Final

CHULA VISTA BAYFRONT HARBOR PARK

Sea-Level Rise Analysis

Prepared for
San Diego Unified Port District

February 2020

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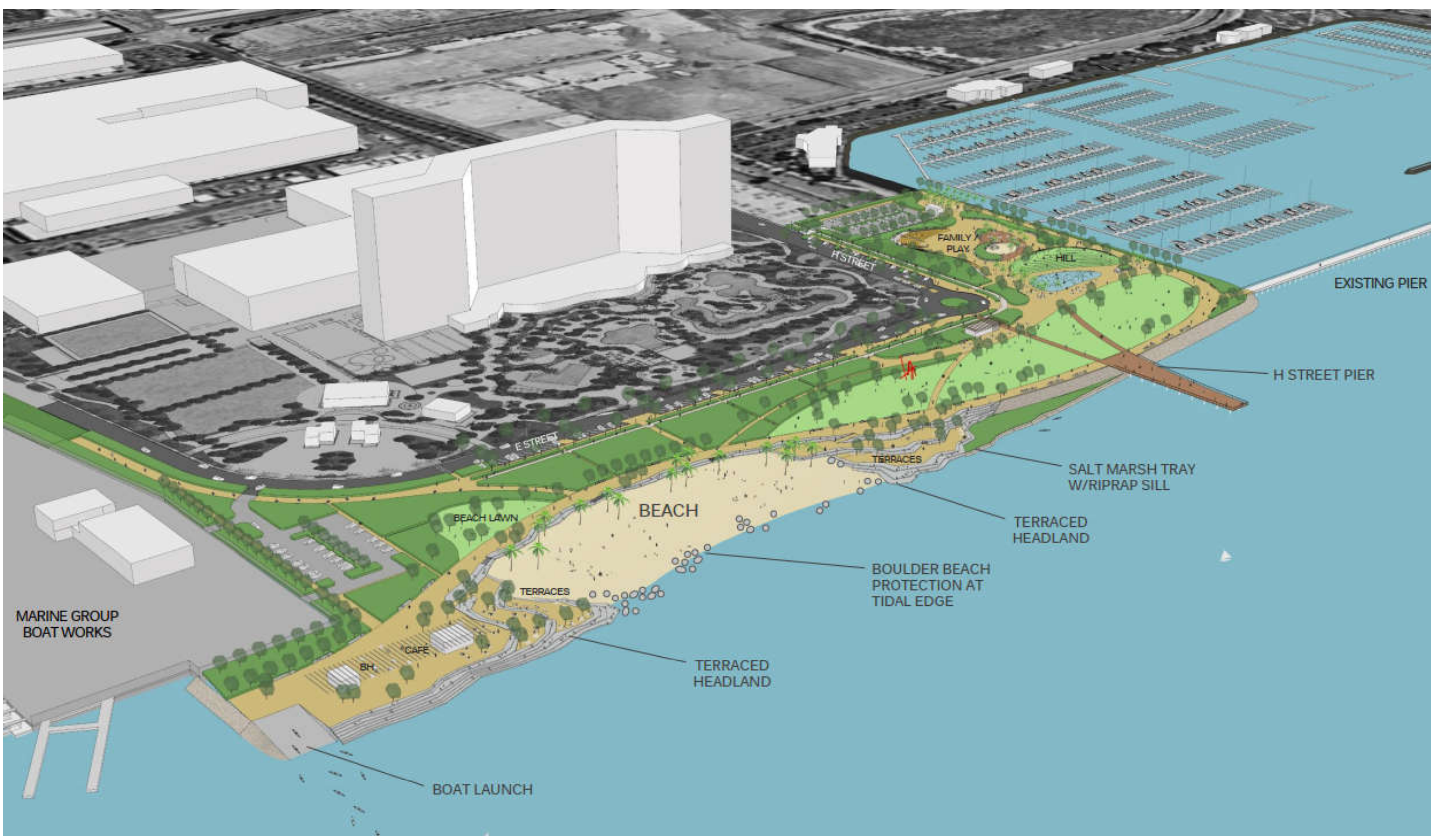

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TABLE OF CONTENTS

Sea-Level Rise Analysis

Page

List of Figures

Page

List of Tables

SECTION 1
Introduction

This report was developed as part of the Chula Vista Bayfront (CVB) Sweetwater and Harbor Parks Sea-Level Rise Analysis, completed by ESA for the San Diego Unified Port District. The CVB project is a proposed 535-acre resort, convention center, residential, and recreation development project on the San Diego Bay shoreline. The CVB project is being planned by the Port, City of Chula Vista, and the Pacifica Companies as a cooperative public/private effort (https://www.portofsandiego.org/chula-vista-bayfront-master-plan.html, http://www.cvbayfront.com/). As part of the CVB project, the Port is proposing improvement/development of two parks, the Sweetwater and Harbor Parks. This report provides an analysis of the potential for future flooding from San Diego Bay with sea-level rise for the proposed Harbor Park. This analysis includes an assessment of potential flood hazards/vulnerabilities and adaptation strategies to reduce the risk of bay flooding with sea-level rise.

Figure 1-1 shows the study area and the park areas proposed for improvement/development by the Port. This study estimates the bay flood level (total water level or TWL) along the CVB project's Harbor District for a variety of storm scenarios under present conditions and sea-level rise projections (Section 2) using available hydrologic and topographic data (Section 3). The TWL at the site is estimated by combining the San Diego Bay water levels near the site (still water level, SWL) with the wave runup, which is a function of the wave height, wave period, and the slope of the shore form (beach, marsh, embankment, etc.), as shown in Figure 1-2. SWL and TWL are expressed in terms of elevation, relative to a specific datum. For this report, all elevations are reported in the North American Vertical Datum of 1988 (NAVD).

The coastal flood analysis conducted in this report consists of calculating the flood levels resulting from tides and waves for conditions expected to occur during the 100-year storm scenario (i.e., the storm scenario that, on average occur once every 100 years; also, the storm scenario that has a 1% chance of occurring in a given year). This analysis also considers the 10-year storm scenario (10% annual chance of occurrence) and the 1-year storm scenario (100% annual chance of occurrence).

Several steps are required to compute the coastal flood levels for these scenarios. First, high water levels (Section 4) and extreme large waves (Section 5) must be computed. Since observed data typically do not include a 100-year event, statistical methods must be employed. Once the wave and high water levels are determined, they are combined to determine the TWL (Section 6). This water level is then used to assess the vulnerability of the parks during the different scenarios (Section 7). Lastly, adaptation measures are identified to reduce the risk of flooding during these scenarios (Section 8).

SOURCE: California Coastal Conservancy TopoBathy 2009-2011, ESRI; ESA 2015; NOAA 2015

Chula Vista Bayfront Sea-Level Analysis

Figure 1-1
Site Map

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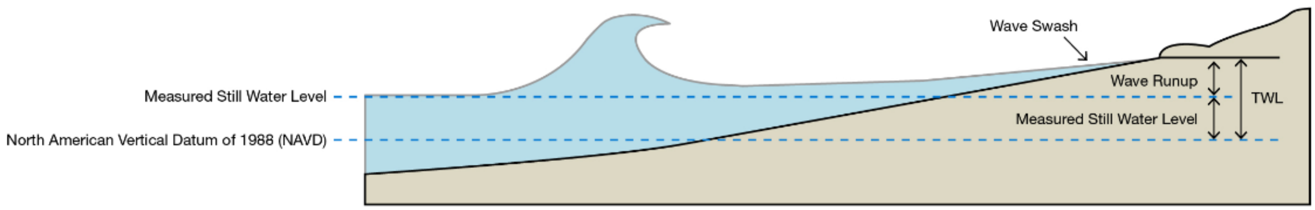


Chula Vista Sea-Level Rise Analysis / D150388,01

SOURCE: FEMA 2005

Figure 1-2
Total Water Level (TWL) Diagram

SECTION 2
Sea-Level Rise Projections and Analysis Scenarios

2.1 Sea-Level Rise Projections

2.1.1 Background and Guidance Documents

Projections of global sea-level rise are well-documented and investigated, with recent research projecting sea-level rise on the order of 2 to 10 feet by 2100 in California (e.g., Cayan et al. 2008; Griggs et al. 2017). This research has been used to develop a series of policy guidance documents by the State of California that recommend including a specific amount of sea-level rise in project planning and design, the most recent being the California Ocean Protection Council's (OPC) *State of California Sea-Level Rise Guidance* (OPC 2018). The OPC (2018) Guidance includes tables of projected relative sea-level rise at well-established tide gages located along the coast of California through 2150 for a range of risk aversion scenarios, including low, medium-high, and extreme (e.g., H++). Table 2-1 shows the projections for San Diego Bay. These projections were developed and summarized with the intention that local planning and design efforts would have a consistent and accepted basis for addressing future sea-level rise.

The California Coastal Commission (CCC) recently updated its *Sea-Level Rise Policy Guidance* in 2018 (CCC 2018). The CCC (2018) Guidance provides a basis for selecting the time horizon and the risk level of the project, which are used to define the appropriate sea-level rise amounts. The CCC (2018) Guidance recommends that project planning and design consider a range of scenarios in order to bracket the possible timing of a given amount of sea-level rise.

TABLE 2-1
PROJECTED SEA-LEVEL RISE (IN FEET) FOR SAN DIEGO

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)					H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE		1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...		5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
				Low Risk Aversion		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030		0.4 -	0.6	0.7	0.9	1.1
	2040	0.7	0.5 -	0.9	1.0	1.3	1.8
	2050	0.9	0.7 -	1.2	1.4	2.0	2.8
Low emissions	2060	1.0	0.7 -	1.3	1.7	2.5	
High emissions	2060	1.2	0.9 -	1.6	1.9	2.7	3.9
Low emissions	2070	1.2	0.9 -	1.6	2.0	3.1	
High emissions	2070	1.5	1.1 -	2.0	2.5	3.6	5.2
Low emissions	2080	1.4	1.0 -	1.9	2.4	3.9	
High emissions	2080	1.9	1.3 -	2.5	3.1	4.6	6.7
Low emissions	2090	1.6	1.0 -	2.2	2.9	4.8	
High emissions	2090	2.2	1.6 -	3.0	3.7	5.7	8.3
Low emissions	2100	1.7	1.1 -	2.5	3.3	5.8	
High emissions	2100	2.6	1.8 -	3.6	4.5	7.0	10.2
Low emissions	2110*	1.9	1.3 -	2.7	3.5	6.4	
High emissions	2110*	2.8	2.0 -	3.7	4.7	7.5	12.0
Low emissions	2120	2.0	1.3 -	3.0	4.1	7.6	
High emissions	2120	3.1	2.3 -	4.3	5.5	8.8	14.3
Low emissions	2130	2.2	1.4 -	3.3	4.6	8.6	
High emissions	2130	3.5	2.6 -	4.9	6.3	10.2	16.6
Low emissions	2140	2.4	1.5 -	3.6	5.1	9.8	
High emissions	2140	3.9	2.8 -	5.4	7.1	11.7	19.2
Low emissions	2150	2.5	1.5 -	3.9	5.7	11.1	
High emissions	2150	4.3	3.0 -	6.1	7.9	13.3	22.0

Source: OPC 2018

The OPC Guidance identifies three levels of risk to consider when planning for sea-level rise (blue boxes in Table 2-1):

- The low-risk aversion scenario is appropriate for adaptive, lower consequence decisions (e.g., unpaved coastal trail), but is not adequate to address high impact, low probability events.
- The medium-high risk aversion scenario is appropriate as a precautionary projection that can be used for less adaptive, more vulnerable projects or populations that will experience medium to high consequences as a result of underestimating sea-level rise (e.g., coastal housing development).

- The extreme risk aversion scenario is appropriate for high consequence projects with little to no adaptive capacity and which could have considerable public health, public safety, or environmental impacts (e.g., coastal power plant, wastewater treatment plant, etc.).

2.1.2 Port of San Diego Sea-Level Rise Projections

The Port recently completed a sea-level rise vulnerability assessment[1] pursuant to Assembly Bill 691. During the development of the Port's AB 691 Report, the OPC Guidance was in draft form and the recommended risk levels (blue boxes in Table 2-1) were not identified. With technical feedback from a Sea Level Rise Ad Hoc Committee comprised of important Port stakeholders, the Port chose to use three sea-level rise projections for years 2030, 2050, and 2100 consistent with the 5% probability identified in the OPC Guidance. Due to the uncertainty of long range projections of sea-level rise, the Port also chose a fourth scenario for 2100, consistent with the 50% probability identified in the OPC Guidance. Table 2-2 presents the scenarios developed for the vulnerability assessment.

TABLE 2-2
PORT OF SAN DIEGO'S SEA-LEVEL RISE PROJECTIONS (IN FEET)

	2030	2050	2100
"Low" projection	n/a	n/a	2.6
"High" projection	0.7	1.4	4.5

2.1.3 CVB Project Sea-Level Rise Scenarios

To assess the potential flood impacts and to inform the park design for CVB project, four sea-level rise amounts were selected to bracket the range of potential projections: 0.7, 1.4, 2.6, and 4.5 feet. These amounts take into consideration both the Port-recommended scenarios and State recommendations. A projection of 7.0 feet by 2100 (medium-high risk aversion scenario) was considered and not included, since the Port considers Harbor Park a low-risk asset, with medium adaptability, per the OPC guidance. Table 2-3 shows the model scenarios and the corresponding time frames under the medium-high to low-risk aversion projection.

TABLE 2-3
CHULA VISTA BAYFRONT SEA-LEVEL RISE PROJECTIONS (IN FEET)

	2025 – 2030	2040 – 2055	2060 – 2080	2080 – 2120
Amounts of sea-level rise	0.7	1.4	2.6	4.5

The first year in the range represents the medium-high risk aversion scenario, while the second year in the range represents the low risk aversion scenario.

