FINAL SEA LEVEL RISE VULNERABILITY ASSESSMENT

City of Huntington Beach

SEA LEVEL RISE VULNERABILITY ASSESSMENT

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Table of Contents

List of Figures

List of Tables

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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.

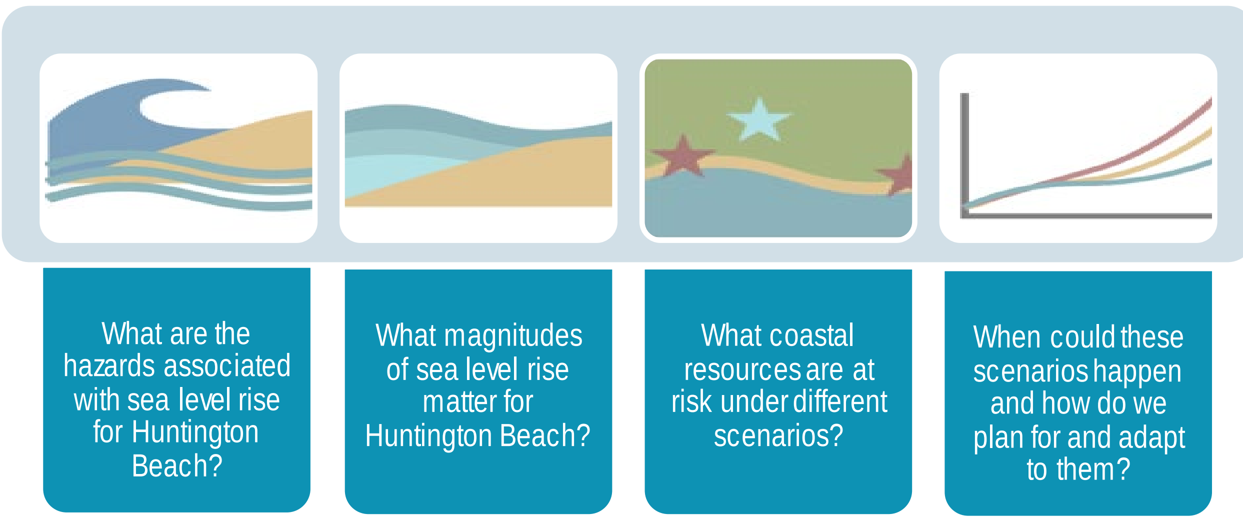


FIGURE 1-1: KEY QUESTIONS USED TO GUIDE THE CITY SLR ASSESSMENT.

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).

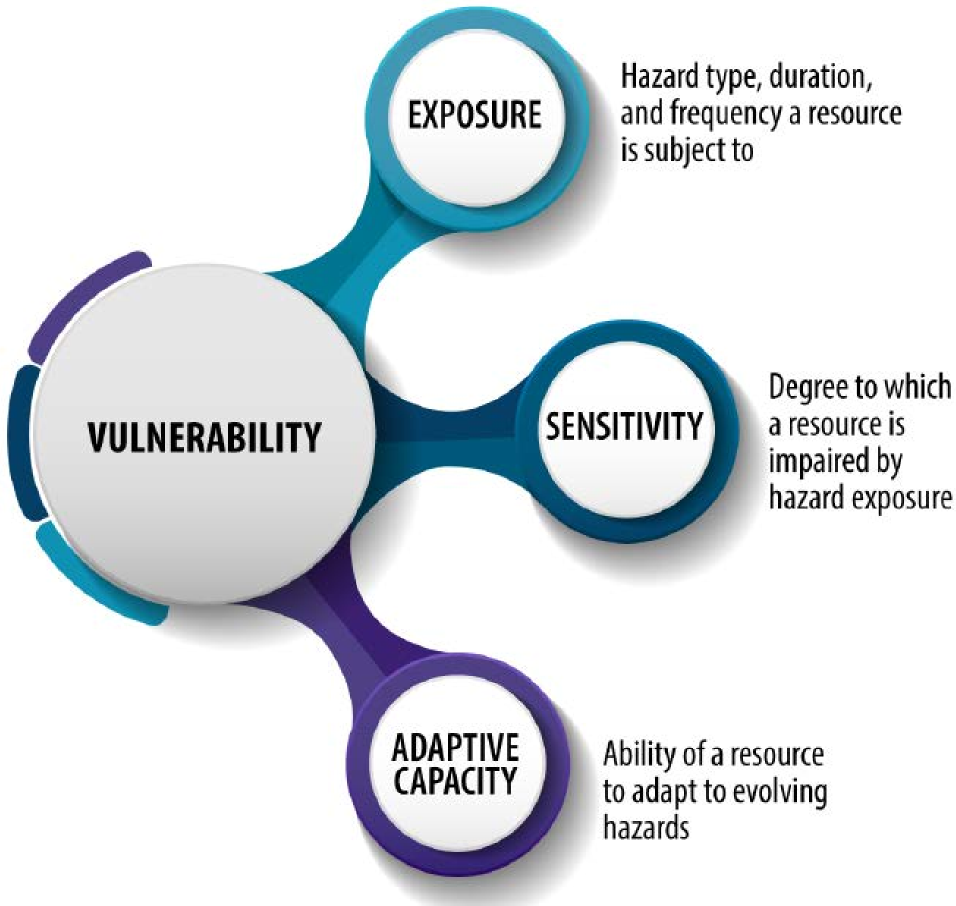


FIGURE 1-2: COMPONENTS OF SLR VULNERABILTY AS DEFINED WITHIN THIS STUDY

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.

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.

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.

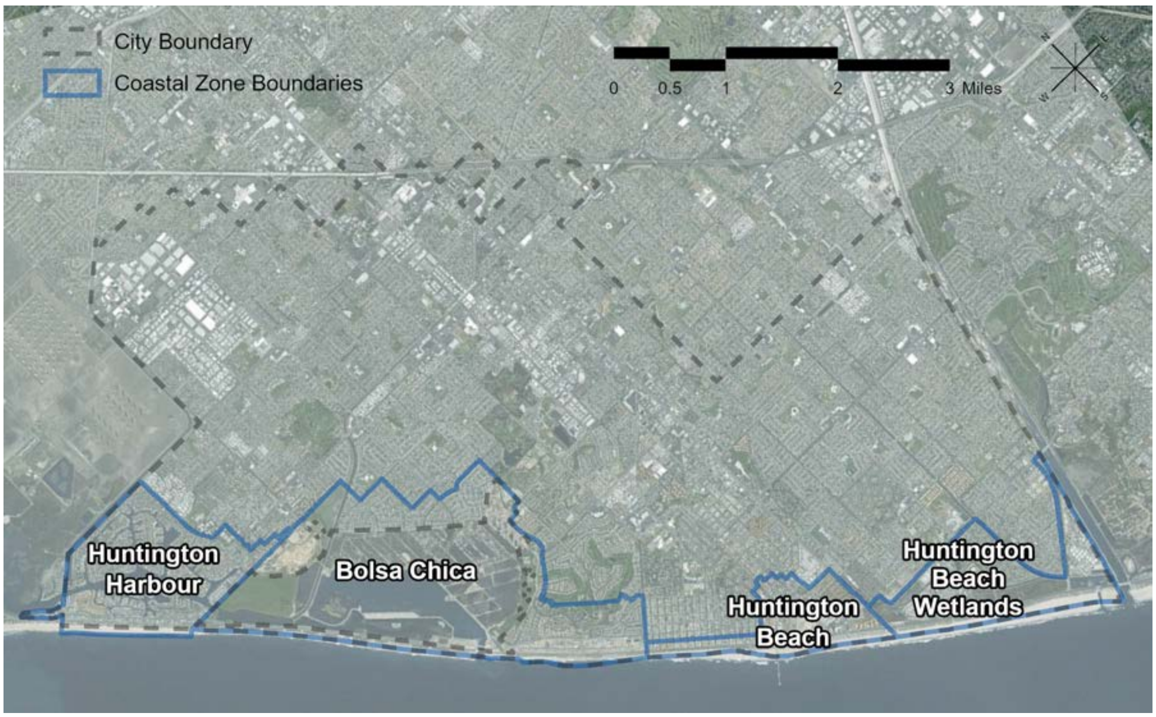


FIGURE 1-3: VULNERABILITY ASSESSMENT STUDY SUB-AREA BOUNDARIES

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 analysed 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.

