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FINAL SEA LEVEL RISE VULNERABILITY ASSESSMENT

City of Huntington Beach

SEA LEVEL RISE VULNERABILITY ASSESSMENT
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1. Introduction

1.1. Study Approach

The Sea Level Rise Vulnerability Assessment for the City of Huntington Beach assesses potential impacts to coastal resources and infrastructure across multiple sea level rise (SLR) scenarios. Analyses first focus on the extent to which local coastal hazards change under multiple sea level rise scenarios. The overlap of projected future hazard zones and existing coastal resources and infrastructure is then used to identify potential future vulnerabilities and the SLR thresholds at which coastal resources and infrastructure could be impacted. For this study, a coastal resource is broadly defined as any natural or constructed feature that provides a benefit to the City. Key questions that guide the SLR assessment are illustrated in Figure 1-1. The SLR Assessment is designed to inform updates to the City Local Coastal Program as well as potential SLR adaptation strategy development as part of the City Coastal Resiliency Plan.

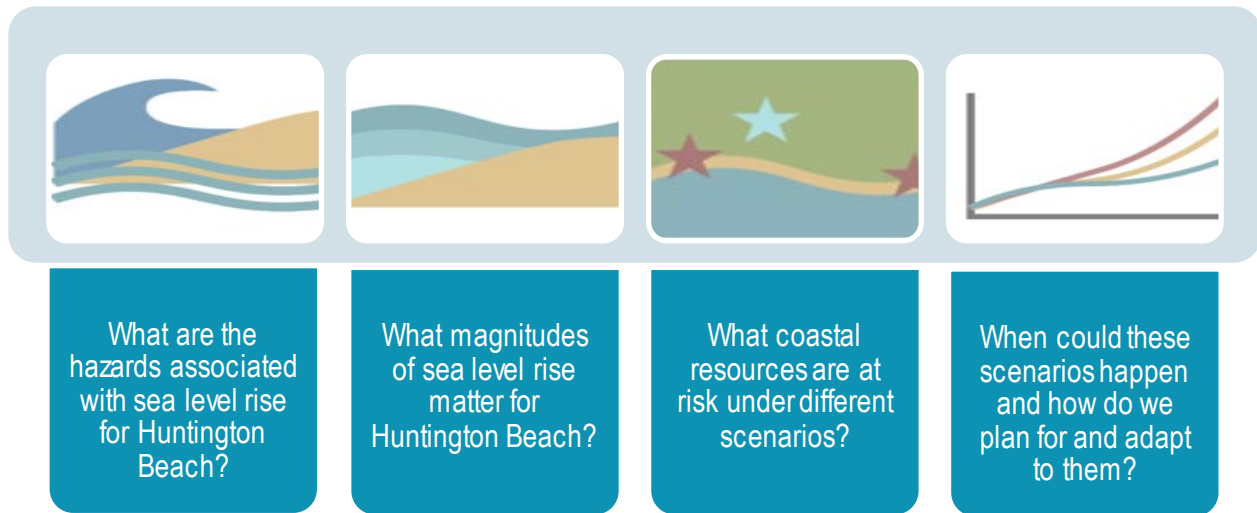


FIGURE 1-1: KEY QUESTIONS USED TO GUIDE THE CITY SLR ASSESSMENT.

Future SLR hazards within the City are analyzed based on the following study areas: Huntington Harbour, Bolsa Chica, Huntington Beach, and Huntington Beach Wetlands, corresponding to existing city coastal zone boundaries. The vulnerability of individual category of resources is also analyzed, including coastal development, utilities infrastructure (stormwater, sewer, potable water infrastructure, and other critical facilities), public safety facilities, transportation infrastructure, coastal access and recreation, and environmental resources. SLR vulnerability is evaluated through an analysis of hazard exposure, sensitivity, and adaptive capacity. Within this assessment, exposure refers to the type, duration, and frequency of coastal hazards a specific resource is subject to under a given SLR scenario. Sensitivity represents the degree to which a resource is impaired by exposure to coastal hazards, and adaptive capacity refers to the ability of a resource to cope with changes in coastal hazards over time (Figure 1-2).

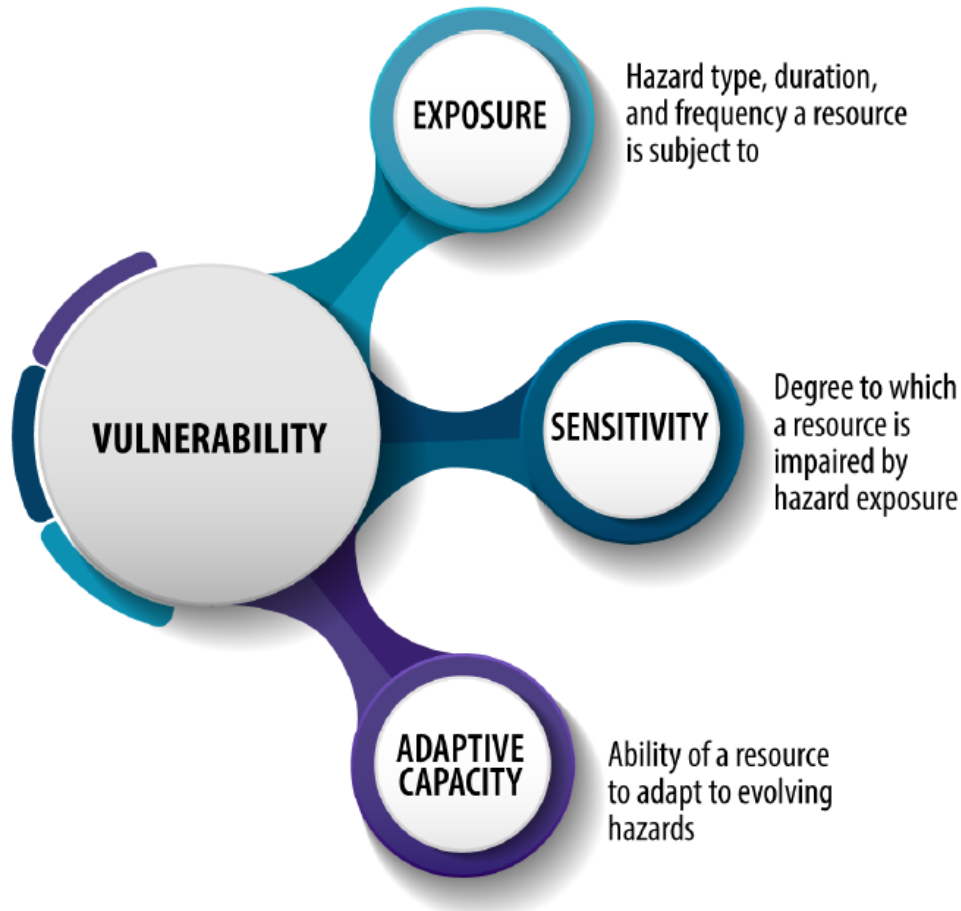


FIGURE 1-2: COMPONENTS OF SLR VULNERABILITY AS DEFINED WITHIN THIS STUDY

1.2. Study Sub-Areas

The study area is sub-divided into the following four sub coastal zones: Huntington Harbour, Bolsa Chica, Huntington Beach, and Huntington Beach Wetlands.

Huntington Harbour

The harbour area is primarily residential and lined with bulkhead structures throughout. Huntington Harbour is tidally influenced and also receives stormwater runoff from major regional flood control channels such as Bolsa Chica Channel, Westminster Channel, Sunset Channel and Anaheim-Barber City Channel. Recreational activities within the Harbour include kayaking, paddle boarding, and swimming.

The Harbour area is also home to Sunset Beach. Adjacent to Anaheim Bay (Naval Weapons Station), Sunset Beach serves as a “feeder” beach for Surfside-Sunset Beach Nourishment Project and has received nearly 18 million cubic yards of nourishment material since 1963. Sunset Beach extends from Anderson Street to the north to Warner Street to the south.