[1] https://pantheonstorage.blob.core.windows.net/environment/FINAL-San-Diego-Unified-Port-District-Sea-Level-Rise-Vulnerability-and-Coastal-Resiliency-Report-AB691.pdf

2.2 Flood Scenarios with Sea-Level Rise

The following flood scenarios with sea-level rise were used in this analysis for Harbor Park:

1. 100-year bay flood level (TWL) with the 2080 – 2120 projection of 4.5 ft of sea-level rise.
2. 100-year bay flood level with the 2060 – 2080 projection of 2.6 ft of sea-level rise.
3. 100-year bay flood level with the 2040 – 2055 projection of 1.4 ft of sea-level rise.
4. 100-year bay flood level with the 2025 – 2030 projection of 0.7 ft of sea-level rise.
5. 10-year bay flood level with the 2080 – 2120 projection of 4.5 ft of sea-level rise. This and the following scenarios were used to assess park vulnerability to more frequently-occurring flooding given that some accommodation for flooding by the 100-year bay flood level with sea-level rise may be acceptable.
6. 10-year bay flood level with the 2060 – 2080 projection of 2.6 ft of sea-level rise.
7. 10-year bay flood level with the 2040 – 2055 projection of 1.4 ft of sea-level rise.
8. 10-year bay flood level with the 2025 – 2030 projection of 0.7 ft of sea-level rise.
9. 1-year bay flood level with the 2080 – 2120 projection of 4.5 ft of sea-level rise.
10. 1-year bay flood level with the 2060 – 2080 projection of 2.6 ft of sea-level rise.
11. 1-year bay flood level with the 2040 – 2055 projection of 1.4 ft of sea-level rise.
12. 1-year bay flood level with the 2025 – 2030 projection of 0.7 ft of sea-level rise.

These scenarios are analyzed and assessed in the following sections.

2.3 Silver Strand Flooding and Erosion Assessment

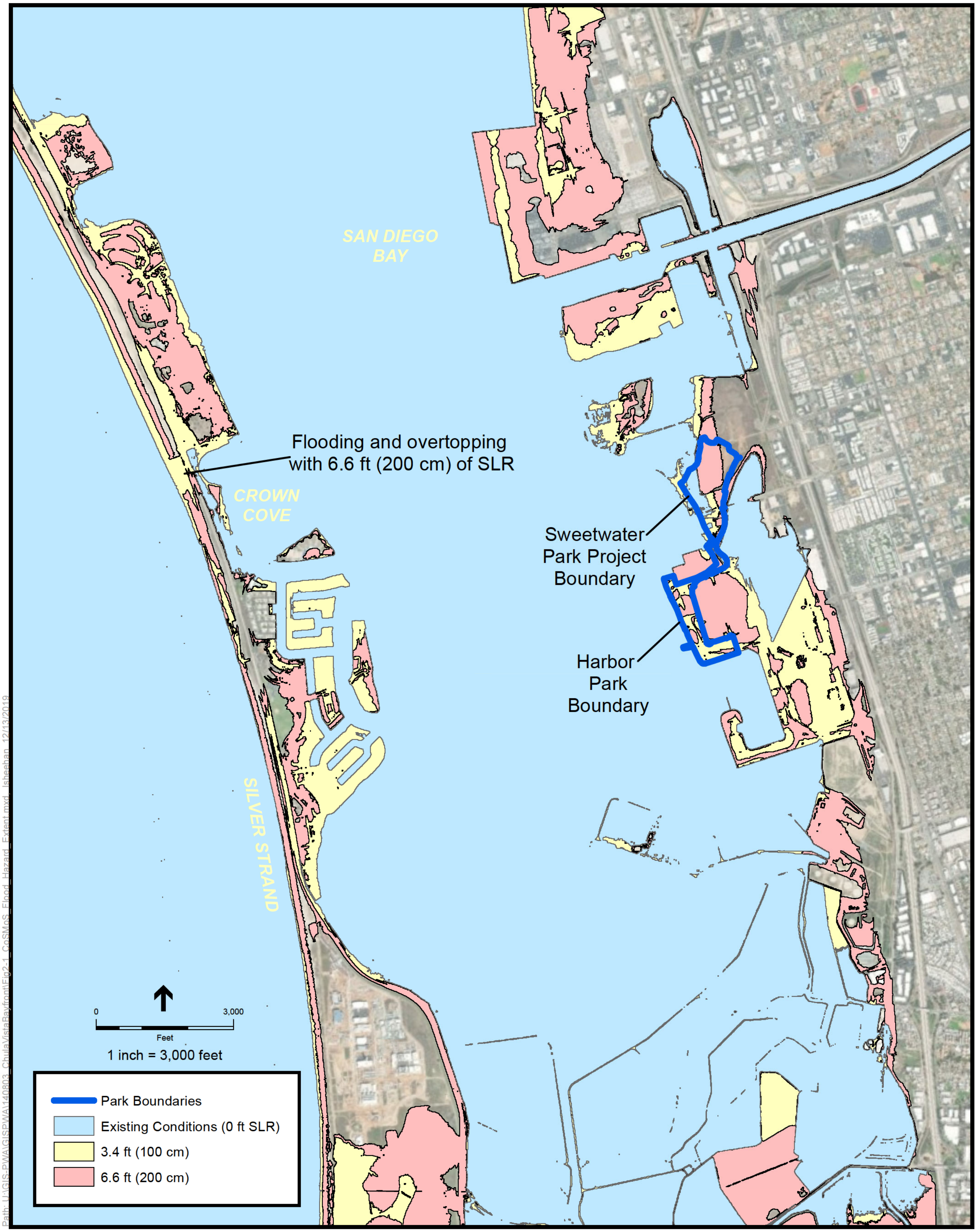
The USGS CoSMoS 3.0 Phase 2 results for San Diego County released in November 2016 are the final CoSMoS results for San Diego County (P. Barnard, USGS, pers. comm., January 2017). The CoSMoS results provide projected shoreline erosion and flooding with sea-level rise for the Southern California region. Figure 2-1 shows the CoSMoS 100-year storm flood hazard extent results for the Silver Strand. These results show that with 100 cm of sea-level rise (3.4 ft, which is expected to occur between 2060 and 2080 under the medium-high risk scenario), the Silver Strand is not completely flooded or overtopped in the 100-year storm. With 200 cm of sea-level rise (6.6 ft, which is comparable to the medium-high risk aversion scenario of 7.0 ft of sea-level rise by 2100), the Silver Strand is flooded and overtopped by the 100-year storm near the northern end of Crown Cove. Figure 2-2 shows the flood depth from CoSMoS for the 100-year storm with 200 cm of sea-level rise, which shows the flood depth over the Silver Strand at Crown Cove is about 2 to 4 ft or less. Figure 2-3 shows the CoSMoS wave height results for the 100-year storm with 200 cm (6.6 ft) of sea-level rise. The wave height results show that large ocean waves are dissipated by the Silver Strand and do not propagate into or across San Diego Bay. The CoSMoS results show wave heights of 3 to 4 ft in San Diego Bay and at the CVB. These CoSMoS results indicate that with 200 cm (6.6 ft) of sea-level rise, the Silver Strand protects the CVB from wind waves during the 100-year storm. Note that these CoSMoS results for the 100-

year storm flood hazard extent, flood depth, and wave heights are modeled for the existing shoreline condition and do not account for projected erosion of the shoreline with sea-level rise.

Projected shoreline erosion with sea-level rise is modeled by CoSMoS separately from the flood hazard modeling described above. Figure 2-4 shows the CoSMoS shoreline erosion projections for the “no hold the line and no continued beach nourishment” model scenario, which is the “worst case” erosion scenario in which erosion is allowed to continue past existing development and no sand is placed to nourish the beach. Figure 2-4 shows the projected shoreline position in 2100 with 1 m (3.3 ft), 2 m (6.6 ft), and 5 m (16.4 ft) of sea-level rise. The results show that with 2 m (6.6 ft) of sea-level rise in 2100, the beach shoreline does not erode past Highway 75 or through the Silver Strand. With 5 m (16.4 ft) of sea-level rise in 2100, which is beyond the extreme risk aversion scenario, the shoreline could potentially erode through the Silver Strand at Crown Cove and south of Coronado Cays. Note that CoSMoS does not include modeling of flood hazards with the projected shoreline erosion. The CoSMoS 100-year storm flood hazard results discussed in the paragraph above and shown in Figures 2-1 through 2-3 are based on the existing shoreline condition and would be more severe with the projected shoreline erosion.

CoSMoS is a regional model for Southern California and was not specifically developed to assess erosion of the Silver Strand; however, the results represent the latest and final information available from the USGS and are intended for use in assessing and planning for sea-level rise hazards in Southern California. As discussed above, projected erosion of the Silver Strand shoreline erosion is expected to increase flood hazards with sea-level rise; however, CoSMoS does not address the increase in flood hazards with projected shoreline erosion. Given that CoSMoS results show that the shoreline is not expected to erode past Highway 75 in 2100 with 2 m (6.6 ft) of sea-level rise in the worst case scenario of “no hold the line and no beach nourishment,” existing high ground along Highway 75 would likely remain and dissipate ocean wave energy during storms similar to how the existing shoreline dissipates waves (per CoSMoS results shown above).

In summary, the CoSMoS results indicate that the Silver Strand is not expected to erode or breach by 2100 for the current medium-high risk aversion scenario of 2 m (6.6 ft) of sea-level rise. The CoSMoS results also indicate that the existing Silver Strand shoreline protects the CVB from ocean waves with high-range sea-level rise projections. This analysis therefore assumes that the Silver Strand will protect the CVB from ocean waves through 2100 as suggested by the CoSMoS results and/or that the Silver Strand will be maintained by others through 2100 with beach nourishment, armoring, and/or other adaptation measures to address potential future erosion with sea-level rise and limit wave propagation over the Strand.



SOURCE: USGS CoSMoS v3.0 Phase 2 - San Diego County

Chula Vista Bayfront SLR

Figure 2-1
CoSMoS Flood Hazard Extent
100-year Flood

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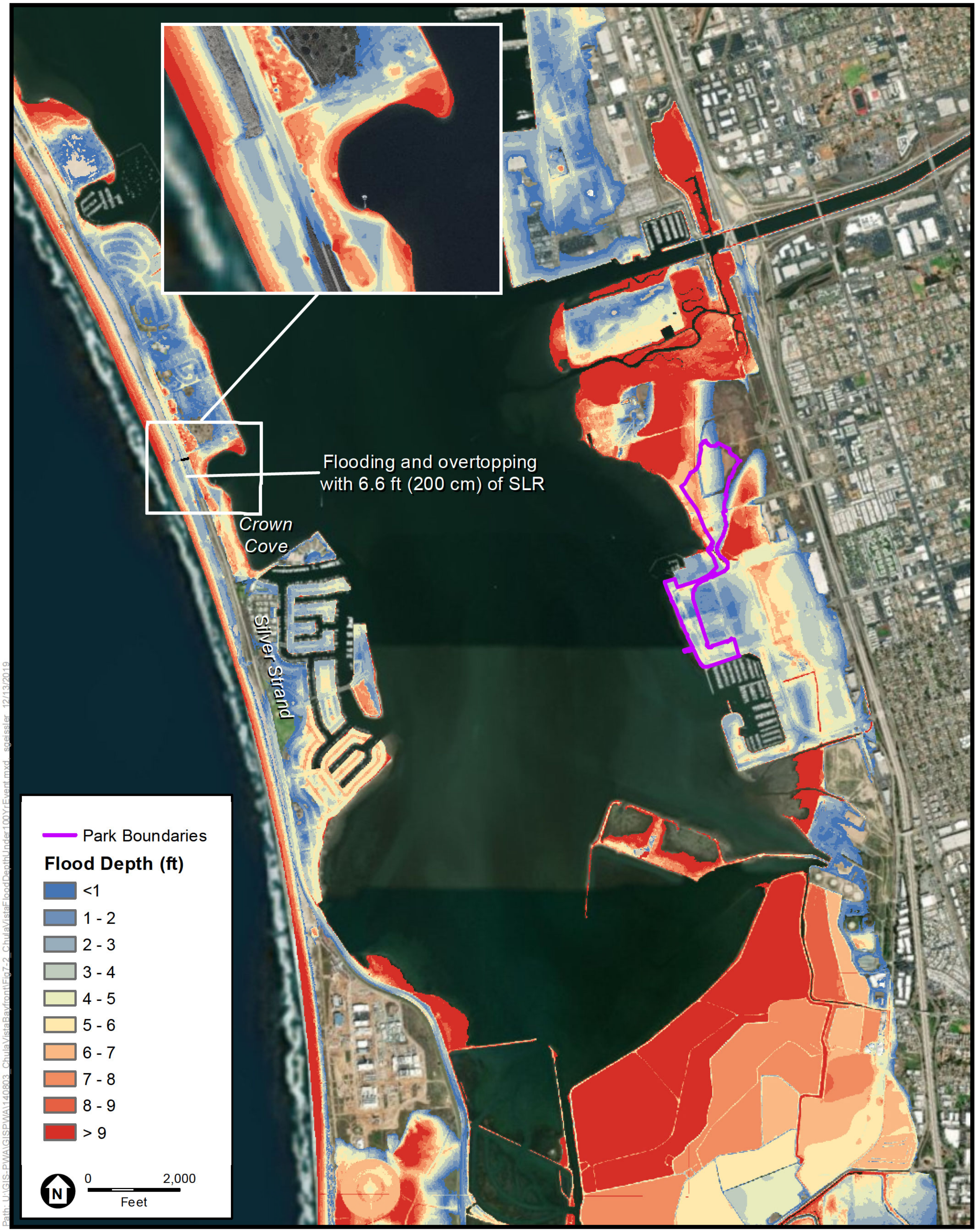
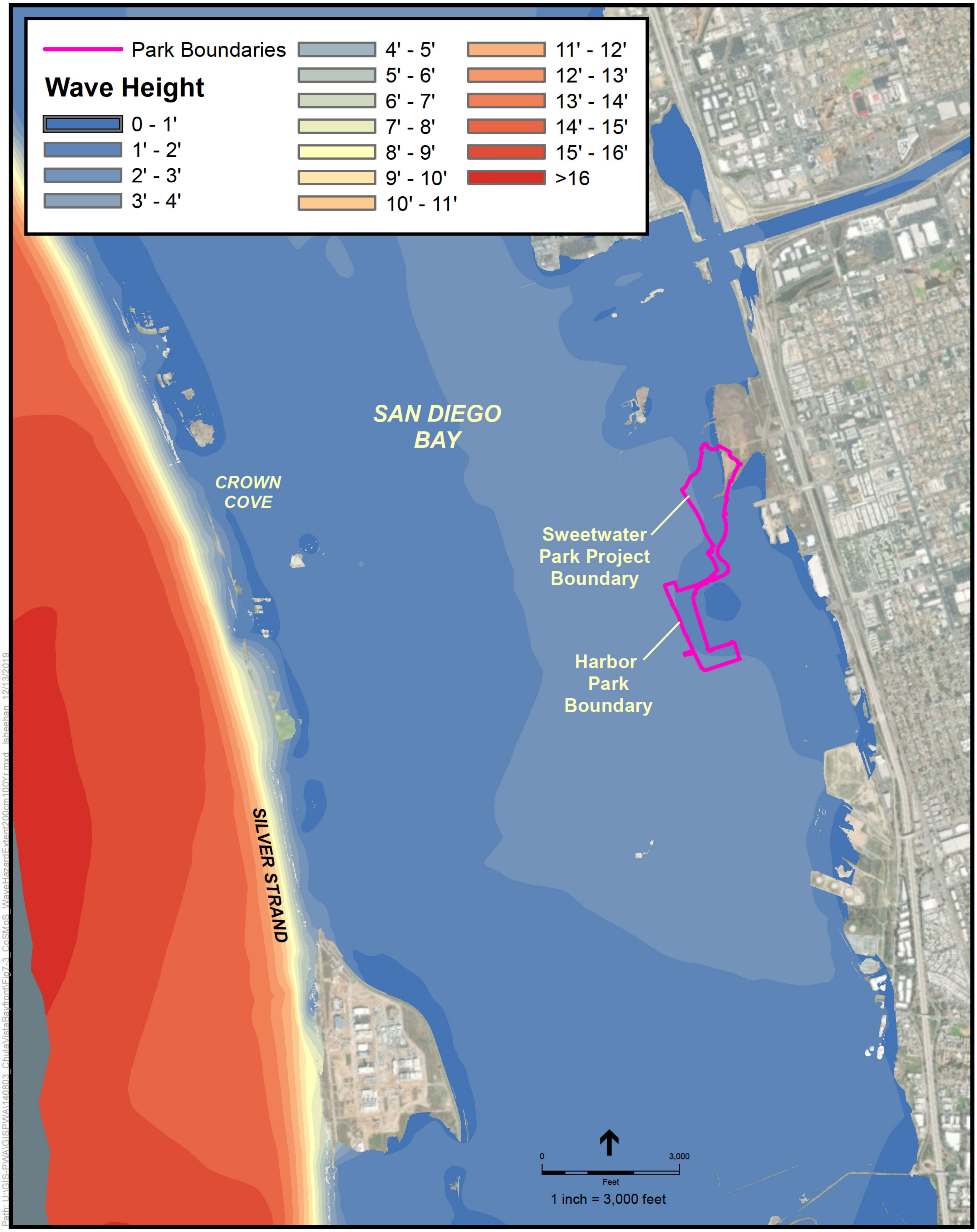


