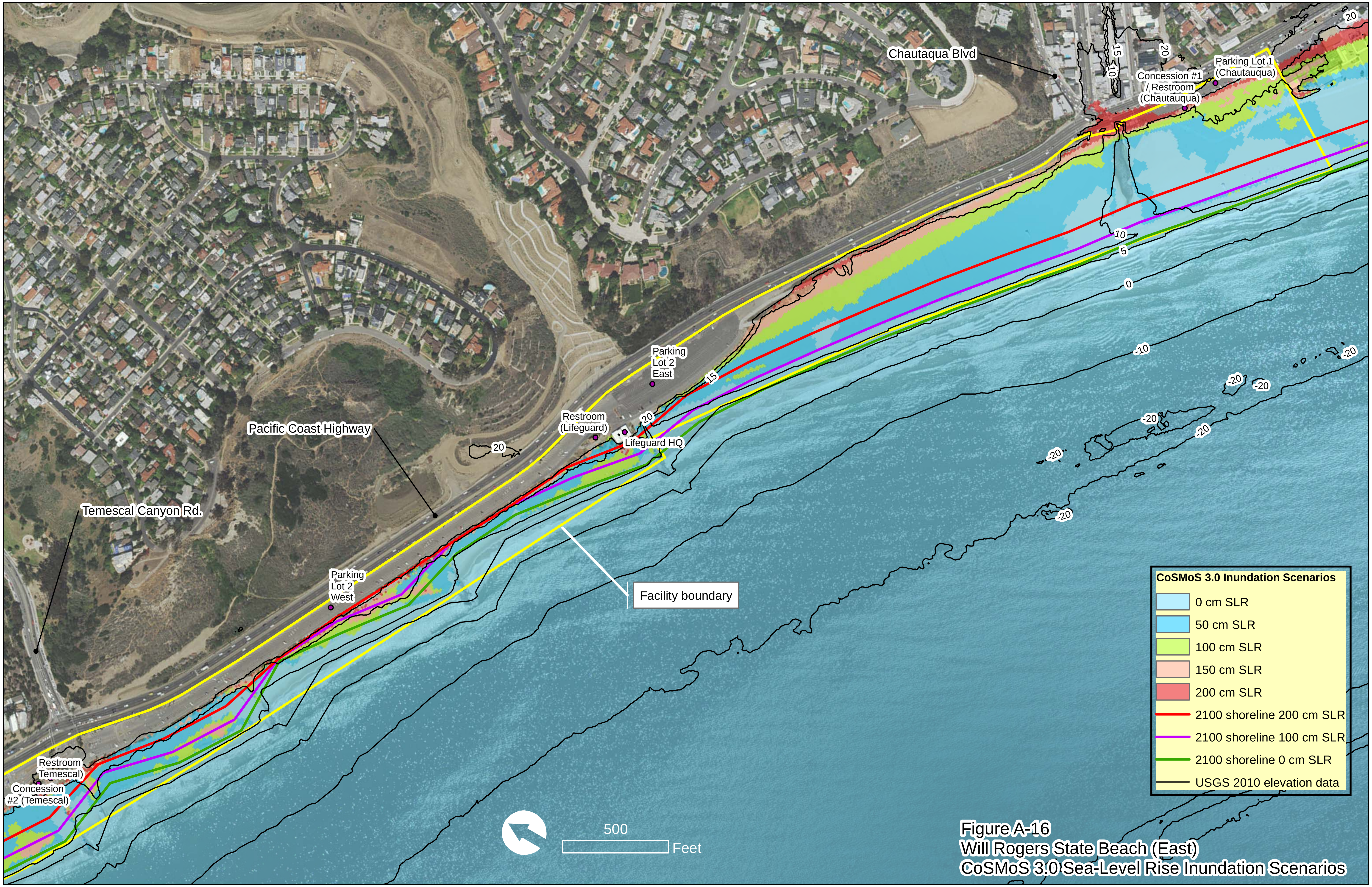


Figure A-16
Will Rogers State Beach (East)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

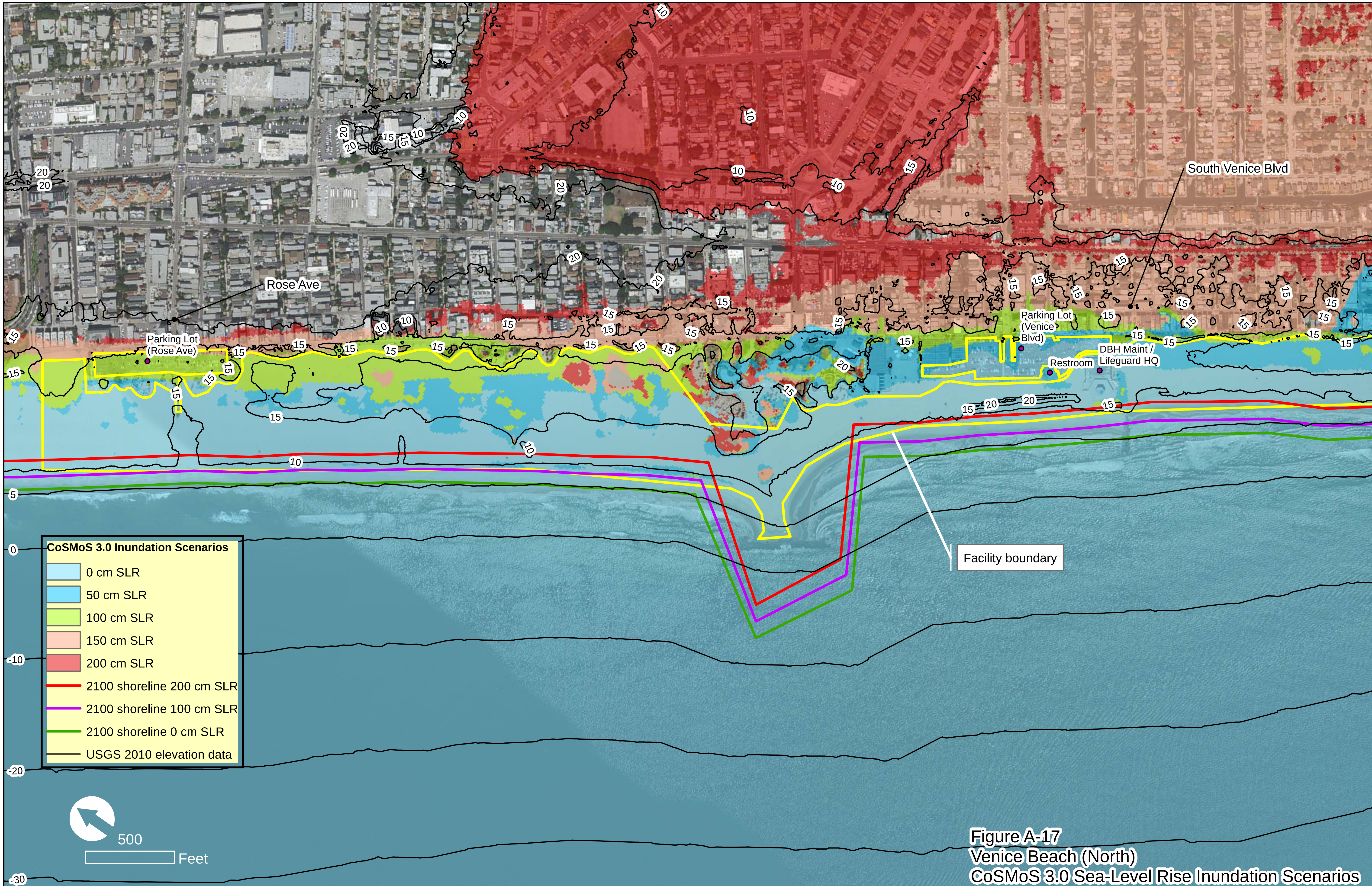


Figure A-17
Venice Beach (North)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

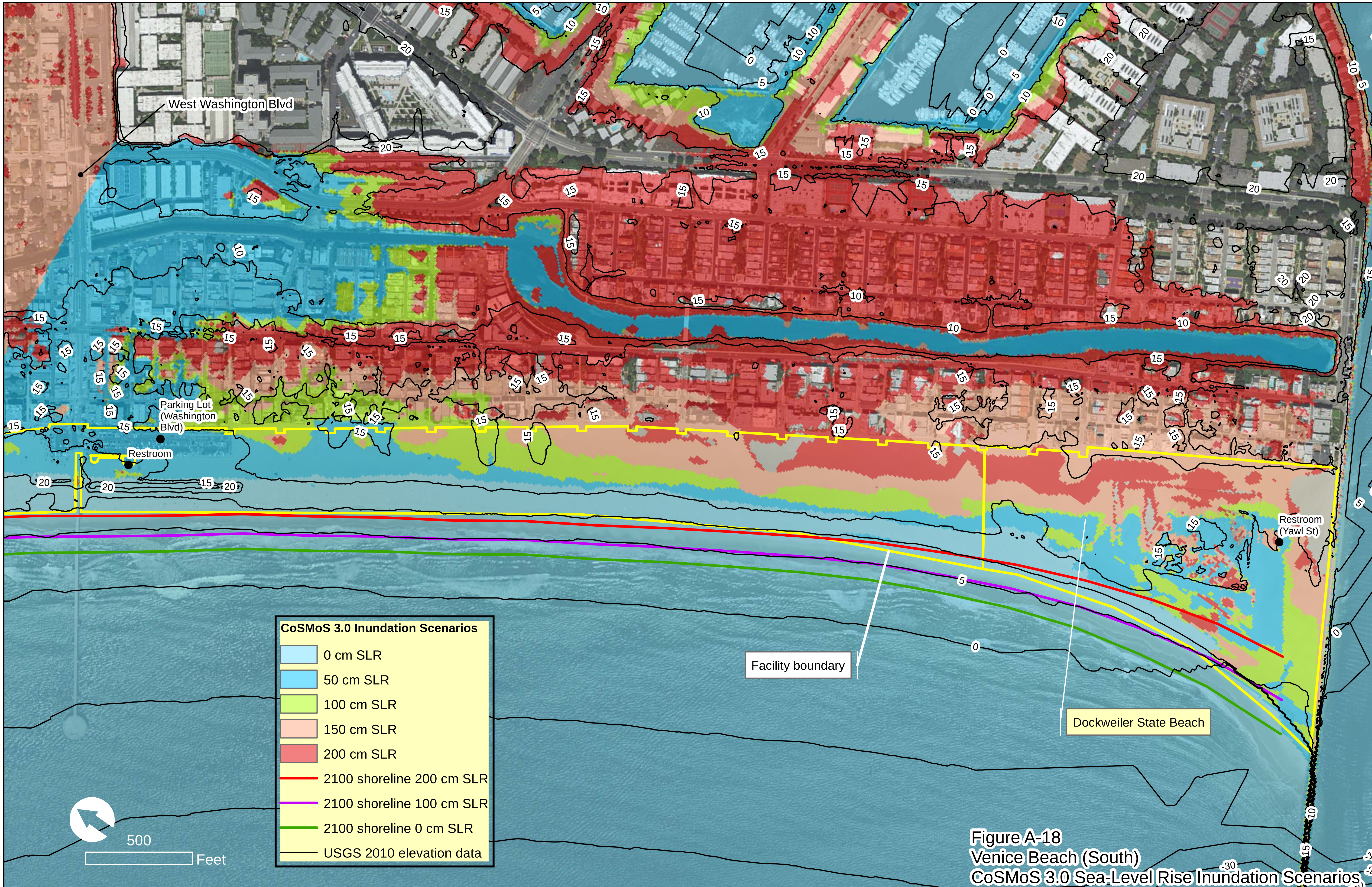
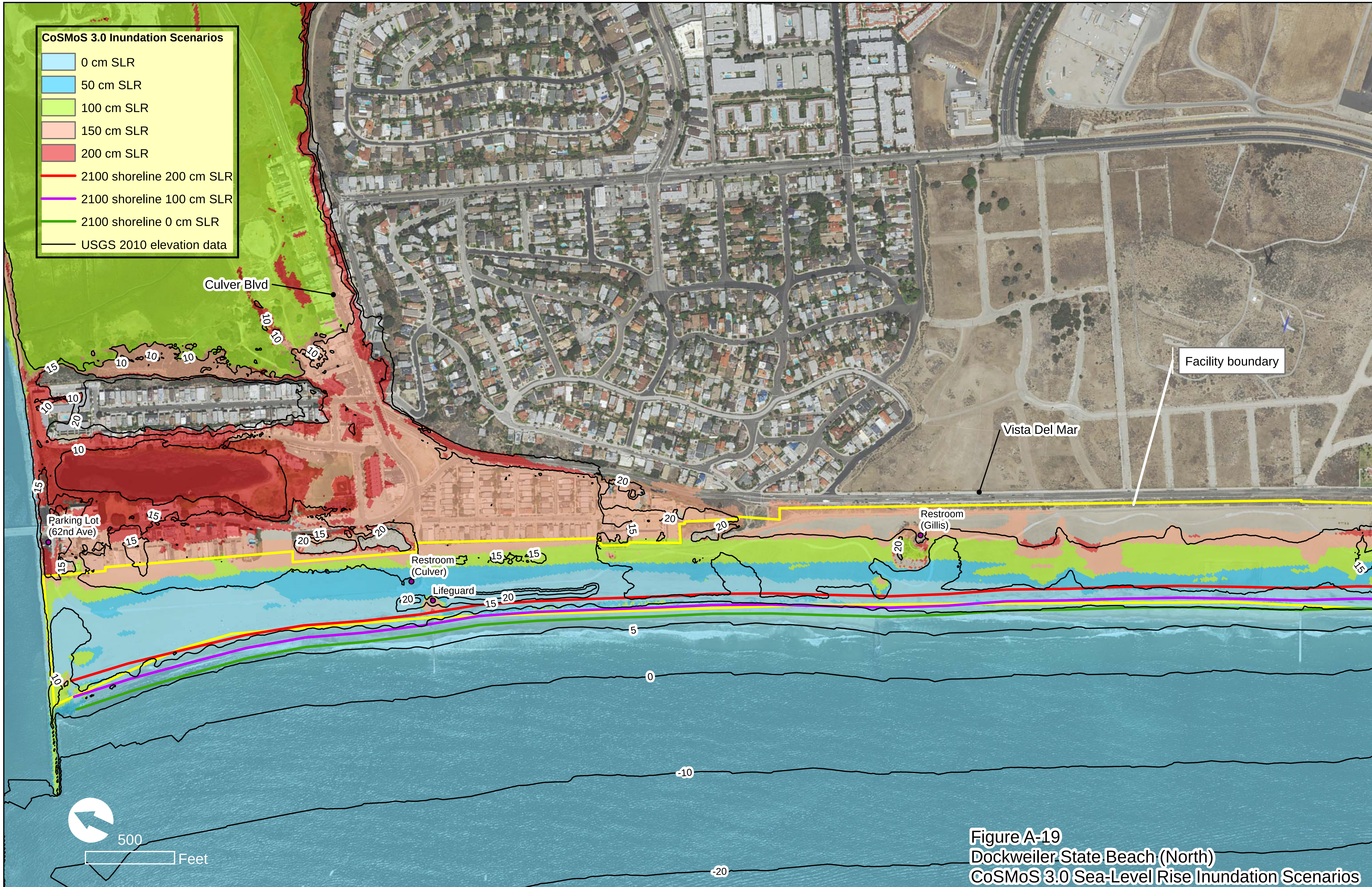


Figure A-18
Venice Beach (South)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios


CoSMoS 3.0 Inundation Scenarios
0 cm SLR
50 cm SLR
100 cm SLR
150 cm SLR
200 cm SLR
2100 shoreline 200 cm SLR
2100 shoreline 100 cm SLR
2100 shoreline 0 cm SLR
USGS 2010 elevation data
Culver Blvd
Facility boundary
Vista Del Mar
Parking Lot (62nd Ave)
Restroom (Culver)
Lifeguard
Restroom (Gillis)
500 Feet
Figure A-19
Dockweiler State Beach (North)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

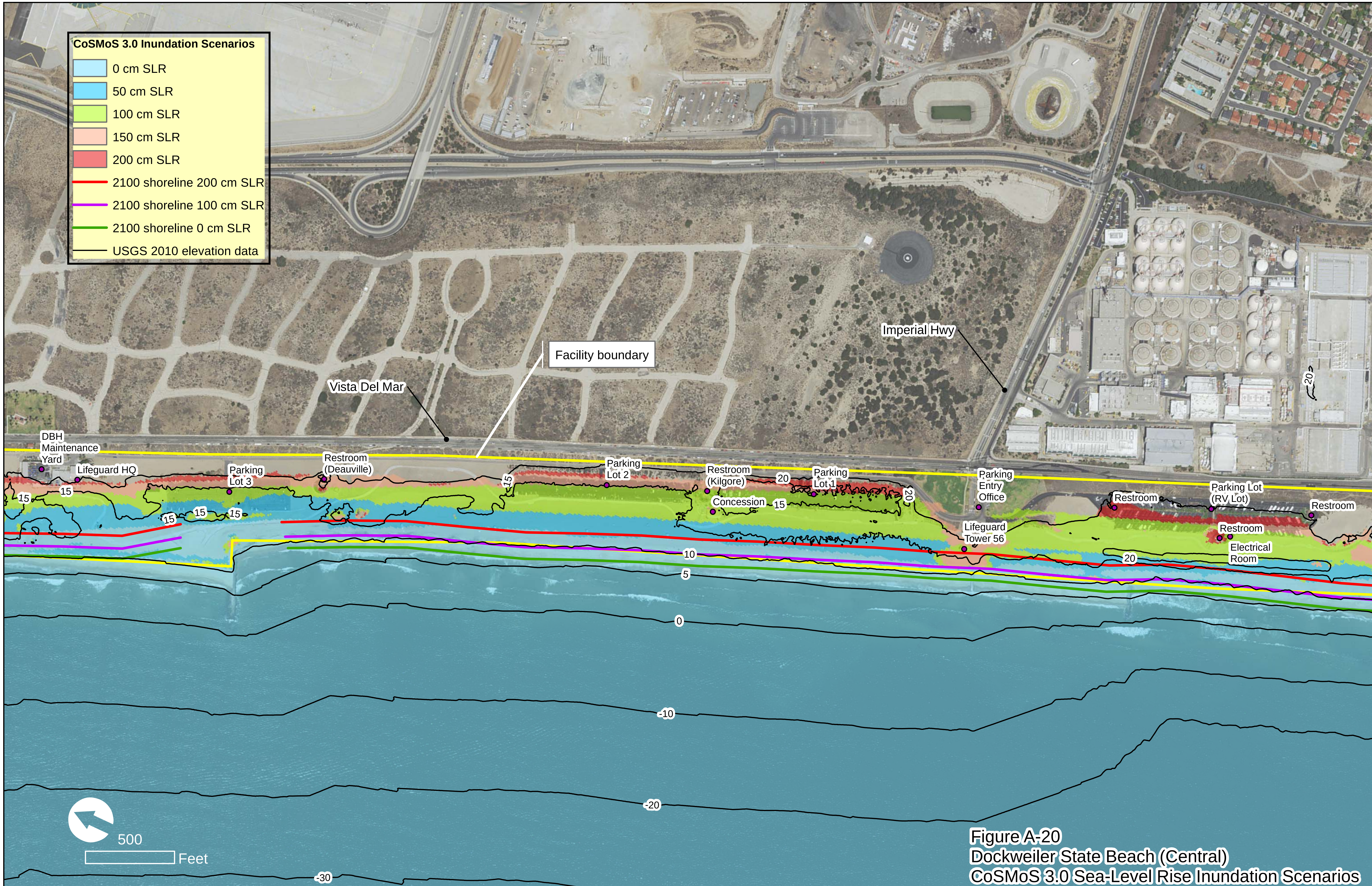


Figure A-20
Dockweiler State Beach (Central)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

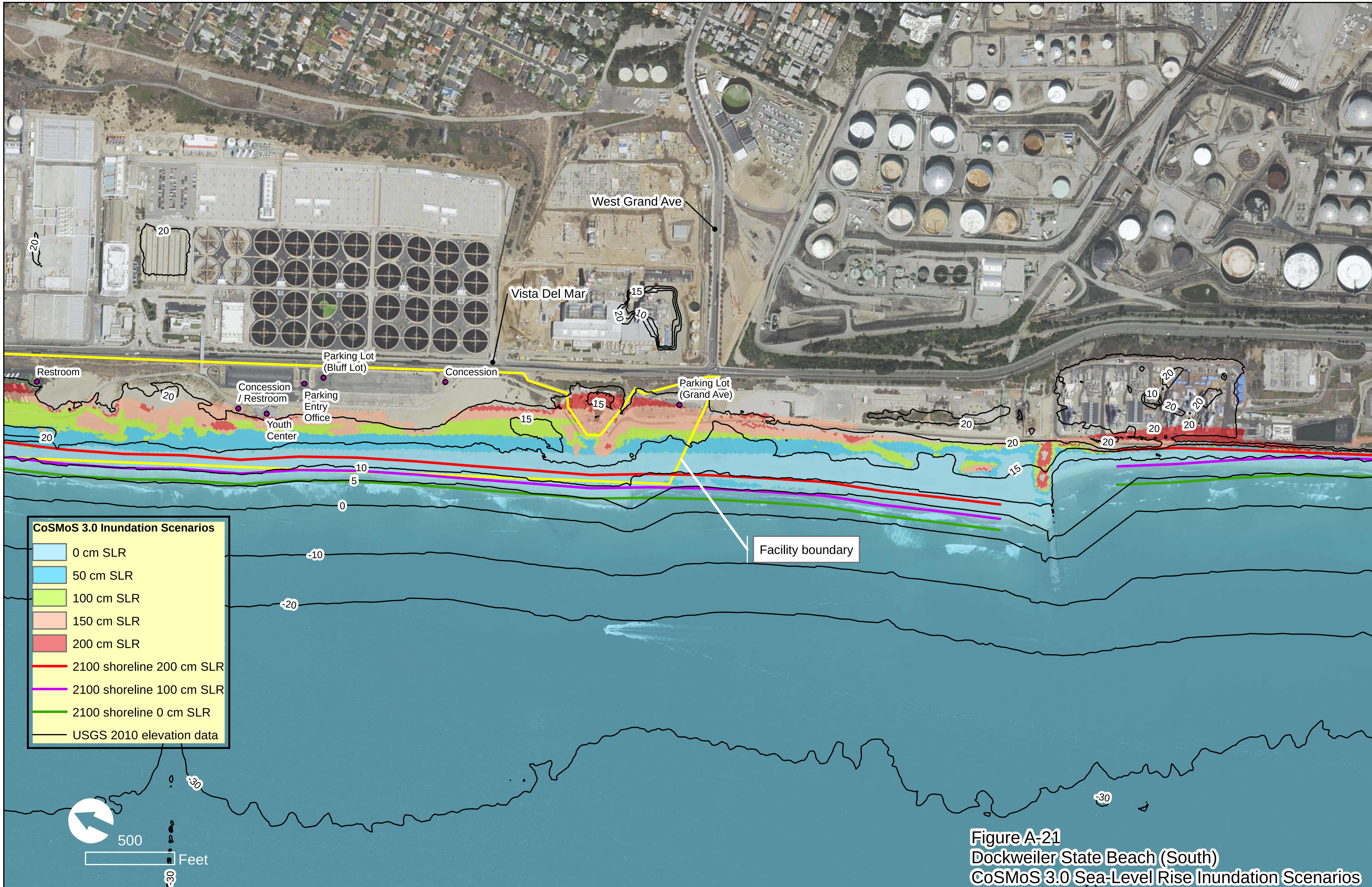


Figure A-21
Dockweiler State Beach (South)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

