Regional AdaptLA:
Coastal Impacts Planning for the Los Angeles Region

Results from the Local Coastal Program Sea Level Rise Grant Program

Executive Summary and Technical Report

Prepared by the University of Southern California Sea Grant Program

University of Southern California

Partners & Funders

Executive Summary Authors/Editors
University of Southern California Sea Grant Program
Phyllis Grifman
Alyssa Newton Mann
Nick Sadrpour

TerraCosta Consulting Group Report Authors
Dr. Reinhard Flick
Dr. Adam Young

Environmental Science Associates Report Authors
James Jackson
Matt Brennan
Bob Battalio

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Table of Contents

Executive Summary

Appendices

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EXECUTIVE SUMMARY

PURPOSE

Regional AdaptLA: Coastal Impacts Planning in the Los Angeles Region is a multi-year project to provide information on the potential impacts of sea level rise to local coastal jurisdictions. In the process, a community of practice on coastal planning is developing in the Los Angeles (L.A.) coastal region. Two science-based projects, developed by the TerraCosta Consulting Group (TCG) and Environmental Science Associates (ESA), modeled shoreline change, coastal erosion and coastal retreat under projected future climate scenarios for the Los Angeles County coast. The University of Southern California (USC) Sea Grant Program has developed this synthesis of the two Regional AdaptLA modeling projects for the benefit of the Regional AdaptLA coalition and stakeholder community. This Executive Summary provides background on the overall project, overviews of the methodologies used to conduct the scientific studies, a summary of major findings, and recommendations for how information provided in these studies can help inform local coastal adaptation planning efforts. This document provides a “bridge” between the technical work by ESA and TCG and the AdaptLA coalition. USC Sea Grant provides capacity building and technical assistance for local jurisdictions as well as coordination among stakeholders and critical government agencies.

For more technical detail, the full reports from the consulting groups can be found at USC Sea Grant’s Regional AdaptLA website: http://dornsife.usc.edu/uscseagrant/adaptla/. A subset of model outputs are available for public access on the Trust for Public Land’s Climate Smart Cities: Los Angeles mapping portal. More information on how to access the portal can be found at the Accessing Information and Results Section.

BACKGROUND

In 2013, Regional AdaptLA, a coalition of coastal municipalities in Los Angeles County, along with a team of support organizations, was established to develop a multisectoral and stakeholder-supported process focused on building capacity for assessing vulnerabilities to coastal change throughout the L.A. region. The goals of this coalition are to strengthen the ability of local jurisdictions to evaluate their vulnerable assets and populations and to begin planning to address the impacts of sea level rise. This coalition was formed following the Sea Level Rise Vulnerability Study conducted by the USC Sea Grant Program in partnership with the City of Los Angeles, which identified the need for regional cooperation in planning for coastal climate impacts.

With leadership from the City of Santa Monica and USC Sea Grant, the region applied for and was awarded $235,000 in state funding from the California Ocean Protection Council (OPC), the Coastal Commission (CCC) and State Coastal Conservancy under the *Local Coastal Program Sea Level Rise Grant* initiative to develop shoreline change and coastal erosion modeling information for Los Angeles County.

As the agent for the coalition of coastal cities in L.A. County, the City of Santa Monica contracted ESA and TCG to develop state-of-the-art shoreline change, coastal erosion and coastal retreat models under projected future climate scenarios for the Los Angeles County coast. Both organizations have extensive experience working with California coastal communities on sea level rise modeling and stakeholder processes. To support The Nature Conservancy's Coastal Resilience project, ESA developed coastal hazard assessments for communities in Ventura, Santa Barbara and Monterey; ESA applied a similar approach in Los Angeles. TCG worked extensively in the San Diego region with the US Navy and was a lead participant in the City of L.A. Sea Level Rise Vulnerability Assessment.

ESA and TCG coordinated throughout the project, and worked closely with the U.S. Geological Survey (USGS) as it developed an updated version of the Coastal Storm Modeling System (CoSMoS 3.0) for Southern California. USGS shared data and outputs, which were utilized by the ESA and TCG teams for the Regional AdaptLA project. USC Sea Grant facilitated coordination, provided technical assistance for local jurisdictions and conducted stakeholder outreach and training.

THE LOS ANGELES COASTAL SETTING

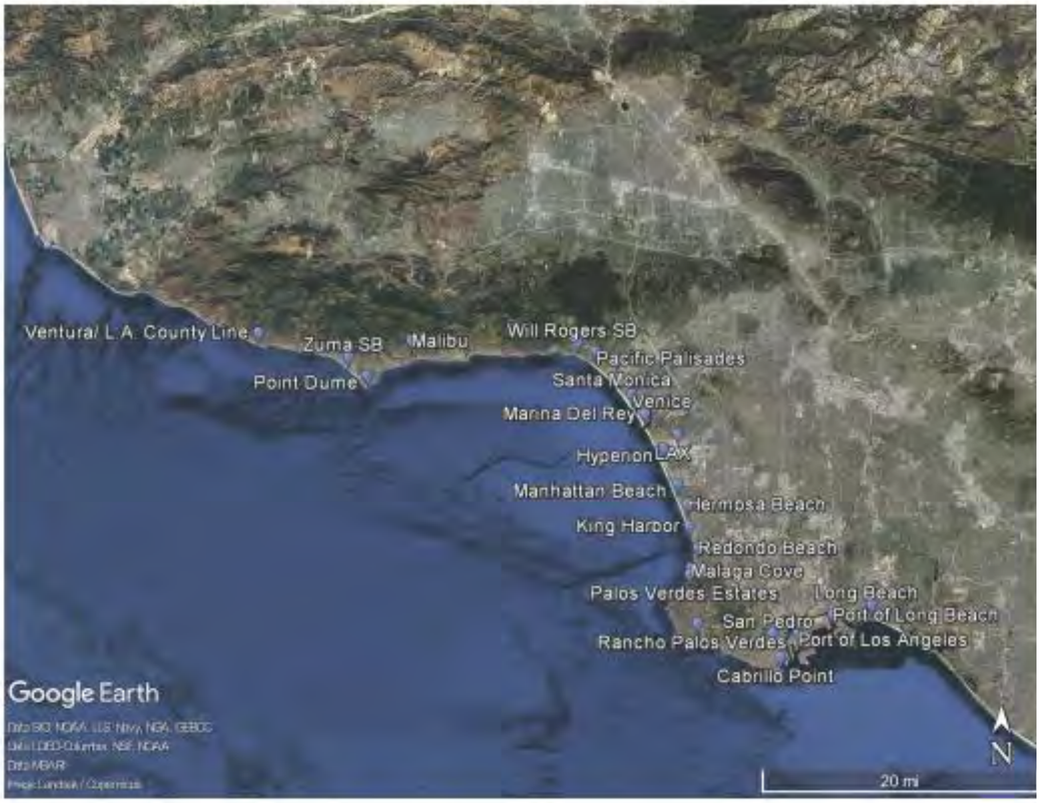


Figure 1. Reference map of Los Angeles County

The L.A. County coast is characterized by a number of distinct coastal subregions. Each subregion has a unique natural setting and a different history of development and human intervention. As a result, each has a distinct suite of current and future coastal problems and different sensitivities to the effects of future sea level rise. Coastal managers will need to consider different adaptation strategies appropriate for the needs, resources, and culture of each region to ensure these areas remain viable.

Malibu to Will Rogers Beach:
The coast from the Ventura County line to Will Rogers State Beach is south-facing, backed with steep hillsides, and sand transport from west to east. Ventura County east to Point Dume is characterized by a series of sea cliffs punctuated by private and public development and a relatively wide state beach at Zuma. East of Point Dume to Will Rogers State Beach, the coastline is dominated by oceanfront homes and the Pacific Coast Highway (PCH), fronting the mountainous coast, and beaches are narrow to non-existent, especially during high tides. This coastal section also features heavily used state and county beaches, such as Will Rogers and Topanga State Beaches. PCH through Malibu and Pacific Palisades is the essential coastal transportation and utility corridor; the only alternate route is Highway 101 located north of the Santa Monica Mountain coastal range. Much of Malibu consists of narrow pocket beaches backed by various shore protection revetments protecting PCH. The extent of existing revetments shows that this reach has in the past and continues to experience episodic erosion that threatens to undermine PCH.

Santa Monica Bay (Will Rogers State Beach to Redondo Beach):
Wider beaches emerge at Will Rogers State Beach and south along the Santa Monica Bay shoreline to Malaga Cove. Will Rogers State Beach is moderately wide owing to a beach groin stabilization system dating from the 1960s. The Santa Monica breakwater located just offshore of Santa Monica pier was built in the 1930s as an unsuccessful attempt to create a small craft harbor, but did lead to a significant increase in beach width and stability. As with the Malibu area beaches, the reach from Santa Monica to Redondo Beach provides major economic benefits from coastal recreation and tourism, boating, and utility and facility siting. These beaches are wide to very wide, largely created by sand supplied as by-products of coastal construction, including Los Angeles International Airport (LAX), Marina Del Rey, and the Hyperion sewage treatment plant. Inland from the Santa Monica Bay beaches, the backshore is comprised of a mix of developed dunes and short cliffs.

Palos Verdes to Long Beach:
The rocky shore stretching around Palos Verdes to Cabrillo Beach and the L.A. Harbor breakwater is comprised of steep eroding cliffs with little to no beach. The peninsula cliff top is heavily urbanized atop a flat coastal terrace that has a 115 ft high sea cliff. The Palos Verdes section of the Peninsula has a long history of geological instability. Most of the peninsula is exposed to the ocean, while the east-facing section is sheltered behind the L.A.-Long Beach outer breakwater, which has its root at Cabrillo Point. The geologic formations at sea level near Cabrillo Point are relatively more resistant to erosion, while there exists more erodible material to the west toward Point Fermin. East of the Port of Long Beach is the Long Beach/Belmont

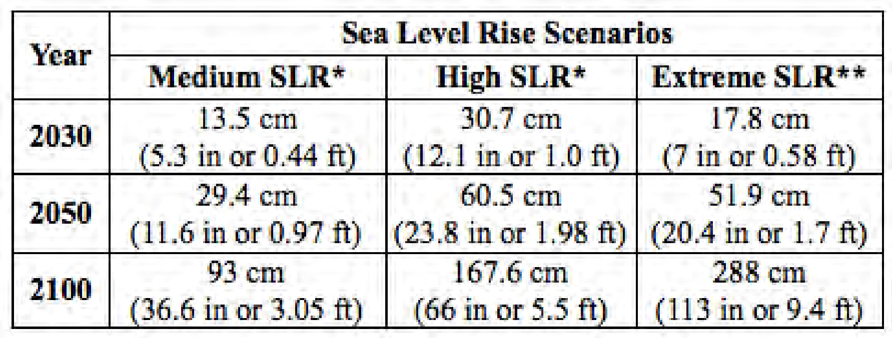
Shore area, which is protected by a breakwater system.

SEA LEVEL RISE SCENARIOS AND STATE OF CALIFORNIA GUIDANCE

To select appropriate and consistent sea level rise scenarios and planning horizons for both projects, the full team met internally on multiple occasions and sought guidance from stakeholders and state representatives from the Ocean Protection Council and California Coastal Commission. Through that process, the team selected planning horizons of 2030, 2050 and 2100, with the medium and high sea level rise projections outlined in the adopted Coastal Commission Sea Level Rise Policy Guidance, which is based on the National Research Council's 2012 study, Sea-Level Rise for the Coasts of California, Oregon and Washington. In addition to these two sea level rise scenarios, the team determined that the study would also address an "extreme" scenario, based on a 2016 study conducted by researchers at the Scripps Institute of Oceanography (SIO) as part of California's ongoing Fourth Climate Assessment (Cayan et al. 2016).

The State of California is also currently updating its guidance to reflect the latest climate change science. This science suggests the rate of ice sheet melting in Antarctica may be greater than previously expected (DeConto and Pollard, 2016, Hansen et al. 2016). While formal guidance from the State has not yet emerged, the project team decided, in close consultation with state agencies, that including discussion of potential higher sea level rise scenarios will be beneficial to local municipalities. The low scenario outlined in the National Research Council's report was not considered in these studies, since the latest science suggests that the low scenario is unlikely given current emissions and sea level rise trends (Pollard et al. 2015, Kopp et al. 2014).

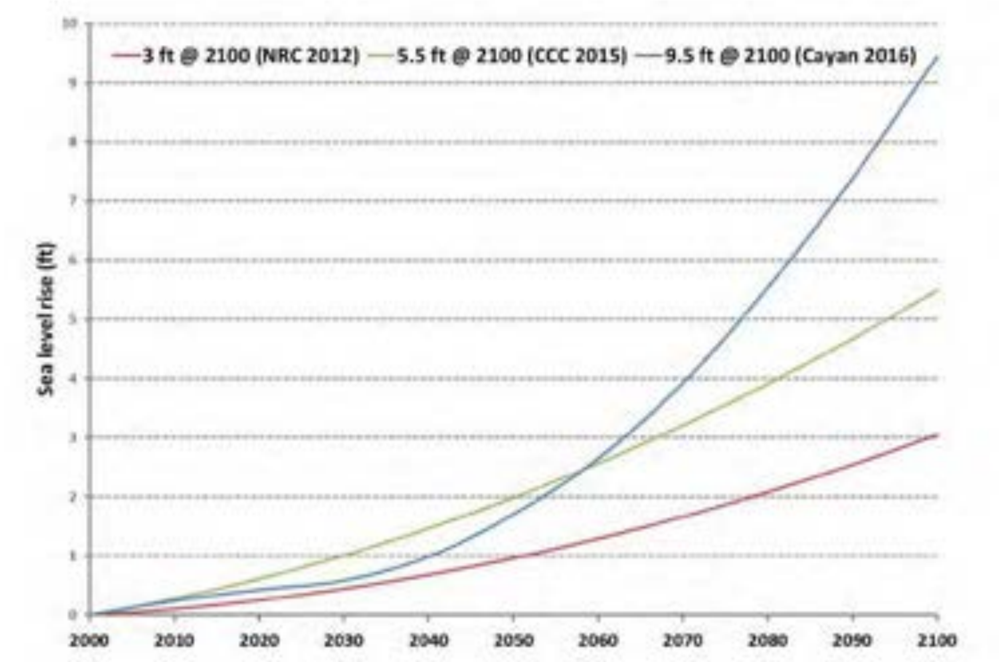
Figure 2, provides an overview of sea level rise projections for the selected planning horizons that were used in both the ESA and TCG studies. These projections are also displayed graphically in Figure 3.



Year	Sea Level Rise Scenarios		
	Medium SLR*	**High SLR***	**Extreme SLR****
2030	13.5 cm (5.3 in or 0.44 ft)	30.7 cm (12.1 in or 1.0 ft)	17.8 cm (7 in or 0.58 ft)
2050	29.4 cm (11.6 in or 0.97 ft)	60.5 cm (23.8 in or 1.98 ft)	51.9 cm (20.4 in or 1.7 ft)
2100	93 cm (36.6 in or 3.05 ft)	167.6 cm (66 in or 5.5 ft)	288 cm (113 in or 9.4 ft)

* Based on projected (for Medium scenario) and upper limit (for High scenarios) values for Los Angeles in Table 5.3 of NRC (2012)
** Based on 99.9th percentile for Representative Concentration Pathway 8.5 from Cayan et al. (2016)

Figure 2. ESA and TCG sea level rise projections.



Source: NRC 2012 Table 5.3; CCC 2015 Equation B3; Cayan 2016.

Figure 3. Sea level rise scenario projections (red=medium, green=high) used in the coastal change modeling and (blue=extreme) used only for discussion purposes (see ESA report).

SUMMARY OF METHODOLOGIES

Due to the science developed as part of the Regional AdaptLA program, coastal municipalities now have access to a suite of sophisticated and complementary sea level rise, coastal storm, shoreline evolution and coastal hazard projections. This work has been conducted by USGS, ESA and TCG. While detailed technical reports are available, below we provide a high level overview of the modeling methodologies.

ESA assessed flooding hazards along the entire Los Angeles County coastline and erosion hazards along the entire L.A. County coastline except the Ports of Los Angeles and Long Beach, because of the heavily managed nature of shoreline within the ports. The TCG study modeled shoreline change projections for the coastal reach from Point Dume in Malibu to Malaga Cove in Redondo Beach.

<u>USGS Coastal Storm Modeling System (CoSMoS)</u>

The USGS has conducted a sea level rise, coastal storm and shoreline evolution modeling study for all of Southern California, including L.A. County, through the update of its Coastal Storm Modeling System (CoSMoS 3.0). ESA and TCG used the USGS modeled hindcast (1980-2011) and forecast (2012-2100) wave and water level predictions at nearshore locations (USGS model output points) at three-hour time intervals as forcing for their modeling. The shoreline results from the CoSMoS modeling effort are not described in this executive summary. Please see the Accessing Information and Results Section for more information.

ESA: Coastal Hazard Assessments

Figure 4. ESA's Study Area: This study assessed coastal hazards from the Ventura-Los Angeles County border to the Los Angeles-Orange County border, excluding the Ports of Los Angeles and Long Beach.

ESA developed a suite of products that provide coastal hazard assessments for a 65-mile stretch of the Los Angeles coastline (Figure 4). The methods were developed to support a statewide study of shore response to sea level rise (Revell et al. 2011). The methods have been improved as described in a series of technical reports for applications to Ventura County, Santa Barbara County, Monterey Bay and Los Angeles County (Battalio et al. 2016). The ESA analysis included four hazard zone components defined below:

- ***Sandy Shoreline Erosion Hazard Zones***: These zones represent future long-term and storm-induced sandy "dune" and beach shoreline erosion hazard zones. Model results incorporate site-specific historic trends in erosion, additional erosion caused by accelerating sea level rise, and (in the case of the "storm erosion hazard zones") the potential erosion impact of a large storm wave event. The inland extents of the hazard zones represent projections of the future crest of the dunes or shoreline position for a given sea level rise scenario and planning horizon.

- ***Cliff Erosion Hazard Zones:*** These zones represent cliff erosion hazard zones between the existing cliff edge and the projected future cliff edge. These results are derived by incorporating site-specific historic trends in erosion, additional erosion caused by accelerating sea level rise, and margin of tolerance to account for longshore variability in cliff erosion rates. The inland extent of the hazard zone represents the future cliff edge projected for each planning horizon and future scenario. Where beaches front cliffs, the beach changes were also modeled and associated hazard zones were mapped (see *Sandy Shore Erosion Hazard Zones*, above).

- ***Coastal Storm Flood Hazard Zones:*** These hazard zones depict flooding that may be caused by a coastal storm and considers a suite of coastal processes, with these processes exacerbated by future sea level rise. These hazard zones do not consider upland fluvial (river) flooding and local rain/run-off drainage, which likely play a large part in coastal flooding, especially around coastal confluences where the creeks meet the ocean. The processes included in the hazard zones are:

    1. Elevated ocean levels due to climate effects (e.g. elevated water levels during El Niño phases) and storm surge (a rise in the ocean water level caused primarily by winds and pressure changes during a storm).
    2. Wave runup, including wave setup and waves running up over the beach and coastal property (calculated using the computed 100-year total water levels).
    3. Extreme lagoon water levels, which can occur when lagoons fill up when the mouths are closed (using maximum potential beach berm elevations).

- ***Extreme Monthly Tidal Flooding Hazard Zones:*** These zones show the area and depth of flooding caused by the effect of rising sea level on the astronomic tides (not considering storms, erosion, or river discharge). The water level mapped in these flooding areas is the Extreme Monthly High Water (EMHW) level, which is a high water level that is occurs approximately once a month. These zones do not, however, consider coastal erosion or wave overtopping, which may increase the extent and depth of regular tidal flooding in the future.

For each section of coast, ESA mapped lines indicating the shoreline (i.e., the waterline) and the backshore (where the beach meets coastal structures such as roads or structures). The margin between the shoreline and backshore line delineates the width of the beach. However, the erosion hazard zones are primarily organized by sandy shoreline and cliff edge, as described above. Two future sea level rise scenarios (medium and high) were assessed at 2030, 2050, and 2100 for each type of hazard. In addition, an extreme scenario was considered, where the projection for 2080 is equivalent to the projection for the high scenario at 2100 (see Figure 3).

TCG: L.A. Region Shoreline Change Projections

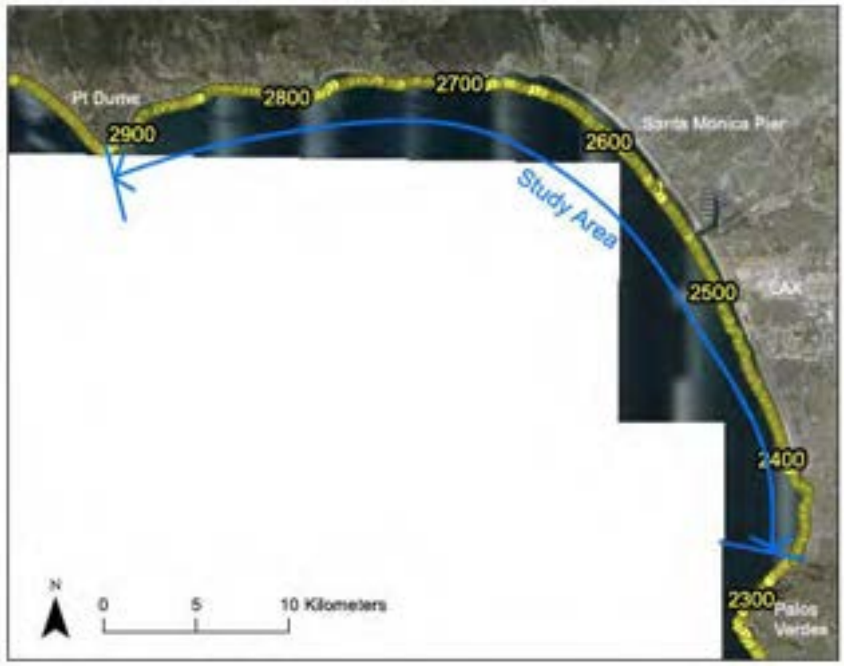


Figure 5. TCG's Study Area: This study modeled shoreline change projections and was geographically limited to the coastal reach from Point Dume in Malibu to Malaga Cove in Redondo Beach. Yellow dots represent model output point

TCG modeled projected coastal change to year 2100 relative to 2000 for a range of mean sea level rise scenarios consistent with the current but evolving State of California guidance (see above) and the sea level rise scenarios utilized by ESA. TCG modeled both short-term wave-driven future shoreline position changes as well as long-term sea level rise-driven future shoreline changes from Point Dume to Malaga Cove, Redondo Beach (Figure 5).

- ***Short-term Wave-driven Shoreline Position Change:*** On the California coast, short-term (day-to-day to seasonal duration) shoreline position changes are driven by wave conditions. Two directions of sand transport are important: cross-shore and longshore. Both of these processes were modeled separately using existing techniques published in the peer-reviewed scientific literature and described in the technical report. TCG modeled 1) time series of daily shoreline position changes associated with short-term wave-driven cross-shore sand transport, and 2) time series of longshore sand transport.

- ***Long-term Sea Level Rise-Driven Future Shoreline Position Change:*** Changes in long-term (100-year) shoreline position were estimated using the Conditionally Decoupled Profile Model (Young et al., 2014), which estimates shoreline retreat considering sea level rise using a sand balance approach. The model conditionally accounts for beach and backshore retreat to occur while maintaining coastal system sand equilibrium.

Spatial Aggregation of ESA and TCG Modeling Results

A set of simple layers were developed to easily visualize the range of hazard outcomes from all of ESA's and TCG's scenarios, a total of 38 scenarios. Existing conditions and all planning horizons (2030, 2050, 2100) hazard zones were overlaid to identify a location's hazard exposure to any coastal hazard type. The level of hazard was quantified by counting the number of hazards to which a location is exposed. This process of overlaying and counting the number of overlapping hazards is called "spatial aggregation," and is shown conceptually in Figure 6.

From ESA's analysis, the spatial aggregation includes:
- Erosion hazards (long-term, event)
- Integrated coastal flood hazard (combined 100-year ocean water level, wave run-up, and lagoon beach berm)
- Extreme monthly tidal inundation hazard for existing conditions (2010)
- Medium and high sea level rise scenarios for 2030, 2050, 2100
- Extreme sea level rise scenario at 2080

From TCG's shoreline position analysis, the spatial aggregation includes:
- Medium and high sea level scenarios for 2030, 2050, and 2100

An example of the spatially aggregated output is shown in Figure 7.

These spatially aggregated layers do not, by any means, contain the complete range of possible future scenarios, and none of the scenarios presented are associated with a particular probability of future occurrence (which requires complex statistical approaches given the large range of uncertainty associated with projections of sea level rise). This is simply a way to visualize the full range of scenarios and hazards assessed and to understand qualitatively how projected future hazards vary (e.g. if a site is hazardous regardless of the scenario, or whether the site is only hazardous for the most extreme scenarios).

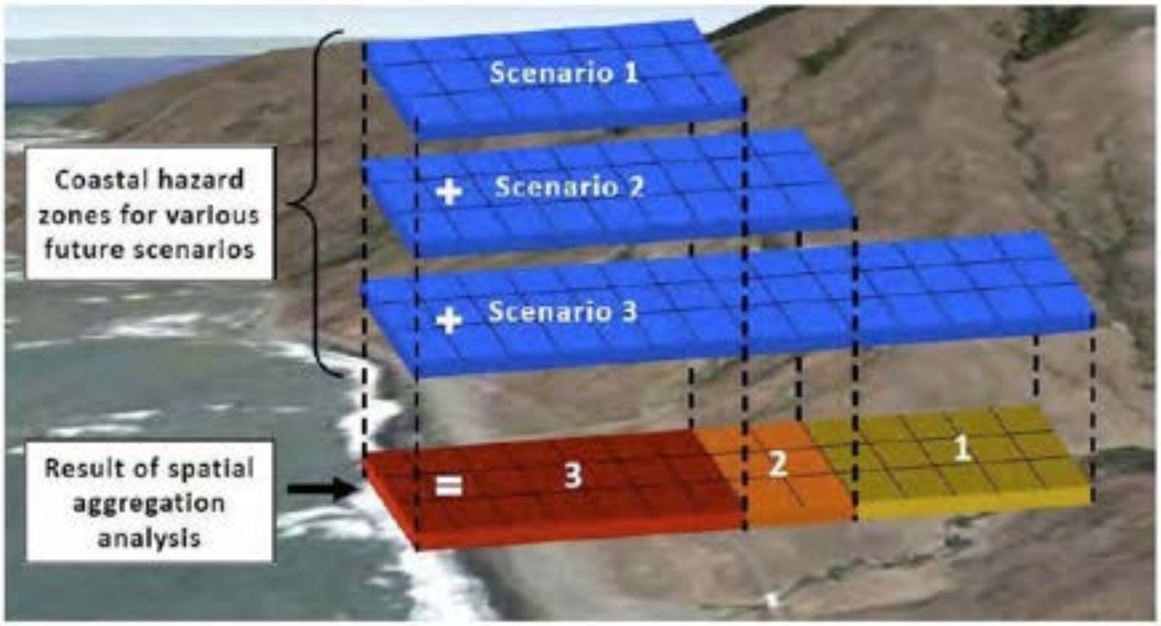


Figure 6: Schematic of how hazard zones are overlaid to provide a composite assessment of how hazardous a given location could be. This process is called "spatial aggregation".

Figure 7: An example of the spatial aggregation map for the northern stretch of Santa Monica. Warmer colors (reds, oranges, yellows) indicate areas where most of the model projections overlap, indicating these locations are most "hazardous," or most vulnerable to coastal erosion and flooding.

SUMMARY OF FINDINGS

Shoreline Change Projections - Major Findings:

- ESA's and TCG's shoreline change projections show similarity of hazard extents across the suite of scenarios.
- Owing to the relatively wide and stable existing beaches, troublesome levels of modeled beach retreat are unlikely to occur before 2050 in and south of Santa Monica, even when the high 1.67 m (5.5 ft) rise by 2100 trajectory is combined with maximum plausible levels of temporary storm erosion.
- In Malibu, both low and high sea level rise scenarios suggest that long segments of beach will essentially disappear by 2030. Cliff retreat will be a simultaneous hazard in this area, particularly for areas that are not armored. However, for armored sections, maintaining beach width will be a difficult task.
- By late this century, and assuming the high sea level rise scenario, beach retreat will be obvious everywhere. This may lead to economic losses due to reduced beach width for recreation, but also due to occasional flooding of coastal facilities and related damages.
- ESA projections for cliff shorelines without significant beaches indicate progressively increasing exposure of property and assets at rates greater than experienced historically. (Discussed in the vulnerability summary, below).

Flooding Projections – Major Findings:

ESA's flooding projections indicate that:

- Low-lying areas of L. A. County, such as the Venice Beach canal district and Long Beach's Belmont Shores and Naples Island neighborhoods, will see significant increase in flood hazard exposure with sea level rise.
- Even if flood management addresses coastal flood hazards in these low-lying areas, they will also be subject to greater flood risk from the impaired capacity of stormwater and groundwater to drain to the ocean.
- Beach erosion, described above, will enable both monthly high tides and wave runup to progress further inland.
- Areas around the County's six lagoons will face increased flood hazard. Seasonal lagoon closures will shift upward in response to sea level rise. This response may alter inland flood conditions.

Initial Vulnerability Assessment – Major Findings:

In addition to the coastal erosion and flooding hazards mapping, ESA conducted an initial vulnerability assessment of assets potentially exposed to coastal hazards. Figure 8 provides a brief synopsis of projected impacts to assets in of L.A. County. This analysis, conducted by ESA, entailed a geospatial overlay of hazard zones with mapped assets. The analysis does not address actual failure mechanisms and precise thresholds for damage, but rather identifies assets that may be damaged because they are within a mapped hazard zone. Exposure zones were determined by the scenarios developed in the hazard mapping. They include: 1) long-term erosion, 2) long-term tidal flooding, 3) storm/event erosion, and 4) storm/event flooding. These four hazards, in order of decreasing severity:

1). Long-term erosion: Areas subject to long-term erosion would be lost entirely.

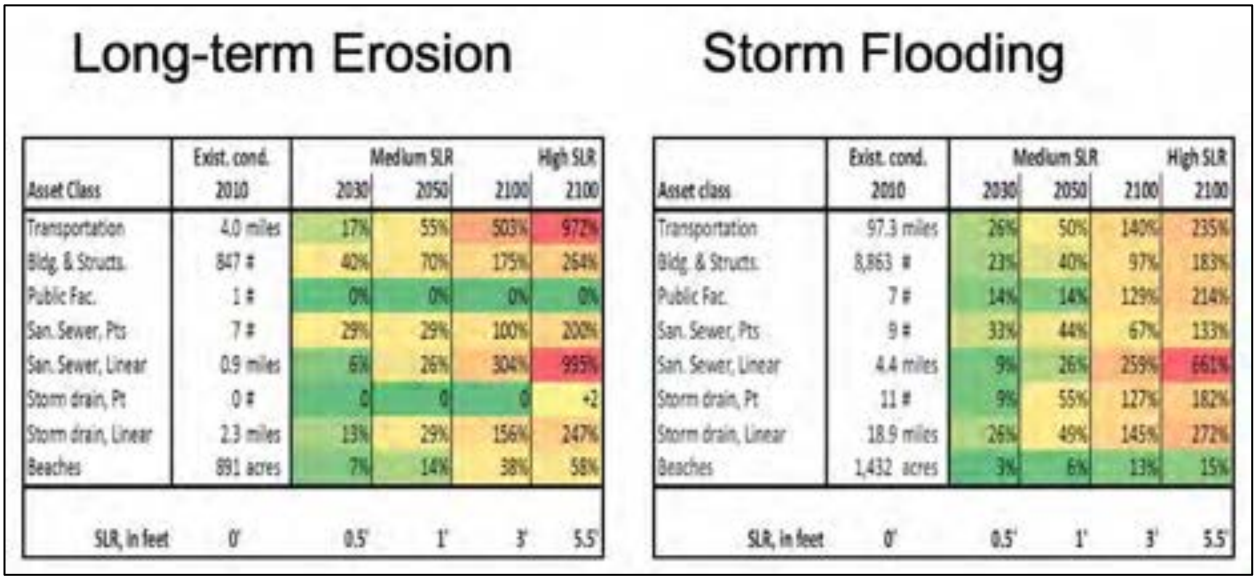
2). Long-term flooding: Areas experiencing long-term tidal flooding would be regularly flooded by monthly high tides.

3). Storm/event erosion: Areas experiencing storm or event erosion are likely damaged but could be recoverable.

4). Storm/event flooding: Areas experiencing storm or event flooding are likely to return to service when floodwaters recede.

In ESA's report, exposed assets are classified by sector and reported by city. The assessed sectors include:

- Transportation infrastructure (miles of roadway)
- Buildings and structures (sum of building and parking lot footprints)
- Public facilities (number of fire, police, hospitals, and schools)
- Sanitary sewer infrastructure (point: sum of water treatment plants and pump stations; linear: miles of sewer pipe)
- Storm drain infrastructure (point: pump stations; linear: sum of gravity mains, force mains, and culverts in miles)
- Ecosystem assets (sum of acres of beaches, salty wetlands, and fresh wetlands)



Long-term Erosion

Asset Class	Exist. cond. 2010	Medium SLR 2030	Medium SLR 2050	Medium SLR 2100	High SLR 2100
Transportation	4.0 miles	17%	55%	503%	972%
Bldg. & Structs.	847 #	40%	70%	175%	264%
Public Fac.	1 #	0%	0%	0%	0%
San. Sewer, Pts	7 #	29%	29%	100%	200%
San. Sewer, Linear	0.9 miles	6%	26%	304%	995%
Storm drain, Pt	0 #	0	0	0	+2
Storm drain, Linear	2.3 miles	13%	29%	156%	247%
Beaches	891 acres	7%	14%	38%	58%
SLR, in feet	0'	0.5'	1'	3'	5.5'

Storm Flooding

Asset class	Exist. cond. 2010	Medium SLR 2030	Medium SLR 2050	Medium SLR 2100	High SLR 2100
Transportation	97.3 miles	26%	50%	140%	235%
Bldg. & Structs.	8,863 #	23%	40%	97%	183%
Public Fac.	7 #	14%	14%	129%	214%
San. Sewer, Pts	9 #	33%	44%	67%	133%
San. Sewer, Linear	4.4 miles	9%	26%	259%	661%
Storm drain, Pt	11 #	9%	55%	127%	182%
Storm drain, Linear	18.9 miles	26%	49%	145%	272%
Beaches	1,432 acres	3%	6%	13%	15%
SLR, in feet	0'	0.5'	1'	3'	5.5'

Figure 8: Assessment of projected impacts to various assets for all of L.A. County for medium and high sea level rise scenarios. The percent increase in exposure for each asset sector is provided relative to the miles, number, or acres using existing conditions of 2010 as a base. For instance, exposed transportation assets in L.A. County during Storm Flooding will increase by 140% (an increase of 136 miles, from 97.3 to 233 miles) compared to 2010 under the medium sea level rise (3 ft) by 2100.

The following table highlights some major findings of the vulnerability assessment. While impacts to each sector are illustrated with a time horizon, it will be important for coastal managers to develop adaptive approaches, such as thresholds or triggers that when reached will elicit an adaptation implementation response (CCC 2015). Planning that includes more flexibility will greatly reduce any temporary or permanent loss of service of critical infrastructure.

Asset Sector	Major Findings
Transportation Infrastructure	• PCH represents a "cross cutting" vulnerability; it acts as a main artery for the coastal communities in L.A. County. If damaged and experiences a significant loss of service, transportation along coast would be impacted. • Under the 5.5' by 2100 scenario, L.A. County could see 143 miles of roadway or bikeway impacted by 2030, and 327 miles by 2100 during a 100-year storm event.
Buildings and Structures	• Long Beach has the most buildings and structures exposed in a 100-year storm hazard event. By 2050 (under the 5.5' by 2100 scenario), nearly half of the structures exposed in L.A. County are in Long Beach (7,617 out of 14,705). • Malibu has the most buildings and structures exposed under the long-term erosion hazard, with 1,136 units exposed out of 1,591 across the county by 2050 (under the 5.5' scenario by 2100).
Public Facilities	• L.A. County will have 11 fire stations, 2 police stations, and 9 schools vulnerable to a 100-year storm hazard event under the 5.5' by 2100 scenario.
Sanitary Sewer and Storm Drain Infrastructure	• Under the 5.5' scenario by 2100, 21 water treatment plants and pump stations across L.A. County could be impacted by 2100 under the long-term erosion hazard and the 100-year storm event. • Hyperion Water Reclamation Plant is elevated and set back from the ocean, so it is not exposed to any of the hazards on the time horizons addressed in this study; however, because much of the county depends on it for the wastewater treatment, it should be considered in any adaptation plans developed by the county. In addition, the current assessment only looks at surface impacts. Coastal storms, flooding, and/or erosion may affect underground infrastructure and thus the operational capacity of the facility. • 19 storm drain pump stations in Long Beach, and 11 in the City of Los Angles would be vulnerable to a 100-year storm hazard event under the 5.5' by 2100 scenario.

Ecosystem Assets	• Over 1,600 acres of L.A. County beaches are susceptible to storm event erosion under the 5.5’ by 2100 scenario. • Long-term tidal flooding at monthly high water may not have detrimental effects on some ecosystems (i.e. beaches and salty marshes). However, changes in the frequency and magnitude of inundation will likely have an effect (positive or negative) on the ecosystems. It is important to assess each ecosystem and its surrounding urbanized environment to assess its vulnerability.

Asset data were provided by Los Angeles County agencies. A summary of the data sources used in this analysis is provided in the final ESA report. Some of these data sources leave gaps in certain cities, since the cities and the county do not always maintain the same data or level of detail. In these cases, it was noted in the ESA report where data were not available. Areas that had data coverage but simply have no assets in the exposure zone for a particular asset sector are listed as zero. Asset data for the electric and energy supply systems were not available, so this asset class was not considered in the assessment.

Use of this Assessment

It is important to note that the scope of this assessment is to develop an inventory of infrastructure, assets and critical resources that fall within the exposure zones for the different hazard scenarios in the ESA study. In addition to identifying assets exposed to the potential hazard, a full physical vulnerability assessment would also evaluate the *sensitivity* and *adaptive capacity* of each asset under that hazard scenario. To learn more about conducting vulnerability assessments, the California Adaptation Planning Guide provides guidance and additional detail. AdaptLA cities and jurisdictions can use the information developed in the ESA Vulnerability Assessment report as a starting point in developing a full physical vulnerability assessment for individual coastal communities.

RECOMMENDATIONS FOR COASTAL JURISDICTIONS

1. Continue to collaborate on local, regional, state, and federal efforts to monitor and model beach/shoreline conditions. Monitoring efforts can contribute to refined assessment and reliability of current models and improving future models.
2. Facilitate continued delivery of any opportunistic sand supplies that become available to appropriate beaches.
3. Maintain records of times, locations, and the extent of overtopping, flooding, cliff failures, and other erosion events. This can aid in planning future geotechnical and engineering adaptation measures. Documenting impacts to crucial regional infrastructure is of particular importance.
4. Identify existing coastal armoring structures and assess their roles in the context of future coastal changes.
5. Address the effects of coastal armoring on beach width.

6. Consider the combined impact of areas potentially affected by both sea level rise and watershed runoff to creeks and rivers. Special attention is recommended for areas adjacent and tributary to coastal lagoons. In these areas flooding is set by the beach berm during closed conditions and elevated exposure and vulnerability are likely given projected future conditions.
7. Improve asset inventory to support a more detailed vulnerability assessment and support modeling the implications of adaptation scenarios.

ACCESSING INFORMATION AND RESULTS

All of the hazard projections from both ESA and TCG are available as shapefiles for use in Geospacial Information Systems (GIS). USC Sea Grant provides a repository of these shapefiles on its webpage: http://dornsife.usc.edu/uscseagrant/adaptla/. A small subset of the results is also available to view on the Trust for Public Lands *Climate Smart Cities: Los Angeles* web viewer. This viewer will be updated in summer 2017 to include a broader range of hazard projections and the updated CoSMoS 3.0 So Cal model results. This will allow users to easily compare model projections. This viewer also includes other climate impacts and provides tools that help the user analyze multiple types of vulnerabilities at once. Users of this web tool can therefore assess their vulnerability to a number of climate impacts in addition to coastal hazards. While access to this viewer is open to anyone interested, the Trust for Public Lands still requires a username and password. Interested users can access the viewer at website listed below with the AdaptLA username and passcode. You can also contact USC Sea Grant or can reach out directly to the Trust for Public Land [fernando.cazares@tpl.org] with any questions.

ESA and TCG Data and Webtool

Webtool - Climate Smart Cities: Los Angeles
The Trust for Public Land
http://web.tplgis.org/losangeles_csc/

Username: **AdaptLa**
Passcode: **AdaptLaPass123**

AdaptLA Webpage: Final Reports and Shapefiles
http://dornsife.usc.edu/uscseagrant/adaptla/

USGS CoSMoS Data and Webtool

Webtool – Our Coast Our Future
Developed by Point Blue Conservation Science
ourcoastourfuture.org

USGS ScienceBase Website: CoSMoS Technical Reports and Shapefiles
https://walrus.wr.usgs.gov/coastal_processes/cosmos/socal3.0/index.html

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Appendix 1

Los Angeles Region Shoreline Change Projections
Prepared by: TerraCosta Consulting Group

LOCAL COASTAL PROGRAM
SEA LEVEL RISE GRANT PROGRAM
LOS ANGELES REGION SHORELINE CHANGE PROJECTIONS

Prepared for
CITY OF SANTA MONICA
Santa Monica, California

Prepared by
TERRACOSTA CONSULTING GROUP, INC.
San Diego, California

Project No. 2391-15
September 30, 2016

TerraCosta
Consulting Group

Geotechnical Engineering
Coastal Engineering
Maritime Engineering

Project No. 2391-15
September 30, 2016

Mr. Garrett Wong
CITY OF SANTA MONICA
Office of Sustainability and the Environment
1717 4th Street, Suite 100
Santa Monica, CA 90401

LOCAL COASTAL PROGRAM SEA LEVEL RISE GRANT PROGRAM
LOS ANGELES REGION SHORELINE CHANGE PROJECTIONS

Dear Mr. Wong:

We are pleased to provide the attached report showing results of the subject study. We conducted the study in cooperation with Environmental Science Associates (ESA), the United States Geological Survey (USGS), and the University of Southern California (USC) Sea Grant Program. We modeled coastal change projections to year 2100 relative to 2000 for a range of sea level scenarios consistent with current State of California guidance, and using wave and other information provided by ESA and USGS.

We have forwarded the model results to you as “shapefiles” suitable for viewing in ArcGIS. Please contact us if you have questions, or require additional study products, such as printed output, or any further information.

Respectfully yours,

TerraCosta Consulting Group, Inc.