SOURCE: USGS 2016

Chula Vista Bayfront SLR

Figure 2-2
CoSMoS Flood Depth
6.6 ft (200 cm) of SLR and 100-year Flood

ESA



SOURCE: USGS CoSMoS v3.0 Phase 2 - San Diego County

Chula Vista Bayfron SLR

Figure 2-3
CoSMoS Wave Hazard Extent
6.6 ft (200cm) of SLR and 100-year Flood

SOURCE: USGS CoSMoS 3.0 Phase 2 - San Diego County

Chula Vista Bayfront Sea Level Rise . 150388.00

Figure 2-4
CoSMoS Shoreline Erosion
Projections with SLR in 2100
No Hold the Line / No Nourishment
Scenario

ESA

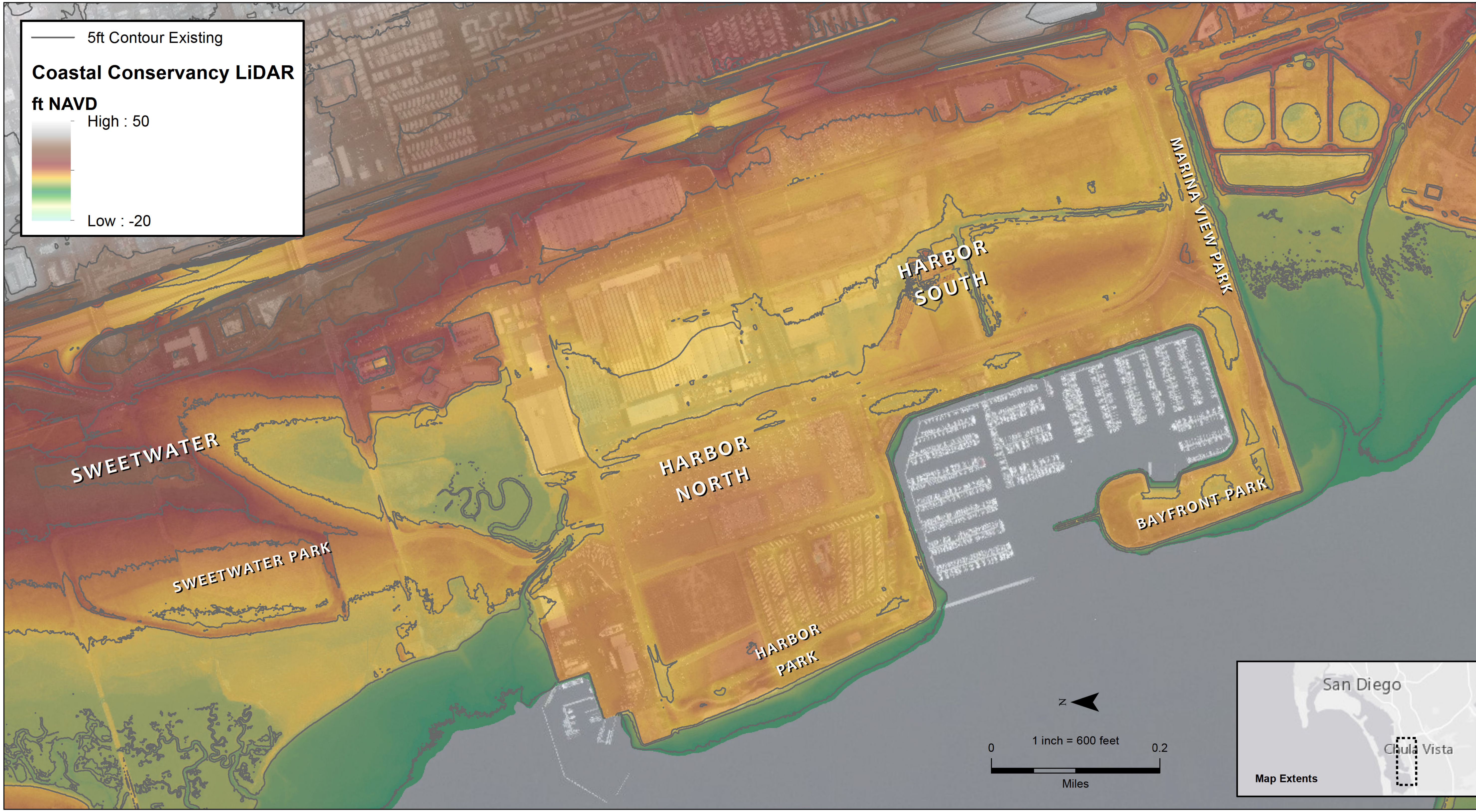
SECTION 3
Data Gathering

Topographic, wind, and water level data were gathered as part of this study and were used as inputs for wind wave and wave runup modeling. Details on the datasets used are described in this section. Where possible, long-term data sets were used because they allow more accurate statistical representations of extreme events.

3.1 Existing and Proposed Topography

The topography used in this analysis was composed of multiple topographic and bathymetric data sources. Existing topography was taken from the 2009-2011 California Coastal Conservancy LiDAR data (Figure 3-1). This regional LiDAR data set provides coverage of the entire CVB project and was used as the base for creating the composite topography. The LiDAR has a resolution of about 3.3 feet, and does not extend offshore below about the -1 foot NAVD contour. Bathymetric data from NOAA National Geophysical Data Center was added in areas lower than the LiDAR extent. The approximately 30-foot resolution bathymetry surface was published in 2012. The upland LiDAR data was supplemented with two topographic surveys made available from Rick Engineering. These surveys were performed for the CVB project design and provide more detailed and up to date topography than the LiDAR data. These surveys cover the Otay and Harbor District areas. Conceptual grading plan surfaces for Harbor Park were also available and used in this analysis. The extents of the topographic and bathymetric data used for this analysis are shown in Figure 3-2.

Six 1-dimensional (1D) profiles were taken through the proposed design for Harbor Park. These profiles were used to evaluate wave runup. The locations of these profiles are shown in Figure 3-3. A revetment height of 13.5 to 14.0 ft NAVD is being considered as part of the design of Harbor Park.



SOURCE: California Coastal ConservancyTopoBathy 2009-2011, ESRI; ESA 2015; NOAA 2015
Document Path: U:\GIS-PWA\GISPWA\140803_ChulaVistaBayfront\Fig3-1_Existing Topography.mxd

Chula Vista Bayfront Sea-Level Analysis . 150388.00

Figure 3-1
Existing Topography

SOURCE: California Coastal ConservancyTopoBathy 2009-2011, ESRI; ESA 2015; NOAA 2015
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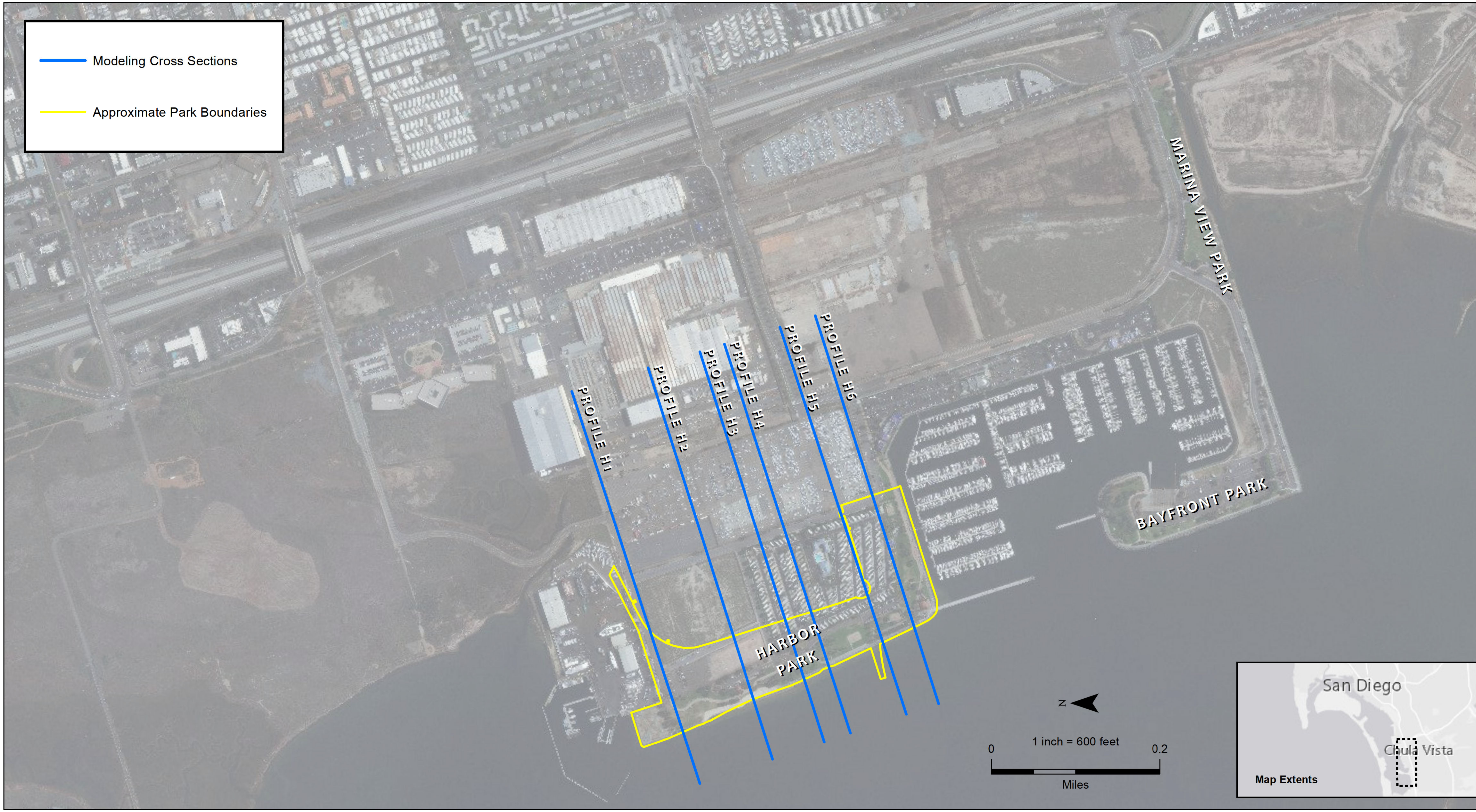
Chula Vista Bayfront Sea-Level Analysis . 150388.00

Figure 3-2
Topography/Bathymetry Data Sources



SOURCE: California Coastal ConservancyTopoBathy 2009-2011, ESRI; ESA 2015; NOAA 2015
Document Path: U:\GIS-PWA\GISPWA\140803_ChulaVistaBayfront\Fig3-3 ModelingCrossSection.mxd

Chula Vista Bayfront Sea-Level Analysis . 150388.00
Figure 3-3
Modeling Cross-Sections

3.2 Wind Data

The wind station with the longest data record near the site is located at the San Diego Lindberg International Airport, approximately 9 miles northwest of the Harbor District (Figure 3-4). Wind data was downloaded from the Lindberg station from 1965 through 2015. The raw data was evaluated and questionable values were removed. Data was adjusted to a standardized height of 33 feet (~10 m) and to a duration of 2 min and corrected from wind over land to wind over water according to Resio and Vincent (1977) and USACE (2006). Figure 3-5 shows the corrected wind time series.