Bolsa Chica

The Bolsa Chica study area extends from Warner Avenue to the north to the downcoast limits of Bluff Top Park (Goldenwest Street) to the south. The area contains wide, sandy beaches backed by a lowland marsh. The shoreline portion of this planning area is operated by the California Department of Parks and Recreation (State Parks). The Pacific Coast Highway (PCH) is the primary coastal transportation corridor along this reach. The bluffs area along the southern end of the reach is comprised of narrow beaches backed by high coastal bluffs. The northern reach consists of wider beaches and low bluffs.

Low-lying wetland Outer Bolsa Bay receives stormwater runoff conveyed by the East Garden Grove Wintersburg (EGGW) Channel. The EGGW channel outlet is equipped with flap gates to prevent seawater back into the channel. The EGGW Channel collects runoff from the Ocean View Channel, Murdy Channel and Slater Channel. Low-lying wetland Inner Bolsa Bay is protected by levees from the tidally influenced Full Tidal Basin of Bolsa Chica wetlands.

Huntington Beach

The area extends from Goldenwest Street to Beach Boulevard, includes wide sandy beaches and concentrated areas of residential and commercial development. Major coastal structures include the Huntington Beach Pier and the condominium complex at 911 Pacific Coast Highway. Several parking lots provide access to beach areas surrounding the Huntington Beach Pier along with beachfront pedestrian pathways and bikeways.

Huntington Beach Wetlands

This low-lying planning area south of Beach Boulevard is protected by a system of levees along regional flood control channels including the Huntington Beach Channel, Talbert Channel, and East Valley-Fountain Valley Channel and roads. These flood control channels feed into local wetland areas such as Talbert Marsh and Magnolia Marsh located just landward of Pacific Coast Highway. As with the Huntington Beach study area, several parking lots along with pedestrian pathways and bikeways provide access to sandy beaches within the study area.



FIGURE 1-3: VULNERABILITY ASSESSMENT STUDY SUB-AREA BOUNDARIES

2. Coastal Processes

2.1. Water Levels

The nearest tidal gauge with long-term sea level records is the Los Angeles Outer Harbor gauge with Station Number 9410660, operated by the National Oceanic and Atmospheric Administration (NOAA). The gauge has been operational for over 90 years. Tides in the region are semidiurnal in nature meaning two highs and two lows occur per day. Tidal datums of the latest published tidal epoch from the gauge are used for the Study and are provided in Table 2-1.

TABLE 2-1: TIDAL DATUMS AT LOS ANGELES OUTER HARBOR (1983-2001 TIDAL EPOCH)

Description	Datum	Elevation (feet, NAVD88)
Highest Observed Water Level (1/10/2005)	HOWL	7.7
Highest Astronomical Tide	HAT	7.1
Mean Higher-High Water	MHHW	5.3
Mean High Water	MHW	4.6
Mean Tide Level	MTL	2.6
Mean Sea Level	MSL	2.6
Mean Diurnal Tide Level	DTL	2.5
Mean Low Water	MLW	0.7
Mean Lower-Low Water	MLLW	-0.2
North American Vertical Datum of 1988	NAVD88	0.0
Station Datum	STND	-4.0
Lowest Astronomical Tide	LAT	-2.2
Lowest Observed Water Level (12/17/1933)	LOWL	-2.9

2.2. Wave Climate

Waves act to carry sand in both the cross-shore and longshore directions and can also cause short-duration flooding events due to wave setup and runup. Thus, the wave climate (or long-term exposure of a coastline to incoming waves) and extreme wave events are important in understanding future SLR vulnerabilities.

Offshore wave data were analyzed for Huntington Beach from Wave Information Studies (WIS) Station 83101 from 1981 to 2011. WIS, developed by the USACE, is an online database of estimated nearshore wave conditions covering U.S. coasts. The wave information is derived based on a database of collected wind measurements (a process known as wave “hindcasting”) and is calibrated with direct wave records from offshore wave buoys. The hindcast data provide a valuable source of decades-long nearshore wave data for coastlines in the U.S.

Deep water significant wave heights under various return periods in Huntington Beach are summarized in Table 2-2. The 50- and 100-year return period wave heights are 16.3 feet (ft) and 18.2 ft, respectively. The deep-water wave parameters of the top 15 extreme wave events within the study area are provided in Table 2-3.



TABLE 2-2: RETURN PERIOD AND SIGNIFICANT WAVE HEIGHT IN HUNTINGTON BEACH

Return Period (year)	Significant Wave Height (feet)
1	9.9
2	10.8
5	11.9
10	13.0
25	14.7
50	16.3
100	18.2

TABLE 2-3: TOP 15 EXTREME WAVE EVENTS WITHIN THE STUDY AREA

Rank	Date of Storm	Significant Wave Height (ft)	Peak Wave Period (sec)	Azimuth (deg)
1	Mar. 1, 1983	33.5	15 - 18	271
2	Jan. 17, 1988	33.1	16 - 17	269
3	Jan. 5, 1939	25.9	18 - 19	288
4	Apr. 2 1958	25.1	16 - 17	295
5	Dec. 23 1940	24.2	17 - 18	274
6	Feb. 14, 1986	24.1	16 - 18	273
7	Feb. 2 1958	24.0	11 - 13	254
8	Jan. 31, 1986	23.9	17 - 20	276
9	Jan. 22 1943	23.3	13 - 14	160
10	Jan. 28, 1981	22.5	15 - 17	265
11	Feb. 9 1963	22.4	15 - 17	270
12	Jan. 25, 1983	20.6	19 - 21	285
13	Dec. 1, 1985	20.3	18 - 19	271
14	Nov. 30, 1982	19.5	14 - 15	290
15	Nov. 12 1953	18.8	16 - 17	277

The majority (54%) of the waves approaching the study area are from the west (270 degrees). The most frequent wave height is 1.5 to 3 ft (Figure 2-1).



