APPENDIX P

Sea Level Rise Vulnerability Assessment

CITY OF HUNTINGTON BEACH

SEA LEVEL RISE VULNERABILITY ASSESSMENT

December 2014

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Technical Appendix A. Sea-Level Rise Vulnerability Assessment Methods and Results for the Shoreline Planning Areas

Technical Appendix B. Sea-Level Rise Modeling Approach and Results for the Inland Waterway Planning Areas

ES1. Executive Summary

With a population of approximately 193,000, the City of Huntington Beach (City) is the largest beach city in Orange County in terms of population. While known for its 9.5-mile-long stretch of sand beaches, mild climate, year-round surfing, and beach culture, the City comprises a broad mix of commercial, residential, public open space, recreational amenities, and ecological resources within the proximity of the shoreline, waterways and flood control channels. Accelerating sea level rise (SLR) increases the vulnerabilities of these resources to coastal flooding and damage. The City is committed to the long-term protection of these coastal resources.

There is broad agreement in the scientific community that the earth is predicted to warm and that sea levels will rise as a result of the thermal expansion of water and increased contributions from melting glaciers (CO-CAT 2013, CCC 2013). Though there is consensus among the scientific community on these concepts, the timing and severity of SLR is relatively uncertain and is dependent on region-specific conditions.

The uncertainty in the SLR projections is a result of future global emissions of carbon dioxide (a function of future social behavior) and the non-linear response of the ocean to warmer temperatures and contributions from land-based ice sources. Local conditions, such as tectonic uplift or subsidence, introduce spatial inconsistences in observed SLR along a particular shoreline. Thus, global rates of SLR need to be considered in combination relative to region-specific conditions.

This SLR Vulnerability Assessment (Study) is supportive of the Coastal Resiliency Plan and the Land Use/Circulation/Safety elements of the General Plan. Consistent with state guidance for conducting SLR vulnerability assessments, this study utilizes the best available science for the region. At the time of this report, the best available SLR projections for California are cited as being from the *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present and Future* released by the National Research Council (NRC) in 2012 (CCC 2013, CO-CAT 2013).

The NRC study predicts sea level to rise between 0.2 and 1.0 ft by 2030, 0.4 and 2.0 ft by 2050 and 1.5 and 5.5 ft by 2100 in the Los Angeles region. This Study uses this range of SLR predictions to characterize future risks in the City.

The Study evaluates where and when SLR impacts may occur, as well as the extent to which exposed community assets may be impacted and whether they may be able to cope or adapt on their own. The assessment was conducted through a combination of modeling, mapping, and discussions with the stakeholder group. Key findings of the Study include:

- The City is most vulnerable in the future to flooding during extreme high tides that exceed the crest elevations of protective barriers such as seawalls (bulkheads) and levees. In some areas this can be expected as early as 2030.

- Coastal resources and infrastructure are vulnerable to flooding from the combination of extreme wave events and high tides.

- Continuation of the federal Surfside/Sunset Beach Nourishment program greatly enhances the adaptive capacity of City beaches to SLR.

- The most vulnerable assets in the City vary with SLR projections:
  - By 2030 and 2050 major roadways, public facilities, and residential areas in the coastal infrastructure are vulnerable during combined extreme high tide and coastal storm wave events.
  - By 2100 there is potential for widespread inundation across large portions of northern Huntington Beach in the vicinity of Huntington Harbour and Bolsa Chica. Critical facilities like the AES Southland (AES) power plant and the Orange County Sanitation District (OCSD) wastewater treatment facility in south Huntington Beach are vulnerable to tidal inundation, extreme wave events, and stormwater runoff. Beaches, stormwater and transportation infrastructure, public facilities, ecosystems, and commercial and residential buildings are also vulnerable.

Similar to other vulnerability assessments, this Study used the terminology of flooding to represent short-term (low frequency of occurrence) events of standing water and inundation to characterize longer-term (higher frequency of occurrence) periods of standing water. (Table ES-1 provides a summary of primary vulnerabilities by asset type.)

As outlined in Table ES-1, on the following page, the City faces a number of threats from rising sea levels. The subsequent preparation of the Coastal Resiliency Plan puts the City on the right track to providing an adaptation roadmap for the City. Based on a review of similar assessments in Southern California, the following adaptation policies are recommended for inclusion in the General Plan or Coastal Land Use Plan:

- Create a staff-level regional SLR adaptation working group consisting of representatives of various stakeholders and interest groups within the City to implement the Coastal Resiliency Plan.
- Consistently utilize guidance provided by the State of California Climate Action Team in developing SLR assumptions for planning purposes.
- Perform more detailed vulnerability assessments at a site-specific level as significant plans or capital projects are undertaken within areas identified as being vulnerable to future SLR.

TABLE ES 1
PRIMARY VULNERABILITIES BY ASSET

Transportation
• The Pacific Coast Highway (PCH) at Warner Avenue currently experiences flooding with high tides and rain events. • About 1 mile of PCH through Sunset Beach is vulnerable to increased flooding from tidal inundation by 2030. Other roads in Huntington Harbour will also experience frequent tidal inundation by 2030. Partial inundation of PCH along Bolsa Chica can also be expected. • By 2050 and 2100, widespread inundation of major transportation infrastructure can be expected as the low and high SLR estimates would exceed the crest elevation of many protective barriers around the City.
Residential and Commercial Buildings
• Properties in Sunset Beach and Huntington Harbour become vulnerable to flooding from tides by 2030. • By 2050 widespread inundation of residential and commercial property occurs inland of Huntington Harbour. • By 2100 widespread inundation of properties can be expected as the projected low and high SLR estimates would exceed the crest elevation of most protective barriers around the City. • Along the coast, the Huntington Beach Condos and commercial buildings at the pier are vulnerable to flooding by the 2050 time horizon. Residential buildings in Sunset Beach and South Huntington become vulnerable to flooding in the 2100 scenario.
Stormwater Facilities
• Stormwater facilities in Huntington Harbour were identified as being vulnerable to flooding and inundation. • Storm drains that gravity-drain to regional flood control channels will lose capacity as the downstream boundary water surface elevation increases. • Pump stations within inundation zones are vulnerable to damage. • Areas serviced by pump stations may also be vulnerable to reversal of flow through the discharge pipes.
Wastewater Treatment Facilities
• OCSD Treatment Facility is vulnerable to flooding and inundation from high tides and extreme rainfall events in the 2100 timeframe. • City lift stations within the inundation zones are vulnerable to flooding and inundation.
Energy Facilities
• The AES power plant is vulnerable to coastal inundation in the 2100 timeframe. • Potential for impact to Southern California Edison (SCE) infrastructure from flooding of low-lying areas.
Public Facilities
• State and City owned facilities, such as public restrooms and storage areas, are vulnerable to coastal flooding by the 2100 timeframe.
Ecosystems
• Estuary and bay ecosystems, which provide habitat for many endangered and threatened species, are extremely vulnerable to inundation that could reasonably be expected to result in habitat shift.
Parks, Recreation, and Public Access
• Beaches throughout the City are vulnerable to significant erosion as a result of any future increases in SLR. • Bike trails are vulnerable to coastal flooding and inundation, particularly by the 2100 timeframe. • A number of City and State owned parking lots are vulnerable to coastal flooding and inundation, particularly by the 2100 time horizon.

1. Introduction

This Vulnerability Assessment (Study) presents a City of Huntington Beach (City) specific sea level rise (SLR) vulnerability assessment to support development of land use and circulation elements in the City's General Plan update, as well as the Coastal Resiliency Plan. The Study evaluates the degree to which important community assets are susceptible to, and unable to accommodate adverse effects of projected SLR. The Study identifies the assets that are likely to be impacted and the causes and components of each asset's vulnerability.

The scientific literature strongly suggests that SLR will accelerate through the end of the 21st Century as a result of climate change (IPCC 2014, NRC 2012). At the time of this Study, there are no probabilities attached to future SLR projections. The uncertainty in the SLR projections is a result of future global emissions of carbon dioxide (a function of future social behavior) and the non-linear response of the ocean to warmer temperatures and contributions from land-based ice sources. Thus, planning for SLR must consider high and low estimates of SLR. Planning for a range of potential future conditions provides the City with the tools to make current and future planning decisions that allow the City's resources to adapt to changing conditions.

The study area was divided into four shoreline and three inland waterway planning areas. These planning areas, shown in Figure 1 through Figure 4, are described as follows:

1) Shoreline Planning Areas

    a) Sunset Beach Area: Adjacent to Anaheim Bay (Naval Weapons Station), serves as a "feeder" beach for Surfside-Sunset Beach Nourishment Project and has received nearly 18 million cubic yards of nourishment material since 1963. Extends from Anderson Street to the north to Warner Street to the south.

    b) Bolsa Chica Area: Extends from Warner Avenue to the north to the northern Bolsa Chica entrance channel to the south. 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). Pacific Coast Highway (PCH) is the primary coastal transportation corridor along this reach.

    c) Huntington Bluffs Area: Extends from the southern Bolsa Chica jetty to the Huntington Beach Pier. The northern end of the reach is comprised of narrow beaches backed by high coastal bluffs. The southern reach consists of wider beaches and low bluffs.

    d) Huntington Beach Area: Extends from the Huntington Beach Pier to the Santa Ana River. Contains wide, sandy beaches. Coastal structures include the Huntington Beach Pier and the Santa Ana River Jetties. The planning area is operated by the City north of Beach Boulevard and by State Parks to the south of Beach Boulevard.

2) Inland Waterway Planning Areas

a) Huntington Harbour Area: The harbor 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. Beaches in the Harbour area were not evaluated in this study. Future work would be needed to characterize impacts to these areas.

b) Bolsa Chica Wetlands Area: Most of this low-lying subarea is protected by levees from the tidally-influenced Bolsa Chica wetlands and stormwater runoff conveyed by the East Garden Grove Wintersburg Channel (EGGWC). EGGWC collects runoff from the Ocean View Channel, Murdy Channel and Slater Channel.

c) Huntington Beach Wetlands Area: This low-lying planning area is protected by a system of levees along the tidally-influenced Huntington Beach wetlands and along regional flood control channels including the Huntington Beach Channel, Talbert Channel, and East Valley-Fountain Valley Channel.

2. Scope of Work

Moffatt & Nichol (M&N), as a sub-consultant to PMC, was scoped to prepare a SLR Vulnerability Assessment that included the following tasks:

1) Gather/Review Existing Data
2) Summarize Current Scientific Guidance for SLR Projections over the Next 100 Years
3) Prepare Geo-referenced Inventory of Coastal Infrastructure Potentially Affected by SLR
4) Model SLR Scenarios in Conjunction with other Coastal Flooding Factors
5) Conduct SLR Vulnerability Assessment
6) Identify Appropriate Adaptation Policies

Subsequent related tasks include the preparation of a Coastal Resiliency Plan. The plan will build off this Study and focus on adaptation strategies within the shoreline and inland waterways planning areas.