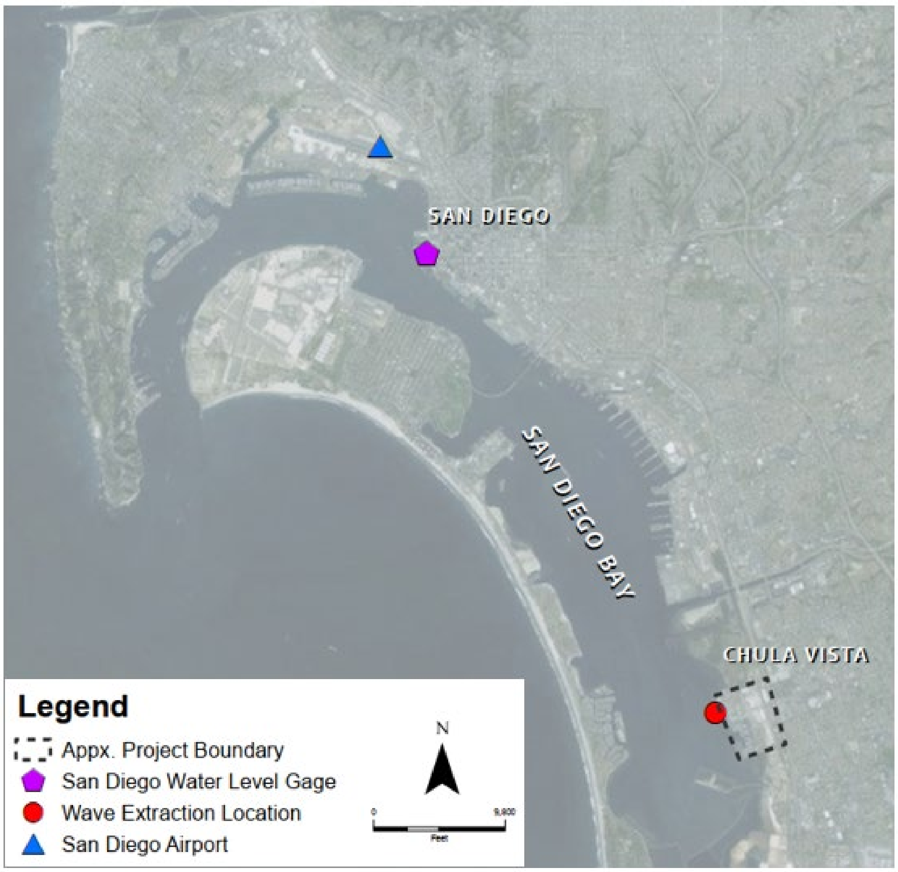


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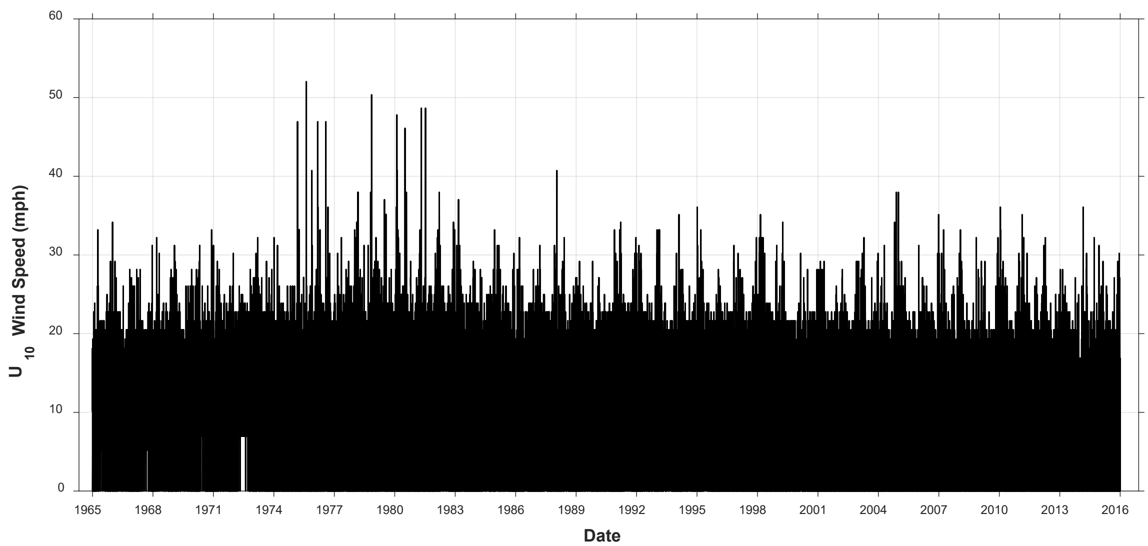
Figure 3-4
Data Locations



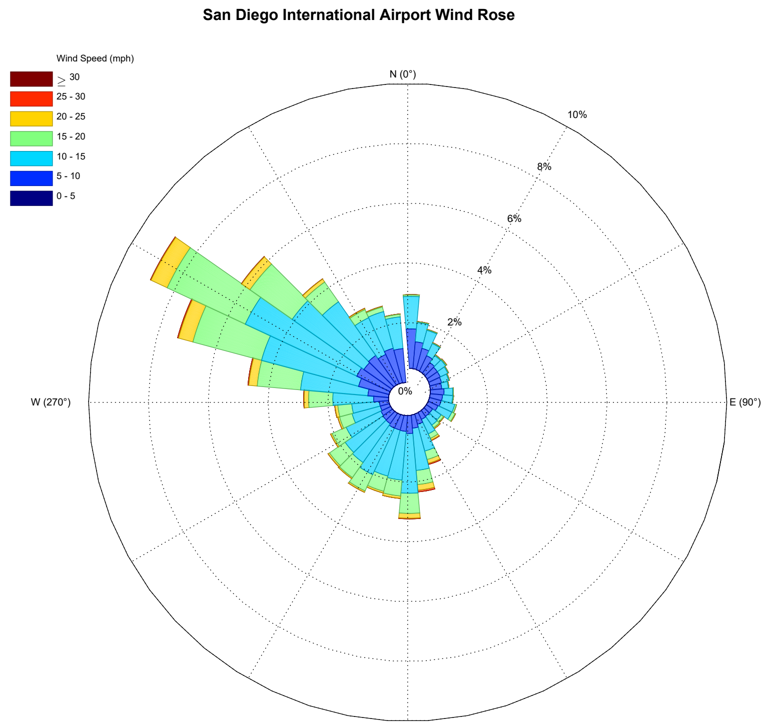
Chula Vista Sea-Level Rise Analysis / D150388.01

SOURCE: NOAA 2016
NOTES: 10-meter, 2-minute adjusted wind speeds

Figure 3-5
Wind Time Series Data from San Diego International Airport, 1965-2016

A summary of recorded high winds at San Diego Bay since the 1870s to 1980s is shown in Table 3-1 (City of Newport Beach 2014). The wind data from the San Diego Airport Station (Figure 3-4) shows wind extreme events to be on the same order of magnitude as the recorded events shown in Table 3-1. Several extreme events happened between the mid-1970s and early 1980s with a maximum observed speed of approximately 52 mph. Table 3-1 shows maximum reported wind speeds up to 57 mph. Typically, annual maximum sustained wind speeds exceed 30 mph.

Figure 3-6 shows the wind directional distribution recorded at the San Diego Airport. The figure shows that winds from the northwest are the most common and can be fairly strong, however strong winds (> 25 mph) are also observed from the south and southwest. Winds are considerably smaller and less frequent from the 330 to 150 degrees. Based on the existing data and reported historic wind observations, the wind was categorized into wind speed and direction classes for input into the numerical wind-wave model to represent the range of likely wind speeds and directions at San Diego Bay.



SOURCE: San Diego International Airport Weather Station

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Figure 3-6
Wind Rose San Diego International Airport

TABLE 3-1
HISTORIC EXTREME WIND CONDITIONS

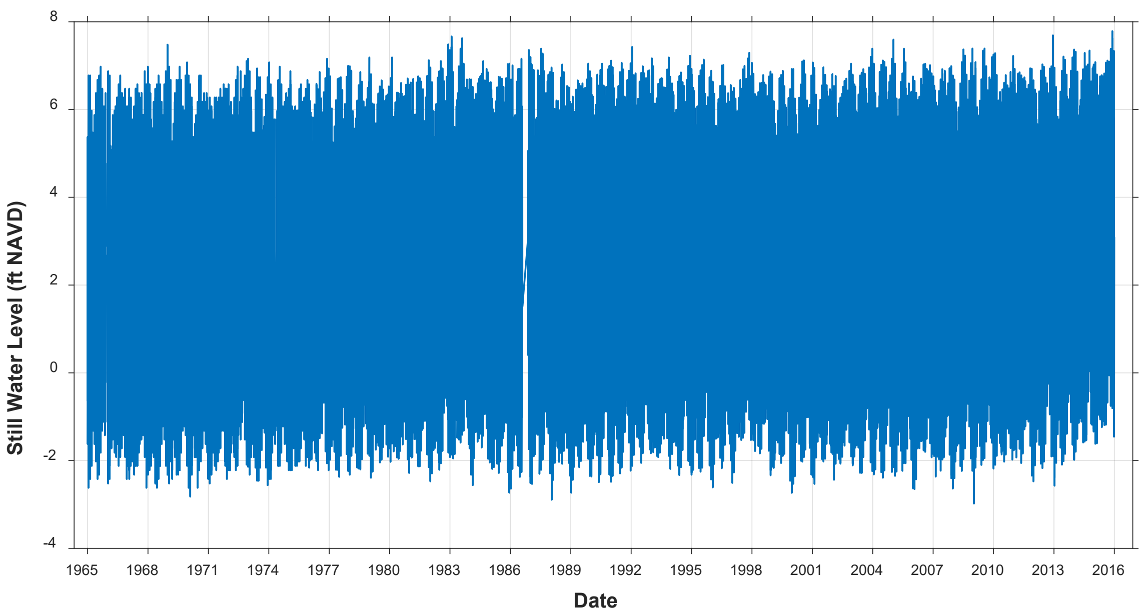
August 11-12, 1873	Tropical storm with strong winds hits San Diego, damaging roofs and felling trees.
January 27, 1916	Strong winds measured in San Diego, with peak winds at 54 mph; maximum gust to 62 mph, and average wind speeds for the day of 26.2 mph.
January 10, 1918	Strong offshore winds; skies full of dust, with visibility limited to 300 yards. At noon, visibility was only a few miles. Peak wind of 31 mph reported in San Diego at 6:38 am
May 23, 1932	Strong winds and low humidity; 12 serious brush fires, blackening nearly 2,000 acres in San Diego Count. The biggest fire was in Spring Valley.
April 13, 1956	Strong storm-related winds hit Chula Vista causing roof damage to 60 homes and one school. Trees uprooted, TV antennas toppled and windows shattered. Flying glass injures 2. Fish sucked out of San Diego Bay and deposited on the ground. Possible tornado.
February 10-11, 1973	Strong storm-related winds clocked at 57 mph in Riverside, 46 mph in Newport Beach. More than 200 trees uprooted in the community of Pacific Beach in San Diego County alone.
September 10, 1976	Hurricane Kathleen brought to the SW the highest sustained winds associated with an eastern Pacific tropical cyclone; sustained winds of 57 mph at Yuma, Arizona.
November 30 – December 1, 1982	Widespread strong winds associated with a big storm result in 1.6 million homes without power.
March 1, 1985	Strong storm winds struck San Diego County toppling trees and antennas, and causing numerous power outages.
February 23-24, 1987	Storm winds to 50 mph in Mt. Laguna; gusts to 34 mph in San Diego
March 15, 1987	Widespread strong storm winds; winds of 25-35 mph sustained all day, gusts to 40 mph in San Diego. Result in power outages all over the San Diego metropolitan area; motor homes toppled in the desert; light standard fell over onto cars in Coronado; boats flipped over in harbors; a 22-foot boat turned over at Mission Beach jetty; Catalina cruise ships delayed, stranding 1,200 tourists there.
November 18, 1987	Strong Pacific storm brought gale-force winds along the coast with winds exceeding 40 mph; downed trees and caused power outages.
December 12-13, 1987	Strong Santa Ana winds in San Bernardino, with 60-80 mph gusts there. 38- mph winds recorded in San Diego. 80 power poles blown down within ½- mile stretch in Fontana and Rancho Cucamonga; downed tree limbs damaged cars, homes and gardens; 1 injured when tree fell on truck; power poles and freeway signs damaged; parked helicopter blown down a hillside in Altadena; trees downed and power outages in San Diego County. In Spring Valley, 1 dead when eucalyptus tree fell on truck.
January 17, 1988	Major Pacific storm produced 64-mph gusts in San Diego, with the highest wind on record at Lindbergh Field. Trees uprooted in San Diego; boats damaged in San Diego harbor; apartment windows ripped out in Imperial Beach, where damage was estimated at $1 million. San Diego Zoo closed for first time in 72 years due to damage; kelp beds damaged
January 21-22, 1988	Strong offshore winds following major Pacific storm with gusts to 80 mph at the Grapevine, 60 mph in Ontario, and 80 mph in San Diego County. Power poles, road signs and big rigs knocked down in the Inland Empire. In San Diego County, 6 injured; roofs blown off houses, trees toppled, and crops destroyed. 20 buildings damaged or destroyed at Viejas; avocado and flower crops destroyed at Fallbrook and Encinitas, respectively, with 5 greenhouses damaged in Encinitas.
May 29, 1988	Gale-force winds hit coastline; gusts to 60 mph in the mountains; 45 mph at LAX; 40 mph in San Diego. Power outages; brush fires started; hang glider crashed and killed.

SOURCE: City of Newport Beach 2014.

3.4 Water Level Data

Water level records (SWL) for the project site were obtained from the San Diego Tide Station (NOAA NOS# 9410170) from 1965 to 2015 (Figure 3-7). While the gage has been collecting data from 1906 to present, the data analyzed was limited to the years for which wind data was available. Elevations were downloaded in NAVD. Tidal datums from this gage are shown in Table 3-2. The greater diurnal tide range at the gage is approximately 5.72 ft.

The USGS collected tide data within the Sweetwater Marsh from September 23, 2011 to October 6, 2014 (~3 years) at two gages (Takekawa et al 2013). The gages were surveyed into NAVD with RTK GPS at the time of deployment and water levels were corrected for local barometric pressure from a barometric logger. The gages were located within marsh channels and dried out at low tides. ESA calculated tidal datums from the USGS data, which are shown in Table 3-2. Since low water was not captured by the gages, the low tide datums are not included. Additionally, during data downloading, the gages were removed and then re-installed, and it is likely that the location of the gages shifted slightly.