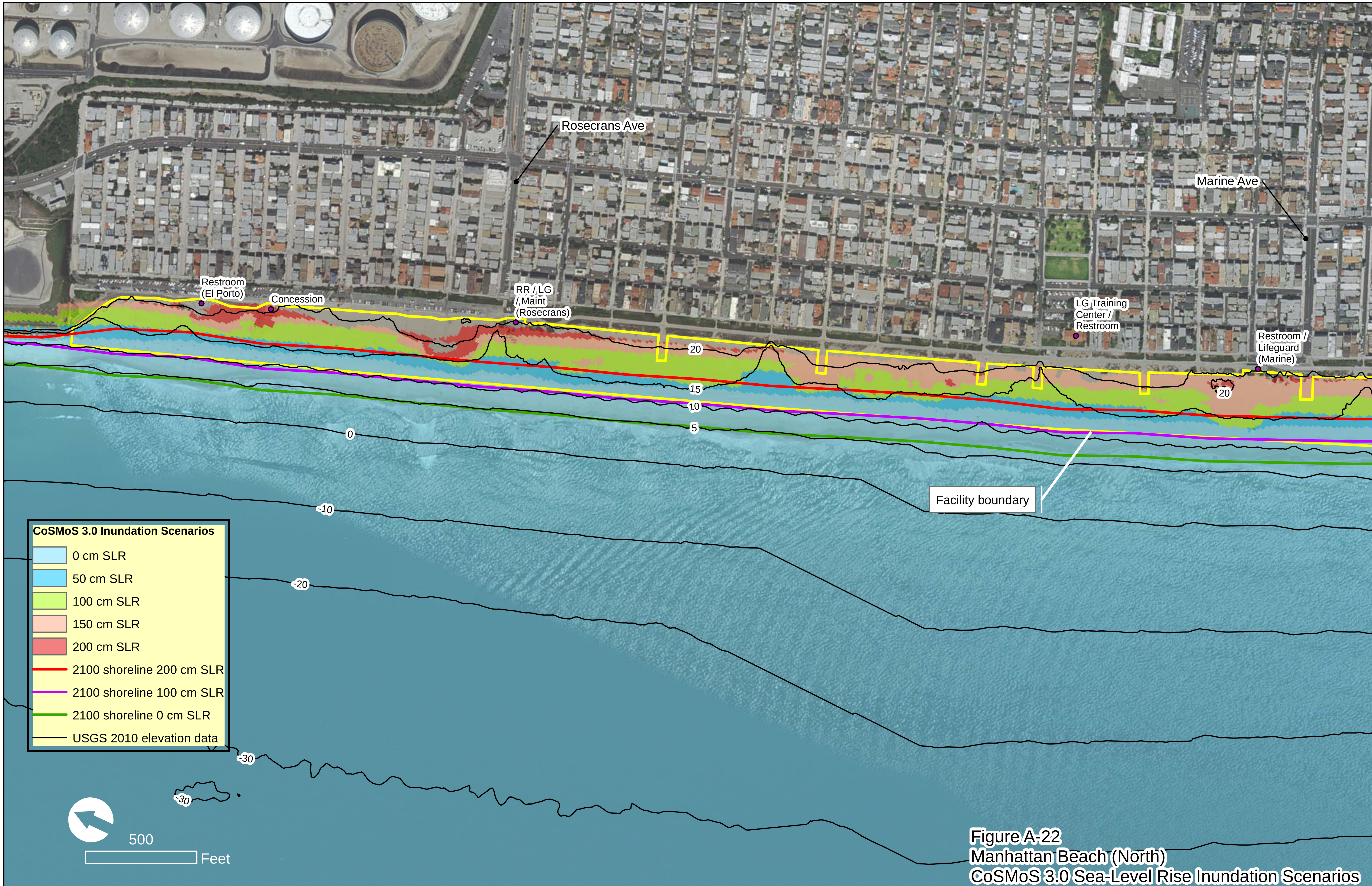


Figure A-22
Manhattan Beach (North)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

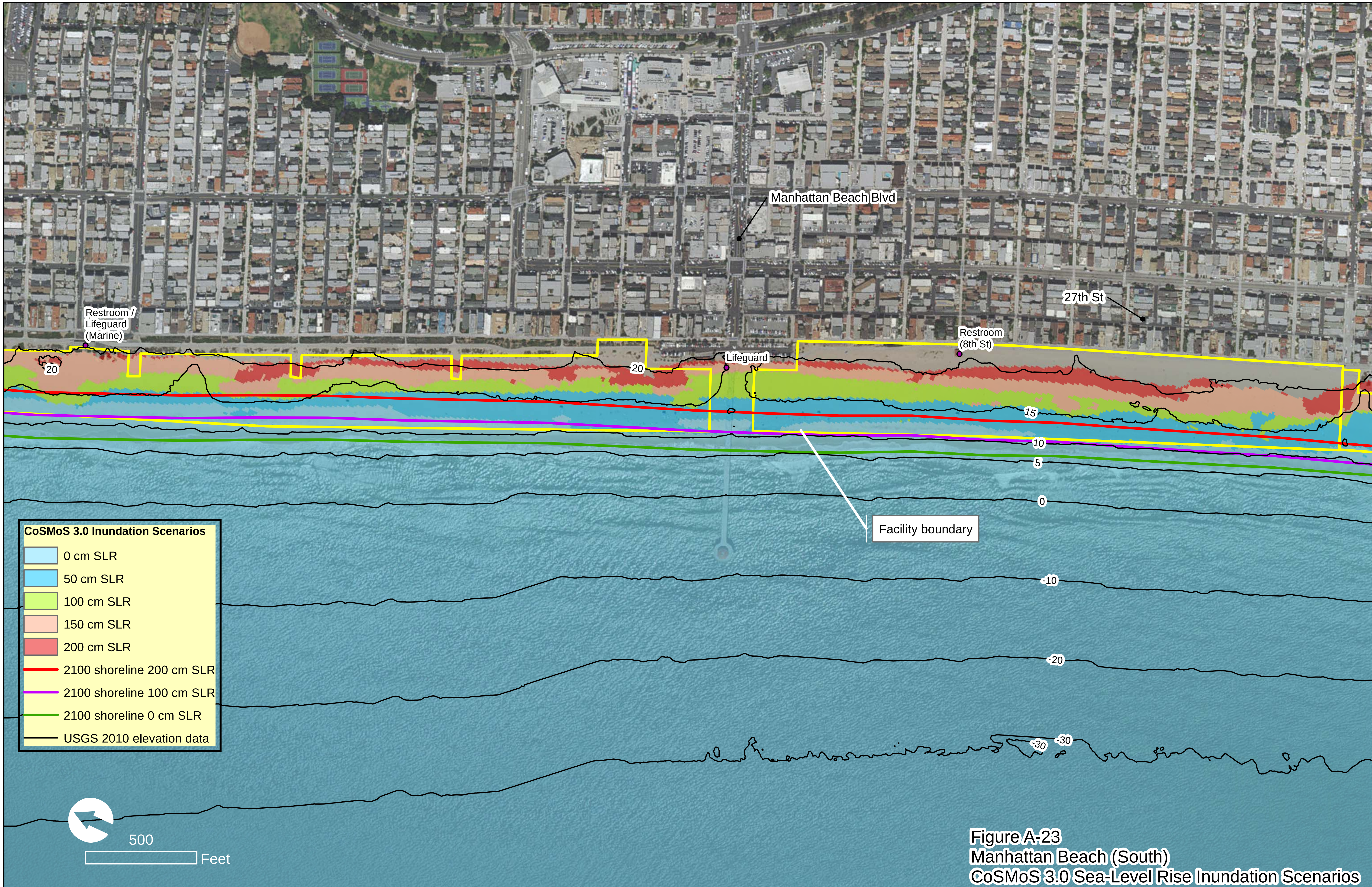


Figure A-23
Manhattan Beach (South)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

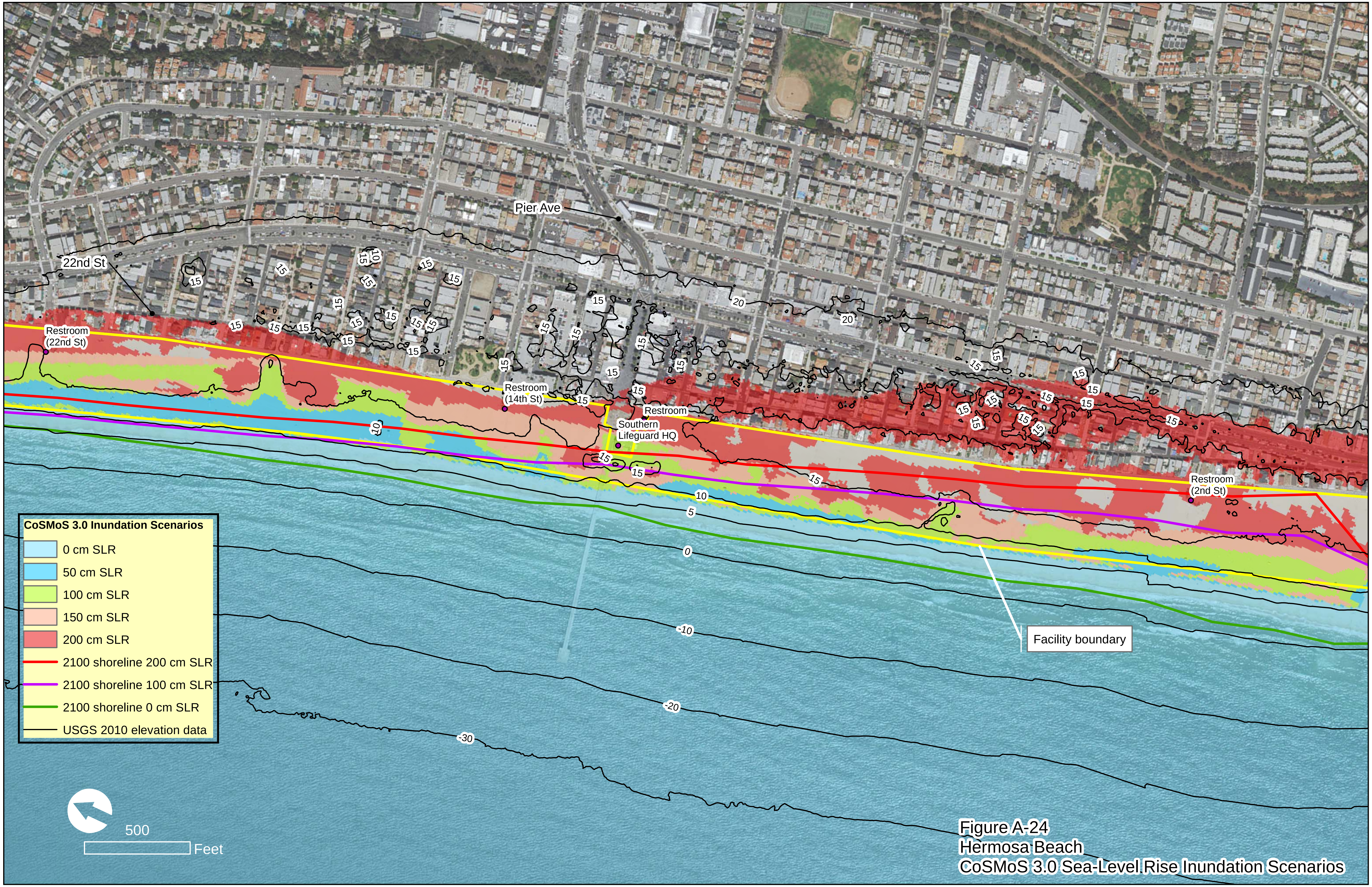


Figure A-24
Hermosa Beach
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

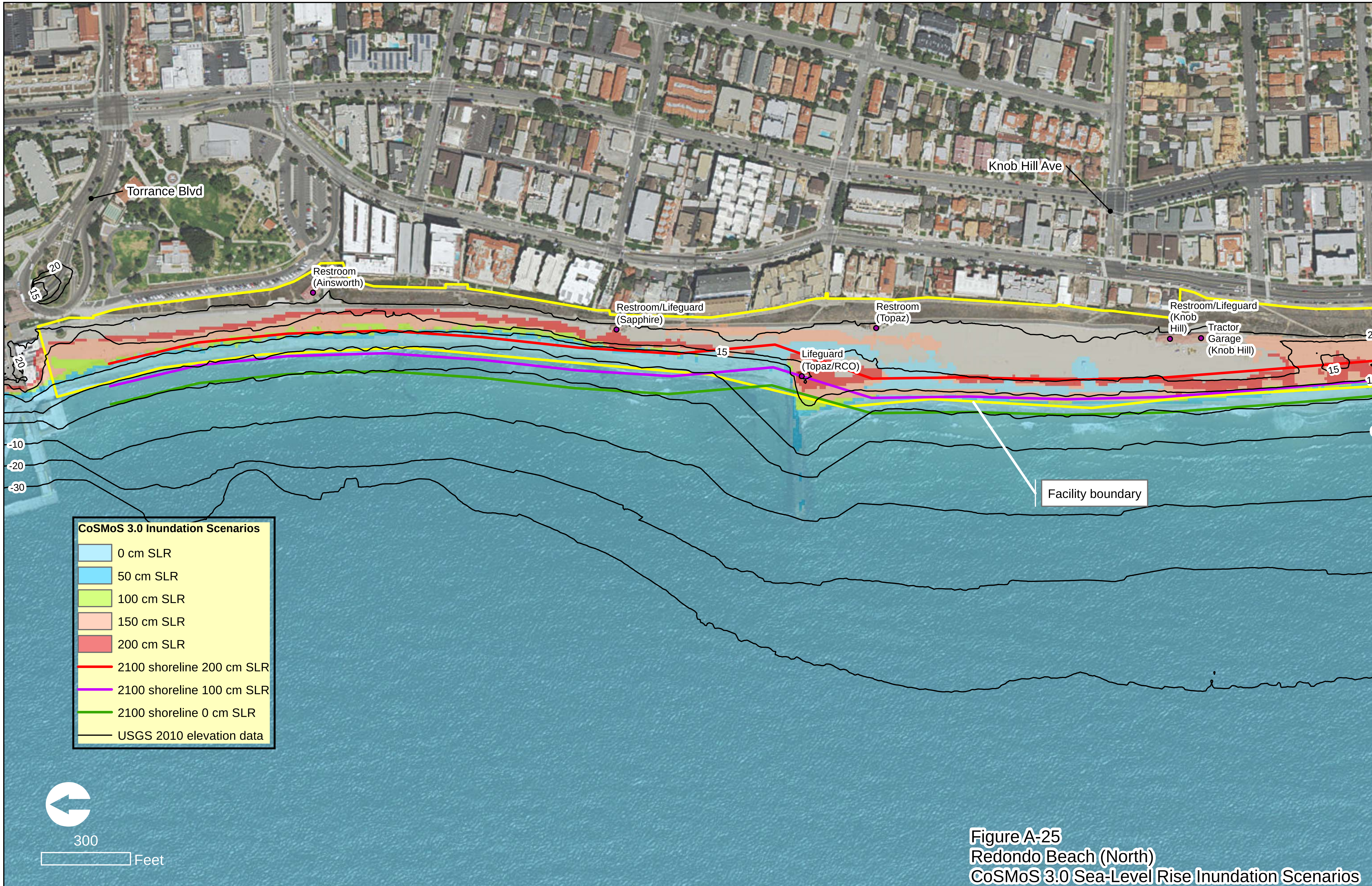


Figure A-25
Redondo Beach (North)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

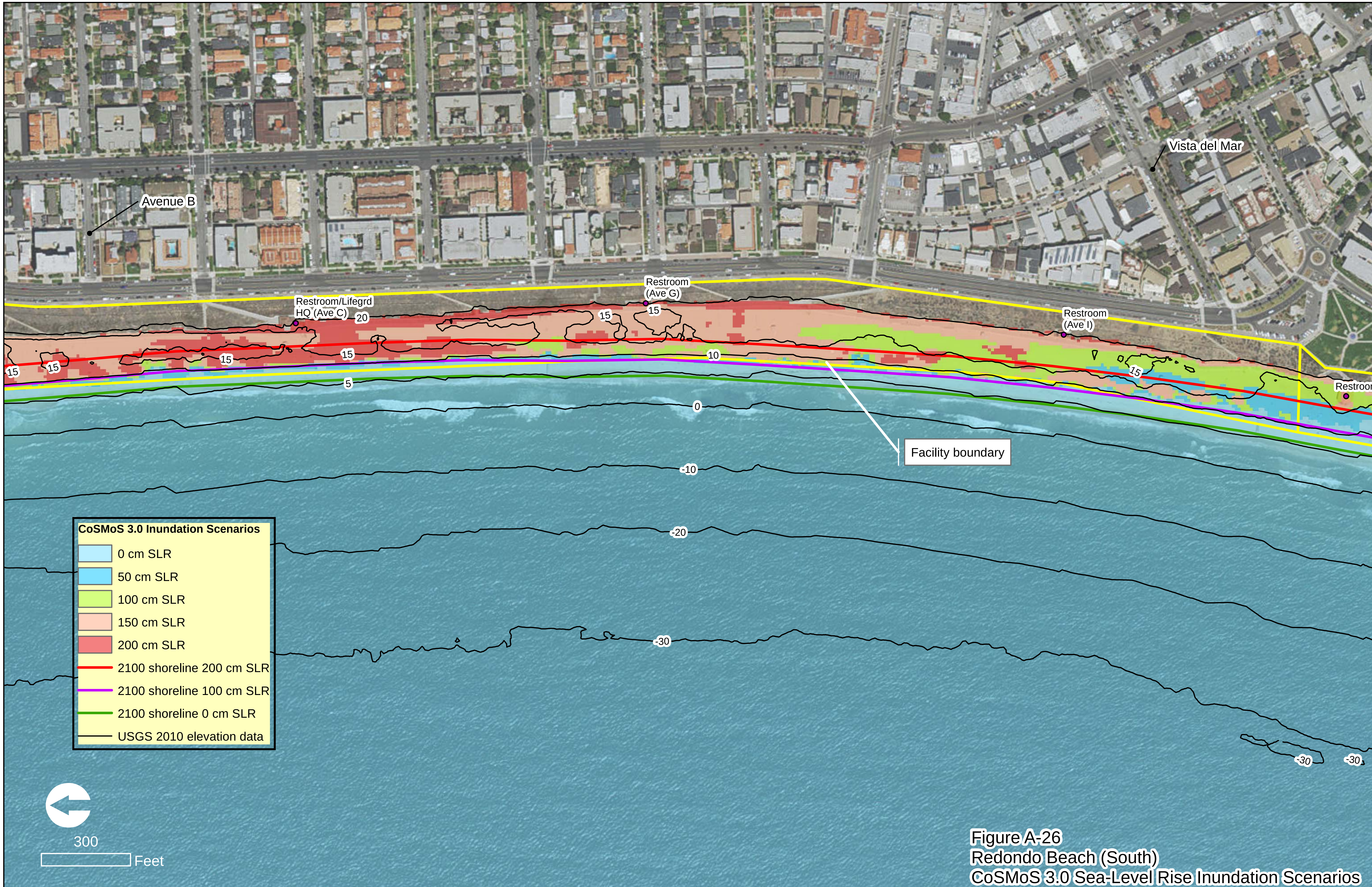


Figure A-26
Redondo Beach (South)
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