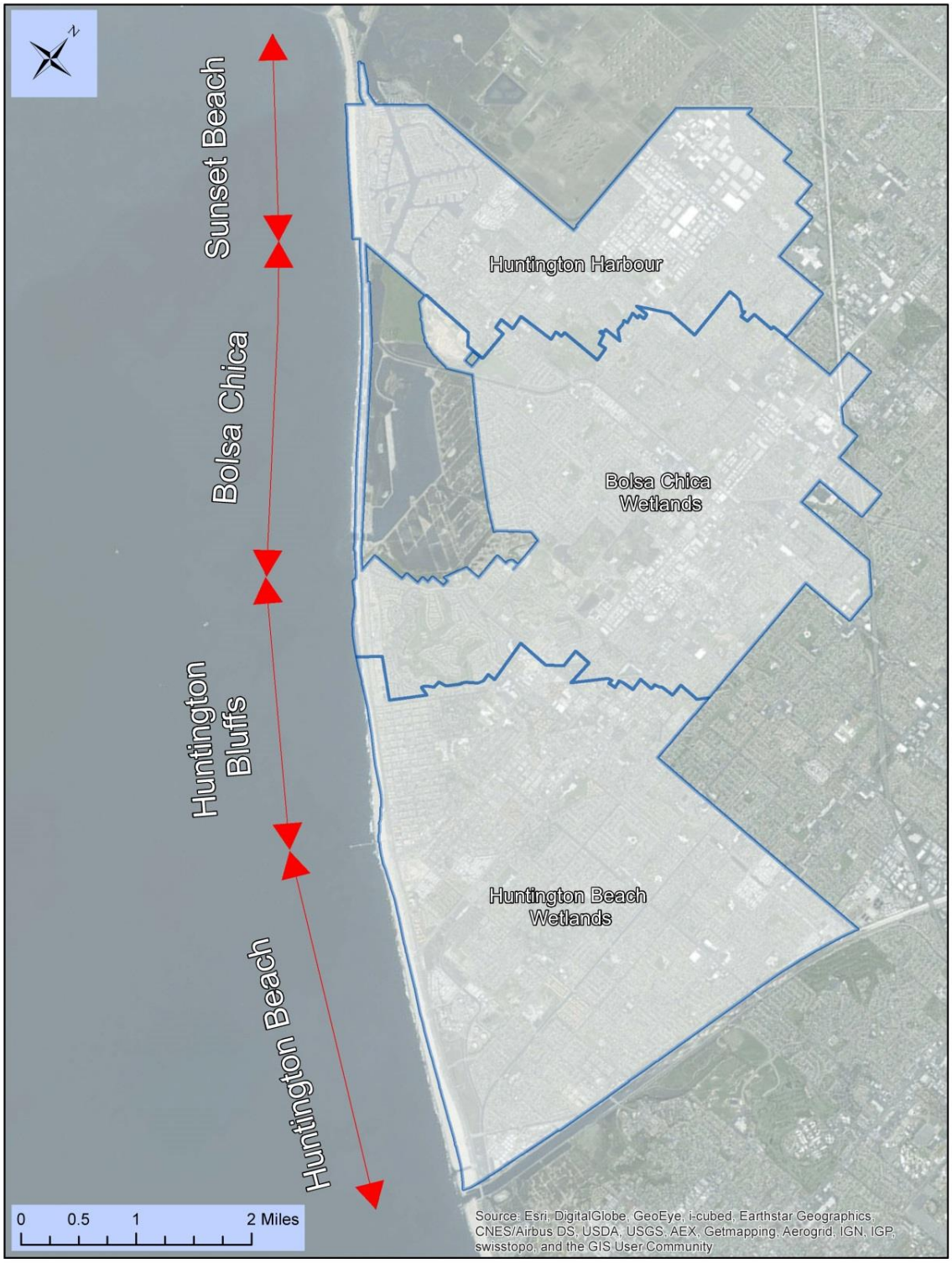


FIGURE 1
VULNERABILITY ASSESSMENT PLANNING AREAS OVERVIEW

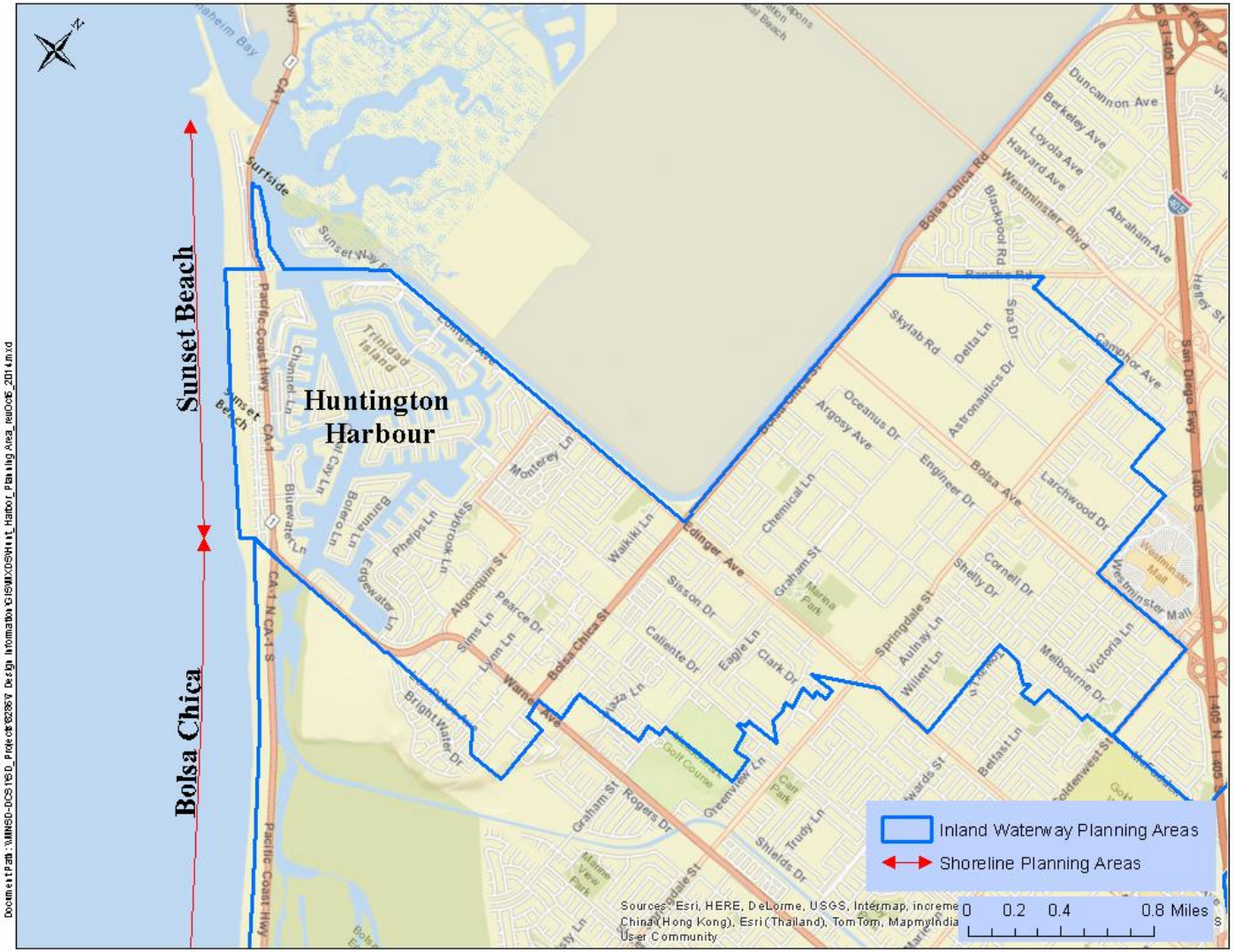


FIGURE 2
NORTHERN PLANNING AREA

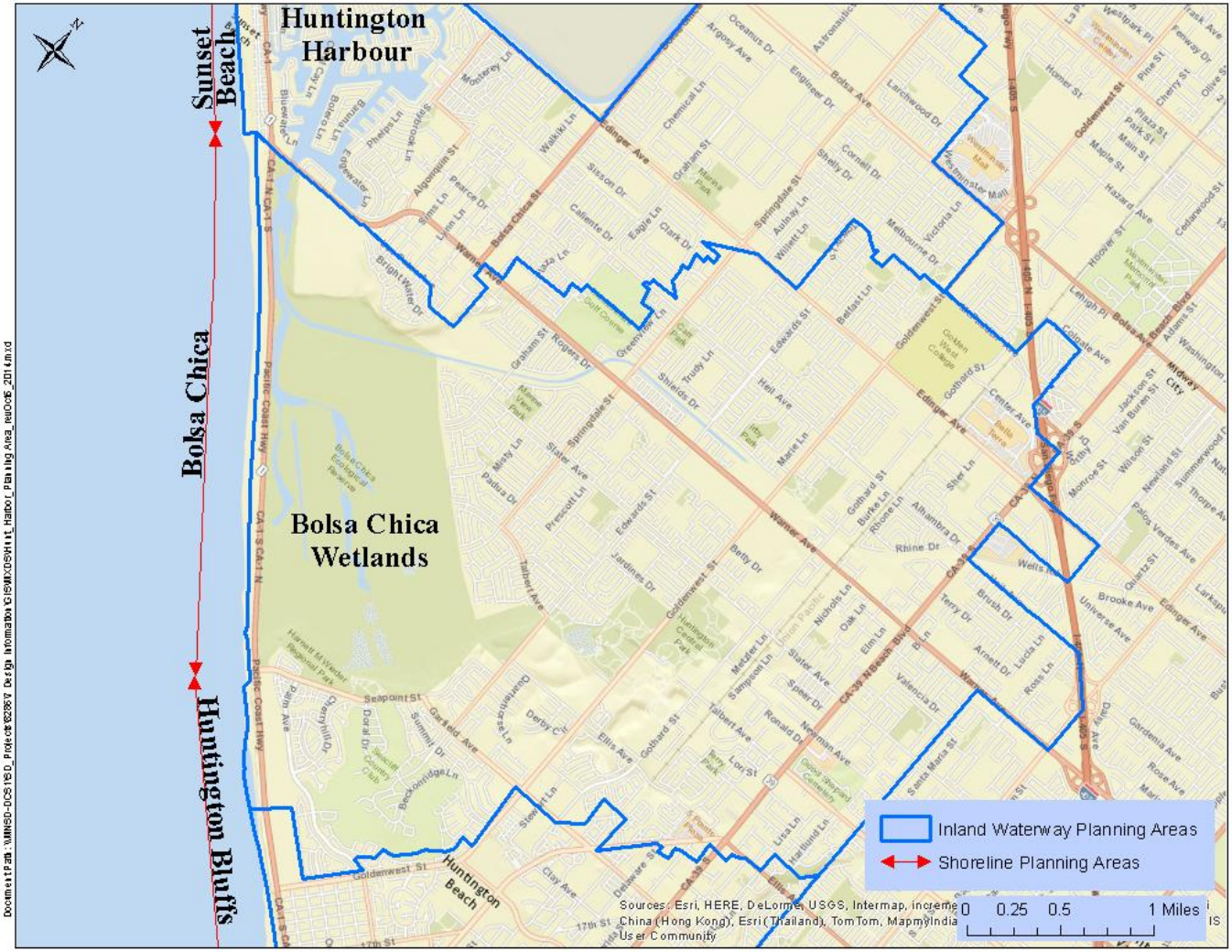


FIGURE 3
CENTRAL PLANNING AREA

FIGURE 4
SOUTHERN PLANNING AREA

3. Sea-Level Rise Science and Projections

Sea levels are projected to rise in coming decades as a result of increased global temperatures associated with climate change (IPCC 2014). When discussing SLR (and when reviewing SLR projections), it is important to distinguish the differences between global and local SLR rates. Global SLR rates discount local effects such as tectonics (i.e., land uplift/subsidence), water temperatures, and wind stress patterns that can act to subdue or amplify the global SLR rates. Local (or relative) SLR refers to the observed changes in sea level relative to the shoreline in a specific region and takes into account these local factors.

Myriad planning and policy-level guidance on SLR have been released by international, federal, and state entities. These guidance documents are generally based on research and publications generated from the scientific community. The most applicable guidance to the City is the State of California SLR Guidance Document (CO-CAT 2013) and the California Coastal Commission Draft SLR Policy Guidance (CCC 2013). These guidance documents are both based in the NRC 2012 study, which provided local SLR projections for the west coast of the United States.

It should be noted that guidance related to SLR evolves as new science is released. The most relevant science and guidance from the international, federal, and state levels at the time of this report is summarized in this section.

3.1. International Sea-Level Rise Science

The most significant international SLR guidance to this study is that which is frequently released by the Inter-governmental Panel on Climate Change (IPCC). The IPCC is an aggregator of peer reviewed scientific literature and provides estimates of global SLR every five or six years in detailed assessment reports.

The IPCC recently released its 5th Assessment Report (5AR) in 2013. The study updated global climate models with a set of new global emission scenarios called Representative Concentration Pathways (RCPs). These emission scenarios make a number of assumptions of future release of carbon dioxide into the atmosphere. The uncertainty in future SLR estimates is largely due to the global release of future emissions being a function of social behavior. Global SLR projections according to the 5AR through year 2100 are shown in Table 1.

Table 1
Global SLR Projections (IPCC 2013)

Scenario	2046- 2065		2081-2100	
	Mean SLR (ft)	**Likely Range (ft)**	**Mean SLR (ft)**	**Likely Range (ft)**
RCP 2.6	0.8	0.6 to 1.1	1.3	0.9 to 1.8
RCP 4.5	0.9	0.6 to 1.1	1.5	1.0 to 2.1
RCP 6.0	0.8	0.6 to 1.1	1.6	1.1 to 2.1
RCP 8.5	1.0	0.7 to 1.3	2.1	1.5 to 2.7

Since the 5AR is a recent release, the 4th Assessment Report (released in 2007) is still commonly used for SLR guidance documents. The global emission scenarios in this

assessment report form the foundation of the National Research Council (2012) report, as discussed in more detail in the following section.

3.2. FEDERAL GUIDANCE

The U.S. Army Corps of Engineers (Corps) released Engineering Circular (EC) No. 1165-2-212 in October 2011 (USACE 2011), which provides guidance on the consideration of the direct and indirect physical effects of SLR across the project life cycle for civil works projects. The EC recommends consideration of three SLR scenarios (low, intermediate, and high) for civil works projects. These scenarios are shown in Figure 5.

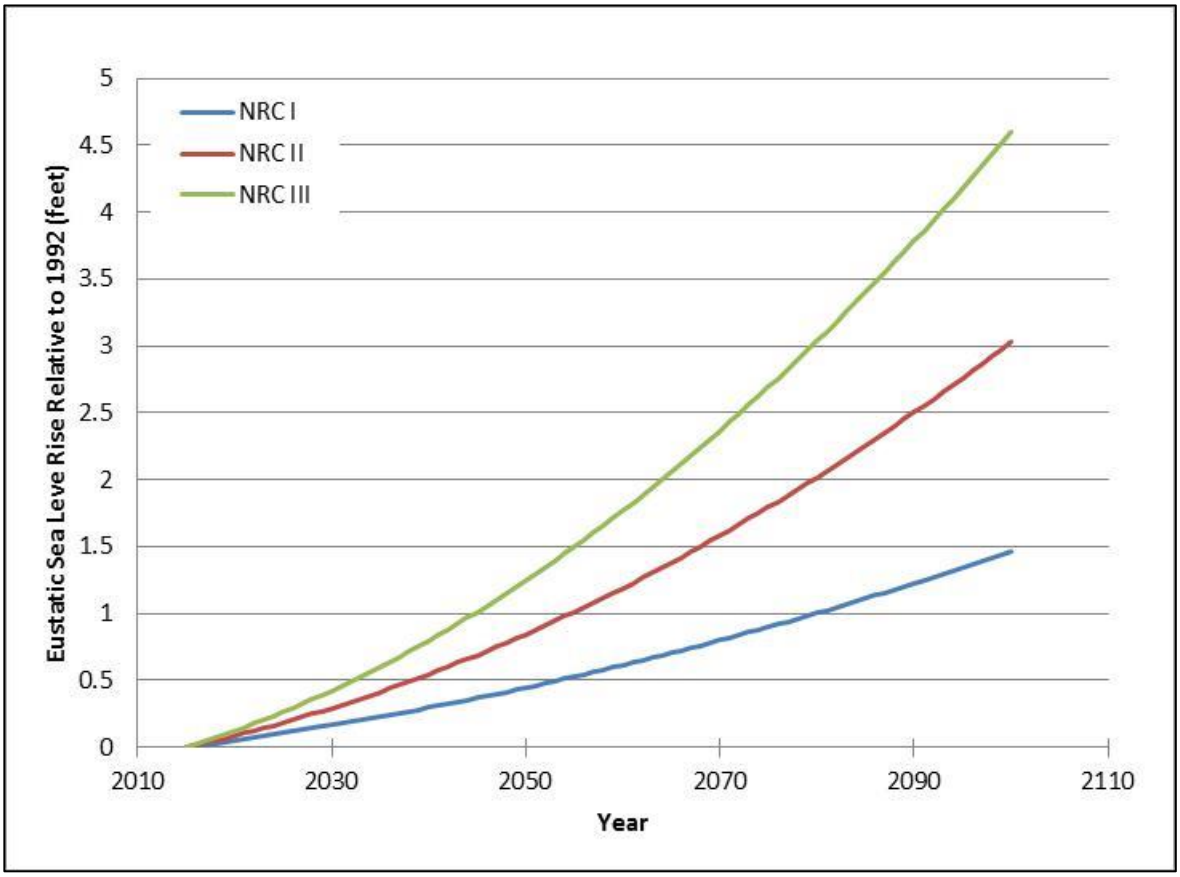


FIGURE 5
PROJECTED FEDERAL SLR RATES (DERIVED FROM USACE 2011)

3.3. STATE GUIDANCE

This section summarizes SLR guidance specific to the State of California and includes: California Coastal Commission Draft SLR Policy Guidance (CCC 2013) and State of California SLR Guidance Document (CO-CAT 2013). Although the IPCC 5AR provides more recent global SLR projections, the National Research Council's (NRC) report, titled *SLR for the Coasts of California, Oregon, and Washington: Past, Present, and Future,* is considered the best available science for the state of California (CCC 2013, CO-CAT 2013). Thus, both state guidance documents utilize the SLR projections from the NRC report.

3.3.1. California Coastal Commission Draft SLR Policy Guidance (CCC 2013)

The document states that the best available science should be utilized when incorporating SLR into planning documents or when applying for a Coastal Development Permit. The NRC 2012 report is generally considered as the best available science for the region at the time of this report. The NRC is a conglomerate of scientists and research organizations that act as an advisory group for government agencies. The NRC study predicts a 0.9-ft increase in relative SLR by 2050 and a 3.1-ft increase by 2100 (Table 2) in the Los Angeles region. The projection values indicate the mean and uncertainty (i.e., standard deviation) for a specific IPCC future greenhouse gas emission scenario (i.e., A1B). The A1B scenario represents a world of rapid economic growth and a balanced use of fossil and non-fossil energy sources. The ranges represent the means for the B1 (low fossil fuel emission scenario) and A1FI (high fossil fuel emission scenario). Note that the confidence in the projections, indicated by the uncertainty values, increases with the projection year as does the range between the low and high projections.

TABLE 2
SLR PROJECTIONS FOR LOS ANGELES REGION

Year	Projected SLR (ft)	Projection Uncertainty (ft, +/-)	Low Range (ft)	High Range (ft)
2030	0.5	0.2	0.2	1.0
2050	0.9	0.3	0.4	2.0
2100	3.1	0.8	1.5	5.5

(Source: NRC 2012)

3.3.2. State of California Sea-level Rise Guidance Document (CO-CAT 2013)

A State SLR guidance document, titled *State of California Sea-Level Rise Guidance Document* (Interim Guidance) (CO-CAT, 2013), was originally released in October 2010 and re-released/ updated in March 2013 to provide guidance to state agencies for incorporation of SLR projections into project planning and decision making. The document recommended use of the ranges of SLR presented in NRC 2012 as a starting place. CO-CAT recommends that specific project design SLR scenario ranges should then be based on agency and context-specific considerations of risk tolerance and adaptive capacity of the affected assets.