Chula Vista Sea-Level Rise Analysis / D150388,01

SOURCE: NOAA 2016

Figure 3-7
Still Water Level Time Series

TABLE 3-2
OBSERVED WATER LEVELS IN SAN DIEGO BAY

Tidal Datum		San Diego (NOAA, Station 9410170)	Sweetwater Marsh (USGS)
Highest Observed (11/25/2015)		7.79	
Highest Observed (12/13/2012)		7.74 (8:12 am)	7.8 (9:24 am)
Highest Astronomical Tide	HAT	7.3	
Mean Higher High Water	MHHW	5.29	5.1
Mean High Water	MHW	4.56	4.5
Mean Tide Level	MTL	2.53	
Mean Sea Level	MSL	2.51	
Diurnal Tide Level	DTL	2.43	
Mean Low Water	MLW	0.51	
North American Vertical Datum	NAVD	0	
Mean Lower Low Water	MLLW	-0.43	
Lowest Astronomical Tide	LAT	-2.54	
Lowest Observed		-3.52	

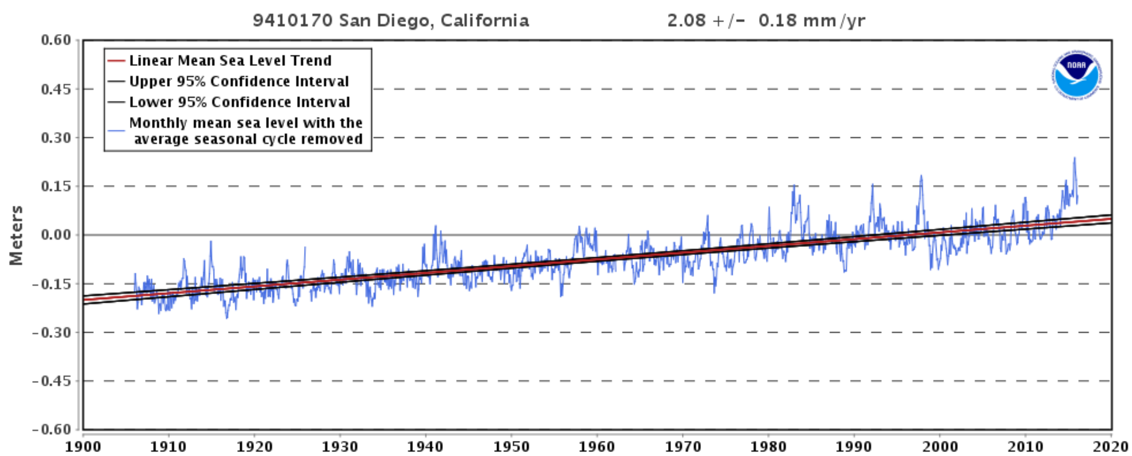
The longer-term NOAA data is expected to provide more accurate tidal datums. Note that the highest observed water level at the NOAA gage on 11/25/2015 occurred after the water level was downloaded for this study. The previous highest observed water level on 12/13/2012 was recorded at both the NOAA gage and the USGS Sweetwater Marsh gage. The higher water level at the USGS Sweetwater Marsh gage of 7.8 ft NAVD may account for some tidal amplification between the NOAA San Diego gage and the Chula Vista Bayfront.

SECTION 4
Still Water Level Analysis

The SWL record from the NOAA San Diego tide gage described in Section 3 was analyzed using a time series approach and an extreme value approach to determine future typical and extreme water levels. The methods and results of this analysis are described below.

4.1 SWL Time Series

Linear, mean sea level trends at the San Diego tide gage have been calculated by NOAA between 1906 and 2015. The trend shows an increase in sea level of approximately 2.08 ± 0.18 mm/year. The available tidal data was used to develop a tide time series that was corrected (normalized) for historic sea-level rise. To normalize for present day flood risk, the trend in historic water level data was removed according to this absolute sea-level rise rate (Figure 4-1). Water levels in the past were increased by the historic sea-level rise rate multiplied by the number of years before the present. By raising the historic elevations, de-trending accounts for the consequence of historic conditions occurring at present day mean sea level conditions.



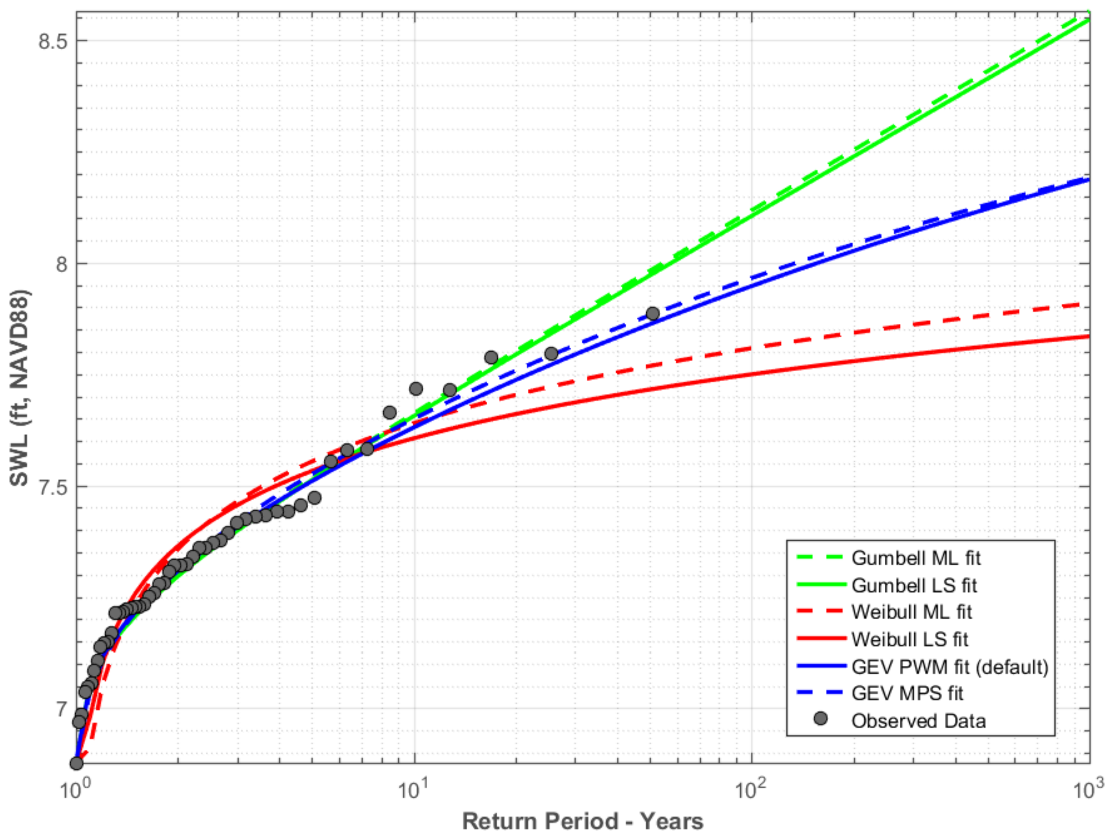
SOURCE: NOAA 2015

Chula Vista Sea-Level Rise Analysis / D150388,01

Figure 4-1
Monthly Mean Sea Level (Tidal Datum) Trend from 1906 to 2014 at San Diego Tide Station

4.2 SWL Extreme Analysis

An extreme-value analysis of 51 years of recorded water levels from 1965 to 2015 was conducted based on the de-trended tide data at the San Diego tide station (Section 4.1). From the de-trended time series, the maximum SWL elevation from each year was obtained and fit to a Gumbel, Weibull, and the General Extreme Value Distribution (GEV) as shown graphically in Figure 4-2. Several distributions were examined in order to find the best distribution for the data set. In this case, the Gumbel distribution provided the best fit to the majority of the extreme data points, and was the most conservative distribution. Table 4-1 summarizes the extreme SWLs obtained from the Gumbel distribution and shows the projected extreme SWL with the different sea-level rise scenarios described in Section 2.1.3.



SOURCE: NOAA, ESA
NOTES:
ML = Maximum Likelihood Method
LS = Least Squares Method
GEV = Generalized Extreme Value
PWM = Probability-Weighted Moment
MPS = Maximum Product of Spacings

Chula Vista Sea-Level Rise Analysis / D150388,01

Figure 4-2
Still Water Level Extreme Value Analysis

TABLE 4-1
EXTREME SWL ELEVATIONS IN FEET NAVD

Return Period (Years)	Present	2025 – 2030 (0.7 ft SLR)	2040 – 2055 (1.4 ft SLR)	2060 – 2080 (2.6 ft SLR)	2080 – 2120 (4.5 ft SLR)
1	6.9	7.6	8.3	9.5	11.4
5	7.5	8.2	8.9	10.1	12
10	7.7	8.4	9.1	10.3	12.2
20	7.8	8.5	9.2	10.4	12.3
50	8.0	8.7	9.4	10.6	12.5
100	8.1	8.8	9.5	10.7	12.6

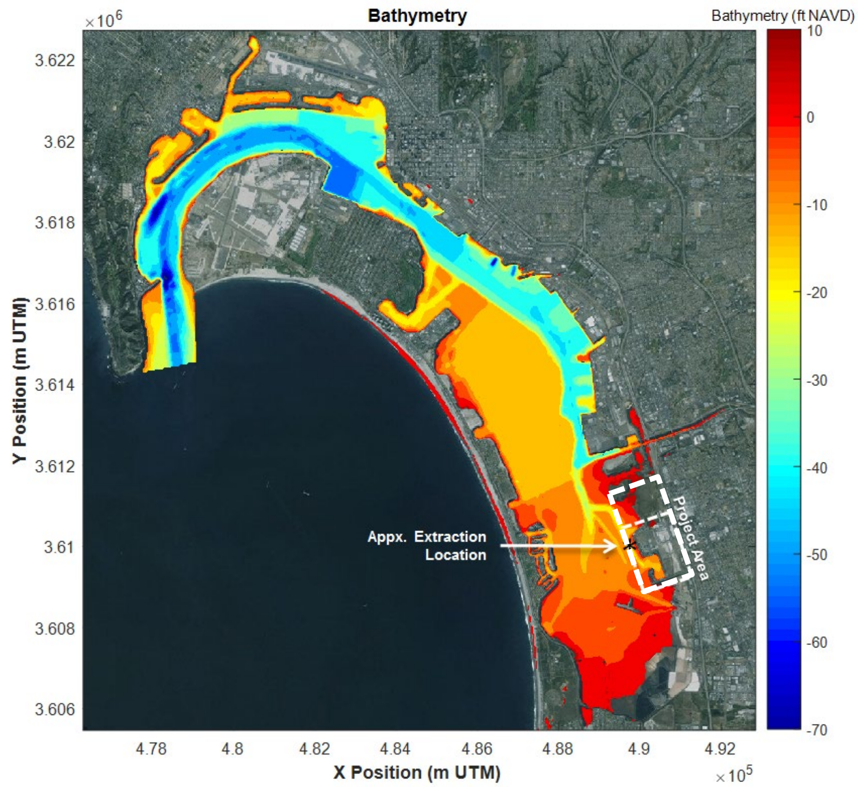
SECTION 5
Wind, Wave, and Wave Runup Analyses

5.1 Wind Setup

Wind setup is the potential effect of wind forcing or "pushing" and "piling up" bay water against the CVB, causing a local increase in the SWL. Wind setups of between 0.1 ft for a 25 mph wind speed and 0.4 ft for a 50 mph wind were approximately estimated for winds blowing from the northwest over the longest fetch across the bay. Wind setup was not explicitly included in the TWL analysis (Section 6); however, this estimate of wind setup provides an indication of the potential uncertainty in the analysis results.

5.2 Wave Parameter Time Series

To model the wave conditions near the site, ESA applied the industry-standard Simulating Waves Nearshore (SWAN) model. This 2-dimensional model predicts waves likely to occur in response to wind speed, wind direction, water level, shoreline geometry, and bathymetry. The relevant wave processes which are included in the SWAN model include wave generation, refraction, shoaling, and breaking. The SWAN model was implemented using the Delft3D modeling suite (Deltares 2014). The modeling was accomplished by developing a large-scale computation grid and a smaller, nested grid. To create the SWAN grids, ESA used a previously developed large-scale 40 m x 40 m grid for the entire San Diego Bay (Figure 5-1).