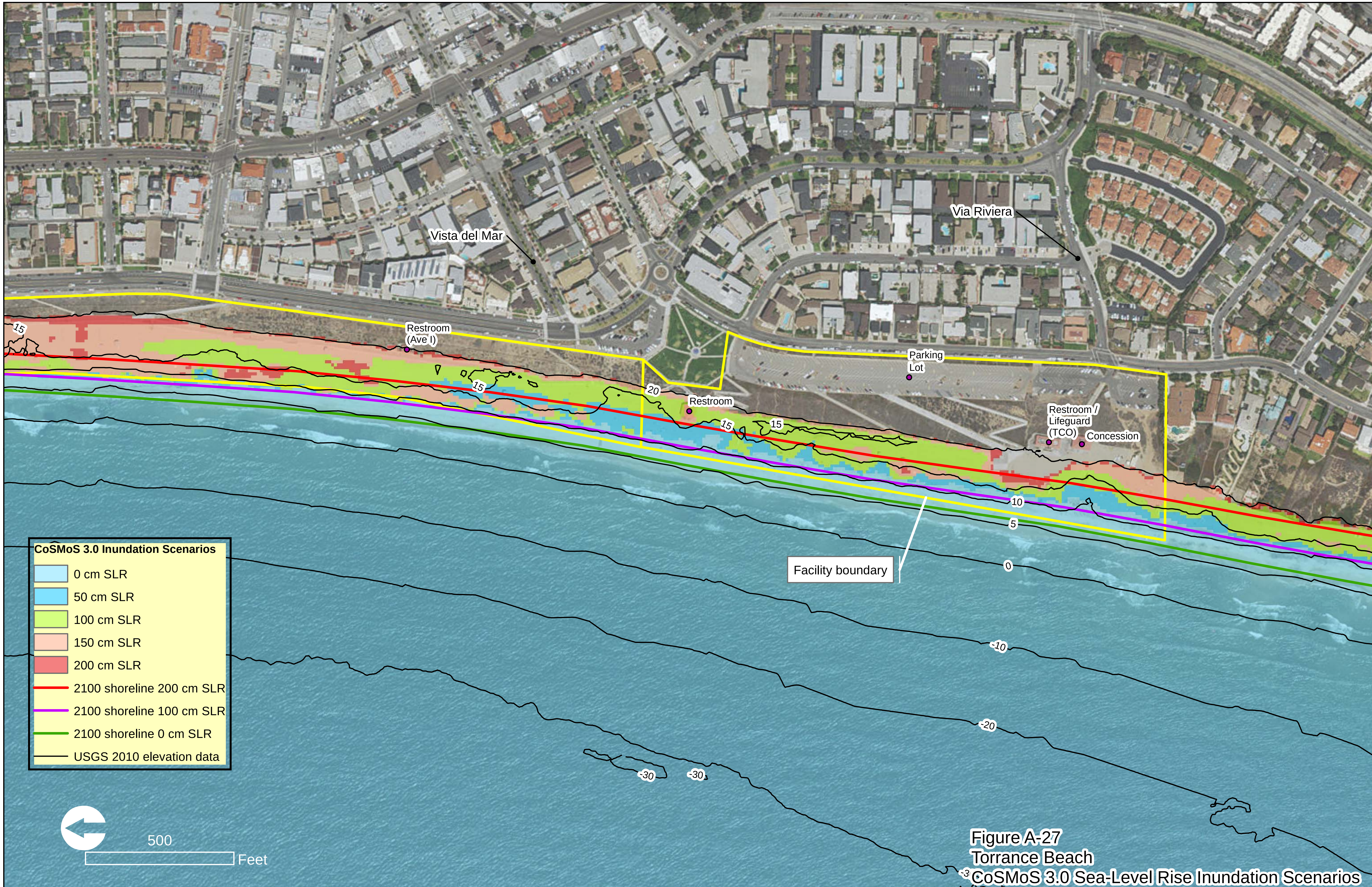


Figure A-27
Torrance Beach
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

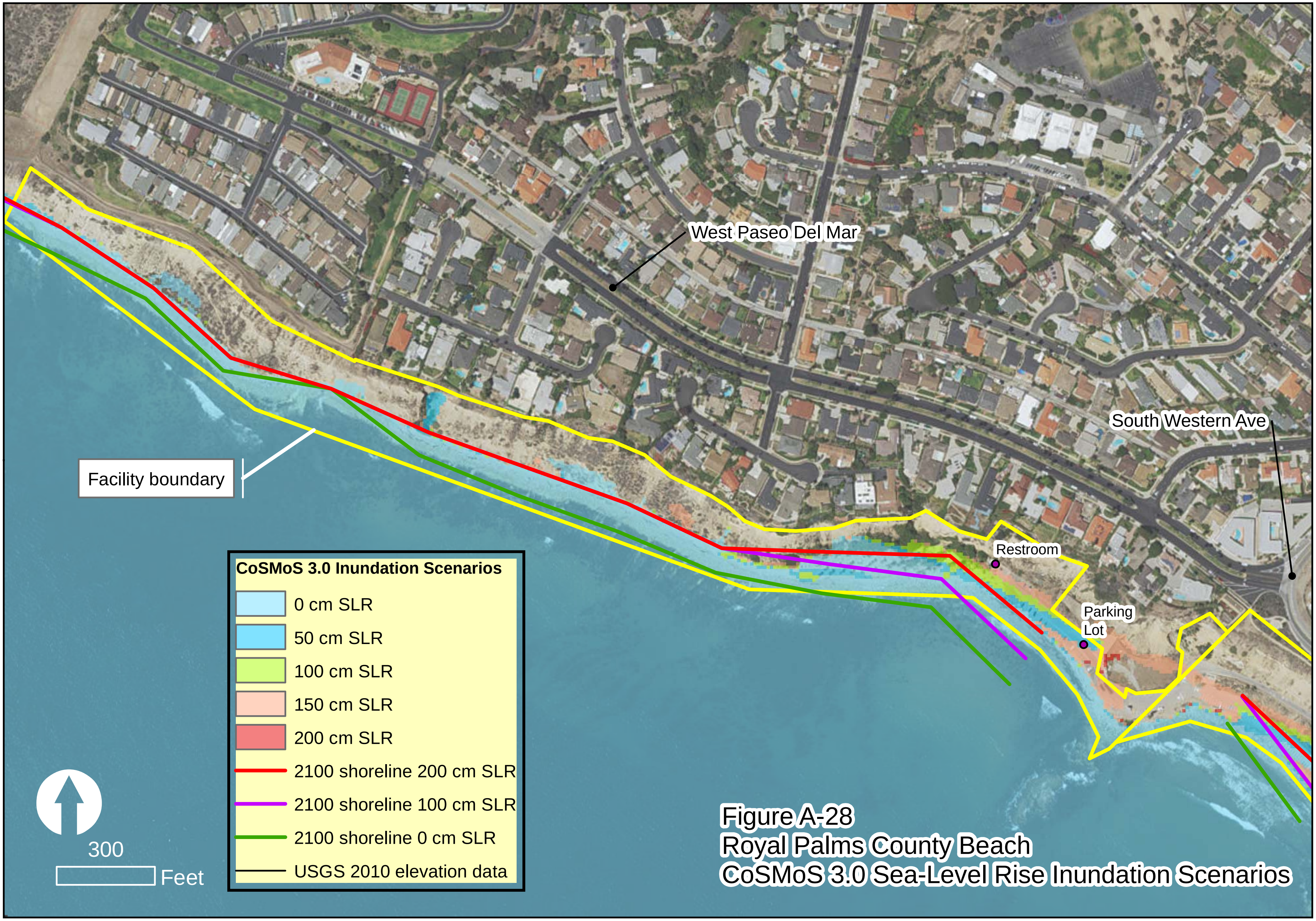


Figure A-28
Royal Palms County Beach
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

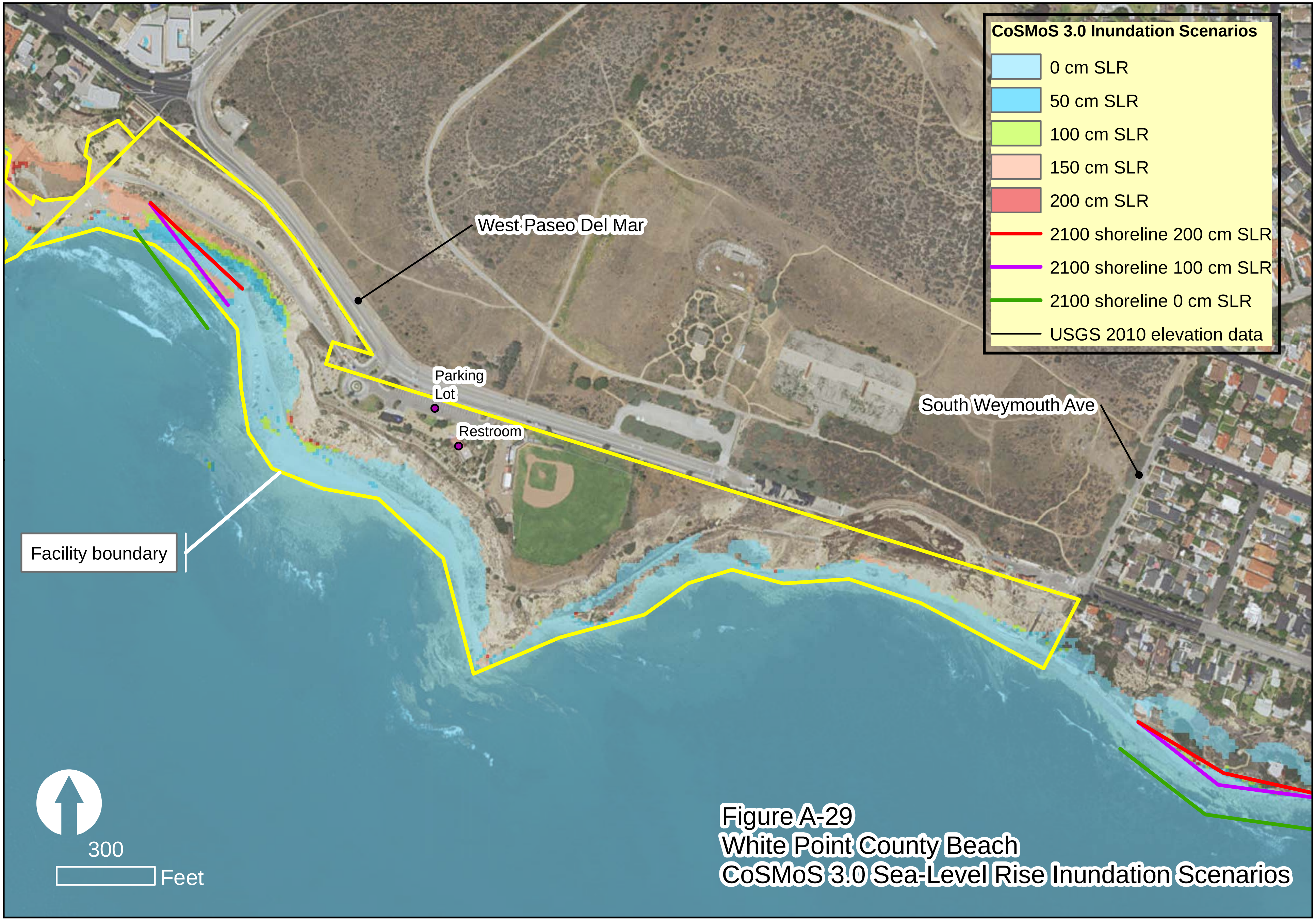


Figure A-29
White Point County Beach
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

Figure A-30
Point Fermin Beach
CoSMoS 3.0 Sea-Level Rise Inundation Scenarios

Appendix B

Coastal Analysis for Seasonal Sand Berm Protection Program

Los Angeles County Department of Beaches and Harbors

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1 INTRODUCTION

The Los Angeles County shoreline is a unique urban setting that is one of the most valuable, if not the most valuable, coastal resources in the State. Its regional beaches, many miles of which have been artificially enhanced and stabilized over the 20th Century, provide recreation and enjoyment for millions of visitors annually. In addition, the beaches generate significant revenue, and provide a natural buffer against storm waves and tides that protects the extensive inland development and infrastructure.

Winter coastal storms with high tides, surf, and beach erosion have been the primary concern for the Los Angeles County shoreline. For this reason, the Department of Beaches and Harbors (DBH) has built and maintained 17 winter sand berms for approximately 30 years at Zuma, Venice, Dockweiler, and Hermosa beaches as a preventive measure to help protect public beach facilities from coastal flood damage. The program represents a modest effort to effectively protect the valuable facilities and carry out the Department's mission to maintain the County's beaches and protect the facilities that allow the maximum public use of them. This purpose will undoubtedly become even more important in the years ahead as climate changes, sea level rises, and public demand for beach use continues to grow.

The purpose of this analysis is to review the Department's winter sand berm protection program in more depth to assess its effectiveness and value to protect the public beach facilities, and to recommend improvements in geometry and placement to maximize the storm damage reduction benefit. The scope of services include the following tasks:

1. Meet with DBH staff to review the County's berm construction history, typical construction details, maintenance practice, and anecdotal evidence of past performance.
2. Develop the representative beach profile, stillwater level, and wave characteristics that shall be input to the wave uprush analysis. Typical winter beach profile scenarios, storm wave heights and periods shall be formulated using Coast of California Storm Tidal Waves Study (CCSTWS) data. Probable stillwater level shall be estimated from the combined parameters of astronomical tide, El Niño effects, and wave setup associated with winter storm occurrence.
3. Perform wave uprush analysis at four beach sites to evaluate the required sand dune crest elevation for storm protection.
4. Prepare a memorandum report that summarizes the findings and recommendations of the study; meet with DBH staff to discuss the results of our study.

2 BACKGROUND

2.1 Hermosa, Dockweiler, and Venice Beaches

The County has been constructing berms for winter storm wave protection on Hermosa Beach, Dockweiler Beach, and Venice Beach since the 1970's (CCC, 2006). The beaches, where the berms have been constructed, are developed with public facilities such as parking lots, restrooms, pedestrian beach access ways, lifeguard headquarters, maintenance facilities, and associated utilities and infrastructure. In April 2003, California Coastal Commission (CCC) approved a request for after-the-fact approval of construction of the berms, which had already constructed in the previous Novembers (CDP No 5-02-385). Based on the 2011 permit approval of CCC, the winter sand berms on these beaches measure approximately 15 feet high and vary in length from approximately 235 feet to 1,343 feet. The locations of the winter berms that have been historically constructed on these three beaches are shown in **Figures B1** through **B3**.

2.2 Zuma Beach

The County of Los Angeles Department of Beaches and Harbors (LADBH, 2013) proposed to construct ten approximately 15 foot high, 20 foot wide seasonal sand berms. Based on the Coastal Development Permit (LADBH, 2013) application that the County submitted to the California Coastal Commission, six of the proposed sand berms would be 215 feet long, three would be 300 feet long, and one would be 250 feet long The locations of these proposed berms are shown in **Figure 4**.

2.3 Storm Damage Protection

In general, the temporary sand berms are built in November of each year in order to be in place during the winter storm season to provide a measure of storm damage protection for the public beach facilities. Using a fleet of bulldozers, the berms are generally built to crest elevations of approximately 12 to 15 feet above existing beach level. Depending upon the length of the berm, it can take anywhere from several days to one week to build each one. The intent is to provide a natural buffer against direct wave attack and sheet flow runup that would otherwise destroy pavement, seriously damage the advanced sewage treatment facilities at the public restrooms, and compromise buildings and utilities. Depending upon the existing beach width at the time of construction, the berms are setback landward as far as possible to avoid exposure during normal tides. However, because of the limited beach width that is available and the need to provide for emergency vehicle access behind the berms at all times, the sand mounds are offset seaward from each public improvement anywhere from 30 to 100 feet. Typical photographs of the berm construction are shown in **Figure B5**.

3 Study Sites

Four winter sand berm sites were included in this analysis, one for each of the four beach sites. The wave uprush analysis was conducted based on the beach profiles and the wave characteristics formulated in the Coast of California Storm and Tidal Waves Study (CCSTWS). CCSTWS for Los Angeles region (NCI, 2010) is a comprehensive effort geared towards the understanding, assessment, evaluation and analysis of the coastal processes along the Los Angeles coastline. Historical beach profiles, which have been collected by the County since the 1930's and augmented with recent comprehensive beach profile surveys, were compiled and analyzed in CCSTWS. Table 1 lists the four beach profile stations that were selected in this analysis to represent the typical beach condition at the four winter sand berm sites, respectively.

The nearshore wave conditions were computed in CCSTWS for 240 stations along the Los Angeles County coastline. The four wave stations that are located at or adjacent to the winter sand berm sites are listed in Table 1. The wave characteristics at these stations were used to represent the wave conditions for the winter berm sites.

Table 1. Representative CCSTWS Beach Profiles and Wave Stations

Site	Beach profile station	Wave station
Hermosa Beach	215+00	74
Dockweiler Beach	44+00	104
Venice Beach	248+00	135
Zuma Beach	90+00	263

4 Beach Profiles

The four representative beach profiles, which were surveyed in May 2005, are shown in Figure 6 through Figure 9 for the four winter sand berm sites, respectively. The May 2005 survey is the most comprehensive beach profile survey in recent years. The nearshore beach slope is approximately 40 (horizontal) to 1 (vertical) or flatter for Hermosa, Dockweiler, and Venice beaches, and is approximately 20 to 1 for Zuma Beach. The front (seaward-side) slopes of the natural sand berms are approximately 10:1 or flatter.

A preliminary measurement of the winter sand berms was made for Hermosa and Dockweiler beaches, and are shown in Figure 6 and Figure 7 together with the surveyed beach profiles. The front slopes of these berms were measured to vary between 3:1 to 4:1. This is consistent with the design slope of 4:1. The winter sand berms for Venice and Zuma beaches were assumed to have the design front slope of 4:1, as shown in Figure 8 and Figure 9.

5 OCEANOGRAPHIC CONDITIONS

5.1 Still Water Level

The still water level along the Los Angeles County shoreline is mainly controlled by the astronomical tide, with additional contributions of El Niño effects and storm surges that are associated with winter storm occurrence. Two tidal gauges have been installed by the National Oceanic and Atmospheric Administration (NOAA) that are close to the project sites. One is NOAA gauge Station 9410840 at Santa Monica and the other is Station 9410660 at Los Angeles Outer Harbor. The tidal datums for the 1983-2001 epoch are listed in Table 2.

Table 2. Tidal Datum at Santa Monica and at Los Angeles Outer Harbor

Tidal datum	Elevation (ft, MLLW)	
	Santa Monica (NOAA 9410840)	LA Outer Harbor (NOAA 9410660)
Highest Measured Water Level	8.50 (11/30/1982)	7.82 (01/27/1983)
Mean Higher High Water (MHHW)	5.42	5.49
Mean High Water (MHW)	4.69	4.75
Mean Tide Level (MTL)	2.81	2.85
Mean Sea Level (MSL)	2.79	2.82
National Geodetic Vertical Datum-1929 (NGVD29)	2.63	2.63
Mean Low Water (MLW)	0.93	0.94
North America Vertical Datum-1988 (NAVD88)	0.20	0.20
Mean Lower Low Water (MLLW)	0.00	0.00
Lowest Measured Water Level	-2.84 (12/17/1933)	-2.73 (12/17/1933)

Source: NOAA Tidal Bench Marks

While the water level measurement started in 1995 for the Santa Monica Station, the Los Angeles Station has a much longer period of data record that started from 1923. Therefore, the data collected at Los Angeles Station was used in this analysis. It is noted that the measured water level data includes not only the astronomical tide, but also the contributions of El Niño effects and storm surges during the winter storm events. Therefore, the water level data measured at the Los Angeles Station was used to represent the still water level condition for the four berm sites. The hourly water level data between 1970 and 2005, which is consistent with the time span of the CCSTWS wave data, was used in this analysis.

5.2 Waves

Wind waves and swells along the Los Angeles County shoreline are produced primarily by six basic meteorological patterns: extratropical storm swells in the northern hemisphere (north or northwest swell); wind swells generated by northwest winds in the outer coastal waters (wind swell); westerly (west sea) and southeasterly (southeast sea) local seas; storm swells of tropical storms or hurricanes off the Mexican coast; and southerly swells originating in the southern hemisphere (southerly swell).

The nearshore wave conditions along the Los Angeles shoreline were computed in CCSTWS study (NCI, 2010) using O'Reilly's spectral back-refraction model. This model transforms the deepwater wave conditions, which were hindcasted with the Global Reanalysis of Ocean Waves (GROW) model, to the nearshore region. The wave transformation processes in the model included island sheltering, wave shoaling and wave refraction. The nearshore wave conditions were computed for every three hours (8 times per day) between 1970 through 2005 for 240 stations with water depths of approximately 10 meters.

The four wave stations that were used for the four beach sites are listed in Table 1. As examples, Figure 10 through Figure 13 show the wave periods, nearshore significant wave heights and the corresponding deepwater wave heights during the 1982-83 winter season for the four sites, respectively.

6 WAVE RUNUP ANALYSIS

6.1 CEM Runup Method

Because of the random nature of ocean waves, the wave conditions and resulting wave runups vary during a wave event. The wave runup used in this analysis is the 10% wave runup that is defined as the average of the highest 10% of the runups during a wave event. The 10% wave runup, $R_{10\%}$, was computed in this analysis using the following equation recommended in Coastal Engineering Manual (USACE, 2003), or CEM:

$$\frac{R_{10\%}}{H_0} = 1.70\xi_0^{\ 0.71}$$

where H_0 is the significant deepwater wave height, and ξ_0 is the Iribarren number, or the surf similarity parameter that is defined as

$$\xi_0 = \tan\beta\left(\frac{H_0}{L_0}\right)^{-1/2}$$

in which $tan\beta$ is the averaged beach slope from the wave breaking point to the wave runup limit, and L_0 is the deepwater wave length. The deepwater wave length L_0 is

$$L_0 = gT^2 / 2\pi$$

where g is the gravitational acceleration and T is the peak wave period.

6.2 Computed Wave Runups

The 10% wave runup was computed for every three hours with the CEM method, using the 3-hourly wave condition (deepwater wave heights and wave lengths) with the corresponding maximum (hourly) still water levels within each of the 3-hour intervals. It is noted that the average beach slope $tan\beta$ used for wave runup calculation depends on the location of the wave runup limit on the beach or berm, which is a function of the wave runup itself. Thus, an iteration procedure was applied in the wave runup computation until the solution converges.

The 3-hourly wave runups and wave runup elevations were computed for 36 years from 1970 to 2005, the same period as the CCSTWS wave data coverage. The wave runup elevation is the sum of the computed wave runup value plus the still water level. Both the with winter sand berm (with-berm) condition and the without winter sand berm (without-berm) condition were included in the analysis. As examples, Figure 14 through Figure 17 show the still water levels, computed 10% wave runups, and the corresponding wave runup elevations during the 1982-83 winter season for the four beach with winter sand berms, respectively.

The monthly and annual maximum wave runup elevations were determined based on the 3-hourly results. Figure 18 through Figure 21 show the monthly maximum wave runup elevations for the four sites, respectively. Figure 22 through Figure 25 show the annual maximum runup elevations. It is noted that the wave runup elevations for the with-berm scenario are generally higher than those for without-berm scenario. This is because the side slope of the winter sand berm (approximately 4H:1V) is steeper than the natural berm and front beach. A steeper slope results in higher wave runup on the slope.

The annual maximum wave runup elevations on the winter sand berm between 1970 and 2005 vary between 16 to 27 feet MLLW for Hermosa Beach, 15 to 25 feet MLLW for Dockweiler Beach, 12 to 22 feet MLLW for Venice Beach, and 12 to 23 feet MLLW for Zuma Beach. The highest wave runup elevation occurred in March 1983 when extremely high waves with long wave periods coincided with high tides.