3.4. REVIEW OF EXISTING SEA LEVEL RISE MODELS

A number of existing SLR modeling efforts have been completed within the Study Area. These models include: SLR and Coastal Flooding Impacts Viewer (NOAA), CAL-Adapt – Threatened Areas Map (USGS and Pacific Institute), and Coastal Storm Modeling System (CoSMoS) 1.0 (USGS). These models utilize various SLR projections and tidal variations to determine areas of flooding and inundation. Past models for the region have generally discounted the effects of local, existing flood defenses (e.g., sheetpile walls) and/or shoreline morphodynamics in response to future rates of SLR. This is a result of the spatial scale of the modeling effort completed by these entities (e.g., the entire state of California). This Study is an effort to resolve

some of these localized factors discounted in prior modeling efforts. However, previous modeling efforts were reviewed as a first-order screening tool to understand potential vulnerabilities. More detail on these past modeling efforts and vulnerabilities is provided in Appendix A.

4. Coastal Setting

4.1. Water Levels

The nearest, long-term sea level record in the study area is the Los Angeles tidal datum operated by the National Oceanic and Atmospheric Administration (NOAA). The buoy has been operational for over 90 years. Tides in the City are semidiurnal in nature meaning two highs and two lows occur per day. Tidal datums used for the Study are provided in Table 3.

Table 3
Study Tidal Datums (Station 9410660, 1983-2001 Tidal Epoch)

Description	Datum	Elevation (feet, MLLW)
Highest Observed Water Level	HOWL	7.9
Highest Astronomical Tide	HAT	7.3
Mean Higher-High Water	MHHW	5.5
Mean High Water	MHW	4.8
Mean Tide Level	MTL	2.8
Mean Sea Level	MSL	2.8
Mean Diurnal Tide Level	DTL	2.7
Mean Low Water	MLW	0.9
Mean Lower-Low Water	MLLW	0.0
North American Vertical Datum of 1988	NAVD88	0.2
Station Datum	STND	-3.8
Lowest Astronomical Tide	LAT	-2.0
Lowest Observed Water Level	LOWL	-2.7

(Source: NOAA 2014)

4.2. Littoral Processes

A littoral cell is a segment of shoreline in which littoral 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 Huntington Bluffs, 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, and coastal subsidence resulting from petroleum extraction. Natural processes impacting the cell include sediment input from the Santa Ana River and 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).

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 4.

TABLE 4
SURFSIDE-SUNSET BEACH NOURISHMENT PROJECT HISTORY

Year	Quantity (cy)	Borrow Site
1964	4,000,000	Naval Weapons Station
1971	2,300,000	Naval Weapons Station
1979	1,600,000	Offshore Borrow Sites
1985	2,700,000	Offshore Borrow Sites/Naval Weapons Station
1990	1,800,000	Offshore Borrow Sites
1997	1,600,000	Offshore Borrow Sites
2001	1,800,000	Offshore Borrow Sites
2009/2010	2,000,000	Offshore Borrow Sites
Total	17,800,000	Not Applicable
Average	2,225,000	Not Applicable

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

4.3. WAVES

Waves act to carry sand in both the cross-shore and longshore directions and can also cause short-duration flooding events by causing dynamic increases in water levels. 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.

Wave data was analyzed offshore for Huntington Beach from Wave Information Studies (WIS) Station 83101 from 1981 to 2011. WIS, developed by the Corps, 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 by offshore wave buoys. The hindcast data provides a valuable source of decades-long nearshore wave data for coastlines in the U.S.

4.3.1. Extreme Waves

Extreme waves for the Study Area are summarized in Table 5. The 50- and 100-year return period wave heights are 16.3 ft and 18.2 ft, respectively. The top 15 extreme wave events within the study area are provided in Table 6.

TABLE 5
EXTREME WAVE RETURN PERIODS (WIS STATION 83101)

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

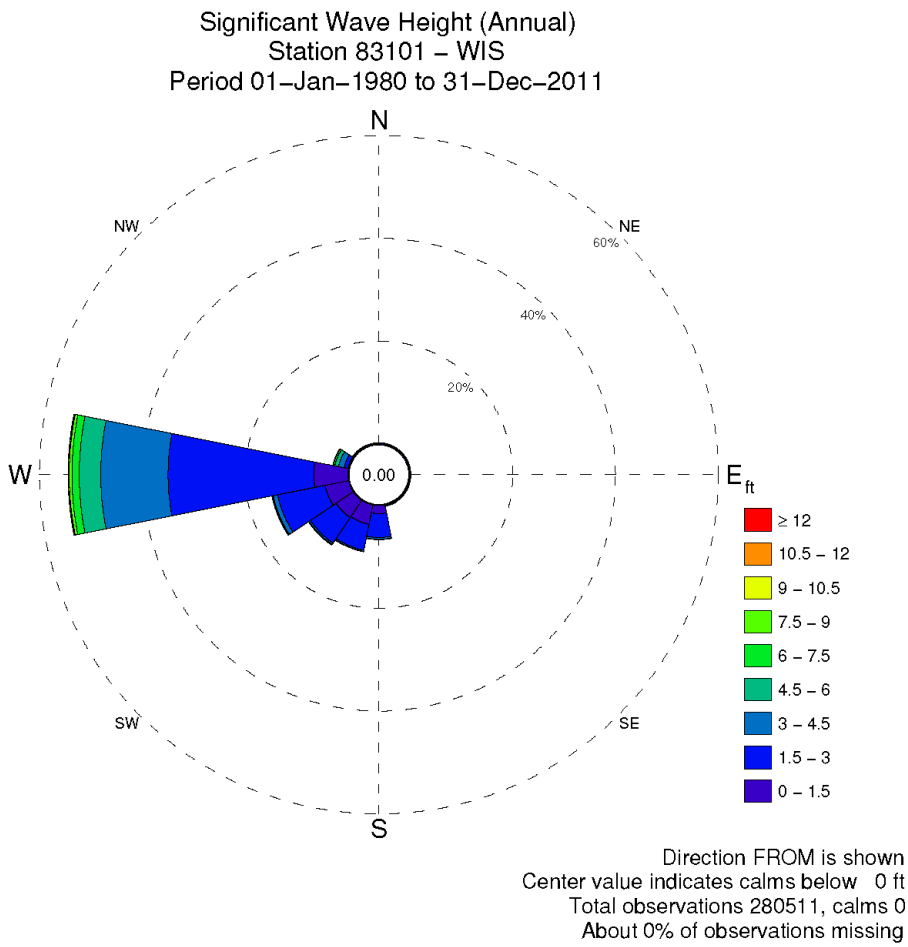
TABLE 6
DEEP WATER EXTREME WAVE EVENTS

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

(Source: USACE 2002)

4.3.2. Wave Climate

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 6). Wave periods were between 10 and 16 seconds with 10-12 seconds occurring the most frequently (Figure 7).



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																	
9													0.17				0.21
7.5													0.53				0.64
6													1.42	0.30			1.81
4.5												0.15	4.17	0.73			5.28
3								0.12	0.35	0.22	0.33	0.86	13.08	1.11			16.16
1.5								0.13	4.64	5.16	6.01	9.42	28.32	0.77	0.11		54.82
0									1.56	3.84	4.01	4.66	6.68	0.14			20.99

FIGURE 6
ANNUAL SIGNIFICANT WAVE HEIGHT DIRECTION AND HEIGHT (WIS STATION 83101)

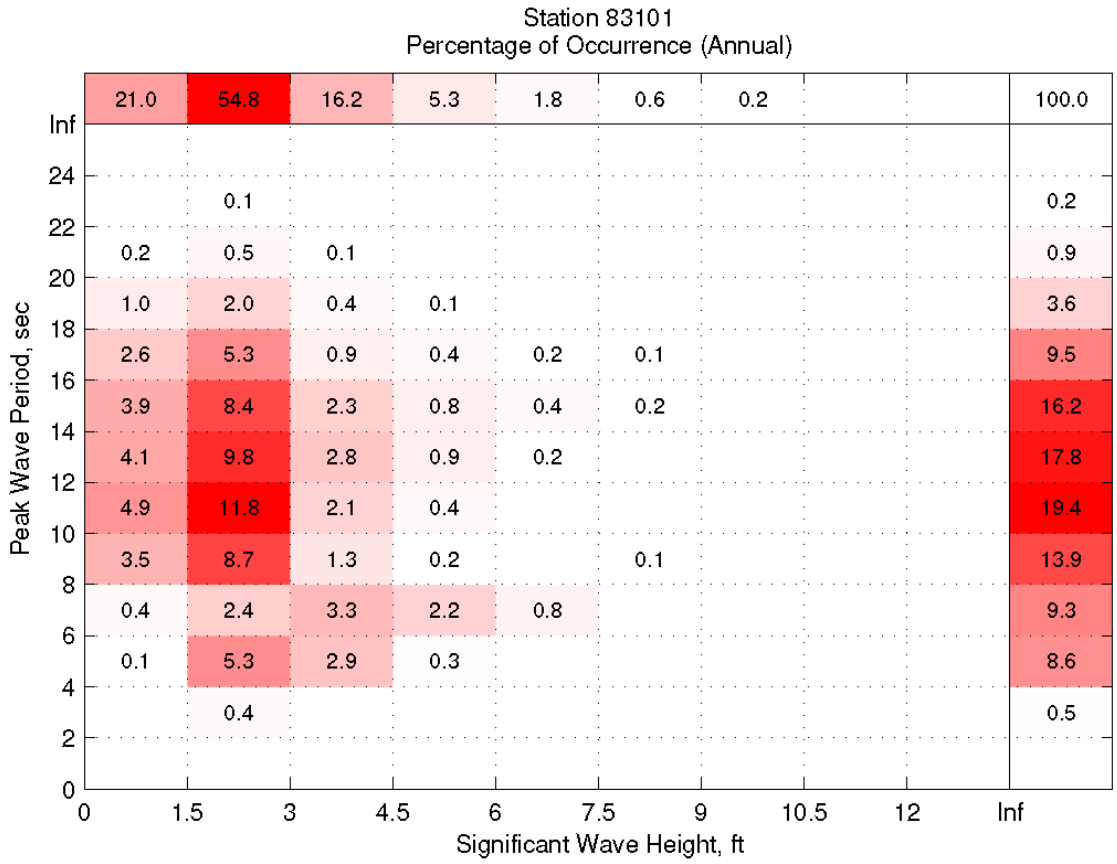


FIGURE 7
SIGNIFICANT WAVE HEIGHT VS. PEAK WAVE PERIOD (WIS STATION 83101)

4.4. 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 (Figure 8). 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. It may, however, be one factor in beach erosion along the base of the Bluffs over time.

Subsidence has also been reported in the Huntington Harbour area due to historic oil production activities. Seawalls/Bulkheads around the Harbour are the primary defense to rising sea levels and subsidence can directly impact the ability 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. Subsidence from these activities has since been slowed by way of underground water injection (M&N 2013).

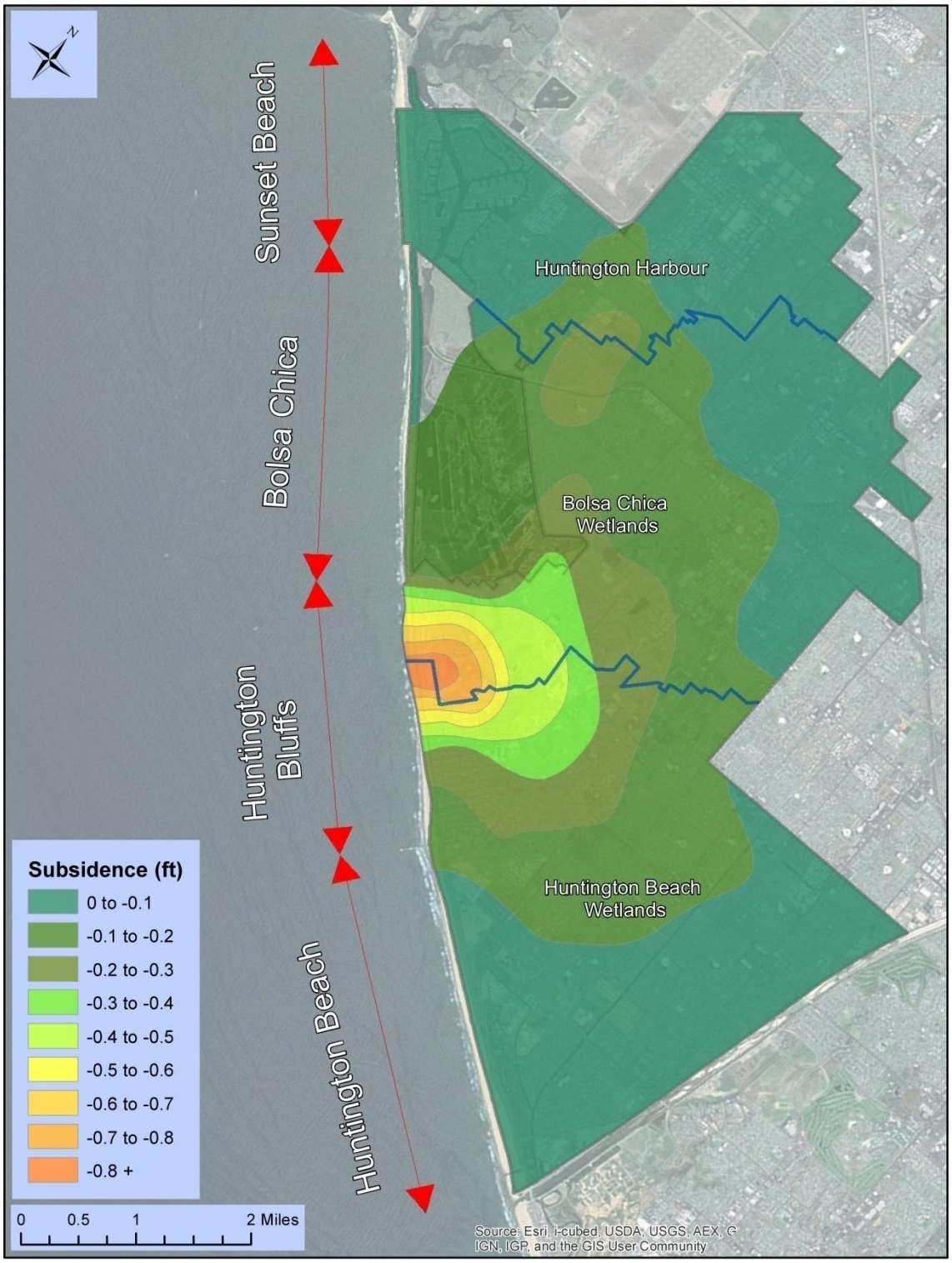


FIGURE 8
SUBSIDENCE WITHIN THE STUDY AREA

4.5. TSUNAMIS

Tsunami inundation maps were developed by the California Emergency Management Agency (CalEMA) now called the Office of Emergency Services (CalOES) and by M&N for the Ports of Long Beach and Los Angeles. These studies were reviewed to assess the Study Area's tsunami vulnerability.

The CalEMA study provides graphics showing a composite of the maximum potential inundation zone and does not provide the wave height associated with these events. Tsunami inundation maps published in the CalEMA study, provided in Appendix A, indicate low lying areas around Huntington Harbour, Bolsa Chica, and south Huntington Beach are within the "credible upper bound" inundation zones.