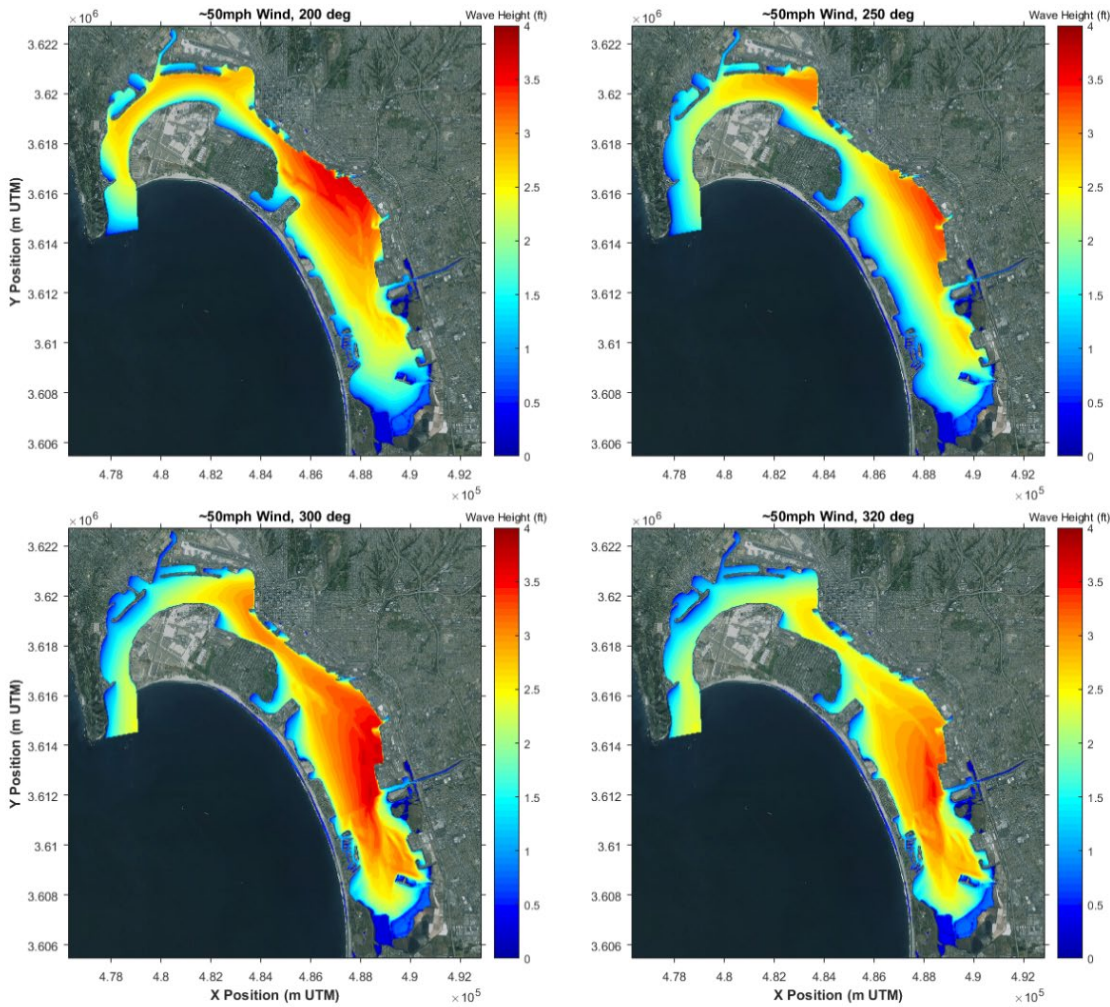


SOURCE: ESA

Chula Vista Sea-Level Rise Analysis / D150388,01

Figure 5-1
SWAN Domain and Bathymetry

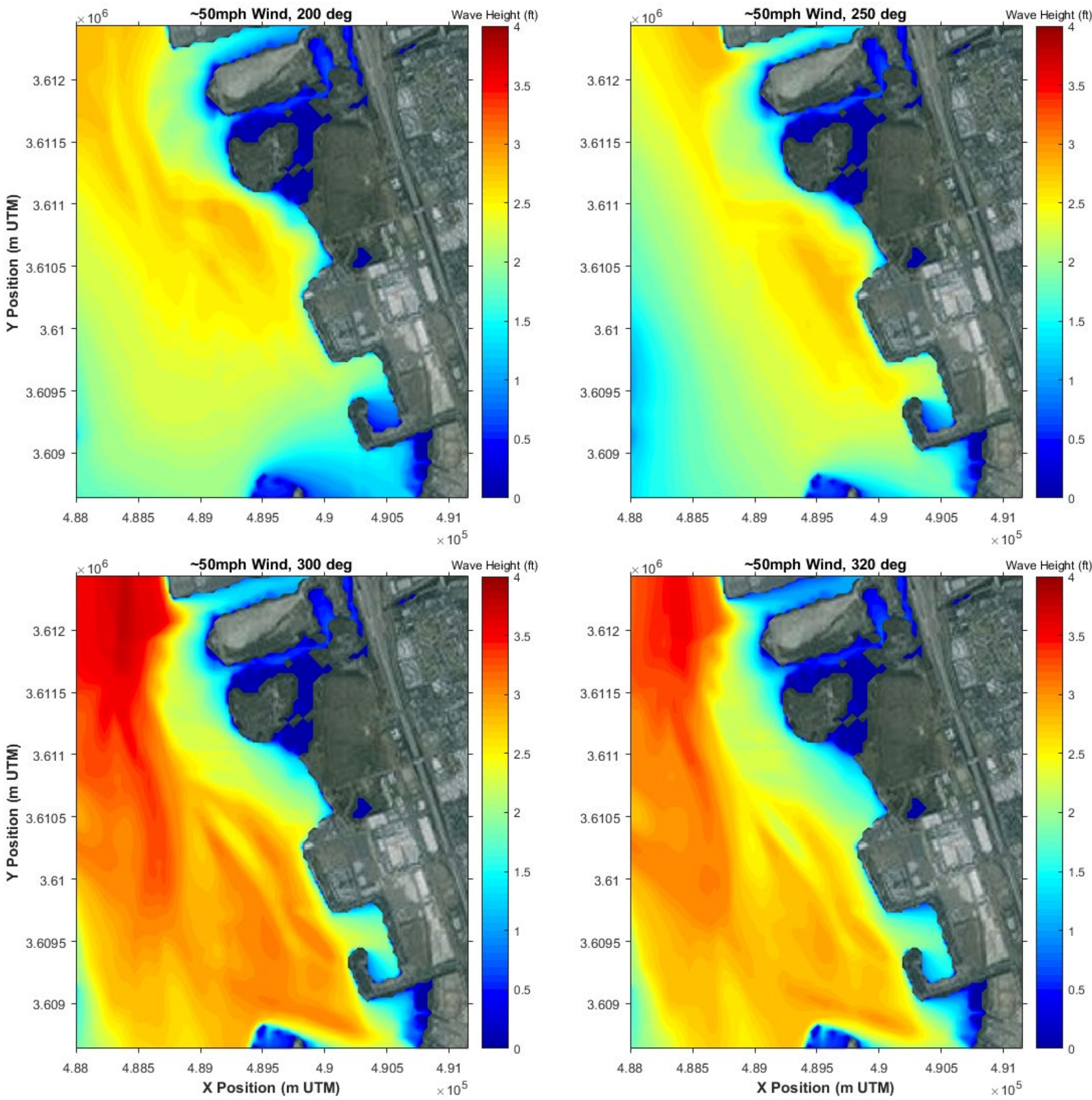
Figure 5-2 and 5-3 shows wave heights obtained from the SWAN model for different wind directions under extreme wind conditions (~50 mph) for the entire domain (Figure 5-3), and at the project site (Figure 5-3). The top left plot shows wind waves generated across a southwesterly fetch of 200 degrees, and the top right plot shows winds generated along a fetch perpendicular to the project (250 degrees). Both of these events generate relatively small waves near the project site, with the most wave exposure occurring to the north of the CVB (< 3-foot wave heights). The lower left figure shows waves generated along the most common fetch direction of 300 degrees, while the bottom right figure shows the longest fetch direction of 320 degrees. Both of these two events generated larger waves near the site (~3.5 feet in height), with the 300-degree fetch direction generating the largest waves offshore of the CVB.



Chula Vista Sea-Level Rise Analysis / D150388,01

SOURCE: ESA

Figure 5-2
Wave Heights for a Southwesterly Fetch (top left), a Fetch Perpendicular to Project (top right), Most Common Fetch (bottom left), and Longest Fetch (bottom right)

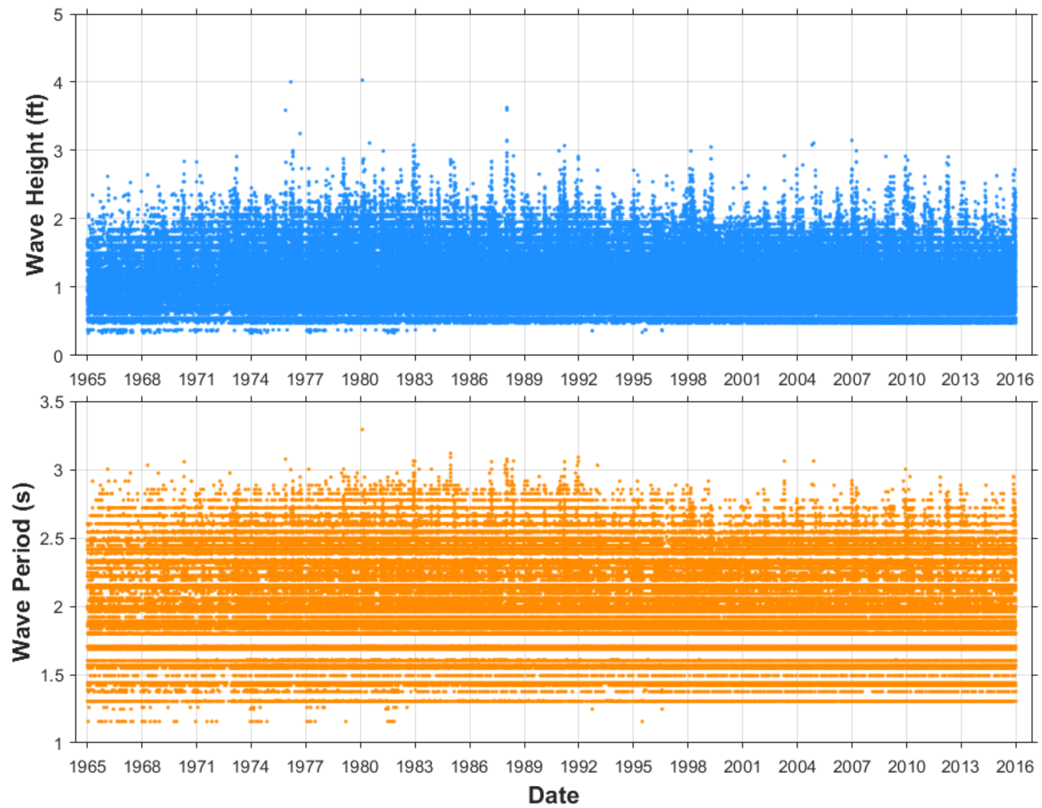


Chula Vista Sea-Level Rise Analysis / D150388,01

SOURCE: ESA

Figure 5-3
Nearshore Wave Heights for a Southwesterly Fetch (top left), a Fetch Perpendicular to Project (top right), Most Common Fetch (bottom left), and Longest Fetch (bottom right)

The predicted wave parameters were then used to create a look-up table that relates wind velocity and direction with wave parameters (wave height, period, and direction) at the site. These look-up tables were used to create nearshore wave parameters time series (Figure 5-4) based on the recorded wind speed and direction time series. The use of a look-up table reduces computational demand (Garrity et al. 2007), facilitating hourly computations of wave runup.

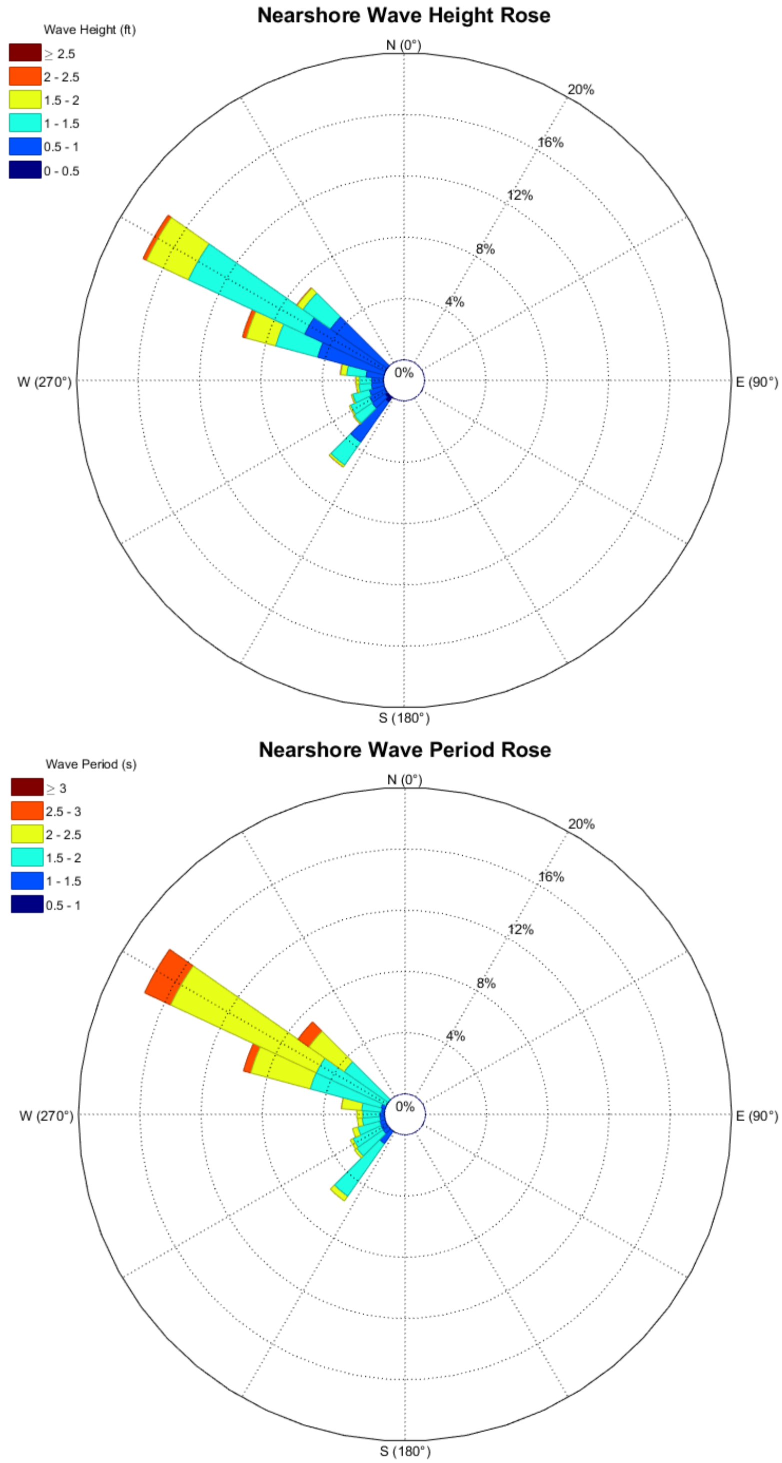


Chula Vista Sea-Level Rise Analysis / D150388,01

SOURCE: ESA

Figure 5-4
Wave Height (H_{mo}) and Wave Period (T_p) Time Series at the Model Extraction Location

The wave height and wave period time series generated from the lookup tables are shown in Figure 5-4. Figure 5-5 shows the directional wave height distribution from the wave hindcast modeling. Maximum wave heights since 1965 were generally less than 3 feet, and met or exceeded 4 feet only twice throughout the entire record. Wind waves were typically largest and most common from the west-northwest, which has the longest fetch, though high waves from southwesterly winds were also hindcast. Wave periods were typically very short, with most wave periods estimated to be less than 3 seconds. A limited number of waves had periods reaching up to 3.3 seconds.