6.3 Return Frequency Analysis for Wave Runup Elevations

A statistical analysis was conducted based on the 36-year annual maximum wave runup elevations to determine the runup elevations for different recurrent frequencies. Figure 26 through Figure 29 show the return frequency (annual chance) curve for runup elevations for the four beach sites, respectively, for the without-berm scenario. Figure 30 through Figure 33 show the results for the with-berm scenario. Both the data and the Weibull curve that best fits the data are shown in these figures. The runup elevations for various return periods are summarized in Table 3 for the without-berm condition, and in Table 4 for the with-berm condition. The return period, also known as a recurrence interval (year), is an estimate of the likelihood of the wave runup elevation to occur. It is noted that the wave runup at Zuma Beach and Venice Beach is lower than the other two beaches. This is because the nearshore waves at Zuma Beach and Venice Beach are lower than the other two beaches, as shown in Figure 10 through Figure 13.

Table 3. Wave Runup Elevations for Various Return Frequencies (Without Berms)

Return period (Year)	10% Wave runup elevation (ft, MLLW)			
	Hermosa	Dockweiler	Venice	Zuma
1	14.5	13.9	11.9	12.3
2	17.1	17.0	13.2	13.4
5	19.2	18.7	14.9	14.7
10	20.6	19.6	16.1	15.8
25	22.2	20.7	17.8	17.1
50	23.4	21.4	19.0	18.2
100	24.5	22.0	20.3	19.2

Table 4. Wave Runup Elevations for Various Return Frequencies (With Berms)

Return period (Year)	10% Wave runup elevation (ft, MLLW)			
	Hermosa	Dockweiler	Venice	Zuma
1	15.5	13.7	12.0	12.1
2	18.7	18.4	13.6	13.8
5	21.4	20.8	15.7	15.9
10	23.2	22.2	17.3	17.6
25	25.3	23.7	19.4	19.8
50	26.8	24.8	21.0	21.4
100	28.1	25.7	22.6	23.1

The coastal flood protection levels in terms of the return frequencies of coastal flood events are summarized in Table 5 for various berm heights. The berm height is defined as the height between crest of the winter sand berm and the seaward edge of the natural beach berm. The elevations for the seaward edge of the natural beach berms, which were determined based on the 2005 surveyed beach profiles, are also listed in Table 5. The minimum berm height required to provide a 50-year coastal flood protection is 13.6 feet for Hermosa Beach, 13.2 feet for Dockweiler Beach, 9.9 feet for Venice Beach, and 10.3 feet for Zuma Beach.

Table 5. Coastal Flood Protection Levels for Various Sand Berm Heights

Return period (Year)	Berm height (above seaward edge of natural beach berm)			
	Hermosa	Dockweiler	Venice	Zuma
1	2.3	2.1	0.9	1.0
2	5.5	6.8	2.5	2.7
5	8.2	9.2	4.6	4.8
10	10.0	10.6	6.2	6.5
25	12.1	12.1	8.3	8.7
50	13.6	13.2	9.9	10.3
100	14.9	14.1	11.5	12.0

Note: elevations for the seaward edge of the natural beach berms are approximately:

13 ft, MLLW -- Hermosa Beach;	12 ft, MLLW -- Dockweiler Beach
11 ft, MLLW -- Venice Beach;	11 ft, MLLW -- Zuma Beach

It is noted that the wave runup used in this analysis is the 10% wave runup that is defined as the average of the highest 10% of the runups during a wave event. Therefore, wave runup higher than the computed 10% runup may occur a few times during a particularly wave event.

7 RECOMMENDATION OF WINTER SAND BERM

We believe that the County's seasonal berm program is a relatively low cost and simple strategy that can be employed to provide effective storm damage protection against the majority of coastal storm scenarios that can be expected to threaten the public beach infrastructure annually. Wave runup analysis indicates that the temporary sand mounds can buffer the beach facilities from storm events that have return periods of 25 to 50 years. The exact level of protection that any of the berms can provide is a function of its proximity to the water's edge, the duration of the storm, and the extent of beach erosion that may undermine the berm. The County regularly maintains each berm throughout the winter season to repair sloughed sections. However, the berms will likely be unable to provide protection for very severe storms events similar to the 1983 sequence that was characterized by prolong periods of high tides, wave attack, and severe beach erosion. As the storm severity increases, the ability of the sand berm to fully protect a particular site will depend upon the County's ability to restore and maintain the full section.

To address severe storm survivability, we recommend that a minimum freeboard of 2 feet be added to the computed wave runup elevations and the corresponding berm heights to take into account the uncertainty of the wave runup analysis and the potential storm-induced erosion of the sand berm that is not included in this analysis. The freeboard is defined as the vertical distance between the crest of the winter sand berm and the computed wave runup elevation. Storm waves may erode away part of the sand berm and thus may lower the crest of sand berm during extreme storm events. For that reason, we recommend that each berm be constructed as high as possible and as far landward as existing conditions allow during time of construction. At a minimum, the following crest elevations and berm heights are recommended for the winter sand berms that correspond to a 50-year wave runup risk level:

- Hermosa Beach: minimum crest elevation = 29 feet MLLW, or berm height = 16 feet
- Dockweiler Beach: minimum crest elevation = 27 feet, or berm height = 16 feet
- Venice Beach: minimum crest elevation = 23 feet MLLW, or berm height = 12 feet
- Zuma Beach: minimum crest elevation = 24 feet MLLW, or berm height = 13 feet

The recommended berm length is a function of the length of the landward facilities and infrastructure that is to be protected. We recommend that at a minimum, individual berm lengths should be extended at least fifty feet upcoast and downcoast beyond the corresponding end of each improvement to be protected. The total berm length should then be rounded up to a total distance that is a multiple of fifty-foot increments. In this manner each berm length may be computed as follows:

		50-foot minimum upcoast extension
	+	Length of facility to be protected
	+	50-foot minimum downcoast extension
Total berm length	=	(round up to nearest 50-foot increment)

We also recommend that the winter sand berms be constructed as shoreward as possible. This will not only reduce the averaged slope for wave runup and thus lower the wave runup elevation on the berms, but also alleviate the storm-induced erosion of the sand berms during extreme storm events.

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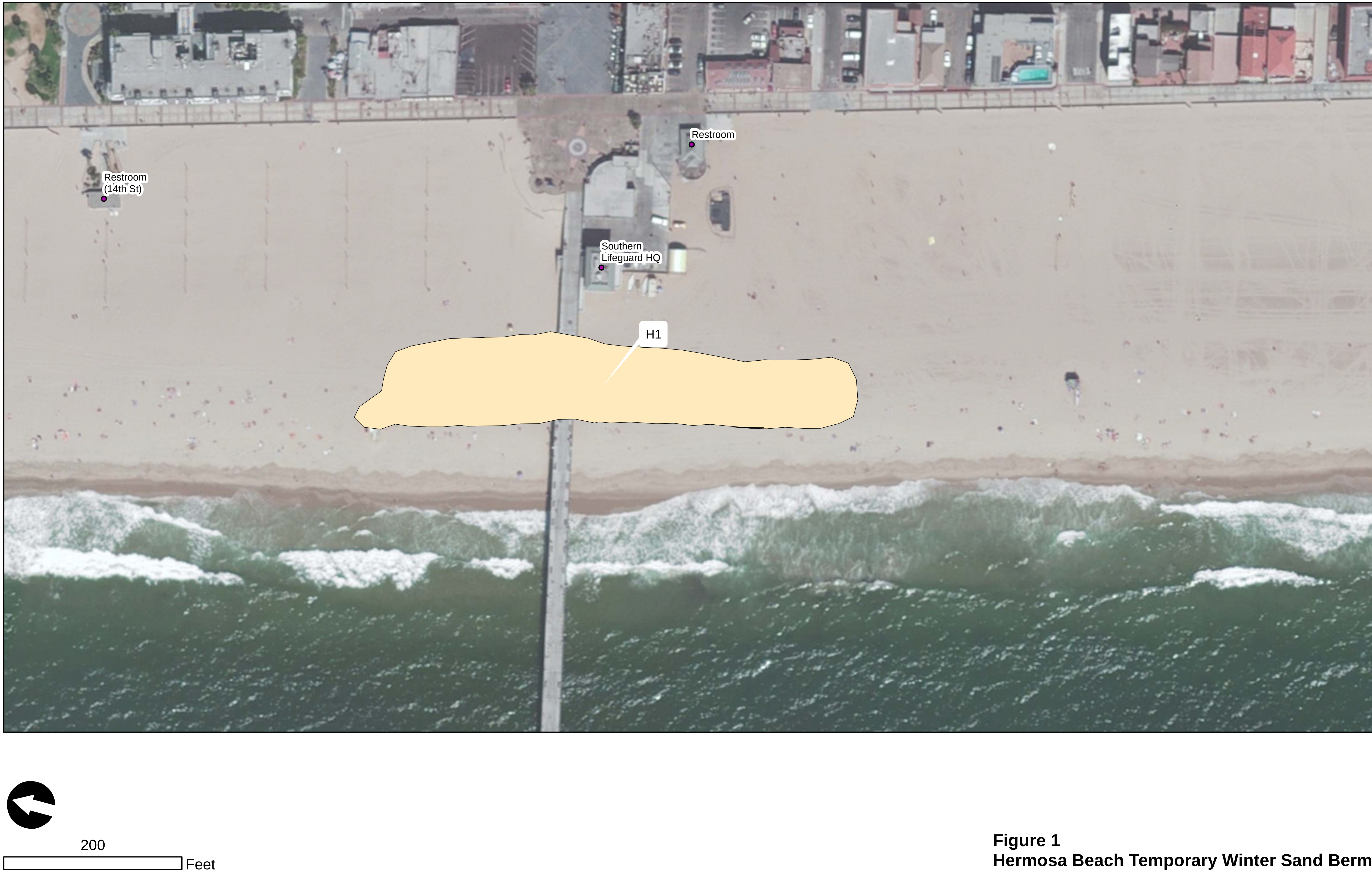
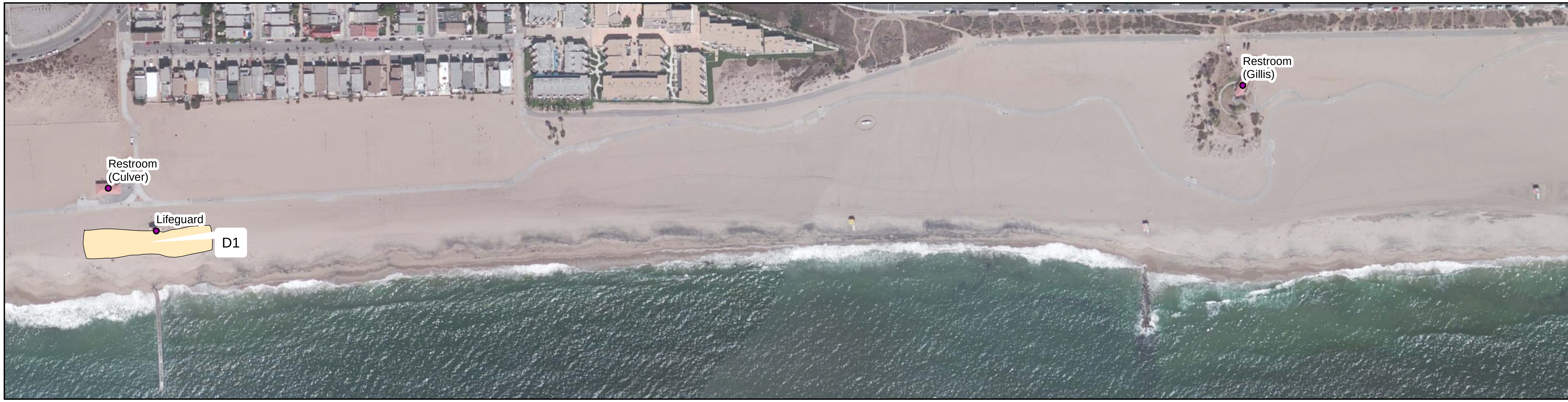