Huntington Beach's exposure to tsunamis is similar to the ports of Long Beach and Los Angeles where a study titled "Tsunami Hazard Assessment for the Ports of Long Beach and Los Angeles" was prepared by M&N in 2007. This study modeled seven potential tsunami sources to determine a potential worst case scenario. Results indicate a landslide in the vicinity of Palos Verdes would be the worst case tsunami for the region, but has a relatively low probability of occurence with return intervals on the order of 1 in 10,000 years (M&N 2007). Analysis of historical tsunami events indicates the region had experienced wave heights on the order of 2 to 3 feet from the magnitude 9.5 earthquake in Chile in 1960 and the magnitude 9.2 earthquake in Alaska in 1964.

5. Vulnerability and Risk Assessment Methodology

The Study provides a qualitative evaluation of the SLR vulnerabilities and risk within the City by modeling future changes in static and dynamic water levels in the shoreline and inland waterway planning areas, as detailed in Section 7 and Section 8. The purpose of the vulnerability assessment and risk assessment is to identify priority planning areas within the City. This section discusses methods used to assess the vulnerability risk of City planning areas.

5.1. Vulnerability Assessment

Assessments for both planning area types applied numerical modeling techniques to define asset exposure to SLR. A Geographic Information System (GIS) was then used to map affected areas and quantify impacts to assets in the City.

Methodology for assessing vulnerabilities and risk were based on the following guidelines:

- *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments* published by ICLEI-Local Governments for Sustainability (Snover, A.K. et al, 2007).

- *California Adaptation Planning Guide, Planning for Adaptive Communities* prepared by CalEMA (now known as California Office of Emergency Services [CalOES]) and the California Natural Resources Agency (CalEMA, 2012).

The overall vulnerability was then assessed as a function of each asset's exposure, sensitivity, and adaptive capacity. These terms are defined as follows in the context of how they were used to develop this vulnerability assessment:

- **Exposure** is the degree to which a system or asset is exposed to SLR. In this Study, asset exposure to projected SLR was determined through numerical modeling and mapping and is defined in terms of flooding and inundation.

- **Sensitivity** is the degree an asset would be impaired by the impacts of SLR. Systems that are greatly impaired by small changes in SLR have a high sensitivity, while systems that are minimally impaired by the same small change in SLR have a low sensitivity.

- **Adaptive capacity** is the ability of an asset to respond to SLR, to moderate potential damages, to take advantage of opportunities, and to cope with the consequences. This does not mean that the system must look the same as before the impact, but it must provide comparable services and functions with minimum disruption or additional cost.

The vulnerability of an asset increases as the sensitivity increases. Adaptive capacity is inversely related to vulnerability in that as the adaptive capacity increases, the vulnerability decreases. For example, PCH through Sunset Beach has a high sensitivity because even minor flooding can cause significant disruption in service. The roadway has a low adaptive capacity to SLR in that it cannot be easily relocated or raised to cope with consequences; thus, it would be classified as a highly vulnerable asset. Beaches along the coastline are sensitive to small changes in sea level but were assigned a moderate vulnerability because of their relatively high adaptive capacity. These relationships are shown graphically in Figure 9.

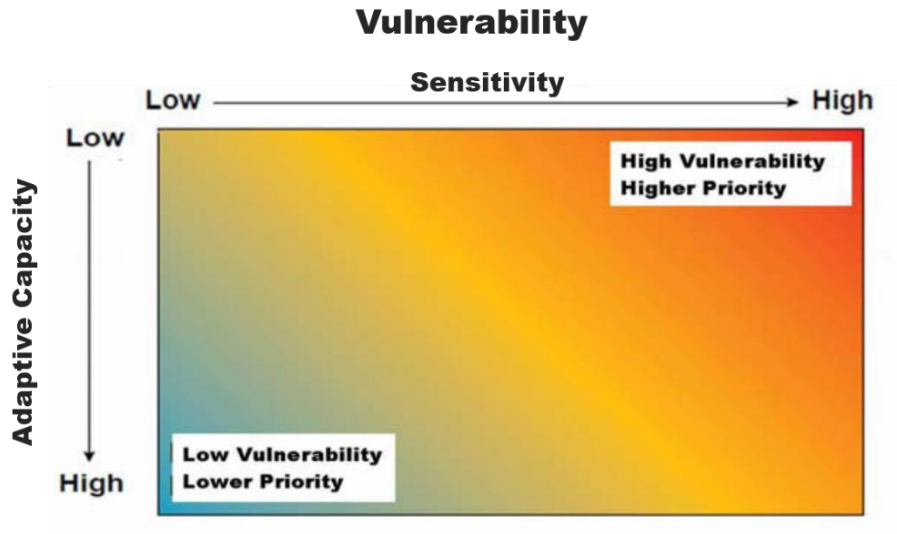


FIGURE 9
RELATIONSHIP BETWEEN SENSITIVITY, ADAPTIVE CAPACITY, AND VULNERABILITY (ICLEI 2012)

5.2. RISK ASSESSMENT

Information collected for the vulnerability assessment is used to estimate the consequence, probability, and resulting risk associated with a specific impact at a specific time horizon. The risk to a given asset depends on: 1) the magnitude of the impact (consequence); and 2) the likelihood of that impact occurring (probability).

This Study includes a qualitative risk assessment based on the “impact threshold” for each asset within each planning area. The “impact threshold” refers to the SLR scenario at which impacts to each asset become significant. A magnitude of the consequence (low/moderate/ high) was assigned based on the potential for damage or disruption of service that each asset would experience for a given SLR scenario. Similarly, a qualitative probability (low/moderate/ high) was assigned based on the probability of occurrence for a given “impact threshold.”

It’s important to note that consequence, probability, and therefore, risk, vary significantly with several factors, including:

- Time – In general, the magnitude of consequence increases with rising sea levels. The probability of SLR at a specific time horizon is inversely related to projected values (low/ medium/high). At a given time horizon, there is a high probability of the low projection occurring and a low probability of the high projection occurring.

  Probabilities for a specific rise in sea level increase with time. For example a 1-ft rise in sea level has a low probability of occurrence for the 2030 time horizon, but a high probability of occurrence by 2050. Similarly, a 3-ft rise in sea level has a low probability of occurrence by 2050 but a high probability of occurrence in 2100.

- Source of Flooding – This Study considers the potential for SLR impacts for three scenarios:

1) High water level combined with SLR

   A 2-year return period water level was selected for this analysis to represent an event that occurs relatively frequently. There is a 50% chance of occurrence in a single year. This scenario has a high probability of occurrence if sea levels rise as projected.

2) 100-year wave event with SLR

   A 100-year wave event has a 1% chance of occurrence in a single year and is generally considered a conservative design event. However, for durations longer than a single year, the probability of an extreme event increases. For example, over a duration of 50 years, an extreme event (100-year) has a 39.5% chance of occurrence.

3) 100-year riverine discharge with SLR

   Similar to the second scenario, this scenario evaluates a 100-year riverine flood event combined with the effects of SLR at the channel outlet.

Based on the assigned values for consequence and probability a risk level was selected for each asset in each planning area. The objective of the risk assessment was to identify priority planning areas for a focused coastal resiliency plan. Planning areas with important assets at risk in relatively short planning horizons (2030 to 2050) will be given priority. Planning areas with important assets at risk over longer planning horizons (2100) will be given lower priority. This does not mean these planning areas are at less risk or are less valuable, only that there is more time to develop coastal resiliency plans and adaptation measures.

6. Modeling Approach

Numerical modeling of coastal erosion and flooding was used to identify the exposure and sensitivity of shoreline planning area assets to a range of SLR projections. Numerical modeling of tidal inundation and runoff from extreme rainfall events was used to identify the exposure and sensitivity of assets around the inland waterway planning areas.

SLR impacts are described in terms of flooding and inundation. Flooding refers to normally dry land being covered with water for a short period of time. Flooding events can be caused by wave run-up associated with extreme wave heights or stormwater flooding from extreme rainfall events, such as the 1% storm event (commonly called the 100-year storm). For the purposes of this Study, flooding caused by wave runup was considered any point that was covered by 8 inches or more of water for 2% (approximately 86 minutes) of the model run-time. For inland waterway planning areas, the extents of flooding were mapped for land below the 50% annual exceedance probability water level (2-year return period). Inundation is when land that was once dry becomes permanently or frequently submerged as a result of increased water levels associated with high tides and projected SLR. For shoreline planning areas, inundated areas are assumed anywhere overlain by the mean higher high water (MHHW) shoreline position in this Study.

The erosion potential of each of the SLR scenarios is also discussed for each of the shoreline planning areas. Erosion is a result of both chronic changes in the shoreline as a result of SLR and episodic changes associated with major storm events. These two mechanisms were coupled in this analysis. Long-term shoreline changes as a result of SLR were first accounted for using the Bruun Rule (Bruun 1962), a commonly used method to estimate the landward shift of a beach profile due to SLR. Episodic changes were then estimated using numerical modeling methods to estimate the effect of a 100-year wave event on this long-term adjusted profile.

6.1. Shoreline Planning Areas

A process-based, two-dimensional (2D) numerical model called *XBeach* was used to model future SLR impacts in the Study Area. A total of 33 transects were developed to create the numerical modeling domain, as shown in Figure 10. These locations correspond to sites used for periodic beach profile monitoring by the Corps and are considered representative of the Study Area.

Best available topographic and bathymetric data were used to generate the beach profiles at each of these locations. Beach profile data collected in 2010 by Coastal Frontiers Corporation were used for the bathymetric portion (approximately -60 ft, MLLW to +14 ft, MLLW). The bathymetric data were augmented with topographic data extracted from a digital elevation model (DEM) developed by the U.S. Geological Survey. These data extended from +14 ft (MLLW) to approximately 10,000 ft landward of the shore.

The Bruun Rule was used to predict the long-term shoreline response to SLR. The Bruun Rule is widely accepted as an approach to predict the chronic erosion of sandy shorelines due to SLR. The rule hypothesizes that as the sea level rises, the shoreface will respond by moving landward. This is shown graphically for Transect 1 in Sunset Beach, as shown in Figure 11. Each of the 33 transects within the modeling domain were adjusted to account for this long-term profile change for each of the planning horizons.

Once the long-term beach profiles were developed, a numerical model called *XBeach* was used to predict the short-term shoreline response and wave run-up during a 100-year storm event. *XBeach* is intended as a tool to compute the coastal response of the nearshore area, beaches, dunes, and back-barrier during storms. *XBeach* is a two-dimensional (2D) model for wave propagation, long waves and mean flow, sediment transport, and morphological changes of the nearshore area, beaches, dunes, and back-barrier during storms (Deltares 2010). *XBeach* is a relatively new numerical model and has several advantages to its predecessors, such as:

- Non-stationary wave driver with directional spreading to account for wave-group generated surf and swash motions;

- Avalanching algorithm suitable for 2D applications that accounts for the fact that saturated sand moves more easily than dry sand by introducing both a critical wet and dry slope. In addition, the avalanching algorithm is not applied only between adjacent cells; rather long-wave swash motions can trigger a chain reaction or avalanching of grid cells along a dune.

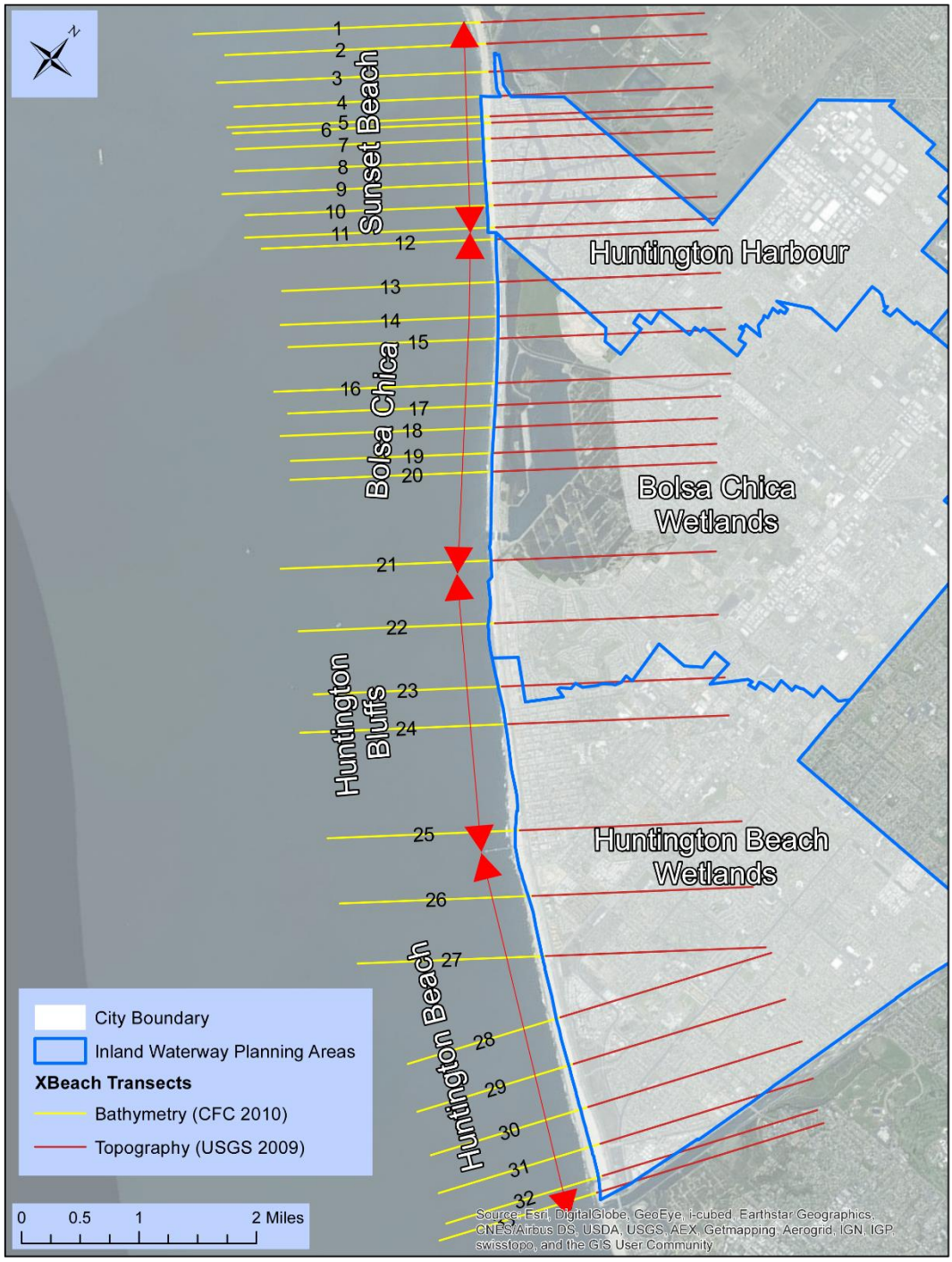


FIGURE 10
XBEACH TRANSECT LOCATIONS

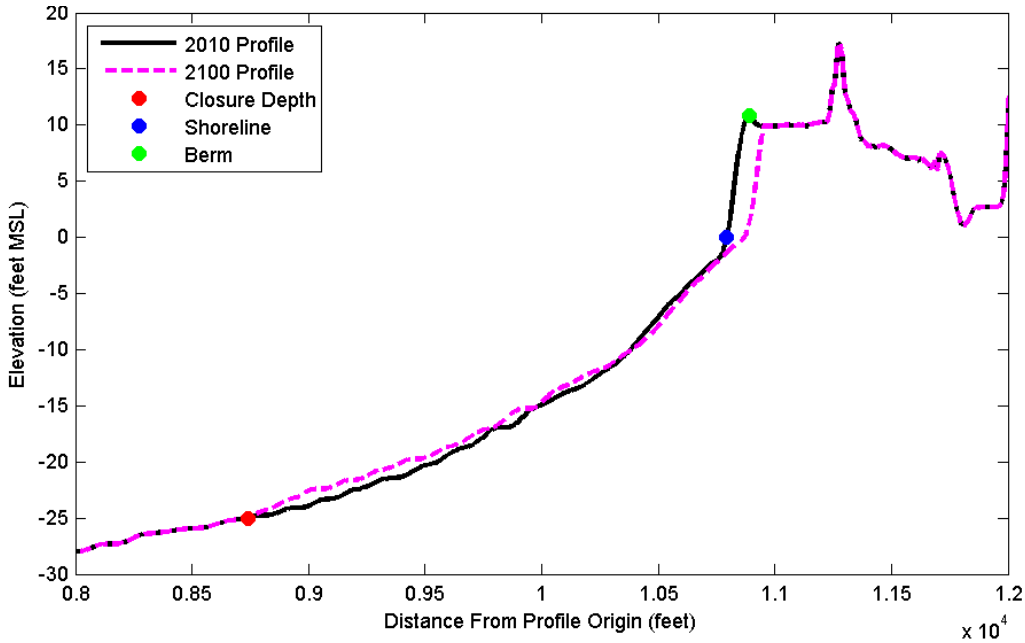


FIGURE 11
LONG-TERM SHORELINE RESPONSE TO SLR (BRUUN RULE), SUNSET BEACH SHORELINE PLANNING AREA, TRANSECT 1

6.1.1. Future Water Level Scenarios

A total of 10 future water level scenarios were modeled for the shoreline vulnerability assessment. These scenarios include some component of SLR in combination with a high tide and a 100-year wave event. The January 1988 storm was scaled up from a peak wave height of 17.6 ft to 18.2 ft to be representative of a 100-year recurrence wave event (Figure 12). These various dynamic and static contributions to the total water level scenarios are shown in Table 7 below.