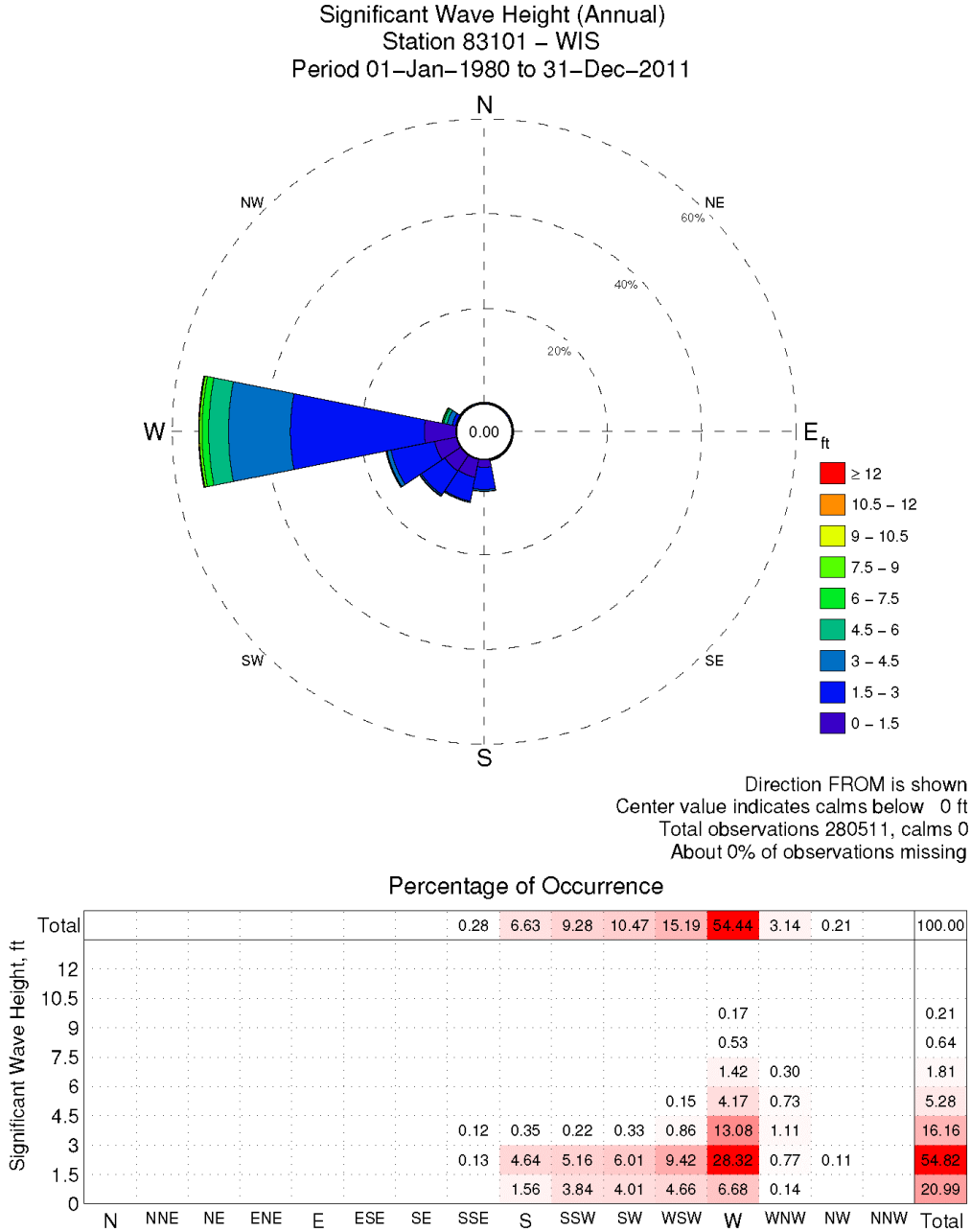


FIGURE 2-1: WAVE MAGNITUDE, DIRECTION AND FREQUENCY IN THE STUDY AREA

2.3. Littoral Processes

A littoral cell is a segment of shoreline in which sediment transport is bounded or contained. The Huntington Beach Littoral Cell extends from the east jetty of Anaheim Bay to the west jetty of Newport Bay, approximately 16 miles. The shoreline consists primarily of wide, sandy beaches except for the Huntington Bluffs area, where the beach narrows to nearly non-existent at high tide (USACE, 2002).

Human intervention has exerted a significant influence on coastal processes in the Huntington Beach Cell. Of particular importance are periodic beach replenishment operations at Surfside-Sunset and West Newport Beach as well as coastal subsidence resulting from petroleum extraction. Natural processes impacting the cell include sediment input from the Santa Ana River, sediment input from bluff erosion at



Huntington Bluffs, the transport of sediment in both the alongshore and cross-shore directions under the influence of waves and currents, and the loss of sediment to Anaheim Bay, Newport Bay, and Newport Submarine Canyon.

Analysis of the sediment budgets from May 1962 to May 1995 found a maximum net southeasterly longshore transport value of 204,000 cubic yards per year (cy/yr) at the boundary between Surfside-Sunset Beach and Bolsa Chica (USACE 2002). The rates reach a minimum value of 23,000 cy/yr at the boundary between West Newport Beach and Balboa Peninsula (USACE 2002). Long-term analysis of beach profiles by the USACE within the reach indicate that the rates of shoreline advance range from +1.6 ft/yr at Huntington Bluffs to +5.2 ft/yr at Surfside-Sunset. The average rate of shoreline advance was +4.1 ft/yr, within the littoral cell (USACE 2002). While long-term trends show an overall increase in beach width, shorelines along Surfside/Sunset and the Huntington Bluffs are currently in an eroded state following sediment placement in 2009/2010.

During the past four decades, the beach nourishment program at Surfside-Sunset Beach has constituted the single largest source of sediment for the Huntington Beach Littoral Cell. The volume of sediment provided to City beaches from this program are provided in Table 2-4. No additional major nourishment events have taken place following placement in 2009/2010.

TABLE 2-4: SURFSIDE-SUNSET BEACH NOURISHMENT VOLUMES AND BORROW SITES.

Year	Quantity (cy)	Borrow Site
1945	202,000	Naval Weapons Station
1947	1,220,000	Naval Weapons Station
1956	874,000	Naval Weapons Station
1964	4,000,000	Naval Weapons Station
1971	2,300,000	Naval Weapons Station
1979	1,600,000	Offshore Borrow Sites
1983/1984	3,300,000	Offshore Borrow Sites/Naval Weapons Station
1988	88,000	Naval Weapons Station
1990	1,800,000	Offshore Borrow Sites
1997	1,600,000	Offshore Borrow Sites
1999	188,000	Naval Weapons Station
2002	2,200,000	Offshore Borrow Sites
2009/2010	1,500,000	Offshore Borrow Sites
Total	20,900,000	Not Applicable

The average sediment volume provided to the shoreline is approximately 2.2 million cubic yards (mcy) per event. Analysis of beach profile data has found that the sediment supplied to the shoreline from this program significantly benefits City beaches (USACE 2002).

2.4. Subsidence

Localized subsidence can affect relative SLR rates through the artificially lowering of land relative to the sea-level. Oil production activities dating back to the 1920s have caused ground subsidence within the Huntington Bluffs portion of the Study Area. The ground has subsided 0.8 ft in this region. This is a relatively high relief portion of the City; thus, the subsidence in this area does not impose an immediate concern. However, measures could be considered to mitigate further subsidence.



Subsidence has also been reported in the Huntington Harbour area due to historic oil production activities. Seawalls and bulkheads around the Harbour are the primary defense to rising sea levels, and subsidence can directly impact the ability of these structures to accommodate SLR. Survey of the bulkhead wall at Sunset Aquatics Marina found the top of wall elevation to range from +8 to +8.2 feet above MLLW, whereas the as-built elevation was +9 feet MLLW. This disparity is attributed to historic underground oil extraction activities in the region and SLR. The MLLW datum had risen 0.2 ft from 1924-1932 tidal epoch to 1983-2001 tidal epoch. Subsidence from these activities has since been slowed by way of underground water injection.



3. Coastal Resource Inventory

TABLE 3-1: INVENTORY OF COASTAL RESOURCE DATA CATEGORIES, TYPES, AND SOURCES

Data Category			Data Type	Source
Coastal Development			City Boundary	City of Huntington Beach GIS
			Coastal Zone Boundary	City of Huntington Beach GIS
			Building Footprints	City of Huntington Beach GIS
			Total Building Value	City of Huntington Beach GIS
Utility Infrastructure			Tidal Channel Locations	City of Huntington Beach GIS
			AES and OCSD Facilities	Digitized based on Aerial Imagery
			CDS Unit Locations	City of Huntington Beach GIS
			Stormwater Outfall Locations	City of Huntington Beach GIS
			Stormwater Pump Locations	City of Huntington Beach GIS
			Stormwater Conveyance Lines	City of Huntington Beach GIS
			Sewer Lift Stations	City of Huntington Beach GIS
			Anode Beds*	City of Huntington Beach GIS
			Blow Off Risers*	City of Huntington Beach GIS
			Check Valves*	City of Huntington Beach GIS
			Fire Service Back Flow*	City of Huntington Beach GIS
			Monitor Devices*	City of Huntington Beach GIS
			Plugs*	City of Huntington Beach GIS
			Pressure Relief Valves*	City of Huntington Beach GIS
			Pump Outs*	City of Huntington Beach GIS
			Reducers*	City of Huntington Beach GIS
			Sample Stations*	City of Huntington Beach GIS
			Turn Outs*	City of Huntington Beach GIS
			Valves*	City of Huntington Beach GIS
			Water Pipes*	City of Huntington Beach GIS
			Air Vacs*	City of Huntington Beach GIS
			Cathode Protection*	City of Huntington Beach GIS
		Hydrants*	City of Huntington Beach GIS	
		Manhole Access Points*	City of Huntington Beach GIS	
		Wells*	City of Huntington Beach GIS	
Public Safety Facilities			Fire Station Locations	City of Huntington Beach GIS
			Hospital/Medical Facility Locations	City of Huntington Beach GIS
			Police Station Locations	City of Huntington Beach GIS
Transportation Infrastructure			Roadways	OpenStreetMap via ESRI
			Bikeways	City of Huntington Beach GIS
Coastal Recreation	Access and		Park Locations	City of Huntington Beach GIS
			Beaches	Aerial Imagery
Environmental Resources			Wetlands	Aerial Imagery

*Visualized in Appendix. Data obtained only in potential flood hazard areas.