Reinhard E. Flick, PhD
Principal Oceanographer

Adam Young

Adam P. Young, PhD
Oceanographer

REF/APY/jg
Attachment

TABLE OF CONTENTS

FIGURES

LOCAL COASTAL PROGRAM SEA LEVEL RISE GRANT PROGRAM

LOS ANGELES REGION SHORELINE CHANGE PROJECTIONS

1 INTRODUCTION

This study of the LA Region builds on the results of the *AdaptLA* overview-level work coordinated by the University of Southern California Sea Grant Program (USC Sea Grant 2013) and prepared for the City of Los Angeles Mayor's Office. TerraCosta Consulting Group (TerraCosta) contributed to the *AdaptLA* work by conducting a review of the major coastal geographic regions within the City of Los Angeles. TerraCosta provided an overview of each section's main issues, potential adaptation strategies, constraints, and possible next steps the City could consider in planning for sea level rise (TerraCosta 2013, USC 2013). We summarize the *AdaptLA* results and other historical background as they apply to the Los Angeles Region in Section 4 below.

Section 2 following this introduction reviews the original scope of work and the changes made necessary and agreed to during the course of the project. A summary of results appears in Section 3. Section 4 presents the coastal overview developed during the *AdaptLA* work. Sections 5 and 6 respectively discuss the sea level rise scenarios and the wave data used for the modeling. Section 7 details the short-term wave-driven shoreline fluctuation model and the long-term sea level rise driven coastal retreat model that were used. Section 8 summarizes the modeling results. A discussion of the longshore transport of sand modeling projections is given in Section 9. Finally, several recommendations arising from the technical work are suggested in Section 10.

2 SCOPE OF WORK

The City of Santa Monica was the lead agency for this study. In accordance with the City's request, TerraCosta is herein providing the summary of state-of-the-art shoreline change and coastal retreat modeling from Pt Dume in Malibu, to Malaga Cove in southern Santa Monica Bay (Figure 1). The digital output files of the modeling results have been provided separately. TerraCosta conducted this work in partnership with Environmental Science Associates (ESA) and the United States Geological Survey (USGS) who provided most of the essential input data, and the University of Southern California (USC) Sea Grant Program, which guided and coordinated the project.

TerraCosta modeled projected coastal change to year 2100 relative to 2000 for a range of mean sea level rise scenarios consistent with the current but evolving State of California guidance. We used wave and other information provided by ESA and USGS, and the model methodologies published by Young *et al.* (2014), Chadwick *et al.* (2011, 2014), and Yates *et al.* (2009). The model output is in the form of "shapefiles" suitable for viewing in ArcGIS.

TerraCosta completed the following tasks:

Task 1. Modeled short-term wave-driven future shoreline position changes.

Task 2. Modeled long-term sea level rise-driven future shoreline changes.

Task 3. Coordinate with USGS (CoSMoS) and ESA-PWA, including determination of suitable mean sea level rise projection scenarios.

Task 4. Participated in public outreach and education support.

Task 5. Participated in the Los Angeles Regional Planning Team.

The tasks completed differed slightly from the work originally proposed due to requests by the City of Santa Monica, unavoidable delays, and other factors that made certain parts of the proposed work impossible or unnecessary. For example, the original proposal specified both historical and projected shoreline fluctuation and coastal cliff retreat modeling limited to Santa Monica Bay from Santa Monica to Redondo Beach. Instead, TerraCosta and the City agreed to extend the projections west to Malibu by forgoing the historical reconstruction, for which insufficient reliable information existed in any case.

3 SUMMARY OF RESULTS

This study was limited to the coastal reach from Pt Dume in Malibu to Malaga Cove in Redondo Beach. This was the extent where input parameters needed to run the coastal retreat model were available. The main findings were:

- Owing to the relatively wide and stable existing beaches, model results suggest that troublesome levels of beach retreat are unlikely to occur before 2050 in and south of Santa Monica, even when the 1.67 m rise by 2100 trajectory is combined with maximum plausible levels of temporary storm erosion.

- In Malibu, model results for both the 0.93 m and 1.67 m sea level rise scenarios suggest that long segments of beach may essentially disappear by 2030 during times of peak tides and high water levels, while cliff retreat will occur simultaneously in areas that remain unarmored.

- By late this century, and assuming the 1.67 m sea level rise scenario, beach retreat will be obvious everywhere in the modelled region. This will lead to economic losses due to reduced beach width for recreation, but also to more frequent and more severe coastal facilities flooding and related damages that will vary by geographic region.

4 COASTAL OVERVIEW

The Los Angeles (LA) Region, comprised of its cities and county, faces numerous planning challenges due to expected climate change impacts. An important element of climate change is sea level rise, which will almost certainly strongly affect the iconic LA coast over the next century and beyond. LA's coast contains extremely valuable private and public property including critical transportation and utility infrastructure and public access, two sewage treatment plants, two power plants, Marina Del Rey and King Harbor small craft harbors, several piers, Los Angeles International Airport, the ports of Los Angeles and Long Beach, and sandy beaches from the Ventura County line through Long Beach.

Sea level rise is the dominant process that will continuously and inexorably exacerbate episodic coastal erosion, flooding, and damages, as most recently demonstrated by Bromirski *et al.* (2016). These problems occur most frequently on the southern California coast when large storm-driven waves coincide with peak high ("King") tides and elevated sea levels related to storm surge and oceanographic effects, including unusually warm coastal waters from El Niño events.

LA encompasses five distinct coastal regions, the first four of which are in Santa Monica Bay: 1) Malibu; 2) Pacific Palisades; 3) Will Rogers State Beach to Redondo Beach; 4) Palos

Verdes, and; 5) San Pedro through LA-Long Beach Harbor. Each region has a unique coastal setting and a different history of development and human intervention. For these reasons, each area has a distinct suite of current and future coastal problems. Similarly, each area likely has dissimilar sensitivity to the effects of future mean sea level rise and so will require different adaptation strategies to remain viable. Detailed descriptions of the LA coast can be found in Orme (2005) and Sherman and Pipkin (2005).

The coast from the Ventura County line to Will Rogers State Beach is south facing with relatively high relief. Sand transport tends to be from west to east. Narrow beaches and heavy development characterizes most of this reach, especially in Malibu east of Pt Dume, with highly valuable residential real estate. However, the reach also features heavily used state and county beaches, such as Zuma State Beach. Pacific Coast Hwy (PCH) through Malibu and Pacific Palisades is the essential coastal transportation and utility corridor as the only alternate route to Fwy 101 located north of the coast mountain range. Much of eastern Malibu and most of the reach from Topanga Canyon to Will Rogers State Beach consists of narrow packet beaches mostly backed by various shore protection revetments protecting the coast highway. The extent of existing revetments shows that this reach has and continues to experience episodic erosion that threatens to undermine PCH.

The coast turns southward at Will Rogers State Beach, which is moderately wide owing to its successful and relatively unobtrusive groin beach stabilization system. Toward the southeast, beach width increases due to the up-coast influence of the Santa Monica breakwater located just offshore of Santa Monica pier. The breakwater, built in the 1930s as an unsuccessful attempt to create a small craft harbor, did lead to an astonishing increase in beach width and equally important, to beach width stability.

The reach from Santa Monica to Redondo Beach provides major economic benefits from coastal recreation and tourism, boating, and utility and facility siting. These beaches are wide to very wide (relative to the southern California norm), and largely created by sand supplied as by-products of coastal construction, including LAX, Marina Del Rey, and the Hyperion sewage treatment plant (Flick, 1993; Leidersdorf and Woodell, 1993, 1994). Between the late 1930s and 1963, over 24 million cubic meters (m^3) of sand were placed.

While these southern Santa Monica Bay beaches have been wide and stable for many decades, gradual retreat is in progress. A major concern for the future arises from the fact that opportunistic sand is unlikely to be available in the quantities it was up to the 1960s. As MSLR accelerates in the future, these iconic LA beaches will undoubtedly narrow at a faster rate, as demonstrated by the model results presented herein. However, it is unlikely that sea level rise alone will appreciably exacerbate storm-wave driven erosion, flooding, or property damage in the near future, meaning several decades. But if MSLR takes one of the higher trajectories, these problems are likely worsen starting about mid-century.

The Palos Verdes Peninsula section of LA has a long history of geological instability (Griggs *et al*. 2005). The south-facing peninsula is exposed to the ocean, while the east-facing section is sheltered behind the LA-Long Beach outer breakwater, which has its root at Cabrillo Point. Both sections are heavily sub-urbanized atop a flat coastal terrace that has a 35 m high sea cliff at its seaward edge. The geology suggests relatively resistant formations at sea level near Cabrillo Point, but more erodible material to the west toward Point Fermin. As MSLR resumes and accelerates, the weaker western cliff sections will be subject to more undermining from wave action and eventual collapse than the more resistant eastern sections.

5 SEA LEVEL RISE SCENARIOS

TerraCosta with the other team members carefully considered the selection of the sea level rise scenarios used for modeling. By mutual agreement with the City of Santa Monica we settled on the California Coastal Commission sea level rise policy guidance (CCC 2015) “projection” and “high” trajectories, supplemented with an “extreme” scenario from Cayan *et al*. (2016). We herein refer to these three trajectories by their 2100 end-point values to avoid confusion among qualitative descriptors like “high” since these are evolving and have will frequently changing end-points.

Figure 2 shows the two trajectories (green and black) with respective 2100 end-points of 0.93 m (about 3 ft) and 1.67 m (5.5 ft) used for the coastal change modeling, and the third (red) trajectory with 2.88 m (9.4 ft) rise by 2100 presented for discussion purposes. Table 2 summarizes the 2030, 2050, and 2100 sea level rise values (relative to 2000) for these trajectories, further described below. Note that approximately 1.67 m of sea level rise is occurs in the 2.88 m scenario by about 2080 (Figure 2). This means that the shoreline retreat for this projection would be about equal to that for the 1.67 m scenario, but occur about 20 years earlier.

The CCC (2015) guidance is based on the National Research Council report (NRC 2012) prepared for California, Oregon, and Washington. The guidance contains three scenarios then recommended for consideration in coastal planning. These included the 0.93 m and 1.67 m trajectories considered herein, and 0.42 m, which was not used because revisions currently underway in California sea level rise policy due in 2018 will very likely eliminate it.[1] An interesting feature of the 2.88 m scenario is that it lies between the 0.93 and 1.67 trajectories until about 2055 when polar ice melt is expected to dominate sea level rise for this scenario (Figure 2).

Table 2. Summary of Projected Sea Level (see Figure 2)

Year	Sea Level Rise Relative to 2000 (meters)		
	0.930 m (3 ft, green)	1.67 m (5.5 ft, black)	2.88 m (9.4 ft, red)
2030	0.150	0.300	0.178
2050	0.290	0.610	0.519
2100	0.930	1.67	2.88

The 2.88 m scenario is derived from the currently evolving State of California sea level rise policy guidance founded on important advances in sea level rise science that have occurred since early 2016. Cayan *et al*. (2016), working in support of the 2018 Fourth Californian Climate Change Assessment, cite DeConto and Pollard (2016) who suggest ice sheet melting in Antarctica will be greater than previously expected. In addition, Kopp *et al.* (2014) have developed a probabilistic approach that assigns likelihoods to various future mean sea level rise scenarios.

Their (current) extreme projection is the 99.9%tile trajectory of the IPCC (2008) RCP 8.5 scenario as tabulated in Cayan *et al.* (2016). This “business as usual” greenhouse gas build up would produce an 8.5 Watt/m^2 radiative imbalance by 2100,[2] with an associated mean sea level rise of 2.88 m. This means, from what we can best estimate now, there is 1 chance in

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[1] In effect, the former medium and high trajectories have become the new low and medium ones, with a new high, now termed “extreme.” This illustrates the confusion these descriptors can promote.

[2] For reference, earth’s current imbalance is about 0.8 Watt/m^2.

1,000 (0.1%) that this extreme scenario will be reached or exceeded, and 999 chances in 1,000 that sea level rise will follow a lower trajectory.

We did not model the shore change associated with this new extreme sea level rise scenario for two reasons. First, the changes that are looming in the state guidance began to appear while the model production runs were nearly complete. While we proposed to model all three CCC (2015) scenarios, the study partners determined that it would be more advantageous to model the 0.93 m and 1.57 m scenarios only, and spend the time saved considering the evolution of the science and guidance. There are several other aspects to this. First, the extreme scenario of 2.88 m sea level rise by 2100 is currently deemed extremely unlikely, as already mentioned. Second, this trajectory is not currently State of California guidance since the pending updates will not be available until 2018, and could change in the meantime.

Finally, the Young *et al.* (2014) coastal retreat model assumes that backshore (usually cliff) erosion can proceed rapidly enough to provide sufficient sand to maintain the “equilibrium” beach shape, which rises and moves landward in response to sea level rise (Bruun 1962). While we did not make a quantitative assessment of the model limits, we recognize that for sufficiently high sea level rise rates some cliffs may not be able to erode fast enough to keep up with the sand supply needed. In such a case, the beach would eventually disappear as the shoreline retreats faster than the cliff can retreat. This is also the situation where sea walls back a retreating beach, and at many headlands, which are usually composed of harder rock at sea level than the surrounding coast, and where wide sandy beaches do not form for this reason.

6 WAVE INPUT DATA

USGS provided modeled hindcast (1980-2011) and forecast (2012-2100) wave parameters at nearshore virtual buoys in approximately 10 m water depth (MOP locations, Figure 1) at three-hour time intervals. The draft Coast of California Storm and Tidal Waves Study (CCSTWS) for the LA region (USACE 2010) provided estimated closure depths at 23 locations in the study area used for the modeling. Closure depth is the depth seaward of which no wave-driven sand transport occurs. It is a critical element of the Young *et al.* (2014) model, as explained Section 7.2 below.

7 COASTAL CHANGE MODELING

We used the wave projections and the equilibrium shoreline change model of Yates *et al.* (2009) to estimate the short-term (three-hourly to seasonal) shoreline position fluctuations at each MOP transect line in the study area from 2012-2100. We used the sea level rise scenarios and the Young *et al.* (2014) model to project longer-term (annual-century) coastal retreat, also at each MOP line, from 2000-2100.

Results for the two scales of temporal variation were added together to provide time series of coastal change at the approximately 100-meter transect intervals. The model was applied to about 600 MOP transects (numbered 2900 to 2300) over the 60-km reach from Pt Dume to Malaga Cove (Figure 1) where model input information was available. Some gaps in model inputs such as beach change coefficients precluded full modeling at all MOP transects.

The following list contains the inputs and modeling and mapping methods and assumptions applied in our approach, and which are presented in more detail in the following sections.

1. Primary Model Inputs
   - USGS wave data
   - USGS bare earth digital elevation model (DEM)
   - USGS beach change coefficients
   - ESA transect profiles (extended offshore)
   - CCC (2015) 0.93 m and 1.67 m sea level rise trajectories
   - USACE (2010) – CCSTWS LA (Draft Report) closure depths
   - Back shore sand content measured from over 70 samples

2. Modeling Methods and Assumptions
   - Model independent of historical erosion rates
   - Future shoreline profile transgression based on equilibrium sand balance from peer-reviewed model (Young *et al.* 2014)
   - Wave-driven beach fluctuations from peer reviewed model (Yates *et al.* 2009)
   - Beach and cliff retreat conditionally decoupled permitting different retreat rates
   - Short-term beach changes projected every three-hours
   - Long-term shoreline retreat projected annually

3. Mapping Methods and Assumptions
    - Model projections at 100-m spaced transects
    - No smoothing applied
    - Retreat results should be interpreted broadly
    - Shorelines clipped at locations where adjacent transects were not modeled (*e.g.,* inlets, transects with infrastructure covering the cliff base/top, etc.)
    - Backshore erosion is initiated when waves reach backshore
    - Armoring not considered in modeling
    - Armored locations are delineated

7.1 Wave-Driven Fluctuations

Yates *et al*. (2009) developed and tested an equilibrium short-term shoreline position model to calculate wave-driven beach fluctuations consisting of both accretion and erosion, depending on wave conditions. Modeling time step is limited only by the frequency of available wave information, in this case every three hours. The model does not account for backshore features such as cliffs or seawalls that can inhibit horizontal erosion, or for bedrock platforms that prevent vertical erosion. In addition, sand budget shortages or surpluses are also not considered, but these can be added *ad-hoc* (Chadwick *et al*. 2014).

The Yates *et al.* (2009) model requires four empirically derived constants for each modeled section of beach. These are denoted a, b, C^+, and C^-, as described in the model governing Equations 1 and 2 below. USGS derived the constants by analyzing beach change data and wave observations and provided them to TerraCosta. The constants were only available for the TerraCosta study area (MOP transects 2900-2300) shown in Figure 1, which limited our modeling to this reach of the LA coast.

Equation 1 expresses the model assumption that for a given wave energy, E_{eq} there exists an “equilibrium” shoreline position S that is constant as long as the waves do not change, and that this position is linearly related to the wave energy through the constants a and b:

$$E_{eq} = aS + b \qquad (1)$$

The model also assumes that the time rate of shoreline change, dS/dt depends on the instantaneous wave energy, E, and energy dis-equilibrium, ΔE (see Footnote[3]):

$$dS/dt = C^{\pm} E^{½} \Delta E, \tag{2}$$

where $\Delta E = E - E_{eq}(S)$, and $C^{\pm}$ are change rate coefficients for accretion (C^{+} when $\Delta E<0$), and erosion (C^{-} when $\Delta E>0$).

The wave-driven beach change model results are available every three hours for the modeled time interval from 2012 to 2100. Figure 3 shows an example of the nearly 100-year long time series of model input wave height and output shoreline position for MOP location 2500 at El Segundo. Maximum wave heights range up to about 3.5 m, while corresponding shoreline retreat reaches 35-40 m. Varying durations of high waves that are not apparent at this time resolution account for larger or smaller shoreline retreat for apparently similar storm wave heights.

Comparable time series of shoreline fluctuations at each transect make possible the calculation of erosion return period statistics at each of the 600 MOP lines, including maximum projected erosion values. Figure 4 shows the 1% (100-year) recurrence and maximum values of storm-driven beach erosion for the study area. The model suggests erosion “hot spots” in the central part of Santa Monica Bay (MOP lines 2550-2480), south of Marina del Rey into Manhattan Beach. Storm erosion magnitude decreases north of Marina del Rey (MOP 2540), but shows a few more hot spots (MOP 2780, 2910) in Malibu.

7.2 Sea Level Rise Driven Coastal Retreat

The “conditionally decoupled profile model” of Young *et al.* (2014) was employed to project the longer-term (annual and longer) sea level rise driven coastal retreat. This model uses a sand balance approach based on Bruun (1962) to derive retreat as a function of sea level rise. The crucial assumption underlying the Bruun model is that as sea level rises, the geometric relationship between the beach profile and sea level remains constant, all other variables (*i.e.* wave climate, sand grain size, and sand availability) being equal. In other words, as sea level goes up, the beach cross section moves upward at the same rate, but also migrates landward eroding the upland at a rate sufficient to provide just enough sand to maintain the shifting

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[3] $E = H^2/16$, where H is wave height (density of water and acceleration of gravity are neglected).

profile. The idea is that beaches look essentially the same relative to sea level no matter what the actual sea level.

Over long time scales, centuries to millennia, this is a reasonable assumption. A crucial improvement made by Young *et al.* (2014) is using actual coastal topography. This advance was possible first by increased computer power, and second by the availability of accurate digital coastal elevation models and reasonably reliable beach cross section profiles. Over shorter timescales such as years to decades, the model also assumes that the upland can erode fast enough and contains sufficient sand to maintain the profile. This criterion is readily met in the case of wide beaches, where sand from the upper profile moves offshore to raise the lower portion of the profile as sea level rises. For narrow beaches backed by sea cliffs, such as those in Malibu, we also considered the percentage of beach size sand in the cliffs.

TerraCosta determined cliff height from the digital elevation model used in the analysis, as shown in Figure 5. We also collected and analyzed sand samples for grain size at 78 cliff and backshore locations throughout the study area. These samples were wet sieved using a 63-micron sieve to determine the percent of backshore sand content available for beach sand balance. Values ranged from 23-100 % with an average of 74%. The highly irregular cliff sand content was smoothed alongshore, as shown in Figure 6.

For each annual time step, the active beach profile (defined as extending from the offshore closure depth to the upper active beach limit) shifts vertically by the amount of projected sea level rise, and the sand needed to accommodate the shift is calculated. As long as the upper beach is sufficiently wide to provide the needed sand, the beach is “decoupled” from the upland, *i.e.,* the cliff, and marine erosion does not affected it. Sea cliffs still provide some sand, however, from subaerial erosion, especially rainfall. Marine-driven cliff erosion occurs when the beach retreats landward sufficiently for the active profile to reach the cliff.

Decoupling the active beach and cliff profiles in the Young *et al.* (2014) model allows the beach and cliff to conditionally retreat at different rates. Typical profile adjustments show that the initial beach landward shifts can obtain sand balance without marine-driven cliff erosion. When the beach buffer width vanishes, waves begin to erode the cliff base and (ignoring possible lag time) the active beach and cliff profile become coupled, retreating at the same rate.

TerraCosta ran the model to project shoreline change from 2000 to 2100 on transects spaced 100 m alongshore. Transects were initially provided by USGS at MOP locations, then edited and reoriented by ESA, and lastly extended farther offshore by TerraCosta. Final transect orientation generally increased from north to south (Figure 7), following the overall coastal trend. North and west of Will Rogers State Beach (around MOP 2650) the prevalence of headlands complicates the coastal orientation.

Topographic and bathymetric profiles were obtained at each transect using a 1-m resolution bare earth digital elevation model provided by USGS. Cliff base and cliff top locations at each transect were initially defined by ESA and edited by TerraCosta. Transect closure depths were interpolated from 23 modeled values in the study area (USACE 2010) and the upper active beach limit was estimated from rectified aerial imagery. Unrepresentative transects and transects with structures covering cliff top and/or base were removed from the analysis. Armoring and seawalls locations were mapped by updating and editing the Coastal Commission armoring shapefile (developed by Jennifer Dare) using more recent oblique and vertical aerial imagery.

Transects that intersected the armoring shapefile were identified and modeled assuming no armoring was present. This should not be taken to suggest that the armoring would or would not fail, or whether and when it would be overtopped. Each section of armored coast would have to be examined in detail by engineers on the ground to make these determinations, which are outside the scope of this study.

8 COASTAL CHANGE PROJECTIONS

TerraCosta computed projected wave-driven beach fluctuations and sea-level driven beach and cliff retreat from 2000-2100 using the methods described respectively in Sections 7.1 and 7.2 above. This section presents statistical summaries of the results and one example map of the projected shoreline positions at Santa Monica for the years 2030, 2050, and 2100.

Figures 8 summarizes the shoreline retreat for beaches in the study area under the two sea level rise trajectories described in Section 5 (endpoints of 0.93 m and 1.67 m) for years 2030, 2050, and 2100 relative to 2000. Long-term retreat ranges from about 5 m, 20 m, and 50 m respectively in the three target years for the 0.93 m sea level rise scenario, and 10 m, 30 m, and 90 m respectively for the 1.67 m scenario. Projected beach retreat is largest for both scenarios in the southern part of the study area, peaking at about MOP 2450 near El Segundo just south of Marina Del Rey. Note that there is large variability in retreat for the 1.67 m scenario by 2100, especially in this southern reach. The reasons for this are not entirely clear, but may provide an estimate of modeling uncertainty.

Figure 9 includes both the long-term beach retreat from sea level rise (for both scenarios) from Figure 8, with the added maximum wave-driven shoreline erosion shown in Figure 4. Coincidentally, the maximum short-term erosion of about 50-65 m also occurs between MOP 2400 and 2500, as mentioned in Section 7.1. When combined, the maximum beach retreat during storm episodes reaches about 90 m and 125 m respectively for the 0.93 m and 1.67 m scenarios.

Figure 10 presents analogous results for the long-term retreat of sea cliffs in the areas with little or no beach. These are mainly in Malibu, north of Will Rogers State Beach, and at the very southern end of the study area in Redondo Beach south of King Harbor. Hapke and Reid (2007) compiled historical erosion rates along the California coast, including on 585 ranges in the LA area. These range from zero to about 1.8 m/yr, with an average rate of nearly 0.4 m/yr. Our results find year-to-year cliff retreat rates of 0-0.8 m/yr. These are within the range of the historical cliff retreat rates suggesting that the region’s unarmored cliffs can in fact erode sufficiently fast to continue to provide sand to the local beaches.

Figure 11 is an example of the high-resolution shoreline retreat maps resulting from the TerraCosta modeling transmitted to the City of Santa Monic electronically. The non-profit organization *Trust for Public Land* is providing electronic access to these maps, along with other work products from this project and related material from many other sources.[4]

It is clear from Figure 11 that troublesome levels of beach retreat are unlikely to occur before 2050, at least in Santa Monica, even when the 1.67 m trajectory is combined with maximum plausible levels of temporary storm erosion. Nevertheless, by late this century, beach retreat will be noticeable. This may lead to economic losses due to reduced beach width for recreation, but also to occasional coastal facilities flooding and related damages.

Figure 12 is a similar example, but for the much narrower beaches at Malibu east of Pt Dume. In this case, projections for the 1.67 m scenario suggest that long segments of beach

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[4] Trust for Public Lands, Climate Smart Cities, Los Angeles website **http://web.tplgis.org/losangeles_csc/**.

will essentially disappear by 2030 during times of peak tides and high water levels, while cliff retreat will occur simultaneously, at least in areas not armored.

If sea level rise actually follows a trajectory such as the 2.88 m by 2100 scenario, then these effects would occur much sooner, as already mentioned. This provides an alternate way to view future projected shoreline retreat: Namely not as a function of sea level trajectory over time, but as shoreline retreat as a function of sea level rise regardless of when it is reached. In other words, the projected shoreline position results shown are valid for the specified levels of sea level rise, subject to the underlying assumptions. In Figure 11, the modeled retreat lines shown for the (2030) 0.300 m, (2050) 0.610 m, and (2100) 1.67 m sea level rise increases are the same no matter when those levels are actually reached.

9 PROJECTED ALONGSHORE SAND TRANSPORT

The former US Army Coastal Engineering Research Center "CERC" equation was used to model projected longshore sand transport (Q_l) at three-hour time steps from 2012-2100 with USGS forecast wave data and parameters (Tp, Dp, Hs, MOP depth). Analysis was conducted on TerraCosta/ESA transect locations using the closest available MOP location. Transect orientation was computed as degrees from North (Figure 6). The breaker wave height (Hb) was solved for iteratively.

$$Q_l = K \frac{\rho g^{0.5}}{16 k^{0.5} (\rho_s - \rho)\,(1-n)} H_b^{\frac{5}{2}} \ \sin(2\ \alpha b) \quad \text{where,}$$

k = breaker index (assumed 0.78)

K = 0.39 (dimensionless coefficient)

ρ_s = density of sediment

ρ = density of seawater

n = pore space factor (assumed 0.4)

g = gravitational constant

Hb = breaker wave height

α_b = breaker wave angle relative to beach

Figure 13 shows a typical time series of the modeled longshore sand transport. In the northern part of the study area, the direction of mean longshore transport rates was scattered but generally northward (Figure 14). In the southern part of the study area the direction was consistently southward. The shape of the Santa Monica Bight and shoreline orientation with respect to the prevailing waves cause the differences in longshore transport direction. Scattered longshore rates in the northern study area resulted from local headlands and points that irregularly alter the breaking wave direction. The center of the study area shows little net transport. Actual longshore transport in the study area is significantly affected by harbors and groins and not modeled here.

10 RECOMMENDATIONS

1. Continue to lead and promote local, regional, state, and federal efforts to monitor and model beach conditions.

2. Monitor all LA Region beaches at least annually in the fall, or more frequently if possible, to provide data to establish the reliability of beach change models and to improve these models, which are needed for projections of future conditions.

3. Facilitate continued delivery of any opportunistic sand supplies that become available for area beaches.

4. Document times, locations, and extent of overtopping, flooding, and erosion undermining of important regional infrastructure, including Pacific Coast Highway, to aid in planning future geotechnical and engineering adaptations.

5. Document times, locations, and extent of cliff failures and other erosion events to aid in developing and planning geotechnical adaptations.

LIMITATIONS

Coastal engineering and science, especially projections of possible future conditions, are characterized by uncertainty. Model results and the related professional judgments presented herein are based on our scientific research experience, our understanding of the Los Angeles area coast, and on evaluation of the technical information and data gathered and produced. Our technical work meets current professional standards. However, we do not guarantee the accuracy or applicability of the modeled shoreline change projections in any respect.

ACKNOWLEDGEMENTS

We gratefully acknowledge the interest and support of the City of Santa Monica, especially Garrett Wong. We appreciate the efforts of our colleagues Matt Brennan, James Jackson, and Bob Battalio at ESA, David Revell of ESA and Revell Coastal, and Patrick Barnard, Li Erickson, and Andrea O'Neill of USGS who provided most of the input data used in this work, and the participation, guidance, and coordination offered by Nick Sadrpour, Alyssa Newton Mann, Phyllis Grifman, and Juliette Finzi Hart of USC Sea Grant. We could not have undertaken or completed this study without their help.

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FIGURES

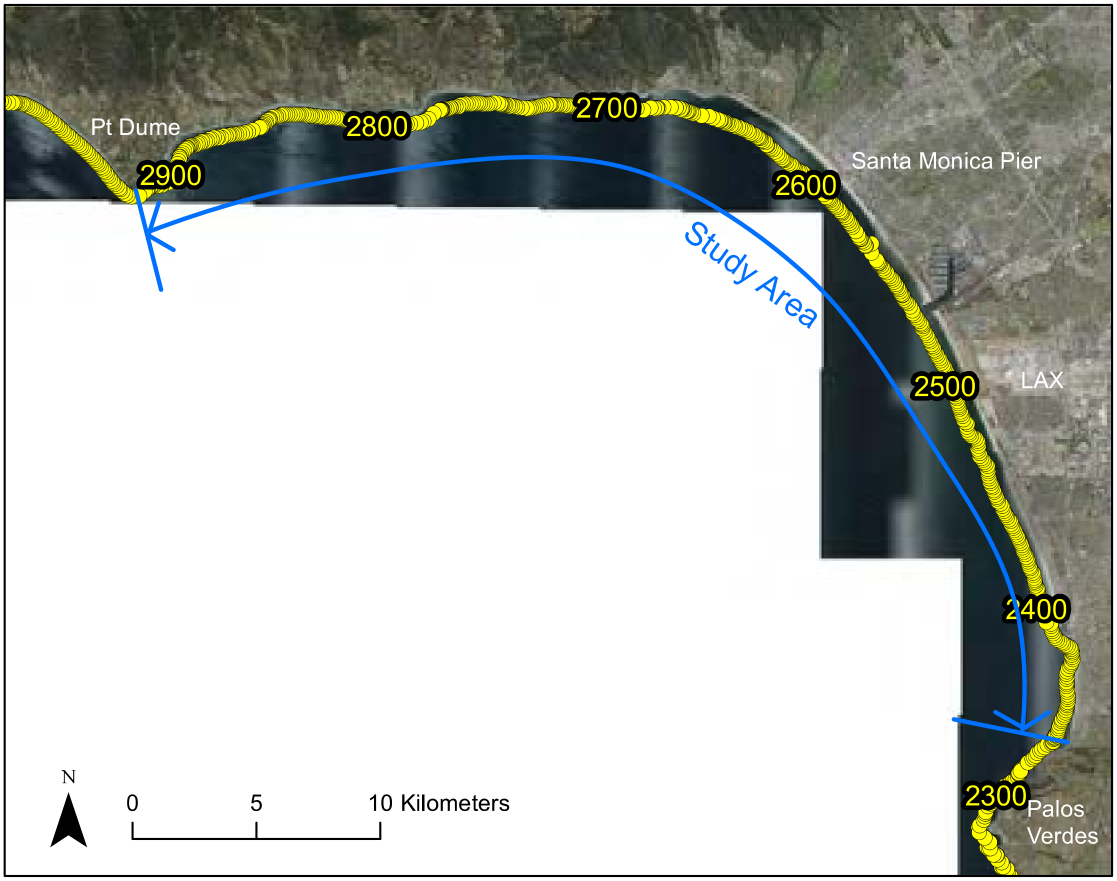

Figure 1. Los Angeles region TerraCosta study area with MOP transects locations.

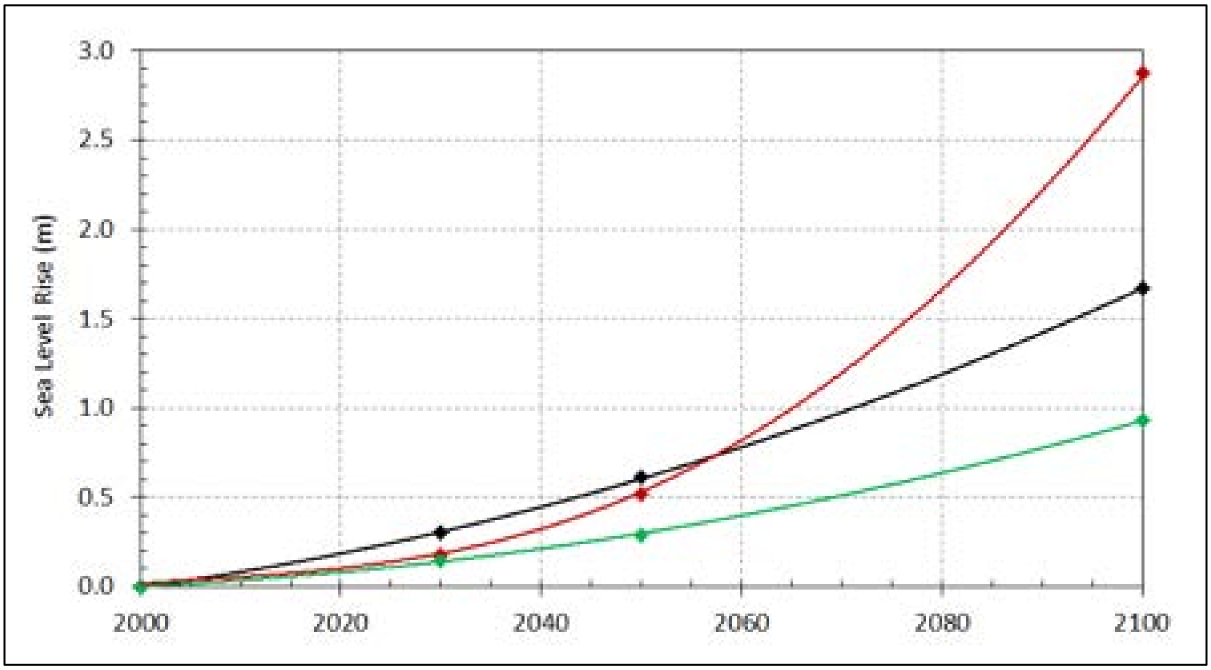

Figure 2. Sea level rise scenario projections (green, black) used in the coastal change modeling and (red) used only for discussion purposes (see text).

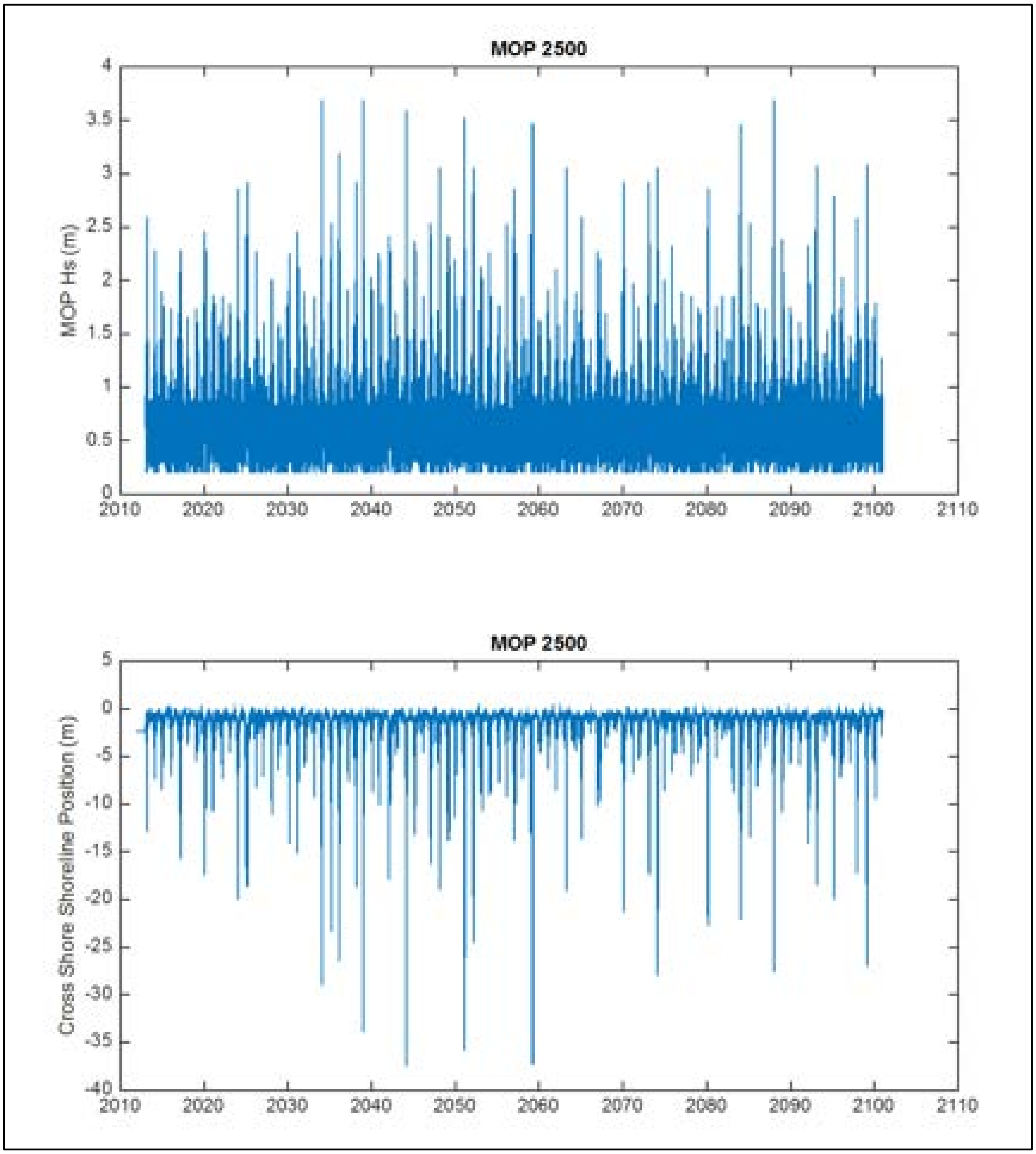

Figure 3. Example time series of wave height (upper) and shoreline fluctuation (lower) from Yates *et al.* (2009) model at MOP 2500.

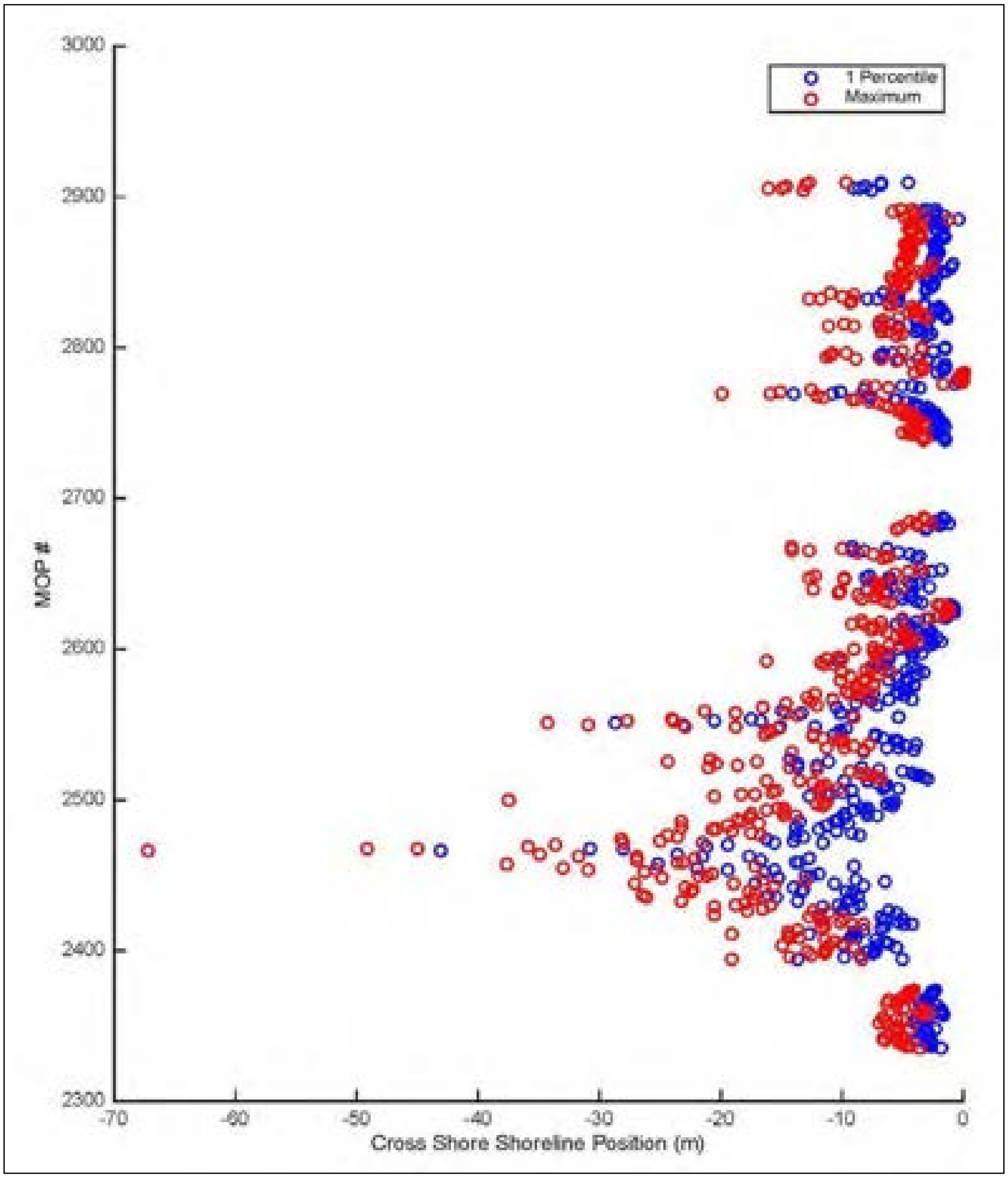

Figure 4. Wave-driven shoreline erosion for the 1%tile (100-year) return period (blue), and maximum (red) events as a function of location (MOP transect).