Figure 1
Hermosa Beach Temporary Winter Sand Berms



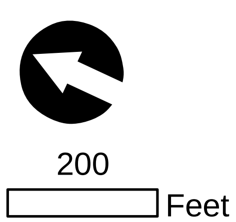


Figure 2
Dockweiler State Beach Temporary Winter Sand Berms

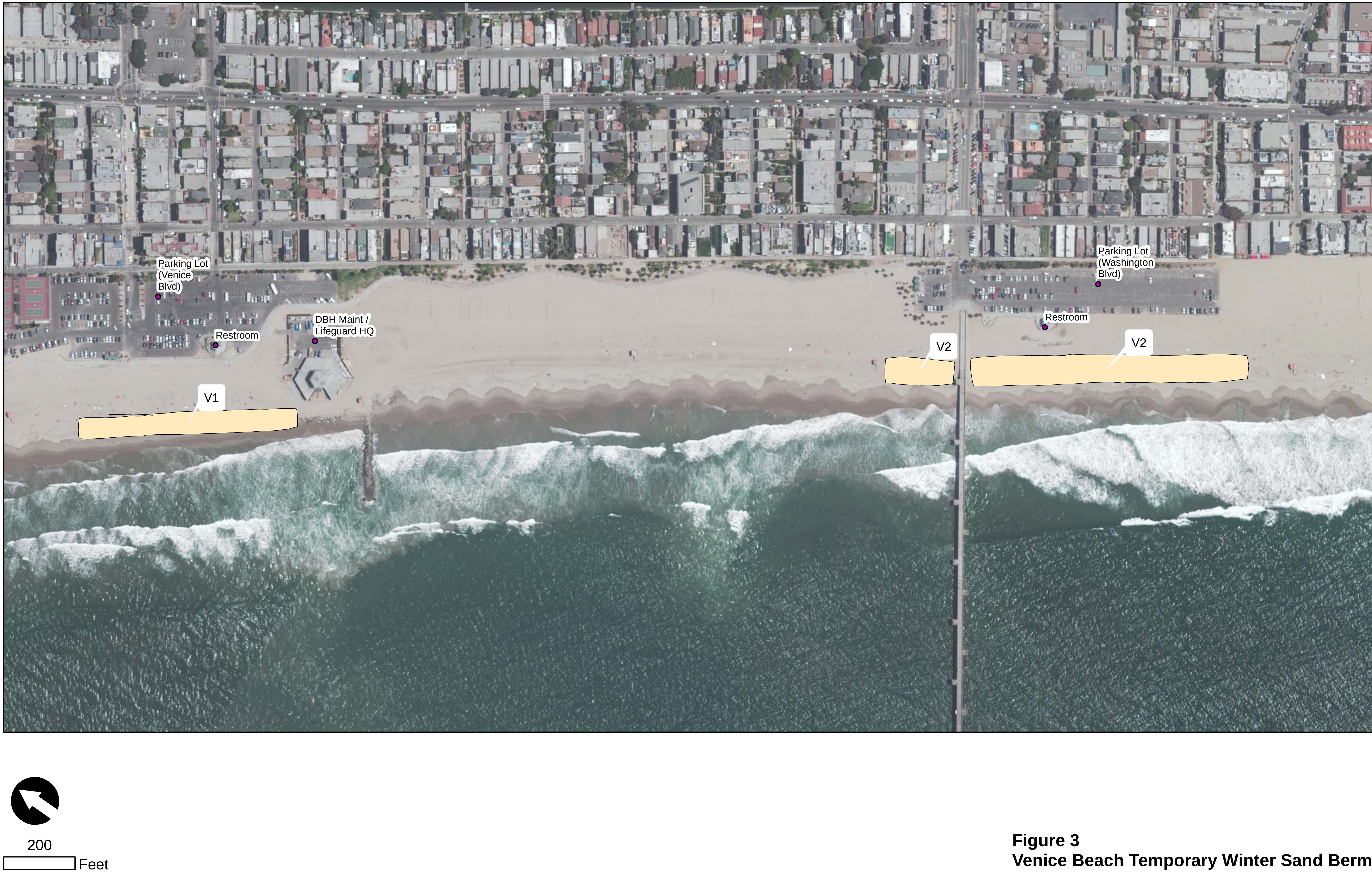


Figure 3
Venice Beach Temporary Winter Sand Berms

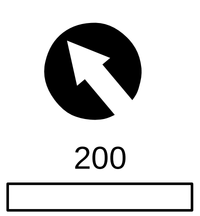


Figure 4
Zuma County Beach Temporary Winter Sand Berms

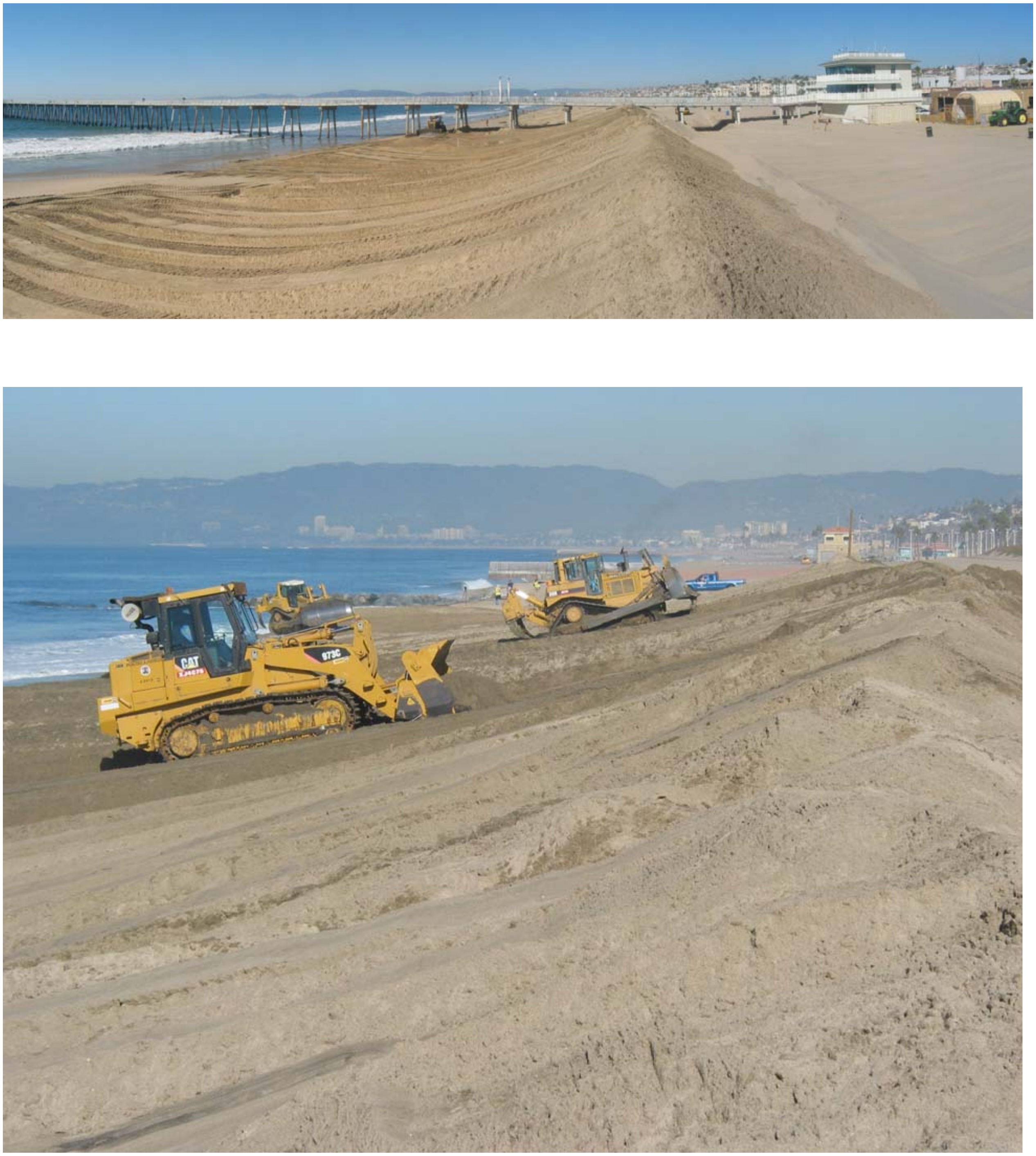


Figure 5 Typical Winter Sand Berm Construction

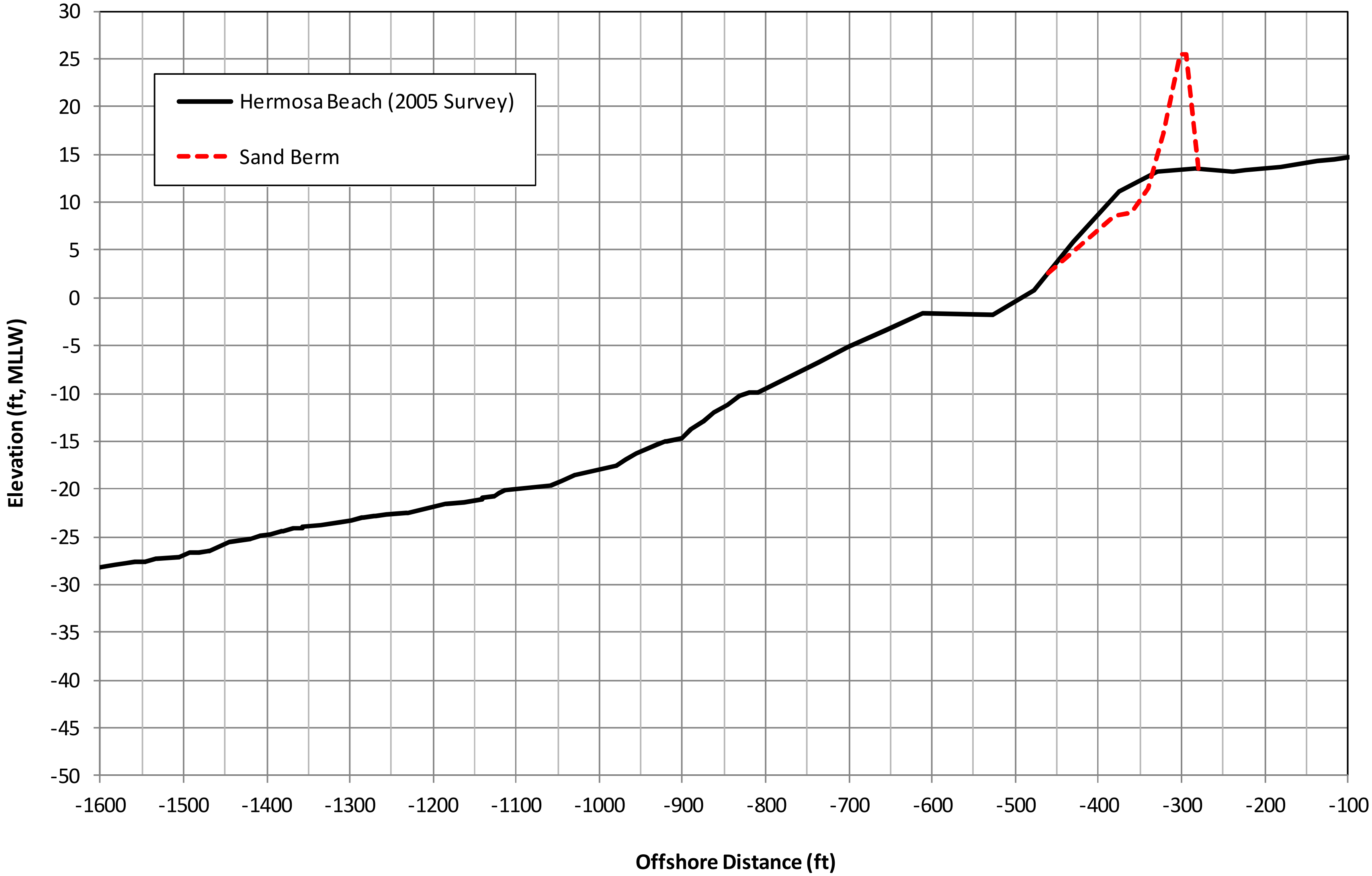


Figure 6. Representative Beach Profile for Hermosa Beach

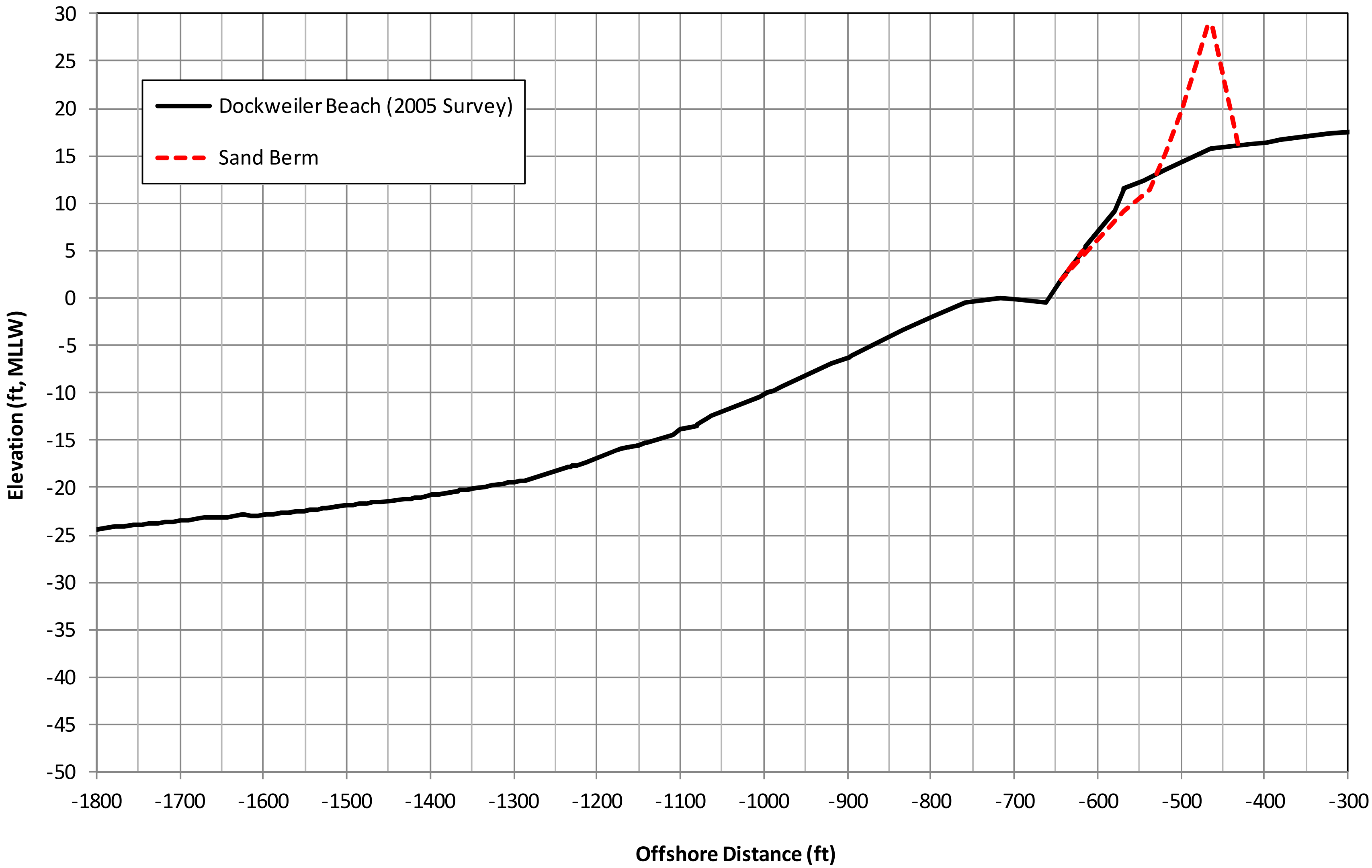


Figure 7. Representative Beach Profile for Dockweiler Beach

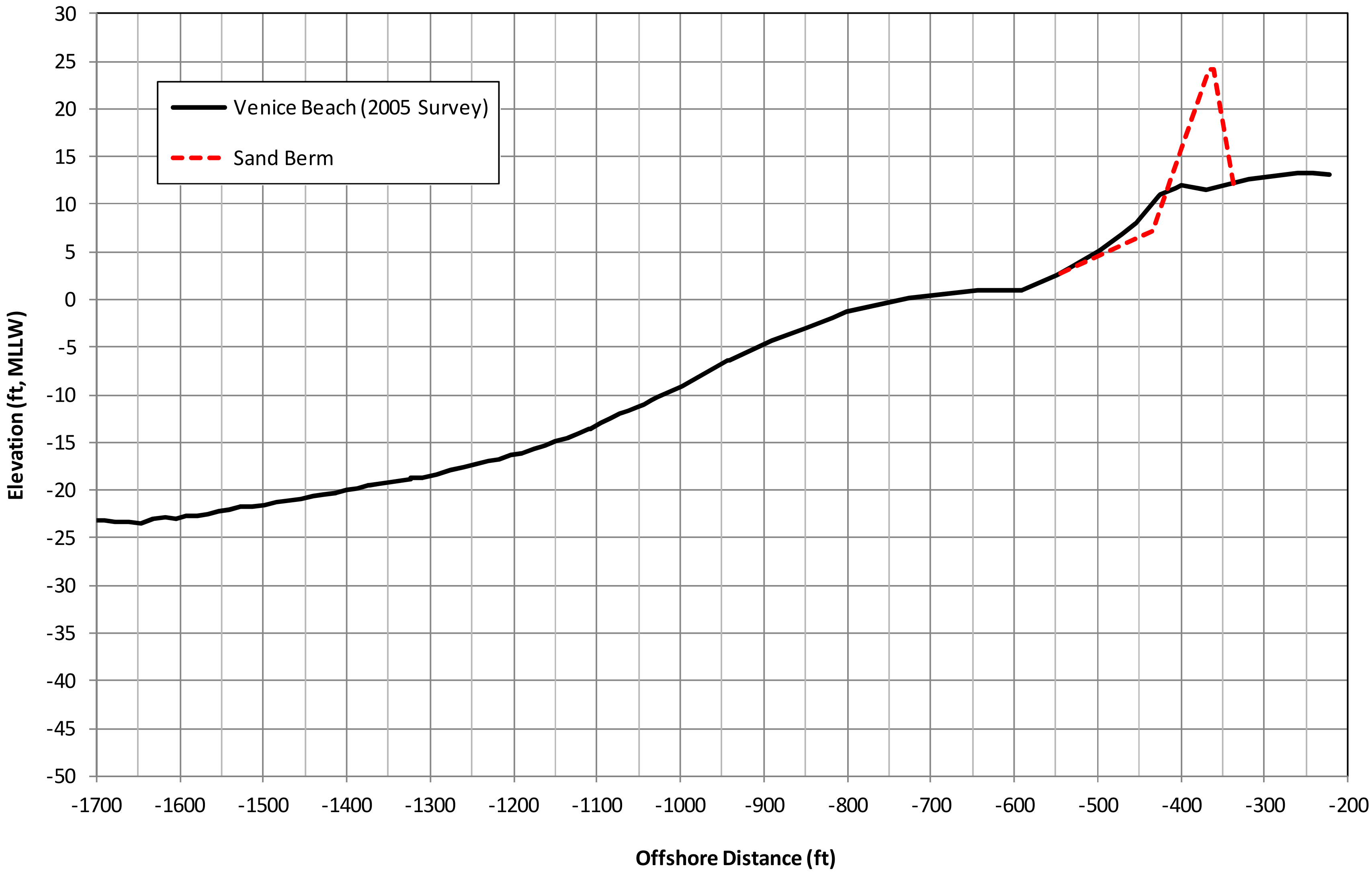


Figure 8. Representative Beach Profile for Venice Beach

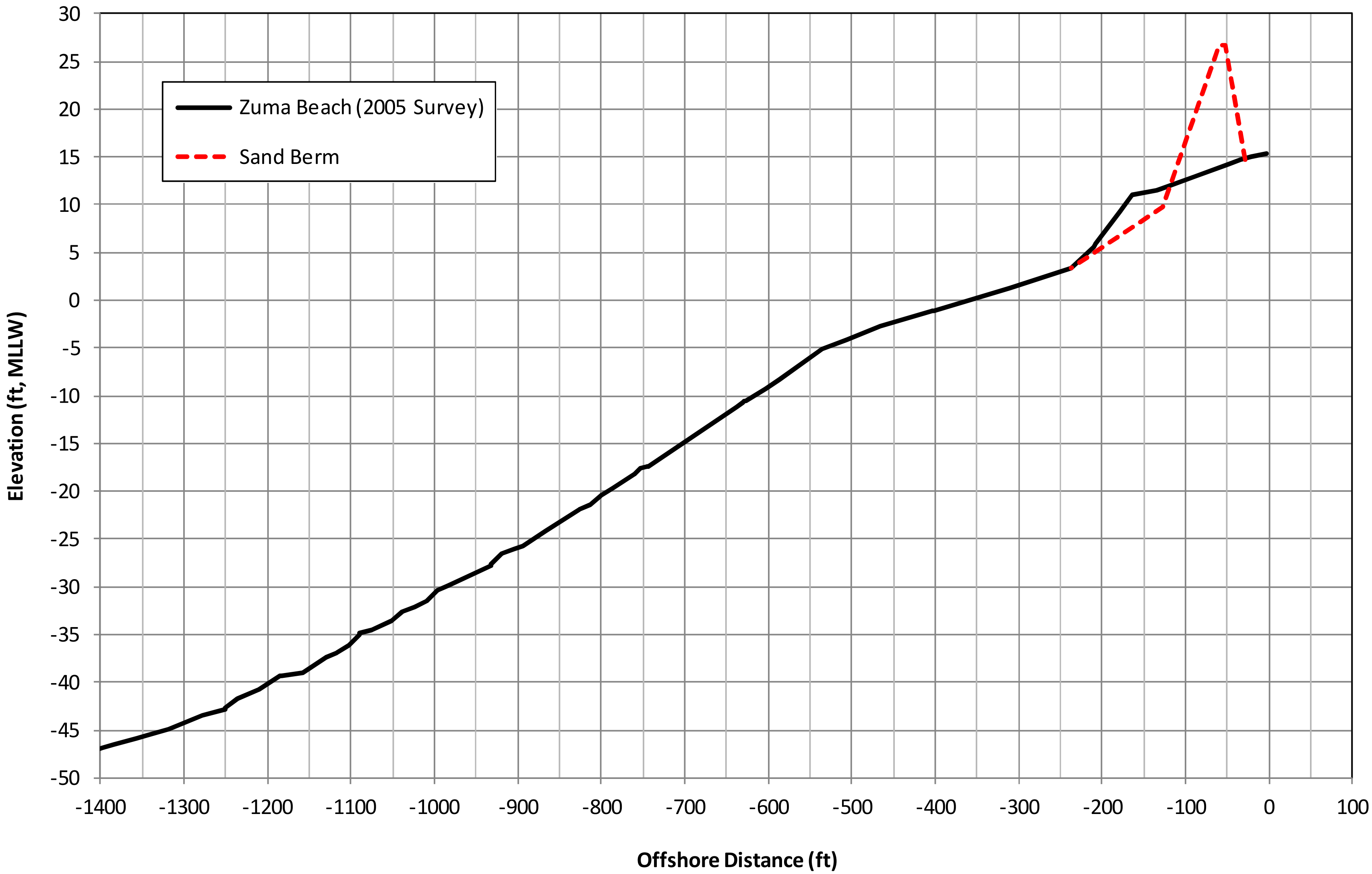


Figure 9. Representative Beach Profile for Zuma Beach

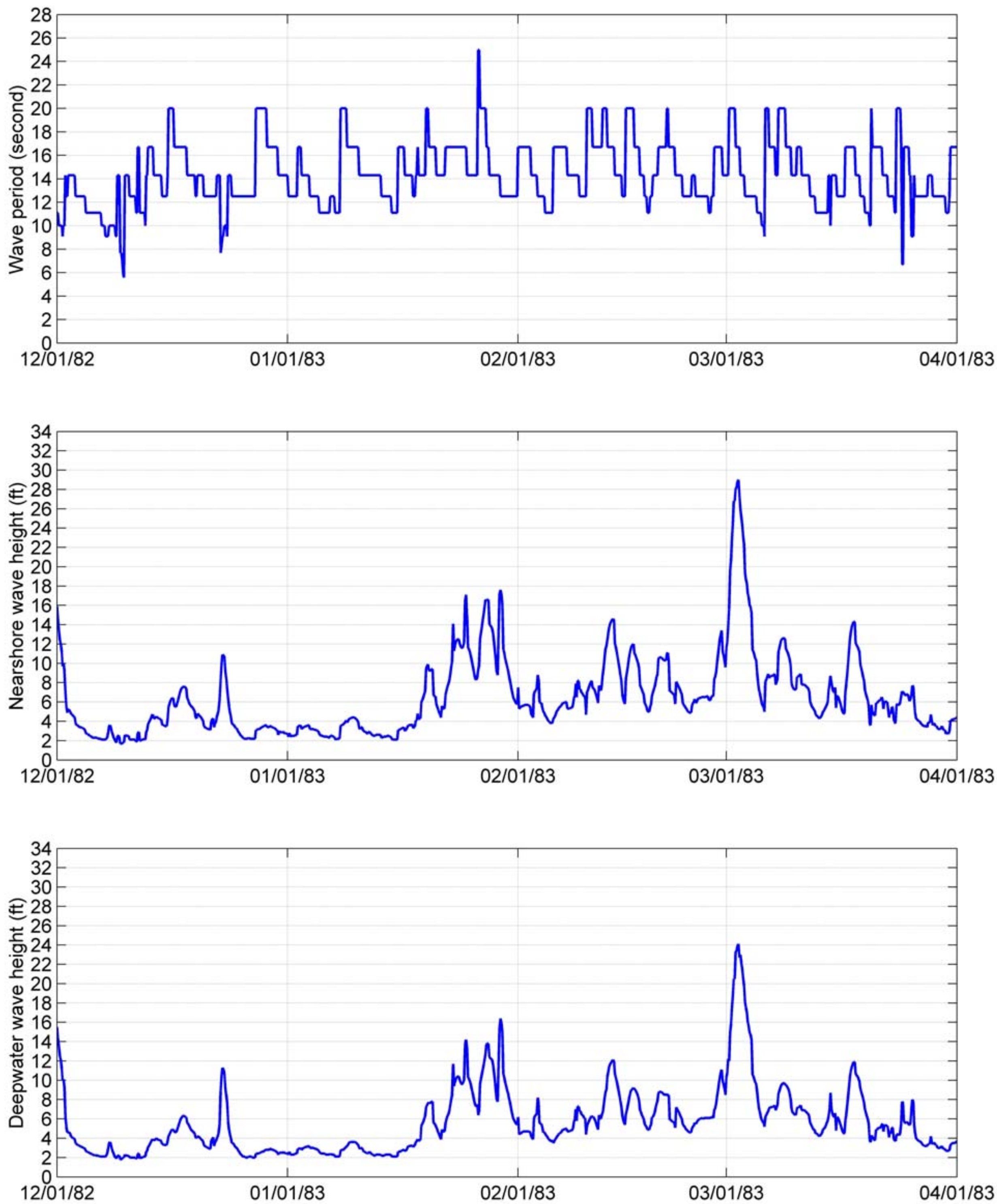


Figure 10. Time Series of Wave Periods and Significant Wave Heights at Hermosa Beach (1982-83 Winter Season)

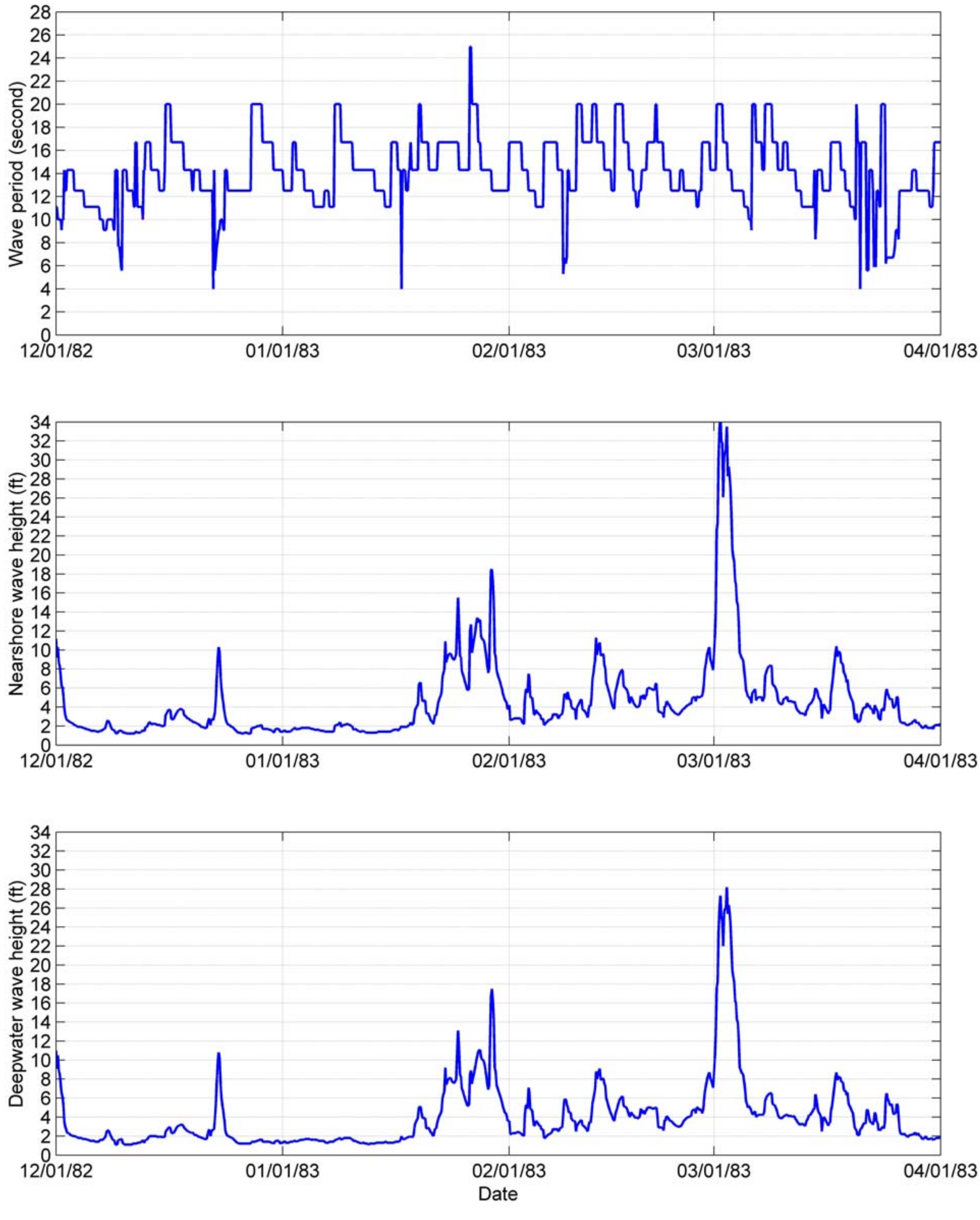


Figure 11. Time Series of Wave Periods and Significant Wave Heights at Dockweiler Beach (1982-83 Winter Season)