4. Sea Level Rise

Sea level rise (SLR) science involves analysis of both global and local physical processes, as illustrated in Figure 4-1. Numerical models are created based on the best scientific understanding of these global and local processes to provide predictions of future SLR. Global climate and oceanographic processes are complex and dynamic. Hence, modelling efforts and predictions are periodically updated to reflect any changes in scientific knowledge. At the state level, the California Coastal Commission (CCC) recommends using the best available SLR science, discussed in Section 4.1, which is expected to be updated approximately every 5 years.

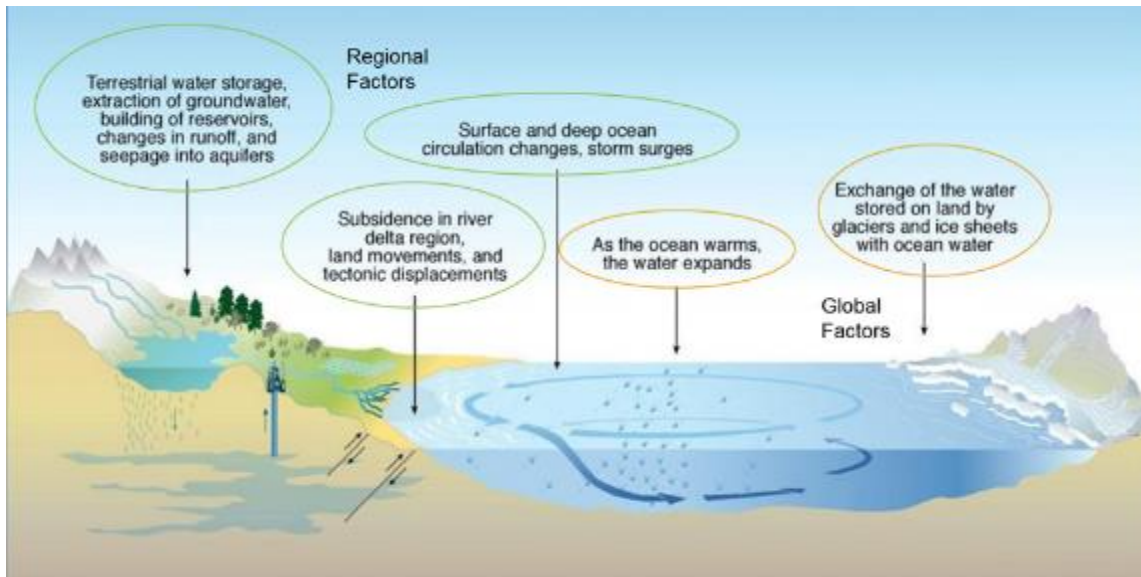


FIGURE 4-1: GLOBAL AND REGIONAL FACTORS THAT CAN INFLUENCE LOCAL RATES OF SLR

4.1. Probability and Timing

The State of California Ocean Protection Council (OPC) Science Advisory Taskforce recently compiled the best available SLR science relevant to California in their report *Rising Seas in California* (Griggs, et al., 2017). This report was then used to update the OPC California State SLR Guidance in 2018 (California Ocean Protection Council, 2018). The 2018 OPC SLR Guidance is now referenced as the best available science throughout updated CCC SLR policy guidance documents (California Coastal Commission, 2018).

The 2018 OPC guidance includes SLR projections for multiple emissions scenarios and uses a probabilistic approach based on Kopp et al., 2014 to generate a range of projections at a given time horizon for 12 tide gauges along the California coast. The projections for the Los Angeles tide gauge under a high-emissions scenario are referenced in this section. CCC SLR policy guidance recommends using projections associated with a high-emissions future given that worldwide emissions are currently following the high emissions trajectory. The 2018 California State SLR Guidance document lays out a risk decision framework that provides recommendations on when to use low or high-risk aversion scenarios in the planning process. Along with this framework, the probabilistic SLR projections are designed to inform a risk-based planning process as opposed to defining an exact rate or level of SLR based on an individual scenario or projection.

OPC SLR guidance defines the likely range of SLR at a given time horizon as the central 66% of projections, or all projections bounded by the 17th and 83rd percentiles, based on methods from Kopp et al., 2014. At the year 2050 time horizon the likely range of SLR is to 0.5 – 1.0 feet. The likely range of SLR at the 2100 time horizon is 1.3 – 3.2 feet. The upper end of the likely range is recommended by the CCC for use in low risk aversion situations, or when considering projects that would have limited consequences or have a higher ability to adapt, such as sections of unpaved coastal trail, public accessways, and other small or temporary structures that are easily removable and would not have high costs if damaged.. This low risk

aversion curve is shown in orange in Figure 4-2. At a given time horizon there is a 17% chance that SLR will meet or exceed these values based on current SLR projections and guidance.

For medium-high risk aversion situations the use of more conservative, or lower probability, SLR projections is recommended by OPC SLR Guidance. At a given time horizon there is a 0.5% chance that SLR meets or exceeds these levels, making them appropriate for use on projects where damage from coastal hazards would carry a high consequence or in cases where the ability to adapt is limited, such as when dealing with residential and commercial structures. For these lower probability cases, SLR of 1.8 feet is projected at the 2050 time horizon, 3.3 feet is projected at the 2070 time horizon, and 6.7 feet is projected at the 2100 time horizon. The medium-high risk aversion curve is shown in red in Figure 4-2 and is most applicable for major upland development.

The OPC guidance also includes a singular extreme SLR scenario, referred to as H++. It is based on projections by Sweet et al., 2017 that incorporate findings of Pollard & Deconto, 2016 related to potential Antarctic ice sheet instability, which could make extreme SLR outcomes more likely than indicated by Kopp et al., 2014 (Griggs et al., 2017). Because the H++ scenario is not a result of probabilistic modelling, the likelihood of this scenario cannot be determined. Due to the extreme and uncertain nature of the H++ scenario, it is most appropriate to consider when planning for development with little to no adaptive capacity that would be irreversibly destroyed or significantly costly to repair, and/or would have considerable public health, public safety, or environmental impacts should that level of sea level rise occur (OPC, 2018). The H++ extreme risk aversion curve is shown in purple in Figure 4-2.