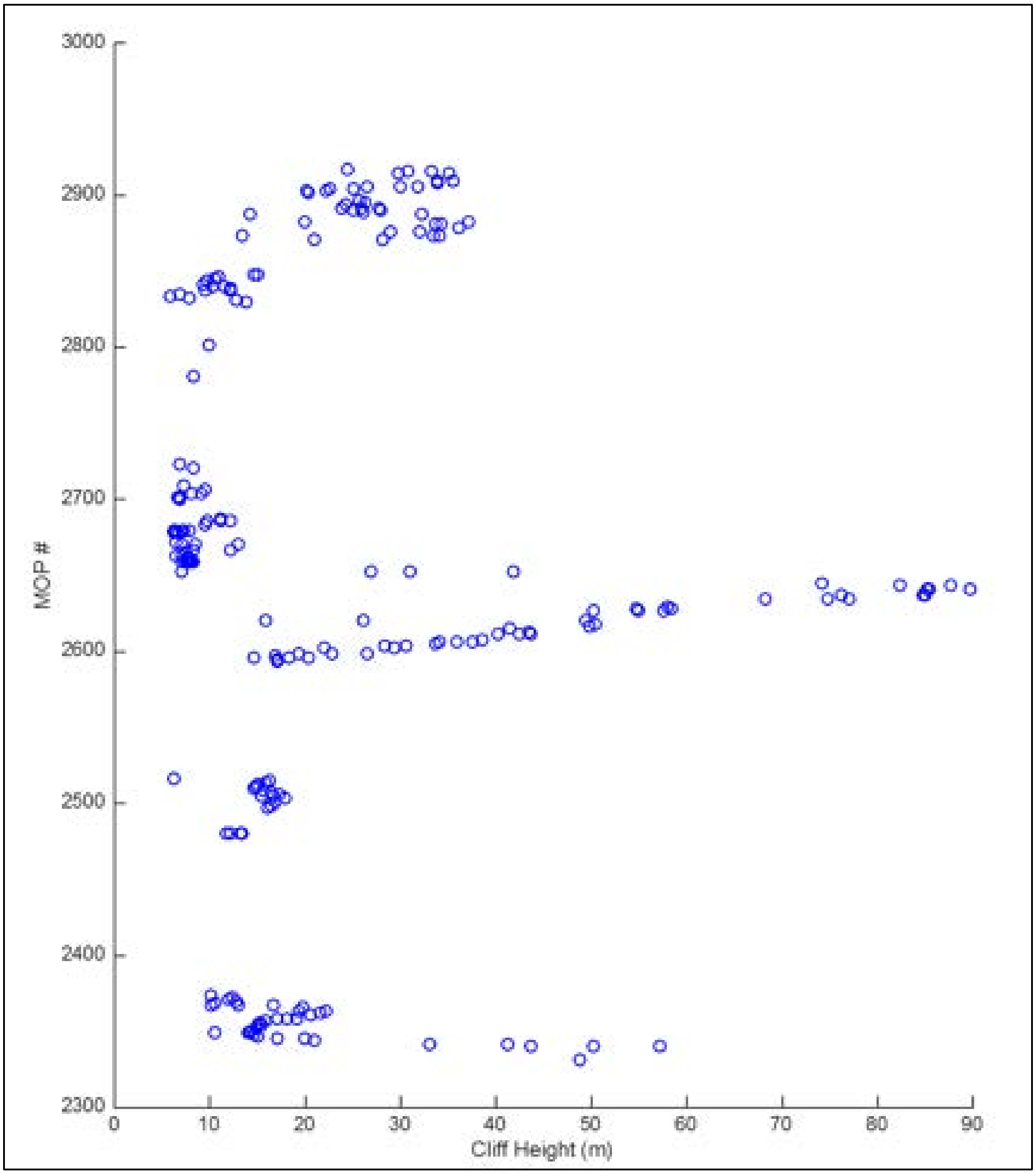

Figure 5. Cliff height as a function of location (MOP transect).

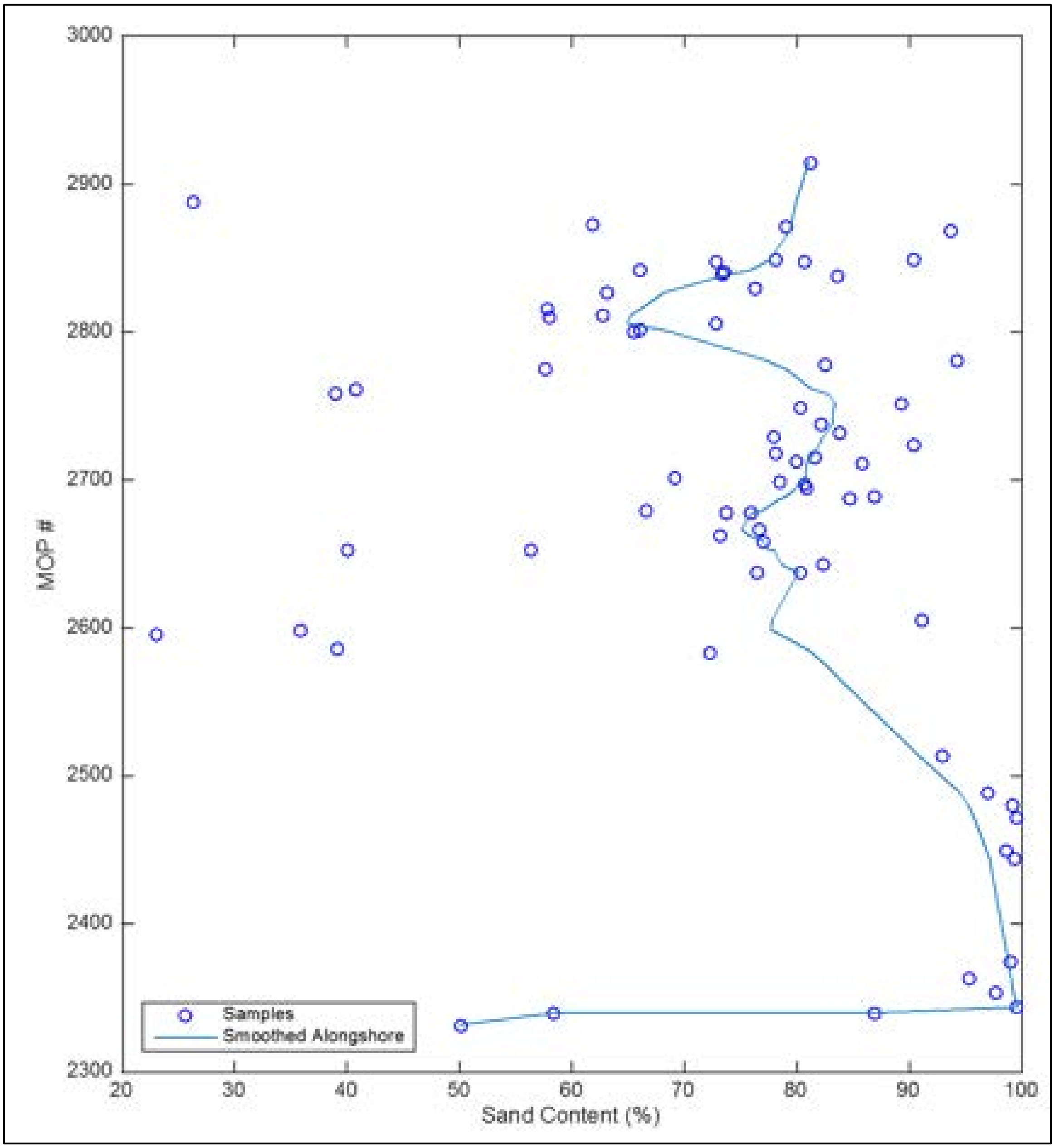

Figure 6. **Backshore sand content at sample locations (circles), and smoothed alongshore values used for model input.**

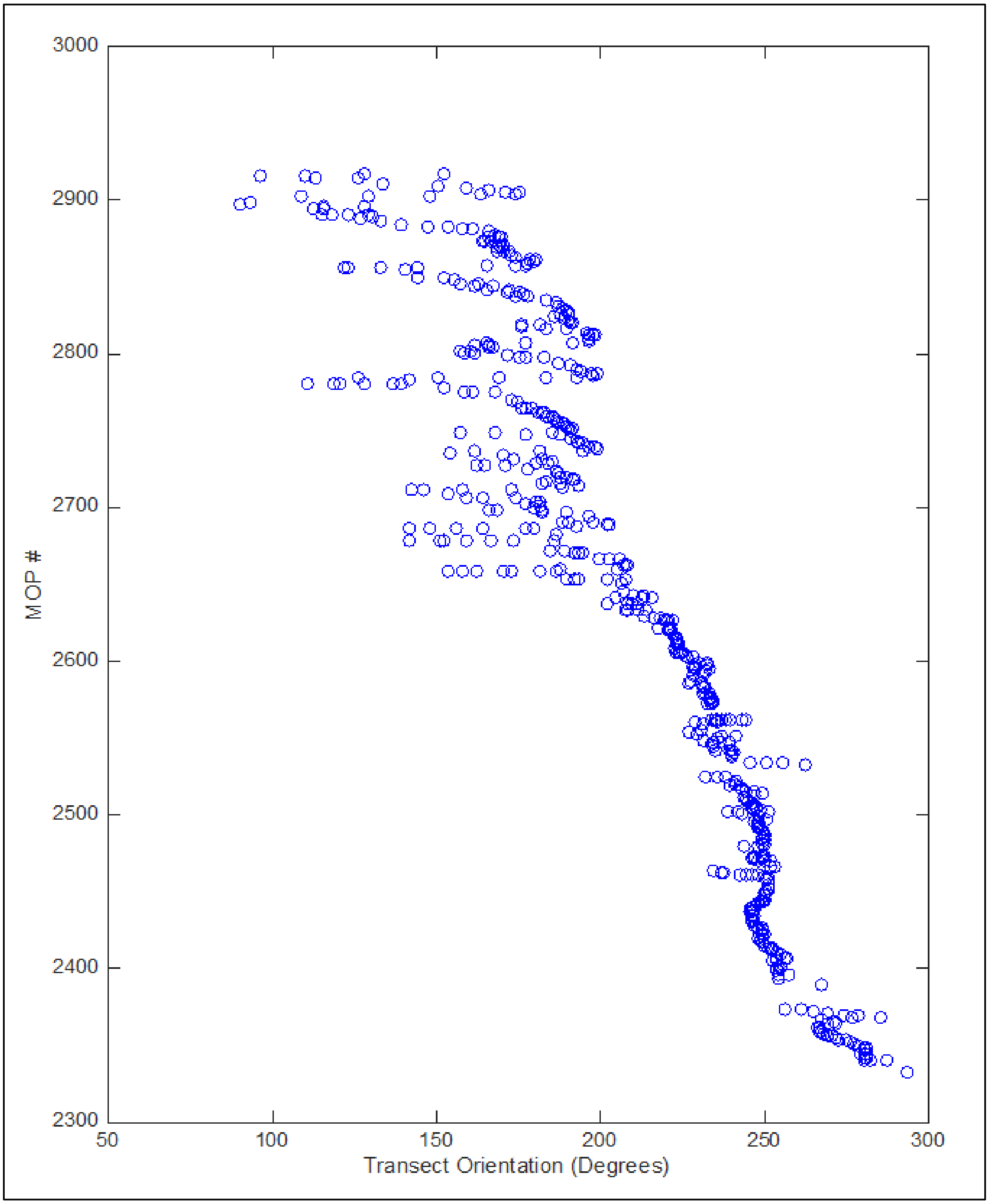

Figure 7. MOP transect orientation.

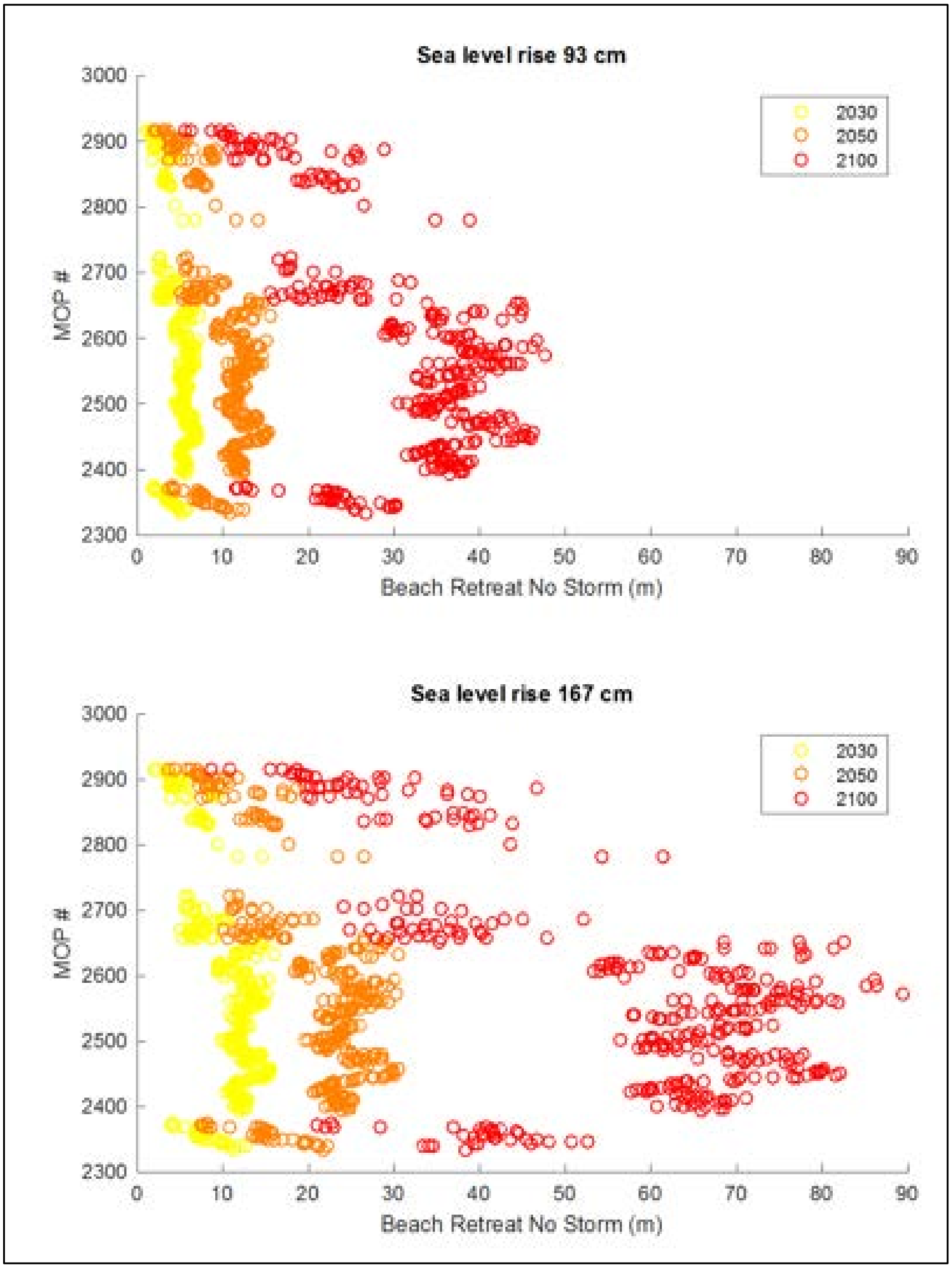

Figure 8. **Beach retreat from sea level rise by 2030, 2050, 2100 for 0.93 m scenario (upper), and 1.67 m scenario (lower), not including wave effects.**

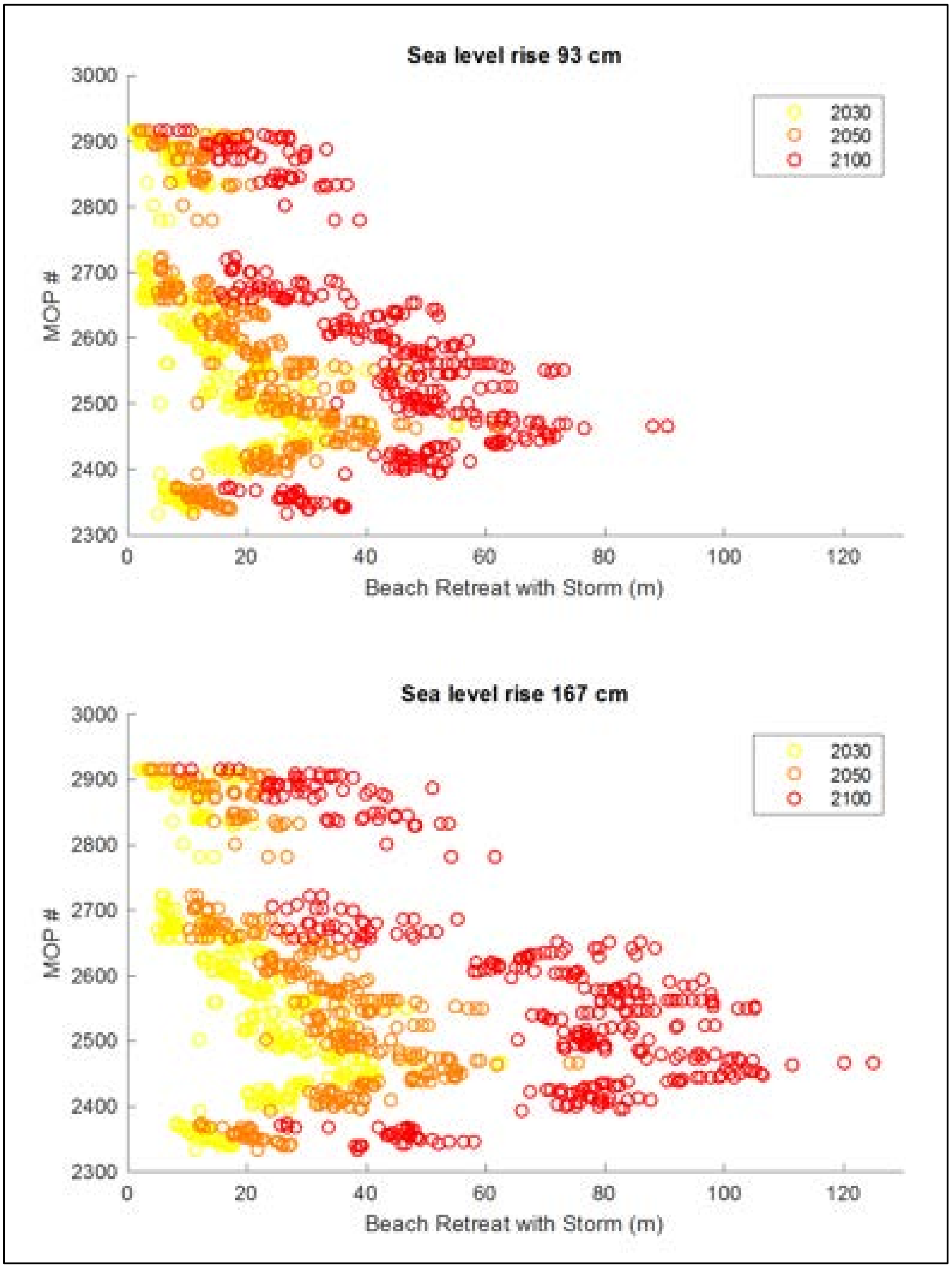

Figure 9. **Same as Figure 8, but including sea level rise beach retreat and added maximum storm erosion from Yates *et al.* (2009) shoreline change model.**

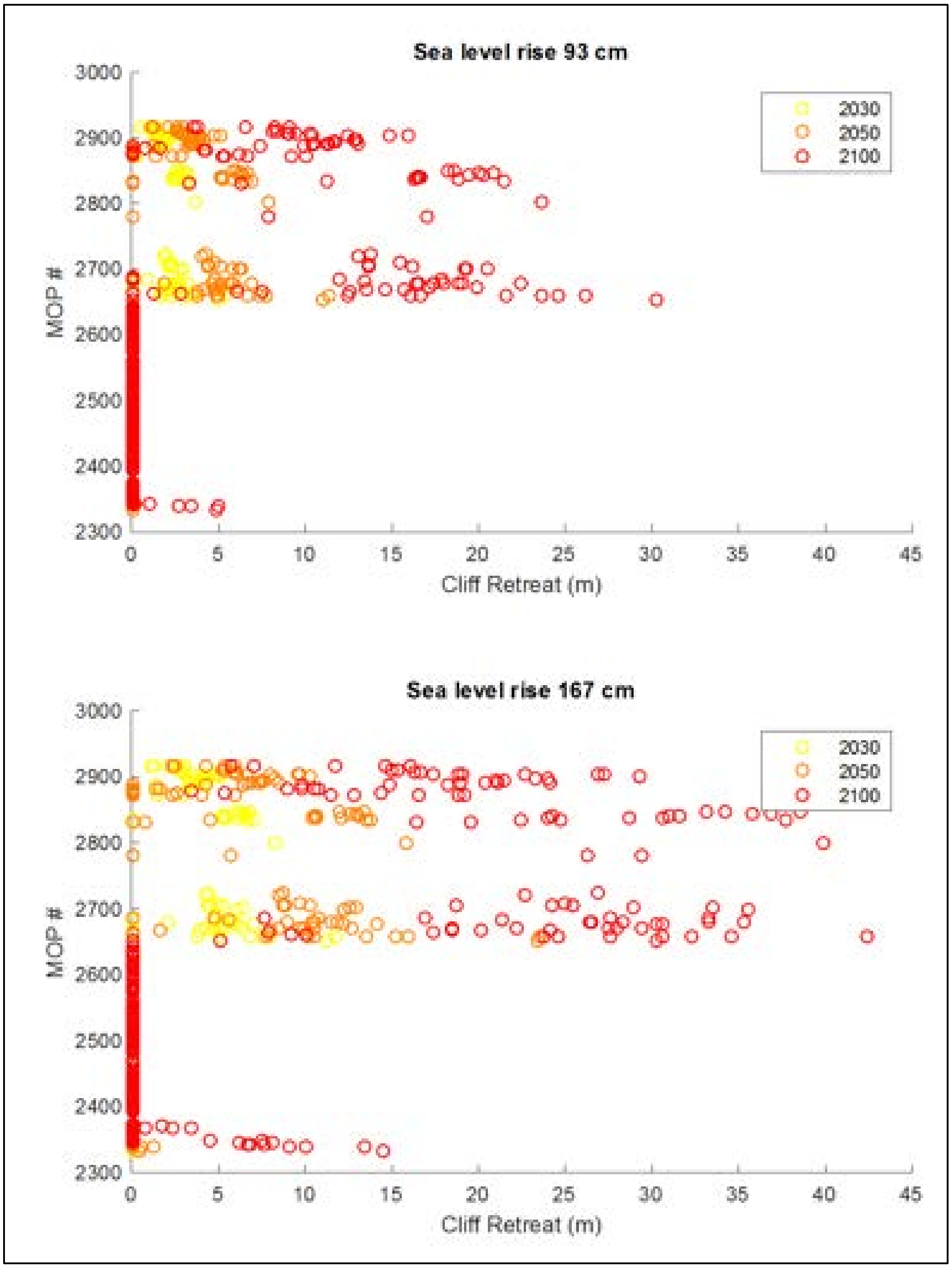

Figure 10. Cliff retreat from sea level rise by 2030, 2050, 2100 for 0.93 m scenario (upper), and 1.67 m scenario (lower).

Figure 11. Shoreline retreat from sea level rise by 2030, 2050, and 2100 for the 1.67 m scenario in the Santa Monica Pier vicinity.

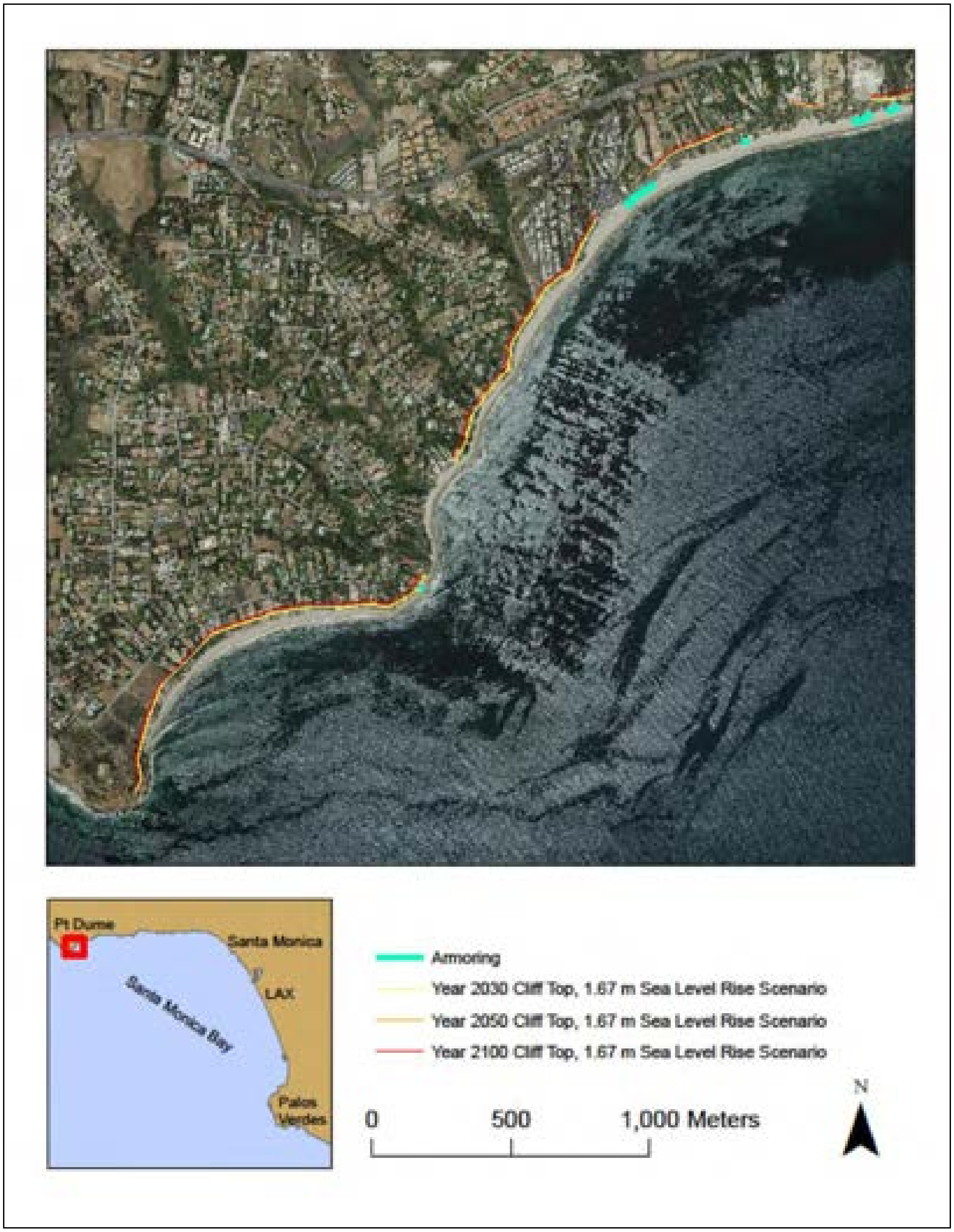

Figure 12. Same as Figure 11 for Malibu east of Pt Dume.

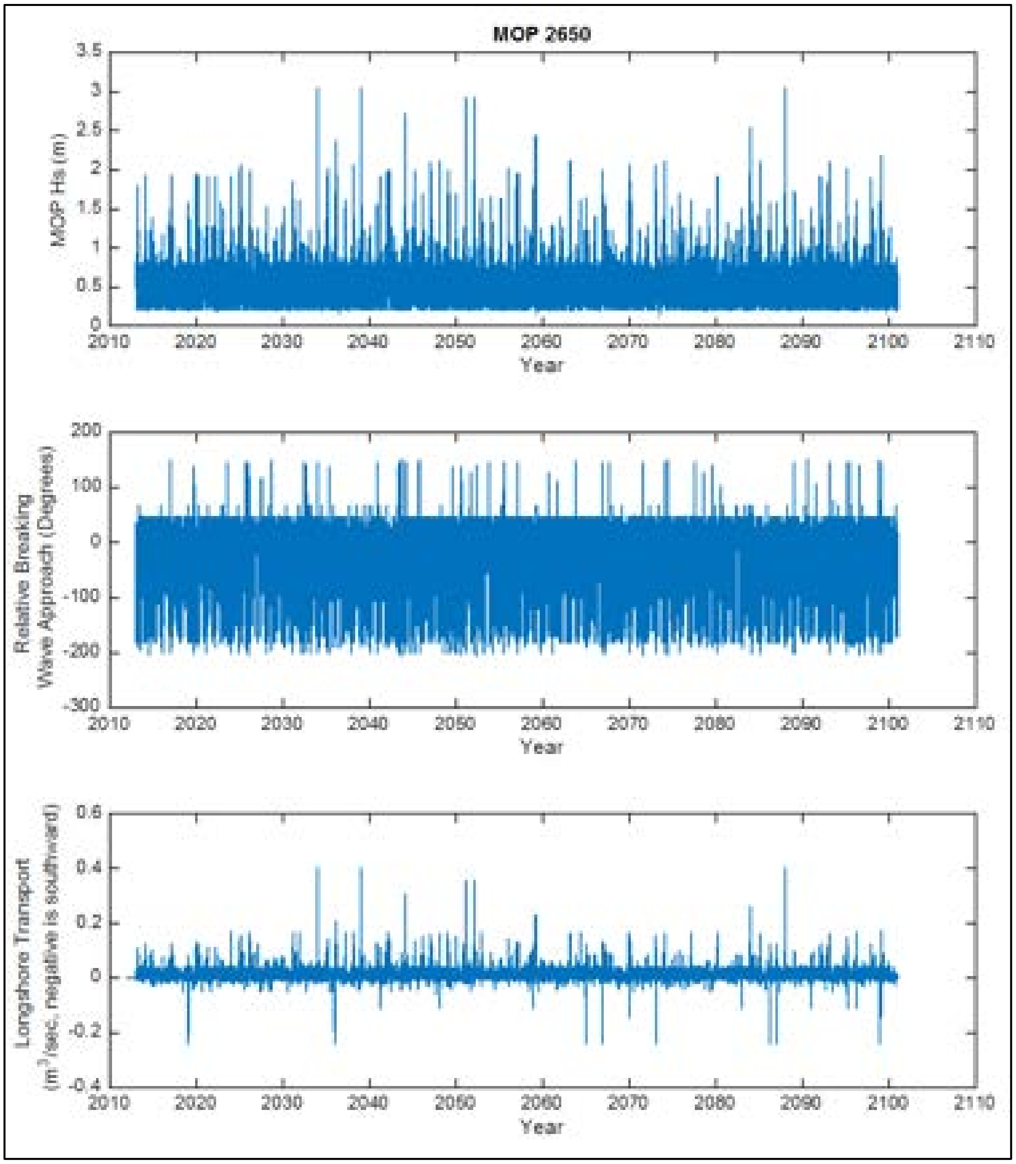

Figure 13. Example of time series of wave height (upper), breaker angle (middle), and model projected longshore sand transport rate from 2012-2100 at MOP 2500.

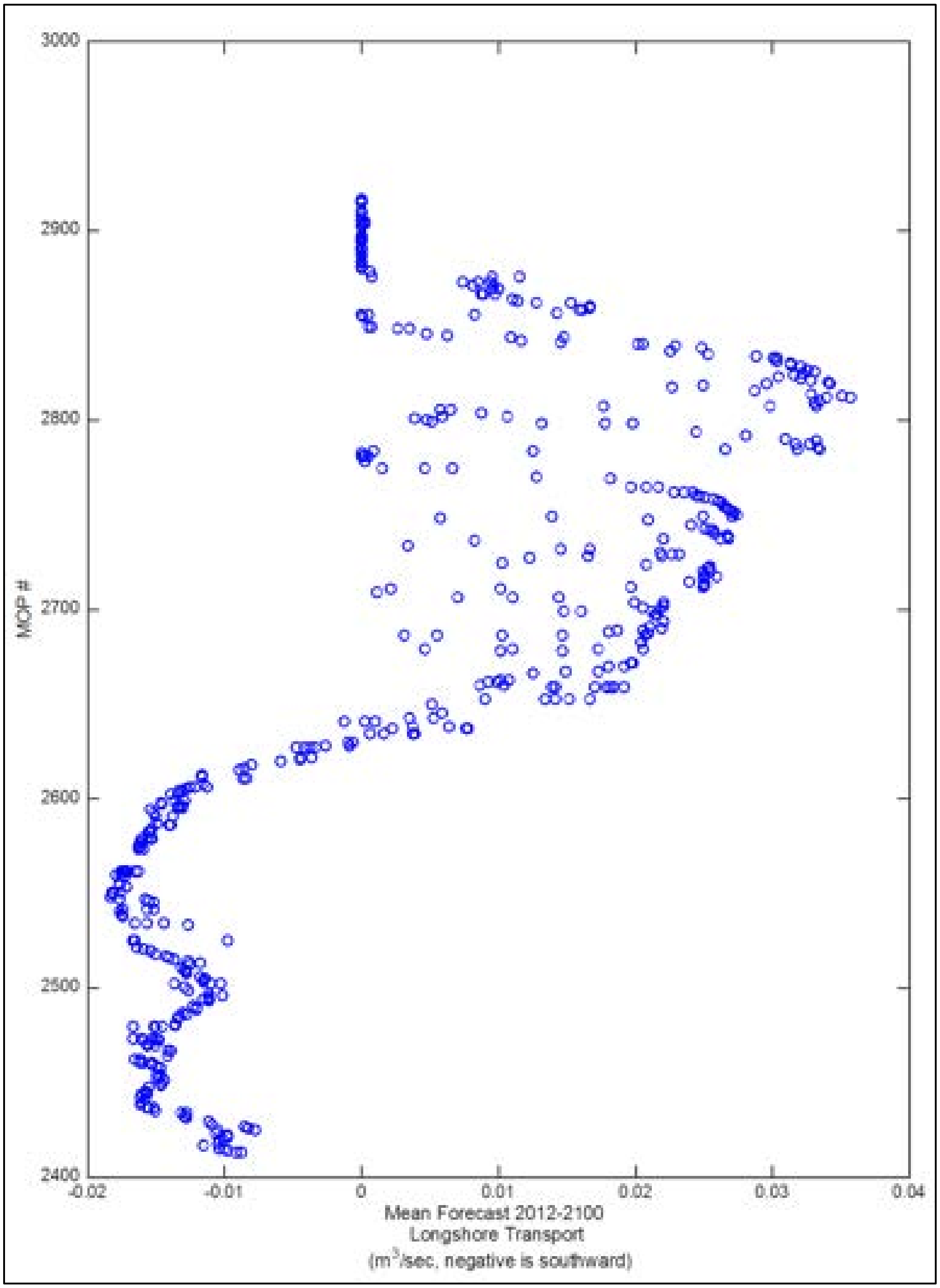

Figure 14. Projected mean longshore sand transport rate averaged from 2012-2100.

Appendix 2

Los Angeles County Coastal Hazard Modeling and Vulnerability Assessment
Prepared by: Environmental Science Associates

Los Angeles County Coastal Hazard Modeling and Vulnerability Assessment

Technical Methods Report

Prepared for
City of Santa Monica

December 23, 2016

TABLE OF CONTENTS

Figures

Tables

Appendices

1. INTRODUCTION

1.1 Purpose

This report presents technical documentation of the methods used to map coastal erosion and flood hazards under projected future climate scenarios for the entire coast of Los Angeles County (County), California (Figure 1). This report supplements the metadata associated with each geospatial dataset by documenting the input data (Section 3), hazard mapping methods (Sections 4-7), and vulnerability analysis (Section 9).

1.2 Background

Los Angeles County is a valuable economic and environmental section of the California coast. Much of the County's coast is eroding, including almost all exposed cliffs and approximately one third of beaches, and some of the developed areas are in the current 100-year flood plain. Both erosion and flooding are expected to increase with sea level rise (SLR). The City contracted ESA to assess the potential impacts of sea level rise on major coastal hazards: erosion, and periodic and episodic flooding.

This Los Angeles County Coastal Hazard Assessment follows the approach ESA developed for The Nature Conservancy's Coastal Resilience Ventura project.[1] For Los Angeles County, ESA, the City of Santa Monica, USC Sea Grant and others are working with local communities to assess the County coastline's vulnerability to potential future impacts of sea level rise.

This project is funded by the Ocean Protection Council (OPC) under the "Local Coastal Program (LCP) Sea Level Rise Adaptation Grant" program and jointly administered by the State Coastal Conservancy (SCC) and California Coastal Commission (CCC). This funding is available for work that supports LCP updates specifically to address sea-level rise, including sea-level rise modeling, vulnerability assessments, adaptation planning, and policy development.

This grant effort was administered by the City of Santa Monica, but was conducted with guidance and close collaboration with 11 participating jurisdictions. As part of this project, USC Sea Grant and ESA also facilitated a stakeholder group to solicit input from local organizations and agencies.

Project collaborators included the University of Southern California (USC) Sea Grant Program; TerraCosta Consulting Group (TCG); and the United States Geological Survey (USGS). USC Sea Grant provided technical coordination and public outreach. TCG provided sea level rise projection guidance and assessed coastal erosion with complimentary methods. The USGS shared data and predictions from their Coastal Storm Modeling System (CoSMoS) for Southern California (also funded by SCC). Other participants included the Los Angeles Regional Collaborative on Climate Action and Sustainability (LARC); Adapt LA, a Los Angeles regional capacity building initiative also funded by the SCC; Heal the Bay; and the Santa Monica Bay Restoration Commission (SMBRC).

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[1] A partnership project with Ventura County, Naval Base Ventura County, and the incorporated Cities of Ventura, Oxnard and Port Hueneme and the Nature Conservancy. See http://coastalresilience.org/

1.3 Previous Coastal Hazards Analysis

Multiple coastal hazards assessments already exist for the Los Angeles study area:

- FEMA flood hazard maps, which are used for the National Flood Insurance Program, present coastal and fluvial flood hazards; however, the current effective maps were published in the 1980s and are believed to underestimate coastal flood hazards. FEMA is currently updating coastal flood hazard maps according to the 2005 Pacific Coast Guidelines (FEMA 2005a). The extent of flood hazards is expected to increase because of changes in FEMA methodology and sea level rise since the 1980s. These maps will only assess existing hazards and will not consider future erosion or projected sea level rise. Provisional updated maps were released in 2016 (personal communication with FEMA IX). The latest FEMA National Flood Hazard Layer is hosted online via an ArcGIS webmap[2].

- In 2012, the NOAA Coastal Services Center created the Digital Coast Sea Level Rise and Coastal Flooding Impact Viewer[3] for the entire U.S. coastline. Users of the viewer can view flooding by existing high tide (Mean Higher High Water) and see how this daily area will change with 1-ft increments of sea level rise. A “confidence” layer, based on uncertainty in the LiDAR surface and modeled tidal surface, classifies hazard areas as high or low confidence. The Viewer also displays qualitative water depth and classifies disconnected low-lying areas separately. The Viewer does not present storm hazards such as extreme tides and wave run-up, and coastal erosion is not considered.

- Tsunami inundation maps, developed by the California Emergency Management Agency (CalEMA), the University of Southern California, and the California Geological Survey, are also available for the entire state of California.

- In 2009, Philip William and Associates, Ltd. (PWA, now ESA) was funded by the Ocean Protection Council to provide the technical hazards analysis supporting the Pacific Institute report on the “Impacts of Sea Level Rise to the California Coast” (“The Pacific Institute study,” PWA 2009). In the course of this work, PWA projected future coastal flooding hazards for the entire state based on a review of existing FEMA hazard maps. In addition, PWA projected future coastal erosion hazard areas for the northern and central California coastline, ending at Santa Barbara. These hazard areas were used in the Pacific Institute study, which evaluated potential socio-economic impacts of sea level rise. The maps completed as part of the Pacific Institute study specifically stated that the results were not to be used for local planning purposes, given the use of “best statewide available data sets”; however, the modeling methods (Revell et al 2011) were developed to be readily re-applied as improved regional and local data became available. An example of coastal flooding hazards mapped in LA for the Pacific Institute study is shown in Figure 2.

- Noble Consultants provided a storm and tidal waves study for the Los Angeles region to the USACE (Noble 2010). The study consisted of an assessment of historic and existing conditions of the coastline, quantification of shoreline changes, evaluation of oceanographic conditions (coastal flooding by waves and tides) considering local environmental and man-made interventions, and formulation of a sand management plan for the County’s coastline.

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[2] http://fema.maps.arcgis.com/home/webmap/viewer.html?webmap=cbe088e7c8704464aa0fc34eb99e7f30

[3] “NOAA SLR Viewer” available at http://coast.noaa.gov/slr/

- Noble also prepared a sea level rise vulnerability assessment for Los Angeles County public beach facilities, funded by Climate Ready Grant No. 13-085 from the CA Coastal Conservancy (Noble 2016). The study area covered all public beach facilities spanning from Nicholas Canyon County Beach to Point Fermin Beach.

The present study has improved the methods from the Pacific Institute Study and applied them to the Los Angeles County study area with higher-resolution local data and review by local experts. This work builds upon enhancements developed during the mapping of Ventura County (ESA 2013), Monterey Bay (ESA 2014) and Santa Barbara County (ESA 2015a). These improved methods provide projections of future coastal hazards that are suitable for local planning processes (e.g. LCP) and General Plan updates, and permit applications).

1.4 Los Angeles County Study Area

This study assesses coastal hazards along approximately 65 miles of coastline from the Ventura-Los Angeles County border to the Los Angeles-Orange County border, excluding the Ports of Los Angeles and Long Beach (Figure 1). The coastline from Ventura County east to Point Dume is characterized by a series of sea cliffs that are punctuated by private and public development and state beaches. East of Point Dume to Will Rodgers State Beach, the coastline is dominated by oceanfront homes and the Pacific Coast Highway, fronting the mountainous coast, and beaches are narrow to non-existent. Armoring along this stretch of coast indicates the existing coastal hazards there. Wider beaches emerge at Will Rodgers State Beach and south along the Santa Monica Bay shoreline to Malaga Cove, a result of numerous historic beach nourishment projects supplied with sand from dredging of Marina Del Rey and Redondo Harbors, as well as other regional offshore and beneficial reuse projects. Inland from the northern Santa Monica Bay beaches, the backshore descends to flat coastal plains, while further south the backshore is comprised of a mix of developed dunes and short cliffs. The shore stretching around Palos Verdes to Cabrillo Beach and the LA Harbor breakwater is comprised of steep eroding cliffs with little to no beach. East of the Port of Long Beach is the Long Beach / Belmont Shore, which is protected by a breakwater system. Additional information can be found in Griggs, Patsch and Savoy (2005).

1.5 Disclaimer and Use Restrictions

Funding Agencies

These data and this report were prepared as the result of work funded by the Ocean Protection Council (OPC) and jointly administered by the State Coastal Conservancy (SCC) and California Coastal Commission (CCC) (“funding agencies”). The data and report do not necessarily represent the views of the funding agencies, their respective officers, agents and employees, subcontractors, or the State of California. The funding agencies, the State of California, and their respective officers, employees, agents, contractors, and subcontractors make no warranty, express or implied, and assume no responsibility or liability, for the results of any actions taken or other information developed based on this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. These study results are being made available for informational purposes only and have not been approved or disapproved by the funding agencies, nor have the funding agencies passed upon the accuracy, currency, completeness, or adequacy of the information in this report. Users of this information agree by their use to hold blameless each of the funding agencies, study participants and authors for any liability associated with its use in any form.