TABLE 7
SHORELINE MODELING SCENARIOS

Scenario	Time Horizon	Sea Level Rise Scenario (NRC 2012)	Sea Level Rise (ft) (NRC 2012)	Tide Level (ft, MLLW)	100-year Significant Wave Height (Hs, ft)
1	2010	None	0.00	6.48	18.2
2	2030	Low	0.15		
3		Medium	0.50		
4		High	1.00		
5	2050	Low	0.40		
6		Medium	0.90		
7		High	2.00		
8	2100	Low	1.40		
9		Medium	3.10		
10		High	5.50		

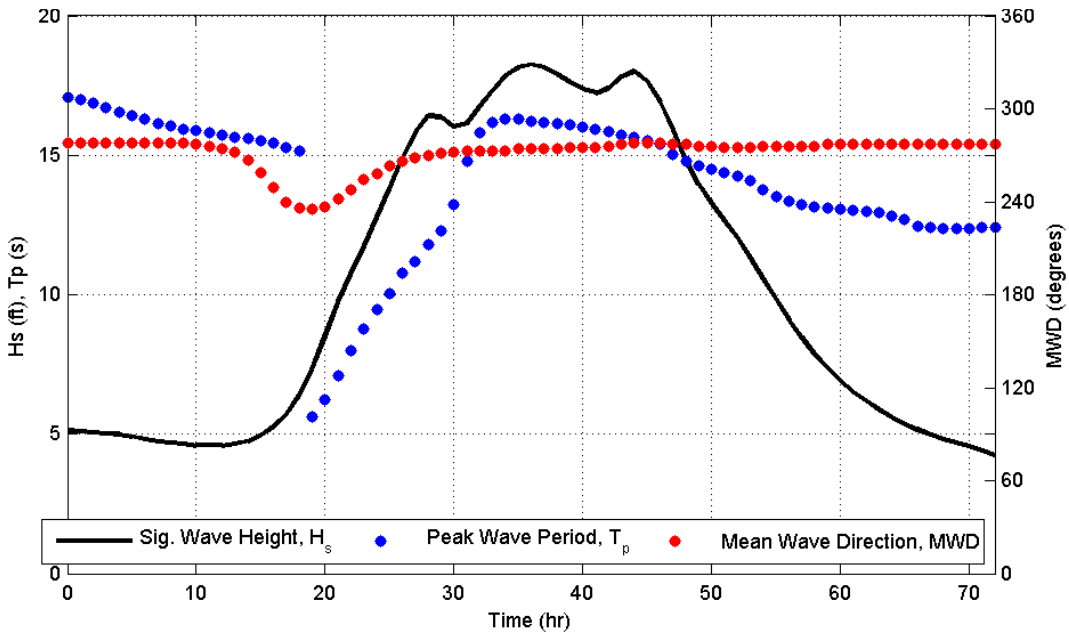


FIGURE 12
100-YEAR RETURN PERIOD WAVE EVENT

6.1.2. Asset Inventory and Vulnerability Mapping

Modeling results were initially displayed as points along each of the 33 transects. These points were mapped by linearly connecting points between beach recession and runup positions. In non-contiguous topographic sections of the shoreline or hinterland areas, the high resolution topography collected by the City in 2013 was used in combination with engineering judgment to locate the position of potential flooding or inundation.

A geo-referenced shoreline asset inventory was created in GIS of impacted and potentially impacted resources within the City. Assets included in the geodatabase include beaches, roads, pedestrian paths, bike paths, parking lots, buildings, walls, revetments, storm drains, and sensitive habitats. The study did not analyze the vulnerability of gas lines, electrical lines, and other underground utilities due to SLR. Asset classes were populated with appropriate attribute information such as critical elevations, structure types, year built, replacement cost, and condition.

6.1.3. Modeling Limitations

Model results were interpolated between the 33 transect locations in order to show the spatial limits of flooding and inundation within the City. Elevation data output from the model was used in combination with high resolution topographic data and engineering judgment to determine the location of flooding limits between transects. This methodology was used due to the availability of data at these transect locations and in order to scale the modeling effort suitably to the schedule and budget.

6.2. Inland Waterways Planning Areas

6.2.1. Tidal Flooding

The most direct impact of rising sea levels on the inland waterway planning areas will be the increased potential for tidal flooding during high tides. Most communities along the inland waterways are currently protected from tidal flooding by seawalls, bulkheads, or levees. The crest elevation and condition of these structures is a controlling factor in the amount and extent of potential flooding for various SLR projections.

The sensitivity of communities to tidal flooding was determined by comparing the extreme water level for each SLR projection with the existing top of levee/seawall/bulkhead elevation. If a projected water level exceeds the estimated top of levee elevation, then flooding can be expected. Flooding limits were mapped using 1-ft contours generated from light detection and ranging (LiDAR) data captured in October 2013.

“As-built” plans, LIDAR topography, and available survey data were used to estimate the crest elevations of existing seawalls and levees. Reasonably accurate crest elevations (± 0.5 ft) could be determined from LIDAR topography for earthen levees, such as those around Bolsa Chica and along the Bolsa Chica C02 and East Garden Grove Wintersburg C05 flood control channels. For sheetpile walls, the top of wall elevations were estimated from “as-built” plans obtained from Orange County Public Works.

Limited data available for seawalls around Huntington Harbour indicate the typical crest elevation ranges from +8 to +10 (ft, NAVD 88). However, some portions of Huntington Harbour do not have any seawall or bulkhead lining. Because of limited “as-built” information and several known areas without a seawall/bulkhead, mapping of tidal flooding in the Harbour area was based only on LIDAR topography and did not account for seawalls/bulkheads. Based on the water levels evaluated in the study (Table 8) existing seawalls with a crest elevation of +8 (ft, NAVD 88) or lower would be overtopped. Even locations around the Harbour with higher seawall/bulkhead crest elevations may still be subject to flooding from adjacent properties with a low crested structure or no structure at all.

The extreme water level selected for the analysis was +7.18 (ft, NAVD 88), which is slightly higher than a typical “King Tide” water level. This water level has a 50% annual exceedance probability (2-year return period) based on analysis of water level data from the Los Angeles tide gauge (NOAA Tides and Currents, Station 9410660, 1983-2001 tidal epoch), which includes the effects of astronomical tide, storm surge, and El Nino Southern Oscillation (ENSO) events. The Los Angeles tide gauge has the longest record of water levels (90+ years) in the region and, therefore, provides more reliable water level statistics. The water levels mapped for each SLR scenario are listed in Table 8.

The high tide elevation used for this tidal flooding analysis (7.18 ft NAVD) is higher than that used for the coastal erosion and flooding analysis (6.48 ft NAVD), and this results in certain areas shown to be tidally-flooded in the future while not being exposed to flooding by high waves and high tides. Results will vary between the coastal flooding analysis and the tidal flooding analysis in this document. Also, this tidal flooding analysis is based on using the highest SLR prediction for a given timeframe, so results are extremely conservative.

TABLE 8
WATER LEVELS FOR TIDAL FLOODING MAPPING

SLR Scenario	SLR (ft)	Water Level (ft, NAVD 88)	Combined Water Level (ft, NAVD 88)
2030 High	1.0	7.18	8.18
2050 High	2.0	7.18	9.18
2100 High	5.5	7.18	12.68

6.2.1.1. LIMITATIONS OF TIDAL FLOODING ANALYSIS

The tidal flooding analysis was based on comparing a specific water level with the top elevation of a levee or seawall/bulkhead where applicable. If the specific water level was higher than the top of levee/wall then flooding landward of the barrier was assumed. The limit of flooding was assumed to extend landward until the ground elevation was higher than the specific water level. This method of analysis includes the following limitations:

- Actual top of levee/wall elevations vary: Actual top of wall elevations may vary from what is shown on the “as-built” plans due to subsidence, settlement or other factors. Levee elevations determined from LIDAR are accurate to within about ±0.5 feet. Seawall/Bulkhead information around Huntington Harbour indicates the top of wall elevation varies from +8 to +10 feet above MLLW. Variations in actual top of wall elevations would influence both duration and extent of flooding for future SLR scenarios in which overtopping may occur.
- Condition of the existing structures not accounted for: The condition of existing levees, seawalls and bulkheads will be an important factor in their ability to tolerate and withstand the effects of higher water levels and overtopping that may occur if sea levels rise as projected.
- Duration of flooding not included: In some cases the extent of flooding will be limited by the volume of water, not the ground elevations. For example, in situations where the specific water level is only slightly higher than the top of levee/wall flooding will occur over a short period of time during peak high tide. The volume of water overtopping the structure over such a limited duration would likely control the extents of flooding. Since the duration of flooding was not accounted for in this analysis, the extents of flooding shown may be conservative.
- Flow reversal in storm drains not included: Flow reversal through storm drains was not accounted for in this analysis. In situations where sea levels rise significantly, there is potential for backflow through storm drains and catch basins to flood areas protected by levees or seawalls.

6.2.2. Flooding from Extreme Rainfall Events

SLR will increase the risk of flooding from extreme rainfall events. Many of the regional flood control channels have low invert elevations, relatively flat slopes, and are controlled at the downstream end by ocean water levels. Numerical modeling of tidal and flood hydraulics was performed to simulate the effects of SLR projections on flood profiles for several major flood control channels in Huntington Beach.

The purpose of this flood modeling was to assess the impact of rising sea levels on the conveyance capacity of the regional flood control channels. The flood levels in these regional channels set the downstream boundary for local (City) storm drains and channels. Although estimates for 100-year water surface elevations are provided, the results of this study should not be used for estimating Federal Emergency Management Agency (FEMA) base flood elevations or floodplain mapping. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by FEMA.

A 2-D, vertically-averaged finite element hydrodynamics model (RMA-2) was used to simulate the tidal and flood hydrodynamics of the Huntington Harbour area and the Huntington Beach wetlands area. RMA-2 is a component of the TABS2 (McAnally and Thomas 1985) modeling system developed by the Corps.

The Huntington Harbour RMA-2 model was based on a previous model developed and calibrated for the Bolsa Chica Restoration project. This model was updated with the most recent geometry, topographic, and bathymetric data available for the harbor area and Bolsa Chica Channel (C02). The Anaheim-Barber City Channel (C03), Westminster Channel (C04) and Sunset Channel (C07) were not evaluated in this study.

The Huntington Beach wetlands RMA-2 model was initially developed to analyze wetland restoration alternatives planned for Magnolia and Brookhurst marshes in south Huntington Beach. This model was refined to reflect an “as-built” condition of the restored wetlands using data from the “as-built” plans and recent LIDAR topography. The model area was expanded to include Huntington Beach Channel (D01), Talbert Channel (D02) and a portion of Fountain Valley Channel (D05) within the City limits.

The EGGWC (C05) was modeled using a Water Surface Pressure Gradient (WSPG) model of the ultimate channel configuration developed by Orange County Public Works. WSPG is a steady state model run that assumes a static water surface elevation at the downstream boundary and a constant flow rate in the channel. Water levels from the RMA-2 model of Huntington Harbour were used to establish the downstream starting water surface elevation at the tide gates.

The RMA-2 simulations were run with variable boundary conditions to better represent actual flow conditions in the inland waterways of Huntington Harbour and Huntington Beach Wetlands. A tide series representative of an average spring high tide was applied at the ocean boundary of each model. The average spring high tide series occurs once to twice per month and, therefore, provides a conservative but reasonable downstream boundary for the flood simulations. The ocean water levels selected for flood modeling are lower than used for tidal inundation mapping because the joint probability of an extreme flood event coinciding with an extreme high tide event is low. The peak high tide of the average spring tide series was 6.44 (ft, NAVD88). The entire tide series was increased for each SLR projection, as shown in Table 9.

TABLE 9
OCEAN WATER LEVELS FOR FLOOD MODELING

SLR Scenario	SLR (ft)	Maximum Water Level (ft, NAVD 88)	Combined Water Level (ft, NAVD 88)
2030 High	1.0	6.44	7.44
2050 High	2.0	6.44	8.44
2100 High	5.5	6.44	11.94

Flood hydrographs were provided by Orange County Public Works (OCPW) for the 100-year storm event for each flood control channel modeled. Hydrographs provided for Bolsa Chica Channel (C02) are from a draft study that has not been finalized, but provides a reasonable estimate of the 100-year discharge. Peak flow rates for the ultimate configuration of the EGGWC (C05) were provided in the WSPG model developed by OCPW. Hydrology for the Talbert Valley channel system was based on design flow rates used for the recent channel improvements that were published in Exhibit KK of the Fountain Valley Channel Diversion Feasibility Report (RBF 1990). This report provides 100-year peak flow rates for the Huntington Beach Channel (D01), Talbert Channel (D02), and Fountain Valley Channel (D05). Where complete hydrographs were not available, a 24-hour pattern hydrograph was scaled to match the peak flow rates.

TABLE 10
100-YEAR PEAK DISCHARGES FOR FLOOD MODELING

Channel	OC Facility ID	100-yr Peak Flow (cfs)	Location
Bolsa Chica Channel	C02	11,917	Downstream of C04
EGGWC	C05	9,290	Tidegates
Huntington Beach Channel	D01	2,315	U/S of D02 Confluence
Talbert Channel	D02	3,325	U/S of D01 Confluence
East Valley-Fountain Valley Channel	D05	1,515	U/S of D02 Confluence

6.2.2.1. LIMITATIONS OF FLOOD MODELING

The purpose of flood modeling was to determine the relative impact of SLR on conveyance capacity of regional flood control channels. The numerical models used and methods applied include the following limitations:

- Culverts not included in RMA-2 models: The models developed for the Huntington Beach Wetlands area did not account for bridge crossings over the Huntington Beach Channel (D01), Talbert Channel (D02), and Fountain Valley Channel (D05). These channels were assumed to be open rectangular channels in which the water surface elevations are not obstructed by the bridge decks. Because of this limitation, the model results may underestimate water surface elevations along these channels.