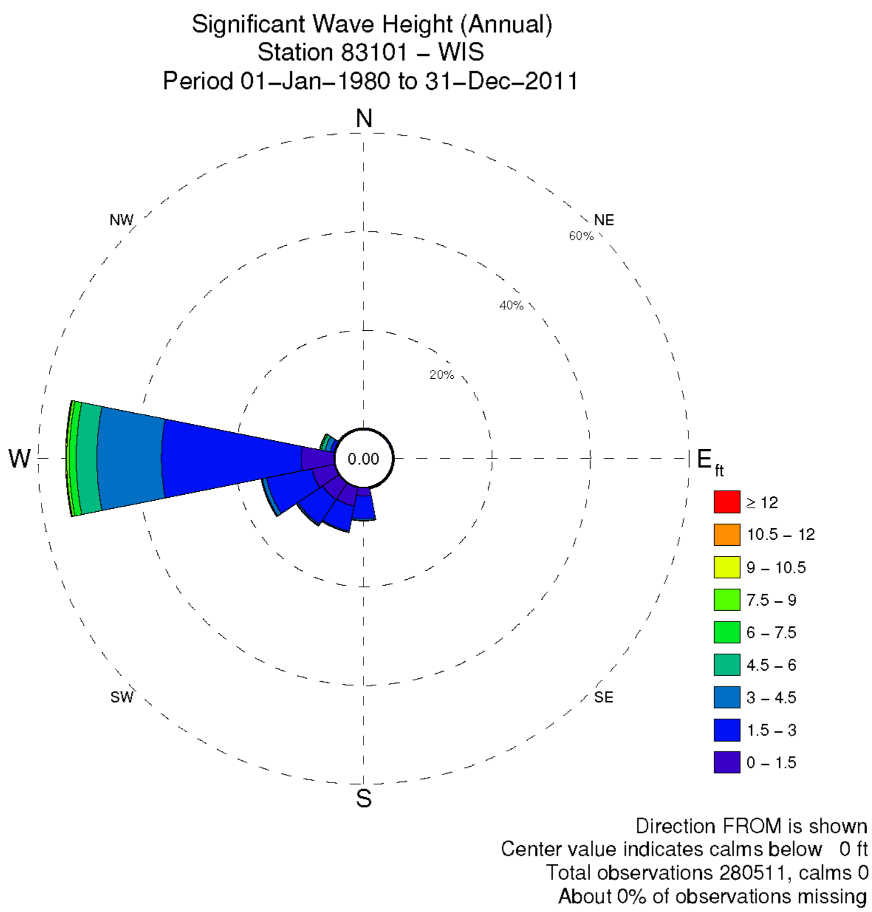
TABLE 2-2: RETURN PERIOD AND SIGNIFICANT WAVE HEIGHT IN HUNTINGTON BEACH

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).



Percentage of Occurrence

Significant Wave Height, ft	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total								0.28	6.63	9.28	10.47	15.19	54.44	3.14	0.21		100.00
≥ 12																	
10.5 – 12																	
9 – 10.5													0.17				0.21
7.5 – 9													0.53				0.64
6 – 7.5													1.42	0.30			1.81
4.5 – 6												0.15	4.17	0.73			5.28
3 – 4.5								0.12	0.35	0.22	0.33	0.86	13.08	1.11			16.16
1.5 – 3								0.13	4.64	5.16	6.01	9.42	28.32	0.77	0.11		54.82
0 – 1.5									1.56	3.84	4.01	4.66	6.68	0.14			20.99

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, a distance of approximately 16 miles. The shoreline consists primarily of wide, sandy beaches with the exception of 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 defence 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 Access and Recreation	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.

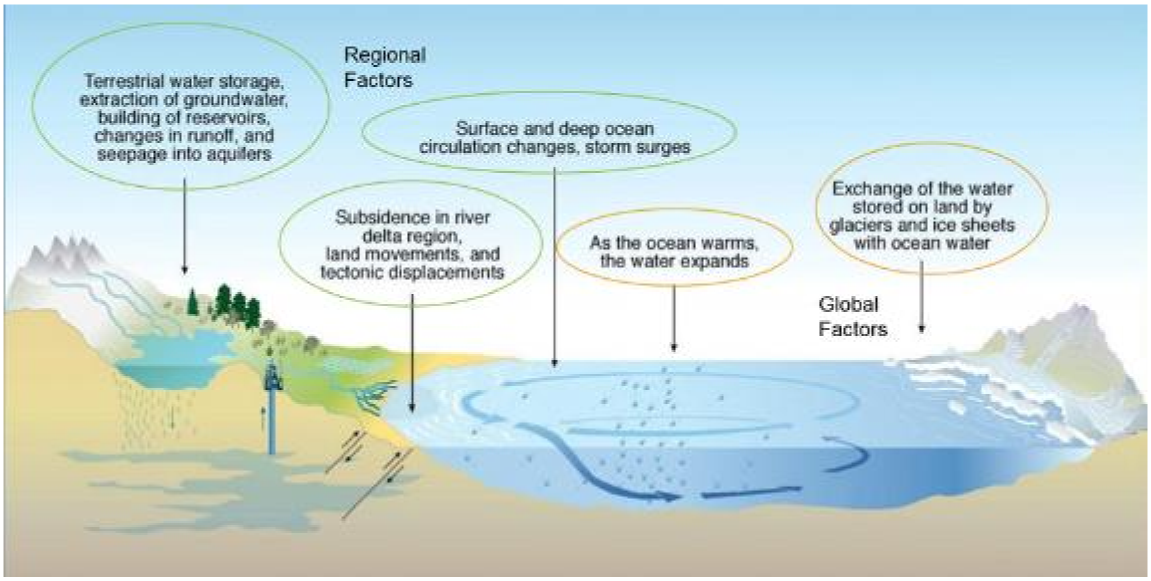


FIGURE 4-1: GLOBAL AND REGIONAL FACTORS THAT CAN INFLUENCE LOCAL RATES OF SLR

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 resources where the consequences of SLR are limited in scale and scope, with minimum disruption and low impact on communities, infrastructure, or natural systems.

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 that poses an extreme risk to public health and safety, natural resources, or critical infrastructure (OPC, 2018). The H++ extreme risk aversion curve is shown in purple in Figure 4-2.

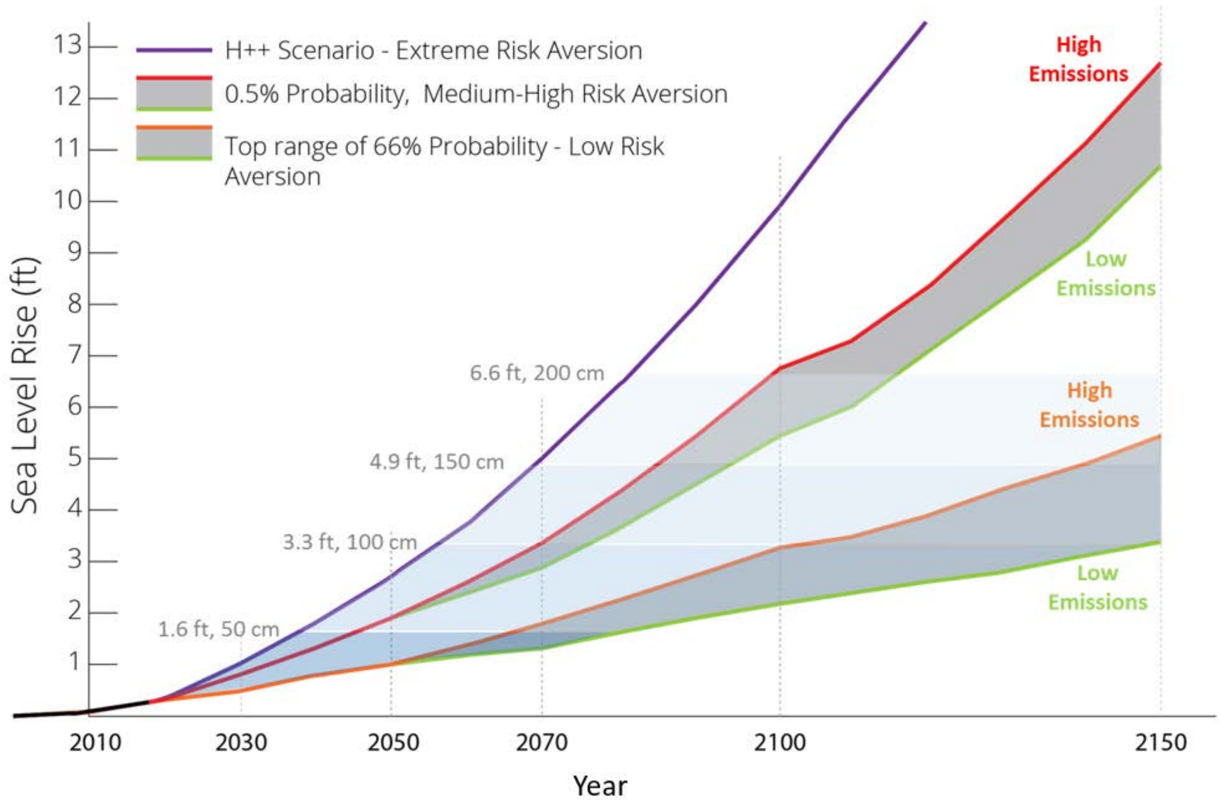


FIGURE 4-2: APPROXIMATE SEA LEVEL RISE PROJECTIONS FOR LOW, MEDIUM-HIGH, AND EXTREME RISK AVERSION LEVELS (OPC, 2018)

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 ASOCIATED 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 Niňo, 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.