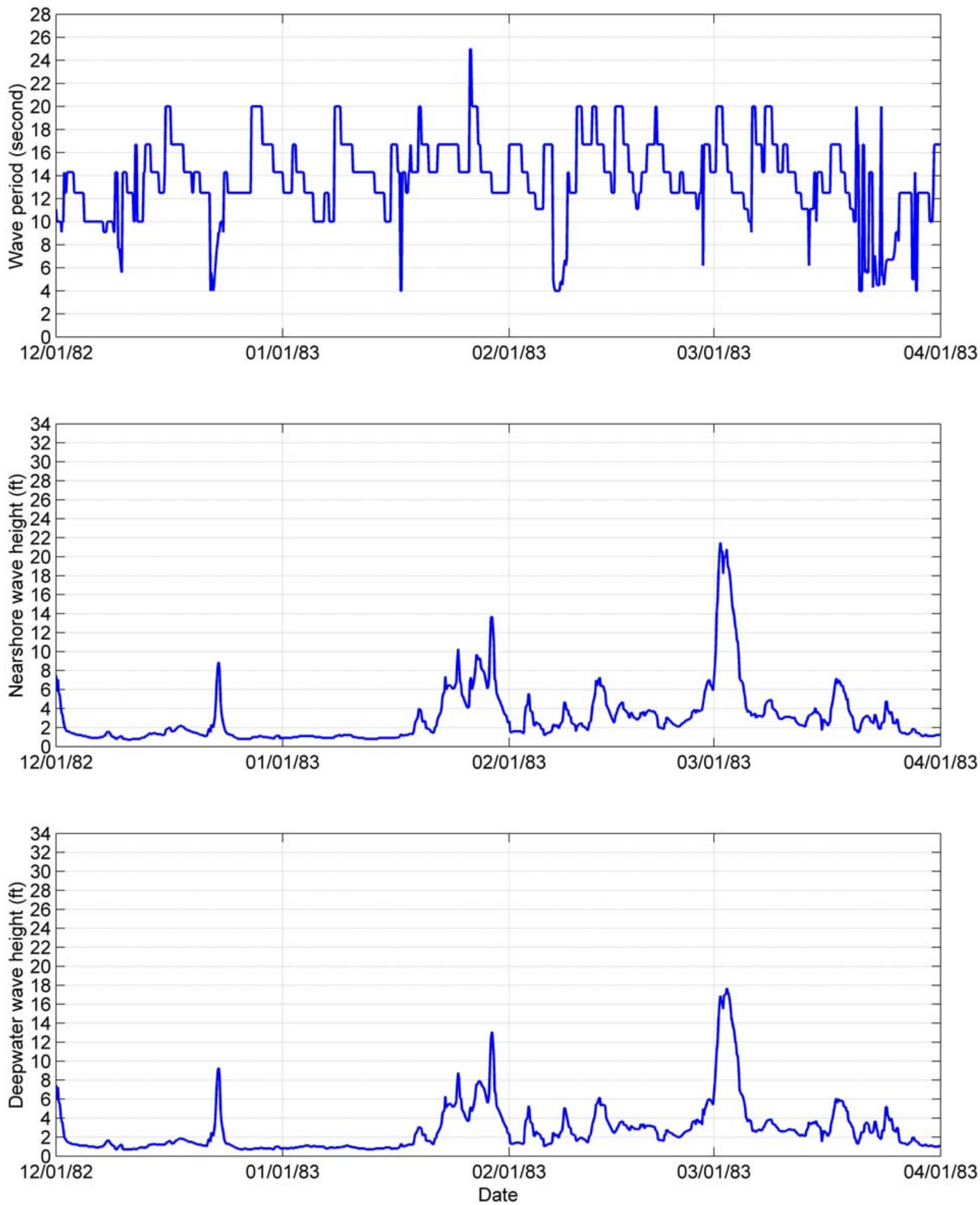


Figure 12. Time Series of Wave Periods and Significant Wave Heights at Venice Beach (1982-83 Winter Season)

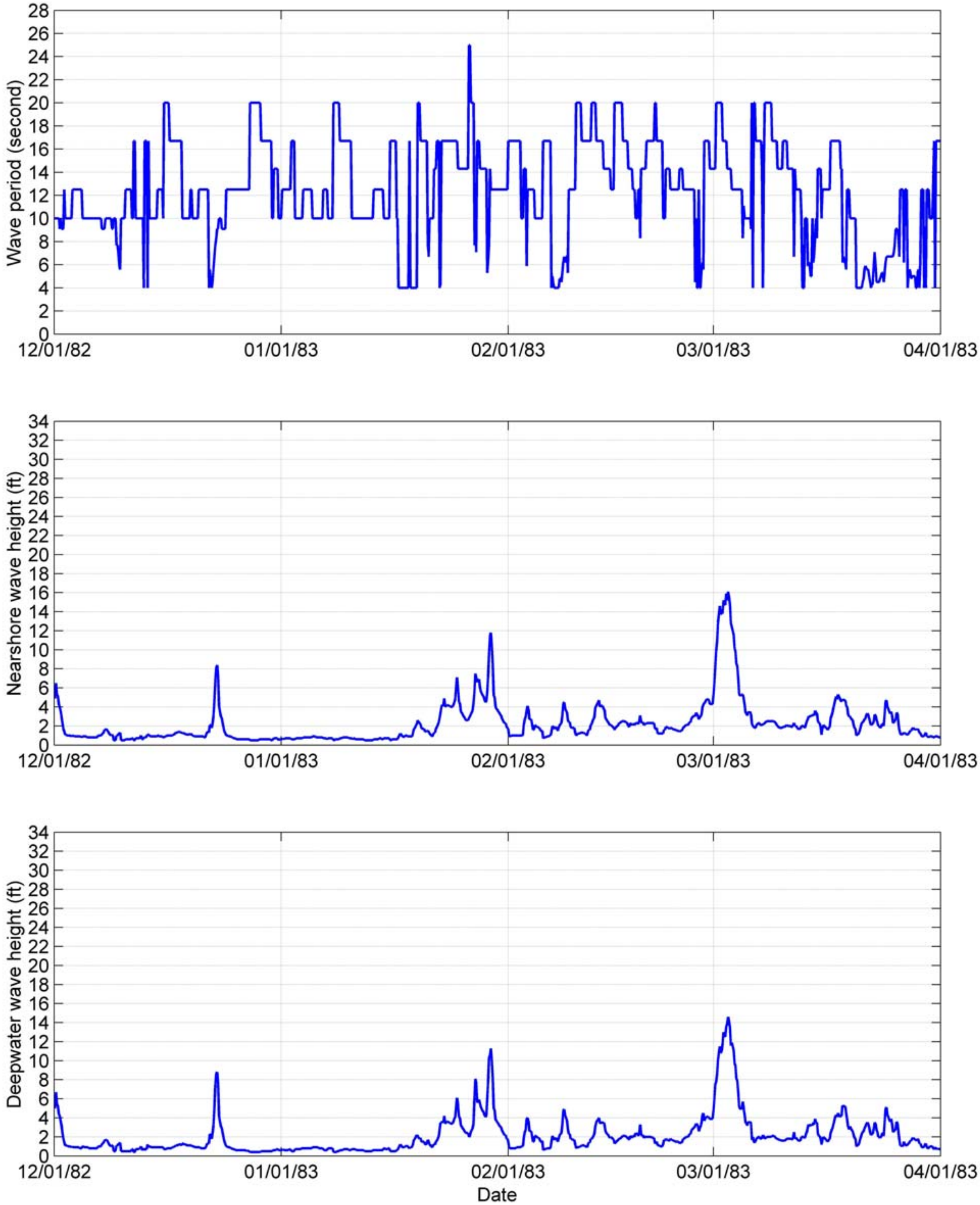


Figure 13. Time Series of Wave Periods and Significant Wave Heights at Zuma Beach (1982-83 Winter Season)

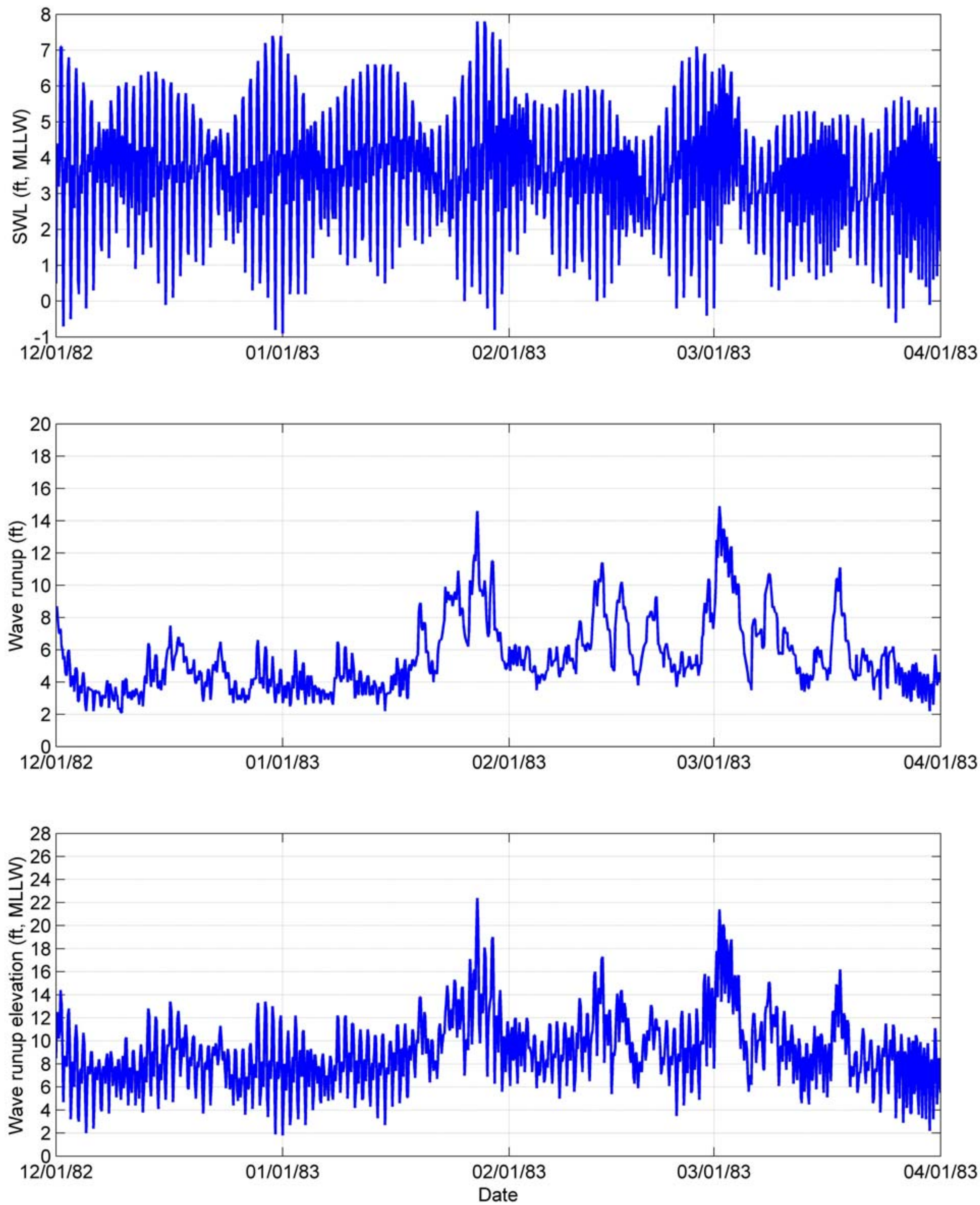


Figure 14. Time Series of Still Water Levels and 10% Wave Runups at Hermosa Beach (With-Berm, 1982-83 Winter Season)

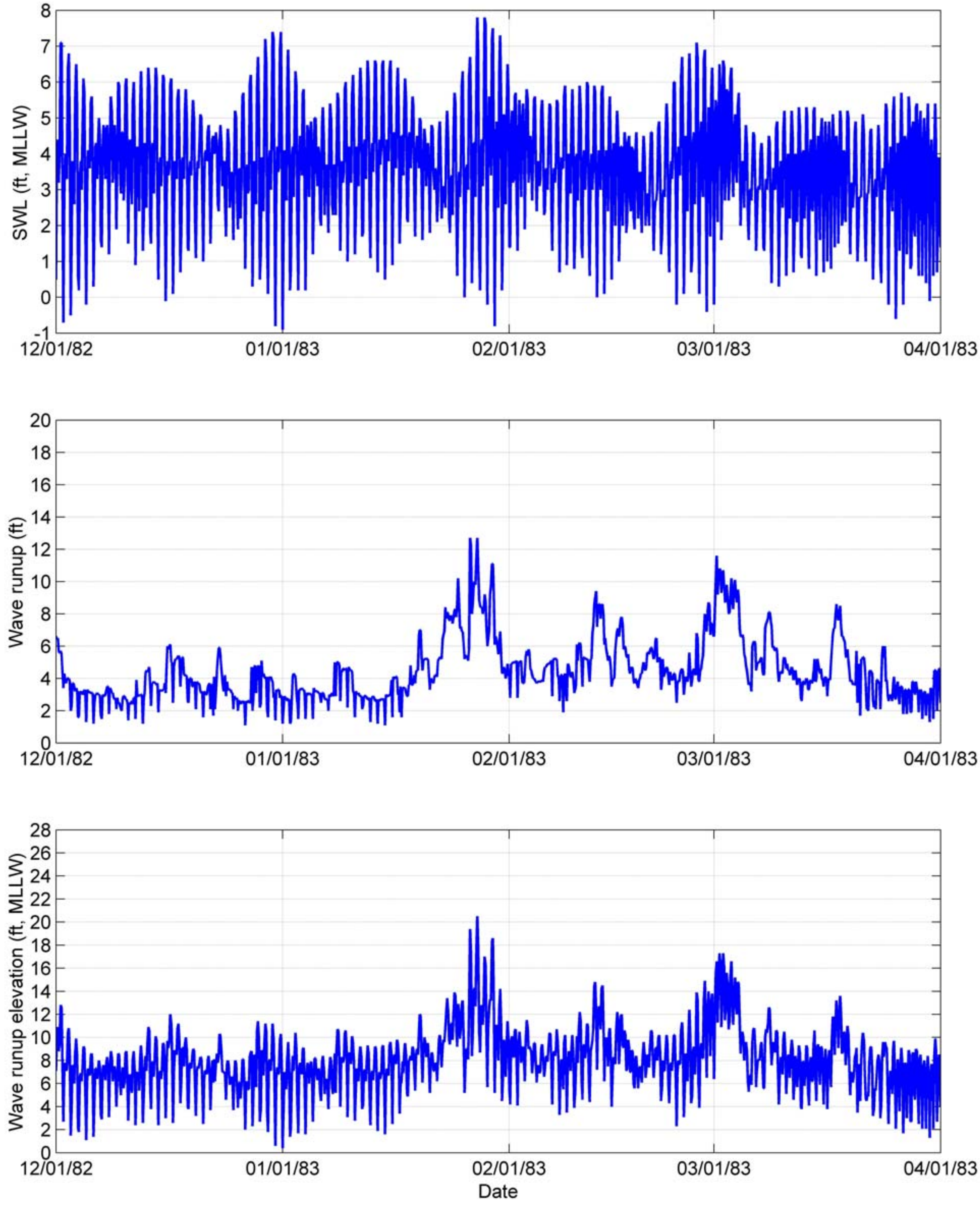


Figure 15. Time Series of Still Water Levels and 10% Wave Runups at Dockweiler Beach (With-Berm, 1982-83 Winter Season)

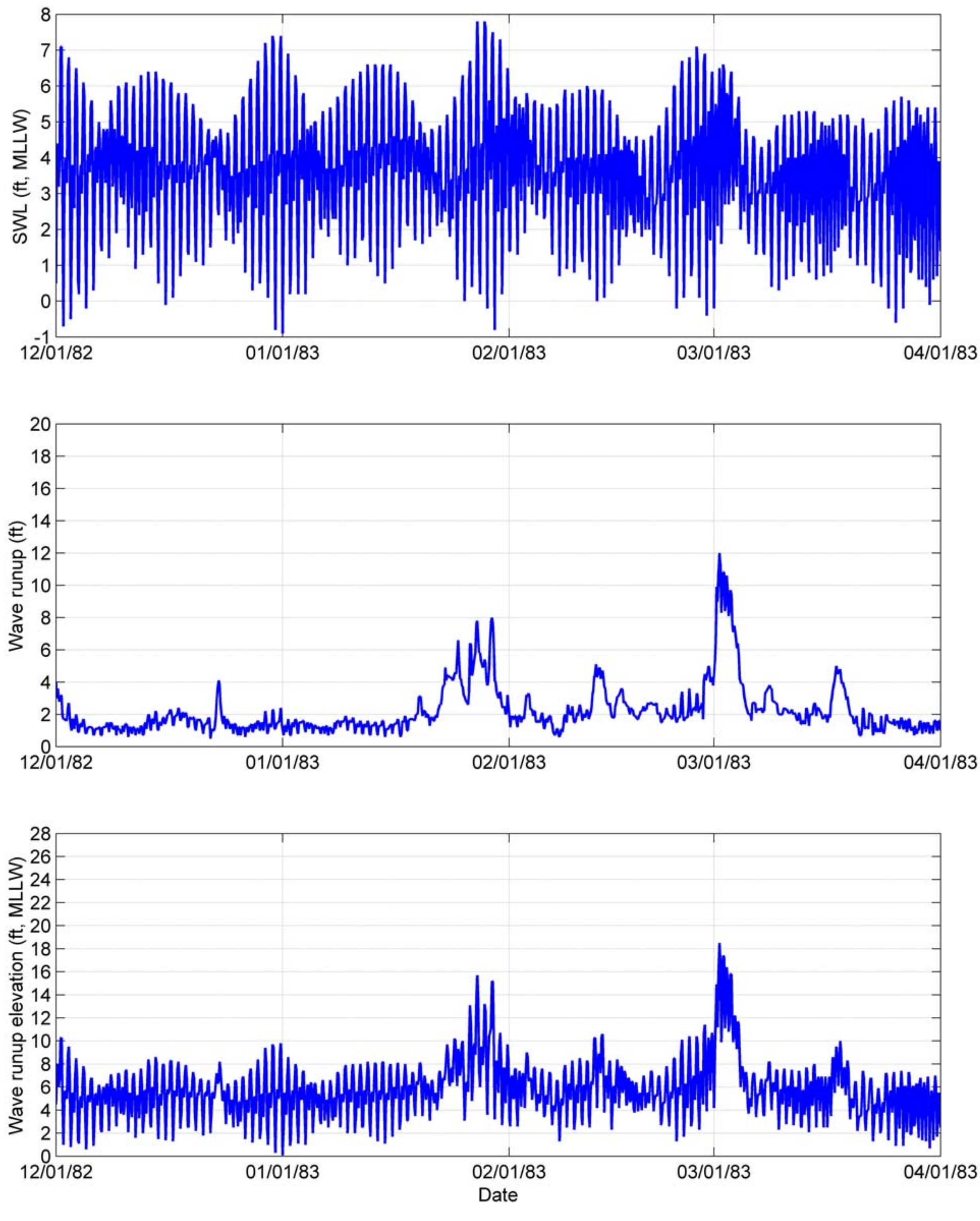


Figure 16. Time Series of Still Water Levels and 10% Wave Runups at Venice Beach (With-Berm, 1982-83 Winter Season)

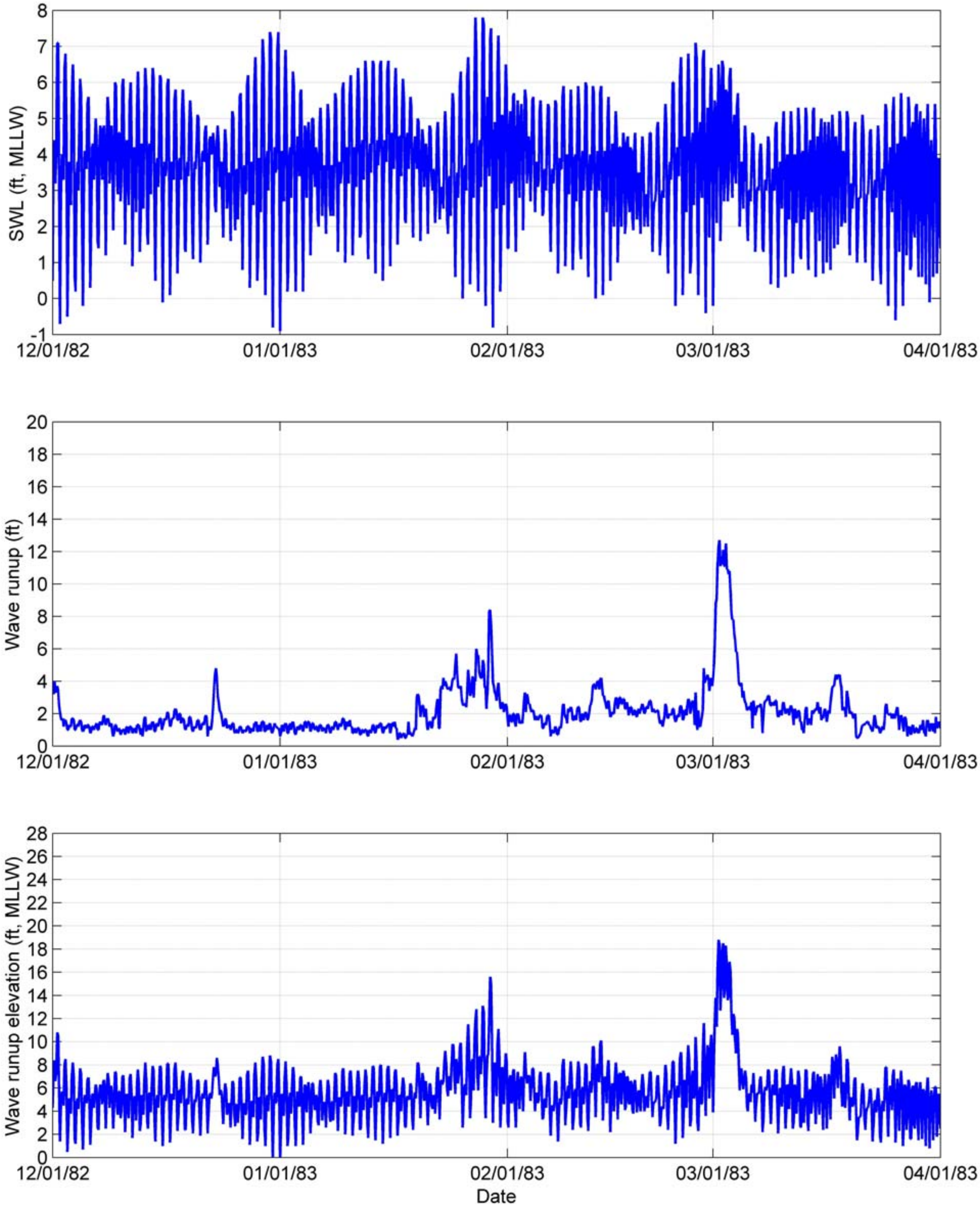


Figure 17. Time Series of Still Water Levels and 10% Wave Runups at Zuma Beach (With-Berm, 1982-83 Winter Season)