- EGGWC (C05) model run in steady state: Due to WSPG model limitations the EGGWC was modeled with a fixed downstream boundary and fixed flow rate. In reality the downstream boundary water surface elevation and flow rate in the channel will vary and the actual water surface profile may also vary.

- EGGWC modeled using future conditions: The model provided by OC Public Works includes the ultimate configuration of the channel. The time horizon at which the ultimate channel configuration will be in place is uncertain and portions of the channel that remain in their existing condition will significantly impact channel capacity.

- Flood hydrographs: The existing 100-yr flow rates were used for each time horizon. The impact of a changing climate on regional hydrology was not accounted for in this analysis.

7. Shoreline Area Vulnerability Assessment

SLR impacts within the shoreline planning areas are discussed in terms of erosion, flooding (as a result of wave run-up), and inundation (as a result of daily tides). Results of the shoreline vulnerability assessment are summarized in this section. Flooding and inundation graphics are only presented in this section for years where assets were impacted. The graphics are zoomed in to areas of greatest vulnerability within the planning area in order to support the discussion. Model output graphics for each planning area for each time horizon, as well as more detail regarding methods, are provided in Appendix A.

7.1. Shoreline Erosion

Predicted shoreline erosion for the Study Area is shown in Table 11. Shoreline erosion estimates were made relative to the May 2010 mean higher high water (MHHW) shoreline position, as measured by Coastal Frontiers Corporation. As shown in Table 11, the largest shoreline recessions were experienced in the Huntington Beach Planning Area. The largest variability (as shown by the standard deviation) was within the 2100 planning horizon. The reason the largest areas of erosion are predicted within the Huntington Beach Area is because that area is the largest of the planning areas, and has the widest beach (i.e., it possesses the largest beach area available for erosion).

Table 11
Shoreline Erosion per Planning Area

Year	SLR Scenario	Sunset Beach Eroded Area (acre)	Bolsa Chica Eroded Area (acre)	Huntington Bluffs Eroded Area (acre)	Huntington Beach Eroded Area (acre)	Average	Standard Deviation (+/-)
2030	Low	4.2	10.2	4.3	12.6	7.8	3.7
	Medium	6.1	14.3	6.0	15.8	10.6	4.5
	High	9.1	20.3	8.5	21.2	14.8	6.0
2050	Low	5.6	12.9	5.4	15.2	9.8	4.3
	Medium	15.2	19.1	8.0	20.5	15.7	4.9
	High	13.9	31.6	12.3	31.8	22.4	9.3
2100	Low	11.0	24.7	9.9	25.4	17.8	7.3
	Medium	17.7	42.0	19.2	45.2	31.0	12.6
	High	28.2	87.3	36.0	122.0	68.4	38.4

7.2. Coastal Flooding and Inundation

Coastal flooding is described in terms of flooding and inundation, as described previously. The Study Area is more vulnerable to flooding (episodically ponded) than to inundation (near-permanent ponding) within the planning horizons considered. Coastal vulnerabilities per planning area are discussed in this section.

In the coastal hazard graphics provided in this section, flooded areas are shown as a blue, semi-transparent polygon, which illustrates the range of potential wave run-up for the horizon year bracketed by the low and high SLR scenarios. Note that the run-up location is a function of the predicted shoreline position for each scenario.

7.2.1. Sunset Beach Planning Area

This area has flooded in the past from a combination of coastal and inland waterway contributions during a high tide and an 11-ft significant wave height event in 2010, as shown in Photo 1 and Photo 2. It should be noted that a winter dike is constructed annually along the beach in this planning area, from approximately Anderson Street to Warner Avenue. The winter dike feature was not included in the model as the intent of the Study was to depict a worst-case scenario for the planning area. Additionally, the design of this feature is currently being reconsidered.

PHOTO 1

PHOTO 2

FLOODING AT ANDERSON STREET IN JANUARY 2010

(Photos courtesy of Susan Brodeur, OC Parks)

A vulnerability assessment of the Sunset Beach planning area was performed following the methodology outlined in Section 5. The results of the vulnerability assessment are summarized in Table 12 and shown in Figure 13.

TABLE 12
SUNSET BEACH PLANNING AREA – VULNERABILITY ASSESSMENT

Asset	Exposure				Sensitivity to SLR	Adaptive Capacity	Vulnerability
	Impact Threshold	Type of Impact	Max. No. Assets Impacted	Rating			
Beaches	2030 - Low	Erosion	4.2 acres	High	Low	High	Low
Residential and Commercial Buildings*	2100 - High	Flooding	30 buildings	Low	Moderate	Low	Moderate
Transportation (Roads)	2100 - High	Flooding	67,584 sq.ft.	Low	High	Low	High

**Only included buildings within City limits.*

Exposure was characterized in terms of type, year, and number of assets impacted. The "impact threshold" refers to the SLR scenario at which impacts to each asset are realized. Adaptive capacity was also assigned qualitatively based on the ability of each asset to accommodate a rise in sea level while maintaining its function or service. Findings of the vulnerability assessment are described per asset below:

- **Beaches** were assigned a low vulnerability because they have a low sensitivity and a high adaptive capacity, assuming the federal beach nourishment project will continue to provide sand to the shoreline and possibly be augmented to meet increased demand. Beaches were assumed to have a high adaptive capacity because they will naturally adjust to a rising sea level and function as a recreational amenity. However, their exposure is high with anticipated erosional impacts with any SLR scenario. The inner beaches around Huntington Harbour are excluded from this category since they have limited ability to adapt to rising sea levels.

- **Residential and commercial buildings** were assigned a moderate vulnerability due to having a low adaptive capacity and moderate sensitivity. However, the adaptive capacity of buildings could potentially be moderate for some parcels with finished floors on an elevated building pad. Even low lying homes have some adaptive capacity in the form of low cost flood barriers (i.e., sandbags, plywood, or other temporary material) to limit damage from minor flooding. However, reliance on temporary measures may not be adequate to accommodate SLR beyond 2100.

  These assets become exposed to flooding in year 2100 under the high SLR scenario, giving them a low overall exposure rating. A total of 30 residential properties were determined to be vulnerable in this scenario.

- **Transportation infrastructure** was assigned a high vulnerability owing to its high sensitivity and low adaptive capacity. Even minor amounts of flooding on the roads can cause significant traffic delays and potentially disrupt emergency service vehicles and

evacuation routes. Maintenance and repair requirements would also increase after significant flooding, but the primary impact is disruption of service.

These assets become exposed to flooding in year 2100 under the high SLR scenario, giving them a low overall exposure rating. A total of 6 transportation assets were determined to be vulnerable in this scenario.

The value of the assets within the planning area was estimated in order to attempt to quantify the resources at risk, as a function of potential consequences. Replacement costs were derived from GIS data provided by the City. Engineering judgment was used in areas where GIS replacement value data were not available. Costs assumed complete replacement of the structure, a very conservative assumption in most cases. However, costs do not include land values or planning and permitting costs associated with rebuilding. The approximate values of the assets at risk within the Sunset Beach planning area are provided in Table 13. Approximately $8 million worth of assets is potentially at risk to future SLR. Results of the risk assessment for each of the asset categories are shown in Table 14.

TABLE 13
SUNSET BEACH PLANNING AREA – EXPOSED ASSET VALUES

Asset Type	Quantity of Assets	Area (sq.ft.)	Replacement Cost*	Asset Cost Estimate Source**	Replacement Value ($)**
Buildings	30	NA	$250,000 / structure	Engineer's Estimate	$7,500,000
Transportation (Roads)	6	68,000	$3 / sq.ft.	Engineer's Estimate	$204,000
				Total Asset Value	**$7,704,000**

**Estimates based on 2014 dollars.*
***Engineer's estimate based on unit cost for recent comparable projects*

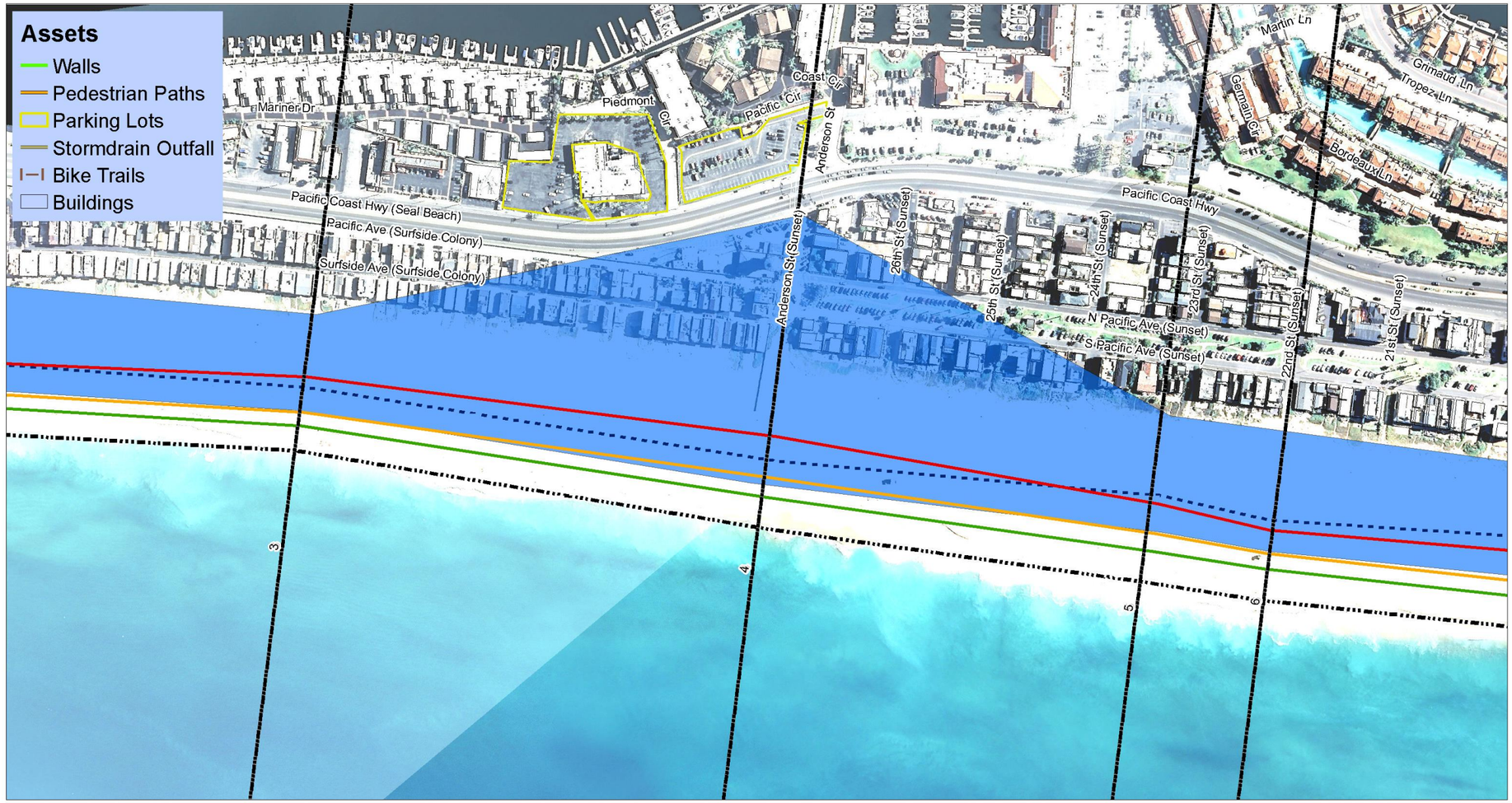
TABLE 14
SUNSET BEACH PLANNING AREA – RISK ASSESSMENT

Asset	Impact	Consequence of Impact	Probability of Impact	Overall Risk to Asset
Beaches	Erosion	MODERATE loss of natural protection, loss of recreational beach area	HIGH Loss of beach is highly likely for future SLR projections	HIGH
Residential and Commercial Buildings	Flooding	HIGH Significant cost to repair buildings / loss of function	LOW unlikely to occur until 2100 time horizon	MODERATE
Transportation (Roads)	Flooding	HIGH Loss of service (traffic, emergency service delays), loss of evacuation routes, higher maintenance & repair cost	LOW unlikely to occur until 2100 time horizon	MODERATE
			Planning Area Risk Rating	**Moderate – High**

Based on these results, this planning area is considered to have a moderate to high overall risk. Findings of the vulnerability assessment are as follows:

- **Beaches** in this planning area are at high risk of impacts from SLR. Increased beach erosion from rising sea levels will reduce the natural barrier to storm waves provided by the sandy beach. There also may be a “soft” economic cost associated with a loss of recreational beach. These impacts are expected for small to moderate rates of SLR and become severe for projected SLR values by 2050 and 2100.

- T**ransportation assets** and **residential and commercial buildings** in this planning area face a moderate risk from impacts related to storm waves and SLR. Model results indicate these assets are not at risk to flooding until 2100 under the high SLR projections are reached, so they were assigned a relatively low probability of occurrence. However, the consequences are high for even small amounts of flooding.



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Coastal Inundation (MHHW Shoreline Position)

- Low SLR
- Projected SLR
- High SLR
- 2010 Shoreline Position (MHHW)

Coastal Flooding (Wave Run-up)

- Wave Run-up (Low to High SLR)
- Wave Run-up (Projected SLR)

XBeach Transects

Job No.: 8286
Date: 04/23/2014

FIGURE 13
IMPACTED ASSETS IN SUNSET BEACH PLANNING AREA – YEAR 2100

7.2.2. Bolsa Chica Planning Area

Assets within the Bolsa Chica Planning Area become vulnerable to coastal flooding and inundation in the 2100 time horizon under the projected high SLR scenario (Figure 14). Vulnerable assets include parking lots, bike trails, buildings, pedestrian paths and transportation. The vulnerability of these assets is detailed in Table 15 and shown graphically in Figure 14.

TABLE 15
BOLSA CHICA PLANNING AREA – VULNERABILITY ASSESSMENT

Asset	Exposure				Sensitivity	Adaptive Capacity	Vulnerability
	Impact Threshold	Type of Impact	Max. Quantity Assets Impacted	Rating			
Beaches	2030	Erosion	87 acres	High	Low	High	Low
Transportation (Roads) PCH	2100 - High SLR	Flooding	5,280 ft	Low	High	Low	High
State Parks Buildings	2100 - High SLR	Flooding and Inundation	9 buildings	Low	Moderate	Low	Moderate
State Parks Parking Lots	2100 - High SLR	Flooding and Inundation	1,229,000 sq.ft.	Low	Moderate	Low	Moderate
Bike Trails	2100 - High SLR	Flooding and Inundation	8,000 ft.	Low	Moderate	Low	Moderate
Pedestrian Trails	2100 - High SLR	Flooding and Inundation	200 ft.	Low	Low	Moderate	Low

Findings of the vulnerability assessment are described per asset below:

- **Beaches** were assigned a low vulnerability because they have a low sensitivity and a high adaptive capacity. However, their exposure is high with anticipated erosional impacts with any SLR scenario. The Surfside-Sunset Beach Nourishment Project increases the resiliency of beaches in the City by providing a frequent source of sediment to the system.

- **Pacific Coast Highway** was assigned a high vulnerability owing to its high sensitivity and low adaptive capacity. Even minor amounts of flooding on the roadway would cause significant traffic delays and potentially disrupt emergency service vehicles and evacuation routes. Maintenance and repair requirements would also increase after significant flooding but the primary impact anticipated would be the disruption of service. PCH becomes exposed to flooding in year 2100 under the high SLR scenario, giving it a low overall exposure.