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. 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

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. As discussed in Section 4, due to exceedingly low likelihood these flood limits are most appropriate for use when planning for highly vulnerable critical infrastructure with a long-term design life. SLR on this scale would likely require mitigation efforts on a city-wide or 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

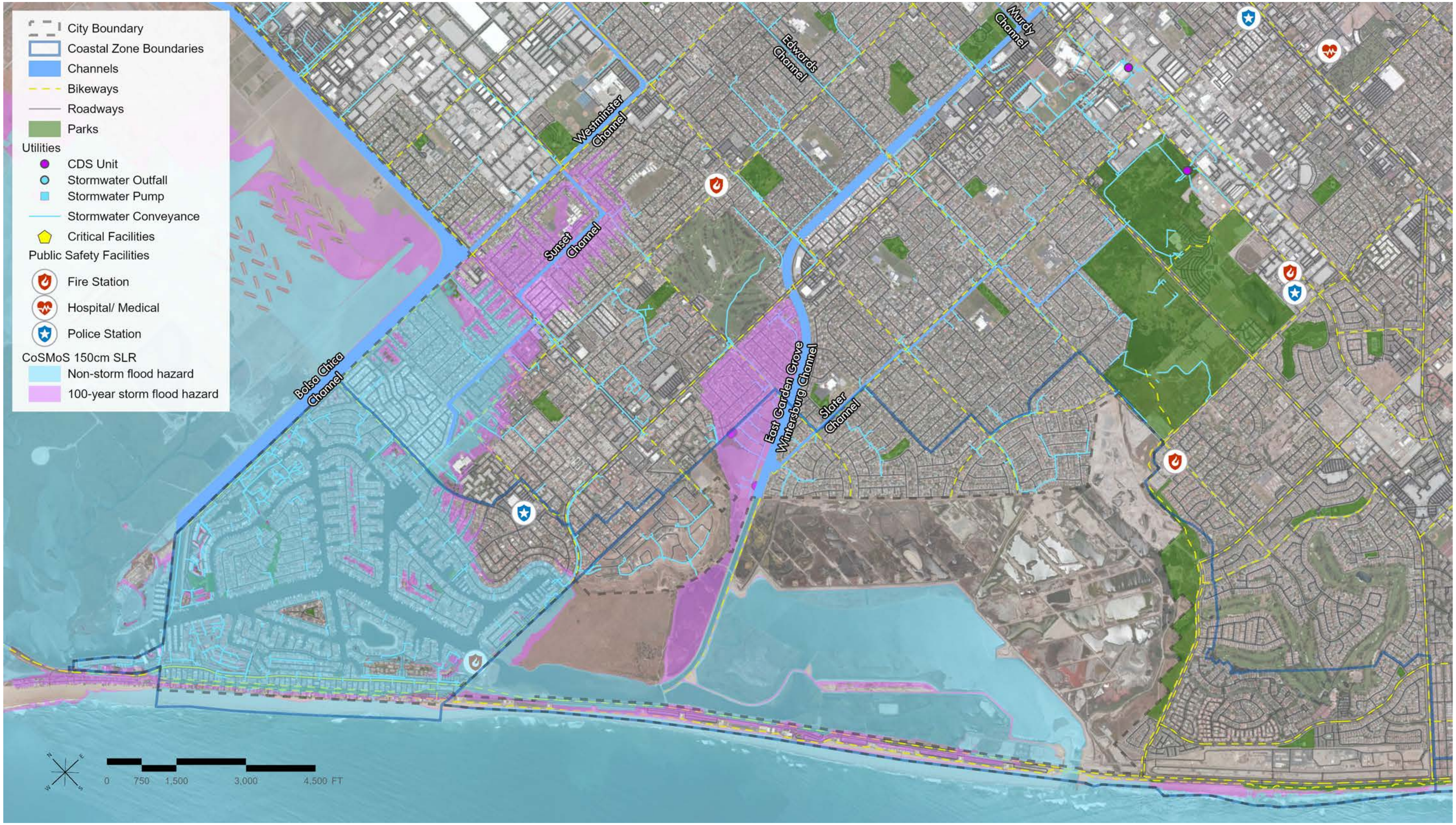


FIGURE 6-7: 4.9FT SLR HAZARDS, NORTHERN STUDY AREAS

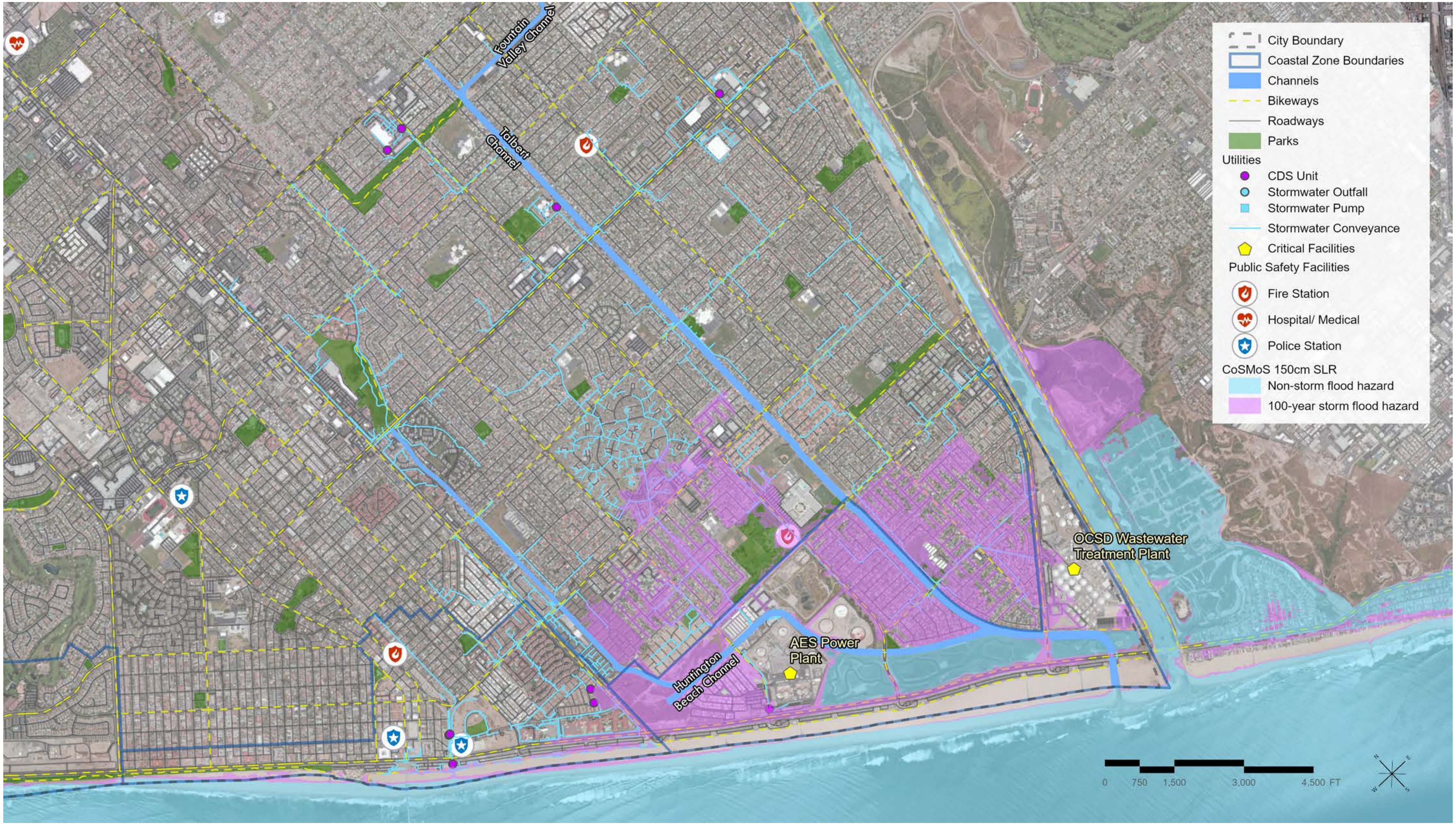


FIGURE 6-8: 4.9FT SLR HAZARDS, SOUTHERN STUDY AREAS

FIGURE 6-9: SUPPLEMENTAL 4.9FT SLR HAZARD BATHTUB ANALYSIS, STUDY AREAS