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The data are provided "as is" without any representations or warranties as to their accuracy, completeness, performance, merchantability, or fitness for a particular purpose. Data are based on model simulations, which are subject to revisions and updates and do not take into account many variables that could have substantial effects on erosion, flood extent and depth. Real world results will differ from results shown in the data. Site-specific evaluations may be needed to confirm/verify information presented in this dataset. This work shall not be used to assess actual coastal hazards, insurance requirements, or property values, and specifically shall not be used in lieu of Flood Insurance Studies and Flood Insurance Rate Maps issued by FEMA.

The entire risk associated with use of the study results is assumed by the user. The City of Santa Monica, ESA and all of the funders shall not be responsible or liable for any loss or damage of any sort incurred in connection with the use of the report or data.

2. SUMMARY OF COASTAL HAZARD ASSESSMENTS

This section summarizes this project's coastal hazard assessments, as represented by the project's GIS deliverables, and points to the relevant sections in this document that describe how each was developed. An example map is included for each type of data. A complete list of GIS deliverables is provided in Appendix 1. Hazard zones were developed for existing conditions (2010) and three planning horizons (2030, 2050, and 2100) based on direction received during the County stakeholder process and consistent with the California Coastal Commission guidance on sea level rise (CCC, 2015). Two future sea level rise scenarios (Medium and High) were assessed for each type of hazard. In addition, an extreme sea level rise scenario was considered, in which the 2100 high scenario occurs earlier, in 2080. These scenarios are summarized in Section 3 and are described in detail in Section 0. All GIS deliverables are provided in the NAD 1983 datum and UTM Zone 11N projection. Horizontal units are in meters.

2.1 Shoreline Erosion Hazard Zones (Sections 5.1 & 5.2, Figure 3)

These zones represent future long-term and storm-induced dune and shoreline erosion hazard zones. Model results incorporate site-specific historic trends in erosion, additional erosion caused by accelerating sea level rise, and (in the case of the "storm erosion hazard zones") the potential erosion impact of a large storm wave event. The inland extents of the hazard zones represent projections of the future crest of the dunes or shoreline position for a given sea level rise scenario and planning horizon.

- Long-term erosion hazard zones
  8 polygon shapefiles: Existing conditions eroded dune/shoreline zone plus 3 planning horizons x 2 SLR scenarios plus extreme SLR scenario

- Storm erosion hazard zones*8 polygon shapefiles: storm erosion from existing dune/shoreline plus 3 planning horizons x 2 SLR scenarios plus extreme SLR scenario*

2.2 Cliff Erosion Hazard Zones (Sections 5.3 & 5.4, Figure 4)

These zones represent cliff erosion hazard zones between the existing cliff edge and the projected future cliff edge. These results are derived by incorporating site-specific historic trends in erosion, additional erosion caused by accelerating sea level rise, and a factor of safety to account for alongshore variability in cliff erosion rates. The inland extent of the hazard zone represents the future cliff edge projected for each planning horizon and future scenario.

- Long-term erosion hazard zones
  8 polygon shapefiles: existing cliff zone plus 3 planning horizons x 2 SLR scenarios plus extreme SLR scenario

- Cliff erosion with factor of safety hazard zones (erosion rate uncertainty)
  8 polygon shapefiles: existing cliff zone with uncertainty buffer plus 3 planning horizons x 2 SLR scenarios plus extreme SLR scenario

- Landslide hazard zone (Palos Verdes only)
  1 polygon shapefile for potential landslide hazard

- Terrestrial erosion zone
  4 polygon shapefiles: existing terrestrial erosion zone plus 3 planning horizons (not SLR dependent)

2.3 Coastal Storm Flood Hazard Zones (Section 6.1, Figure 5)

These hazard zones depict flooding that may be caused by a coastal storm and are described separately by mechanism. The processes considered include (1) elevated ocean levels due to climate effects (e.g. elevated water levels during El Niño phases) and storm surge (a rise in the ocean water level caused primarily by winds and pressure changes during a storm), (2) wave run-up (includes wave setup and waves running up over the beach and coastal property (calculated using the computed 100-year total water levels), (3) extreme lagoon water levels, which can occur when lagoons fill up when the mouths are closed (using maximum potential beach berm elevations), and (4) additional flooding caused by rising sea level in the future. These hazard zones do NOT consider upland fluvial (river) flooding and local rain/run-off drainage, which likely play a large part in coastal flooding, especially around coastal confluences where the creeks meet the ocean. For item (1) “elevated ocean levels”, the 100-year recurrence water level based on tide gauge data was used.

- Storm flood hazard zones
  8 polygon shapefiles: existing conditions and 3 planning horizons x 2 SLR scenarios plus extreme SLR scenario

  There are two types of storm flood areas: (1) areas that appear to have a surface connection over the existing digital elevation through low topography, and (2) other low-lying areas that don’t have an apparent connection, as indicated by the digital elevation model, but are low-lying and flood prone from groundwater levels and any connections (culverts, underpasses) that are not captured by the digital elevation model. This difference is captured in the “Connection” attribute (either “connected” or “connectivity uncertain”) in each geospatial dataset. We recommend these be mapped as separate colors, as shown in Figure 5*).*

2.4 Extreme Monthly Tidal Flooding Zones (Section 6.2, Figure 6 & Figure 7)

These zones show the area and depth (in meters) of flooding caused by rising tide and groundwater levels (not considering storms, erosion, or river discharge). The water level mapped in these flooding areas is the Extreme Monthly High Water (EMHW) level, which is a high water level that is reached approximately once a month (2.0 m (6.55 ft) NAVD, calculated from LA Harbor Tide gauge data). These zones do not, however, consider coastal erosion or wave overtopping, which may change the extent and depth of regular tidal flooding in the future.

- Potential tidal flooding area of Extreme Monthly High Water (Figure 7)
  8 polygon shapefiles: existing conditions and 2 planning horizons x 3 SLR scenarios plus extreme SLR scenario

  Note: There are two types of tidal flooding areas: (1) areas that appear to be connected over the existing digital elevation through low topography, and (2) other low-lying areas that don't have an apparent connection, as indicated by the digital elevation model, but are low-lying and flood prone from groundwater levels and any connections (culverts, underpasses) that are not captured by the digital elevation model. This difference is captured in the "Connection" attribute (either "connected" or "connectivity uncertain") in each geospatial dataset. We recommend these be mapped as separate colors, similar to the NOAA SLR Viewer (described in Section 1.3).

- Depth of water within the rising tidal flooding zone (in meters) (Figure 8)
  8 rasters (1 meter cell size): existing conditions and 3 planning horizons x 2 SLR scenarios plus extreme SLR scenario

  Note: A value of 999 represents areas where depth data is voided for the input digital elevation model.

2.5 Spatial Aggregation Relative Risk Zones (Section 7, Figure 8)

These data layers represent the overlap of all of the scenarios and hazards mapped through 2100. The intent is to represent the uncertainty associated with the various projections by clearly illustrating which areas are always hazardous at a given time horizon and which areas are only hazardous during more extreme scenarios of sea level rise and storminess. To the extent that this project is used to make individual permit decisions, it is our recommendation that this spatial aggregation layer be used to evaluate the potential coastal hazards for a specific location. The higher the attributed number, the more likely the area is to become exposed to coastal hazards.

3. INPUT DATA

This study relied upon multiple existing data as input for the coastal hazard assessments. This section describes the data types, sources, and extents.

3.1 Planning Horizons and Sea Level Rise Projections

The selected planning horizons of 2030, 2050, and 2100 were based on stakeholder input. These planning horizons are consistent with the recent guidance document from the California Coastal

Commission (CCC, 2015) and therefore suitable for use in the LCP process. The CCC (2015) guidance recommends scenario-based planning by examining the consequences of multiple sea level rise projections, as well as extreme water levels and waves associated with storms. The two primary sea level rise scenarios used in this project are based on the study by the National Research Council (NRC, 2012) that has been adopted as State guidance (OPC, 2013).

The Medium and High sea level rise projections are based on the ranges for Los Angeles in NRC (2012)'s Table 5.3. Sea level rise policy guidance from the California Coastal Commission (CCC, 2015) recommends using the regional values reported in NRC (2012) and provides polynomial fit functions for projecting SLR for the High scenario (Equation B4 in CCC (2015)'s Appendix B: Developing Local Hazard Conditions). NRC (2012) provides sea level rise amounts relative to 2000, rather than 2010 (the baseline year for this study), but following CCC (2015) guidance, sea level rise was assumed to be zero for the 2010 baseline. This project's SLR projections used for the Medium and High scenarios are shown in Table 1. for this project's selected planning horizons. These SLR projects are also depicted as continuous curves in Figure 9.

Ongoing discussions on the state level suggest that there will be revised guidance on what SLR scenarios should be considered. Revised guidance will probably recommend that the Low scenario (42 cm by 2100) should not be considered. The Low scenario is largely based on 20th century sea level rise rates, which are unlikely given current emission and sea level rise trends (Cayan et al., 2016). In addition, revised guidance will probably recommend that an extreme scenario should be considered. The extreme case "is currently considered the maximum of what is physically possible" (Cayan et al., 2016). Accordingly, this study dropped the NRC Low scenario and qualitatively considers the Extreme scenario listed in Table 1 and Figure 9.

Cayan et al. (2016) also provide probabilistic estimates of SLR projections given a specific emission scenario. At 2030 and 2050, the NRC medium projection is between the 50th and 95th percentiles of all the emission scenarios, and the NRC High projection is higher than the 95th percentiles of all the emission scenarios. However, at 2100, the NRC Medium projection is typically between the 25th and 75th percentile for all but the lowest emission scenario and the NRC High projection is exceed by more than three feet by the 95th percentile of the highest emission scenario. The Extreme scenario corresponds to the 99.9th percentile, or conditions that only have a 1-in-1,000 chance of being exceeded.

Table 1. Sea level rise projections used in this study,

Year	Sea Level Rise Scenarios		
	Medium SLR*	***High SLR****	***Extreme SLR*****
2030	13.5 cm (5.3 in)	30.7 cm (12.1 in)	17.8 cm (7 in)
2050	29.4 cm (11.6 in)	60.5 cm (23.8 in)	51.9 cm (20.4 in)
2100	93 cm (36.6 in)	167.6 cm (66 in)	288 cm (113 in)

* Based on projected (for Medium scenario) and upper limit (for High scenarios) values for Los Angeles in Table 5.3 of NRC (2012)

** Based on 99.9th percentile for Representative Concentration Pathway 8.5 from Cayan et al. (2016)

The San Andreas regional vertical land motion rate of -1.5 mm/yr (from Table 5.3 of NRC 2012) is included in the Medium and High SLR scenarios in Table 1. . The sea level rise scenarios used in this study are defined as Medium (3 ft SLR by 2100), High (5.5 ft SLR by 2100), and Extreme (9.4 ft SLR by 2100) in this report.

3.2 Aerial Imagery

Digital Orthophotography

ESA downloaded the aerial mosaics from the NOAA Digital Coast Data Access Viewer (NOAA, 2012a). This imagery is the California Coastal ADS40 4-Band 8-bit dataset collected from May to October 2010 as part of the 2009 – 2011 Coastal LiDAR project. This imagery is reported to have 30 cm resolution with a horizontal accuracy of 2 meters or better at the 95% confidence level.

Oblique Aerial Imagery

ESA used the California Coastal Records Project website to identify coastal armoring and other relevant structures along the coast and to inform the backshore characterization. These photos were accessed through the project website (Adelman and Adelman, 2013). The most recent photos in Los Angeles County were collected in September 2013.

3.3 Digital Elevation Model

This study used the same merged digital elevation model (DEM) that was developed by the USGS for the CoSMoS 3.0 modeling effort. The majority of the data in the DEM was derived from the Coastal CA Data Merge Project. It is mostly comprised of the 2013 NOAA Coastal California TopoBathy Merge Project[4], updated with bathymetry in harbors and nearshore areas that were previously devoid of data and interpolated.

Coastal California Data Merge Project

This merged DEM combines topographic and bathymetric elevation data along the entire California coastline (NOAA 2013). Topographic LiDAR data was provided by NOAA, collected for the California Coastal Mapping Project (CCMP). Bathymetric LiDAR data were provided by the Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX), also collected for the CCMP. Multibeam Acoustic data was provided by the California Seafloor Mapping Program (CSMP), Ocean Protection Council, NOAA, and USGS where available.

The topographic LiDAR dataset used in this merged project was from the 2009-2011 CA Coastal Conservancy LiDAR Project. The data were collected between October 2009 and August 2011[5]. This was the primary DEM used for conducting topographic analysis and mapping coastal erosion and flood hazard zones. The dates associated with the 2009-2011 LiDAR were determined from the flight lines, which were important in updating the USGS historic cliff and sandy shore erosion rates.

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[4] https://data.noaa.gov/dataset/2013-noaa-coastal-california-topobathy-merge-project-digital-elevation-model-dem

[5] Additional metadata can be found at: http://www.ngdc.noaa.gov/docucomp/page?xml=NOAA/NESDIS/NGDC/MGG/Lidar/iso/xml/2013_CA_TopoBathy_m2612.xml&view=getDataView&header=none

3.4 Geology

Several geologic maps were used to classify the backshore into contiguous geologic units (Dibblee 1999, Dibblee 2007, Dibblee and Ehrenspeck 1990, Yerkes and Cambpell 1980 and 1994, Campbell et al 1996). Figure 10 shows the spatial distribution of coastal geology. The geology map was used in development of the backshore classification and division of the coast into analysis blocks.

3.5 Tides

The Los Angeles tide gauge (NOAA #9410660) tidal datum was selected because it is within the study area. The primary use of this datum was for shoreline analysis and flood mapping. Mean high water (MHW) was used as the representative elevation for shoreline change analysis (see Section 4.1) and the Extreme Monthly High Water (EMHW) was mapped for the tidal hazard zones (see Section 6.1). These tide levels are listed in Table 2 and the tide gauge's location is shown in Figure 11.

Table 2. Los Angeles tidal datums

Tide	meters, NAVD88	feet, NAVD88
100-year High Water Level*	2.34	7.67
Highest Observed Water Level (Jan 27, 1983)	2.35	7.71
Extreme Monthly High Water**	2.00	6.56
Mean Higher High Water	1.61	5.28
Mean High Water	1.39	4.56
Mean Tide Level	0.81	2.66
Mean Sea Level	0.8	2.62
Mean Low Water	0.22	0.72
NAVD88	0	0
Mean Lower Low Water	-0.06	-0.20
Lowest Observed Water Level	-0.89	-2.92

Notes: The tidal datum analysis period was 1983 - 2001 at National Oceanic and Atmospheric Administration stations #9410660; NAVD88 = North American Vertical Datum of 1988. Sources: Tidal Datums (NOAA, 2005)
* from NOAA Tides & Currents "Exceedance Probability Levels and Tidal Datums," for the Los Angeles tide gauge available at http://tidesandcurrents.noaa.gov/est/est_station.shtml?stnid=9410660. Accessed 9/3/2015.
** Extreme Monthly High Water was calculated by averaging the maximum monthly high water for all monthly data available at the Los Angeles tide gauge (553 months).

3.6 Waves and Water Levels

Wave and water levels were provided by project collaborators at the USGS. These data were predicted for future conditions using the Coastal Storm Modeling System (CoSMoS) implemented for Southern California (Version 3.0).

Regional Wave and Water Level Data

CoSMoS 3.0 combines the inputs of offshore waves with nearshore wind and atmospheric conditions from global climate models to generate synthetic projections of nearshore waves and non-tidal residuals (NTRs) along the southern California coastline. As in previous studies (ESA 2015a), these CoSMoS output data were reviewed by ESA prior to implementation and then used unmodified as inputs to the coastal erosion model and flood calculations (Section 4.2).

Synthetic Nearshore Wave Data: ESA worked with USGS staff to incorporate the wave climate output from global climate modeling of the moderate emission scenario[6]. Future projected wave conditions at a standard offshore location coincident with CDIP Buoy 028 - Santa Monica Bay (labeled MOP 4809, see Figure 11 for location) were compared to real historic records at the buoy. These future predictions were found to be similar to the real wave data. Discussions with USGS indicated this finding to be consistent with their research, with the potential for the highest 1% waves to come from a more westerly direction with more intense global warming[7] Owing to computational demands, wave spectra were not available and only wave parameters were provided by the USGS: significant wave height, peak spectral period, and peak direction. A cumulative distribution comparison of the significant wave height (Hs), peak spectral period (Tp), and peak spectral direction (Dp) for real data from the Santa Monica Bay Buoy (CDIP Station 028) and synthetic data from the global model[8] provided by the USGS (at location MOP 4809 in Figure 11) are shown in Figure 12. Real data spans from 1981-2016; synthetic data is broken up by planning horizon. A comparison of the real and synthetic wave roses (frequency plots of wave direction and height) is shown in Figure 13.

Synthetic Water Levels: The USGS also provided CoSMoS synthetic water level non-tidal residuals (NTRs) that were generated coincident with the synthetic wave data. These data did not include all non-tidal residual constituents but did provide coincident timing that is important to capture the combined effect of storm events on waves and water levels. Synthetic water level NTRs from climate modeling at MOP 2080 (near south LA Harbor entrance) were compared with real data from the Los Angeles Harbor tide gauge. The locations of MOP 2080 and the LA Harbor tide gauge are shown in Figure 11. Overall, the synthetic data has closer agreement with real data than previous CoSMoS results. In Figure 14, the probability density distributions show that the CoSMoS model predictions compare favorably with observed Los Angeles water levels in terms of the mean being slightly greater than LA historic in the near term (2013-2030) and shifting further positive by 2100. In Figure 15, the cumulative distribution is used to show that the higher values of the synthetic distribution are smaller than the observations. This suggests that while the synthetic data are similar to historic in the overall distribution, the highest NTRs are under-predicted. Despite this finding, no modifications were made to the model predictions to remain consistent with CoSMoS nearshore modeling. The unadjusted synthetic NTR data at MOP 2080 were added to projected astronomic tides for the LA Harbor location based on publicly available software called Xtide (a tool from the model Ttide)[9] and used with the synthetic waves.

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[6] The global climate models used moderate emission scenario Representative Concentration Pathway 4.5, often considered similar to the prior B2 "mid-range" climate scenario.

[7] E.g. Representative Concentration Pathway 8.5.

[8] GFDL-ESM2M for climate scenario RCP4.5

[9] http://www.flaterco.com/xtide/ last visited June, 2015.

CoSMoS Model Output Locations

ESA selected 39 locations to represent the varied wave exposure along the Los Angeles County shoreline. CoSMoS 3.0 model coverage spans from Point Conception to San Diego, and includes nearshore model output points at approximately 10-m depth at approximately 100-m spacing alongshore. These selected MOP locations can be seen in Figure 11. Coordinates for the chosen MOP locations are given in Table 3 below.

Table 3. Locations of USGS MOP points used in Los Angeles County study area

MOP ID	Northing UTM Z11 (meters)	Easting UTM Z11 (meters)	MOP ID (cont'd)	Northing UTM Z11 (meters)	Easting UTM Z11 (meters)
1888[1]	3733260.568	395135.1447	2583	3762888.83	361745.3026
1912[1]	3734732.599	393391.1647	2610	3764657.021	359923.8368
1939[1]	3735623.611	391085.3348	2644	3766370.172	357363.4184
2094	3729876.038	381102.0245	2663	3766916.605	355709.4376
2119	3730672.561	378609.4266	2681	3767025.148	354418.2523
2134	3731265.713	377319.4303	2691	3767088.076	353218.7227
2174	3733239.713	373916.2488	2719	3767149.311	350726.3138
2202	3734007.273	372073.2473	2739	3767105.473	348601.6034
2243	3734815.083	368933.9645	2759	3767212.87	346756.3472
2284	3737852.948	367401.0925	2788	3766379.071	344156.7867
2298	3739384.014	368163.2307	2821	3766673.784	341113.8489
2331	3741493.675	370414.4635	2862	3765984.087	337315.2221
2346	3742397.923	370797.066	2885	3765418.811	335365.6362
2363	3744015.624	370911.5695	2927	3764197.032	332295.5626
2374	3745087.473	371203.7525	2967	3766865.476	329479.6115
2406	3747580.427	369757.0774	2992	3767495.19	327181.9832
2426	3749418.978	369134.6997	3022	3767926.765	324234.439
2494	3755624.36	366354.2712	3053	3768441.012	321658.0804
2520	3757891.133	365277.0792	3061	3768526.786	320643.7938
2551	3760409.98	363649.6115	-	-	-

[1] Diffraction applied to MOP 9495 to yield nearshore wave conditions

By comparing the NTRs at each of the MOP locations in Table 3 above, it was determined that NTRs from MOP 2080 could be applied for the entire coastline.

Long Beach Harbor wave transformations

CoSMoS wave modeling outputs within the Long Beach Harbor are overestimated due to the lack of resolution in the wave modeling grids and relative orientation of the grid and breakwaters (Li Erikson, personal communication, June 15 2015). To increase the nearshore resolution and accuracy of the results, wave heights within the Harbor at MOPs 1939, 1912, and 1888 were estimated by ESA by manually diffracting waves from MOP 9495 (shown in Figure 16). The Goda et al. (1978) method was used to calculate diffracted wave height ratios inside of the eastern breakwater, represented as a straight, semi-infinite breakwater, based on the offshore MOP 9495.

To perform diffraction analysis, several assumptions were made. Wave conditions at the easternmost edge of the breakwater were assumed to be the same as those specified at the offshore MOP ID 9495, located east of the breakwater. Waves were assumed to approach normal to the breakwater, and the period of the waves was assumed to be unchanged by interaction with the breakwater.

A set of wavelengths were calculated at each of the Harbor points using each site's respective depth and a specified range of likely wave periods (4 to 26 seconds, in 2 second intervals). The horizontal and vertical distance offsets from the easternmost edge of the breakwater to MOPs 1939, 1912, and 1888 were calculated and then scaled by the range of Harbor wavelengths for each point. The scaled offsets were then used on a shallow-water diffraction diagram, reproduced in Figure 16, to estimate wave height ratios. Estimated wave height ratios were applied to the MOP 9495 time series to generate wave time series at each of the Harbor MOP points. Wave height ratios estimated using the Goda method were also checked using the Weigel (1962) method, which yielded similar results.

3.7 Historic Shoreline Positions

USGS National Assessment of Shoreline Change for Sandy Shorelines

This California-wide USGS assessment calculated short- (1970s to 1998) and long-term (1870s to 1998) shoreline change rates for sandy shorelines along the California Coast (Hapke et al. 2006) and was downloaded from the USGS website[10]. The report includes a GIS database containing three historic shorelines and other GIS files used to calculate the rates of change. The shoreline position error for each time period ranged from 1.5 to 17.8 meters. Section 4.1 discusses how these erosion rates were updated with the 2009-2011 LiDAR dataset.

USGS National Assessment of Cliff Erosion

This California-wide USGS assessment calculated long-term cliff edge erosion rates (end point rate between 1930s and 1998) along the California Coast (Hapke and Reid 2007) and was downloaded from the USGS website[11]. The report includes a GIS database containing two historic cliff edges and other GIS files used to calculate the rates of change. The annualized retreat rate uncertainty for California cliff edges was reported at 0.2 m/year, with the major uncertainties attributed to georectification of historic (1930s) T-Sheets. Section 4.1 discusses how these erosion rates were updated with an additional cliff edge digitized from recent LiDAR.

Zoulas & Orne Shoreline Data

Additional shoreline data developed by James Zoulas (Zoulas & Orne 2007) were obtained for select beaches and added to the USGS shoreline dataset to update historic shoreline erosion. Shorelines were added for Sequit East and West, Zuma, and Westward beaches.

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[10] http://pubs.usgs.gov/of/2006/1251/
[11] http://pubs.usgs.gov/of/2007/1112/

3.8 Coastal Armoring Database

The coastal armoring database (Dare, 2005) was based on interpretation of oblique aerial photography from the California Coastal Records Project (www.californiacoastline.org). The dataset provides offset reference line representing the observable coastal armoring structures. The polyline layer of coastal armoring was updated using the aforementioned aerial topography and imagery, and used in the development of erosion hazard zones that consider armor, discussed in Section 5.5.

4. ANTECEDENT DATA ANALYSIS

Prior to conducting the coastal erosion and flood hazard analysis, ESA conducted antecedent analysis using some of the data described above. This antecedent analysis transformed the input data into parameters used to predict the hazard zones.

4.1 Topographic Analysis

Shore and Cliff Profiles

Shore and cliff profiles were analyzed to identify topographic features pertinent to the coastal erosion analysis. Every 100 meters along the shore, a shore-normal profile were extracted from the digital elevation model described in Section 3.3. The points in each profile were spaced 1 meter apart. These profiles were then plotted and analyzed to identify various geomorphic features including the foreshore beach slope (approximately between mean low water and mean high water), back beach (dune, seawall) toe, and beach crest elevations. All geomorphic feature locations were then mapped in plan-view over high-resolution aerial imagery and DEM hillshade to verify the profile-based interpretation. In some areas, especially where development encroaches on the beach and the profile shows a consistently flat beach surface, a “dune crest elevation” was estimated by choosing a point directly shoreward of development.

Shore Change and Cliff Edge Erosion Rates

Shoreline change rates were computed from the USGS 2006 National Assessment of Shoreline Change[12] updated with a 2010 MHW shoreline extracted from the 2009-2011 LiDAR. Cliff erosion rates were also computed from the USGS assessment updated with the digitized cliff edge from the 2009-2011 LiDAR dataset. Linear regression rates for shorelines and cliffs were measured at 100-meter spacing alongshore and compiled. Cliff erosion rates were checked against erosion rates from local studies covering most of the County coastline west of Los Angeles Harbor (Deiner, 2000). The updated USGS historic rates for sandy shoreline and cliff erosion along Los Angeles County are presented in Figure 17 and Figure 18, respectively.

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[12] GIS shorelines available at; http://pubs.usgs.gov/of/2006/1251/#gis.

From the updated USGS erosion rates analyses, the linear regression rate (LRR, the rate computed from more than two cliff edges) was used as the primary erosion rate. There are data gaps in the USGS geodatabase for cliff erosion, so the longest end point rate (EPR, computed from two cliff edges) was used when the LRR could not be calculated. For shoreline erosion, short-term rates were selected to exclude the effect of historic sand placement activities. Because the beaches in Los Angeles oscillate with large storms and Pacific Decadal Oscillation cycles, it was assumed that any accretion rates (negative erosion rates) were a short-term oscillation and not indicative of a long-term trend: All historic accretion rates were set to zero (neither eroding nor accreting) for baseline conditions. Table 4 lists the geologic units and average erosion rates (computed from the USGS cliff erosion database updated with the 2009-2011 LiDAR cliff edge).

Table 4. Geologic units in coastal Los Angeles County

Geologic Unit	Average Erosion Rate (m/yr)	Standard Deviation of Erosion Rates, Along Shore (m/yr)
Kt	-0.28	0.17
Qal	0.03	0.22
Qls	-0.29	0.71
Qoa	-0.06	0.24
Qos	-0.09	0.06
Qs	-0.09	0.1
Qsp	-0.37	0.21
Qtc	-0.08	0.11
Qtm	-0.12	0
Qtn	-0.11	0.12
Qts	-0.08	0.08
Tb	-0.12	0.39
Tcb	-0.83	0.01
Tcob	-0.1	0
Tm	-0.14	0.17
Tma	-0.18	0.26
Tmat	-0.17	0.35
Tmd	-0.26	0.35
Tmf	-0.19	0.17
Tmg	-0.34	0.2
Tr	0.1	1.43
Ts	-0.73	0.51
Tso	-0.59	1.22
Tt	-0.13	0.04
Ttls	0.02	0.51
Tttc	-0.39	0.52
Ttub	-0.12	0.09
Ttus	-0.2	0.23
Tv	-0.89	0.21
Tz	-0.22	1.05

4.2 Backshore Characterization

ESA used a backshore characterization scheme that follows previous studies ESA conducted for the Pacific Institute, Monterey Bay and Ventura County (ESA 2013; ESA 2014; Revell et al 2011; PWA 2009). An offshore baseline (smoothed line offset seaward from the current shoreline) was divided into units based on backshore type (dune/sandy shoreline, inlet, or cliff) and geology. The baseline units were then segmented at 500-meter spacing (“blocks”) to conduct the coastal modeling at a scale appropriate to decision making. The datasets described in Section 3 and the results from the topographic analysis (Section 4.1) were summarized into each of these alongshore blocks (269 in total). Each block was assigned a set of parameters including backshore type (shore/cliff/inlet), presence of coastal armor, geology, erosion rates, median/minimum toe elevations, dune/cliff crest elevation, beach slope, foreshore slope, and the 100-year water level (see Section 6.1, below).

4.3 Wave Run-up Calculations and Total Water Level Curves

The total water level is a water elevation determined by the sum of tides, waves, and wave run-up, as well as other components including nearshore currents, storm surge, and atmospheric forcing. As sea level rises, total water levels will rise, as well, such that the amount of time that water reaches the backshore will increase. This increase is the key driving factor forcing the backshore erosion model.

For each alongshore study block, the wave run-up was calculated with inputs of median beach slope for the block and the time series of wave height and period at the nearest of the 39 nearshore CoSMoS model output points (Section 3.6). Wave run-up was added to the ocean water levels. As described in Section 3.6, ocean water levels were generated by combining astronomic tides and synthetic NTRs with synthetic wave conditions. The ocean water levels were added to the computed run-up to produce a total water level time series for each block. Sea level rise amounts were then added to these computed total water levels for future conditions.

The time series of total water levels for each block and scenario was converted to a total water level exceedance curve, which shows the relative amount of time that wave run-up reaches a certain elevation. These curves are the key input to the shoreline erosion model discussed in the following section. An example of total water level exceedance curves for an exposed (high total water level) and sheltered (low total water level) location is presented in Figure 19.

The Stockdon run-up equation was developed for natural shores and includes wave setup and run-up. It is used as a first approximation for run-up but is replaced with a more accurate representation for backshores where inland extents of wave run-up are computed (Section 6.1 Wave Run-up). Some steep portions of the coast were not suited for the Stockdon (2006) method that was developed for flat wide beaches. For the blocks that had beach slopes steeper than 0.1, the TAW method of wave run-up calculation was used in computing the total water level time series (TAW 2002).

5. COASTAL EROSION HAZARD ZONES

5.1 Shoreline Erosion Methods

Shoreline erosion hazard zones were developed by modifying the methodology described in the Pacific Institute (PI) study, with the backshore characterization as the main input (see Section 4.2). The most important variables in the PI model are the backshore toe elevation and the total water level curve, with the beach berm elevation used in place of the backshore toe at wide beaches. This section gives a brief description of the erosion hazard zone methods. For more details about the methods please see the complete Pacific Institute study (PWA 2009 and Revell et al 2011).

Existing erosion methods from previous studies were modified to account for the wide beaches in Los Angeles County that have been artificially widened (Zuma, Santa Monica, etc.). The sandy backshore is not currently eroding at these wide beaches; historic shoreline erosion therefore does not directly correspond to backshore erosion in these locations. To account for these existing conditions, coastal erosion was first projected from the existing shoreline instead of the backshore. Once the calculated beach width dropped below a certain threshold (and in locations where it is currently below the threshold), increased coastal erosion was projected to occur at the backshore. In reality, the backshore is protected against wave attack by a wide beach; the level of backshore toe protection is a function of beach width. Everts (1991) studied beach widths and backshore erosion in Oceanside, CA and found that there was little backshore erosion when the fronting beach was greater than 30 m wide, and near complete protection was provided against large coastal storms by a 60-m beach width. Thus, a trigger distance of 60 m was selected to activate backshore erosion at sandy beaches in the Los Angeles County study area. An example of the mapping result is shown in Figure 3; the beach width north of Venice Pier drops below 60 m between 2050 and 2100 and erosion is projected from the backshore while the beach south of the pier remains wider than 60 m and erosion is only projected form the shoreline.

Types of Shoreline Erosion Hazard Zones

Two types of shoreline erosion hazard zones were prepared for this study. This separation was provided to further delineate long-term SLR induced changes from storm induced changes. These shoreline erosion zones represent the potential maximum retreat of the shoreline for any given year. While the shoreline used for erosion offsets was digitized from October 2010, the shoreline typically reaches its maximum yearly retreat at the end of the winter season. Thus an envelope of seasonal shoreline variation was included in each type of shoreline erosion hazard zone until backshore erosion was activated. In lieu of observational data for the entire Los Angeles County coastline, a representative value was gleaned from prior studies. The USACE conducted a breakwater feasibility study for Santa Monica Bay in which they used observational data from Bolsa Chica to the south that showed seasonal shoreline fluctuation of 15 meters. This value is consistent with the seasonal shoreline fluctuations found by Zoulas and Orne (2007).

1. **Long-Term Erosion.** This can be interpreted as the potential future location of the shoreline (defined as the MHW[13] contour). Not all areas within the hazard zone are expected to erode to this extent by the specified planning horizon, but any location has the potential to erode to

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[13] MHW: A tidal datum. The average of all the high water heights observed over the National Tidal Datum Epoch. MHW at the Los Angeles tide gauge equals 4.56 ft NAVD88.

this extent (for the scenario specified). This type of coastal erosion hazard zone is the sum of two components: historic erosion and additional erosion due to sea level rise. The historic erosion rate is multiplied by the planning horizon to get the baseline erosion. The shoreline retreat from sea level rise is calculated by multiplying the increase in run-up above the berm elevation by the overall profile slope (between the beach berm and the depth of closure). The potential erosion model ignores the effect of coastal armoring at mitigating erosion; however, if shoreline armoring has been present and maintained over a number of years its presence will be reflected in the calculated historic erosion rates. Additionally, the model does not account for other shore management actions such as sand placement to mitigate future shore recession. The long-term shoreline erosion zones are based on an October-November shoreline, and thus can be considered the typical future fall shoreline position, when the beaches are their widest.

2. **100-Year Storm Erosion.** This type of erosion hazard zone adds the erosion caused by a large storm event to the long-term zone described above and includes an offset to account for seasonal shoreline fluctuations. The potential inland shoreline retreat caused by the impact from a large storm event (100-year) was estimated using the geometric model of dune erosion originally proposed by Komar et al (1999) and applied with different slopes to make the model more applicable to sea level rise (Revell et al 2011). This method is consistent with the FEMA Pacific Coast Flood Guidelines (FEMA 2005a). The 100-year (0.01 annual exceedance probability) was computed by extrapolation with the generalized extreme value distribution (GEV) fitted to the computed total water level time series and compared to the beach berm elevation. Following the FEMA guidelines, the erosion extent was limited by a duration factor of 50% for cases of activated backshore erosion to account for material that would be provided to the beach from the backshore. For cases of projected erosion of the shoreline, no duration factor was applied.

5.2 Shoreline Erosion Mapping

The shoreline erosion hazard zones were mapped for each type of hazard zone (long-term and with 100-year storm), sea level rise scenario and planning horizon using a one-sided buffer (offset) in ESRI's ArcGIS software with an ArcINFO® license. The reference line for the erosion hazard zone is the location of the MHW shoreline at the time of the statewide LiDAR data collection. The hazard zone also includes the area from the arbitrary offshore baseline to the reference line, as this area is already in the active erosive coastal zone. Resulting hazard zones were visually inspected and edited for anomalies. The hazard zones thus represent the inland retreat of the shoreline or backshore, depending on whether the backshore is triggered. An additional set of shoreline erosion hazard zones was developed to consider existing coastal armoring structures, discussed in Section 5.5.

5.3 Cliff Erosion Methods

Similar to the two sets of shoreline erosion hazard zones that were developed in this study, cliff erosion was projected for both long-term rates and with a factor of safety included for uncertainty. Additional non-coastal erosion zones were also identified for particular areas in the County.

Long-Term Erosion

The Pacific Institute study (PWA 2009 and Revell et al 2011) estimated future erosion rates using the following equation,

$$Erosion\ Rate_{future}(t) = Erosion\ Rate_{historic} * \left(1 + \alpha \frac{P_f - P_e}{P_e}\right)$$

Where P_f and P_e are the future and existing probability of total water level exceedance above the cliff toe elevation, respectively. Since the Pacific Institute study, a number of studies have proposed additional relationships for estimating cliff/bluff erosion rates under accelerated sea level rise (Walkden and Dickson 2008, Ashton et al 2011). Walkden and Dickson (2008) found that the following equation applied well for the cliff backed/low volume beaches undergoing a historic trend in sea level rise at the Naze Peninsula on the Essex coast in Southern England:

$$Erosion\ Rate_{future}(t) = Erosion\ Rate_{historic} * \left(\frac{Rate\ of\ Sea\ Level\ Rise\ (t)}{Rate\ of\ Sea\ Level\ Rise\ (historic)}\right)^{m}$$

In this equation m =0.5. Ashton et al 2011 investigated the value of m using various data sets for calibration and confirmed that m = 0.5 applies to cliffs/bluffs dominated by wave-driven erosion. In particular, rocky shore platforms and cliffs fronted by low-sediment-volume beaches, both of which apply for the cliffs of Western Los Angeles County.

For this study, Walkden and Dickson 2008 equation was modified, as follows:

$$Erosion\ Rate_{future}(t) = Erosion\ Rate_{historic} * \left(\frac{A\ (t)}{A\ (historic)}\right)^{m}$$

Where A is the area below the total water level exceedance curve and above the existing toe elevation (Figure 20). This area is a combination of the duration of wave impact above the toe elevation and the intensity of that contact (how high above the toe the waves and wave run-up are reaching). The exponent, m, was kept at 0.5, in agreement with the previous studies.

Erosion landward of wide beaches

There are a number of reaches along the LA coastline characterized by artificially widened beaches (due to historic sand nourishment) that front a coastal cliff, suggesting that the backshore is not exposed to wave action under current conditions. To account for the effect of wide beaches on limiting cliff erosion, the beach width trigger of 60 m was used (see Section 5.1) to initiate accelerated cliff erosion. For years when a fronting beach is above the threshold, the measured historic erosion rates were projected at these particular cliff locations.

Erosion Factor of Safety

The future erosion rates were integrated through time to obtain an erosion distance at each of the planning horizons. To include a factor of safety, an additional offset was included in the erosion distances for each block as a second set of cliff erosion hazard zones. This second set of erosion hazards includes two standard deviations in the alongshore erosion rate for each block.

Terrestrial Erosion / Landslide Zones

In addition to ocean-driven erosion, cliffs along the Los Angeles County coast are subject to erosion from terrestrial forces. USGS National Assessment of Shoreline Change (Section 4.1) indicated that many of the cliffs in the western part of the county are eroding due to runoff and gravity, even if they are not directly affected by the ocean, and geologic maps of the Palos Verdes region clearly indicate that landslides have played a major role in shaping the landscape. Though these hazards are not ocean-driven, since they occur in the coastal zone, this study includes terrestrial erosion hazards, albeit in a cursory manner. For planning projects in areas with potential for significant terrestrial erosion or landslides, additional analysis is needed.

Much of the western part of Los Angeles County is dominated by cliffs. Erosion of the cliff closest to the ocean was analyzed according to the methods outlined above. The next set cliffs are subject to terrestrial erosion. To indicate general erosion patterns and the associated terrestrial erosion hazard area, an annual erosion rate from the USGS National Assessment of Shoreline Change across the county was used to project the cliff edge (digitized as described in Section 4.1) inland for each time horizon in this study. Since cliff erosion often occurs in large events, an additional uncertainty buffer was added to this hazard zone representing 100 years of erosion under the annual rate. This represents the case where there is steady erosion through the time horizon under consideration, plus a severe “100-year” event.

The terrestrial erosion rates were selected as follows. The USGS rates are reported on a transect-by-transect basis and were determined using digitized cliff edges from the 1930s to the 1990s. In many cases, the cliff edges have moved due to human action, i.e. road construction or terracing, yielding very high rates in the USGS study that are not actually representative of natural terrestrial erosion rates. To compare, statistics from the full set of transects intersecting this study’s terrestrial cliff line (“All Transects”) and from a subset including only transects that do not cross significant man-made features (“Natural Transects”) are reported in the Table 5below (in m/yr). Because there is a lot of spatial variability in the USGS erosion rates, it was decided to round the median rate from natural transects up to 10 cm/yr and use that for all terrestrial cliffs. Therefore, the severe event buffer, 100 years of the annual erosion rate, is 10 meters. An example of terrestrial erosion zones is shown in Figure 21 along with the coastal erosion hazards.

Table 5. Statistics from annual terrestrial erosion rates presented by USGS.

	All Transects	Natural Transects
Min	-1.77	-1.19
Max	0.00	0.00
Mean	-0.44	-0.15
Median	-0.30	-0.09
Mode	-0.03	-0.03
StDev	0.43	0.18

Further east, the Palos Verdes region has been greatly influenced be landslides. Similar to the severe event considered in the terrestrial erosion hazard envelope in the west of the county, these events are infrequent but large. To account for this additional hazard, a landslide hazard envelope was developed for the Palos Verdes region using a geologic map of the area (Dibble 1999) and the digital elevation model (c.f. Section 3.3 and Section 3.4). According to the geologic map, Palos

Verdes is primarily composed of two geologic units: the lower and upper parts of Tertiary Altamira Shale. In each geologic unit, the maximum landslide width (measured in the cross-shore direction) indicated on the geologic map and the maximum width measured from the digital elevation model and orthoimagery were compared, and the largest width from these two sources was used. This led to a buffer of 360 meters for lower Altamira Shale (at the northwest and southeast of the region) and 1975 meters for upper Altamira Shale (in the southwest of the region, e.g. Portuguese Bend and its environs). The Palos Verdes landslide zone is shown in Figure 22 along with the coastal erosion hazard zone under high SLR at 2100 for reference.

5.4 Cliff Erosion Mapping

The cliff erosion hazard zones were mapped for each sea level rise scenario and planning horizon using a one-sided buffer (offset) in ESRI's ArcGIS software with an ArcINFO® license. The reference line for the erosion hazard zone is the edge of the cliff, which was digitized from recent LiDAR. The hazard zone also includes the beach area shoreward of the cliffs, as this area is already in the active erosive coastal zone. Resulting hazard zones were visually inspected and edited for anomalies.

5.5 Mapping Revisions for Coastal Armoring

The coastal armoring structure data described in Section 3.8 were used to generate a separate set of erosion hazard zones for a theoretical management scenario in which existing armoring structures were maintained and upgraded into the future. This scenario was modeled at the request of study leaders as one "bookend" that compliments the alternative "bookend" that armoring is removed or ineffective, thereby providing a range of mapped hazards associated with the range of potential future armor effectiveness. The erosion hazard zones developed in this study were simply clipped landward of the existing coastal armoring structures in GIS, as shown in Figure 23. These "theoretical" hazards assume the following:

- Existing coastal armoring structures are sufficiently engineered to stop coastal erosion under existing conditions.
- Future scenarios – coastal armoring structures are maintained and upgraded to withstand increased loadings associated with sea level rise and thereby prevent erosion during a 100-year coastal storm, even with the much greater loadings expected in the future due to sea level rise.
- Modeling does not consider active erosion processes (e.g. increased erosion associated with the effects of armoring).
- Resulting hazard zones do not consider maintenance costs, loss of natural beach defenses (ecosystem services), or recreational value associated with eco-tourism and indirect benefits. ESA is mapping the City's anticipated management scenario of maintain armoring to contrast with the approximate "no armoring" hazard zones.