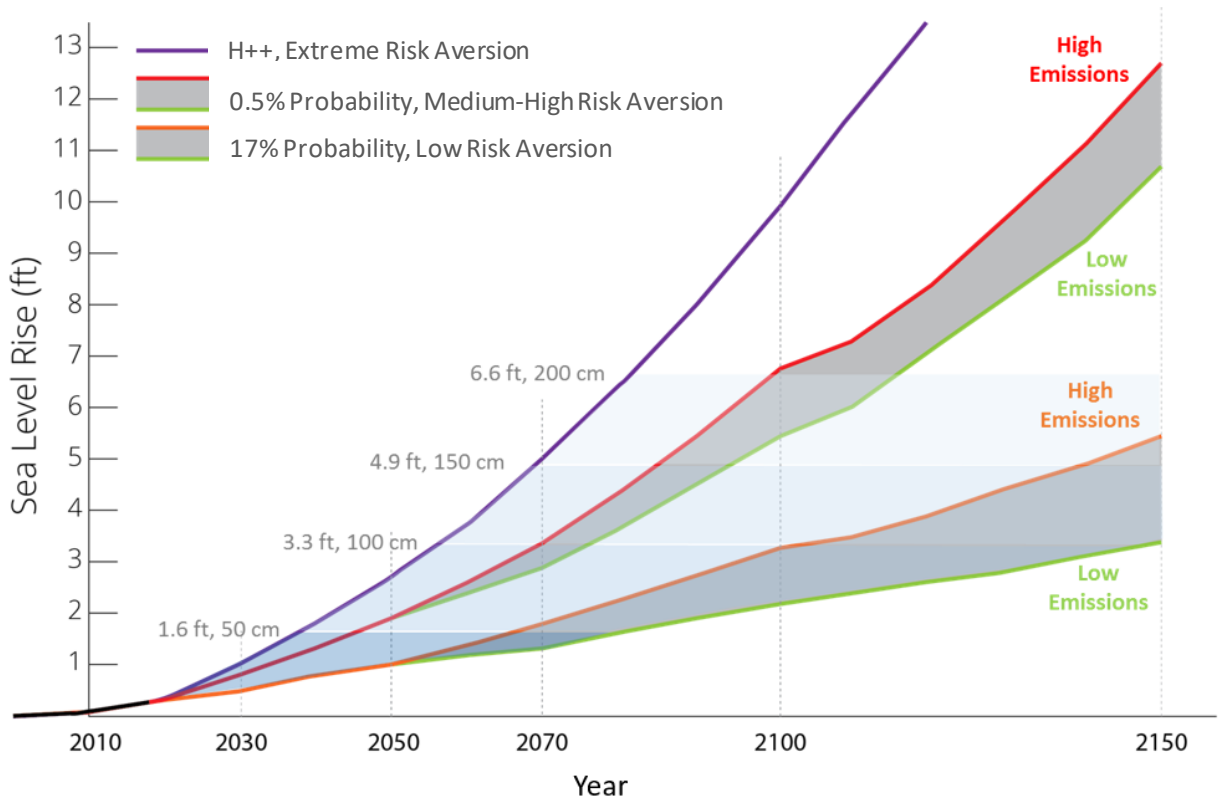


FIGURE 4-2: APPROXIMATE SEA LEVEL RISE PROJECTIONS FOR LOW, MEDIUM-HIGH, AND EXTREME RISK AVERSION LEVELS (OPC, 2018)

4.2. Selected SLR Scenarios

Climate science is a constantly changing field, often with high degrees of uncertainty. In the case of SLR in California, the OPC has high confidence in estimates to approximately year 2050, after which emissions scenarios cause predictions to diverge. Due to the high degree of uncertainty associated with predicting when and at what rate SLR will occur, this study looks at a range of SLR values starting with present day



conditions and including extreme SLR by the end of the century. Four scenarios have been selected for primary analysis within this study that consider increments of SLR between 1.6ft and 6.6ft. The assessment also includes an overview of potential non-storm conditions with 10-ft SLR in 2100 to account for a worst-case H++ scenario. Selected SLR scenarios also consider available hazard data for the region, which is available in 0.8ft increments. All levels of SLR and their corresponding recommendations for use based on time horizons and level of risk are described below and in Table 4-1. Due to the 0.8ft increment of available data, minor approximations with regard to the exact timing and probability of selected SLR scenarios have been made as needed to align with risk aversion designations in OPC SLR guidance. Coastal hazards under each increment of SLR are evaluated under both non-storm and 100-year coastal storm conditions. The non-storm condition is the high spring tide condition, which usually occurs twice a month.

1. Sea level rise of 1.6ft (50 cm) is representative of the medium-high risk aversion projection for 2050 and the low risk aversion projection for 2070. Under the extreme H++ scenario this amount of SLR could occur by 2040.
2. Sea level rise of 3.3ft (100cm) is representative of the medium-high risk aversion projection for 2070 and the low risk aversion projection for 2100. Under H++ conditions this amount of SLR could occur by 2060.
3. Sea level rise of 4.9ft (150 cm) is representative of the medium-high risk aversion projection for the 2080-2090 time horizon. If using projections for low risk aversion conditions, this level of SLR corresponds to a time horizon beyond 2100; however, under the extreme H++ SLR scenario this amount of SLR could occur by 2070.
4. Sea level rise of 6.6ft (200 cm) is representative of the medium-high risk aversion projection for 2100. If considering extreme risk aversion under H++ conditions this amount of SLR could occur by 2080. Low risk aversion SLR projections do not reach this level until beyond 2150.

TABLE 4-1: PROBABILITY AND POTENTIAL TIMING ASSOCIATED WITH SELECTED SLR SCENARIOS

SLR Scenario (ft)	Probability and Timing for Each SLR Scenario		
	Low Risk Aversion (17% probability)	Medium-High Risk Aversion (0.5% probability)	Extreme Risk Aversion (H++)
1.6	2070	2050	2040
3.3	2100	2070	2060
4.9	2100+	2080-2090	2070
6.6	2100+	2100	2080



5. Coastal Hazard Evaluation

Coastal hazards due to SLR are analysed under three separate baseline conditions as part of this study:

- **Non-storm:** High spring tide and background wave conditions. Refers to USGS CoSMoS model results under average conditions (discussed in Section 5.1).
- **Extreme high tide:** 2-year return period tidal elevation of 7.18ft NAVD88. Refers to supplementary bathtub modelling results (discussed in Section 5.2)
- **Storm:** 1% annual chance coastal storm event in conjunction with a high spring tide. Refers to CoSMoS model results under 100-year storm conditions.

5.1. USGS Coastal Storm Modelling System (CoSMoS)

The effects of SLR on storm and non-storm related flooding were primarily evaluated using results of the Coastal Storm Modelling System (CoSMoS) Version 3.0, Phase 2, a multi-agency effort led by the United States Geological Survey (USGS) to make detailed predictions of coastal flooding and erosion based on existing and future climate scenarios for Southern California. Other SLR hazard viewers such as the NOAA Sea Level Rise Viewer are also available, but these tools lack the regional focus and depth of information provided in CoSMoS modelling efforts.

The CoSMoS modelling system incorporates state-of-the-art physical process models to enable prediction of currents, wave height, wave runup, and total water levels (Erikson, et al., 2017). A total of 10 SLR scenarios are available, increasing in 0.8ft (0.25 m) increments from 0ft to 6.6ft (0m to 2m), also including an extreme SLR scenario of 16.4ft (5 m). CoSMoS modelling results provide predictions of shoreline erosion, cliff erosion, and coastal flooding under both average conditions and extreme events.

Hazard analyses for the City of Huntington Beach focus primarily on shoreline erosion and coastal flood modelling results, with additional bluff hazard projections analysed within the Huntington Bluffs area south of the Bolsa Chica Inlet. The hazards depicted in this report are presented solely based on the assumptions and limitations accompanying the CoSMoS data available at the time of this study unless otherwise noted.

5.1.1. Wave Modelling

Available CoSMoS coastal storm scenarios include annual, 20-year, and 100-year return period storm events. Future storm conditions are downscaled from winds, sea-level pressures, and sea surface temperatures of an established global climate model (Erikson et al., 2017). Additional modeling was performed to transport projected deep water waves to shore, simulating additional regional and local wave growth. Due to the large geographical extent of CoSMoS modeling efforts, the same representative storm events are used across southern California to model wave impacts. Each of the selected representative storm events produces waves from a W-NW direction typical of winter storms (Table 5-1).

TABLE 5-1: COASTAL STORM CONDITIONS ASSOCIATED WITH EACH COSMOS MODELLED SCENARIO

Scenario	Significant Wave Height (ft)	Wave Period (s)	Wave Direction (degrees)	Maximum Wind Speed (m/s)
Storm Condition	5.7	12	286	NA
1-year storm #1	14.4	16	284	22.8
20-year storm #1	19.2	18	281	22.3
20-year storm #2	20.1	18	292	28.7
100-year storm #1	20.3	16	264	26.6
100-year storm #2	22.3	18	287	30.3



5.1.2. Coastal Flood Projections

CoSMoS coastal flooding projections simulate the effects of erosion, wave runup, and overtopping during storm events. Coastal flood extents are calculated and mapped at profiles spaced approximately 300 ft along the shoreline. The projected coastal water levels used in flood mapping consider future shoreline change, tides, sea level anomalies like El Niño, storm surge, and SLR. Future wave conditions used in the model are based on forecasted conditions out to year 2100. All flood events are modelled in conjunction with a high spring tide, a tide height that occurs approximately twice a month, to represent a near worst-case scenario (Erikson et al., 2017).