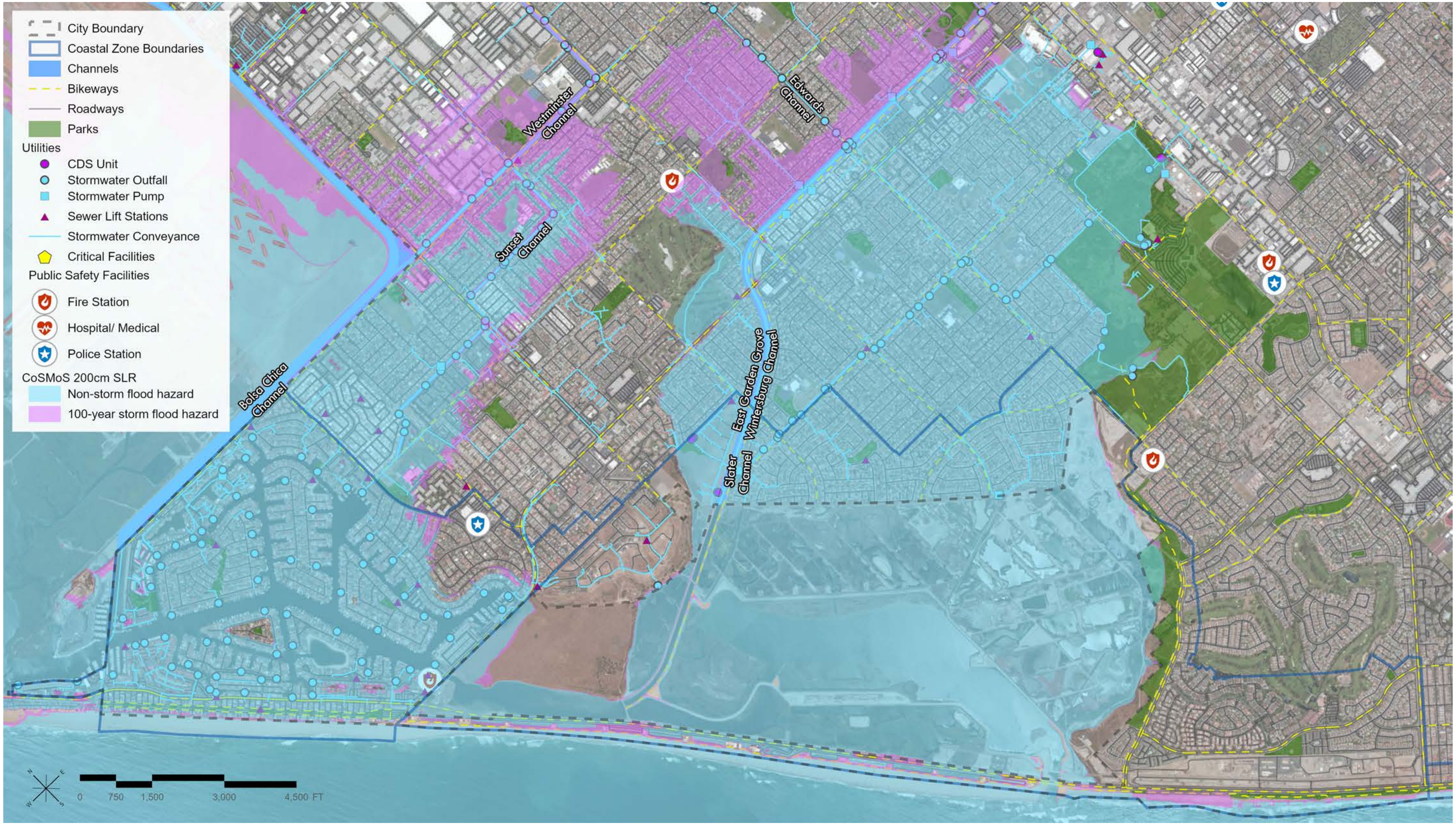


FIGURE 6-10: 6.6FT SLR HAZARDS, NORTHERN STUDY AREAS

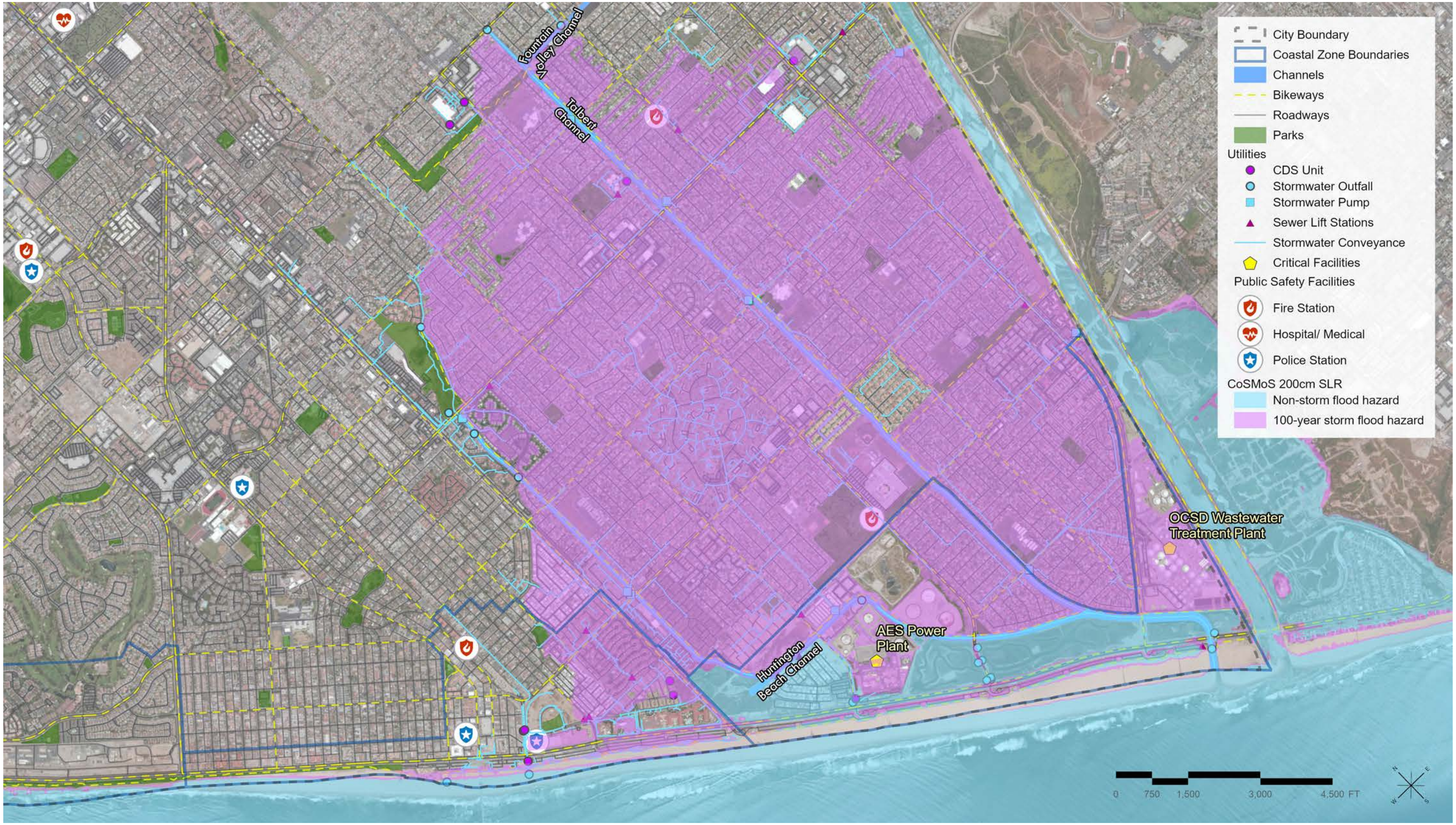


FIGURE 6-11: 6.6FT SLR HAZARDS, STUDY AREAS

FIGURE 6-12: SUPPLEMENTAL 6.6FT SLR HAZARD BATHTUB ANALYSIS, SOUTHERN STUDY AREAS

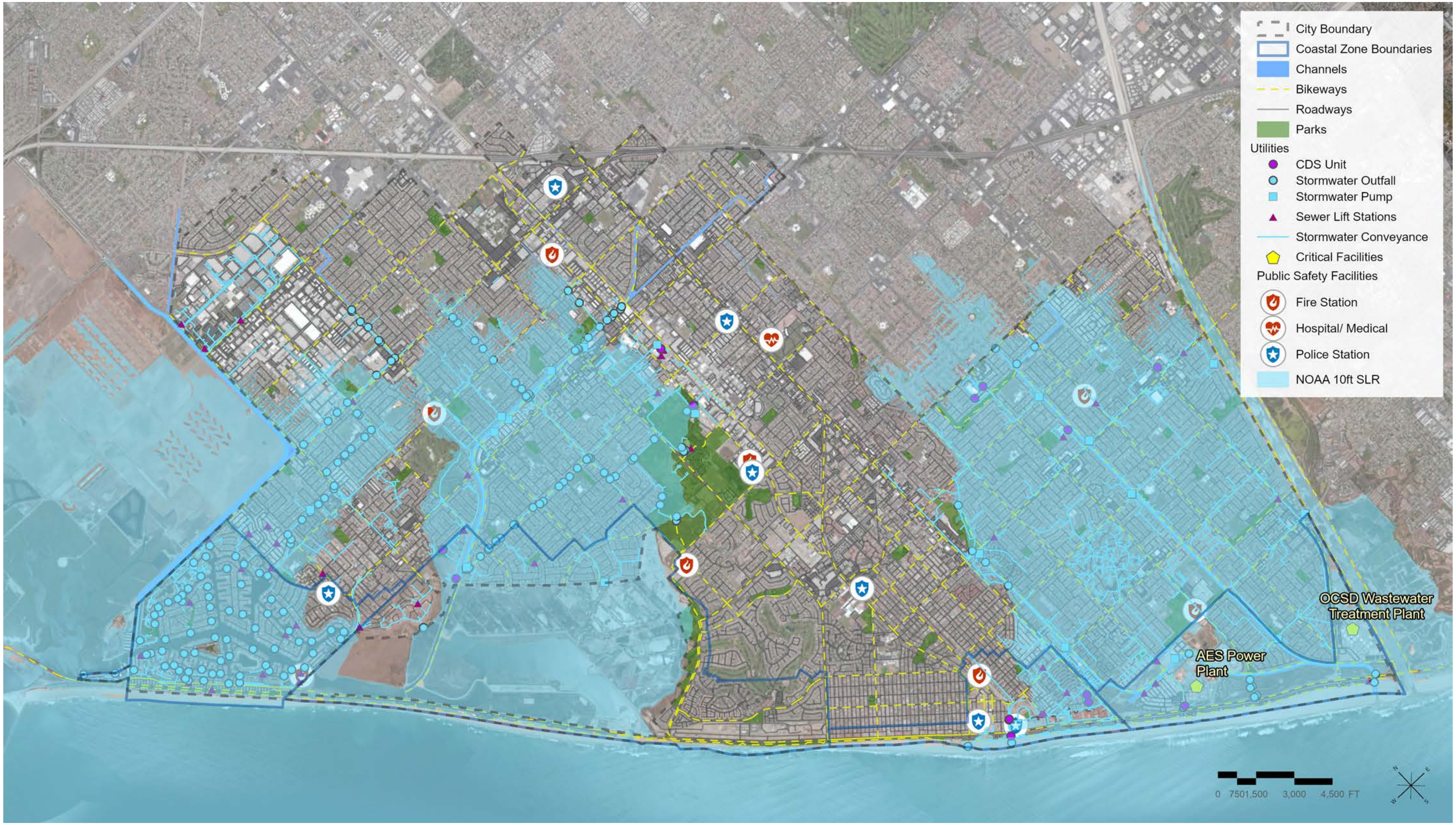


FIGURE 6-13: PROJECTED NON-STORM FLOOD HAZARD AREAS UNDER THE EXTREME H++ SLR SCENARIO IN 2100

6.2. Shoreline Erosion Hazards

Shoreline erosion hazards (Figure 6-14 to Figure 6-19) are primarily seen within the Huntington Harbour and Bolsa Chica study areas. While beach width declines with each increment of SLR within the Huntington Beach and Huntington Beach Wetlands study areas, a relatively wide beach still remains even under a 6.6ft SLR scenario.