6. COASTAL FLOOD HAZARD ZONES

Three types of coastal flood zones were developed for this study to characterize potential impacts associated with a coastal storm event: back beach flooding (lagoon flooding behind a built up beach berm), wave run-up (computed from maximum historic and projected wave conditions), and 100-year tidal flooding (generated in tidally open systems). Another set of hazard zones was developed to illustrate changes in coastal inundation associated with more frequent high water levels caused by increasing extreme monthly high water.

6.1 Coastal Storm Flood Hazard Zones

Flooding along the coast is driven by various processes, with the dominant process (likely to cause the most flooding) varying by location and geomorphology. Most sea level rise analyses and maps focus on ocean-storm related flooding (e.g. how a 100-year ocean water level will change with sea level rise). While this may be the dominant process in many sheltered, open-tidal systems, this simplistic approach ignores many of the dominant processes in the Los Angeles study area. For this study, the shoreline was broken into regions based on the geomorphology and dominant process driving coastal flood levels (Figure 24). The following flood processes were considered:

- 100-year water level
- Wave run-up
- Beach berm closure of seasonal lagoons

The subsequent sections describe how these processes were analyzed and mapped for this study. The last section describes how these maps were then combined with the effects of coastal erosion on flooding to create the final coastal storm flood hazard zones.

The major processes that have not been considered are (1) flooding from large precipitation events and (2) river run-off. When combined with high tides and sea level rise at the coastal confluences, these processes likely dominate flooding along the major creeks and rivers in the study area, particularly in the urbanized watersheds. Climate change may also increase rainfall intensity, which would increase 100-year storm flood extents along creeks and rivers (ESA PWA 2015; ESA 2016). This potential effect of climate change was not evaluated in this study.

100-year Ocean Water Level

The 100-year water level (2.34 m NAVD88, Table 2) was assumed to be the major coastal flood process in predominantly open tidal systems as presented in Figure 24 (e.g. Malibu Lagoon, Marina Del Rey, Ballona Creek, Redondo Harbor, Los Angeles/Long Beach Harbor, Alamitos Bay and the San Gabriel River). The 100-year water level was raised by sea level rise for future planning horizons.

Wave Run-up

The wave run-up elevation typically exceeds that of the 100-year tide water level and the lateral extent of flooding is therefore greater in a number of locations, and especially important in low-lying areas. In these areas a wave run-up analysis was conducted to estimate the limit of wave run-up on the profile.

Thirty-five representative profiles were analyzed along the entire Los Angeles County study area (Figure 25). The profiles were taken from the topography and bathymetry datasets described in Section 3.3. Profile locations were optimized locally to limit the amount of interpolated profile resulting from bathymetric data gaps. They reflect the wide range in topography and bathymetry across the Los Angeles County study area.

The Stockdon run-up method (Stockdon et al 2006), developed to calculate run-up on natural, gently-sloping beaches, was used to identify the wave event that caused the maximum run-up at every study block. These wave parameters (significant wave height, wave length, direction) were then used as inputs to a run-up program that is valid for a wider range of profile configurations than just natural beaches. This run-up program, developed by ESA (previously PWA) and consistent with FEMA guidelines, was used to iteratively calculate the dynamic water surface profile along each representative shore profile, the nearshore depth-limited wave, and the run-up elevation at the end of the profile. The dynamic water surface is the water level at the coast that is driven by sets of waves (or wave groups) that cause superelevation of these water levels. Wave run-up is computed using the method of Hunt (1959) which is based on the Iribarren number (also called the Surf Similarity Parameter), a non-dimensional ratio of shore steepness to wave steepness. The run-up is limited to a maximum of about three times the incident wave height, which is generally consistent with other methods that rely on the Iribarren number, as depicted in Figure 26. While there are a variety of run-up equations, they provide a range of results and hence the most simple and direct was chosen (Hunt, 1959).

The program also uses the Direct Integration Method (DIM) to estimate the static and dynamic wave setup and resulting high dynamic water surface profile (FEMA 2005a; Dean and Bender 2006; Stockdon 2006). The methodology is consistent with the FEMA Guidelines for Pacific Coastal Flood Studies for barrier shores, where wave setup from larger waves breaking farther offshore and wave run-up directly on barriers combine to generate the highest total water level and define the flood risk (FEMA 2005a). This program also incorporates overland and structure surface roughness, which act as friction on the uprush of the waves, thus reducing the extent of wave run-up. This method also uses a composite slope technique as outlined in the Shore Protection Manual (USACE 1984) and Coastal Engineering Manual (USACE 2002).

The wave run-up inland extents were projected inland from the zero-meter NAVD contour (reference elevation for composite slope run-up computations) to develop the flood hazard map for the regions where wave run-up was identified as the dominant flood hazard (Figure 24). The calculated maximum elevation of run-up was then used to limit run-up extents over the topography within the mapped extent using tools in ArcGIS.

Seasonally Closed Lagoons

The Los Angeles County shoreline is punctuated by coastal lagoon systems, which occur at confluences between creeks/rivers and the ocean. These systems, also referred to as ‘bar-built estuaries’ are seasonally controlled by opposing forces: (1) waves that build up the sandy beach, causing the lagoon to close (usually in the summer/fall) and fill with water behind the beach and (2) rainfall runoff that encourages the lagoon to breach the sandy beach and flow into the ocean through a channel. Unlike open tidal systems, these seasonally closed lagoons often experience their highest water levels during closed conditions, when a high beach berm develops and runoff fills the lagoon but does not breach it. This is complicated by management activity (e.g. mechanical or artificial breaching), which varies greatly between lagoons. For this study, a number of seasonally closed lagoons were identified along the Los Angeles shoreline (Figure 24). By using the spring 2009-2011 LiDAR combined with geomorphic assessment of sediment grain size characteristics, beach slopes and wave exposure, the maximum potential beach berm elevation that would back up lagoon waters and cause the highest flooding were estimated (Table 6). It was assumed that the maximum flood level would occur when the lagoon filled up to the beach berm just before spilling over and naturally breaching, which is typically during rainfall events. These water levels are not associated with a return interval (e.g. 100-year), which would require a joint probability analysis of waves building up the beach with the timing/ magnitude/probability of large rainfall events, and is beyond the scope of this project.

Table 6. Geomorphic estimates of maximum berm crest elevations for seasonally closed lagoons – existing conditions

Name	**"Maximum" Berm Crest** *ft NAVD88*
Arroyo Sequit	11.5
Trancas Canyon	11.8
Zuma Canyon	12.8
Malibu Lagoon	12.8
Topanga Creek	11.5
Santa Monica Canyon	12.1

In the future, the sediment supply is assumed to be consistent with existing conditions to allow the "maximum beach berm elevation" to rise in equilibrium with sea level (i.e. the maximum flood elevation in the closed lagoon rises at the same rate as sea level). The existing and future maximum flood elevations were mapped over existing topography to identify the flood hazard zone in these seasonally closed lagoons systems.

Mapping Coastal Storm Flood Hazard Zones

The individually mapped regions described in the previous sections were merged with the shoreline and cliff erosion hazard zones for each SLR scenario and time horizon. This merging was to include all areas that become hazardous due to future erosion in the future flood hazard zones. Flooded areas with connectivity to the ocean (over the digital elevation model) were mapped, as well as any pools (greater than 3 m^2) within 5 meters of areas connected to the ocean to conservatively account for seepage and potential errors in the DEM. For the same reason, patches of dry land that are smaller than 1 acre and completely surrounded by inundated area are also shown as flooded. Areas without apparent connection to the ocean were kept but were labeled as "connectivity uncertain" in the attribute table. These should be displayed in a different shade to show that unless there is a connection (e.g. through a culvert/under a bridge), those areas will not necessarily flood due to coastal processes. Wave run-up flood hazard areas are considered "connected" as the modeling results show that wave run-up can connect those low-lying areas to the ocean.

6.2 Extreme Monthly Tidal Flooding Hazard Zones

To address coastal flooding based on higher water levels becoming generally more frequent, the Extreme Monthly High Water (EMHW) (highest tidal water level per month, on average) was mapped along the coastline, for existing conditions and future sea level rise (not considering storm events). Two types of datasets were developed: a general tidal flooding area and a depth grid (or raster). These hazard areas do not consider future erosion, so the coastal erosion hazard zones should be used in combination with these rising tidal flooding zones for any applications in the planning process.

EMHW was estimated by averaging the maximum monthly water level for every month recorded at the Los Angeles tide gauge (EMHW = 2.0 meters (6.6 ft) NAVD88). In reality, EMHW varies along the coast, especially in the inlets and sloughs; however, for this project, which is focused on the open coast, a single value of EMHW was used. Sea level rise projections were added to the EMHW for each sea level rise and planning horizon (Section 3.1) and mapped over the DEM (Section 3.3). Areas in the DEM below the flood elevation were marked as flooded, and those areas with a direct connection with the ocean were labeled “connected” in the “Connection” attribute. The other low-lying areas were also included and were labeled “connection uncertain”. The connectivity of these areas should be assessed for individual sites in the planning process to determine whether they are connected to the ocean (e.g. through culverts, under bridges).This method is similar to the identification of “low lying areas” in the NOAA SLR viewer. Areas that are labeled as “connection uncertain” may become impacted by rising groundwater levels in the future, whether or not they are connected to the ocean over the ground surface.

Depth maps (separate datasets for the “connected” and “connectivity uncertain” maps) were developed by overlaying the monthly tidal flooding area over the topography and using the difference between the flood elevation and the topography to calculate depth. The 2009-2011 CA Coastal Conservancy DEM is hydroflattened, which means that the reported elevations in wet areas correspond to an approximate water surface elevation rather than the actual bathymetry. These areas (as identified by the 3D breaklines provided with the DEM) were assigned a value of 999. This value was specified because depth could not be calculated in these areas (as the LiDAR does not penetrate water). These areas are considered already hazardous as they are already flooded.

7. DISCUSSION OF MODEL UNCERTAINTY

Coastal erosion and flood modeling include uncertainties regarding the input data, shore and human responses, and the methodologies employed. Some uncertainties are more easily managed than others. This section describes the uncertainties inherent to coastal erosion modeling results for this regional level assessment, and presents recommendations on how to interpret the results with caution. There are also uncertainties with coastal flood modeling which are generally more intuitive and therefore not described here.

Uncertainty Alongshore

In some cases, projected erosion can vary significantly between two adjacent coastal analysis blocks (blocks are sections of shore; Section 4.2). Uncertainty in erosion is partially addressed within each analysis block by including an uncertainty buffer that is calculated based on the along-shore range in erosion rates per block (Section 5.3), but significant variations in the range of erosion extents exist in the historical data, and therefore future erosion may also vary substantially by location.

Projected erosion can vary significantly between 2050 and 2100 between adjacent blocks, even those of similar type (cliff) and geology. Variation can be due to differences in key backshore attributes (i.e. shore geometry, toe elevation, slope, geology) or oceanographic conditions (i.e.

waves, water levels, sea level rise). Also, localized variations in erosion resistance are not modeled except to the extent represented in historical erosion. The methods for modeling accelerated coastal erosion were developed for cliffs that are currently eroding under existing conditions and are exposed to the ocean total water levels to some degree (Section 5.3). If the toe of a cliff is not exceeded under current conditions (meaning that waves do not presently induce erosion), even a small change in exposure to wave action is a large relative increase from historical conditions. Mathematically, the resulting erosion rate increases drastically due to the ratio of future to existing exposure. This is seen in a number of locations along the coastline, and an example is shown in Figure 27 along with plots of the relevant analysis components. To conservatively account for possible erosion extents, the interpreter may look to adjacent blocks of similar backshore type and geology to determine the range of projected erosion for a given year. This comparison will indicate greater uncertainty than the local uncertainty (block-averaged deviations from the mean erosion rate), and a greater maximum erosion. This concept is illustrated in Figure 27, where the greater erosion extent is projected to an adjacent area.

Projected erosion can vary significantly between adjacent backshore types. This is due to the simplified modeling approach which was developed for either sandy shorelines or cliffs, rather than accounting for the full range of intermediate conditions (see Section 5.1 and 5.3, respectively, for a discussion of sandy and cliff backshores). An example of different erosion extents for different adjacent backshore types is shown in Figure 28, where erosion of sandy shores is greater than those characterized as cliffs, resulting in discontinuities in the potential erosion extents at the reach boundaries.

It is important to note that these erosion hazard zones are not predictions of the future shore and cliff edges, but rather envelopes of potential erosion extents. This means that the erosion could extend to these limits in any particular location, but erosion may not extend to the mapped limits in all locations by the date specified. Of course, it is also possible that these hazard zones under-predict localized erosion extents. Therefore, these maps do define boundaries between risky and risk-free areas, but rather provide a geo-spatial and temporal estimate of hazard extents for planning purposes: The risk to assets near the ocean is inherent in their location and therefore independent of the accuracy and uncertainty associated with erosion and flooding forecasts.

8. ASSESSING A RANGE OF SCENARIOS

This study considered a range of future scenarios related to sea level rise and coastal erosion. A single layer was developed to integrate the range of hazard outcomes from all scenarios. For existing conditions and all planning horizons (2030, 2050, 2100), all the ESA and TCG hazard zones were overlaid to identify how “hazardous” a given location is by any coastal hazard type. The hazard level was quantified by counting how many, out of 38 possible hazard layers, a location is exposed to. This process of overlaying and counting the number of overlapping hazards is called “spatial aggregation,” and is shown in Figure 29. From ESA, the spatial aggregation includes four hazard types and eight scenarios, a total of 32 hazard layers. The four hazard types include: long term erosion, storm event erosion, storm event flooding (100-year ocean water level, wave run-up, lagoon beach berm), and monthly high tide. The eight scenarios include: existing conditions (2010); medium and high SLR for 2030, 2050, 2100; and the extreme SLR case at 2080. From TCG, the spatial aggregation includes six erosion hazard zones for medium and high SLR for 2030, 2050, and 2100. An example of the spatially aggregated output is shown in Figure 8. Spatial aggregation maps for the County are provided in Appendix 2.

These spatially aggregated layers do not, by any means, contain the complete range of possible future scenarios, and none of the scenarios presented are associated with a particular probability of future occurrence (which requires statistical approaches which are exceedingly complex given the large range of uncertainty associated with projections of sea level rise). This is simply a way to visualize the full range of scenarios and hazards assessed and understand qualitatively, how projected future hazards vary (e.g. if a site is hazardous regardless of the scenario, or whether the site is only hazardous for the most extreme scenarios).

9. VULNERABILITY ASSESSMENT

This section describes the assets vulnerable to the different coastal erosion and flood hazard scenarios. The county's assets are classified by sector into transportation infrastructure, buildings and structures, public facilities (fire, police, hospitals, and schools), sanitary sewer infrastructure, storm drain infrastructure, and ecosystem assets. The data sources for each asset class are described in the sections below, along with tables tallying the number of assets in each city and unincorporated regions of the county that are vulnerable to different hazard scenarios.

The vulnerability assessments in the sections below divide hazards into four groups: long-term erosion, long-term tidal flooding, storm/event erosion, and storm/event flooding. Long-term erosion includes both shoreline and cliff erosion (Section 5.1 and Section 5.3). Long-term inundation comes from the extreme monthly high water analysis (Section 6.2). Storm/event erosion combines shoreline and cliff erosion with their standard deviations and wave run-up areas to account for a single storm event's erosion (Section 5.1, Section 5.3, and Section 6.1, Wave Run-up). Storm/event flooding combines the 100-year tide, wave run-up areas, bar built estuaries, and long-term erosion of shorelines and cliffs (Section 6.1, Section 5.1, and Section 5.3). These four hazards represent decreasing severity:

- areas subject to long-term erosion would be lost entirely
- areas experiencing long-term tidal flooding would be regularly flooded by monthly high tides
- areas experiencing storm or event erosion are likely damaged but could be recoverable
- areas experiencing storm or event flooding are likely to return to service when floodwaters recede.

The tables in the sections below are presented in this order of decreasing severity.

While the severity of consequences decreases across these hazards, the number of assets affected may not increase because different regions are more exposed to different risk. This is particularly clear when comparing long-term tidal flooding exposure and event erosion exposure between communities like Malibu and Long Beach. The former is dominated by cliffs, so event erosion generally affects more assets, while the latter is dominated by lower, sandy shorelines, so long-term tidal flooding generally affects more assets. Nevertheless, the first two hazards are steadily rising into the future, while the second two occur in sudden steps (storm events) at an unknown time in the future, so it is logical to order them this way.

It is also worth noting that the number of assets affected increase over time and with increasing sea level rise scenario, except for the Extreme case, with 5.5 feet of sea level rise in 2080. For hazards that include an erosion component (long-term erosion, event erosion, and storm flooding), the High 2100 case and the Extreme 2080 case have the same water level, but the High 2100 case includes an additional 20 years of erosion. Thus, even though the Extreme case includes a more aggressive sea level rise estimate, it may have fewer assets exposed in areas where long-term erosion plays a significant role.

In addition to the tables summarizing the intersection of the hazard and asset layers, planners may also choose to review this study's hazard and asset layers using GIS software. Within the GIS environment, planners can select their area(s) of interest from the county's 65 miles of coastline, choose an appropriate viewing scale, and add other information, such as an aerial photograph as a basemap. The formats and availability of the GIS files are described in Appendix 1.

9.1 Methodology

To assess the vulnerability of the county's assets, the assets in different categories were identified and intersected with each hazard layer. For each city and for the county as a whole, point assets in each hazard zone were counted, linear assets (like roads and pipelines) were measured by mile, and planar assets (like ecosystem areas) were measured by acre. These results are reported in tables in the following sections.

Asset data were provided by Los Angeles County and city agencies. Some of these data leave gaps in certain cities, since the cities and the county do not always maintain the same data or level of detail. Asset data for the electric and energy supply systems were not available, so this asset class was not considered. The asset data provided by the county and their sources are summarized in Table 7.

TABLE 7. DATA SOURCES

Dataset	Source	Year
Roads	LA Department of Beaches and Harbors	2016
Bikeways	LA County GIS Portal	2012
Building Footprints	Los Angeles Region Imagery Acquisition Consortium (LARIAC) *via LA County GIS Portal*	2008
Parking Lot Footprints	LARIAC *via LA County GIS Portal*	2014
Public Facilities	Location Management System via *via LA County GIS Portal*	2016
Wastewater Treatment Plants	LA Department of Public Works	2013
Sanitary Pump Stations	LA Department of Public Works City of Santa Monica	2013 2016
Sanitary Sewer Pipelines	LA Department of Public Works City of Santa Monica	2013 2016
LA CSD Sanitary Pipelines	LA County Sanitation Districts	2015
Storm Drain Pump Stations	LA Department of Public Works	2013
Storm Drain Gravity Mains	LA Department of Public Works	2013
Storm Drain Force Mains	LA Department of Public Works	2013
Storm Drain Culverts	LA Department of Public Works	2013
Wetlands and Beaches	National Wetlands Inventory	2016

9.2 Transportation Infrastructure

Data Sources

Transportation data include road centerlines and bikeway centerlines. Road data were taken from the Los Angeles County Department of Beaches and Harbors (Noble 2016), and bikeway data were taken from the Los Angeles County GIS portal[14]. Airports and major rail stations (Amtrak and Intermodal stations) were also considered, but none was impacted under any of the hazard scenarios.

Countywide Infrastructure

Though transportation infrastructure has been divided by city and community, there are some assets that would affect the entire county if interrupted. In particular, Highway 1 acts as a main artery for the coastal communities in Los Angeles County, and if it were damaged and experienced a significant loss of service, transportation along coast would be impacted. Even if the reach of Highway 1 in a particular city were unaffected, damage in a neighboring city could cause similar disruption, making this a “cross-cutting” vulnerability. As such, it was deemed valuable to emphasize the length of Highway 1 at risk in the entire county under each hazard scenario.

TABLE 8. COUNTYWIDE TRANSPORTATION - HIGHWAY 1 VULNERABILITY

	Baseline	**3' SLR by 2100**			**5.5' SLR by 2100**			**5.5’ SLR by 2080**
Hazard	2010	2030	2050	2100	2050	2050	2100	2080
Long-term Erosion	0	0	0	2.1	0	0	5.9	2.5
Long-term tidal flooding	0.3	0.3	0.3	0.4	0.3	0.4	2.2	2.2
Storm/Event Erosion	2.9	3.5	4.7	9.8	4.1	8.5	12.5	12.4
Storm/Event Flooding	3.3	3.8	5.8	12.6	4.5	9.1	16.3	14.3

NOTES:
Measurements given in miles of roadway.

Vulnerability Summary

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[14] http://egis3.lacounty.gov/dataportal/

TABLE 9. TRANSPORTATION – LONG-TERM EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo	0	0	0.2	0.4	0.2	0.4	0.5	0.5
Hermosa Beach	0	0	0	0.8	0	0	1.4	1.3
Long Beach	0	0.3	0.6	2.2	0.4	1.1	4.0	3.7
Los Angeles	0.5	0.7	1.2	5.7	1.1	1.6	11.0	8.1
Malibu	1.3	1.3	1.6	8.1	1.4	1.9	13.6	9.7
Manhattan Beach	0	0	0	1.1	0	0.1	2.6	2.6
Palos Verdes Estates	0.3	0.3	0.4	1.4	0.3	0.4	2.5	1.6
Rancho Palos Verdes	0.4	0.4	0.4	1.3	0.4	0.4	1.8	1.0
Redondo Beach	1.2	1.3	1.3	1.3	1.3	1.3	2.1	2.0
Santa Monica	0	0	0	0	0	0	0	0
Torrance	0.4	0.4	0.4	0.5	0.4	0.4	1.0	0.6
Unincorporated	0	0.1	0.2	1.4	0.1	0.4	2.5	1.8
Full County	4.0	4.7	6.2	24.1	5.5	8.1	42.9	33.0

NOTES:

Measurements given in miles of roadway and bikeway affected.

TABLE 10. TRANSPORTATION – LONG-TERM TIDAL FLOODING (MONTHLY HIGH WATER) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2050	2050	2050	2100	2080
Carson	0	0	0	0.1	0	0	0.3	0.3
El Segundo	0	0	0	0	0	0	0	0
Hermosa Beach	0	0	0	0	0	0	0	0
Long Beach	17.3	26.5	40.2	90.5	41.2	72.9	130.4	130.4
Los Angeles	18.5	24.7	30.2	51.6	30.6	41.3	86.2	86.2
Malibu	0.1	0.1	0.1	0.3	0.1	0.1	0.5	0.5
Manhattan Beach	0	0	0	0	0	0	0	0
Palos Verdes Estates	0	0	0	0	0	0	0	0
Rancho Palos Verdes	0	0	0	0	0	0	0	0
Redondo Beach	0	0	0	0.2	0	0	1.3	1.3
Santa Monica	0	0	0	0.1	0	0	0.5	0.5
Torrance	0	0	0	0	0	0	0	0
Unincorporated	1.3	1.4	1.4	2.4	1.4	1.5	4.0	4.0
Full County	37.3	52.7	71.8	145.1	73.3	115.8	223.2	223.2

NOTES:

Measurements given in miles of roadway and bikeway affected.

TABLE 11. TRANSPORTATION – STORM EVENT EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5' SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo	0.4	0.4	0.5	0.5	0.5	0.5	0.8	0.8
Hermosa Beach	0	0.1	1.1	4	0.4	3	5.9	5.7
Long Beach	3.8	4.3	4.9	6.2	4.8	5.7	8.2	8.1
Los Angeles	3.9	4.7	6.6	16.7	5.5	8.8	23.6	21.2
Malibu	7	9.3	14	25.7	11.5	20.7	29.6	27.7
Manhattan Beach	0.2	0.6	1.3	2.4	1.3	2.1	6.4	6.4
Palos Verdes Estates	0.3	0.4	0.7	2.2	0.4	0.8	3.7	2.2
Rancho Palos Verdes	0.4	0.7	1.2	3.1	0.7	1.2	3.6	2.6
Redondo Beach	1.6	1.7	1.7	2.2	1.7	1.7	4.3	3.3
Santa Monica	0.2	0.2	0.7	3	0.3	2.7	4.3	4.3
Torrance	0.4	0.4	0.4	0.9	0.4	0.4	1.2	0.9
Unincorporated	1.8	2.3	2.5	3.7	2.4	2.7	4.2	3.9
Full County	20	25.1	35.6	70.7	29.8	50.3	95.9	87.1

NOTES:

Measurements given in miles of roadway and bikeway affected.

TABLE 12. TRANSPORTATION – STORM FLOODING (100-YEAR EVENT) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5' SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0.2	0	0.1	0.5	0.5
El Segundo	0	0.1	0.3	0.4	0.3	0.4	0.5	0.5
Hermosa Beach	0	0.1	1.1	3.3	0.4	3.0	5.0	5.0
Long Beach	48.4	65.7	77.7	113.1	78.1	95.2	147.1	147.1
Los Angeles	36.2	41.7	47.6	78.4	47.5	59.3	122.1	120.3
Malibu	7.0	8.5	11.4	22.4	10.1	19.9	26.9	25.8
Manhattan Beach	0.2	0.5	1.1	2.1	1.0	2.1	2.6	2.6
Palos Verdes Estates	0.3	0.3	0.4	1.4	0.3	0.4	2.5	1.6
Rancho Palos Verdes	0.4	0.4	0.4	1.3	0.4	0.5	1.8	1.1
Redondo Beach	1.3	1.3	1.3	2.0	1.3	1.6	4.0	4.0
Santa Monica	0.2	0.2	0.7	3.0	0.3	2.7	4.3	4.3
Torrance	0.4	0.4	0.4	0.5	0.4	0.4	1.0	0.6
Unincorporated	3.2	3.4	3.6	5.7	3.5	4.8	8.2	8.1
Full County	97.3	122.4	145.9	233.6	143.4	190.4	326.5	321.4

NOTES:

Measurements given in miles of roadway and bikeway affected.

9.3 Buildings and Structures

Data Sources

Building and structure data include building and parking lot footprints. The building and parking lot footprints were taken from the LA County GIS portal, which provides building footprints generated in 2008 and parking lot footprints generated in 2014.

In the tables below, buildings and parking lots are counted in each city and community and in the county as a whole. Buildings and parking lots crossing the border between two cities are counted in both of the cities, but only once in the full county sum. This avoids double-counting in the full county sum, but it means that the sum of buildings in each city may be more than the full county sum.

Vulnerability Summary

TABLE 13. BUILDINGS AND STRUCTURES – LONG-TERM EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5' SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo	0	1	4	11	4	7	25	25
Hermosa Beach	0	0	0	9	0	0	92	85
Long Beach	27	58	100	243	72	136	321	280
Los Angeles	52	76	106	382	83	130	581	469
Malibu	698	917	1054	1419	1011	1136	1629	1576
Manhattan Beach	0	0	0	2	0	0	40	46
Palos Verdes Estates	12	34	56	97	34	58	139	98
Rancho Palos Verdes	27	39	43	74	39	47	86	78
Redondo Beach	12	14	16	23	14	19	62	56
Santa Monica	2	2	2	3	2	2	6	6
Torrance	13	42	48	52	42	48	87	56
Unincorporated	4	6	8	14	7	9	17	15
Full County	847	1189	1436	2328	1308	1591	3083	2788

NOTES:

Numbers reported are the sum of building and parking lot footprints affected by this hazard.

TABLE 14. BUILDINGS AND STRUCTURES – LONG-TERM TIDAL FLOODING (MONTHLY HIGH WATER) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5' SLR by 2080
City	2010	2030	2050	2050	2050	2050	2100	2080
Carson	5	6	6	20	6	11	194	194
El Segundo	3	3	3	4	3	3	4	4
Hermosa Beach	0	0	0	6	0	1	57	57
Long Beach	1080	1958	3686	7503	3775	6435	10147	10147
Los Angeles	1729	2373	2903	4733	2940	3881	7080	7080
Malibu	159	183	214	343	216	267	553	553
Manhattan Beach	0	0	0	0	0	0	0	0
Palos Verdes Estates	0	0	0	0	0	0	0	0
Rancho Palos Verdes	0	0	0	0	0	0	0	0
Redondo Beach	16	19	20	34	20	29	58	58
Santa Monica	2	2	2	4	2	4	16	16
Torrance	0	0	0	0	0	0	0	0
Unincorporated	26	31	43	110	43	56	263	263
Full County	3020	4575	6876	12754	7004	10683	18365	18365

NOTES:

Numbers reported are the sum of building and parking lot footprints affected by this hazard.

TABLE 15. BUILDINGS AND STRUCTURES – STORM EVENT EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5' SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo	10	13	16	26	18	25	33	33
Hermosa Beach	3	4	7	223	6	126	326	312
Long Beach	278	293	325	447	316	364	593	552
Los Angeles	150	214	305	788	232	346	1218	995
Malibu	1218	1279	1368	1707	1290	1505	1939	1854
Manhattan Beach	0	0	0	48	0	1	396	403
Palos Verdes Estates	24	57	77	116	57	79	171	123
Rancho Palos Verdes	39	53	77	127	57	78	142	109
Redondo Beach	47	49	51	56	50	55	108	101
Santa Monica	10	14	19	71	16	31	161	161
Torrance	39	49	51	81	49	51	125	82
Unincorporated	9	15	15	22	15	16	40	32
Full County	1826	2039	2309	3710	2105	2675	5250	4755

NOTES:

Numbers reported are the sum of building and parking lot footprints affected by this hazard.

TABLE 16. BUILDINGS AND STRUCTURES – STORM FLOODING (100-YEAR EVENT) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5' SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	7	7	11	71	11	21	374	374
El Segundo	3	4	7	14	7	10	26	26
Hermosa Beach	3	5	8	158	7	132	343	337
Long Beach	4278	5713	6610	8722	6658	7617	12066	12066
Los Angeles	3222	3673	4156	6224	4159	5032	9378	9268
Malibu	1205	1299	1364	1695	1324	1520	1916	1874
Manhattan Beach	0	0	0	2	0	0	40	46
Palos Verdes Estates	12	34	56	97	34	58	139	98
Rancho Palos Verdes	27	39	47	78	41	51	90	82
Redondo Beach	31	37	43	71	41	54	132	127
Santa Monica	10	14	20	72	17	32	165	165
Torrance	13	42	48	52	42	48	87	56
Unincorporated	54	59	66	222	67	136	327	325
Full County	8863	10924	12430	17472	12403	14705	25073	24834

NOTES:

Numbers reported are the sum of building and parking lot footprints affected by this hazard.

9.4 Public Facilities

Data Sources

Public Facilities data include police stations, fire stations, hospitals, and schools. Building footprints available through the LA County GIS portal were combined with infrastructure identifications from the County Location Management System (also available through the LA County GIS portal) to determine the footprints of public facilities. In some cases, construction since 2008 (the source year of the footprint data) led to public facility points without footprints, and in these cases the footprints were digitized from satellite imagery. Thus, these counts include any buildings identified as public facilities, whose footprints intersect each hazard area.

Vulnerability Summary

Tables list four public facilities separated by slashes: Fire Stations \ Police Stations \ Hospitals \ Schools.

TABLE 17. PUBLIC FACILITIES – LONG-TERM EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	**2010**	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**	**2080**
Carson	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
El Segundo	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Hermosa Beach	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Long Beach	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Los Angeles	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Malibu	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Manhattan Beach	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Palos Verdes Estates	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Rancho Palos Verdes	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Redondo Beach	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0
Santa Monica	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Torrance	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Unincorporated	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Full County	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0

NOTES:

Numbers reported are the sum of public facility footprints affected by this hazard. They are divided as: Fire Stations \ Police Stations \ Hospitals \ Schools

TABLE 18. PUBLIC FACILITIES – LONG-TERM TIDAL FLOODING (MONTHLY HIGH WATER) HAZARD

	Baseline	**3' SLR by 2100**			**5.5' SLR by 2100**			**5.5’ SLR by 2080**
City	**2010**	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**	**2080**
Carson	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
El Segundo	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Hermosa Beach	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Long Beach	1 \ 0 \ 0 \ 0	1 \ 0 \ 0 \ 1	2 \ 0 \ 0 \ 1	2 \ 0 \ 0 \ 1	2 \ 0 \ 0 \ 1	2 \ 0 \ 0 \ 1	3 \ 0 \ 0 \ 4	3 \ 0 \ 0 \ 4
Los Angeles	3 \ 0 \ 0 \ 0	3 \ 0 \ 0 \ 0	3 \ 0 \ 0 \ 0	3 \ 0 \ 0 \ 0	3 \ 0 \ 0 \ 0	3 \ 0 \ 0 \ 0	4 \ 0 \ 0 \ 2	4 \ 0 \ 0 \ 2
Malibu	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Manhattan Beach	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Palos Verdes Estates	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Rancho Palos Verdes	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Redondo Beach	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0
Santa Monica	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Torrance	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Unincorporated	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	1 \ 0 \ 0 \ 0	1 \ 0 \ 0 \ 0
Full County	4 \ 1 \ 0 \ 0	4 \ 1 \ 0 \ 1	5 \ 1 \ 0 \ 1	6 \ 1 \ 0 \ 1	5 \ 1 \ 0 \ 1	6 \ 1 \ 0 \ 1	9 \ 1 \ 0 \ 6	9 \ 1 \ 0 \ 6

NOTES:

Numbers reported are the sum of public facility footprints affected by this hazard. They are divided as: Fire Stations \ Police Stations \ Hospitals \ Schools

TABLE 19. PUBLIC FACILITIES – STORM EVENT EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5' SLR by 2080
City	**2010**	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**	**2080**
Carson	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
El Segundo	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Hermosa Beach	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Long Beach	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Los Angeles	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Malibu	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	1 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	2 \ 0 \ 0 \ 0	2 \ 0 \ 0 \ 0
Manhattan Beach	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Palos Verdes Estates	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Rancho Palos Verdes	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Redondo Beach	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0
Santa Monica	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Torrance	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Unincorporated	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Full County	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	0 \ 1 \ 0 \ 0	2 \ 1 \ 0 \ 0	2 \ 1 \ 0 \ 0

NOTES:

Numbers reported are the sum of public facility footprints affected by this hazard. They are divided as: Fire Stations \ Police Stations \ Hospitals \ Schools

TABLE 20. PUBLIC FACILITIES – STORM FLOODING (100-YEAR EVENT) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	**2010**	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**	**2080**
Carson	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
El Segundo	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Hermosa Beach	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Long Beach	2 \ 0 \ 0 \ 1	2 \ 0 \ 0 \ 1	2 \ 0 \ 0 \ 1	3 \ 0 \ 0 \ 3	2 \ 0 \ 0 \ 1	2 \ 0 \ 0 \ 2	3 \ 0 \ 0 \ 6	3 \ 0 \ 0 \ 6
Los Angeles	3 \ 0 \ 0 \ 0	3 \ 0 \ 0 \ 0	3 \ 0 \ 0 \ 0	4 \ 0 \ 0 \ 1	3 \ 0 \ 0 \ 0	3 \ 0 \ 0 \ 0	4 \ 0 \ 0 \ 3	4 \ 0 \ 0 \ 3
Malibu	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	2 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	2 \ 0 \ 0 \ 0	2 \ 0 \ 0 \ 0
Manhattan Beach	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Palos Verdes Estates	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Rancho Palos Verdes	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Redondo Beach	0 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0
Santa Monica	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Torrance	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0
Unincorporated	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	1 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	0 \ 0 \ 0 \ 0	1 \ 1 \ 0 \ 0	1 \ 1 \ 0 \ 0
Full County	5 \ 1 \ 0 \ 1	6 \ 1 \ 0 \ 1	6 \ 1 \ 0 \ 1	11 \ 1 \ 0 \ 4	6 \ 1 \ 0 \ 1	6 \ 1 \ 0 \ 2	11 \ 2 \ 0 \ 9	11 \ 2 \ 0 \ 9

NOTES:

Numbers reported are the sum of public facility footprints affected by this hazard. They are divided as: Fire Stations \ Police Stations \ Hospitals \ Schools

9.5 Sanitary Sewer Infrastructure

Data Sources

Sanitary sewer data include sewer pipes, pump stations, and wastewater treatment plants. The data provided for this study are from the Consolidated Sewer Maintenance District (SMD, administered by the Los Angeles County Department of Public Works). This organization (SMD) maintains sanitary and collection systems, not trunk systems, thus the dataset was augmented with main lines from the Los Angeles County Sanitation Districts (CSD, a partnership of wastewater districts in the county). The City of Santa Monica (not maintained by SMD or CSD) provided data on their municipal infrastructure, but infrastructure maintained by other sanitation districts in the county (municipal or otherwise) was not included in the files provided for this study.

Countywide Infrastructure

Though sanitary sewer infrastructure has been divided by city and community, there are some assets that would affect the entire county if interrupted. In particular, much of county depends on the Hyperion Water Reclamation Plant in Playa Del Rey for treatment of wastewater. Without this plant, the collection systems in each city and community that pump to the facility would begin to back up. Even though the asset itself is technically within the City of Los Angeles, the impacts of a loss of service would be felt countywide. The plant is elevated and set back from the ocean, so it is not exposed to any of the hazards on the time horizons addressed in this study; however, it is an important enough asset that it should be considered in any adaptation plans developed by the county.

Vulnerability Summary

TABLE 21. SANITARY SEWER (POINT) – LONG-TERM EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo	0	0	0	0	0	0	0	0
Hermosa Beach	0	0	0	0	0	0	0	0
Long Beach	0	0	0	0	0	0	0	0
Los Angeles	1	1	1	4	1	2	7	7
Malibu	1	1	1	2	1	2	2	2
Manhattan Beach	0	0	0	1	0	0	2	2
Palos Verdes Estates	0	1	1	1	1	1	1	1
Rancho Palos Verdes	0	0	0	0	0	0	0	0
Redondo Beach	4	4	4	4	4	4	7	6
Santa Monica	0	0	0	0	0	0	0	0
Torrance	1	1	1	1	1	1	1	1
Unincorporated	0	1	1	1	1	1	1	1
Full County	7	9	9	14	9	11	21	20

NOTES:

Numbers reported are the sum of water treatment plants and pump stations affected by this hazard.

TABLE 22. SANITARY SEWER (POINT) – LONG-TERM TIDAL FLOODING (MONTHLY HIGH WATER) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2050	2050	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo	0	0	0	0	0	0	0	0
Hermosa Beach	0	0	0	0	0	0	0	0
Long Beach	0	0	0	0	0	0	0	0
Los Angeles	0	0	0	0	0	0	0	0
Malibu	0	0	0	0	0	0	0	0
Manhattan Beach	0	0	0	0	0	0	0	0
Palos Verdes Estates	0	0	0	0	0	0	0	0
Rancho Palos Verdes	0	0	0	0	0	0	0	0
Redondo Beach	0	0	0	0	0	0	0	0
Santa Monica	0	0	0	0	0	0	0	0
Torrance	0	0	0	0	0	0	0	0
Unincorporated	0	0	0	0	0	0	0	0
Full County	0	0	0	0	0	0	0	0

NOTES:

Numbers reported are the sum of water treatment plants and pump stations affected by this hazard.

TABLE 23. SANITARY SEWER (POINT) – STORM EVENT EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5' SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo	0	0	0	0	0	0	0	0
Hermosa Beach	0	0	0	0	0	0	0	0
Long Beach	0	0	0	0	0	0	0	0
Los Angeles	3	4	4	7	4	5	11	11
Malibu	1	2	2	2	2	2	2	2
Manhattan Beach	0	0	0	2	0	0	3	3
Palos Verdes Estates	0	1	1	1	1	1	2	1
Rancho Palos Verdes	0	0	0	1	0	0	1	1
Redondo Beach	4	4	5	6	5	5	7	6
Santa Monica	0	0	0	0	0	0	0	0
Torrance	1	1	1	1	1	1	1	1
Unincorporated	0	1	1	1	1	1	1	1
Full County	9	13	14	21	14	15	28	26

NOTES:

Numbers reported are the sum of water treatment plants and pump stations affected by this hazard.

TABLE 24. SANITARY SEWER (POINT) – STORM FLOODING (100-YEAR EVENT) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5' SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo	0	0	0	0	0	0	0	0
Hermosa Beach	0	0	0	0	0	0	0	0
Long Beach	0	0	0	0	0	0	0	0
Los Angeles	3	4	4	4	4	4	7	7
Malibu	1	1	1	2	1	2	2	2
Manhattan Beach	0	0	0	1	0	0	2	2
Palos Verdes Estates	0	1	1	1	1	1	1	1
Rancho Palos Verdes	0	0	0	0	0	0	0	0
Redondo Beach	4	4	5	5	5	5	7	6
Santa Monica	0	0	0	0	0	0	0	0
Torrance	1	1	1	1	1	1	1	1
Unincorporated	0	1	1	1	1	1	1	1
Full County	9	12	13	15	13	14	21	20

NOTES:

Numbers reported are the sum of water treatment plants and pump stations affected by this hazard.

TABLE 25. SANITARY SEWER (LINEAR) – LONG-TERM EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo [a]	0	0	0	0	0	0	0	0
Hermosa Beach [a]	0	0	0	0	0	0	0	0
Long Beach [a]	0	0	0	0	0	0	0	0
Los Angeles [a]	0.7	0.7	0.7	0.8	0.7	0.7	0.9	0.8
Malibu [a]	0.1	0.1	0.2	0.8	0.1	0.3	1.2	0.9
Manhattan Beach [a]	0	0	0	0	0	0	2.2	2.2
Palos Verdes Estates	0	0	0.1	1.1	0	0.2	2.3	1.4
Rancho Palos Verdes	0	0	0	0.6	0	0.1	1.6	1.2
Redondo Beach [a]	0	0	0	0	0	0	0.5	0.2
Santa Monica	0.08	0.09	0.09	0.10	0.09	0.09	0.11	0.11
Torrance [a]	0	0	0	0.1	0	0	0.5	0.2
Unincorporated	0	0	0	0.1	0	0	0.1	0.1
Full County	0.9	1.0	1.2	3.6	1.0	1.4	9.5	7.1

NOTES:

Measurements reported are the sum of sewer pipes from SMD, CSD, and Santa Monica affected by this hazard in miles.

[a] Only trunk line data were provided for in this city, so exposure to hazard refers only to these. Full County is mixed.