- **State Parking Buildings, Parking Lots and Bike Trails** were assigned a moderate vulnerability due to their moderate sensitivity and low adaptive capacity.

- **Pedestrian Trails** were determined to have a low vulnerability due to having a low sensitivity and moderate ability to cope with future flooding and inundation.

The approximate values of the assets at risk within the Bolsa Chica planning area are provided in Table 16. Approximately $6 million worth of assets is potentially at risk to future rates of SLR. Results of the risk assessment for each of the asset categories are shown in Table 17.

TABLE 16
BOLSA CHICA PLANNING AREA – EXPOSED ASSET VALUES

Asset	Quantity of Impacted Assets	Replacement Costs (USD)*	Asset Cost Estimate Source**	Replacement Value (USD)***
Parking Lots	1,229,000 sq.ft.	$3 / sq.ft.	Engineer's Estimate	$3,687,000
Bike Trails	8,000 ft. (48,000 sq.ft.)	$10 / sq.ft. ($60/ft assuming 6-foot width)	Engineer's Estimate	$478,000
Pedestrian Trails	200 ft. (1,200 sq.ft.)	$10 / sq.ft. ($60/ft assuming 6-foot width)	Engineer's Estimate	$13,000
Buildings	9 structures	$150,000 / structure	Engineer's Estimate	$1,350,000
Transportation (Roads) - PCH	5,280 ft (211,200 sq.ft.)	$3 / sq.ft.	Engineer's Estimate	$634,000
			Total Asset Value	**$6,162,000**

**Estimates based on 2014 dollars.*
***Engineer's estimate based on unit cost for recent comparable projects*
**** Replacement value rounded to the nearest thousand.*

TABLE 17
BOLSA CHICA PLANNING AREA – RISK ASSESSMENT

Asset	Impact	Consequence of Impact	Probability of Impact	Overall Risk to Asset
Beaches	Erosion	MODERATE loss of natural protection, loss of recreational beach area	HIGH Loss of beach is highly likely for future SLR projections	HIGH
Transportation (Roads), PCH	Flooding	HIGH Loss of service (traffic, emergency service delays), loss of evacuation routes, higher maintenance & repair cost	LOW Unlikely to occur until 2100 time horizon	MODERATE

Asset	Impact	Consequence of Impact	Probability of Impact	Overall Risk to Asset
State Parks Buildings	Flooding and Inundation	HIGH Significant cost to repair buildings / loss of function	LOW Unlikely to occur until 2100 time horizon	MODERATE
State Parks Parking Lots	Flooding and Inundation	MODERATE Significant cost to repair buildings / loss of function	LOW Unlikely to occur until 2100 time horizon	LOW-MODERATE
Bike Trails	Flooding and Inundation	LOW Low cost to repair trails / loss of function	LOW Unlikely to occur until 2100 time horizon	LOW
Pedestrian Trails	Flooding and Inundation	LOW Low cost to repair trails / loss of function	LOW Unlikely to occur until 2100 time horizon	LOW
			Planning Area Rating	**MODERATE**

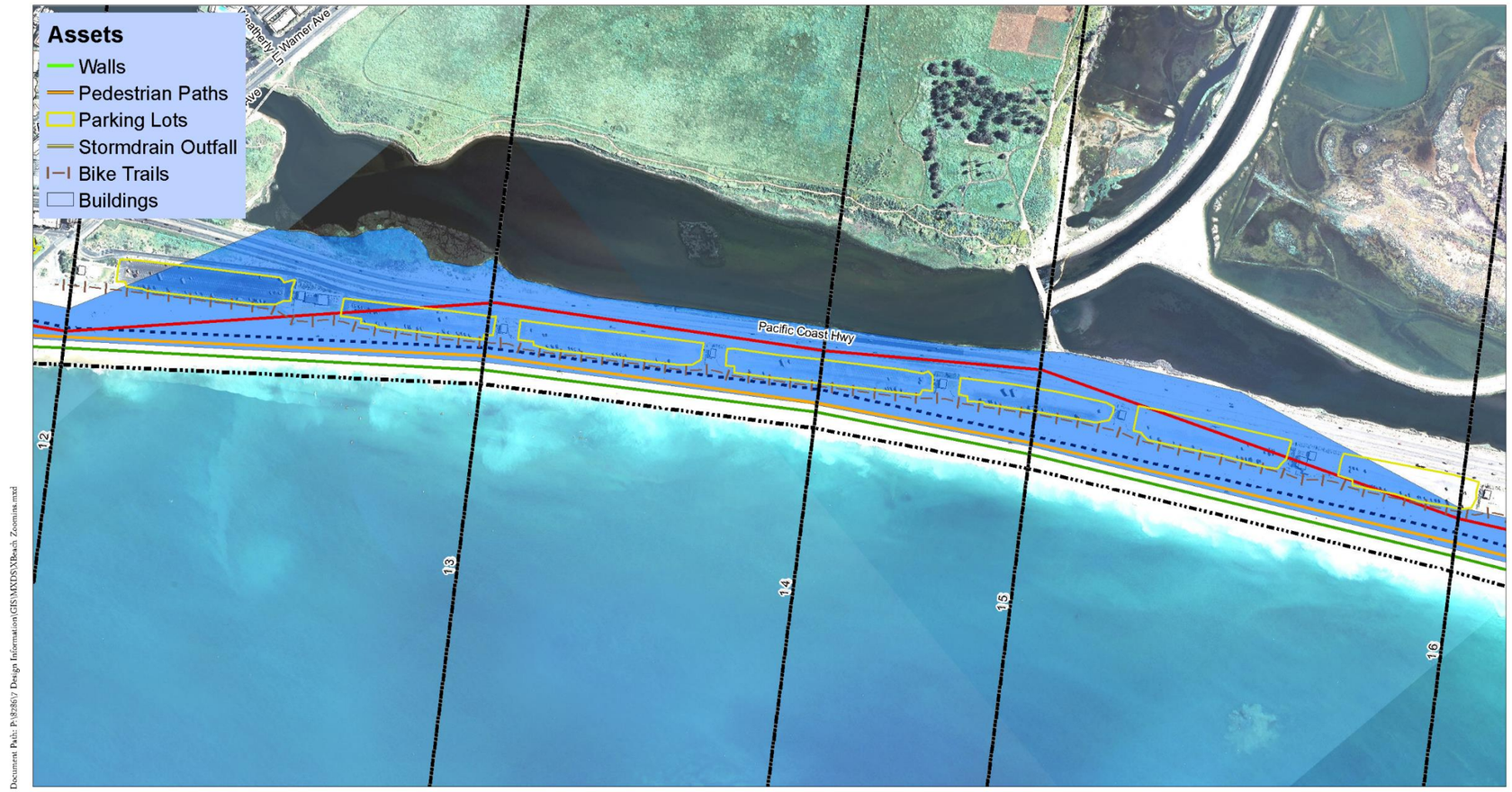
Based on these results, this planning area is considered to have a moderate overall risk. Findings of the vulnerability assessment are as follows:

- **Beaches** in this planning area are at high risk of impacts from SLR. Increased beach erosion from rising sea levels will reduce the natural barrier to storm waves provided by the sandy beach. There may be a “soft” economic cost associated with a loss of recreational beach. These impacts are expected for small to moderate rates of SLR and become severe for projected SLR values by 2050 and 2100.

- **Pacific Coast Highway** and **State Parks Buildings** in this planning area face a moderate risk from impacts related to storm waves and SLR. Model results indicate these assets are not at risk to flooding and inundation until 2100 under the high SLR projections, so they were assigned a relatively low probability of occurrence. However, the consequences are high for even small amounts of flooding, which results in a moderate risk to these assets.

- **Bike Trails** and **Pedestrian Trails** were determined to have a low risk of impact from SLR. The consequences associated with these impacts were considered low due to the cost to repair these structures being relatively low. Model results indicate these assets are not at risk to flooding and inundation until 2100 under the high SLR projections are reached, so they were assigned a relatively low probability of occurrence.

- **State Parks Parking Lots** were determined to have a low-moderate risk. The consequences associated with these impacts were considered moderate due to the cost to repair these structures. Model results indicate these assets are not at risk to flooding and inundation until 2100 under the high SLR projections, so they were assigned a relatively low probability of occurrence.



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Coastal Inundation (MHHW Shoreline Position)
- Low SLR
- Projected SLR
- High SLR
- 2010 Shoreline Position (MHHW)

Coastal Flooding (Wave Run-up)
- Wave Run-up (Low to High SLR)
- Wave Run-up (Projected SLR)

XBeach Transects

Job No.: 8286
Date: 04/23/2014

FIGURE 14
IMPACTED ASSETS IN BOLSA CHICA PLANNING AREA – YEAR 2100

7.2.3. Huntington Bluffs Planning Area

Assets within the Huntington Bluffs Planning Area become vulnerable to coastal flooding and inundation starting in the 2050 time horizon under the projected high SLR scenario. Impacts in the 2050 timeframe are relatively limited and increase in the 2100 timeframe. Vulnerable assets in the 2100 timeframe include residential and commercial buildings, City buildings, bluffs, bike trails, parking lots, storm drain outfalls, walls and pedestrian trails. The vulnerability of these assets is detailed in Table 18 and shown graphically for year 2100 in Figure 15.

The results below are representative of the entire planning area, which extends from Bolsa Chica entrance channel to the Huntington Beach Pier. As such, results representative of the entire planning area may not be representative of specific locations within the planning area. One example is the vulnerability of assets along the existing bluffs between Seapoint Street and Goldenwest Street. The pedestrian path, bike trail, park area and utilities along the bluffs are currently vulnerable to slope failures along un-protected sections of the bluff. These areas require frequent maintenance to relocate the assets away from the edge of the bluff. A recommendation of this study is to prepare a site specific (rather than City wide) vulnerability assessment of the existing bluffs to account for the unique site conditions and variable level of protection at this location.

TABLE 18
HUNTINGTON BLUFFS PLANNING AREA – VULNERABILITY ASSESSMENT

Asset	Exposure				Sensitivity	Adaptive Capacity	Vulnerability
	Impact Threshold	Type of Impact	Max. No. Assets Impacted	Rating			
Beaches	2030	Erosion	36.0 acres	High	Low	High	Low
Residential and Commercial Buildings	2050 - High SLR	Flooding	90 buildings	Moderate	Moderate	Low	Moderate
City Buildings	2100 - High SLR	Flooding	1 building	Low	Moderate	Low	Moderate
Bike Trails	2050 - High SLR	Bluff retreat, Flooding and Inundation	2,020 ft.	Moderate	Moderate	Low	Moderate
Parking Lots	2050 - High SLR	Flooding	29,400 sq.ft	Moderate	Moderate	Low	Moderate
Storm Drain Outfall	2050 - High SLR	Outfall Flooding and Inundation - Pipe backup	3 Outfalls	Low	Low	Low	Low
Walls	2050 - High SLR	Flooding	1,120 linear feet	Moderate	Moderate	Low	Moderate
Pedestrian Trails	2050 - High SLR	Bluff retreat, Flooding and Inundation	365 ft.	Moderate	Low	Moderate	Moderate

Findings of the vulnerability assessment are described per asset below:

- **Beaches** were assigned a low vulnerability because they have a low sensitivity and a high adaptive capacity. However, their exposure is high with anticipated erosional impacts with any SLR scenario.

- **Residential Buildings, City Buildings, Bike Trails, Parking Lots, and Walls** were determined to have a moderate vulnerability due to having a moderate sensitivity and low adaptive capacity.

- **Storm Drain Outfalls** were assigned a low vulnerability due to their low sensitivity to direct SLR impacts. However, indirect impacts in the form of water backups could result during periods of time when the beach storm drain outlets are flooded or inundated. This condition could result in drainage backing up and flooding upland areas that feed into the storm drain system.

- **Pedestrian Trails** were determined to have a low vulnerability due to having a low sensitivity and moderate ability to cope with future flooding and inundation.

The approximate values of the assets at risk within the Huntington Bluffs planning area are provided in Table 19. It was determined that approximately $32 million worth of assets is potentially at risk to future rates of SLR. Storm drain assets were not quantified as direct damage as a result of SLR because that condition would not be anticipated to directly damage these structures. Results of the risk assessment for each of the asset categories are shown in Table 20.

TABLE 19
HUNTINGTON BLUFFS PLANNING AREA – EXPOSED ASSET VALUES

Asset	Quantity of Assets	Replacement Costs (USD)*	Asset Cost Estimate Source**	Replacement Value (USD)***
Parking Lots	29,400 sq.ft.	$3/ sq.ft.	Engineer's Estimate	$88,000
Bike Trails	2,020 ft. (12,120 sq.ft.)	$10/ sq.ft. ($60/ft assuming 6-foot width)	Engineer's Estimate	$121,000
Pedestrian Trails	365 ft. (2,190 sq.ft.)	$10/ sq.ft. ($60/ft assuming 6-foot width)	Engineer's Estimate	$22,000
Walls	1,120 ft.	$150/ ft. (assuming 3-foot wall height)	Engineer's Estimate	$168,000
BUILDINGS				
Beach Facilities	1 facility	$150,000	Engineer's Estimate	$150,000
Huntington Beach Condos	90 units	$346,000 (Average)	City GIS Data	$31,140,000
			Total Asset Value	**$31,689,000**

**Estimates based on 2014 dollars.*
***Engineer's estimate based on unit cost for recent comparable projects*
**** Replacement value rounded to the nearest thousand.*

TABLE 20
HUNTINGTON BLUFFS PLANNING AREA RISK ANALYSIS

Asset	Impact	Consequence of Impact	Probability of Impact	Overall Risk to Asset
Beaches	Erosion	MODERATE loss of natural protection, loss of recreational beach area	HIGH Loss of beach is highly likely for future SLR projections	HIGH
Residential & Commercial Buildings	Flooding	MODERATE Significant cost to repair or replace buildings	MODERATE Impacts possible at 2050 High SLR scenario	MODERATE
City Buildings	Flooding	MODERATE Significant cost to repair or replace buildings	LOW Unlikely to occur until 2100 time horizon	LOW-MODERATE
Bike Trails	Flooding and Inundation	MODERATE Significant cost to repair trail	MODERATE Impacts possible at 2050 High SLR scenario	MODERATE
Parking Lots	Flooding	MODERATE Significant cost to repair buildings / loss of function	MODERATE Impacts possible at 2050 High SLR scenario	MODERATE
Storm Drains	Flooding and Inundation	LOW Damage to assets minimal. Indirect consequences should be considered.	MODERATE unlikely to occur until 2050 time horizon	LOW-MODERATE
Walls	Flooding	MODERATE Significant cost to repair walls	MODERATE Impacts possible at 2050 High SLR scenario	MODERATE
Pedestrian Trails	Flooding and Inundation	LOW Low cost to repair trails / loss of function	MODERATE Impacts possible at 2050 High SLR scenario	LOW-MODERATE
			Overall Planning Area Risk Rating	**MODERATE**

Based on these results, this planning area is considered to have a moderate overall risk. Findings of the vulnerability assessment are as follows:

- Beaches in this planning area are at high risk of impacts from SLR. Increased beach erosion from rising sea levels will reduce the natural barrier to storm waves provided by the sandy beach. There also may be “soft” economic costs associated with the loss of a recreational beach. These impacts are expected for small to moderate rates of SLR and become severe for projected SLR values by 2050 and 2100. Beach erosion could lead to an acceleration of bluff erosion, if shoreline protection is not adequate to stabilize the bluff. Bluff erosion could then start to impact upland infrastructure. Further study is needed to quantify the potential SLR impacts along this reach.