Huntington Harbour Study Area

Shoreline erosion projections along Sunset Beach within the Huntington Harbour study area move landward with 1.6ft SLR, but still leave usable beach areas along the length of the study area. With 3.3ft SLR the shoreline is projected to extend up to the development line along substantial portions of the study area, with sandy beaches primarily remaining in central portions of the study area. Shoreline projections under the 4.9ft and 6.6ft SLR scenarios extend up to the development line across almost the entirety of the study area.

Bolsa Chica Study Area

A similar pattern of shoreline erosion is seen for shoreline projections within the Bolsa Chica study area. Under the 1.6ft SLR, beach retreats from their existing position but remains some width along both the north and south sides of the Bolsa Chia Inlet. Shoreline projections with 3.3ft SLR show continuous, but narrower beach areas on the upcoast side of the Bolsa Chica Inlet. Shoreline projections along the downcoast side of the Inlet extend back to existing shoreline protection structures in select areas. Shoreline projections under a 4.9ft SLR scenario extend up to the development line along the entirety of the study area except for areas just upcoast of the Bolsa Chica Inlet. Shoreline projections along this small portion of the coast extend further inland with 6.6ft SLR. Blufftop position projections within the Bolsa Chica study area remain in a fixed location along the protected portion of Bluff Top Park, while blufftop position projections in unprotected areas show an incremental landward migration as SLR increases.

6.3. Groundwater Emergence Hazards

SLR can cause groundwater levels to rise. Flooding can occur if groundwater levels approach the surface, even without significant rainfall or coastal storms. This type of flood hazard, where shallow groundwater levels rise near or above the ground surface, is referred to as a "groundwater emergence hazard" within this study. CoSMoS groundwater emergence hazard projections (Figure 6-20, Figure 6-21) are concentrated in areas inland of the Bolsa Chica wetlands and the Huntington Beach wetlands. The majority of groundwater emergence hazard area projections surrounding the Bolsa Chica wetlands are present under current conditions. Hazard area projections then extend landward incrementally as SLR increases. Groundwater emergence projections in the Huntington Beach wetlands area are limited under current conditions and 1.6ft SLR scenarios. Hazard area projections become more widespread with 3.3ft SLR, extending inland in areas between the Huntington Beach Channel and Talbert Channel. Hazard area projections continue to extend landward in these areas under 4.9ft and 6.6ft SLR scenarios, also becoming more widespread in areas south of Talbert Channel.

FIGURE 6-14: SHORELINE POSITION PROJECTIONS, SUNSET BEACH

FIGURE 6-15: SHORELINE POSITION PROJECTIONS, BOLSA CHICA STATE PARK

FIGURE 6-16: SHORELINE POSITION PROJECTIONS, HUNTINGTON BLUFFS

FIGURE 6-17: BLUFFTOP POSITION PROJECTIONS, HUNTINGTON BLUFFS

FIGURE 6-18: SHORELINE POSITION PROJECTIONS, HUNTINGTON BEACH

FIGURE 6-19: SHORELINE POSITION PROJECTIONS, HUNTINGTON BEACH WETLANDS

FIGURE 6-20: PROJECTED GROUNDWATER EMERGENCE HAZARD AREAS, NORTHERN STUDY AREAS

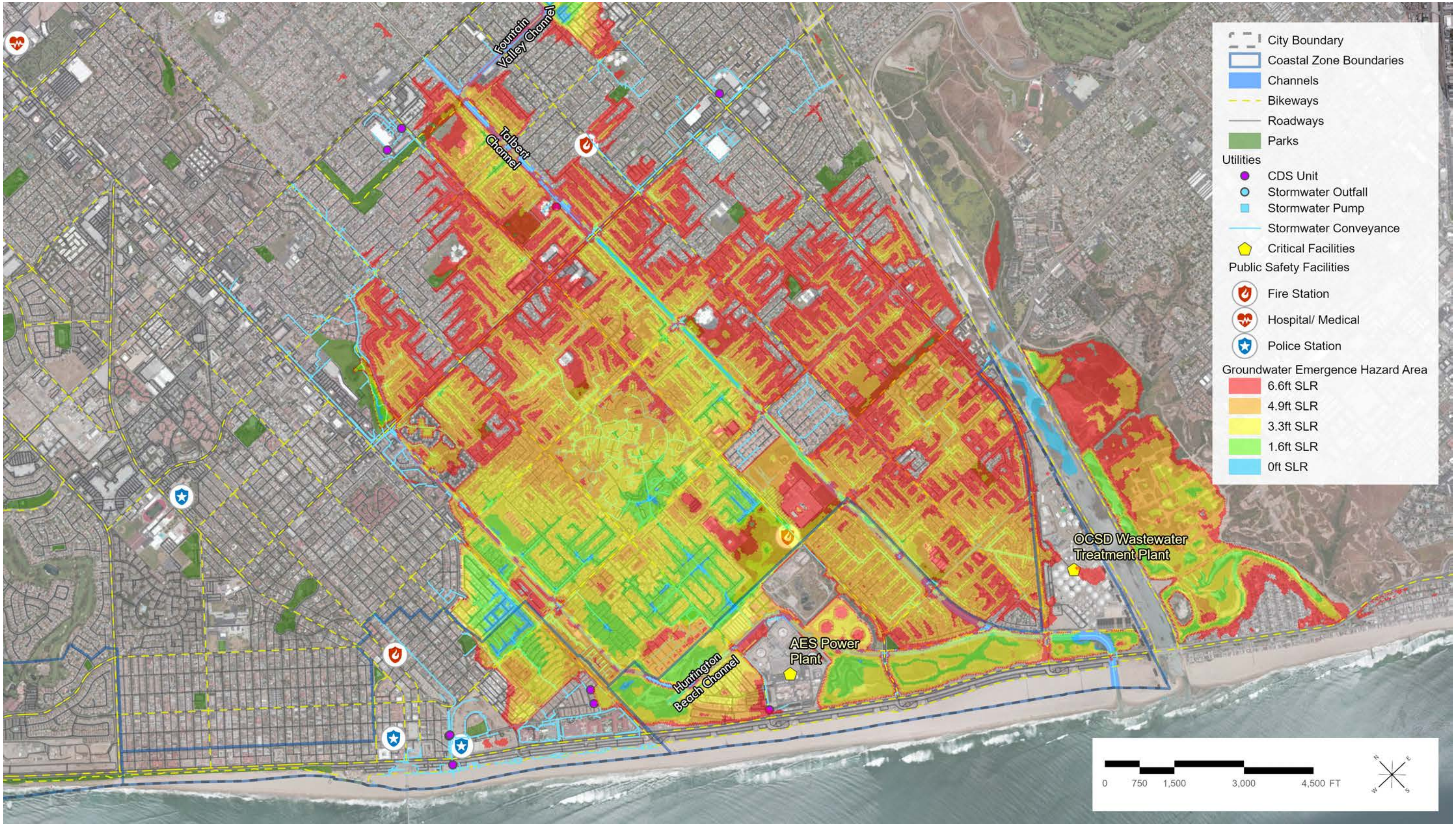


FIGURE 6-21: PROJECTED GROUNDWATER EMERGENCE HAZARD AREAS, SOUTHERN STUDY AREAS

7. Vulnerability Assessment

7.1. Coastal Development

7.1.1. Hazard Exposure

The total value of coastal development projected to be exposed to flood hazards under non-storm and storm conditions is presented in Table 7-1 and Table 7-2. These values are intended to provide an order of magnitude estimate of exposed development value. Property value for each building exposed to flood hazards was taken from City GIS data. The value of exposed buildings was calculated based on the total value of the structure. A building was counted as flooded if the center of the structure was located within projected flood hazard boundaries under each SLR scenario. If flood projections reached only the outer portions of a structure it was not included as flooded in exposure calculations. Exposure is then discussed on a study area by study area basis.

TABLE 7-1: CITY-WIDE FLOOD HAZARD EXPOSURE FOR DEVELOPMENT UNDER NON-STORM CONDITIONS

SLR	Number of Buildings Exposed to Flood Hazards	Total Value of Exposed Development ($)
0ft	37	37,034,743
1.6ft	332	161,517,269
3.3ft	2,460	1,480,887,447
4.9ft	3,587 (17,712*)	2,229,929,928 (9,932,112,254*)
6.6ft	10,532 (26,813*)	5,944,198,584 (14,958,495,085*)

*includes exposure from supplementary bathtub flood modelling

TABLE 7-2: CITY-WIDE FLOOD HAZARD EXPOSURE FOR DEVELOPMENT UNDER 100-YEAR STORM CONDITIONS

SLR	Number of Buildings Exposed to Flood Hazards	Total Value of Exposed Development ($)
0ft	259	158,423,901
1.6ft	1,888	1,093,567,611
3.3ft	3,480	2,158,010,201
4.9ft	6,835	3,769,159,817
6.6ft	25,433	14,531,926,892

Huntington Harbour: High

Development within the Huntington Harbour study area has the highest exposure to SLR hazards, with storm and non-storm flood projections becoming widespread with 1.6ft SLR and 3.3ft of SLR, respectively. Areas inland of the Harbour also show significant flood projections under 3.3ft and greater SLR scenarios.