CoSMoS coastal flood modelling results assume that future shoreline retreat will be halted at the existing development line and that no beach nourishment events will occur to maintain existing beach widths. Projected coastal flood extents, unlike shoreline erosion, are permitted to extend beyond the line of development. Assumptions regarding the specific type, height, and shoreline profile of existing coastal protection structures are not immediately available for large-scale modelling efforts such as CoSMoS. These parameters are key in providing precise evaluations of the wave runup height and potential for flooding landward of specific structures, and thus it may be prudent to verify CoSMoS findings in a subsequent coastal flood modelling effort if considering specific design of adaptation measures.

5.1.3. Shoreline and Bluff Erosion Projections

CoSMoS shoreline erosion projections include long-term erosion resulting from SLR and projected wave conditions. Shoreline erosion projections are modelled with the CoSMoS Coastal One-line Assimilated Simulation Tool (COAST), which includes a suite of models that consider historic erosion trends, long-shore and cross-shore sediment transport, and shoreline changes due to increased water levels. These models were tuned with historic data to account for unresolved sediment transport processes and inputs such as sediment loading from rivers and streams, regional sediment supply including beach nourishment and bypassing, and long-term erosion. The CoSMoS-COAST shoreline projections are developed from an initial shoreline mapped from a 2009-2011 LIDAR data set (Erikson, et al., 2017). CoSMoS modelling also provides cliff erosion projections based on a range of SLR scenarios. Similar to shoreline erosion modelling, historic rates of cliff retreat were used to inform future rates of bluff erosion, including the effects of SLR.

CoSMoS shoreline and bluff erosion projections for each level of SLR are based on four management scenarios. Management scenarios are defined by the presence or absence of shoreline armoring and beach nourishment.

- **Hold-the-Line:** Incorporates the use of shoreline and bluff armoring. Shoreline erosion modelling under this scenario assumes that the existing boundary between sandy beach areas and development is maintained with coastal structures.
- **No Hold-the-Line:** Assumes no armoring is in place and allows shoreline erosion projections to propagate inland to the maximum potential extent based solely on topography.
- **Beach Nourishment:** Assumes that historical beach nourishment practices are continued into the future
- **No Beach Nourishment:** Assumes the beach is left in its current state.

The Hold-the-Line and Beach Nourishment scenarios are used for hazard analyses within this study in order to document the full suite of potential SLR hazards with the continuation of current practices. Shoreline position projections for the No Hold-the-Line scenario are largely similar to the Hold-the-line scenario for 4.9 ft and greater SLR. With 4.9 ft and greater SLR, shoreline position projections extend into developed areas within Sunset Beach, across the bicycle pathway and parking infrastructure in the northern portion of Bolsa Chica State Beach, and into the roadways and parking infrastructure just south of Bolsa Chica Inlet. These areas can be approximated by moving the shoreline projecting with 3.3 ft SLR 75 ft and 150 ft landward for the 4.9 ft SLR and 6.6 ft SLR scenarios respectively. Bluff erosion projections under a No Hold-the-Line scenario extend further landward across parking lots and Pacific Coast Highway in areas south of Bolsa Chica Inlet with 3.3 ft and greater SLR.



The Hold-the-Line scenario was chosen for analysis in this study based on the relative performance of modeling results compared to the No Hold-the-Line scenario. Analyses in this study are designed to identify hazard thresholds and provide actionable information for adaptation planning. The Hold-the-Line scenario allows for the identification of when erosion projections will impact current development or shoreline infrastructure without the assumption that all existing infrastructure is removed. In an initial review of modeling results it was determined that shoreline erosion projections under the No Hold-the-Line may also overestimate erosion in areas south of Bolsa Chica Inlet, where retreat rates remain constant despite the transition from a relatively flat beach to a steep bluff face. Given the additional assumptions and uncertainties for a No Hold-the-Line scenario, potential issues in areas with both bluffs and sandy beaches, and the similar results for scenarios of 4.9 ft and greater SLR, it was determined that the Hold-the-Line scenario was more appropriate for inclusion.

5.1.4. Groundwater Emergence Projections

SLR impacts on groundwater will be evaluated using the recently published USGS CoSMoS results on projected responses of the coastal water table for California using present-day and future sea-level rise scenarios. Groundwater modelling efforts use the USGS groundwater flow software MODFLOW to simulate changes in the water table and groundwater flow for coastal California under all SLR scenarios examined (Befus, Hoover, Barnard, & Erikson, 2020). Results presented within this study are based on model results using a Local Mean Sea Level boundary condition and a horizontal hydraulic conductivity value of 10 meters per day. Hydraulic conductivity of 10 meters per day is an approximate value for fine sand to coarse, well-sorted sand based on prior geologic mapping of the region. Alluvium (Qal) and quaternary nonmarine terrace deposits (Qt) are dominant in the study area (Fetter, 1994; Poland & Piper, 1956; State of California Department of Conservation, 1965). Groundwater hazards can be influenced by a number of local factors that may not be captured in regional modelling efforts. Full verification of these results is beyond the scope of this study, and so results presented within this report are intended to be used as an initial screening of potential hazard areas.

5.1.5. CoSMoS Modelling Limitations

The regional focus of the CoSMoS modeling effort results in certain limitations when applied at smaller scales or specific locations. The limitations are most evident at locations where wave action and littoral processes are heavily influenced by coastal structures and sediment management activities. Some limitations of the CoSMoS model and how they may influence the projected exposure of resources in Huntington Beach are discussed in this section based on the project team's general understanding of the CoSMoS regional modeling approach compared with our local knowledge of coastal hazards in Huntington Beach.

The majority of flooding projected by CoSMoS appears to be from tidally influenced water bodies. Since the CoSMoS model does not model extreme fluvial events the flooding within inland areas is a result of SLR in combination with high ocean water levels, but the hydraulic connection (i.e., flood path) from these water bodies is not well defined or described in the CoSMoS data. It is uncertain precisely how existing flood control measures such as levees, berms, and walls were accounted for in the flood modeling, as the topography surface resolution used in the CoSMoS model may not precisely resolve the elevation of narrow features such as levees or flood walls. If a hydraulic connection does exist, the amount of flooding can also be limited by the volume of water conveyed through a particular connection over a period of time (i.e., peak of the tide cycle).

Another potential limitation of the model results in Huntington Beach is the starting shoreline used downcoast of the Anaheim Bay entrance. The CoSMoS shoreline projections and flood mapping are based on an initial shoreline mapped from a 2009-2011 LIDAR data set, which represents a post-nourishment condition at Surfside/Sunset Beach where the beach is at its widest. Approximately 2 million cubic yards were placed immediately south of the Anaheim Bay east jetty in 2009/2010 nourishment. Beaches in this area are subject to significant variation over a typical nourishment cycle, and so modelling results may underestimate the potential for erosion and flooding along the shoreline of Sunset Beach.



5.2. Supplementary Modelling

5.2.1. 2100 H++ Conditions

Due to a gap in CoSMoS data from 2m SLR to 5m SLR, the 2100 extreme 10ft SLR scenario will be evaluated using results from NOAA SLR inundation mapping made available as part of the NOAA Office for Coastal Management Sea Level Rise Viewer. The NOAA SLR flood hazard modelling data uses a modified bathtub approach to account for local and regional tidal variability as well as hydrological connectivity, mapping SLR on top of existing mean higher high water (MHHW) conditions. While NOAA SLR data does not specifically account for storm-driven hazards, tidal inundation extents will be sufficient to inform long-term planning of critical infrastructure given the high levels of uncertainty associated with the extreme H++ scenario.