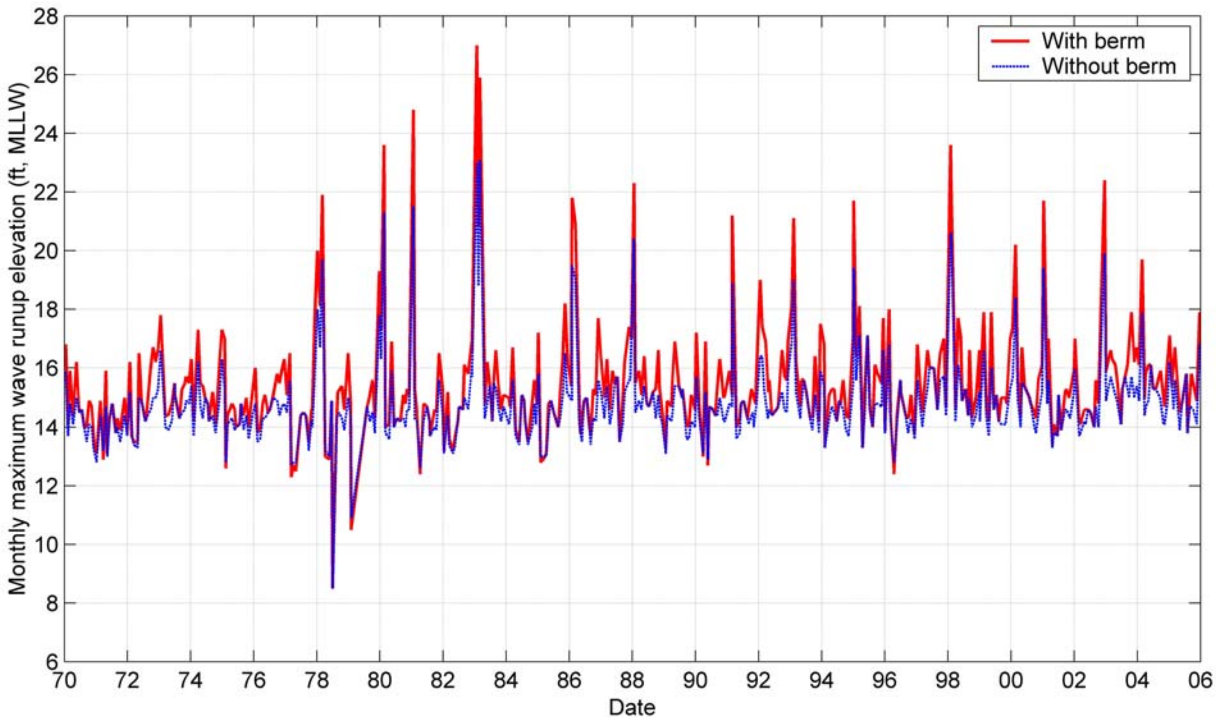


Figure 18. Monthly Maximum 10% Wave Runup Elevations at Hermosa Beach

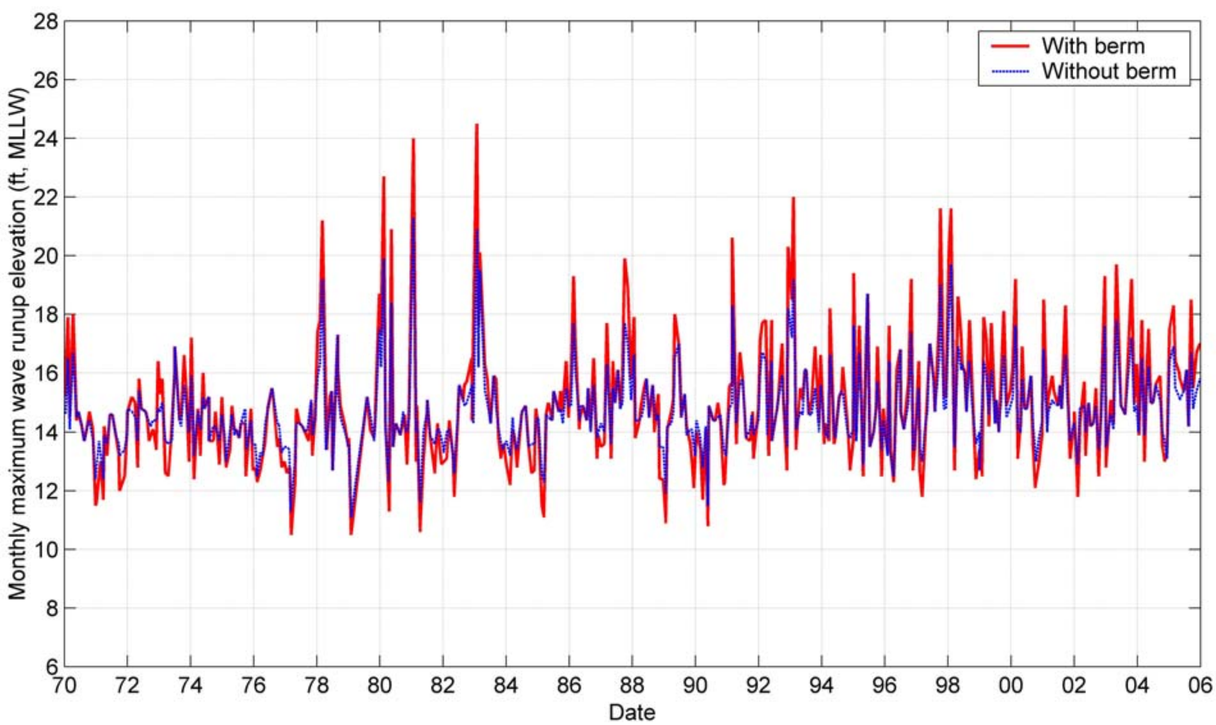


Figure 19. Monthly Maximum 10% Wave Runup Elevations at Dockweiler Beach

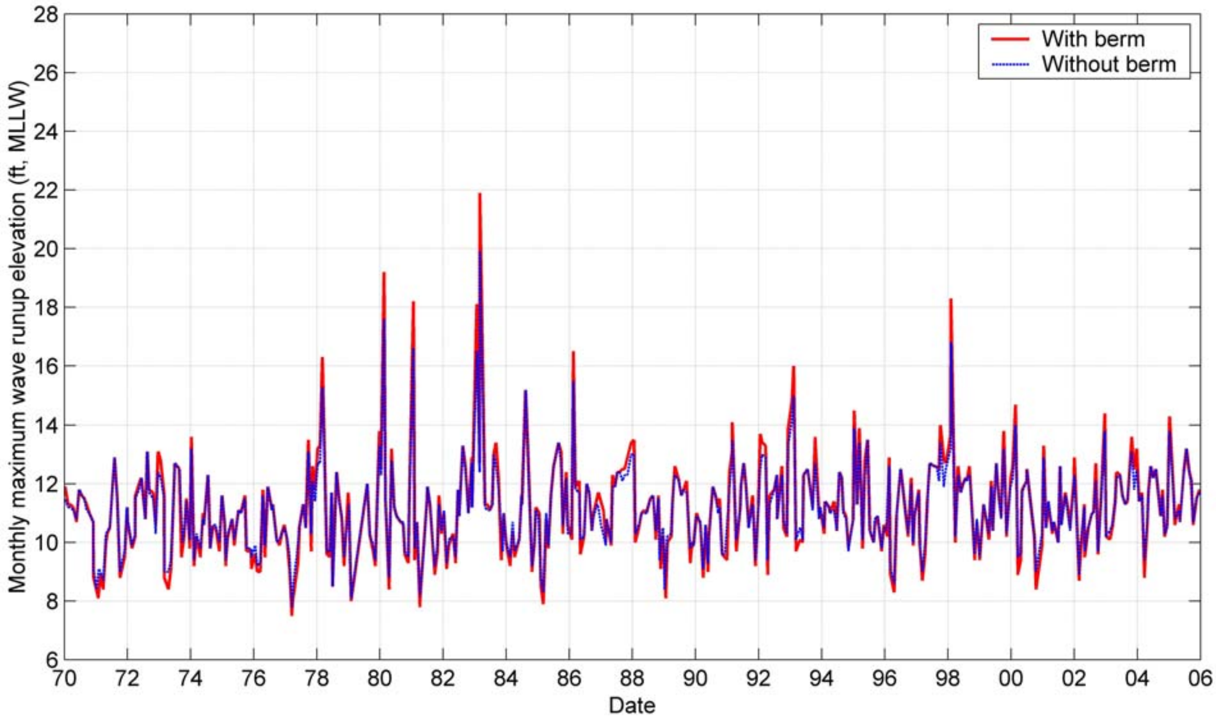


Figure 20. Monthly Maximum 10% Wave Runup Elevations at Venice Beach

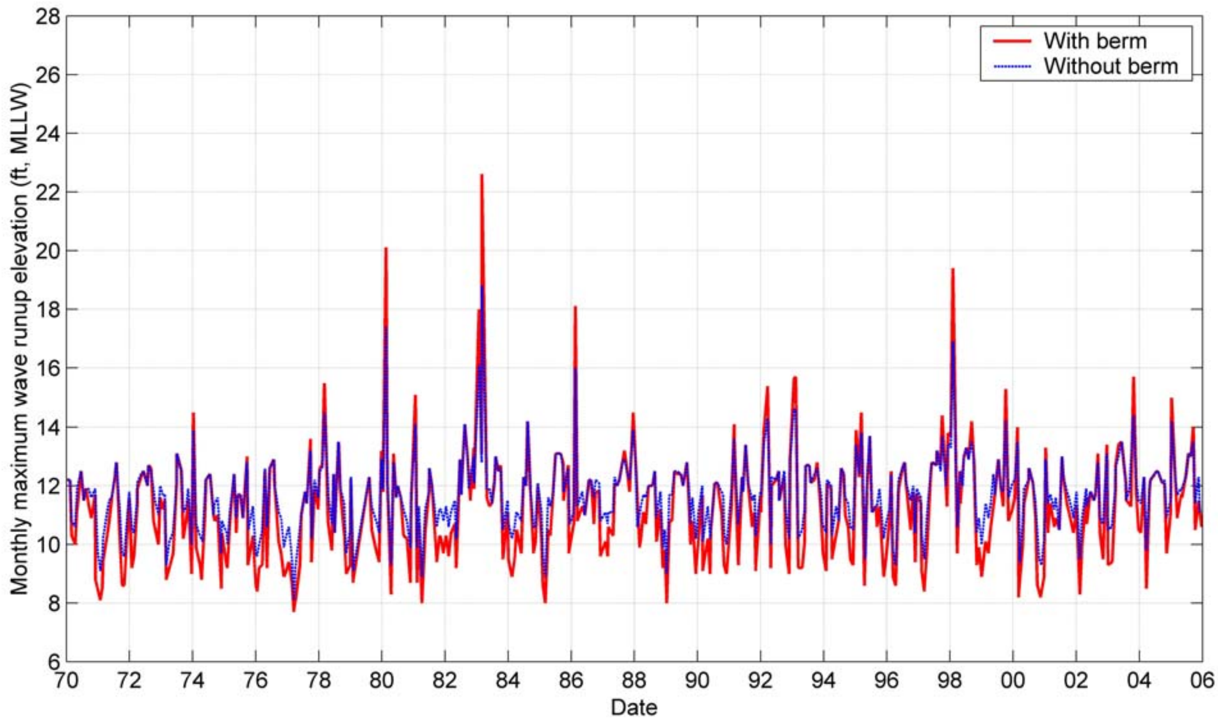


Figure 21. Monthly Maximum 10% Wave Runup Elevations at Zuma Beach

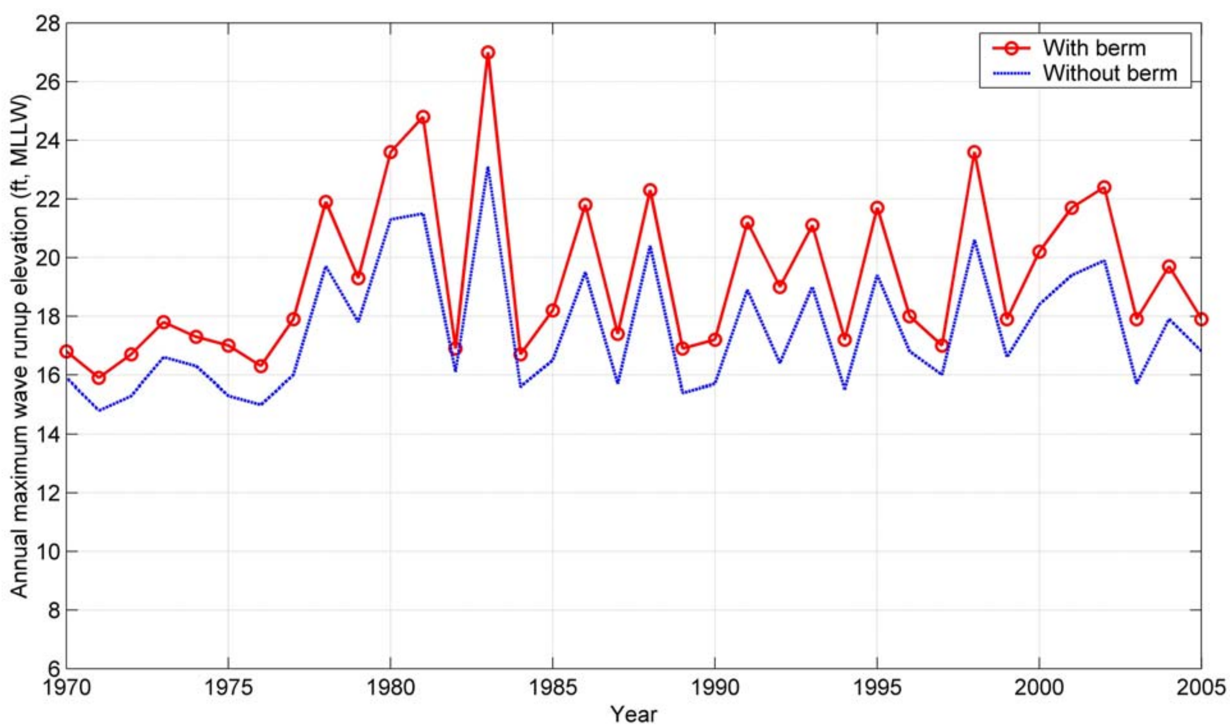


Figure 22. Annual Maximum 10% Wave Runup Elevations at Hermosa Beach

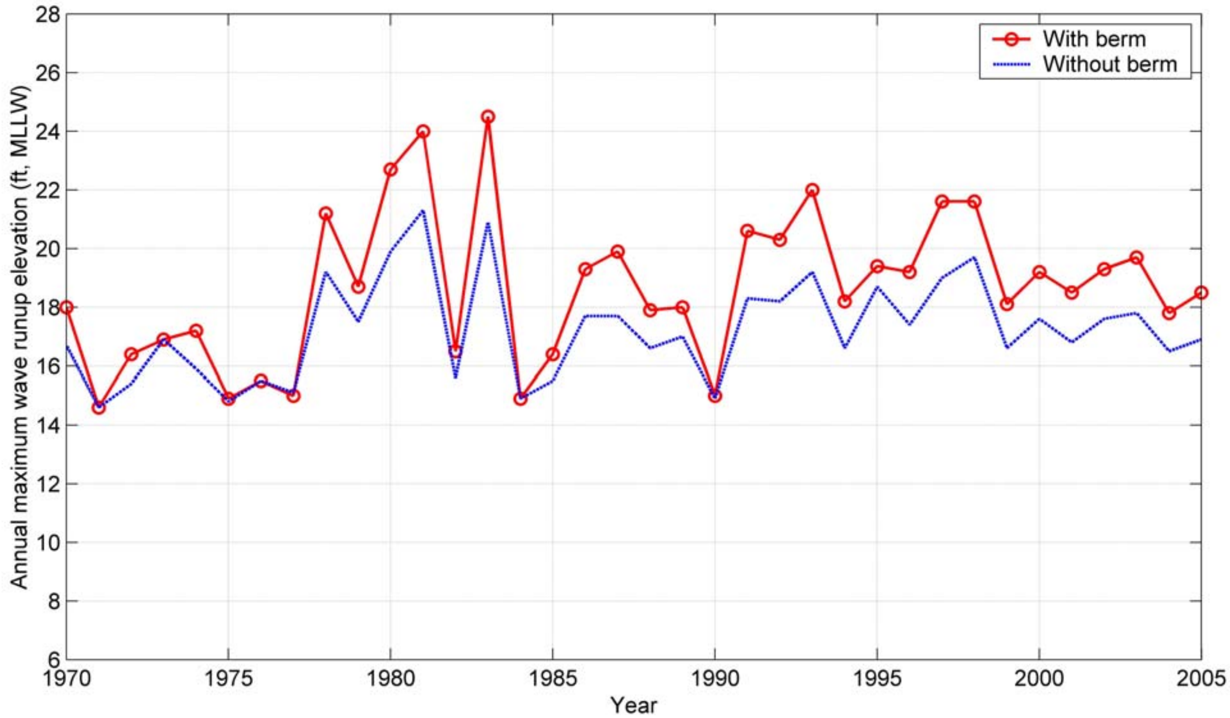


Figure 23. Annual Maximum 10% Wave Runup Elevations at Dockweiler Beach

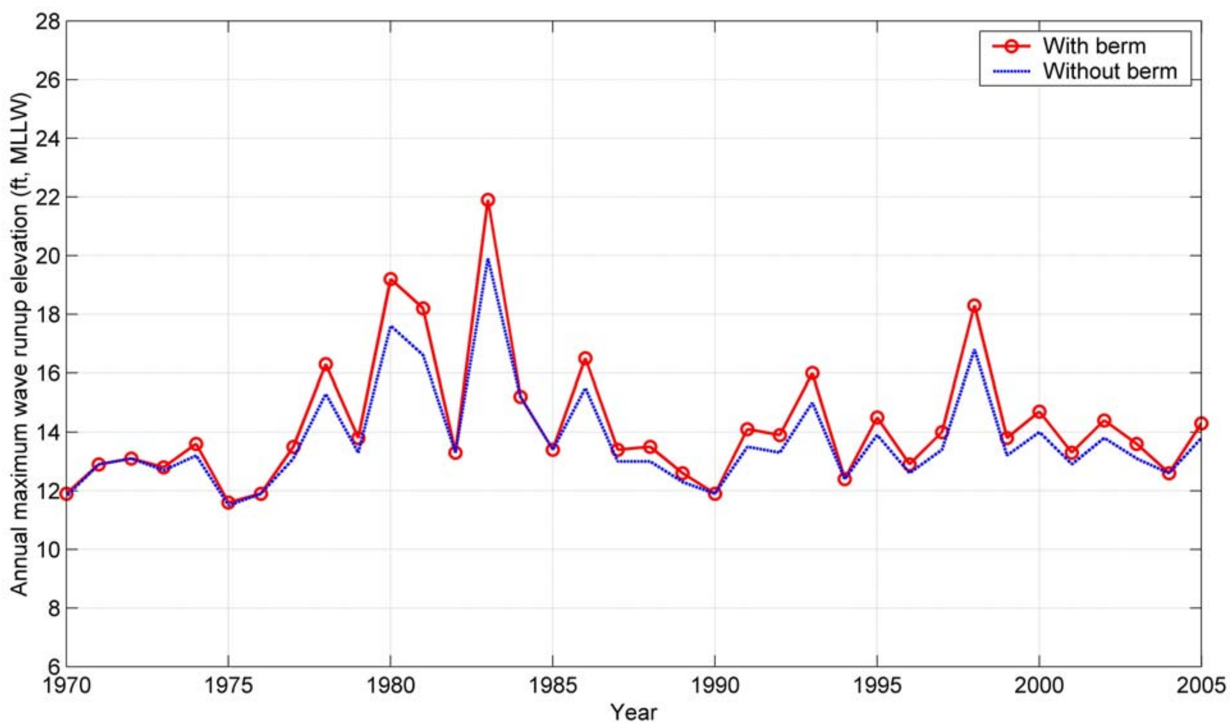


Figure 24. Annual Maximum 10% Wave Runup Elevations at Venice Beach

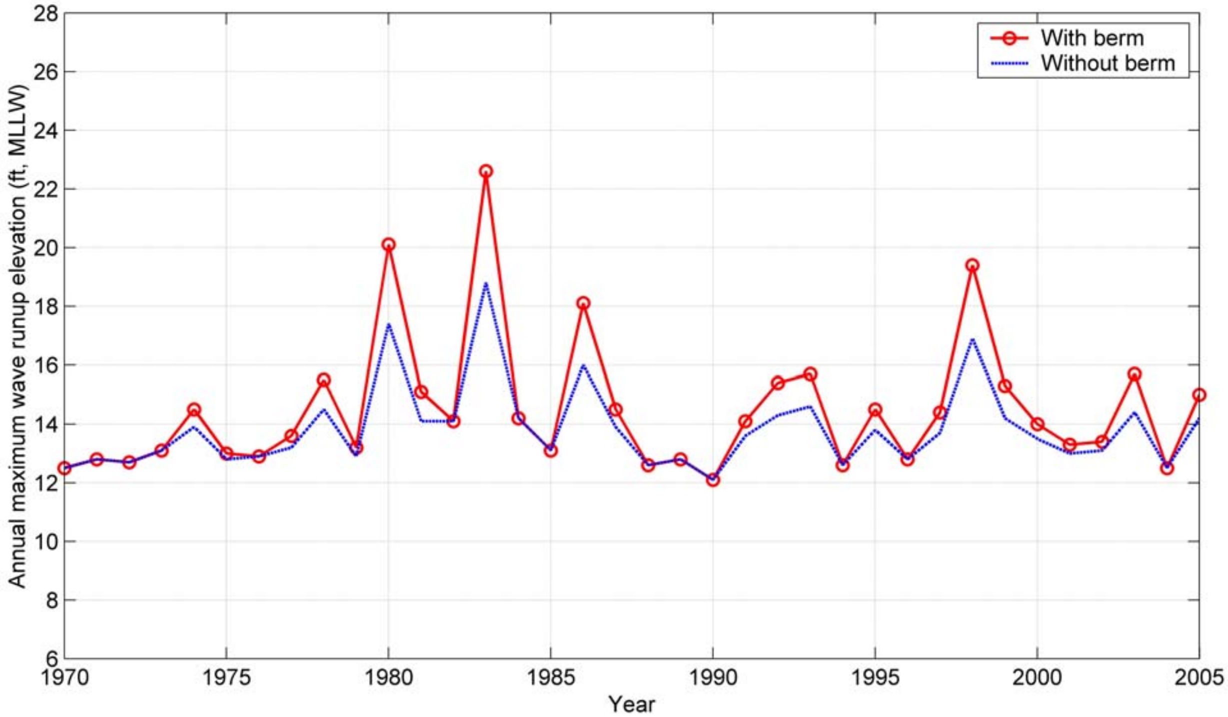


Figure 25. Annual Maximum 10% Wave Runup Elevations at Zuma Beach

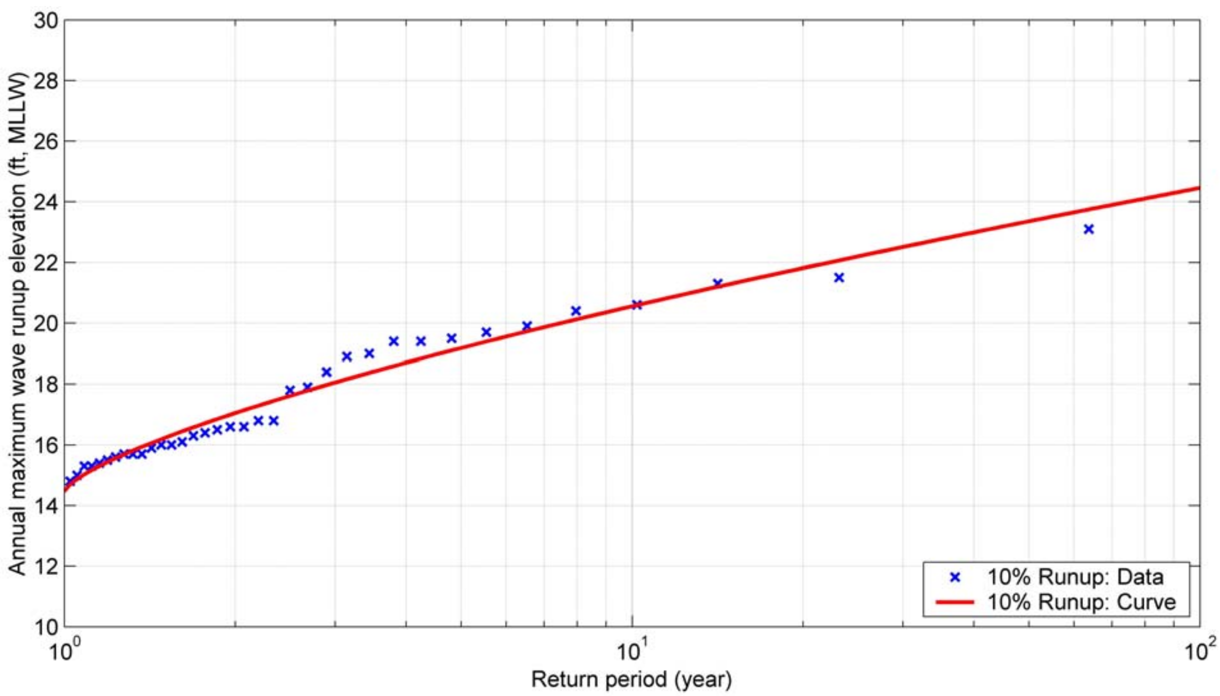


Figure 26. Annual Occurrence Frequency of Wave Runup Elevations at Hermosa Beach (Without Berm)