These 3.3ft SLR and 1.6ft SLR hazard thresholds are largely what contribute to the jumps in value of development exposed to flood hazards shown in Table 7-1 and Table 7-2. Additional erosion hazards are also present along the shoreline of Sunset Beach under 3.3ft and greater SLR scenarios.

Bolsa Chica: Moderate
Projected hazards to development within the Bolsa Chica study area are largely absent under SLR scenarios up to 3.3ft, and flood hazard projections under the 4.9ft SLR scenario appear only in limited areas under severe storm conditions. It is not until 6.6ft SLR that a tipping point is reached, and projected hazard exposure becomes widespread under non-storm conditions. While overall exposure remains low up to this point, this exposure threshold warrants a moderate rating given the potential for non-storm flood impacts over a large area.

Huntington Beach: Low
Projected hazard exposure for coastal development within the Huntington Beach study area remains minimal up to the 6.6ft SLR scenario, with exposure in earlier scenarios primarily limited to the Huntington Beach Pacific House Condo Complex located seaward of the Pacific Coast Highway. Storm flood projections extend across select portions of the study area with 6.6ft SLR, stemming from inland flooding in areas surrounding Huntington Beach Channel.

Huntington Beach Wetlands: High
Hazard exposure projections within the Huntington Beach Wetlands study area follow a similar pattern to the Bolsa Chica study area. Projected hazard exposure is minimal for the 1.6ft and 3.3ft SLR scenarios. CoSMoS flood hazard projections become more widespread with 4.9ft SLR but remain limited to severe storm events, while bathtub modelling shows potential for widespread non-storm flood hazard impacts under this scenario. CoSMoS storm flood projections increase dramatically under the 6.6ft SLR scenario, with non-storm flood projections based on supplementary bathtub modelling increase incrementally.

7.1.2. Hazard Sensitivity

High
Coastal development has a high overall sensitivity to both storm and non-storm SLR hazards, particularly those structures with a first floor that sits at ground level. Though temporary, widespread storm flood impacts as projected under a 1.6ft SLR within the Huntington Harbour study area and 4.9ft and greater SLR scenarios within other study areas are likely to cause substantial damage to any inundated structures, potentially disrupting use of major residential, commercial, and recreational resources for an extended amount of time as repairs are made. Non-storm flood projections are likely to frequently result in structural damages and disruption of use and services within affected areas.

7.1.3. Adaptive Capacity

Low
Overall adaptive capacity is low for coastal development due to the challenges and costs associated with implementing traditional flood hazard mitigation measures such as structure elevation, flood protection, or floodproofing, especially when considering the potential for widespread non-storm flood hazard impacts under severe, long-term SLR scenarios. This is particularly true for the Harbour study area, where the majority of protective seawalls vary in type, condition, and elevation and have a relatively low crest with limited ability to accommodate SLR without significant structural improvements. Despite overall low adaptive capacity, select development areas that have finished floors on an elevated building pads may have improved capacity for adaptation. Options also remain present over the short-to-medium term for low lying development areas in the form of low-cost flood barriers designed to limit damage from temporary, storm-related flooding. However, reliance on temporary measures may not be adequate to accommodate.

7.2. Stormwater and Sewer Infrastructure

7.2.1. Hazard Exposure

Stormwater and sewer infrastructure projected to be exposed to flood hazards under non-storm and storm conditions is presented in Table 7-3 and Table 7-4. The projected exposure of stormwater and sewer infrastructure was calculated based on the total number of infrastructure located within projected flood hazard boundaries under each SLR scenario.

TABLE 7-3: CITY-WIDE FLOOD HAZARD EXPOSURE FOR STORMWATER AND SEWER INFRASTRUCTURE UNDER NON-STORM CONDITIONS

SLR	Number of Stormwater Outfalls	Number of Stormwater Pump Stations	Number of Sewer Lift Stations
0ft	30	0	2
1.6ft	57	0	5
3.3ft	77	4	9
4.9ft	81 (98*)	4 (39*)	15 (27*)
6.6ft	145 (180*)	24 (42*)	24 (37*)

*includes exposure from supplementary bathtub flood modelling

TABLE 7-4: CITY-WIDE FLOOD HAZARD EXPOSURE FOR STORMWATER AND SEWER INFRASTRUCTURE UNDER 100-YEAR STORM CONDITIONS

SLR	Number of Stormwater Outfalls	Number of Stormwater Pump Stations	Number of Sewer Lift Stations
0ft	55	0	3
1.6ft	80	1	9
3.3ft	84	4	15
4.9ft	102	7	19
6.6ft	170	63	35

Huntington Harbour: High

A number of stormwater outfalls, stormwater pump stations, and sewer lift stations lie within projected flood hazard areas within the Huntington Harbour study area, resulting in high overall hazard exposure. Impacts to stormwater and wastewater systems could be felt as soon as the 1.6ft SLR scenario as storm flood projections extend across the majority of outfalls, lift stations, and the stormwater pump stations located within the Harbour. Higher tidal elevations under non-storm conditions may also impact the numerous stormwater outfalls located along local waterways. 3.3ft SLR again represents a potential impact threshold as non-storm flooding is projected across the study area, likely to cause frequent disruption in the use and function of stormwater and sewer utilities.

Bolsa Chica: Low

Projected hazard exposure for stormwater and sewer utilities within the Bolsa Chica study area is low given the overall limited amount of exposed infrastructure up to the 6.6ft SLR scenario, though impacts from higher groundwater elevations may occur sooner. Flood projections become widespread under the 6.6ft SLR scenario, the relatively low density of stormwater conveyance lines in inland areas helps to limit exposure. If the 6.6ft SLR flood threshold is exceeded the pump locations along the East Garden Grove Wintersburg Channel and the Bolsa Chica wetland levee system would pose the greatest risk. Flood projections also cover several CDS units under 4.9ft and greater SLR scenarios.

Huntington Beach: Low
Projected hazard exposure for stormwater and sewer utilities infrastructure within the Huntington Beach study area is low, as flood hazard projections are largely absent up to the 6.6ft SLR scenario. Storm flood projections cover several sewer lift stations and CDS units within the study area with 6.6ft SLR. Stormwater outfall locations surrounding the Huntington Beach Pier are also projected to become exposed to flooding under non-storm conditions under this scenario.

Huntington Beach Wetlands: High
Stormwater and sewer utilities infrastructure within the Huntington Beach Wetlands study area is given a high rating due to the relatively high concentration of stormwater pump stations along Huntington Beach Channel and Talbert Channel and widespread stormwater conveyance lines located in surrounding areas. While flood hazard projections within the area are limited to severe storm conditions under 3.3ft and lower SLR scenarios, the potential for widespread impacts and disruption of utility infrastructure function under more severe SLR scenarios due to higher tidal elevations and potential groundwater emergence contributes to the high exposure rating.

Two additional critical utility facilities, the AES Power Plant and OCSD Wastewater Treatment Plant (WWTP), are also projected to become exposed to flood hazards under 4.9ft and greater SLR scenarios. CoSMoS flood hazard projections show limited flooding under storm conditions with 4.9ft SLR and increased flooding under the 6.6ft SLR scenario. Supplementary bathtub modelling shows the potential for flooding in significant portions of the OCSD WWTP under extreme high tide conditions with 4.9ft SLR, with flooding also projected in select areas of the AES Power Plant. With 6.6ft SLR extreme high tide inundation projections extend across the majority area of each facility.

7.2.2. Hazard Sensitivity

High
Hazard sensitivity for stormwater and sewer utilities infrastructure in high overall, as the normal operation of stormwater infrastructure can be affected if water levels rise to the point where backwater effects occur. A backwater effect occurs when a channel restriction or obstruction at the downstream end raises the surface of the water upstream from it, potentially leading to flooding. Trash filtration systems such as CDS units can also become damaged or lose functionality if inundated frequently. Non-storm flood projections in areas such as Huntington Harbour under 3.3ft and greater SLR scenarios are likely to impact stormwater operations if outfall locations become inundated for extended periods of time. Any stormwater infrastructure that relies on gravity flow is also likely to experience some reduction in capacity due to higher downstream water levels. Wastewater lift stations are also likely to experience disruptions in service if inundated during flood events. Underground storage vaults may also be subject to increased buoyancy forces with higher groundwater levels. The AES Power Plant and OCSD WWTP are also highly sensitive to SLR hazards, as even minor structural damages or disruptions in service may have extensive impacts to surrounding areas.

7.2.3. Adaptive Capacity

Low
Adaptive capacity of stormwater infrastructure, sewer infrastructure, and critical facilities such as the AES Power Plant and OCSD WWTP are low overall due the built nature of the infrastructure in fixed locations and the need to maintain utility functions if any adaptation measures are implemented. Any adaptation measures for stormwater and sewer infrastructure in highly exposed areas would likely require additional hydraulic studies if significant changes are made to ensure utility functions are not adversely impacted as a result. Though a potential challenge, opportunities exist to coordinate elevation of infrastructure such as outfalls, pumps, and lift stations with any future improvements to or elevation of coastal infrastructure if necessary.