TABLE 26. SANITARY SEWER (LINEAR) – LONG-TERM TIDAL FLOODING (MONTHLY HIGH WATER) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2050	2050	2050	2100	2080
Carson	0.3	0.3	0.3	0.4	0.3	0.4	2.6	2.6
El Segundo [a]	0	0	0	0	0	0	0	0
Hermosa Beach [a]	0	0	0	0	0	0	0	0
Long Beach [a]	0.6	0.8	1.1	3.0	1.1	1.7	7.4	7.4
Los Angeles [a]	0.4	0.4	0.4	0.5	0.4	0.5	0.6	0.6
Malibu [a]	0	0	0	0	0	0	0	0
Manhattan Beach [a]	0	0	0	0	0	0	0	0
Palos Verdes Estates	0	0	0	0	0	0	0	0
Rancho Palos Verdes	0	0	0	0	0	0	0	0
Redondo Beach [a]	0	0	0	0	0	0	0	0
Santa Monica	0.08	0.108	0.08	0.09	0.08	0.08	0.12	0.12
Torrance [a]	0	0	0	0	0	0	0	0
Unincorporated	1.6	1.7	1.8	4.6	1.8	2.0	7.4	7.4
Full County	3.0	3.3	3.7	8.5	3.7	4.6	18.0	18.0

NOTES:

Measurements reported are the sum of sewer pipes from SMD, CSD, and Santa Monica affected by this hazard in miles.

[a] Only trunk line data were provided for in this city, so exposure to hazard refers only to these. Full County is mixed.

TABLE 27. SANITARY SEWER (LINEAR) – STORM EVENT EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo [a]	0	0	0	0	0	0	0	0
Hermosa Beach [a]	0	0	0	0.2	0	0	0.5	0.5
Long Beach [a]	0	0	0	0	0	0	0	0
Los Angeles [a]	0.7	0.8	0.9	1.2	0.8	0.9	1.4	1.2
Malibu [a]	0.1	0.3	0.6	1.2	0.4	0.6	1.4	1.4
Manhattan Beach [a]	0	0	0	0.4	0	0	2.8	2.8
Palos Verdes Estates	0	0.1	0.4	2.0	0.1	0.5	3.8	2.1
Rancho Palos Verdes	0	0.1	0.4	3.3	0.1	0.4	4.1	2.8
Redondo Beach [a]	0	0	0	0.8	0	0.1	1.2	1.1
Santa Monica	0.1	0.2	0.2	0.3	0.2	0.2	1.6	1.6
Torrance [a]	0	0	0.1	0.5	0	0.1	0.6	0.6
Unincorporated	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Full County	1.2	1.6	2.7	10.1	1.7	3.1	17.5	14.0

NOTES:

Measurements reported are the sum of sewer pipes from SMD, CSD, and Santa Monica affected by this hazard in miles.

[a] Only trunk line data were provided for in this city, so exposure to hazard refers only to these. Full County is mixed.

TABLE 28. SANITARY SEWER (LINEAR) – STORM FLOODING (100-YEAR EVENT) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0.3	0.4	0.4	0.7	0.4	0.4	5.0	5.0
El Segundo [a]	0	0	0	0	0	0	0	0
Hermosa Beach [a]	0	0	0	0	0	0	0	0
Long Beach [a]	1.1	1.3	1.7	5.1	1.7	3.1	10.8	10.8
Los Angeles [a]	0.9	0.9	1.0	1.2	1.0	1.0	1.5	1.4
Malibu [a]	0.1	0.1	0.2	0.8	0.1	0.3	1.2	0.9
Manhattan Beach [a]	0	0	0	0	0	0	2.2	2.2
Palos Verdes Estates	0	0	0.1	1.1	0	0.2	2.3	1.4
Rancho Palos Verdes	0	0	0	0.6	0	0.1	1.6	1.2
Redondo Beach [a]	0	0	0	0	0	0	0.5	0.2
Santa Monica	0.1	0.2	0.2	0.3	0.2	0.2	1.6	1.6
Torrance [a]	0	0	0	0.1	0	0	0.5	0.2
Unincorporated	1.9	2.0	2.1	6.4	2.2	4.8	8.1	8.1
Full County	4.6	5.0	5.7	16.2	5.6	10.2	35.3	33.0

NOTES:

Measurements reported are the sum of sewer pipes from SMD, CSD, and Santa Monica affected by this hazard in miles.

[a] Only trunk line data were provided for in this city, so exposure to hazard refers only to these. Full County is mixed.

9.6 Storm Drain Infrastructure

Data Sources

Storm drain data include pump stations, gravity mains, force mains, and culverts used in stormwater conveyance and management that are exposed to different hazards at different time horizons. These data were provided by the LA County Department of Public Works. The tables for this category have been split between pump stations, which are point assets counted by instance, and mains and culverts, which are linear assets measured in miles.

Vulnerability Summary

TABLE 29. STORM DRAIN PUMP STATIONS) – LONG-TERM EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo	0	0	0	0	0	0	0	0
Hermosa Beach	0	0	0	0	0	0	0	0
Long Beach	0	0	0	0	0	0	0	0
Los Angeles	0	0	0	0	0	0	2	2
Malibu	0	0	0	0	0	0	0	0
Manhattan Beach	0	0	0	0	0	0	0	0
Palos Verdes Estates	0	0	0	0	0	0	0	0
Rancho Palos Verdes	0	0	0	0	0	0	0	0
Redondo Beach	0	0	0	0	0	0	0	0
Santa Monica	0	0	0	0	0	0	0	0
Torrance	0	0	0	0	0	0	0	0
Unincorporated	0	0	0	0	0	0	0	0
Full County	0	0	0	0	0	0	2	2

NOTES:

Numbers reported are the number of pump stations affected by this hazard.

TABLE 30. STORM DRAIN (POINT) – LONG-TERM TIDAL FLOODING (MONTHLY HIGH WATER) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2050	2050	2050	2100	2080
Carson	1	1	1	1	1	1	1	1
El Segundo	0	0	0	0	0	0	0	0
Hermosa Beach	0	0	0	0	0	0	0	0
Long Beach	6	7	10	15	10	14	18	18
Los Angeles	0	0	0	2	0	0	5	5
Malibu	0	0	0	0	0	0	0	0
Manhattan Beach	0	0	0	0	0	0	0	0
Palos Verdes Estates	0	0	0	0	0	0	0	0
Rancho Palos Verdes	0	0	0	0	0	0	0	0
Redondo Beach	0	0	0	0	0	0	0	0
Santa Monica	0	0	0	0	0	0	0	0
Torrance	0	0	0	0	0	0	0	0
Unincorporated	0	0	0	0	0	0	0	0
Full County	7	8	11	18	11	15	24	24

NOTES:

Numbers reported are the number of pump stations affected by this hazard.

TABLE 31. STORM DRAIN (POINT) – STORM EVENT EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo	0	0	0	0	0	0	0	0
Hermosa Beach	0	0	0	0	0	0	0	0
Long Beach	0	0	0	0	0	0	0	0
Los Angeles	0	0	0	5	0	4	5	5
Malibu	0	0	0	0	0	0	0	0
Manhattan Beach	0	0	0	0	0	0	0	0
Palos Verdes Estates	0	0	0	0	0	0	0	0
Rancho Palos Verdes	0	0	0	0	0	0	0	0
Redondo Beach	0	0	0	0	0	0	0	0
Santa Monica	0	0	0	0	0	0	0	0
Torrance	0	0	0	0	0	0	0	0
Unincorporated	0	0	0	0	0	0	0	0
Full County	0	0	0	5	0	4	5	5

NOTES:
Numbers reported are the number of pump stations affected by this hazard.

TABLE 32. STORM DRAIN (POINT) – STORM FLOODING (100-YEAR EVENT) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	1	1	1	1	1	1	1	1
El Segundo	0	0	0	0	0	0	0	0
Hermosa Beach	0	0	0	0	0	0	0	0
Long Beach	10	11	15	16	15	16	19	19
Los Angeles	0	0	1	8	1	4	11	11
Malibu	0	0	0	0	0	0	0	0
Manhattan Beach	0	0	0	0	0	0	0	0
Palos Verdes Estates	0	0	0	0	0	0	0	0
Rancho Palos Verdes	0	0	0	0	0	0	0	0
Redondo Beach	0	0	0	0	0	0	0	0
Santa Monica	0	0	0	0	0	0	0	0
Torrance	0	0	0	0	0	0	0	0
Unincorporated	0	0	0	0	0	0	0	0
Full County	11	12	17	25	17	21	31	31

NOTES:
Numbers reported are the number of pump stations affected by this hazard.

TABLE 33. STORM DRAIN (MAINS AND CULVERTS) – LONG-TERM EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo	0	0	0	0	0	0	0	0
Hermosa Beach	0	0	0	0.1	0	0	0.2	0.2
Long Beach	0	0	0	0.3	0	0	0.5	0.4
Los Angeles	0.6	0.7	0.9	1.9	0.8	1.0	2.7	2.3
Malibu	0.6	0.7	0.8	1.1	0.7	0.8	1.2	1.1
Manhattan Beach	0	0	0	0	0	0	0.2	0.2
Palos Verdes Estates	0.5	0.6	0.6	1.3	0.6	0.7	1.7	1.4
Rancho Palos Verdes	0.3	0.3	0.3	0.7	0.3	0.3	0.9	0.7
Redondo Beach	0.1	0.1	0.1	0.2	0.1	0.2	0.3	0.2
Santa Monica	0	0	0	0.1	0	0.1	0.1	0.1
Torrance	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.2
Unincorporated	0	0	0	0	0	0	0	0
Full County	2.3	2.6	2.9	5.8	2.7	3.2	7.9	6.9

NOTES:

Measurements reported are the sum of gravity mains, force mains, and culverts affected by this hazard in miles.

TABLE 34. STORM DRAIN (MAINS AND CULVERTS) – LONG-TERM TIDAL FLOODING (MONTHLY HIGH WATER) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2050	2050	2050	2100	2080
Carson	0.1	0.1	0.1	0.1	0.1	0.1	1.4	1.4
El Segundo	0	0	0	0	0	0	0	0
Hermosa Beach	0	0	0	0	0	0	0	0
Long Beach	3.0	5.9	9.6	21.9	9.9	17.0	32.4	32.4
Los Angeles	1.8	2.6	3.5	8.4	3.6	5.9	14.8	14.8
Malibu	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Manhattan Beach	0	0	0	0	0	0	0	0
Palos Verdes Estates	0	0	0	0	0	0	0	0
Rancho Palos Verdes	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Redondo Beach	0	0	0	0	0	0	0.2	0.2
Santa Monica	0	0	0	0.1	0	0	0.2	0.2
Torrance	0	0	0	0	0	0	0	0
Unincorporated	0.1	0.2	0.2	0.3	0.2	0.2	0.8	0.8
Full County	5.3	9.0	13.6	31.1	14.1	23.6	50.0	50.0

NOTES:

Measurements reported are the sum of gravity mains, force mains, and culverts affected by this hazard in miles.

TABLE 35. STORM DRAIN (MAINS AND CULVERTS) – STORM EVENT EROSION HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0	0	0	0	0	0	0	0
El Segundo	0	0	0	0	0	0	0.1	0.1
Hermosa Beach	0.1	0.1	0.2	0.4	0.2	0.3	0.6	0.6
Long Beach	0.3	0.4	0.5	0.8	0.4	0.6	1.2	1.1
Los Angeles	1.3	1.5	1.9	3.8	1.6	2.1	4.9	4.5
Malibu	0.9	1.0	1.2	1.5	1.1	1.3	1.6	1.5
Manhattan Beach	0	0	0	0	0	0	0.6	0.6
Palos Verdes Estates	0.6	0.6	0.9	1.8	0.6	0.9	2.1	1.8
Rancho Palos Verdes	0.3	0.4	0.7	1.1	0.4	0.7	1.2	1.0
Redondo Beach	0.2	0.2	0.2	0.4	0.2	0.3	0.5	0.5
Santa Monica	0.2	0.2	0.2	0.5	0.2	0.3	0.8	0.8
Torrance	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.2
Unincorporated	0	0	0	0	0	0	0	0
Full County	4.1	4.6	5.9	10.5	4.9	6.7	13.9	12.7

NOTES:

Measurements reported are the sum of gravity mains, force mains, and culverts affected by this hazard in miles.

TABLE 36. STORM DRAIN (MAINS AND CULVERTS) – STORM FLOODING (100-YEAR EVENT) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	2010	2030	2050	2100	2030	2050	2100	2080
Carson	0.1	0.1	0.1	0.5	0.1	0.1	2.5	2.5
El Segundo	0	0	0	0	0	0	0.1	0.1
Hermosa Beach	0.1	0.1	0.2	0.3	0.2	0.3	0.5	0.5
Long Beach	11.0	14.7	17.5	27.1	17.7	22.3	37.7	37.7
Los Angeles	5.4	6.3	7.3	13.2	7.3	10.0	22.2	21.9
Malibu	0.9	1.0	1.1	1.7	1.1	1.4	2.1	2.1
Manhattan Beach	0	0	0	0	0	0	0.2	0.2
Palos Verdes Estates	0.5	0.6	0.6	1.3	0.6	0.7	1.7	1.4
Rancho Palos Verdes	0.3	0.3	0.4	0.8	0.3	0.4	0.9	0.8
Redondo Beach	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.5
Santa Monica	0.2	0.2	0.2	0.5	0.2	0.3	0.8	0.8
Torrance	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.2
Unincorporated	0.2	0.2	0.3	0.5	0.3	0.4	0.9	0.9
Full County	18.9	23.8	28.1	46.3	28.1	36.2	70.3	69.5

NOTES:

Measurements reported are the sum of gravity mains, force mains, and culverts affected by this hazard in miles.

9.7 Ecosystem Assets

Data Sources

Ecosystem data include beaches, brackish wetlands (i.e. estuarine), and fresh wetlands (i.e. riverine), as identified by the National Wetlands Inventory (US FWS 2015). The data were divided into these three categories based on “System,” the highest-level categorization provided by NWI. Marine systems were marked as beaches; estuarine systems were marked as brackish wetlands; and riverine, lacustrine, and palustrine systems were marked as fresh wetlands. To avoid erroneously identifying offshore areas as beaches, areas marked as “Marine, sub-tidal” were removed from the beach category. Finally, man-made structures were removed from the ecosystem layers. Most of these were rubble-mound breakwaters or groins, which had been marked “Marine, rocky, artificial substrate.” While they do act as habitats, they have been removed from this section since they function primarily as coastal protection structures.

It is worth noting that long-term tidal flooding at monthly high water may not have detrimental effects on some of these ecosystems (i.e. beaches and salty marshes), especially not in the same way as the other three hazards; however, changes in inundation will likely have an effect – positive or negative. For that reason and for consistency with the other sectors in this report, the areas are still tabulated in Table 38 below.

Vulnerability Summary

Tables list areas for three types of ecosystem separated by slashes: Beaches \ Salty Wetlands \ Fresh Wetlands. Areas are reported in acres, rounded to the nearest acre.

TABLE 37. ECOSYSTEM – LONG-TERM EROSION HAZARD

	Baseline	**3' SLR by 2100**			**5.5' SLR by 2100**			**5.5’ SLR by 2080**
City	**2010**	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**	**2080**
Carson	0 \ 0 \ 0	0 \ 0 \ 0	0 \ 0 \ 0	0 \ 0 \ 0	0 \ 0 \ 0	0 \ 0 \ 0	0 \ 0 \ 0	0 \ 0 \ 0
El Segundo	14 \ 0 \ 0	15 \ 0 \ 0	16 \ 0 \ 0	21 \ 0 \ 1	16 \ 0 \ 0	19 \ 0 \ 0	29 \ 0 \ 1	29 \ 0 \ 1
Hermosa Beach	27 \ 0 \ 0	32 \ 0 \ 0	38 \ 0 \ 0	53 \ 0 \ 0	37 \ 0 \ 0	46 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0
Long Beach	53 \ 0 \ 0	61 \ 0 \ 0	69 \ 0 \ 0	96 \ 0 \ 0	69 \ 0 \ 0	83 \ 0 \ 0	125 \ 0 \ 0	125 \ 0 \ 0
Los Angeles	231 \ 0 \ 0	257 \ 0 \ 0	289 \ 1 \ 0	392 \ 1 \ 0	282 \ 1 \ 0	329 \ 1 \ 0	462 \ 1 \ 0	460 \ 1 \ 0
Malibu	312 \ 10 \ 1	318 \ 13 \ 2	322 \ 16 \ 2	331 \ 23 \ 3	322 \ 14 \ 2	328 \ 17 \ 2	341 \ 29 \ 4	342 \ 25 \ 3
Manhattan Beach	37 \ 0 \ 0	43 \ 0 \ 0	50 \ 0 \ 0	77 \ 0 \ 0	50 \ 0 \ 0	62 \ 0 \ 0	103 \ 0 \ 0	103 \ 0 \ 0
Palos Verdes Estates	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1
Rancho Palos Verdes	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 2	66 \ 0 \ 1
Redondo Beach	31 \ 0 \ 0	32 \ 0 \ 0	33 \ 0 \ 0	34 \ 0 \ 0	33 \ 0 \ 0	34 \ 0 \ 0	35 \ 1 \ 0	35 \ 1 \ 0
Santa Monica	57 \ 0 \ 0	63 \ 0 \ 0	70 \ 0 \ 0	97 \ 0 \ 0	71 \ 0 \ 0	83 \ 0 \ 0	130 \ 1 \ 0	130 \ 1 \ 0
Torrance	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0
Unincorporated	36 \ 0 \ 0	38 \ 0 \ 0	38 \ 1 \ 0	38 \ 1 \ 0	38 \ 0 \ 0	38 \ 1 \ 0	38 \ 1 \ 0	38 \ 1 \ 0
Full County	891 \ 11 \ 3	949 \ 14 \ 3	1014 \ 17 \ 4	1232 \ 26 \ 6	1007 \ 15 \ 3	1112 \ 19 \ 4	1412 \ 33 \ 8	1410 \ 29 \ 7

NOTES:

Measurements reported are the sum of ecosystem areas (in acres) affected by this hazard. They are divided as: Beach \ Salty Wetland \ Fresh Wetland

TABLE 38. ECOSYSTEM – LONG-TERM TIDAL FLOODING (MONTHLY HIGH WATER) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	**2010**	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**	**2080**
Carson	0 \ 16 \ 84	0 \ 16 \ 85	0 \ 16 \ 86	0 \ 16 \ 90	0 \ 16 \ 86	0 \ 16 \ 88	0 \ 16 \ 93	0 \ 16 \ 93
El Segundo	7 \ 0 \ 0	8 \ 0 \ 0	8 \ 0 \ 0	10 \ 0 \ 0	8 \ 0 \ 0	9 \ 0 \ 0	17 \ 0 \ 0	17 \ 0 \ 0
Hermosa Beach	21 \ 0 \ 0	22 \ 0 \ 0	23 \ 0 \ 0	26 \ 0 \ 0	23 \ 0 \ 0	24 \ 0 \ 0	34 \ 0 \ 0	34 \ 0 \ 0
Long Beach	39 \ 2435 \ 134	43 \ 2441 \ 153	48 \ 2446 \ 176	102 \ 2465 \ 218	48 \ 2447 \ 177	72 \ 2460 \ 204	165 \ 2474 \ 248	165 \ 2474 \ 248
Los Angeles	183 \ 1788 \ 73	189 \ 1798 \ 106	195 \ 1804 \ 113	223 \ 1820 \ 133	195 \ 1805 \ 113	208 \ 1812 \ 121	267 \ 1826 \ 146	267 \ 1826 \ 146
Malibu	198 \ 29 \ 0	206 \ 31 \ 0	212 \ 34 \ 0	238 \ 41 \ 1	213 \ 34 \ 0	226 \ 38 \ 1	277 \ 43 \ 4	277 \ 43 \ 4
Manhattan Beach	30 \ 0 \ 0	31 \ 0 \ 0	32 \ 0 \ 0	36 \ 0 \ 0	32 \ 0 \ 0	34 \ 0 \ 0	44 \ 0 \ 0	44 \ 0 \ 0
Palos Verdes Estates	9 \ 0 \ 0	10 \ 0 \ 0	10 \ 0 \ 0	10 \ 0 \ 0	10 \ 0 \ 0	10 \ 0 \ 0	10 \ 0 \ 0	10 \ 0 \ 0
Rancho Palos Verdes	43 \ 0 \ 0	46 \ 0 \ 0	48 \ 0 \ 0	53 \ 0 \ 0	48 \ 0 \ 0	51 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0
Redondo Beach	15 \ 102 \ 0	16 \ 102 \ 0	17 \ 102 \ 0	20 \ 104 \ 0	17 \ 102 \ 0	19 \ 103 \ 0	25 \ 104 \ 0	25 \ 104 \ 0
Santa Monica	49 \ 0 \ 0	51 \ 0 \ 0	52 \ 0 \ 0	60 \ 1 \ 0	52 \ 0 \ 0	56 \ 1 \ 0	95 \ 1 \ 0	95 \ 1 \ 0
Torrance	9 \ 0 \ 0	9 \ 0 \ 0	9 \ 0 \ 0	11 \ 0 \ 0	9 \ 0 \ 0	10 \ 0 \ 0	12 \ 0 \ 0	12 \ 0 \ 0
Unincorporated	21 \ 375 \ 5	22 \ 377 \ 6	23 \ 379 \ 6	26 \ 386 \ 6	23 \ 379 \ 6	25 \ 382 \ 6	31 \ 386 \ 7	31 \ 386 \ 7
Full County	626 \ 4745 \ 297	653 \ 4766 \ 351	678 \ 4783 \ 382	816 \ 4832 \ 456	680 \ 4784 \ 384	743 \ 4811 \ 424	1037 \ 4850 \ 512	1037 \ 4850 \ 512

NOTES:

Measurements reported are the sum of ecosystem areas (in acres) affected by this hazard. They are divided as: Beach \ Salty Wetland \ Fresh Wetland

TABLE 39. ECOSYSTEM – STORM EVENT EROSION HAZARD

	Baseline	**3' SLR by 2100**			**5.5' SLR by 2100**			**5.5’ SLR by 2080**
City	**2010**	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**	**2080**
Carson	0 \ 0 \ 0	0 \ 0 \ 0	0 \ 0 \ 0	0 \ 0 \ 0	0 \ 0 \ 0	0 \ 0 \ 0	0 \ 0 \ 0	0 \ 0 \ 0
El Segundo	23 \ 0 \ 0	24 \ 0 \ 0	24 \ 0 \ 1	27 \ 0 \ 1	24 \ 0 \ 1	26 \ 0 \ 1	30 \ 0 \ 1	30 \ 0 \ 1
Hermosa Beach	58 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0
Long Beach	141 \ 2 \ 0	148 \ 2 \ 0	153 \ 3 \ 0	159 \ 3 \ 0	151 \ 3 \ 0	157 \ 3 \ 0	163 \ 4 \ 0	163 \ 4 \ 0
Los Angeles	460 \ 3 \ 0	476 \ 4 \ 0	494 \ 4 \ 0	527 \ 6 \ 0	488 \ 4 \ 0	519 \ 6 \ 0	540 \ 7 \ 0	539 \ 7 \ 0
Malibu	342 \ 17 \ 2	343 \ 19 \ 2	343 \ 21 \ 3	345 \ 29 \ 5	343 \ 19 \ 3	345 \ 23 \ 3	346 \ 34 \ 6	346 \ 30 \ 5
Manhattan Beach	68 \ 0 \ 0	73 \ 0 \ 0	80 \ 0 \ 0	101 \ 0 \ 0	79 \ 0 \ 0	94 \ 0 \ 0	104 \ 0 \ 0	104 \ 0 \ 0
Palos Verdes Estates	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1
Rancho Palos Verdes	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 2	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 3	66 \ 0 \ 2
Redondo Beach	35 \ 1 \ 0	35 \ 1 \ 0	35 \ 1 \ 0	35 \ 1 \ 0	35 \ 1 \ 0	35 \ 1 \ 0	35 \ 2 \ 0	35 \ 2 \ 0
Santa Monica	167 \ 1 \ 0	176 \ 1 \ 0	192 \ 1 \ 0	221 \ 1 \ 0	185 \ 1 \ 0	211 \ 1 \ 0	226 \ 1 \ 0	226 \ 1 \ 0
Torrance	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0
Unincorporated	38 \ 0 \ 0	38 \ 1 \ 0	38 \ 1 \ 0	38 \ 1 \ 1	38 \ 1 \ 0	38 \ 1 \ 0	38 \ 1 \ 1	38 \ 1 \ 1
Full County	1424 \ 25 \ 4	1461 \ 28 \ 5	1510 \ 32 \ 6	1603 \ 42 \ 9	1493 \ 29 \ 5	1575 \ 36 \ 6	1632 \ 50 \ 12	1631 \ 46 \ 10

NOTES:

Measurements reported are the sum of ecosystem areas (in acres) affected by this hazard. They are divided as: Beach \ Salty Wetland \ Fresh Wetland

TABLE 40. ECOSYSTEM – STORM FLOODING (100-YEAR EVENT) HAZARD

	Baseline	3' SLR by 2100			5.5' SLR by 2100			5.5’ SLR by 2080
City	**2010**	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**	**2080**
Carson	0 \ 16 \ 87	0 \ 16 \ 88	0 \ 16 \ 88	0 \ 16 \ 92	0 \ 16 \ 88	0 \ 16 \ 90	0 \ 16 \ 94	0 \ 16 \ 94
El Segundo	22 \ 0 \ 0	23 \ 0 \ 0	24 \ 0 \ 0	26 \ 0 \ 1	23 \ 0 \ 0	25 \ 0 \ 0	30 \ 0 \ 1	30 \ 0 \ 1
Hermosa Beach	58 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0	58 \ 0 \ 0
Long Beach	143 \ 2449 \ 181	152 \ 2458 \ 196	159 \ 2460 \ 205	170 \ 2470 \ 229	158 \ 2461 \ 206	165 \ 2466 \ 218	177 \ 2477 \ 263	177 \ 2477 \ 263
Los Angeles	464 \ 1807 \ 114	479 \ 1810 \ 118	498 \ 1814 \ 123	528 \ 1824 \ 140	491 \ 1814 \ 123	523 \ 1821 \ 134	542 \ 1829 \ 149	542 \ 1829 \ 149
Malibu	343 \ 43 \ 7	344 \ 43 \ 8	344 \ 43 \ 9	347 \ 43 \ 15	344 \ 43 \ 9	347 \ 43 \ 12	347 \ 43 \ 21	347 \ 43 \ 21
Manhattan Beach	68 \ 0 \ 0	72 \ 0 \ 0	79 \ 0 \ 0	96 \ 0 \ 0	76 \ 0 \ 0	92 \ 0 \ 0	104 \ 0 \ 0	104 \ 0 \ 0
Palos Verdes Estates	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1	10 \ 0 \ 1
Rancho Palos Verdes	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 1	66 \ 0 \ 2	66 \ 0 \ 1
Redondo Beach	37 \ 102 \ 0	37 \ 103 \ 0	37 \ 103 \ 0	37 \ 104 \ 0	37 \ 103 \ 0	37 \ 104 \ 0	37 \ 104 \ 0	37 \ 104 \ 0
Santa Monica	167 \ 1 \ 0	176 \ 1 \ 0	192 \ 1 \ 0	221 \ 1 \ 0	185 \ 1 \ 0	211 \ 1 \ 0	226 \ 1 \ 0	226 \ 1 \ 0
Torrance	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 0	14 \ 0 \ 1	14 \ 0 \ 1
Unincorporated	38 \ 380 \ 7	38 \ 381 \ 7	38 \ 383 \ 7	38 \ 386 \ 8	38 \ 383 \ 7	38 \ 386 \ 7	38 \ 386 \ 10	38 \ 386 \ 10
Full County	1432 \ 4798 \ 399	1470 \ 4812 \ 420	1520 \ 4820 \ 437	1613 \ 4844 \ 498	1503 \ 4821 \ 438	1588 \ 4837 \ 471	1652 \ 4857 \ 560	1652 \ 4857 \ 559

NOTES:

Measurements reported are the sum of ecosystem areas (in acres) affected by this hazard. They are divided as: Beach \ Salty Wetland \ Fresh Wetland

10. LIST OF PREPARERS

This report was prepared by James Jackson, P.E. (Hydrologist), with technical oversight by Matt Brennan (Project Manager); Bob Battalio, P.E. (Project Director). Additional support was provided by, Dane Behrens, Ph.D., P.E., Hannah Snow, EIT, and Alex Trahan, EIT.

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12. FIGURES

Figure 1

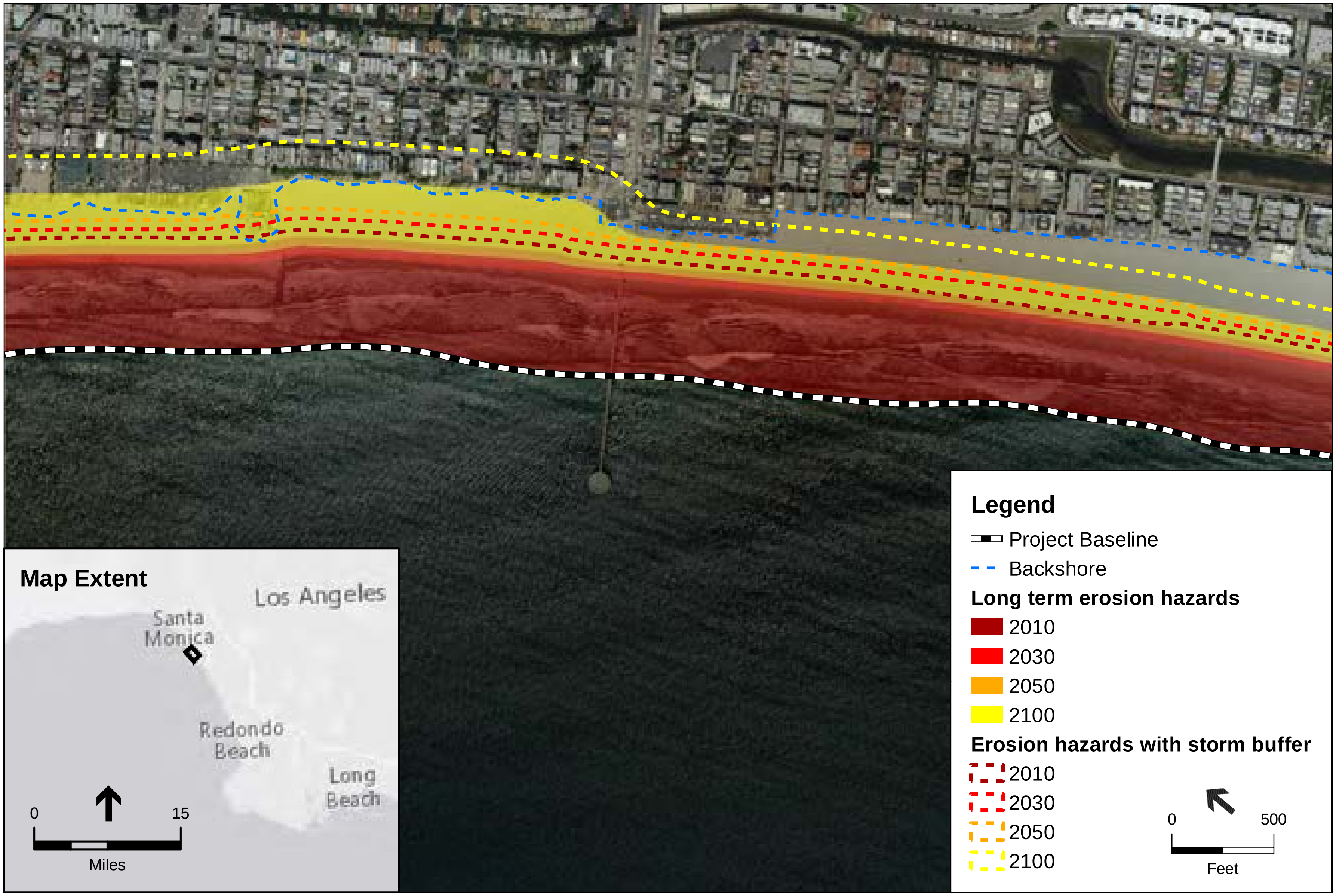
Los Angeles County study area

SOURCE: PWA 2009

LA County Coastal Hazards Modeling . 130524.00

Figure 2

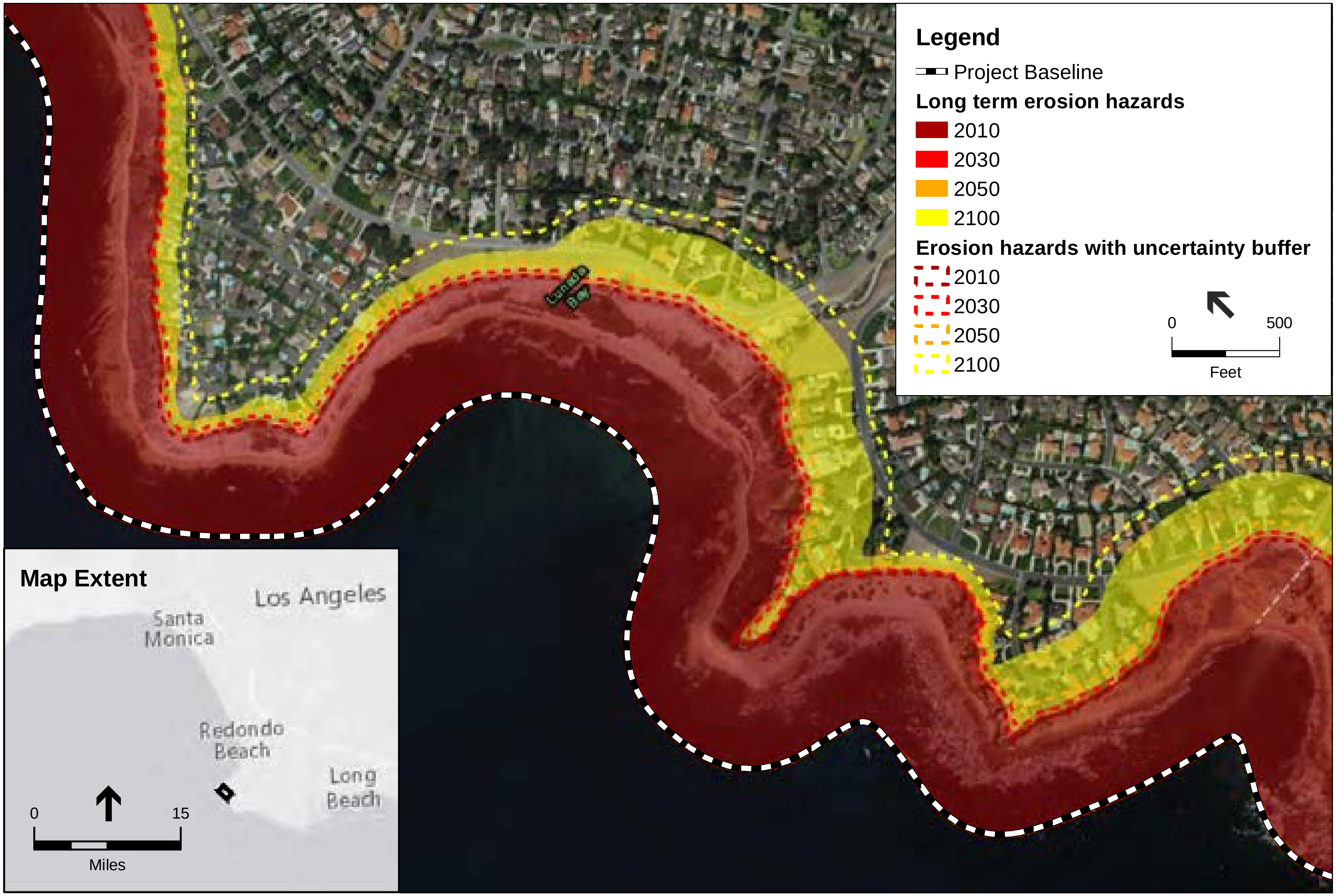
Pacific Institute Coastal Flooding Hazard Zones



NOTE: The hazards shown are for the "high sea level rise" scenario of 1.68 meters of SLR by 2100 relative to 2010. These hazard zones do not consider coastal armoring.

Figure 3

Example of sandy shoreline erosion hazard zones



NOTE: The hazards shown are for the "high sea level rise" scenario of 1.68 meters of SLR by 2100 relative to 2010. These hazard zones do not consider coastal armoring.

Figure 4

Example of cliff erosion hazard zones

LA County Coastal Hazards Modeling . 130524.00

Figure 5

Coastal Flooding Hazard Zones

NOTES:
1. These future tidal flooding zones are for the High sea level rise scenario of 1.68 meters by 2100.
2. Assumes a monthly extreme water level of 2.0 m NAVD88 in 2010, as estimated by ESA.
3. This hazard zone does not consider future erosion of the coast and should be used in conjunction with the coastal erosion hazard zones.

LA County Coastal Hazards Modeling . 130524.00

Figure 6

Example of monthly tidal flooding area

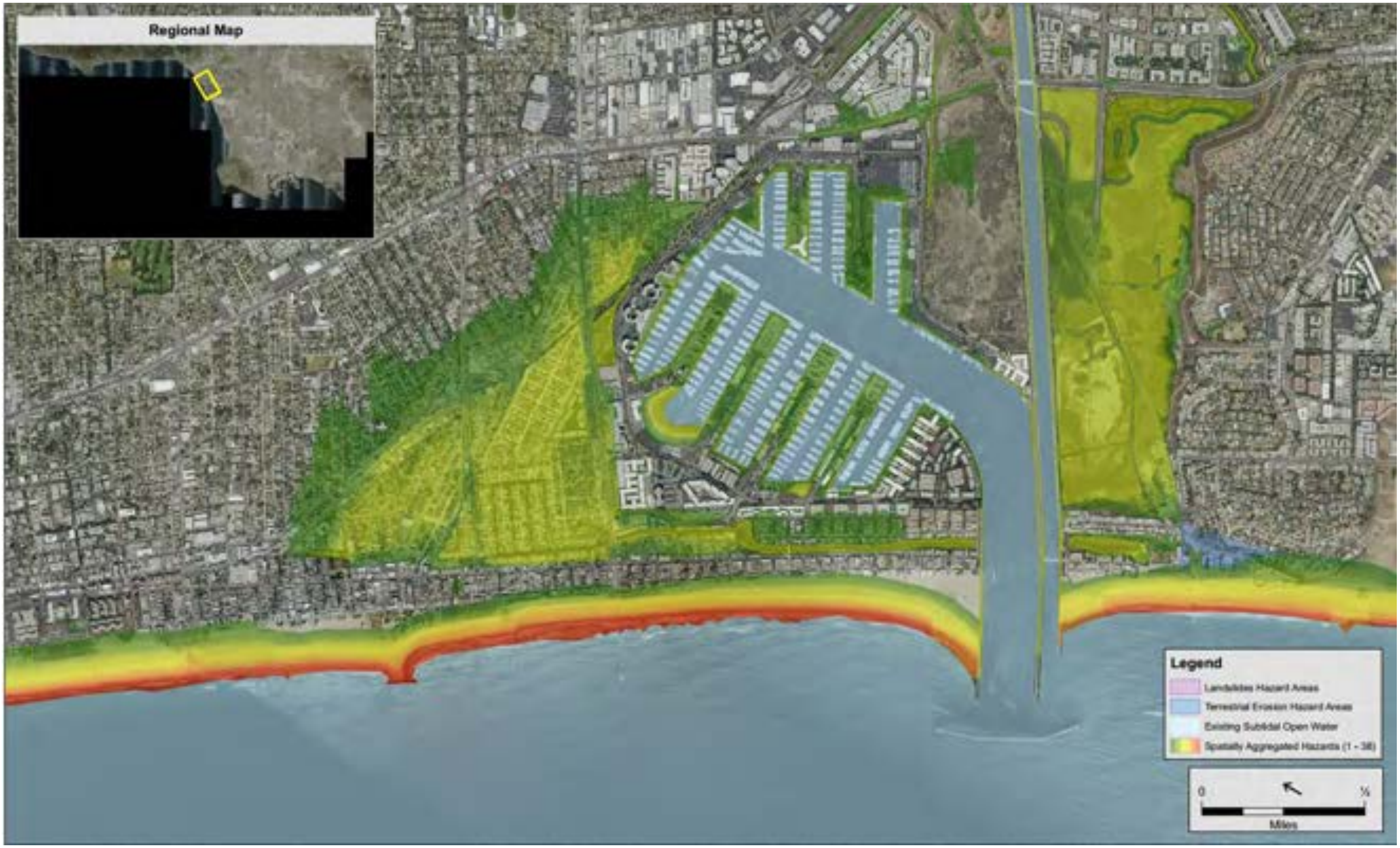
NOTES:

1. These future tidal flooding zones are for the High sea level rise scenario of 1.68 meters by 2100.
2. Assumes a monthly extreme water level of 2.0 m NAVD88 in 2010, as estimated by ESA.
3. This hazard zone does not consider future erosion of the coast and should be used in conjunction with the coastal erosion hazard zones.

LA County Coastal Hazards Modeling . 130524.00

Figure 7

Example of monthly tidal flooding depth

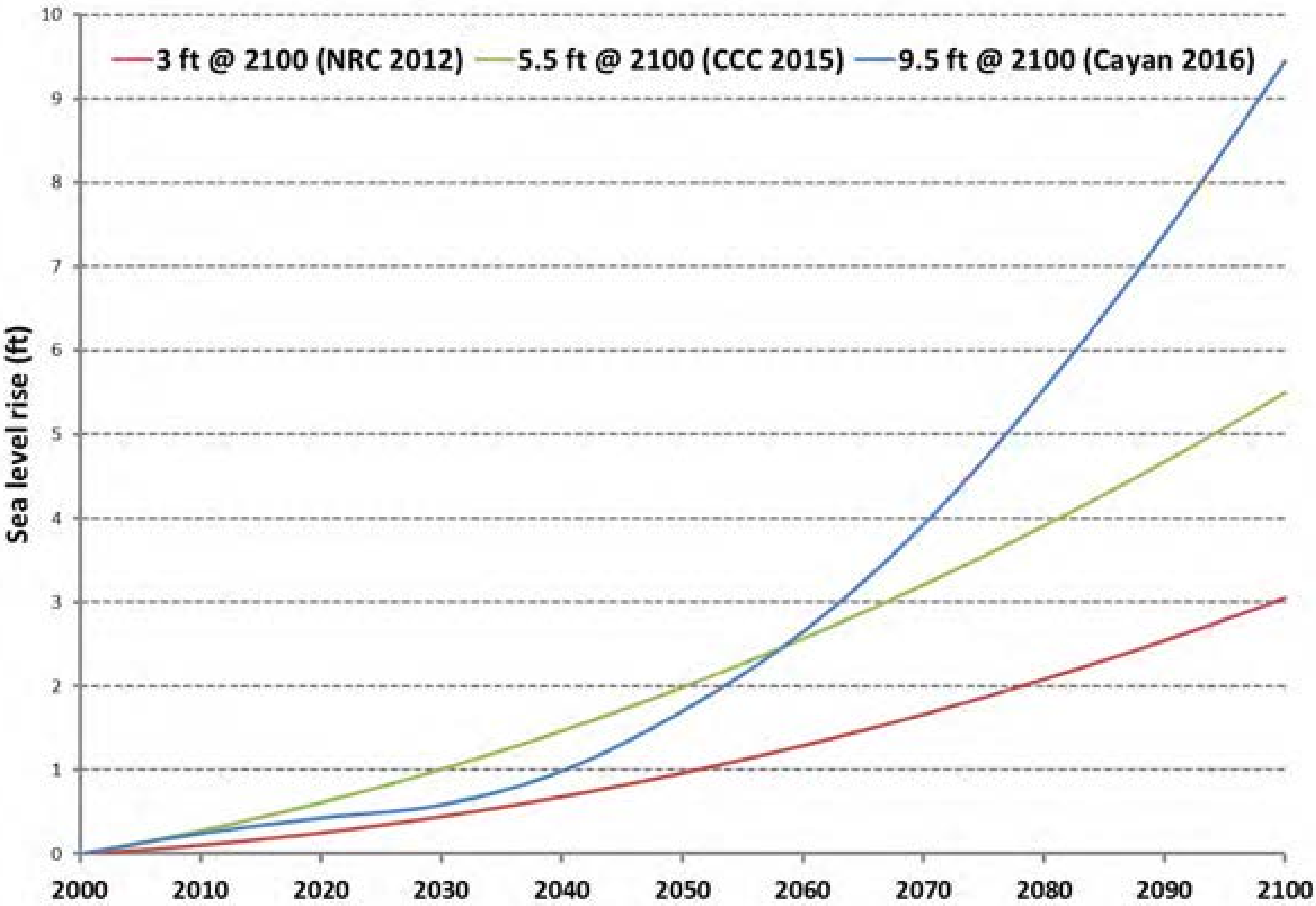


NOTE:. This is an example of the spatial aggregation of hazards in Appendix 2. For maps of the rest of the Los Angeles County coastline, please see the appendix.