5.2.2. Huntington Beach Wetlands Study Area

During review of CoSMoS modelling results potential limitations were noted within inland portions of the Huntington Beach Wetlands study area. Water level elevations within the Huntington Beach and Talbert Channels were significantly lower than what would be expected based on previous modelling conducted in the area. This is most likely due to the open coast tidal elevations not being sufficiently translated to inland areas through the channels. This issue was not present along tidal channels within the Huntington Harbour and Bolsa Chica study areas.

Additional flood hazard modelling was performed to address this potential gap in coastal hazard modelling results. A bathtub flood hazard modelling approach, in which a constant flood elevation is applied over an area, was applied to the Wetlands study area using a 2-year return period tidal elevation (7.18ft NAVD88) as a baseline for consistency with analyses conducted in previous SLR vulnerability assessments within the City (Moffatt and Nichol, 2014). Bathtub analyses were conducted for the 4.9ft and 6.6ft SLR scenarios. Overtopping of tidal channels is not projected under 3.3ft and lower SLR scenarios based on channel elevations (Table 5-2, Table 5-3). All bathtub analyses utilized elevation surface data from the USGS Coastal National Elevation Database (Danielson, et al., 2016), the same data used as part of CoSMoS analyses.

TABLE 5-2: HUNTINGTON BEACH CHANNEL BANK ELEVATIONS

Huntington Beach Channel Location	Top of Levee/Floodwall Elevation (ft, NAVD 88)
Brookhurst Marsh	12.2
Magnolia St	12.4
Newland St	13.1
Atlanta Ave	13.6
Indianapolis Ave	14.1
Adams Ave	14.5

TABLE 5-3: TALBERT CHANNEL BANK ELEVATIONS

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Talbert Channel Location	Top of Levee/Floodwall Elevation (ft, NAVD 88)
D01 Confluence	11.2
Banning Ave	11.9
Hamilton Ave	12.3
Atlanta Ave	13.9
Indianapolis Ave	15.2
Adams Ave	15.7
Yorktown Ave	16.3
D05 Confluence	15.7
Garfield Ave	15.1



6. Future Sea Level Rise Hazards

6.1. Flood Hazards

Current time horizon, no SLR (Figure 6-1, Figure 6-2)

CoSMoS flood hazard projections are limited to select areas during severe storm events. Storm flood hazard projections with 0ft SLR are located primarily in the Huntington Harbour study area along the Pacific Coast Highway, where flood projections extend across areas of the roadway and neighbouring development in Sunset Beach. Limited storm flood projections are also present along the Pacific Coast Highway in the upcoast portion of the Bolsa Chica study area.

1.6ft (50cm) SLR scenario (Figure 6-3, Figure 6-4)

Flood hazard projections are again concentrated within the Huntington Harbour study area. Non-storm flood hazard projections are seen within the Huntington Harbour study area under this scenario, covering low-lying roadways in select areas of the Harbour as well as Sunset Beach development bordering the Pacific Coast Highway. Non-storm flood projections also cover a small area of the Pacific Coast Highway in the upcoast portion of the Bolsa Chica study area.

Storm flood projections with 1.6ft SLR extend further inland, approximately covering the first row of development bordering waterways within the Harbour, significant portions of development in Sunset Beach, and select inland areas currently outside the coastal zone. All flood hazard projections under this scenario stem from the Harbour side rather than the coastline, where flood hazard projections remain limited to sandy beach areas.

3.3ft (100cm) SLR scenario (Figure 6-5, Figure 6-6)

This scenario represents a threshold for flood hazard projections within the Huntington Harbour study area, as non-storm flooding is projected to impact coastal resources and infrastructure throughout the Harbour, Sunset Beach, and inland areas between Bolsa Chica Channel and Sunset Channel. Flood projections also reach the development line on the coastal side of Sunset Beach under this scenario.

Flood projections also increase within the Bolsa Chica study area under this scenario, with non-storm flood projections covering a greater portion of the Pacific Coast Highway and storm flood projections extending across several parking lots within Bolsa Chica State Park. Flood hazard projections in other portions of the City remain limited to sandy beach areas.

4.9ft (150cm) SLR scenario (Figure 6-7, Figure 6-8)

Flood hazard projections become more widespread throughout the City. The Huntington Harbour study area continues to show the greatest level of flooding with nearly the entirety of the Harbour area and Sunset Beach projected to be impacted under non-storm conditions. Non-storm flood projections also extend further inland in areas between Bolsa Chica Channel and Sunset Channel. Storm flood projections also extend further inland along Sunset Channel. Non-storm flood projections within the Bolsa Chica study area are seen in several locations along the Pacific Coast Highway, and storm flood projections cover the majority of Bolsa Chica State Park parking lots as well as select inland areas bordering the East Garden Grove Wintersburg Channel. Flooding along this channel is due to floodwaters travelling inland across low lying areas after projected overtopping where the channel empties into Bolsa Bay.

Storm flood projections also begin to move inland within the Huntington Beach study area with 4.9ft SLR, extending across portions of Huntington Beach Pier and State Park parking lots as well as the Huntington Pacific Beach House Condo Complex. The Huntington Beach Wetlands study area shows a significant increase in storm flood hazard projections with 4.9ft SLR as projections extend inland in areas bordering Talbert Channel and Huntington Beach Channel. CoSMoS non-storm flood projections remain limited within the HB Wetlands study area under this scenario, as Talbert Inlet tidal connection was likely not fully captured in CoSMoS modeling. As discussed in Section 5.2.2, supplementary bathtub modelling was performed, and the result indicates the potential for widespread flooding during an extreme high tide event due to overtopping along the Talbert and Huntington Beach Channels (Figure 6-9).



6.6ft (200cm) SLR scenario (Figure 6-10, Figure 6-11):

This scenario represents a significant flood hazard impact threshold for the City as inland flood projections within the Bolsa Chica and Huntington Beach Wetlands study areas increase substantially. This scenario is the first in which flood projections extend inland of the Bolsa Chica wetlands, resulting in a drastic increase in non-storm flood projections inland of the levees. Coastal areas along Bolsa Chica State Park are also projected to be almost entirely flooded under non-storm conditions with 6.6ft SLR.

CoSMoS non-storm flood projections within the Huntington Beach Wetlands study area remain limited to coastal areas bordering the Huntington Beach Channel as Talbert Inlet tidal connection was likely not fully captured in CoSMoS modelling. As discussed in Section 5.2.2, supplementary bathtub modelling was performed and the result shows potential for widespread inundation under an extreme high-tide event, approximately covering the area bordered by the Huntington Beach Channel, Santa Ana River, and Fountain Valley Channel (Figure 6-12). These flood impacts stemming from the Wetlands area also extend across development within the Huntington Beach study area.

10ft (H++) SLR scenario (Figure 6-13)

Non-storm flood projections become widespread inland of Huntington Harbour, the Bolsa Chica wetlands, and Huntington Beach wetlands, inundating approximately 50% of the City and exceeding the capacity of all flood control infrastructure in coastal areas. Only elevated areas such as portions of downtown and areas landward of coastal bluffs remain free of flood projections. As discussed in Section 4, due to uncertainty associated with the projections involved in the H++ scenario, these flood limits are most appropriate for use when planning for critical infrastructure with a long-term design life. SLR on this scale would completely reshape land use, development patterns, and infrastructure throughout the City and would require mitigation efforts on a city-wide and regional basis.