7.3. Potable Water Infrastructure

7.3.1. Hazard Exposure

Potable water infrastructure projected to be exposed to flood hazards under non-storm and storm conditions is presented in Table 7-5 and Table 7-6. The projected exposure of potable water infrastructure was calculated based on the total number or length of infrastructure located within projected flood hazard boundaries under each SLR scenario. All water infrastructure was evaluated under non-storm conditions. Only above-ground water infrastructure was evaluated under 100-year storm conditions, as any temporary flood impacts to underground infrastructure during a storm event are expected to be minimal.

TABLE 7-5: CITY-WIDE FLOOD HAZARD EXPOSURE FOR POTABLE WATER INFRASTRUCTURE UNITS UNDER NON-STORM CONDITIONS

Infrastructure Type	0ft SLR	1.6ft SLR	3.3ft SLR	4.9ft SLR	6.6ft SLR
Anode Beds	0	0	4	4	6
Blow Off Risers	0	18	72	80	213
Check Valves	0	0	0	0	0
Fire Service Back Flow	1	13	56	69	189
Monitor Devices	0	0	0	0	0
Plugs	1	14	20	24	31
Pressure Relief Valves	1	1	1	1	3
Pump Outs	0	0	0	0	10
Reducers	0	1	3	4	6
Sample Stations	0	1	4	5	10
Turn Outs	0	0	0	0	0
Valves	8	236	764	955	2525
Water Pipes (mi)	0.84	8.56	28.35	35.10	102.02
Air Vacs	1	3	4	5	17
Cathode Protection	1	1	7	7	26
Hydrants	0	58	240	305	827
Manhole Access Points	0	0	0	0	2
Wells	0	0	0	0	1

TABLE 7-6: CITY-WIDE FLOOD HAZARD EXPOSURE FOR POTABLE WATER INFRASTRUCTURE UNITS UNDER 100-YEAR STORM CONDITIONS

Infrastructure Type	0ft SLR	1.6ft SLR	3.3ft SLR	4.9ft SLR	6.6ft SLR
Air Vacs	1	4	5	8	44
Cathode Protection	1	7	7	7	39
Hydrants	33	206	301	636	2225
Manhole Access Points	0	0	0	0	7
Wells	0	0	0	0	2

Hazard exposure for potable water infrastructure is limited under current conditions and the 1.6ft SLR scenario. The majority of infrastructure types show minimal to non-existent exposure for non-storm conditions under these scenarios, the exceptions being valves, water pipes, and hydrants that are located throughout the potable water infrastructure network. Hazard exposure for hydrants increases for the 1.6ft SLR scenario under 100-year storm conditions, but hazard exposure for other above-ground infrastructure remains limited.

Hazard exposure increases among select infrastructure types under the 3.3ft and 4.9ft SLR scenarios. Underground infrastructure including anode beds, blow off risers, fire service back flow valves, and plugs show increased exposure under non-storm conditions. Above ground infrastructure such as air vacs and cathode protection devices additionally show potential exposure under non-storm and 100-year storm conditions. The 6.6ft SLR scenario represents a significant hazard exposure threshold for potable water infrastructure. The only infrastructure types that are not projected to be exposed to hazards under non-storm conditions for the 6.6ft SLR scenario are check valves, monitor devices, and turn outs. Hazard exposure for the majority of other infrastructure types shows a significant increase in terms of number or length of infrastructure impacted, increasing by a factor of 2-3 in many cases.

7.3.2. Hazard Sensitivity

Moderate

Hazard sensitivity for potable water infrastructure is moderate overall considering the balance of underground and above-ground infrastructure. Underground infrastructure has significantly lower sensitivity than above-ground infrastructure. Impacts to underground infrastructure are limited to flooding under non-storm conditions, where infrastructure access and maintenance activities have the potential to be disrupted on a regular basis. Direct damage to underground infrastructure is unlikely to result from above-ground flooding but may occur if elevated groundwater levels apply forces beyond the current design capacity. Damage may also occur if elevated salt water levels cause increased corrosion to water infrastructure. The potential for corrosion damage is dependent on the material water infrastructure is made of. Infrastructure such as anode beds and cathode protector are unlikely to be damaged by contact with salt water. Ductile iron or cast iron can experience increased corrosion if exposed to salt water, but degrade at rates much slower than metals such as copper.

Above-ground infrastructure has a higher hazard sensitivity as even temporary flood impacts can damage infrastructure and impact overall potable water system functions. The potential for corrosion damage is also increased due to direct contact with salt water during flood events. In addition to corrosion damage, potential damage to different types of above-ground infrastructure are listed in Table 7-7.

TABLE 7-7: POTENTIAL DAMAGE TO ABOVE-GROUND POTABLE WATER INFRASTRUCTURE DURING FLOOD EVENTS

Infrastructure Type	Potential Flood Damage
Air Vacs	Structural degradation due to corrosion. Flood waters could prevent air from escaping if flooding occurs frequently or over an extended period of time. Damage may occur due to pressure build up if air is unable to exit. Potential contamination of potable water system with flood water.
Cathode Protection	Though resistant to corrosion, any structural damage to cathode protection units could lead to increased corrosion throughout the water utility system until units are repaired or replaced.
Hydrants	Structural degradation due to corrosion. Loss of access during flood events. Impacts to emergency services.
Manhole Access Points	Structural degradation due to corrosion. Loss of access during flood events. Impacts to utility network monitoring and maintenance. Risk of flooding and corrosion to any underground infrastructure located near manhole. Potentially increased loads to water treatment systems and pressure in storm drain systems.
Wells	Structural degradation due to corrosion. Loss of access during flood events, Potential structural damage during floods if hydrostatic forces exceed structural design, leading to extended loss of functions. Potential contamination of groundwater or oil spill.

7.3.3. Adaptive Capacity

Low

Similar to stormwater and sewer infrastructure, the adaptive capacity of potable water infrastructure is low overall due to the potential difficulty of relocating infrastructure and the need to maintain overall infrastructure system functionality. Hydraulic studies would again likely be required if significant changes are made to the potable water infrastructure network, and any adaptation measures for above ground potable water infrastructure would need to consider elevation of surrounding infrastructure such as roadways and development. Long-term corrosion protection may also require replacing existing infrastructure with more corrosion resistant material such as PVC in high hazard areas. Corrosion protection can also be increased within high-hazard areas through measures such as polyethylene encasement, application of metallized arc spray zinc coating, or cathodic protection retrofits.

7.4. Public Safety Facilities

7.4.1. Hazard Exposure

Low

Projected hazard exposure for public safety facilities such as fire stations, police stations, and major medical facilities is low overall. The only facility projected to be impacted up to 3.3ft SLR is the Warner Avenue fire station within Huntington Harbour. Additional facilities projected to be impacted under 4.9ft SLR are the Magnolia Street and Bushard street fire stations based on supplementary bathtub modelling. Projected facility exposure increases slightly with 6.6ft SLR, including the Pacific Coast Highway police station under extreme high tide conditions based on supplementary bathtub hazard modelling.

7.4.2. Hazard Sensitivity

High

Hazard sensitivity for public safety facilities is given a high rating as these facilities are often major structures containing highly specialized equipment. The services provided by these facilities are also critical to the health and safety of surrounding communities, and so even a short-term disruption in service caused by structural damage or lack of access to facilities could potentially have high consequences.

7.4.3. Adaptive Capacity

Moderate

Overall adaptive capacity for public safety facilities is moderate given that the primary hazard projection is flooding in select areas under severe storm conditions. Traditional flood mitigation actions such as wet or dry floodproofing remain as options to address these temporary, storm-driven flood impacts. Facilities could also potentially be relocated as part of long-term planning efforts if other adaptation measures prove to no longer be feasible.

7.5. Transportation Infrastructure

7.5.1. Hazard Exposure

Transportation infrastructure projected to be exposed to flood hazards under non-storm and storm conditions is presented in Table 7-5 and Table 7-6. The projected exposure of transportation infrastructure was calculated based on the total length of infrastructure locations within projected flood hazard boundaries under each SLR scenario.

TABLE 7-8: CITY-WIDE FLOOD HAZARD EXPOSURE FOR TRANSPORTATION INFRASTRUCTURE UNDER NON-STORM CONDITIONS

SLR	Roadways (mi)	Bikeways (mi)
0ft	0.6	0.3
1.6ft	11.8	2.2
3.3ft	35.1	5.4
4.9ft	46.1 (217.7*)	9.9 (43.5*)
6.6ft	148.1 (344.3*)	25.9 (65.7*)

*includes exposure from supplementary bathtub flood modelling

TABLE 7-9: CITY-WIDE FLOOD HAZARD EXPOSURE FOR TRANSPORTATION INFRASTRUCTURE UNDER 100-YEAR STORM CONDITIONS

SLR	Roadways (mi)	Bikeways (mi)
0ft	8.4	2.8
1.6ft	33.2	5.7
3.3ft	46.6	10.3
4.9ft	108.5	21.9
6.6ft	350.9	64.3

Huntington Harbour: High
Projected hazard exposure for transportation infrastructure within the Huntington Harbour study area is high overall. Storm flooding is projected to impact major coastal roadways such as the Pacific Coast Highway under current conditions. With 1.6ft SLR non-storm flood projections extend across the Pacific Coast highway and several local roadways, resulting in frequent inundation and loss of service. Nearly all roadways within the Harbour are projected to flood under non-storm conditions with 3.3ft SLR as flood extents extend inland.