LA County Coastal Hazards Modeling . 130524.00

Figure 8

Example of spatial aggregation layers



SOURCE: NRC 2012 Table 5.3; CCC 2015 Equation B3; Cayan 2016.

NOTE: Data show NRC LA Regional curves with regional vertical land motion for the San Andreas region (-1.5 mm/yr).

Figure 9
Sea level rise curves

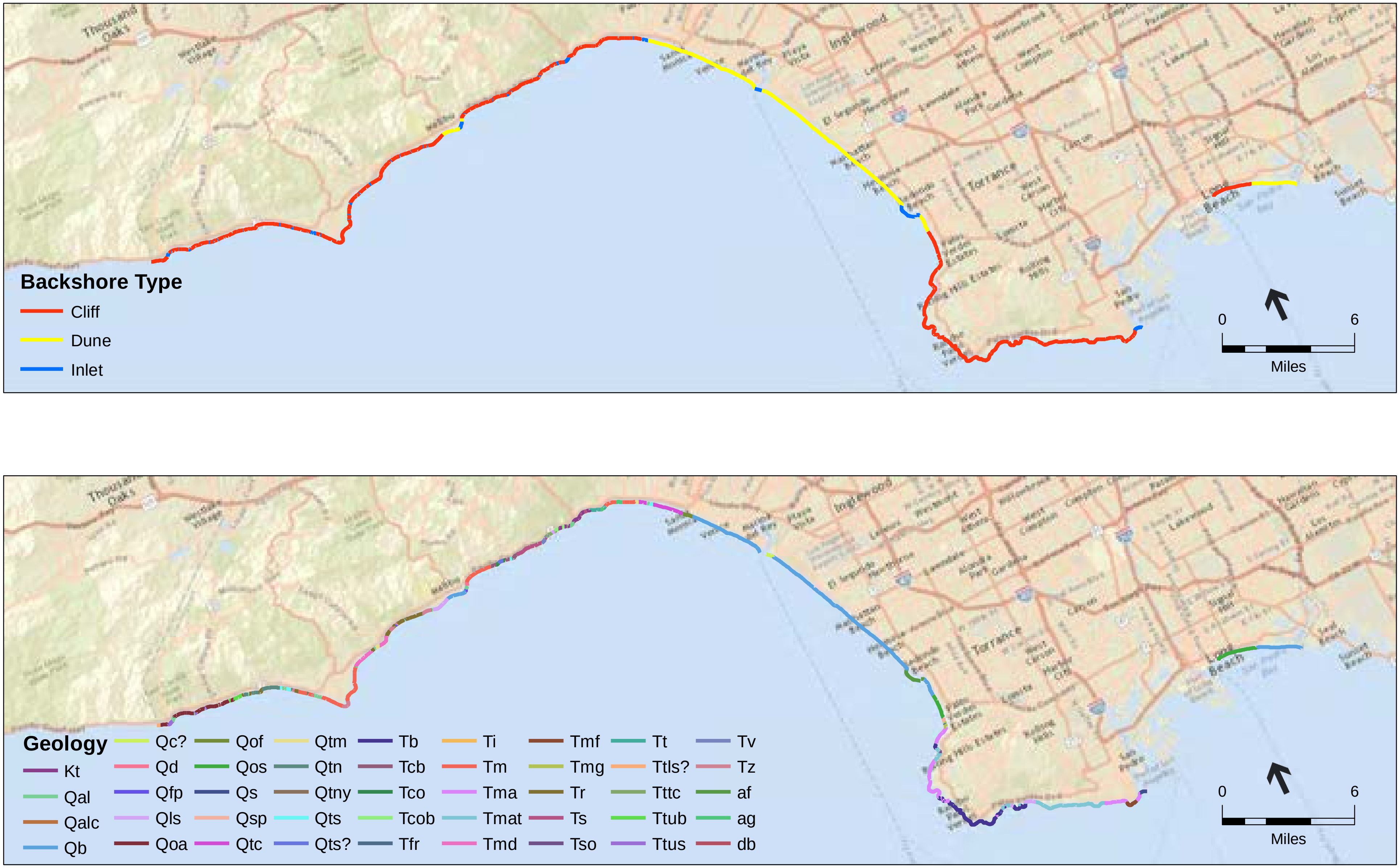
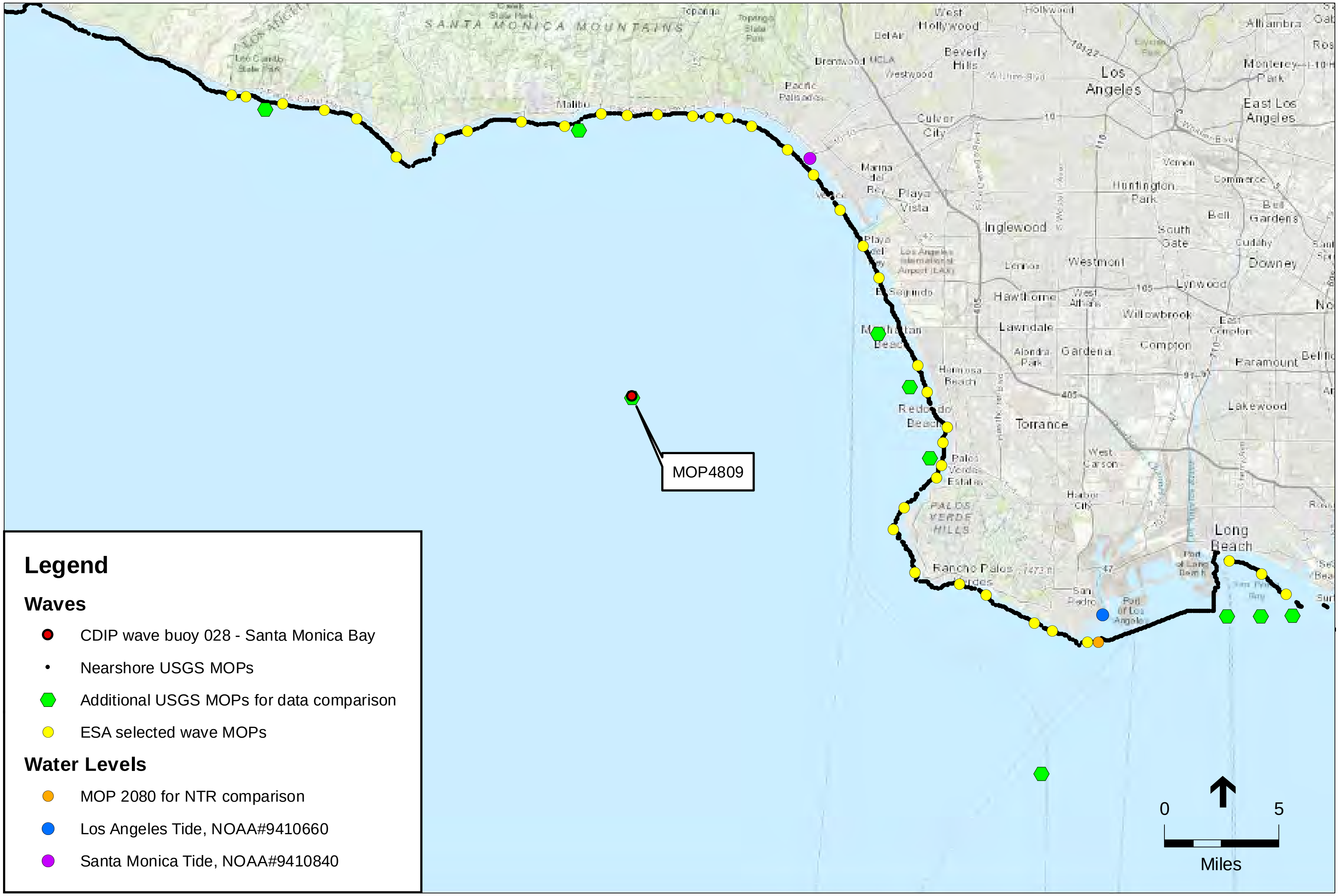


Figure 10

Los Angeles County backshore and geology

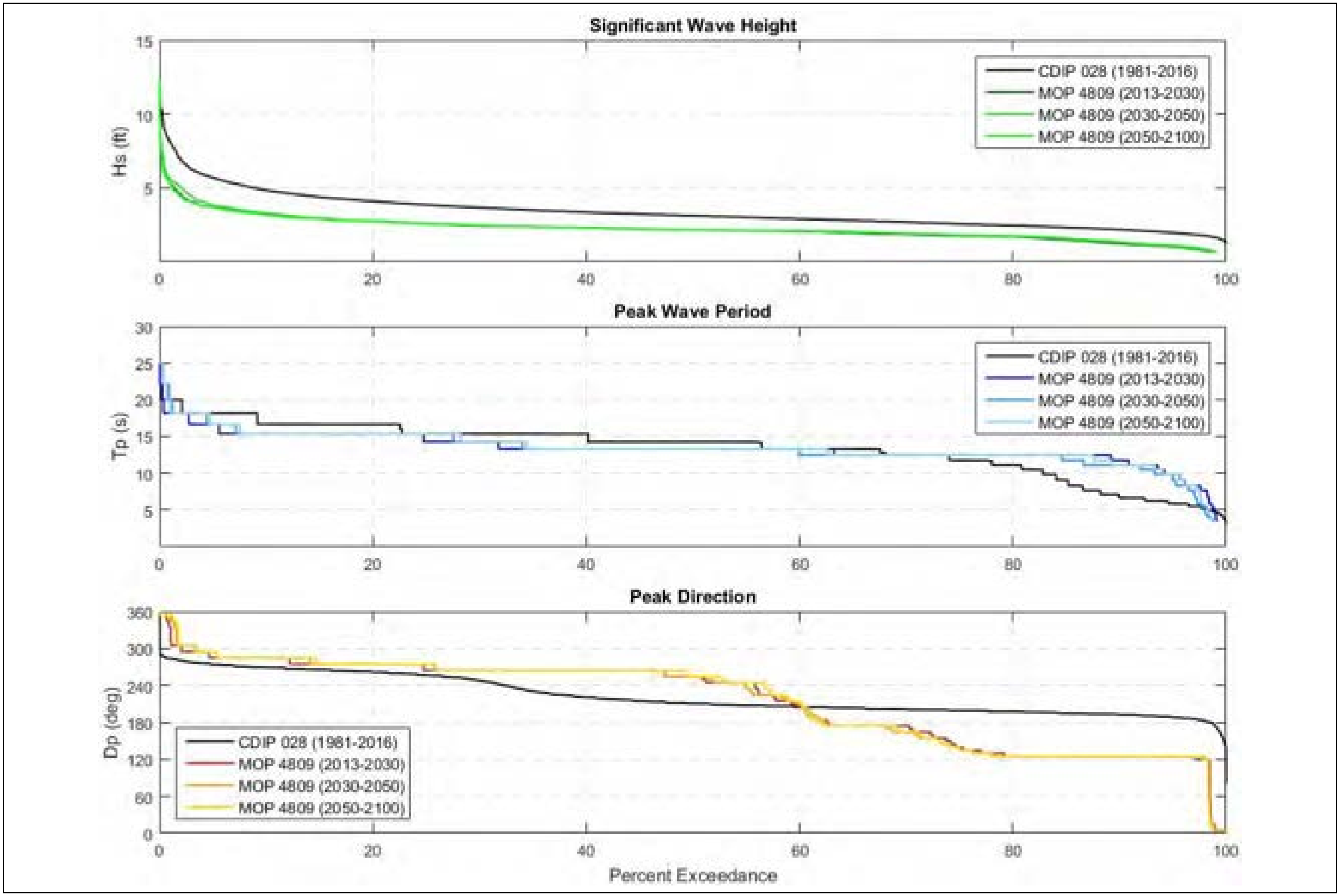


SOURCE: USGS, CDIP

LA County Coastal Hazard Modeling . 130524.00

Figure 11

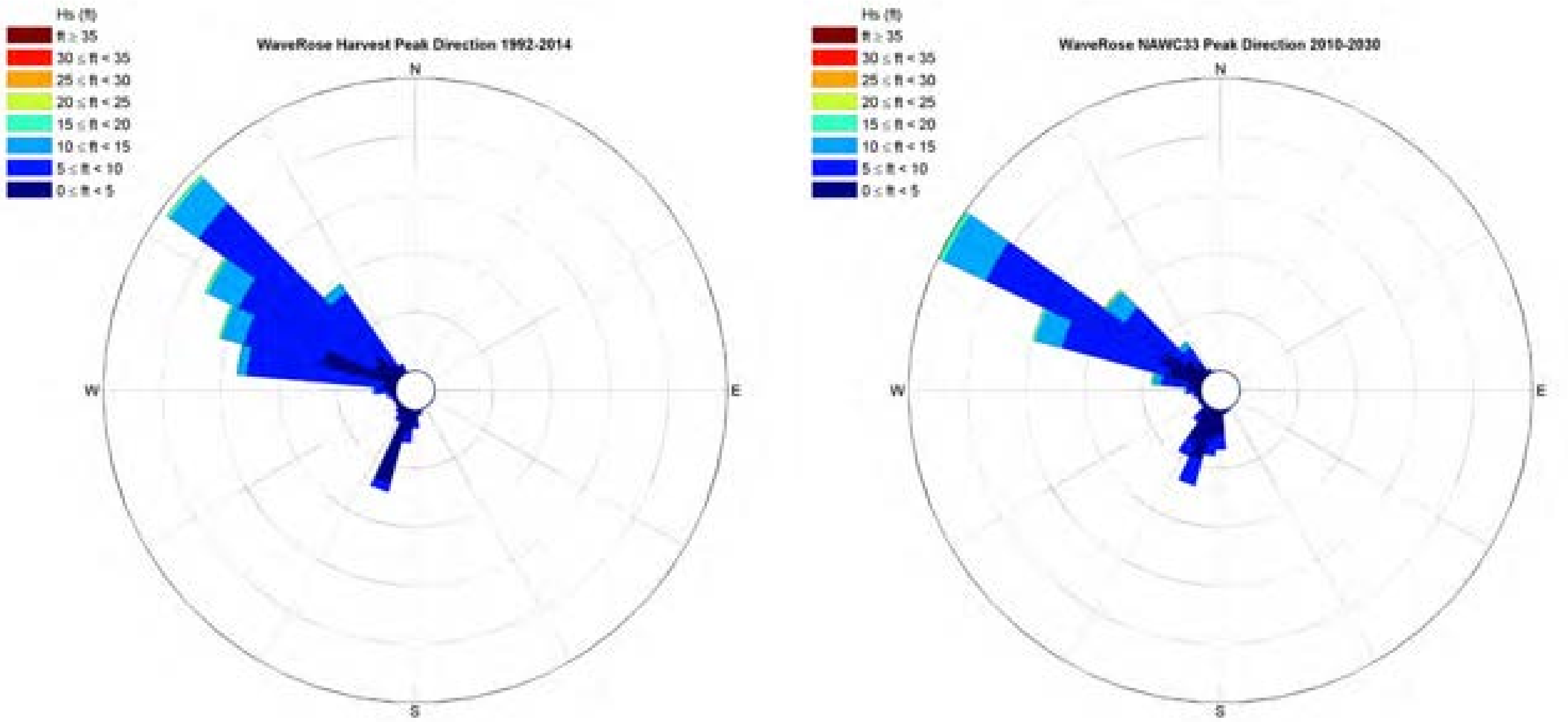
Wave buoys, tide gauges and MOP locations



SOURCE: NDBC, 2016; USGS, 2015.

Figure 12

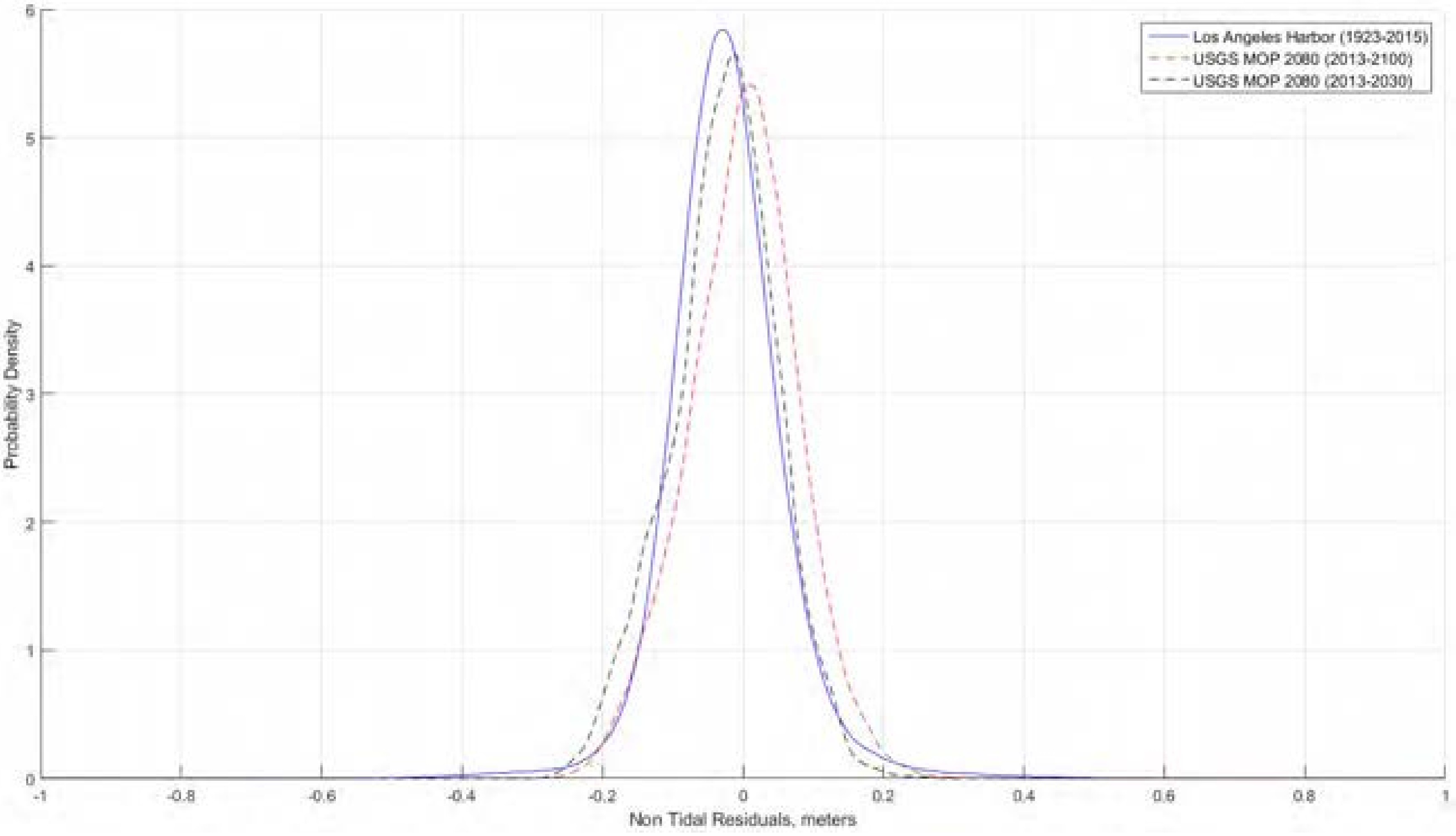
Cumulative distributions of wave parameters at the Santa Monica Bay buoy (real data at CDIP 028) and GCM output (synthetic data at MOP 4809)



SOURCE: NDBC, 2014; USGS, 2015.

Figure 15

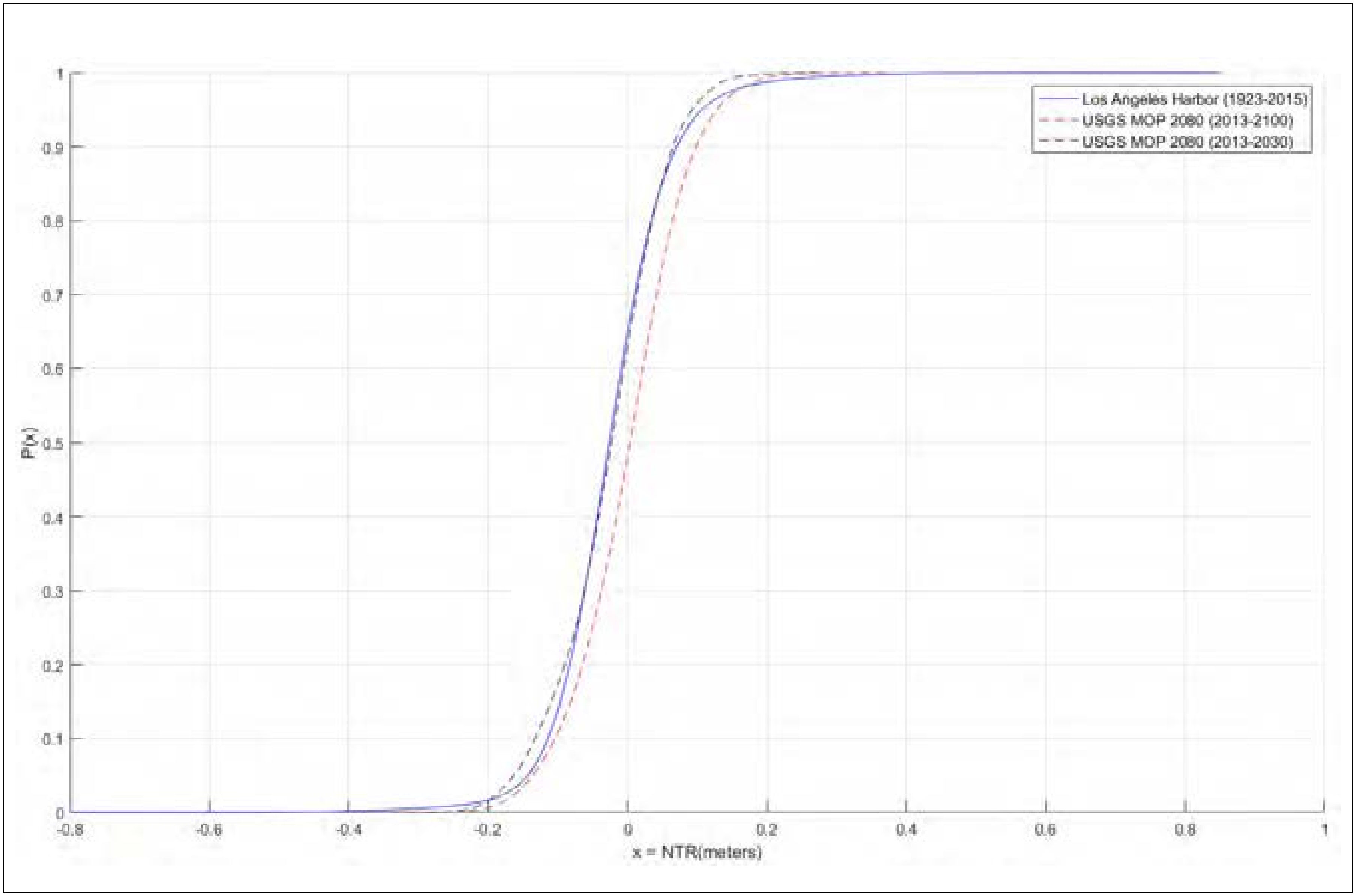
Wave roses for the Harvest gauge (real data) and the GCM output (synthetic data, from NAWC33)



SOURCE: NOAA, 2015; USGS, 2015.

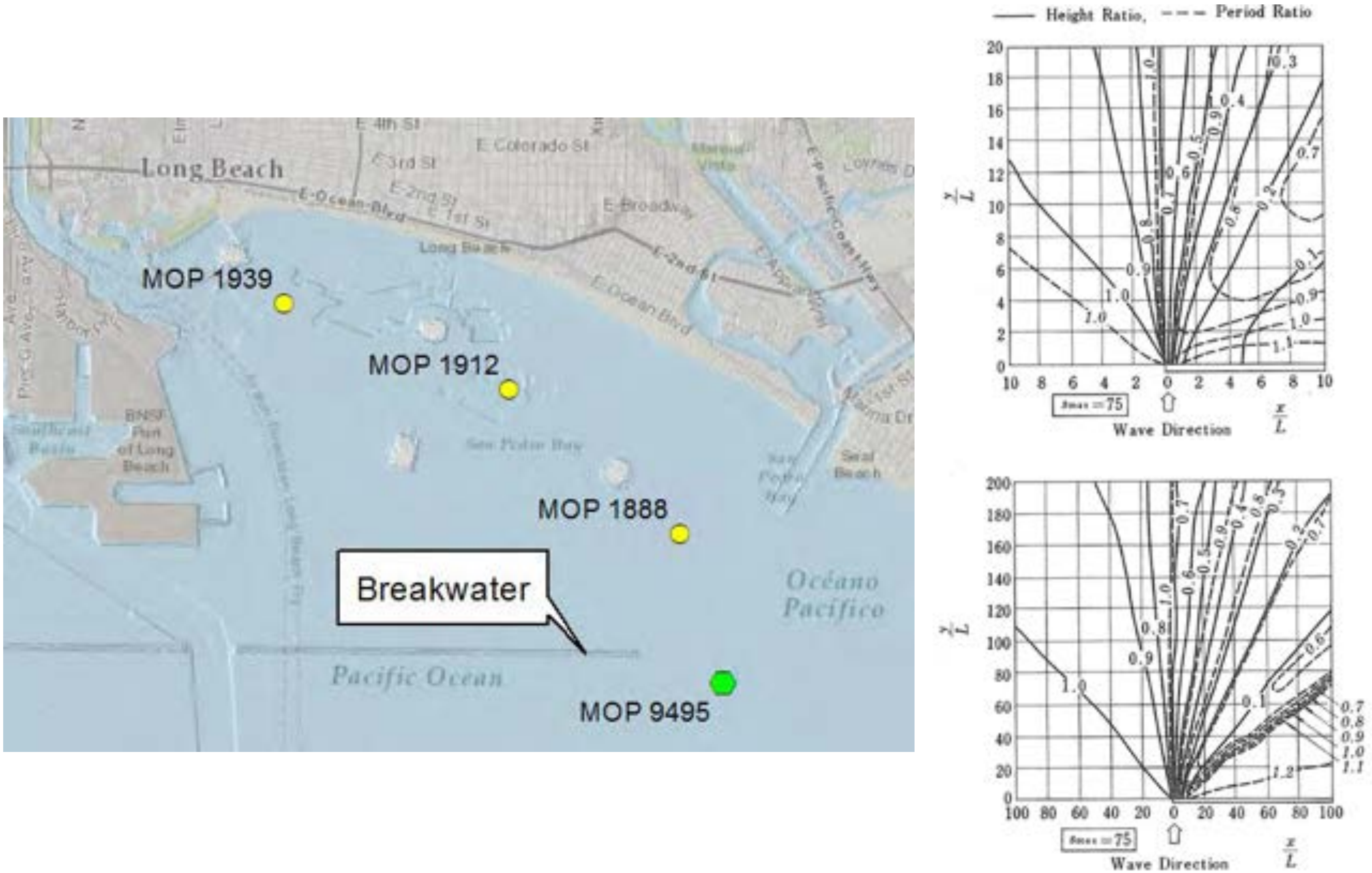
Figure 14

Synthetic water level non-tidal residuals from climate modeling compared with real data from LA Harbor tide gauge



SOURCE: NOAA, 2015; USGS, 2015.

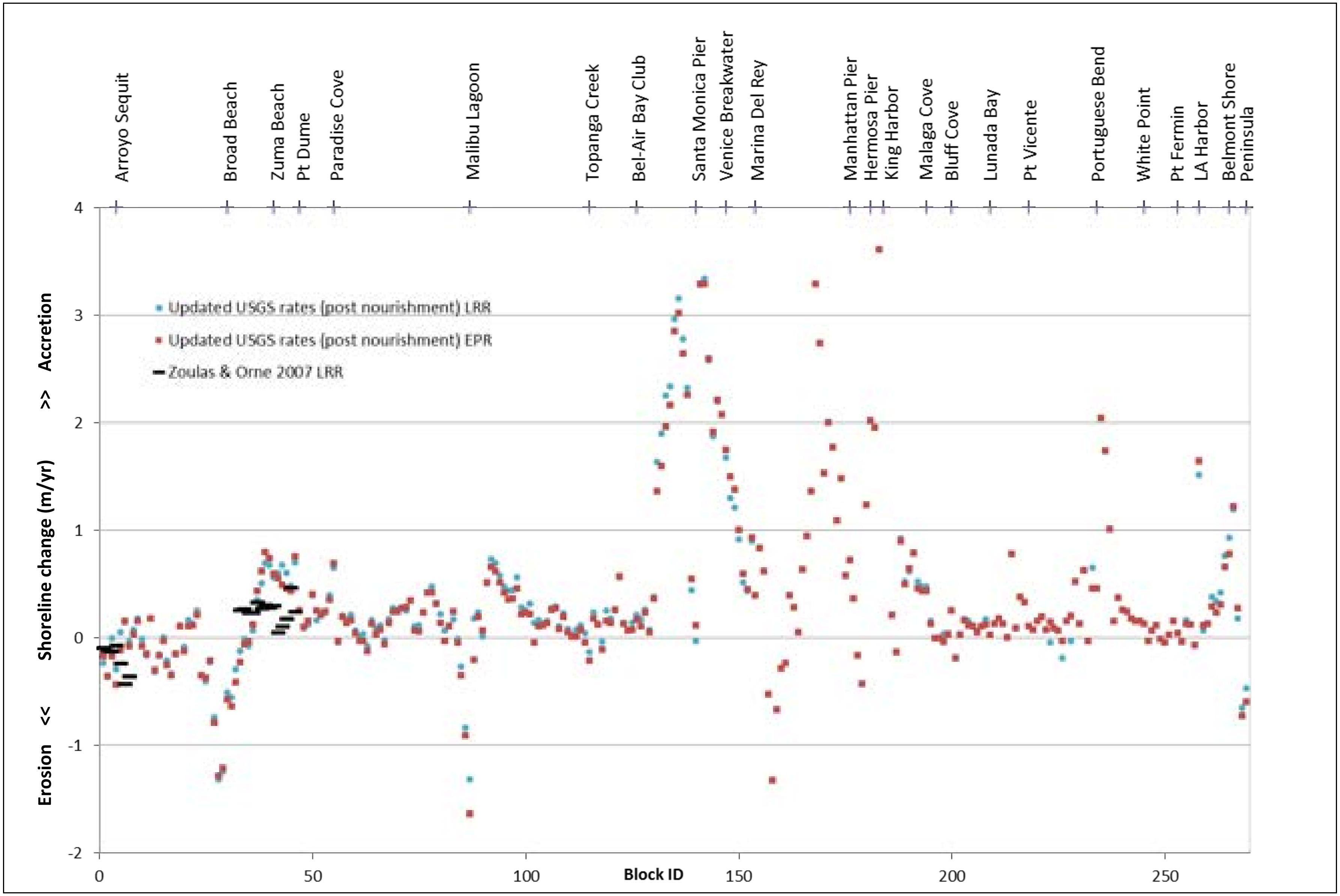
Figure 15
Synthetic water level non-tidal residuals cumulative distribution compared against LA historic records



NOTE:. Diffraction diagrams are for a semi-infinite breakwater for random sea waves of normal incidence. Solid lines for wave height ration and dash lines for wave period ration. Diagrams reproduced from Goda 1978. Diagrams from Goda present a breakwater from right, so they were mirrored to represent the Long Beach breakwater (from the left).

Figure 16

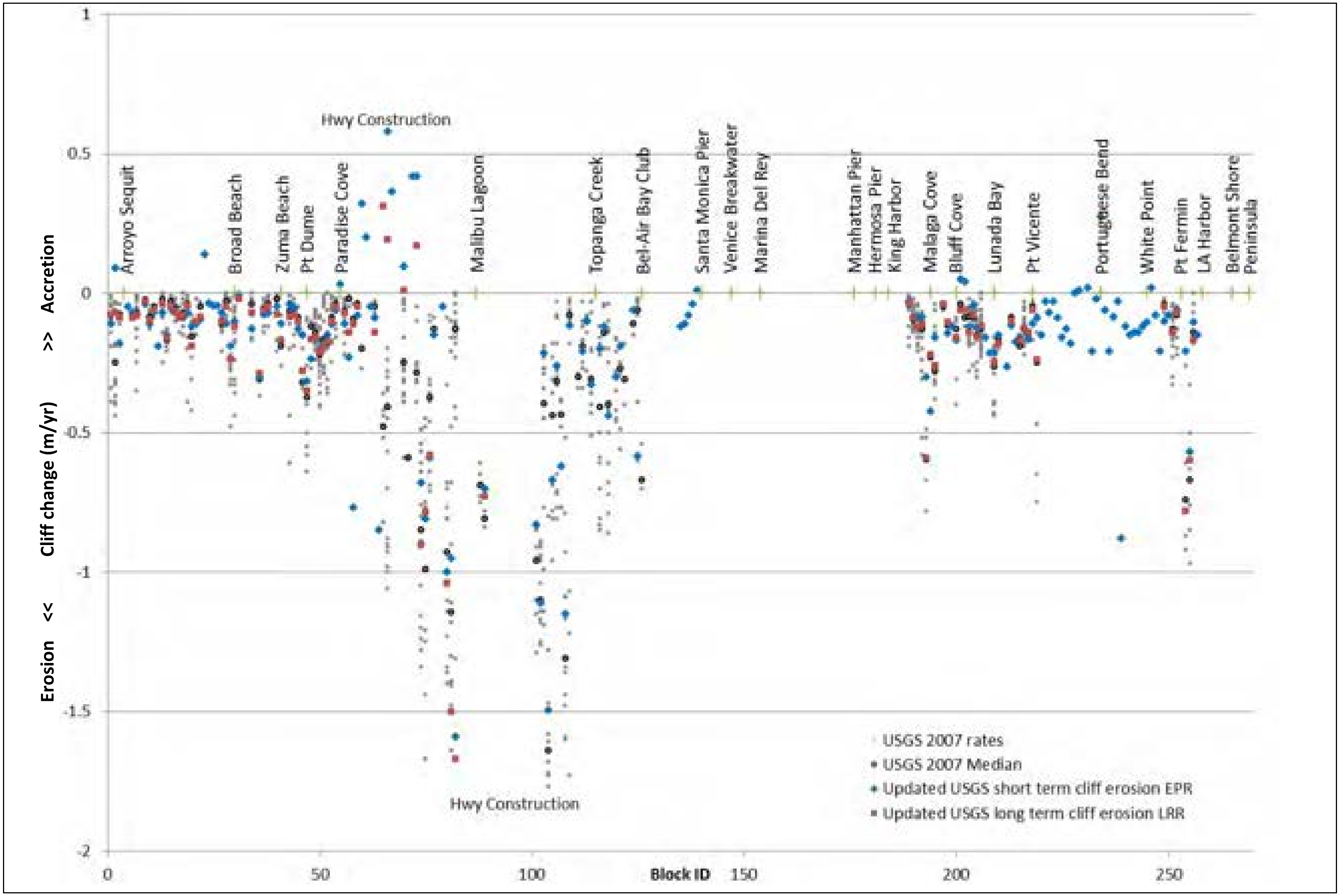
MOPs used in manual diffraction of waves within Long Beach Harbor and Shallow water diffraction diagram for straight, semi-infinite breakwater



NOTE: Negative values are erosion, positive values are accretion.

Figure 17

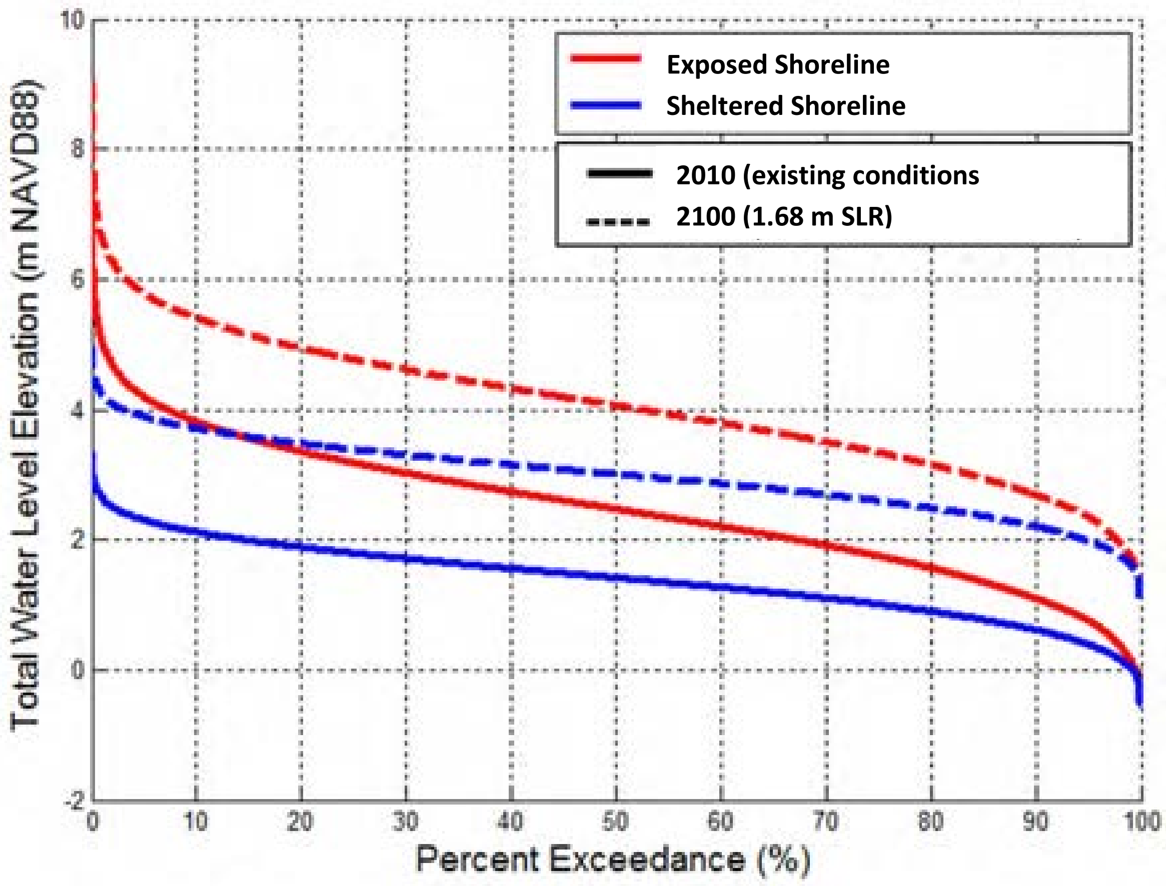
Historic sandy shoreline change rates in Los Angeles County



NOTE: Negative values are erosion, positive values are the result of Hwy 1 construction and other human activities.

Figure 18

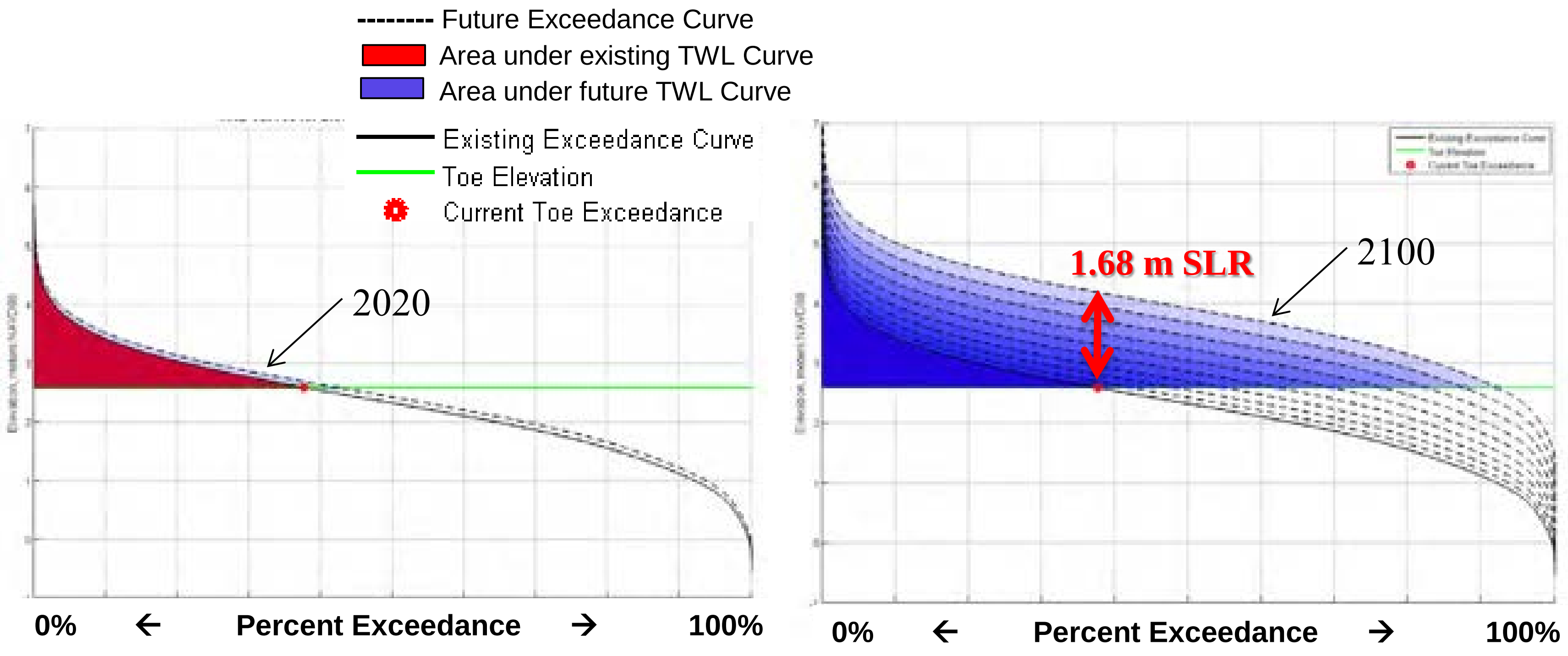
Historic cliff edge erosion rates in Los Angeles County



SOURCE: ESA, 2016.