FIGURE 6-1: 0FT SLR HAZARDS, NORTHERN STUDY AREAS





FIGURE 6-2: 0FT SLR HAZARDS, SOUTHERN STUDY AREAS



FIGURE 6-3: 1.6FT SLR HAZARDS, NORTHERN STUDY AREAS



FIGURE 6-4: 1.6FT SLR HAZARDS, SOUTHERN STUDY AREAS

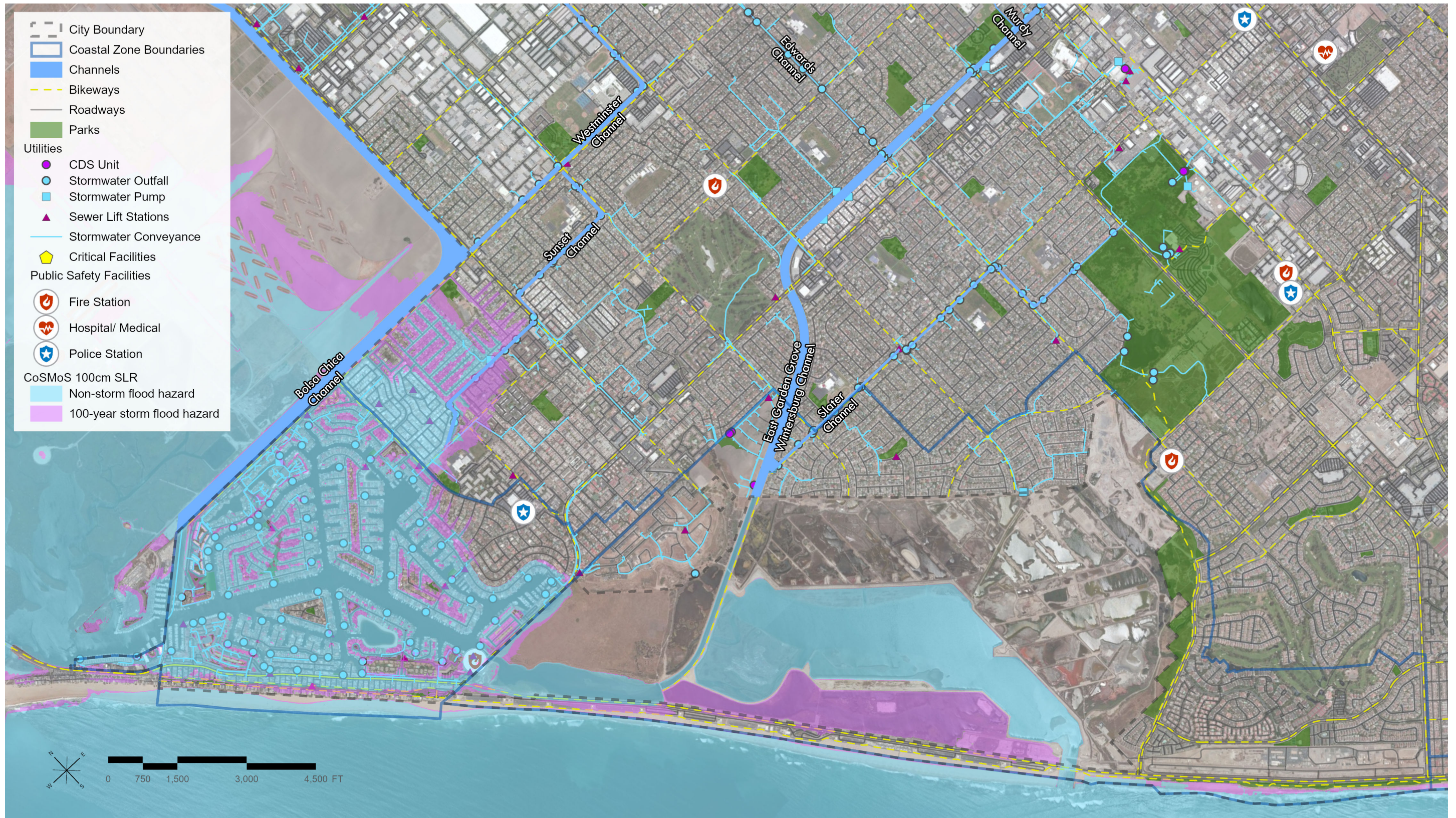


FIGURE 6-5: 3.3FT SLR HAZARDS, NORTHERN STUDY AREAS



FIGURE 6-6: 3.3FT SLR HAZARDS, SOUTHERN STUDY AREAS

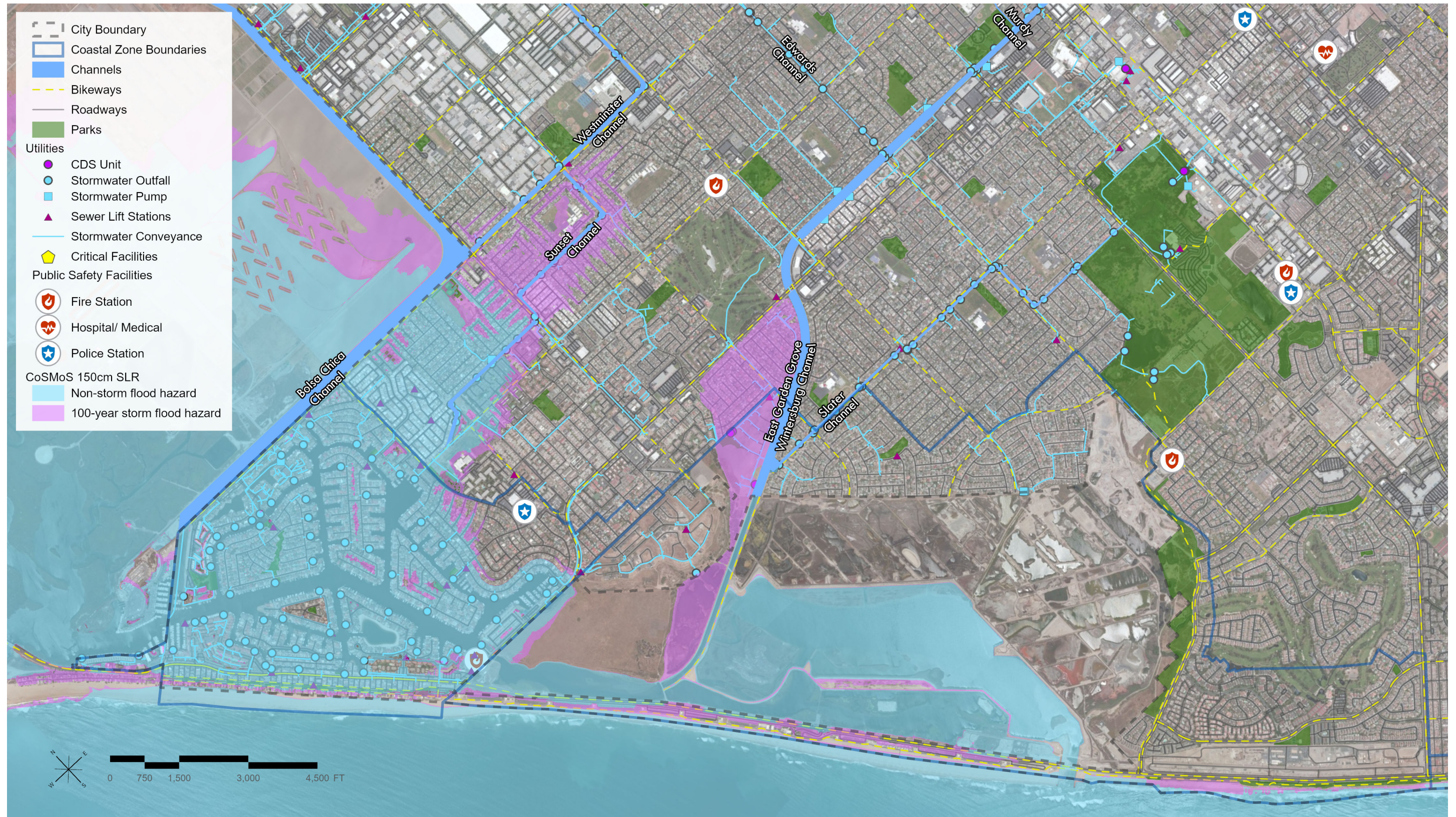


FIGURE 6-7: 4.9FT SLR HAZARDS, NORTHERN STUDY AREAS