Bolsa Chica: Moderate
Though the exposure of transportation infrastructure within the Bolsa Chica study area does not become widespread until the 6.6ft SLR scenario, hazard exposure for this study area is rated as moderate due to the projected impacts to the Pacific Coast Highway, the only coastal roadway and primary means of transportation across the area. Select areas of the Highway are projected to flood under current conditions during a severe storm event. Non-storm flood projections are seen in select areas with 1.6ft SLR, becoming more widespread with 3.3ft SLR. A number of locations along the highway are projected to become exposed to non-storm flood impacts with 4.9ft SLR. With 6.6ft SLR nearly the entirety of the Pacific Coast Highway upcoast of the Bolsa Chica Inlet is projected to flood under non-storm conditions. Local roadways inland of the Bolsa Chica wetlands are also projected to become inundated on a widespread basis with 6.6ft SLR.

Huntington Beach: Low
Hazard exposure for transportation infrastructure within the Huntington Beach study areas is highly limited, with flood projections absent until the 4.9ft SLR scenario. Even under 4.9ft and greater SLR scenarios projected hazard exposure is largely limited to select areas of the Pacific Coast Highway and local roadways in the downcoast portion of the study area under severe storm conditions.

Huntington Beach Wetlands: High
Though hazard projections for transportation infrastructure within the Huntington Beach Wetlands study area show exposure only under 4.9ft and greater SLR scenarios, the potential for widespread non-storm flood impacts under the 4.9ft SLR scenario seen in supplementary hazard modelling warrants a high exposure rating. These non-storm flood projections with 4.9ft SLR include major roadways such as the Pacific Coast Highway as well as the majority of local roadways in the area. Hazard exposure increases incrementally with 6.6ft SLR as flood projections extend further inland.

7.5.2. Hazard Sensitivity

Moderate
The hazard sensitivity for transportation infrastructure is moderate overall, but is variable based on the type of hazard. Transportation infrastructure typically has a low sensitivity to shallow and short duration flooding, as minor flooding is unlikely to result in significant damage. This sensitivity can be reduced further if roadways subject to coastal flooding are constructed with marine corrosion resistant materials. As flooding becomes more frequent and severe, transportation infrastructure becomes more sensitive to hazards as longer interruptions in service and more extensive damage become likely along roadways. Infrastructure along the shoreline is also sensitive to erosion and undermining, which can result in prolonged closures, safety concerns, and costly repairs. Widespread flooding, traffic congestion from road closures, or damage to key roads may also impact emergency response times.

7.5.3. Adaptive Capacity

Moderate
Transportation infrastructure has a moderate adaptive capacity overall. Strategies such as elevation are generally more feasible for select portions of roadways as compared to residential or commercial development, but the location of coastal roadways is often inflexible due to the lack of available area landward and the need to connect multiple high-use coastal recreational services within the City. The adaptive capacity of these coastal transportation corridors is also dependent on the ability of existing natural and constructed features along the shoreline to dissipate wave energy during extreme events, preventing recurring structural damages. Given these factors, adaptation strategies will likely require measures to accommodate extreme storm flood impacts and limit potential for more frequent tidal inundation events along coastal roadways as SLR increases.

7.6. Coastal Access and Recreation

7.6.1. Hazard Exposure

Park areas projected to be exposed to flood hazards under non-storm and storm conditions are presented in Table 7-7 and Table 7-8. The projected exposure of park areas was calculated based on the total acreage of park areas within projected flood hazard boundaries under each SLR scenario.

TABLE 7-10: CITY-WIDE FLOOD HAZARD EXPOSURE FOR PARKS UNDER NON-STORM CONDITIONS

SLR	Parks (acres)
0ft	2.8
1.6ft	3.6
3.3ft	7.6
4.9ft	17.4 (129.3*)
6.6ft	189.3 (314.2*)

*includes exposure from supplementary bathtub flood modelling

TABLE 7-11: CITY-WIDE FLOOD HAZARD EXPOSURE FOR PARKS UNDER 100-YEAR STORM CONDITIONS

SLR	Parks (acres)
0ft	3.4
1.6ft	8.4
3.3ft	16.4
4.9ft	44.9
6.6ft	333.2

Huntington Harbour: Moderate

Coastal access and recreational resources, including sandy beaches and parks in coastal areas, have a moderate exposure to SLR hazards within the Huntington Harbour study area. Usable beach area is projected to remain in place with 1.6ft SLR, with areas becoming more limited with 3.3ft SLR. Beach areas are projected to be largely absent with 4.9ft SLR, the same threshold at which the Sunset Beach Linear Park is projected to become regularly inundated.

Bolsa Chica: Moderate

Continuous sandy beach areas are projected to remain in place along Bolsa Chica State Park under both the 1.6ft and 3.3ft SLR scenarios. Limited beach areas are projected to remain in place with 4.9ft SLR, located in areas just upcoast of the Bolsa Chica Inlet. With 6.6ft SLR these remaining areas are projected to be minimal. Parking lots along the State Park are projected to experience flooding in select areas during severe storms with 3.3ft SLR. These impacts become more widespread with 4.9ft SLR, and regular inundation of parking lots is projected with 6.6ft SLR.

The bluffs area to the south of Bolsa Chica Inlet has greater exposure at earlier SLR thresholds. Beach areas narrow with 1.6ft SLR, and select beach areas are projected to become absent with 3.3ft SLR as the shoreline extends back to existing protection structures. Beach areas are projected to be virtually non-existent along this stretch of shoreline with 4.9ft and greater SLR. Bluff erosion projections along Bluff Top

Park remain fixed where existing toe stabilization infrastructure is present, while unprotected upcoast areas of the park are projected to receded landward over time.

Huntington Beach: Low
Relatively wide sandy beach areas are projected to remain in place along the Huntington Beach study area across all SLR scenarios examined and be save for the far upcoast portions of the study area and areas fronting the Huntington Pacific Beach House Condo Complex, where beach width narrows under the 6.6ft SLR scenario. Parking lots surrounding the Huntington Beach Pier and Huntington State Beach also have low hazard exposure, with flood projections seen only in 4.9ft and greater SLR scenarios under severe storm conditions.

Huntington Beach Wetlands: Low
Wide sandy beach areas are projected to remain in place along the Huntington Beach Wetlands study area across all SLR scenarios examined. Flood projections within coastal parking lots are only observed in 4.9ft and greater SLR scenarios.

7.6.2. Hazard Sensitivity

Moderate
Overall hazard sensitivity for coastal access and recreation resources within the City can be characterized as moderate based on the relatively low potential for hazard impacts within the Huntington Beach and Huntington Beach Wetlands study areas combined with the higher potential for impacts within the Bolsa Chica and Huntington Harbour study areas. Beaches fronting development or protective structures within these areas are the most sensitive to erosion hazards as potential landward migration to higher elevations is limited. This sensitivity is exacerbated in areas where beaches are currently narrow or become narrower over time following significant nourishment events.

7.6.3. Adaptive Capacity

High
Coastal access and recreation resources within the City have a high overall adaptive capacity. The wide beaches present across significant portions of the City provide a significant buffer to SLR impacts, with many areas in southern portions of the City showing the ability to maintain recreational use even under 6.6ft SLR. Inherent adaptive capacity of beach areas is reduced within the Bolsa Chica and Huntington Harbour study areas due to relatively narrower beach widths, but adaptive capacity is aided by the presence of the major federal beach nourishment program that could potentially be augmented over time to meet increased demand.

7.7. Environmental Resources

7.7.1. Hazard Exposure

High
Coastal environmental resources such as wetlands have a high exposure to SLR hazards as these areas are continuously exposed to changes in tidal water elevations over time. While specific impact thresholds are challenging to quantify due to the number of interdependent ecological process involved, potential thresholds can potentially be estimated based on changes in non-storm flood projections within current wetland areas. Non-storm flood projections within the Huntington Beach Wetlands remain absent up to the 4.9ft SLR scenario where flood projections extend across all current wetland areas, indicating the potential for complete inundation of these areas on a frequent basis, which will result in major habitat conversion from vegetated salt marsh to subtidal areas.

7.7.2. Hazard Sensitivity

High
Though wetlands are largely resistant to temporary inundation hazards, coastal wetlands can be highly sensitive to consistently elevated non-storm water levels, as these changes can significantly alter the structure and function of wetland ecosystems. This is particularly true if the inland migration of tidal floodwaters exceeds the landward migration rate or sediment accretion rate of wetland areas. If wetlands

areas cannot match the gradual increase in tidal elevations due to SLR these systems will gradually transition to subtidal areas, covered by water at all states of the tide.

7.7.3. Adaptive Capacity

Moderate

The adaptive capacity of wetland areas is highly dependent on the ability of these natural features to maintain their relative elevation to water levels over time. In natural systems, sediment supply from river discharge or bluff erosion can offset the impacts of SLR on wetland areas through sediment accretion, which increases land elevation over time. This potential adaptive capacity is highly dependent on a number of dynamic processes including rates of SLR, coastal sediment accretion, and the ability of wetland species to colonize new areas, and as such may require ongoing monitoring efforts to ensure preservation of ecological functions. Given the relative lack of open space surrounding wetlands within Huntington Beach, alternative methods such as thin-layer sediment placement may also be employed to mitigate SLR impacts by gradually elevating wetland areas as SLR increases.

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Appendix

FIGURE A-1: POTABLE WATER INFRASTRUCTURE WITHIN POTENTIAL FLOOD HAZARD AREAS, NORTHERN STUDY AREAS.

FIGURE A-2: POTABLE WATER INFRASTRUCTURE WITHIN POTENTIAL FLOOD HAZARD AREAS, SOUTHERN STUDY AREAS.