Chula Vista Sea-Level Rise Analysis / D150388,01

SOURCE: ESA

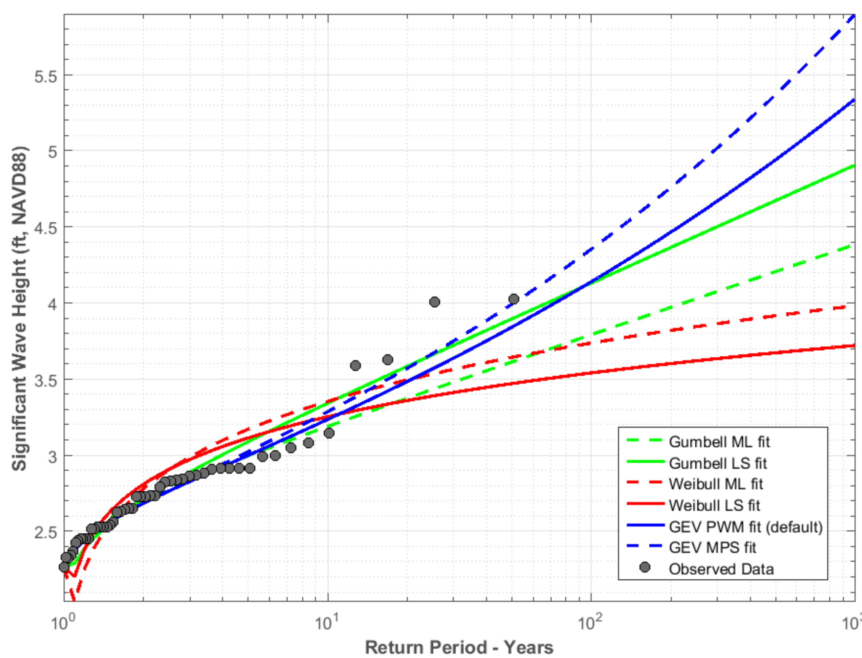
Figure 5-5
Nearshore Wave Rose at the Model Extraction Location

5.3 Extreme Wave Height Analysis

An extreme value analysis was conducted on the estimated wave height time series from 1965 through 2015. A maximum wave height value for each year was found and fit to Gumbel, Weibull, and GEV distribution, as shown graphically in Figure 5-6. The GEV Maximum Product of Spacings (MPS) distribution shows the best fit for the data. Table 5-1 summarizes the return periods and annual probabilities from the GEV distribution. The 100-year (or 1% annual chance) significant wave height is estimated to be 4.1 feet, based on the 52-year record of wave hindcast data.

TABLE 5-1
EXTREME WAVE HEIGHT (FT)

Return Period (Years)	Annual probability of occurrence	GEV
1	100%	2.3
5	20%	3.0
10	10%	3.2
20	5%	3.5
50	2%	3.8
100	1%	4.1



Chula Vista Sea-Level Rise Analysis / D150388,01

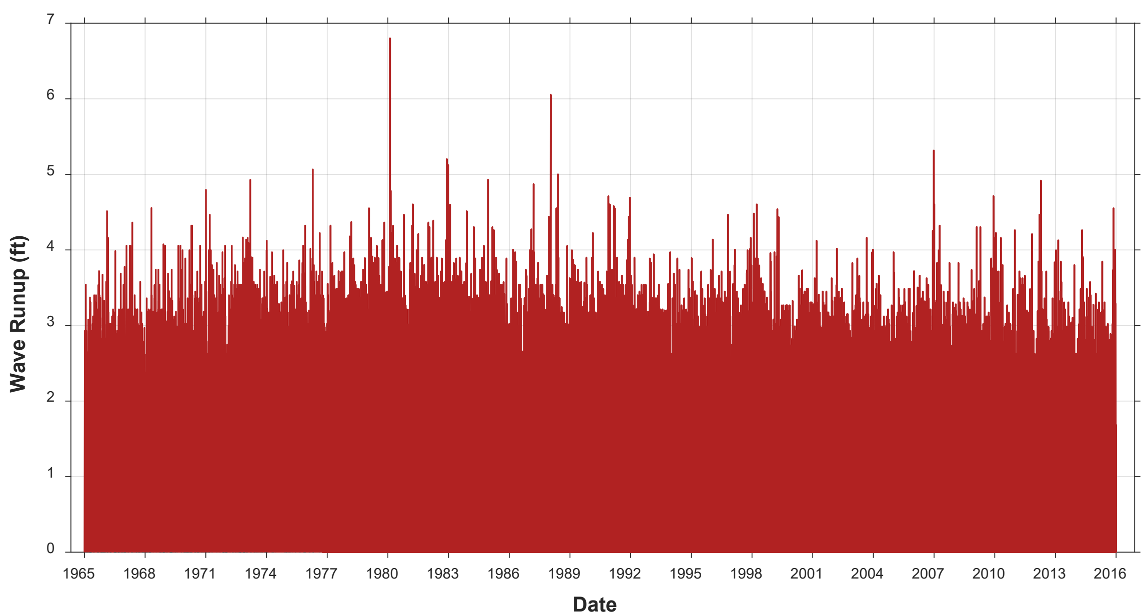
Figure 5-6
Wave Height Extreme Value Analysis

SOURCE: ESA
NOTES:
ML = Maximum Likelihood Method
LS = Least Squares Method
GEV = Generalized Extreme Value
PWM = Probability-Weighted Moment
MPS = Maximum Product of Spacings

5.4 Wave Runup Time Series

Wave runup along the CVB was modeled using the estimated wave parameter time series (Section 5.2) and the still water level time series (Section 4.1) applied along simplified shoreline profiles. The simplified profiles were based on the local beach slope at the intersection of the hourly water level and the bathymetric profile. For medium slopes, the Direct Integration Method (DIM) was used to calculate hourly wave runup (FEMA 2005). For steep slopes, the TAW method was used (TAW 2002) to estimate the runup. An estimation of setup due to waves was included in the runup time series for both methods. Figure 5-7 shows the wave runup time series calculated for this study.

The use of simplified slopes is computationally much simpler than computing runup on the complex natural shore profiles, but is also less accurate. TWLs estimated using simplified slopes are typically higher than TWLs calculated using actual profiles because the simplified slope is projected vertically above the actual shoreline profile elevations to simulate the potential wave runup and TWL at the shoreline. However, the simplified computations allow creation of a 52-year time series, thereby improving the statistical certainty of the extreme high values.



Chula Vista Sea-Level Rise Analysis / D150388,01

SOURCE: ESA

Figure 5-7
Wave Runup Time Series

SECTION 6
Total Water Level Analyses

TWL is the elevation of the computed wave runup height (described in Section 5.4) added to the SWL elevation (Section 4.1). ESA computed a TWL time series at the site and applied an extreme value analysis to calculate a 100-year TWL scenario. Wave and water level pairs, called “events”, which would result in the 100-year TWL scenario were then selected. These events are selected for use in the “scenario analysis” using detailed shore profiles, as explained in Section 7.

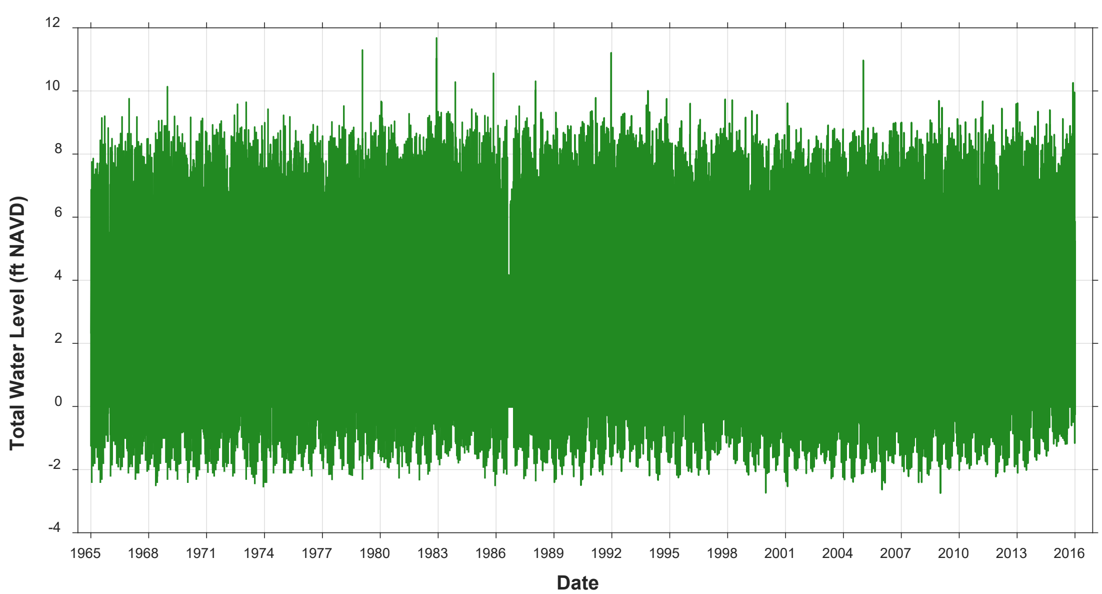
6.1 TWL Time Series

TWL is estimated by combining the water levels near the site and coincident wave runup on the shore, according to the following relationship:

[1] $TWL(t) = SWL(t) + Run\ Up(t) + sea\text{-}level\ rise(t)$

Where t is time.

Figure 6-1 shows the TWL time series for the CVB.



Chula Vista Sea-Level Rise Analysis / D150388,01

SOURCE: ESA

Figure 6-1
Total Water Level Time Series

6.2 Extreme TWL Analysis

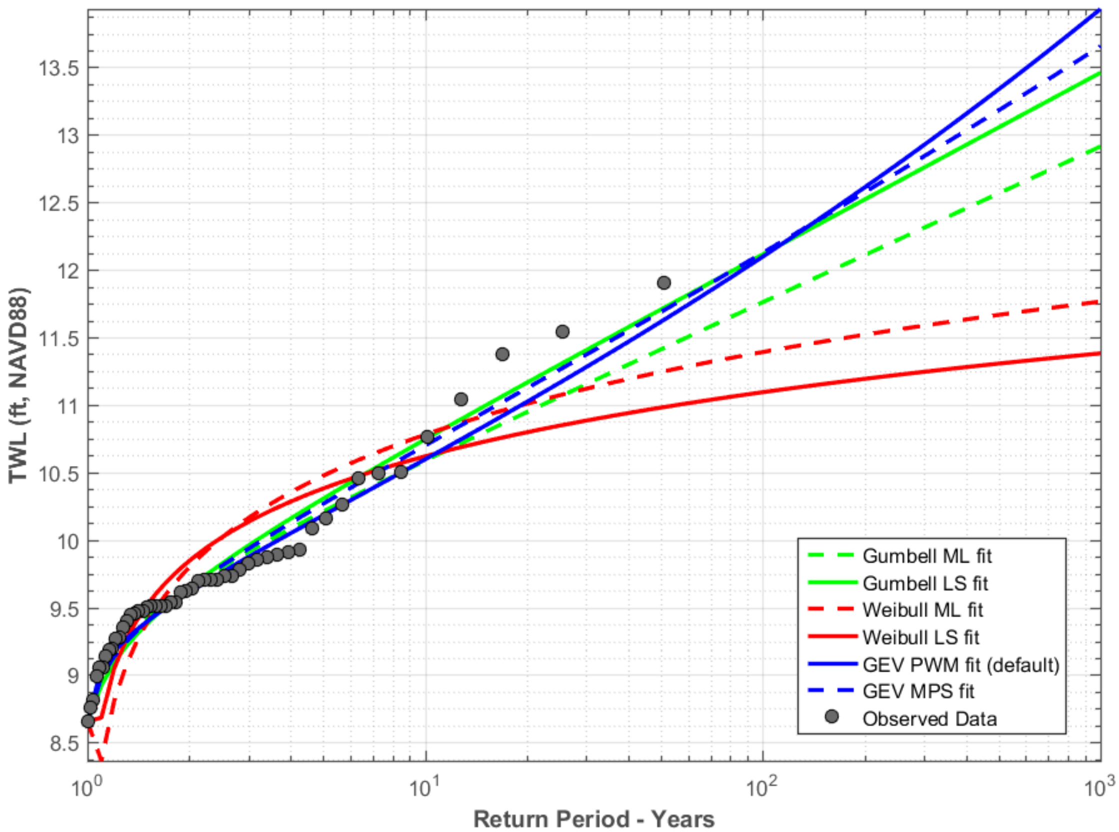
An extreme analysis of TWL instead of only the SWL is evaluated because high winds and high water levels are partly, but not completely dependent. Since coastal flooding results from both high water levels and large waves, the joint occurrence of these two parameters is also important. However, joint-occurrence statistics (e.g. how often a particular wave height is exceeded for a given water level) are not well defined, and the probability of a corresponding flood elevation is not directly defined by the probability of the parameters (Garrity et al. 2007). Hence, the TWL time series is analyzed, thereby incorporating implicitly the joint probability of simultaneous water level, waves, and the non-linear processes resulting in wave runup.

The analysis was conducted on the estimated TWL time series by fitting the 52-year TWL time series to a Gumbel, Weibull, and GEV distribution, as shown graphically in Figure 6-2. The GEV MPS distribution shows the best fit to the majority of the extreme data points. Table 6-1 summarizes the return values and annual probabilities of the TWL time series for the GEV fit. The results show a present-day 100-year TWL of 12.1 feet.