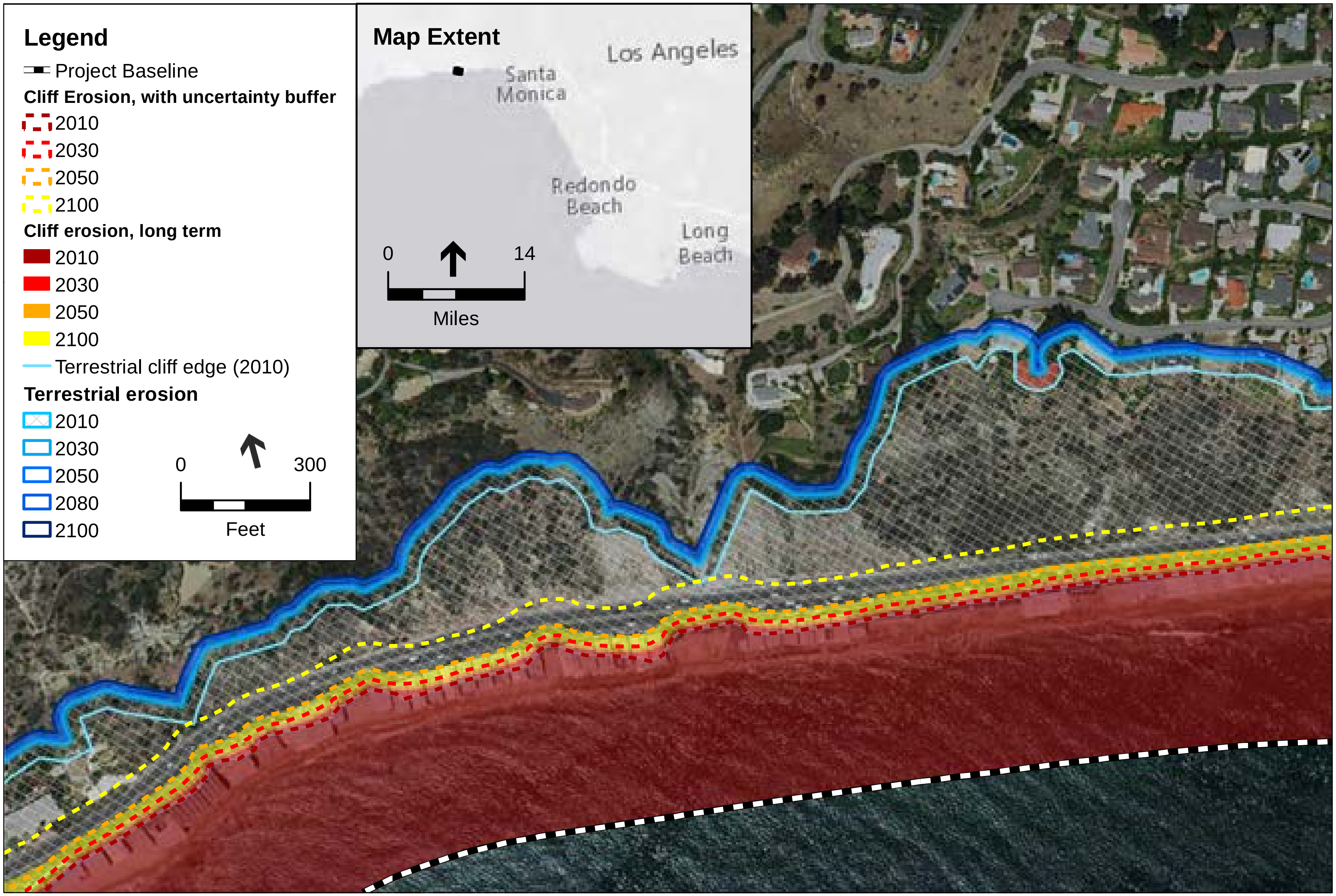
Figure 19

Example of total water level exceedance curves



SOURCE: ESA

Figure 20
Cliff erosion methods



NOTE: The cliff erosion hazards shown are for the "high sea level rise" scenario of 1.68 meters of SLR by 2100 relative to 2010. These hazard zones do not consider coastal armoring. Terrestrial erosion zones do not depend on SLR.

Figure 21

Example of terrestrial erosion zones

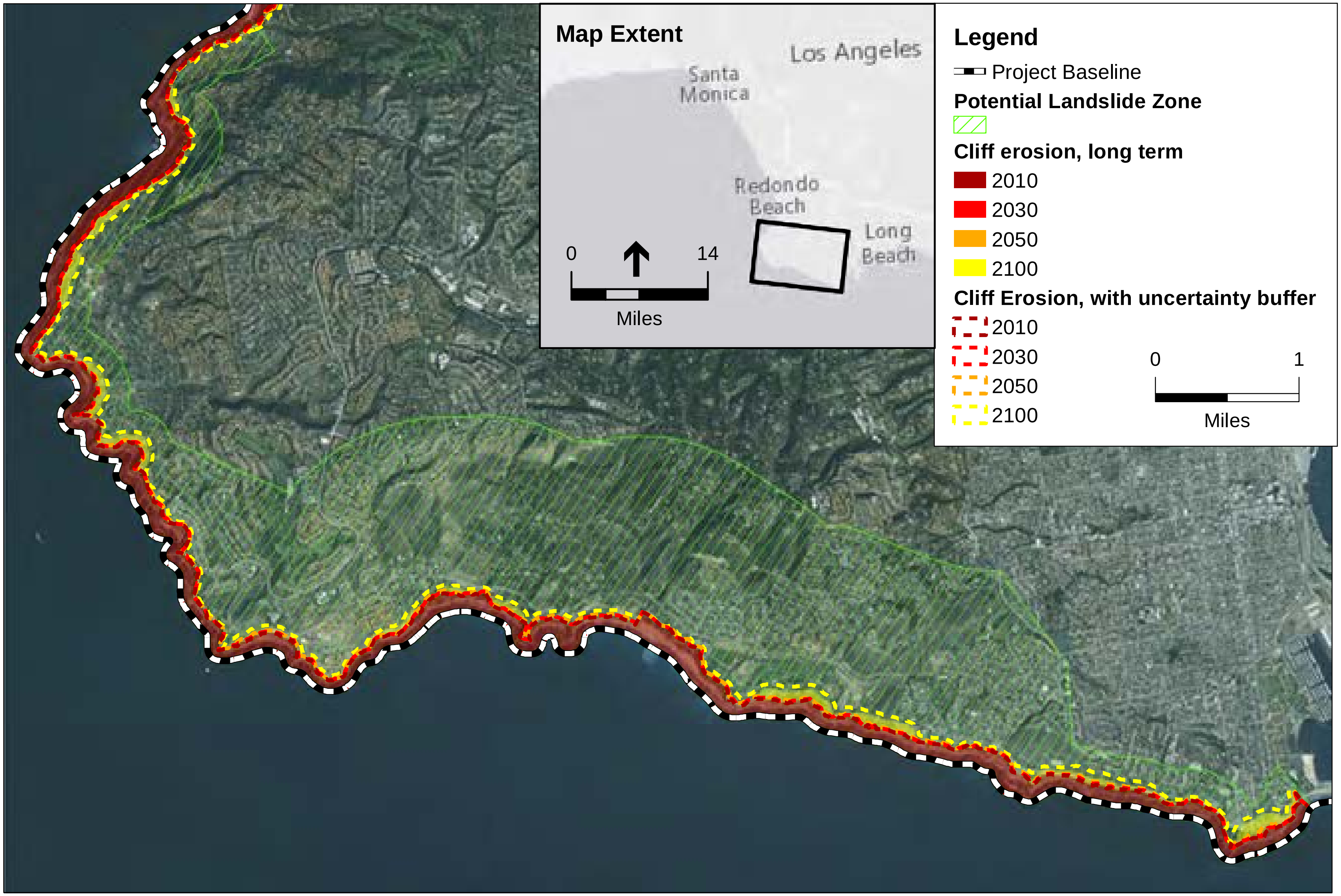
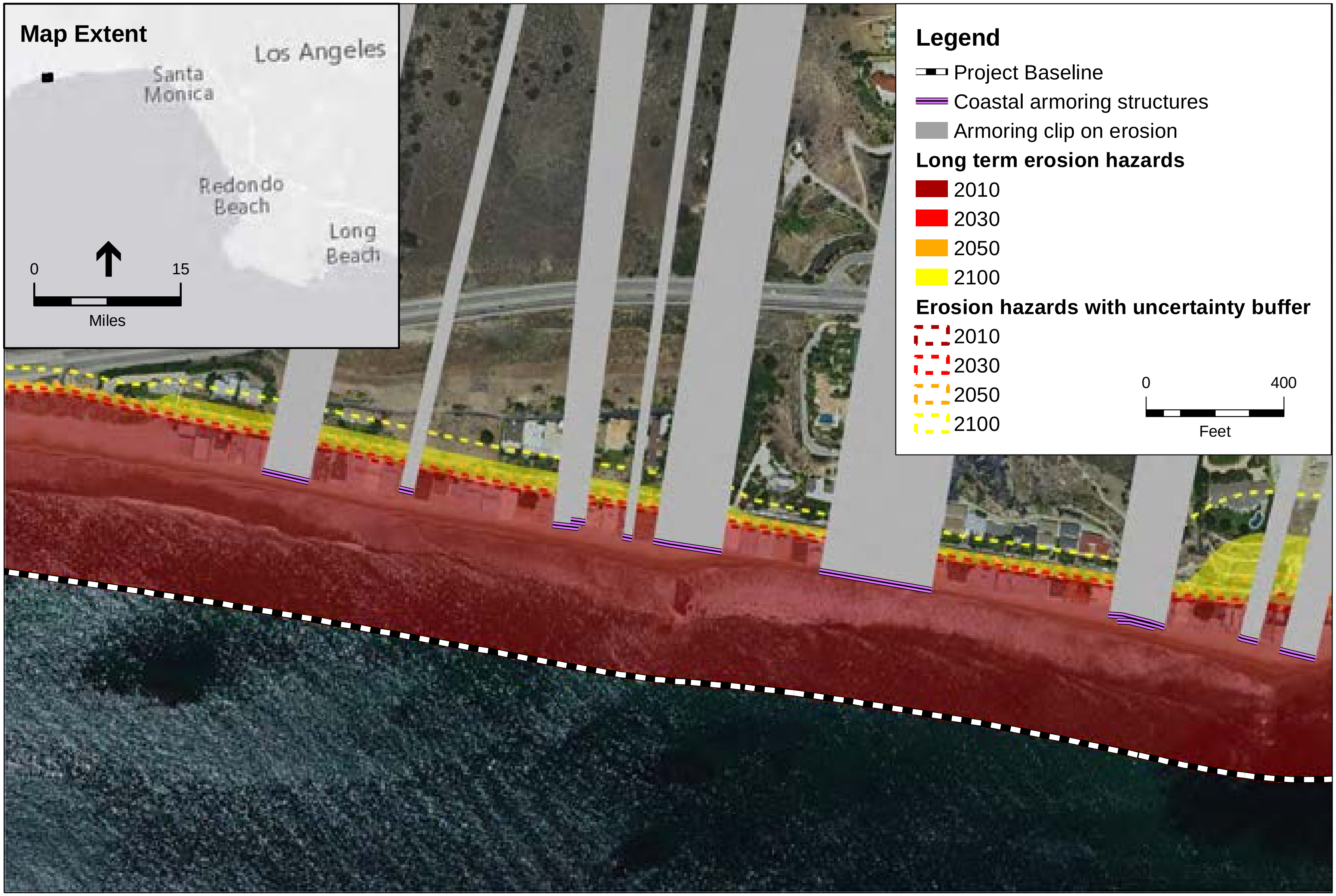


Figure 22

Potential landslide zone in Palos Verdes

NOTE: The hazards shown are for the "high sea level rise" scenario of 1.68 meters of SLR by 2100 relative to 2010. These hazard zones do not consider coastal armoring.



NOTE: The hazards shown are for the "high sea level rise" scenario of 1.68 meters of SLR by 2100 relative to 2010.

LA County Coastal Hazards Modeling . 130524.00

Figure 23

Example of coastal erosion armoring clip

SOURCE: USGS MOPs

Figure 24
Coastal Flooding Methods

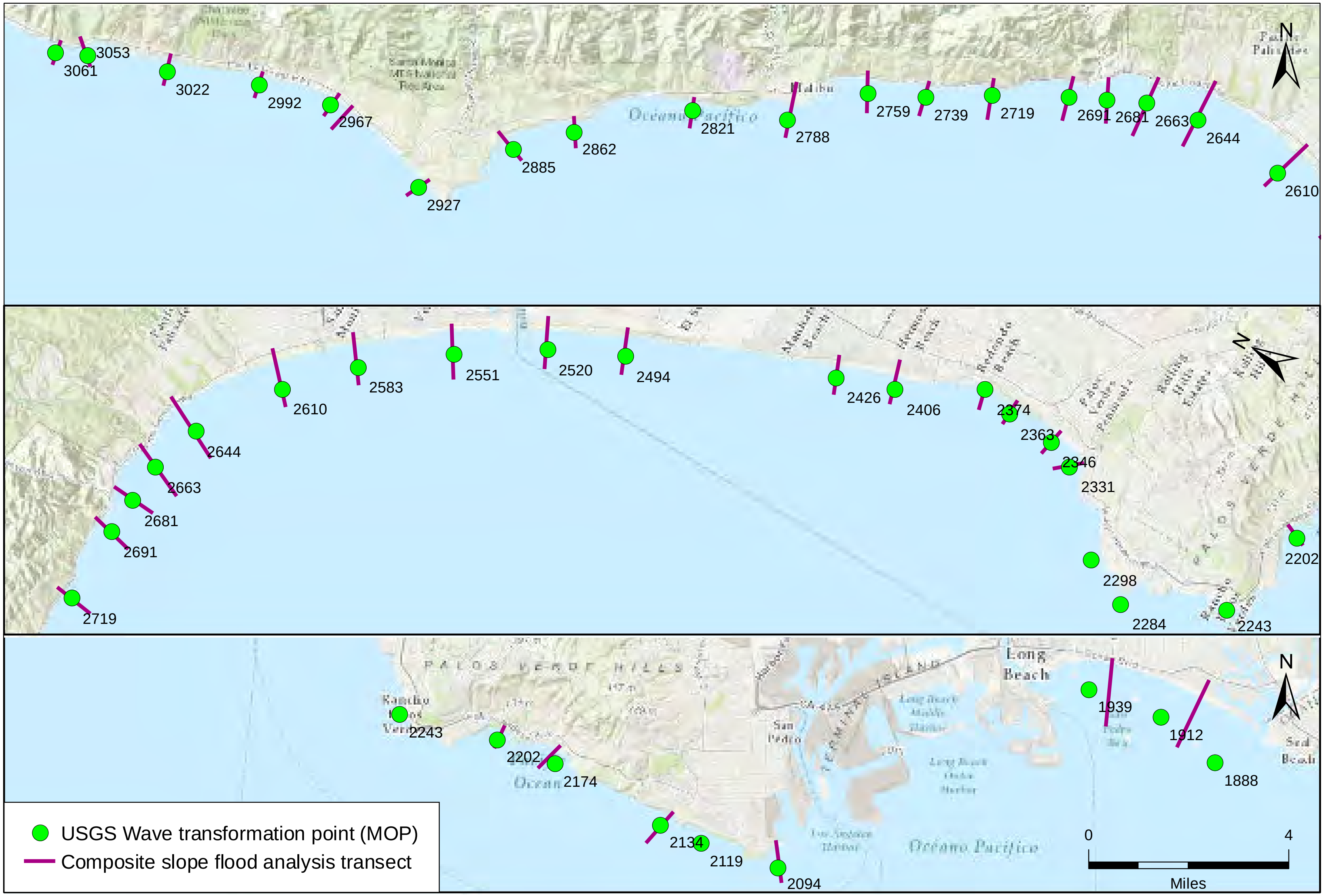
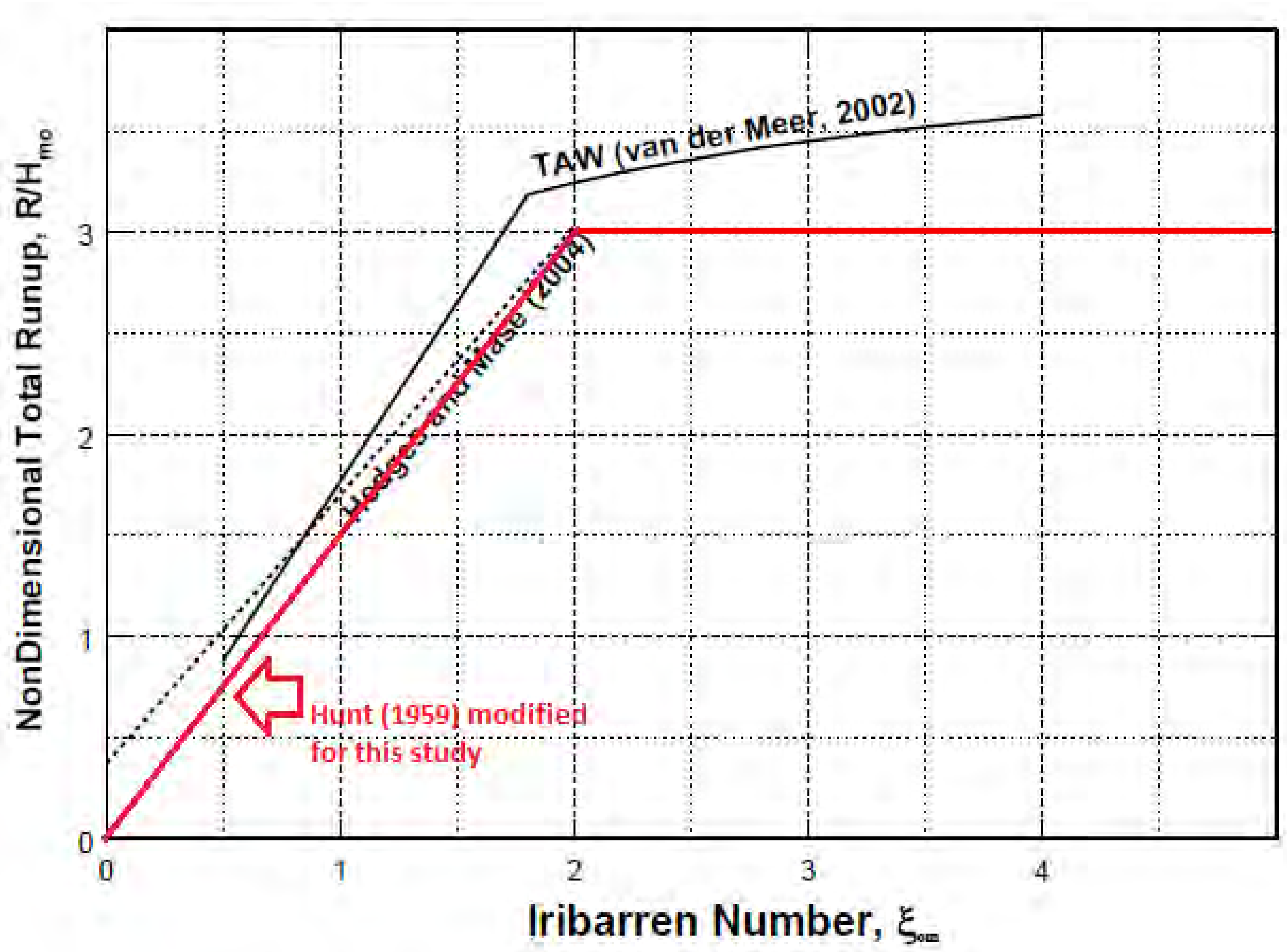


Figure 25

Composite slope profile locations

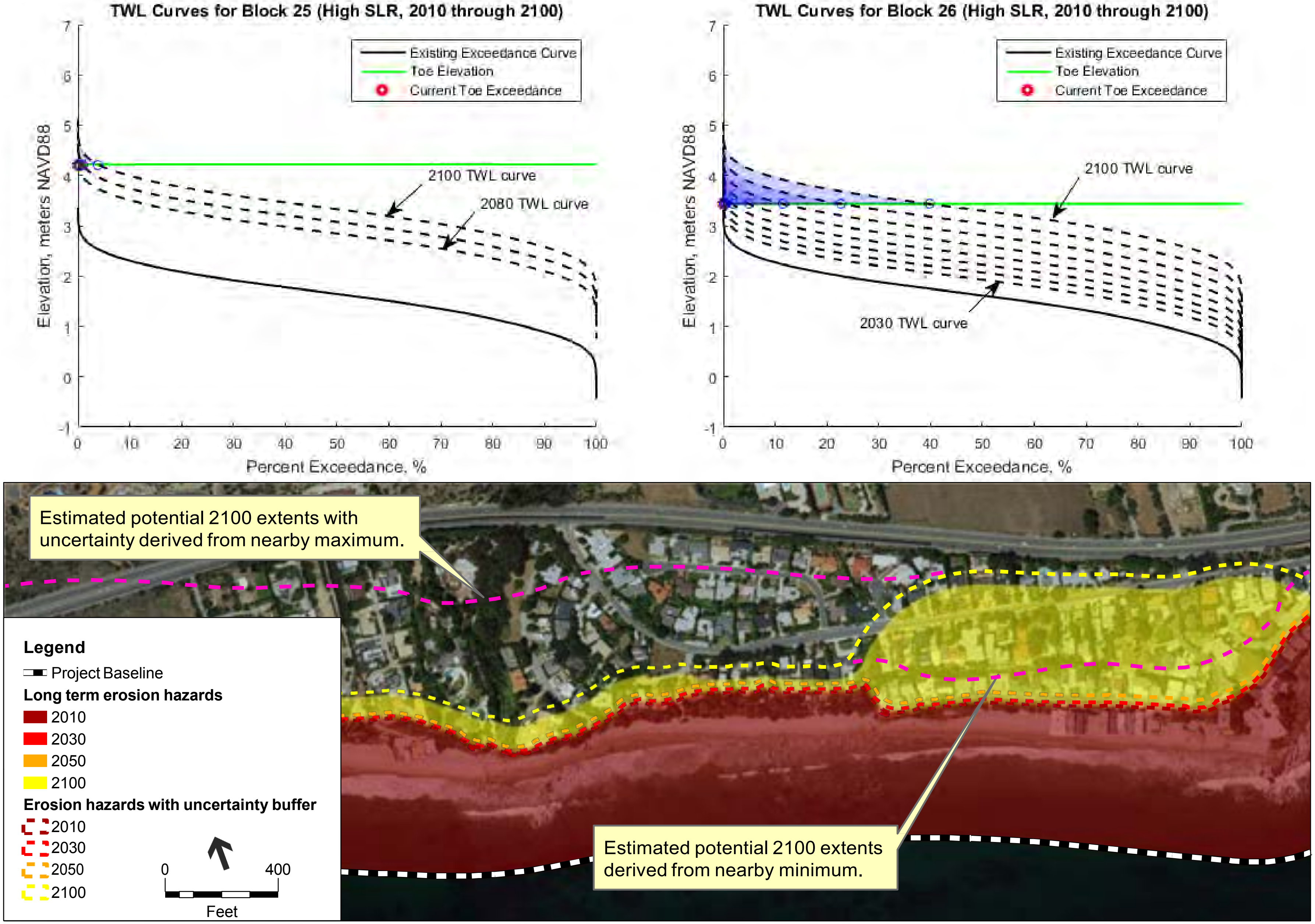


Wave run-up relative to wave height is modeled as being proportional to the Iribarren Number, also known as the Surf Similarity Parameter, which is the ratio of the beach slope to the square root of wave steepness (relative slope steepness). Note that the wave run-up is limited above a value of three times the incident wave height.

SOURCE: FEMA 2005a

Figure 26

Non-dimensional total runup vs. Iribarren Number



Estimated potential 2100 extents with uncertainty derived from nearby maximum.

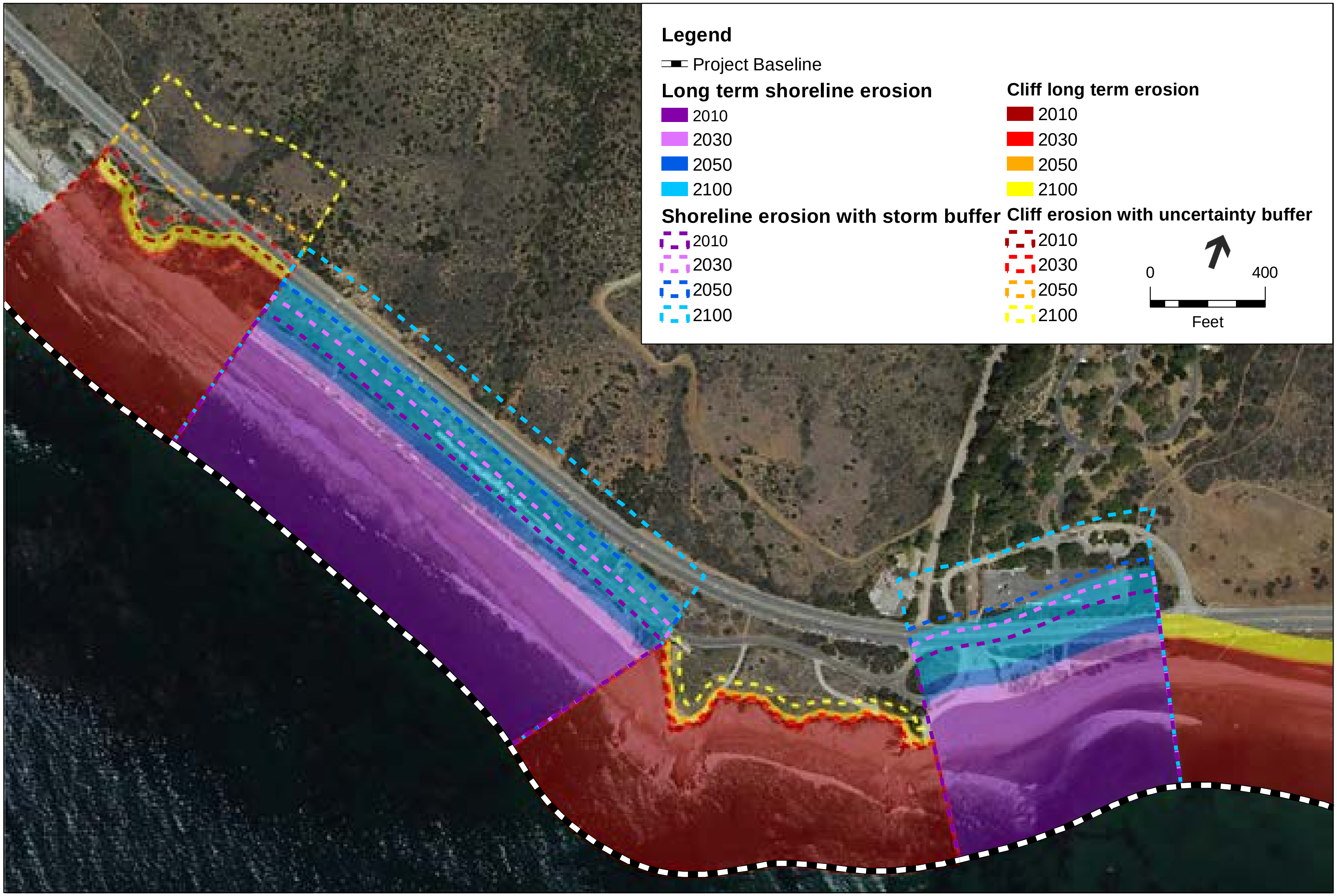
Estimated potential 2100 extents derived from nearby minimum.

NOTE: The hazards shown are for the "high sea level rise" scenario of 1.68 meters of SLR by 2100 relative to 2010. These hazard zones do not consider coastal armoring. TWL curves are only shown for years were cliff toe is exceeded.

Figure 27

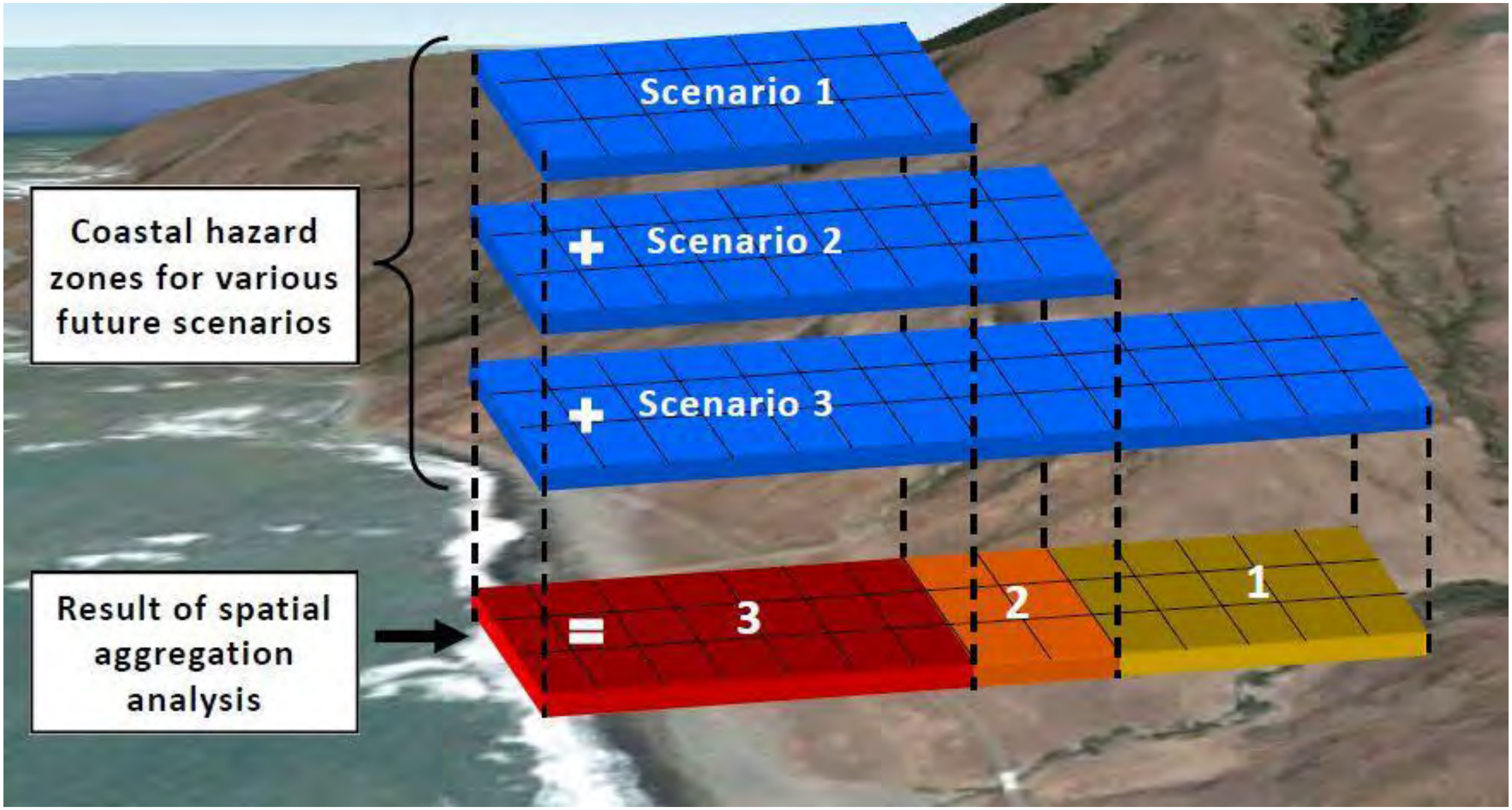
Model uncertainty example

Adjacent blocks of similar backshore type



NOTE: The hazards shown are for the "high sea level rise" scenario of 1.68 meters of SLR by 2100 relative to 2010. These hazard zones do not consider coastal armoring.

Figure 28
Model uncertainty example
Adjacent blocks of different backshore type



NOTE:. Spatially Aggregated Hazard maps for Los Angeles County Coastline are presented in Appendix 2.

Figure 29

Spatial Aggregation Schematic

APPENDIX 1. LIST OF LOS ANGELES COUNTY COASTAL HAZARD GIS FILES

File Naming Convention

The naming conventions for the GIS deliverables are based on hazard zone type, erosion projection type, sea level rise scenario, and planning horizon, as follows:

Shoreline and cliff erosion hazard zones (Section 5):
Hazard zone type + _ + erosion projection type +_+ sea level rise scenario + planning horizon +_+ armoring consideration

Hazard zone types:
coastal_erosion_hz – Coastal erosion hazard zone (shoreline and cliff together)

Erosion projection type:
longterm – A continuation of historic erosion with additional erosion caused by sea level rise. Does not include potential impacts of a large storm
event –Includes long-term erosion and the potential erosion of a large storm event (e.g. 100-year storm) for shorelines and an uncertainty buffer of two standard deviations for cliffs

Flood hazard zones (Section 6):
Hazard zone type + _ + sea level rise scenario + planning horizon + _ + armoring consideration + _cnnct

Hazard zone types:
coastal_floodhz – Coastal storm flood hazard zone
EMHW – High tide (Extreme Monthly High Water) inundation area
dep – Inundation zone depth in areas with a definite connection to ocean tides

Sea level rise scenarios (Section 3.1):
ec – Existing conditions (2010)
s2 – Medium sea level rise (3 ft or 93 cm by 2100)
s3 – High sea level rise (5.5 feet or 167 cm by 2100)
s4 – Extreme sea level rise (167 cm at 2080 only, a trajectory to reach 9.4 by 2100)

Planning horizons (Section 3.1):
2010 (Existing conditions)
2030, 2050, 2100 (Future conditions)
2080 (Extreme Future conditions)

Armoring consideration (Section 5.5):
Arm – Indicates that coastal armoring structures were considered by stopping erosion at the limit of known existing structures.

Example: The *long-term* coastal erosion hazard zone with medium *sea level rise* (s2) at *2100* that considers existing coastal armoring is named:

“coastal_erosion_hz_longterm_s22100_Arm.shp”

Appendix 1. List of Los Angeles County Coastal Hazard GIS Files

* = layers included in spatial aggregation (Section 8)

File Name	Folder	File Type	Hazard Zone Type	Prefix	Projection Type	Sea Level Rise	Planning Horizon	Coastal Armor?
coastal erosion hazard zones								
coastal_erosion_hz_event_ec2010_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	ec	2010	Yes
coastal_erosion_hz_event_s22030_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s2	2030	Yes
coastal_erosion_hz_event_s22050_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s2	2050	Yes
coastal_erosion_hz_event_s22100_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s2	2100	Yes
coastal_erosion_hz_event_s32030_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s3	2030	Yes
coastal_erosion_hz_event_s32050_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s3	2050	Yes
coastal_erosion_hz_event_s32100_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s3	2100	Yes
coastal_erosion_hz_event_s42080_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s4	2080	Yes
coastal_erosion_hz_longterm_ec2010_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	ec	2010	Yes
coastal_erosion_hz_longterm_s22030_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s2	2030	Yes
coastal_erosion_hz_longterm_s22050_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s2	2050	Yes
coastal_erosion_hz_longterm_s22100_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s2	2100	Yes
coastal_erosion_hz_longterm_s32030_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s3	2030	Yes
coastal_erosion_hz_longterm_s32050_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s3	2050	Yes
coastal_erosion_hz_longterm_s32100_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s3	2100	Yes
coastal_erosion_hz_longterm_s42080_Arm.shp	/CoastalErosion/Armor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s4	2080	Yes
coastal_erosion_hz_event_ec2010.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	ec	2010	No
coastal_erosion_hz_event_s22030.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s2	2030	No
coastal_erosion_hz_event_s22050.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s2	2050	No
coastal_erosion_hz_event_s22100.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s2	2100	No
coastal_erosion_hz_event_s32030.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s3	2030	No
coastal_erosion_hz_event_s32050.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s3	2050	No
coastal_erosion_hz_event_s32100.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s3	2100	No
coastal_erosion_hz_event_s42080.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	event	s4	2080	No
coastal_erosion_hz_longterm_ec2010.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	ec	2010	No
coastal_erosion_hz_longterm_s22030.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s2	2030	No
coastal_erosion_hz_longterm_s22050.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s2	2050	No
coastal_erosion_hz_longterm_s22100.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s2	2100	No
coastal_erosion_hz_longterm_s32030.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s3	2030	No
coastal_erosion_hz_longterm_s32050.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s3	2050	No
coastal_erosion_hz_longterm_s32100.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s3	2100	No
coastal_erosion_hz_longterm_s42080.shp*	/CoastalErosion/NoArmor	polygon shapefile	Coastal Erosion Hazard Zone	coastal_erosion_hz	longterm	s4	2080	No

Appendix 1. List of Los Angeles County Coastal Hazard GIS Files

* = layers included in spatial aggregation (Section 8)

File Name	Folder	File Type	Hazard Zone Type	Prefix	Projection Type	Sea Level Rise	Planning Horizon	Coastal Armor?
coastal storm flood hazard zones								
coastal_floodhz_ec2010_Arm_cnnct.shp	/CoastalStormFlooding/Armor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	ec	2010	Yes
coastal_floodhz_s22030_Arm_cnnct.shp	/CoastalStormFlooding/Armor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s2	2030	Yes
coastal_floodhz_s22050_Arm_cnnct.shp	/CoastalStormFlooding/Armor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s2	2050	Yes
coastal_floodhz_s22100_Arm_cnnct.shp	/CoastalStormFlooding/Armor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s2	2100	Yes
coastal_floodhz_s32030_Arm_cnnct.shp	/CoastalStormFlooding/Armor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s3	2030	Yes
coastal_floodhz_s32050_Arm_cnnct.shp	/CoastalStormFlooding/Armor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s3	2050	Yes
coastal_floodhz_s32100_Arm_cnnct.shp	/CoastalStormFlooding/Armor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s3	2100	Yes
coastal_floodhz_s42080_Arm_cnnct.shp	/CoastalStormFlooding/Armor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s4	2080	Yes
coastal_floodhz_ec2010_cnnct.shp*	/CoastalStormFlooding/NoArmor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	ec	2010	No
coastal_floodhz_s22030_cnnct.shp*	/CoastalStormFlooding/NoArmor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s2	2030	No
coastal_floodhz_s22050_cnnct.shp*	/CoastalStormFlooding/NoArmor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s2	2050	No
coastal_floodhz_s22100_cnnct.shp*	/CoastalStormFlooding/NoArmor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s2	2100	No
coastal_floodhz_s32030_cnnct.shp*	/CoastalStormFlooding/NoArmor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s3	2030	No
coastal_floodhz_s32050_cnnct.shp*	/CoastalStormFlooding/NoArmor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s3	2050	No
coastal_floodhz_s32100_cnnct.shp*	/CoastalStormFlooding/NoArmor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s3	2100	No
coastal_floodhz_s42080_cnnct.shp*	/CoastalStormFlooding/NoArmor	polygon shapefile	Coastal Storm Flood Hazard Area	coastal_floodhz	event	s4	2080	No
extreme monthly tides inundation zones, area								
EMHW__ec2010.shp*	/TidalFlooding_EMHW/Extents	polygon shapefile	EMHW Inundation Zone	EMHW	longterm	ec	2010	No
EMHW__s22030.shp*	/TidalFlooding_EMHW/Extents	polygon shapefile	EMHW Inundation Zone	EMHW	longterm	s2	2030	No
EMHW__s22050.shp*	/TidalFlooding_EMHW/Extents	polygon shapefile	EMHW Inundation Zone	EMHW	longterm	s2	2050	No
EMHW__s22100.shp*	/TidalFlooding_EMHW/Extents	polygon shapefile	EMHW Inundation Zone	EMHW	longterm	s2	2100	No
EMHW__s32030.shp*	/TidalFlooding_EMHW/Extents	polygon shapefile	EMHW Inundation Zone	EMHW	longterm	s3	2030	No
EMHW__s32050.shp*	/TidalFlooding_EMHW/Extents	polygon shapefile	EMHW Inundation Zone	EMHW	longterm	s3	2050	No
EMHW__s32100.shp*	/TidalFlooding_EMHW/Extents	polygon shapefile	EMHW Inundation Zone	EMHW	longterm	s3	2100	No
EMHW__s42080.shp	/TidalFlooding_EMHW/Extents	polygon shapefile	EMHW Inundation Zone	EMHW	longterm	s4	2080	No
extreme monthly tides inundation zones, depth								
depec2010.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	ec	2010	No
deps22030.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s2	2030	No
deps22050.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s2	2050	No
deps22100.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s2	2100	No
deps32030.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s3	2030	No
deps32050.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s3	2050	No
deps32100.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s3	2100	No
dep_s42080	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s4	2080	No
dep_lec2010.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	ec	2010	No
dep_ls22030.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s2	2030	No
dep_ls22050.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s2	2050	No
dep_ls22100.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s2	2100	No
dep_ls32030.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s3	2030	No
dep_ls32050.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s3	2050	No
dep_ls32100.	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s3	2100	No
dep_l_s42080	/TidalFlooding_EMHW/Extents	raster	EMHW Inundation Zone	EMHW	longterm	s4	2080	No
non-coastal erosion hazards								
LandslideHazardZones.shp	/CoastalErosion/NonCoastalErosion	polygon shapefile	Non-Coastal Erosion Hazard Zone	N/A	event	N/A	N/A	No
TerrErZone_2010	/CoastalErosion/NonCoastalErosion/lalcp_TerrestrialErosionHZ.gdb	polygon feature class	Non-Coastal Erosion Hazard Zone	TerrErZone	event	N/A	2010	No
TerrErZone_2030	/CoastalErosion/NonCoastalErosion/lalcp_TerrestrialErosionHZ.gdb	polygon feature class	Non-Coastal Erosion Hazard Zone	TerrErZone	event	N/A	2030	No
TerrErZone_2050	/CoastalErosion/NonCoastalErosion/lalcp_TerrestrialErosionHZ.gdb	polygon feature class	Non-Coastal Erosion Hazard Zone	TerrErZone	event	N/A	2050	No
TerrErZone_2080	/CoastalErosion/NonCoastalErosion/lalcp_TerrestrialErosionHZ.gdb	polygon feature class	Non-Coastal Erosion Hazard Zone	TerrErZone	event	N/A	2080	No
TerrErZone_2100	/CoastalErosion/NonCoastalErosion/lalcp_TerrestrialErosionHZ.gdb	polygon feature class	Non-Coastal Erosion Hazard Zone	TerrErZone	event	N/A	2100	No

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