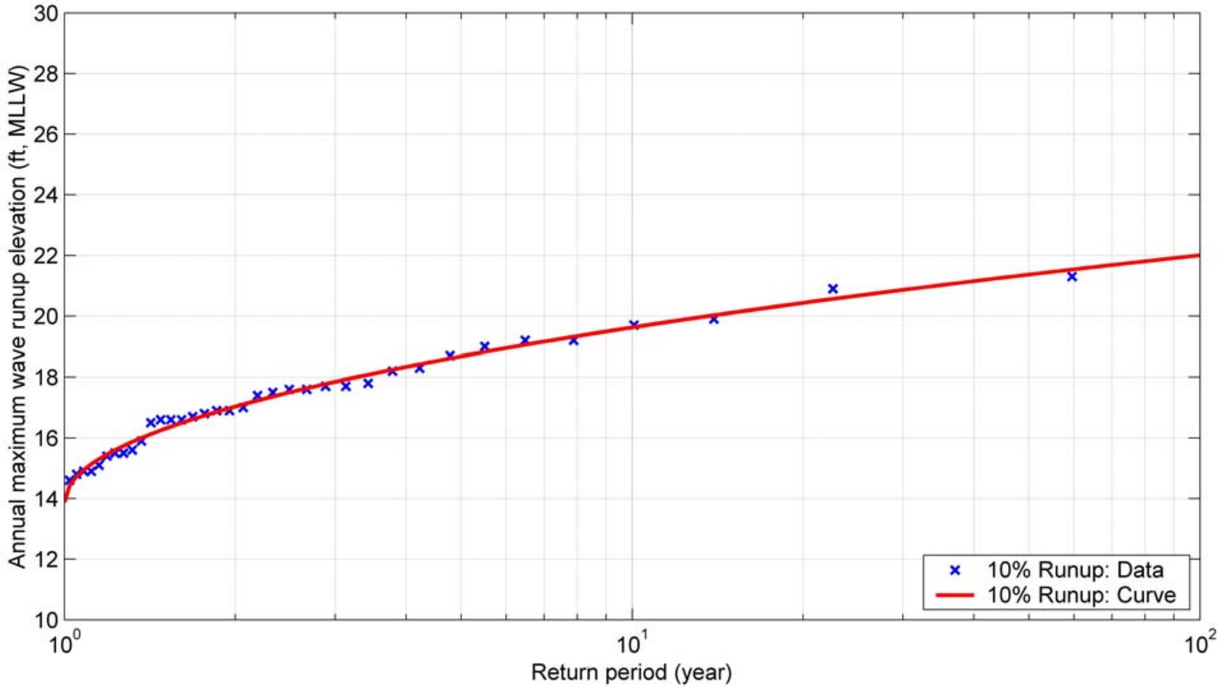


Figure 27. Annual Occurrence Frequency of Wave Runup Elevations at Dockweiler Beach (Without Berm)

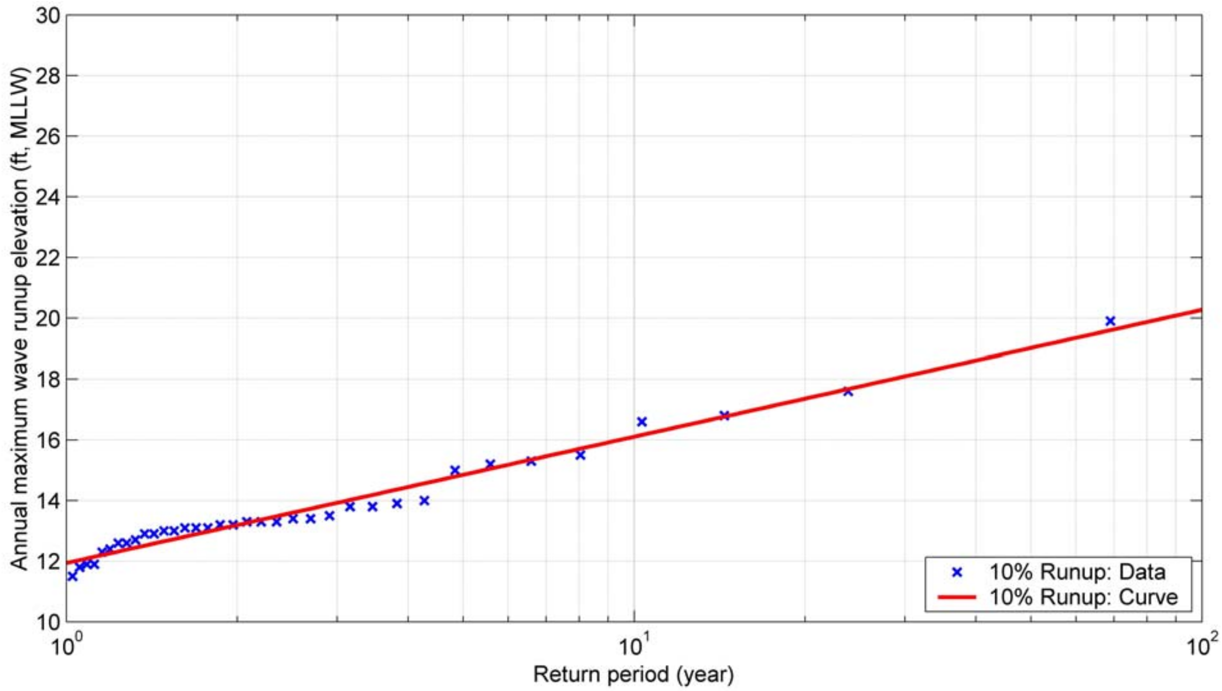


Figure 28. Annual Occurrence Frequency of Wave Runup Elevations at Venice Beach (Without Berm)

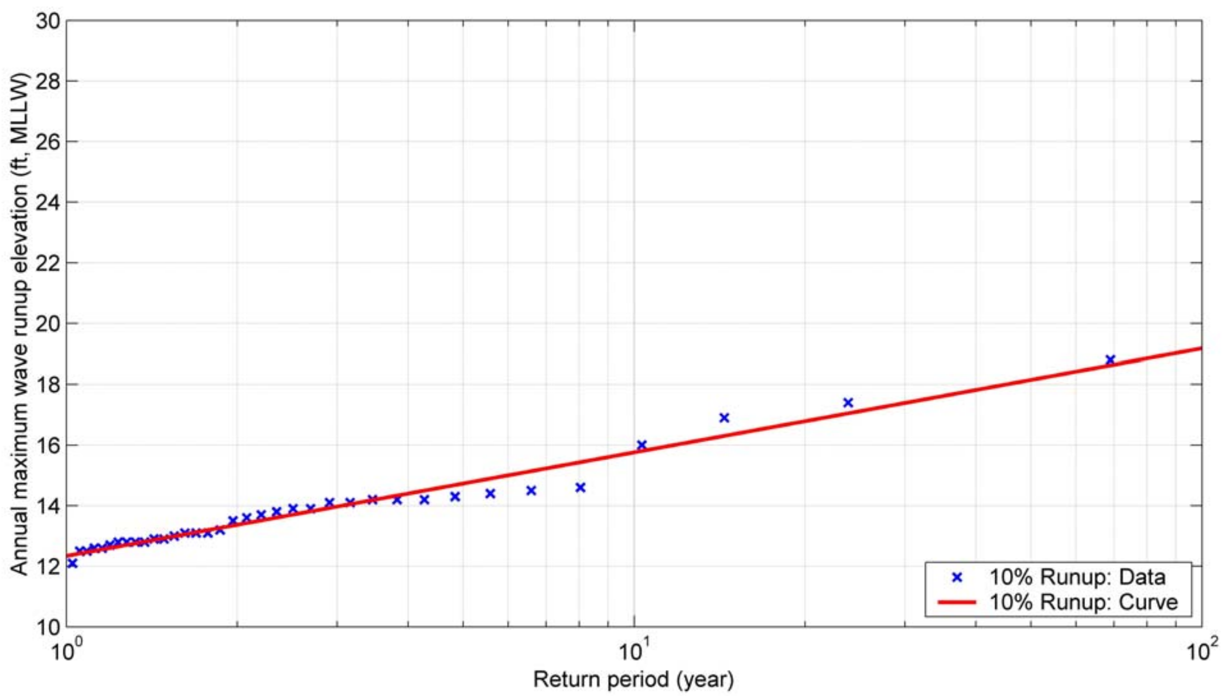


Figure 29. Annual Occurrence Frequency of Wave Runup Elevations at Zuma Beach (Without Berm)

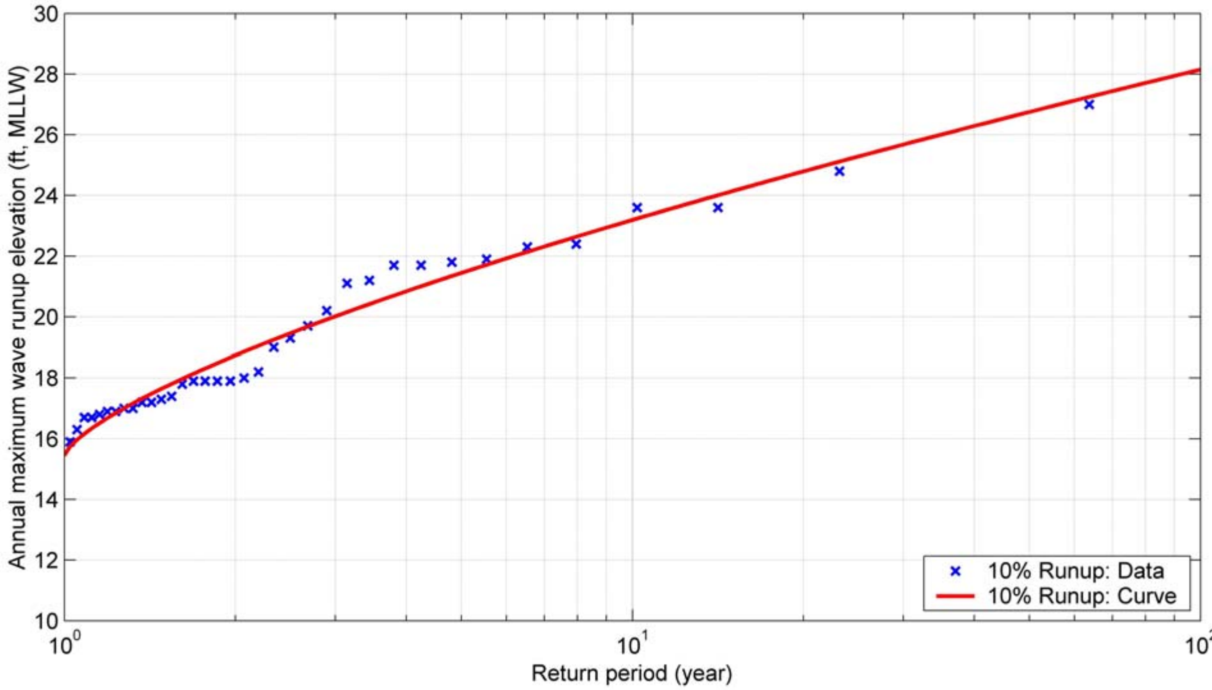


Figure 30. Annual Occurrence Frequency of Wave Runup Elevations at Hermosa Beach (With Berm)

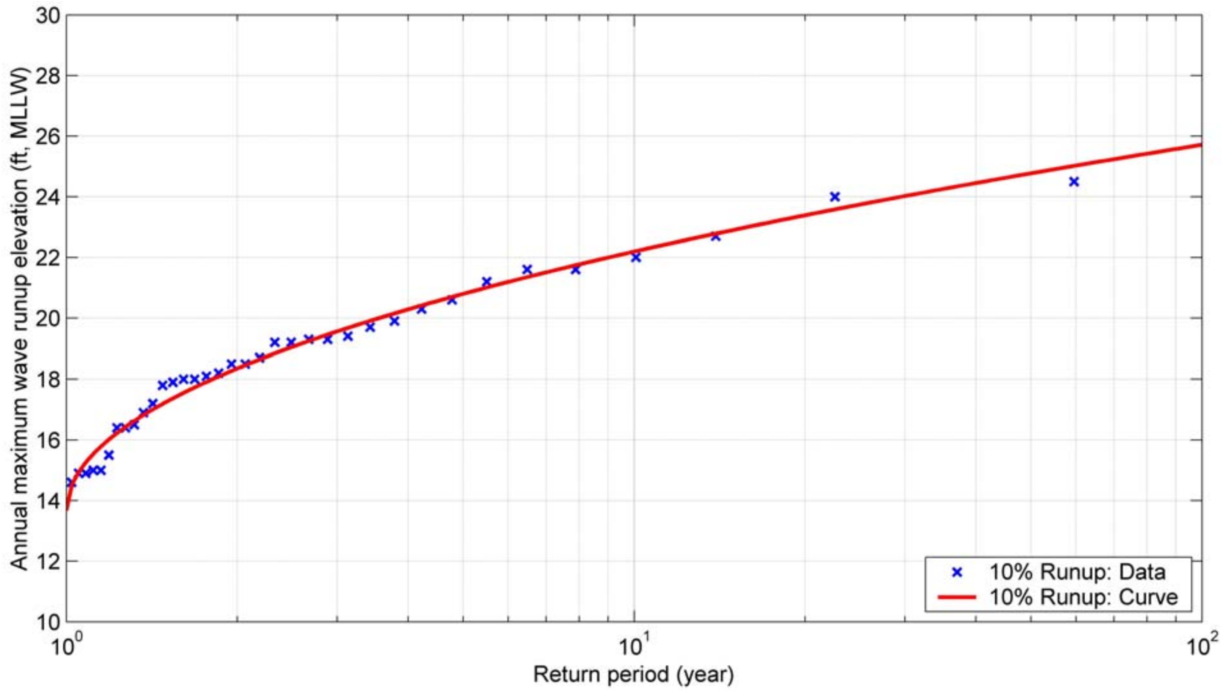


Figure 31. Annual Occurrence Frequency of Wave Runup Elevations at Dockweiler Beach (With Berm)

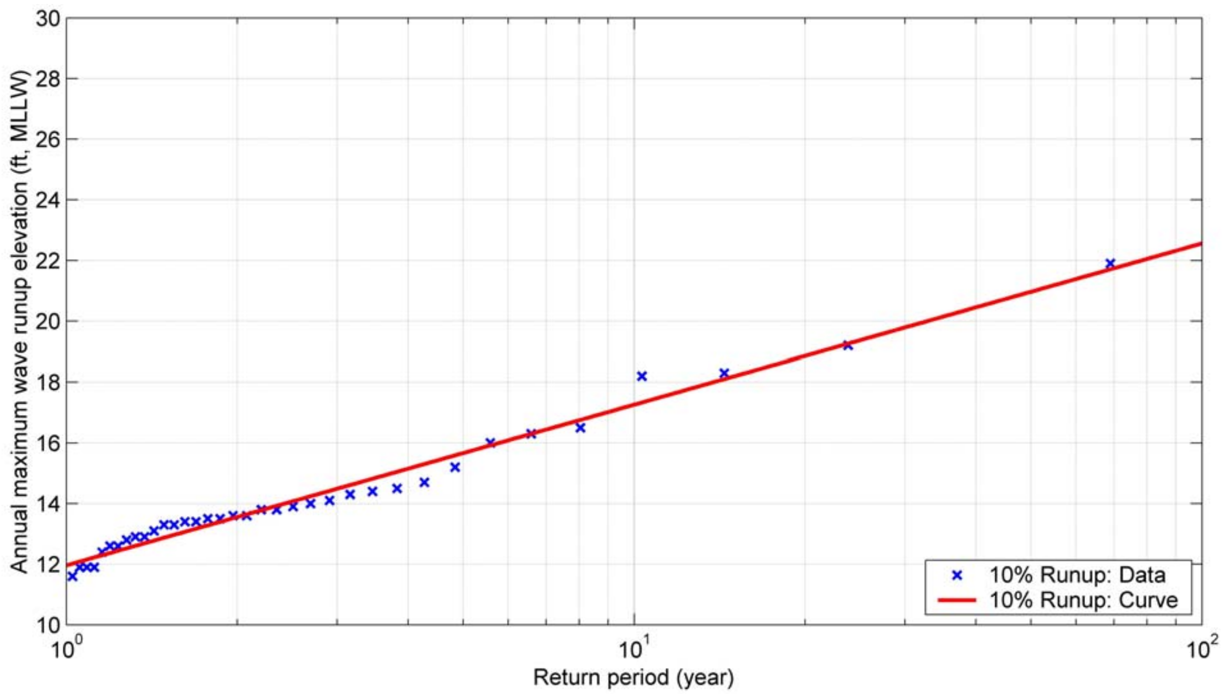


Figure 32. Annual Occurrence Frequency of Wave Runup Elevations at Venice Beach (With Berm)

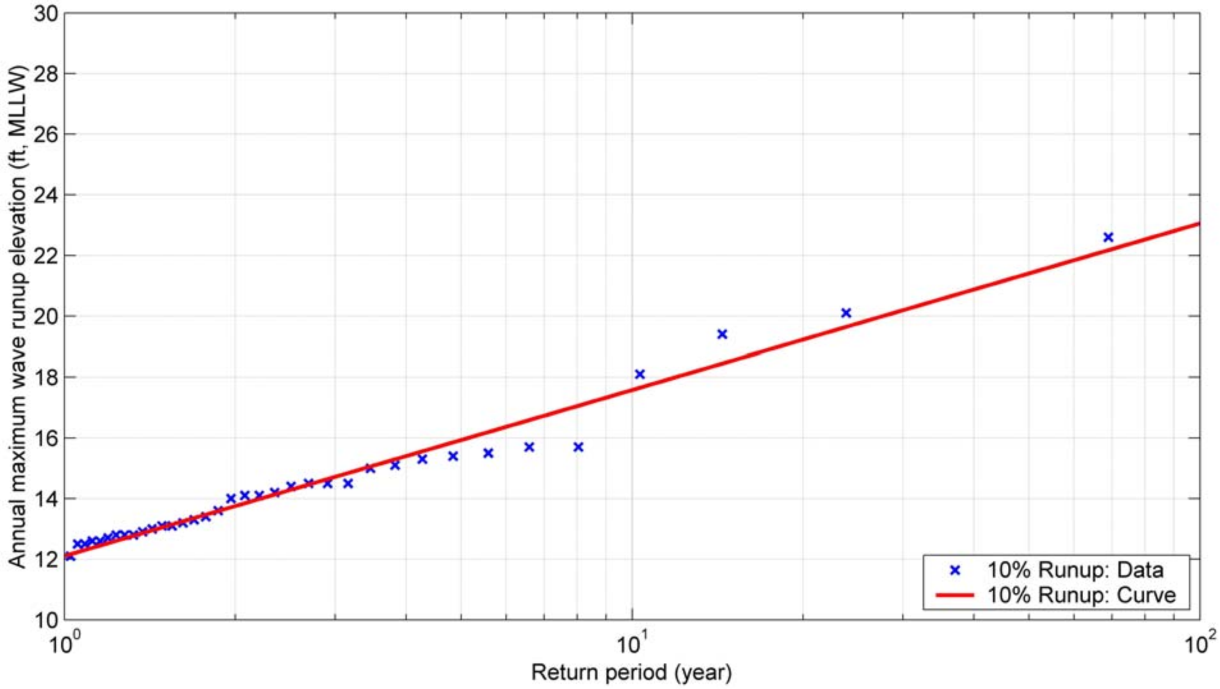


Figure 33. Annual Occurrence Frequency of Wave Runup Elevations at Zuma Beach (With Berm)