TABLE 6-1
EXTREME TWL ELEVATIONS

Return Period (Years)	Annual probability of occurrence	GEV (ft)
1	**100%**	8.7
5	**20%**	10.3
10	**10%**	10.7
20	**5%**	11.1
50	**2%**	11.7
100	**1%**	12.1

DATUM: NAVD88 FT



Chula Vista Sea-Level Rise Analysis / D150388,01

SOURCE: ESA
NOTES:
ML = Maximum Likelihood Method
LS = Least Squares Method
GEV = Generalized Extreme Value
PWM = Probability-Weighted Moment
MPS = Maximum Product of Spacings

Figure 6-2
Total Water Level Extreme Value Analysis

SECTION 7

Coastal Inundation Modeling

7.1 Selection of Events

The approximate 100-year TWL values computed with the extreme value distribution are extrapolations from the synthetic 52-year runup time series. Statistically, a 100-year scenario is expected to be exceeded about once in 100 years (or it has a 1% annual chance of occurrence). Therefore, it is not likely that the 100-year event has occurred in the 52-years of record, so the water levels and waves that force the 100-year TWL are not known. Different combinations of water level and wind wave pairs were evaluated to identify the pairs that would result in the 100-year TWLs.

Two scenarios were estimated to represent the 100-year TWL:

1. 100-year SWL with the 1-year wave height yielding roughly the 100-year TWL

2. 100-year wave height with the 1-year SWL yielding roughly the 100-year TWL

Note that a 100-year SWL event coincident with a 100-year wave height event was not considered, as this event would generate a TWL greater than a 100-year TWL scenario and would, therefore, be associated with a TWL or flood scenario that is more extreme than a 100-year storm event.

Details on the two selected events, including the 1-year wave heights, wave periods, and still water levels, are shown in Table 7-1 for present conditions (e.g., without sea-level rise).

TABLE 7-1
EVENTS FOR THE APPROXIMATE 100-YEAR TWL AT THE SHORELINE

Events	SWL (ft, NAVD88)	H_{mo} (ft)	Tp (s)
100-Year SWL + Wave Height = 100-Year TWL	8.1	2.5	3
100-Year Wave Height + SWL = 100-Year TWL	6.9	4.1	3

Once the extreme values calculated using the simplified slope are known, the simultaneous water level and wave “events” that cause them can be applied in more accurate computations using real, complex shore profiles or 2-dimensional bathymetry and topography and advanced numerical models that take into account complex wave process that occurs on the nearshore zone. This “hybrid” method was established to balance the need for statistical confidence and accuracy for flood studies along the Pacific coast of the US (FEMA, 2005; Garrity et al. 2007). Once the events have been selected, they can be applied for a wide range of shore profiles and treatments with maximum efficiency and confidence.

7.2 Harbor Park Analysis

For Harbor Park, the full complex shore profiles, rather than simplified slopes, were used to compute more accurate TWLs. The events defined in Table 7-1 were analyzed with the sea-level rise scenarios described in Section 2.2.

7.2.1 Coastal Inundation Modeling

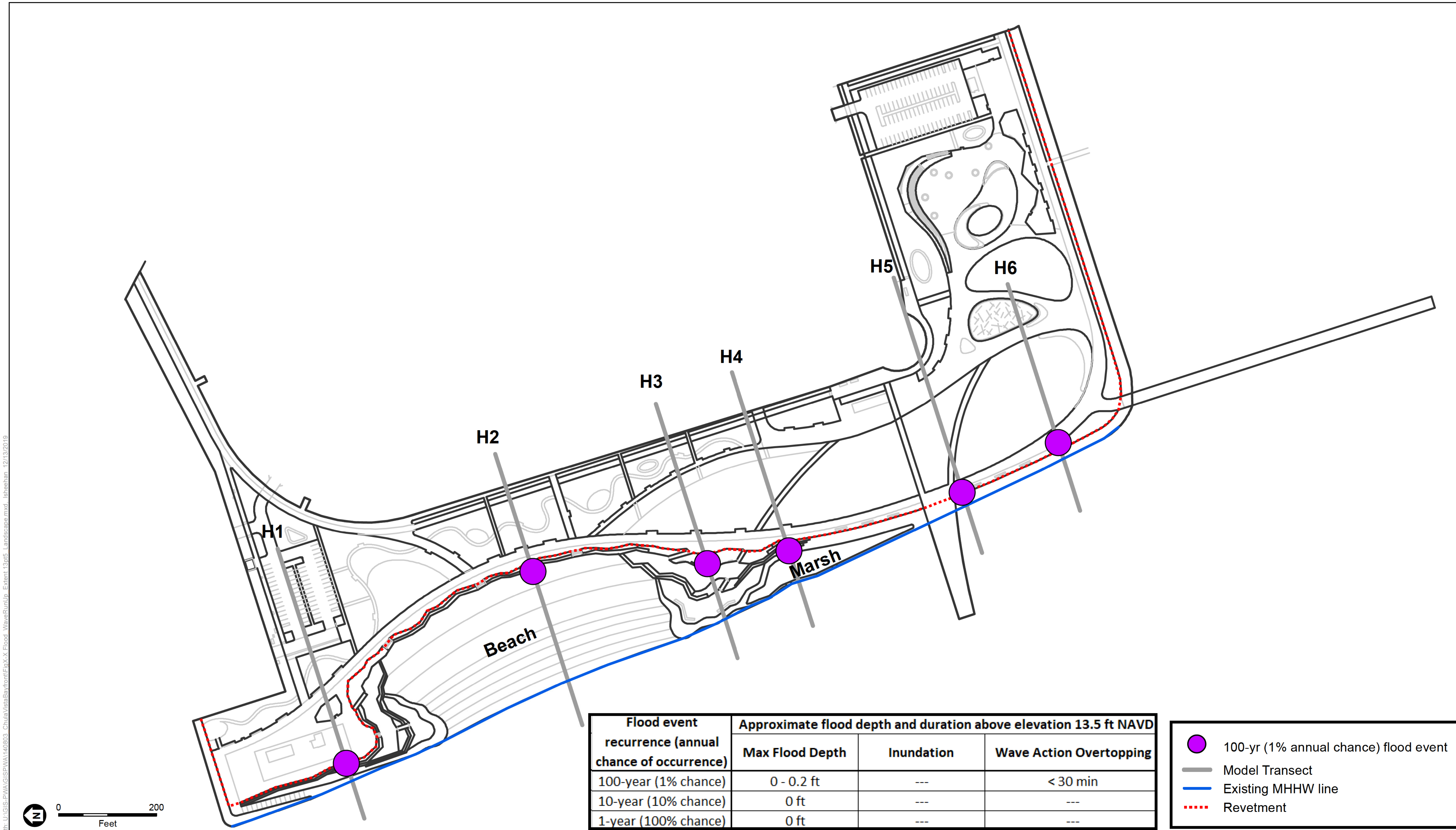
A process-based model for the nearshore and coast called XBeach (Roelving et al. 2009) was applied in 1D to estimate the wave runup, the peak water level, the landward extent of flooding, and the flood duration. XBeach models waves non-hydrostatically to resolve wave by wave flow and surface elevations variations as waves collide with the shoreline. This approach captures the relevant swash zone processes, including wave interactions with steep slopes, dynamic setup, and complex bathymetry. The use of a storm response model like XBeach allows a quantitative estimate of a complex process such as the peak wave runup, overtopping flow, and velocity.

The selected sea-level rise scenarios described in Section 2.2 were modeled on the profiles shown in Figure 3-3 in combination with the events presented in Table 7-1. The model was run to simulate a five-hour storm starting 2 feet below the defined peak SWL shown in Table 7-1, reaching the peak at the third hour and finishing 2 feet below the peak water level.

7.2.2 TWL at Harbor Park

The detailed estimates of TWL and inland extents of flooding for the 100-year TWL event at present conditions (e.g., without sea-level rise) and under the different sea-level rise projections described in Section 2.2 are tabulated in Table 7-2 and shown in Figure 7-1.

The inland extent of flooding is the most landward extent of inundation during a coastal flood. The distances reported are measured from the present location/extent of MHHW (5.29 feet NAVD) along the six profiles shown in Figure 3-3. Inland extents were measured based on the topography described in Section 3.1. Note that the distances reported represent the flooding of shoreline areas from wave effects. The areas where there is a measured inland extent are along the transects through the beach, steps down to the shore, and the constructed wetland, where the inland extent would be expected to increase due to the design of the park. Low-lying areas landward of these distances, which are not addressed by this study, may be inundated by the SWL. Also, note that the TWL reported in Table 7-2 corresponds to the TWL at the inland extent of flooding. This TWL represents the water level that would be observed at the landward edge of flooding for each scenario.



Flood event recurrence (annual chance of occurrence)	Approximate flood depth and duration above elevation 13.5 ft NAVD		
	Max Flood Depth	Inundation	Wave Action Overtopping
100-year (1% chance)	0 - 0.2 ft	---	< 30 min
10-year (10% chance)	0 ft	---	---
1-year (100% chance)	0 ft	---	---

SOURCE: Schematic design from Petersen Studio
NOTE: 4.5 ft of sea-level rise is projected in 2080 (medium-high risk scenario) to 2120 (low risk scenario) per CA Coastal Commission (2018) and Ocean Protection Council (2018)

ESA

Chula Vista Harbor Park Sea-Level Analysis

Figure 7-1
Flood (Wave Runup) Extent with 4.5 ft of Sea-Level Rise with a 13.5 ft NAVD Revetment

TABLE 7-2
BEACH RESULTS FOR MAXIMUM 100-YEAR TWL (FT NAVD) AT THE INLAND EXTENT OF FLOODING AND THE INLAND EXTENT (FT)[1] FOR EACH PROFILE

	Present		0.7 ft of SLR (2025-2030)		1.4 ft of SLR (2040-2055)		2.6 ft of SLR (2060-2080)		4.5 ft of SLR (2080-2120)	
Profile	**TWL**	**Inland Extent[1]**	**TWL**	**Inland Extent**	**TWL**	**Inland Extent**	**TWL**	**Inland Extent**	**TWL**	**Inland Extent**
H1	9.6	--	9.8	--	10.7	--	12.0	--	13.5	--
H2	8.6	13	9.2	57	9.8	97	11.1	185	13.6	208
H3	9.0	31	9.4	48	10	54	11.3	87	13.0	117
H4	9.9	61	10.1	64	10.9	66	11.7	71	13.6	77
H5	10	--	10.6	--	11.3	--	12.5	--	13.7	--
H6	9.2	--	9.8	--	10.6	--	12.0	--	13.6	1

1. Inland extent inundation is measured from present MHHW (blue line in Figure 7-1) to the inland extent of the flooding along the profile (purple dots in Figure 7-1). Cells without a value indicate no inland flooding.

SECTION 8
Vulnerability Assessment

With 4.5 ft of sea-level rise, which is projected between 2080 – 2120 (medium-high to low-risk aversion scenario), there is only minor flooding at the edge of the 13.5 ft NAVD proposed revetment in Harbor Park during a 100-year event and no flooding for the 10-year and 1-year events (Table 8-1). Therefore, the 13.5 ft NAVD revetment elevation is expected to be resilient to flooding with 4.5 ft of sea-level rise.

TABLE 8-1
FLOOD DEPTH AND DURATION ABOVE A 13.5 FT NAVD REVETMENT UNDER 4.5 FT OF SEA-LEVEL RISE

Flood event recurrence (annual chance of occurrence)	Max Flood Depth	Flood Duration
100-year (1% chance)	0.0 – 0.5 ft	< 0.5 hrs
10-year (10% chance)	0.0 ft	0 hrs
1-year (100% chance)	0.0 ft	0 hrs

The proposed beach at Harbor Park is expected to migrate inland and erode at the bay-ward edge with sea-level rise, unless an adaptation strategy, such as beach nourishment, is implemented.

SECTION 9
Potential Adaptation Measures

This study identifies potential adaptation measures to reduce the vulnerability of the proposed park improvements to flooding in the future with sea-level rise. These potential adaptation measures are described at a conceptual planning-level of detail to identify possible future options for adaptation. The implementation of actual adaptation measures in the future will be based on monitoring of sea-level rise and flood risk and more detailed project-level planning and design of adaptation measures. Any actual adaptation measures may differ from those identified below.

As discussed in Section 8 above, the proposed Harbor Park improvements include raising the revetment from an average height of 11 ft to 13.5 to 14.0 ft NAVD. At this elevation, the park is vulnerable to minor flooding along the revetment during a 100-year storm event, which is considered an extreme event, in the 2080 – 2120 time frame (with 4.5 ft of sea-level rise). For a 13.5 ft revetment, adaptation to reduce flooding may be necessary between 2070 and 2100. The economic life of the Harbor Park's three small park support buildings is estimated to be 50 years, and it is anticipated that these buildings may be raised or relocated (if needed) in the 2080-2120 timeframe. Adaptation could also include raising the revetment by several feet, preparing certain areas to be resilient to flooding (e.g., salt-water-tolerant planting palette), or removing structures or infrastructure from potential flood areas as sea levels rise. Harbor Park's shoreline improvements are being designed to accommodate future raising of the revetment.

Additionally, as discussed in Section 8, the proposed beach at Harbor Park is expected to erode with sea-level rise if no action is taken. The project proposes regular nourishment to maintain the beach. Continued beach nourishment could act as an adaptation strategy to provide flood protection for the areas behind the beach.

SECTION 10
Summary and Conclusions

Proposed development on Port tidelands is required to provide a site-specific hazard assessment addressing the potential for flooding and/or damage from natural forces including, but not limited to, tidal action, waves, and storm surge. Consistent with this policy, the CVB Harbor Park Sea-Level Rise Analysis and resulting conclusions do not set a standard and/or precedent for assessment and/or hazard response elsewhere on Port tidelands.

In summary, per Section 8, the flood vulnerability of the proposed CVB Harbor Park improvements is as follows:

1) Not vulnerable to 100-year storm flooding under:
    a) Current conditions, and
    b) 2060 – 2080 sea-level rise projection of 2.6 ft of sea-level rise.
2) Vulnerable along the edge of the revetment to 100-year storm flooding under 2080 – 2100 sea-level rise projection of 4.5 ft of sea-level rise.
3) Vulnerable to erosion along the beach without regular nourishment, which is planned as part of the project.

In conclusion, the proposed Harbor Park improvements with the raised revetment elevation at 13.5 to 14.0 ft NAVD are not expected to be flooded by the 100-year storm event scenario until 2080 with sea-level rise approaching 4.5 ft. Without adaptation, some flooding along the revetment could occur in the 2080 – 2100 time frame with 4.5 ft of sea-level rise; however, this level of flood risk could likely be accommodated and, therefore, represents an acceptable level of risk. Beyond 4.5 ft of sea-level rise, flooding would increase and potential adaptation measures may be needed, such as raising the revetment.

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