- Residential Buildings, Bike Trails, Parking Lots, and Walls face a moderate risk from impacts related to storm waves and SLR. Model results indicate these assets are not at risk to flooding and inundation at year 2050 under the high SLR projections, so they were assigned a moderate probability of occurrence. Consequences are moderate for even small amounts of flooding for these assets resulting in a moderate overall risk to these assets.

- City Buildings were determined to have a low to moderate risk of impact from SLR. The consequences associated with these impacts were considered moderate due to the relatively high cost to repair or replace these structures. Model results indicate these assets are not at risk to flooding and inundation until 2050 under the high SLR projections, so they were assigned a relatively low probability of occurrence.

- Storm Drains and Pedestrian Trails were determined to have a moderate risk. The consequences associated with direct impacts of SLR were considered low to moderate in that inundation would likely not result in direct damage to these structures. However, indirect impacts to stormdrains in the form of tail water backups in upland areas should be considered. Model results indicate that stormdrains and pedestrian trails will become vulnerable to flooding in the 2050 high SLR scenario and will be vulnerable to flooding and inundation in the 2100 high SLR scenario. Thus, they were assigned a moderate probability of occurrence.

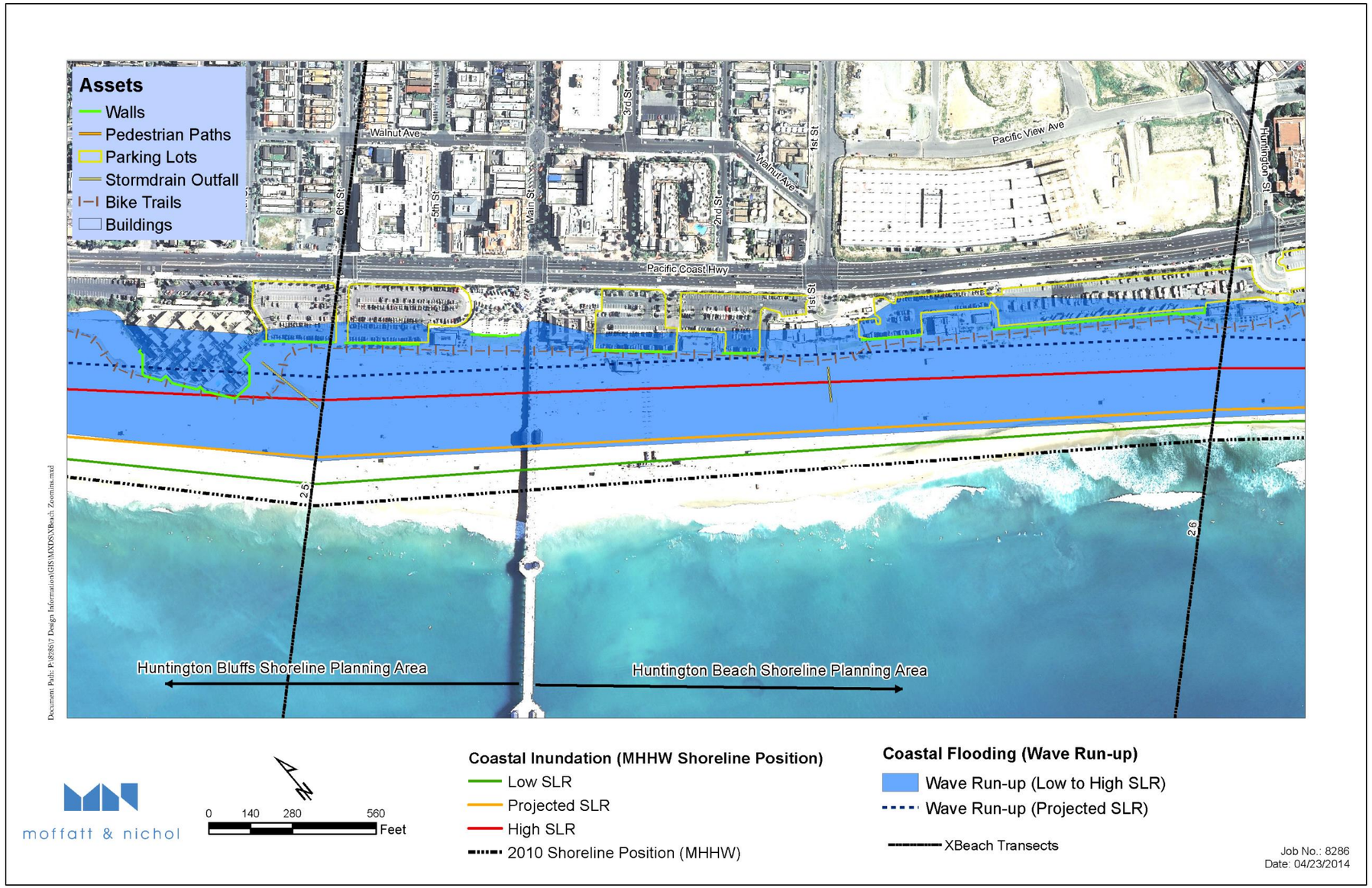


FIGURE 15
IMPACTED ASSETS IN HUNTINGTON BLUFFS PLANNING AREA – YEAR 2100

7.2.4. Huntington Beach Planning Area

Assets within the Huntington Beach Planning Area become vulnerable to coastal flooding and inundation starting in the 2050 time horizon under the projected high SLR scenario. Impacts in the 2050 timeframe are relatively limited and increase in the 2100 timeframe. More assets in the planning area become vulnerable in the 2100 time horizon, as shown in Figure 16. Vulnerable assets include residential, commercial, City and industrial buildings, bike trails, transportation parking lots, storm drain outfalls, walls and pedestrian trails. The vulnerability of these assets is detailed in Table 21. Impacts to the RV parking lot were included in the parking lot impacts.

TABLE 21
HUNTINGTON BEACH PLANNING AREA – VULNERABLE ASSETS

Asset	Exposure				Sensitivity	Adaptive Capacity	Vulnerability
	Year First Impacted	Type of Impact	Max. No. Assets Impacted	Rating			
Beaches	2030	Erosion	122 Acres	High	Low	High	Low
Residential Buildings	2100 - High SLR	Flooding	352 buildings	Low	Moderate	Low	Moderate
Commercial Buildings	2050 - High SLR	Flooding	4 buildings	Moderate	Moderate	Low	Moderate
Industrial Buildings	2100 - High SLR	Flooding	12 buildings	High	High	Low	High
City & State Buildings	2050 - High SLR	Flooding and Inundation	34 buildings	Moderate	Moderate	Low	Moderate
Bike Trails	2050 - High SLR	Flooding and Inundation	12,931 ft.	Moderate	Moderate	Low	Moderate
Parking Lots	2100 - High SLR	Flooding	936,650 sq.ft.	Low	Moderate	Low	Moderate
Storm Drains (Seaward of 1st St.)	2050 - High SLR	Flooding and Inundation	1 outfall	Moderate	Low	Low	Low
Walls	2100 - High SLR	Flooding	1,316 ft.	Low	Moderate	Low	Moderate
Pedestrian Trails	2100 - High SLR	Flooding and Inundation	2,086 ft.	Low	Low	Moderate	Moderate
Transportation (Roads)	2100 - High SLR	Flooding	707,520 sq.ft.	Low	High	Low	High

Findings of the vulnerability assessment are described per asset below:

- **Beaches** were assigned a low vulnerability because of they have a low sensitivity and a high adaptive capacity. However, their exposure is high with anticipated erosional impacts with any SLR scenario.

- **Residential Buildings, Commercial Buildings, City & State Buildings, Bike Trails, Parking Lots, and Walls** were determined to have a moderate vulnerability due to having a moderate sensitivity and low adaptive capacity.

- **Industrial Buildings (i.e., AES)** were assigned a high vulnerability due to their high sensitivity and low adaptive capacity.

- **Storm Drains** were assigned a low vulnerability due to their low sensitivity to direct SLR impacts. However, indirect impacts in the form of water backups could result during periods of time when the beach stormdrain outlets are inundated. This condition could result in drainage backing up and flooding upland areas that feed into the stormdrain system.

- **Pedestrian Trails** were determined to have a low vulnerability due to having a low sensitivity and moderate ability to cope with future flooding and inundation.

- **Transportation Infrastructure** was assigned a high vulnerability owing to its high sensitivity and low adaptive capacity. Even minor amounts of flooding on PCH and Newland Street could cause significant traffic delays and potentially disrupt emergency service vehicles and evacuation routes. Maintenance and repair requirements would also increase after significant flooding, but the primary impact is disruption of service. These assets become exposed to flooding in year 2100 under the high SLR scenario, giving them a low overall exposure rating.

The approximate values of the assets at risk within the Huntington Beach Planning Area are provided in Table 22. It was determined that approximately $176 million worth of assets is potentially at risk to future rates of SLR. Storm drain assets were not quantified as direct damage as a result of SLR would not be anticipated to these structures.

TABLE 22
HUNTINGTON BEACH PLANNING AREA – EXPOSED ASSET VALUES

Asset	Quantity of Assets	Replacement Costs (USD)*	Asset Cost Estimate**	Replacement Value (USD)***
Residential Buildings	352 buildings	Vary	City GIS Data	$63,884,000
Commercial Buildings	4 buildings	Vary	City GIS Data	$6,436,000
Industrial Buildings	12 buildings	Vary	City GIS Data	$82,658,000
City & State Buildings	34 buildings	Vary	Engineer's Estimate/ City GIS Data	$17,109,000
Bike Trails	12,931 ft. (77,586 sq.ft.)	$10/sq.ft. ($60/ft assuming 6-foot width)	Engineer's Estimate	$776,000

Parking Lots	936,650 sq.ft.	$3/sq.ft.	Engineer's Estimate	$2,810,000
Walls	1,316 ft	$150/linear foot (assuming 3-foot wall height)	Engineer's Estimate	$197,000
Pedestrian Trails	2,086 ft. (12,516 sq.ft.)	$10/sq.ft. ($60/ft assuming 6-foot width)	Engineer's Estimate	$125,000
Transportation (Roads)	707,520 sq.ft.	$3/sq.ft.	Engineer's Estimate	$2,123,000
			Total Asset Value	**$176,118,000**

**Estimates based on 2014 dollars.*
***Engineer's estimate based on unit cost for recent comparable projects.*
**** Replacement values rounded to the nearest thousand.*

Results of the risk assessment for each of the asset categories are shown in Table 23.

TABLE 23
HUNTINGTON BEACH PLANNING AREA RISK ANALYSIS

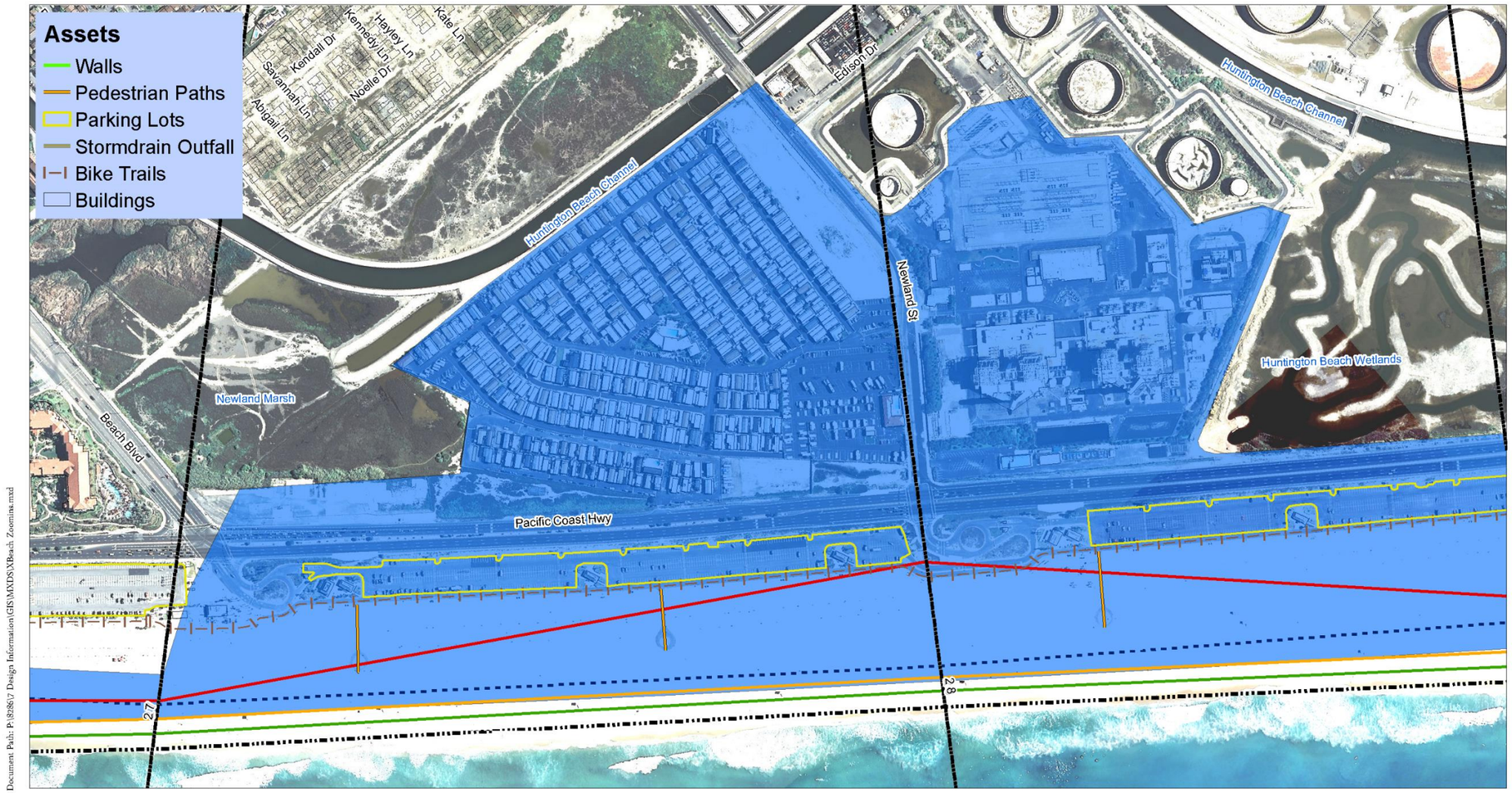
Asset	Impact	Consequence of Impact	Probability of Impact	Overall Risk to Asset
Beaches	Erosion	MODERATE loss of natural protection, loss of recreational beach area	HIGH Loss of beach is highly likely for future SLR projections	HIGH
Residential Buildings	Flooding	MODERATE Moderate cost to repair or replace buildings	LOW Unlikely to occur until 2050 time horizon	LOW-MODERATE
Commercial Buildings	Flooding	HIGH Significant cost to repair or replace buildings	MODERATE Impacts possible at 2050 High SLR scenario	MODERATE-HIGH
Industrial Buildings	Flooding	HIGH Significant cost to repair or replace buildings	LOW Unlikely to occur until 2100 time horizon	MODERATE
City & State Buildings	Flooding and Inundation	HIGH Significant cost to repair or replace buildings	MODERATE Impacts possible at 2050 High SLR scenario	MODERATE-HIGH
Bike Trails	Flooding and Inundation	LOW Relatively low cost to repair trails	MODERATE unlikely to occur until 2050 time horizon	LOW-MODERATE
Parking Lots	Flooding	MODERATE Moderate cost to repair or replace parking lots	LOW Unlikely to occur until 2050 time horizon	LOW-MODERATE

Storm Drains	Flooding and Inundation	LOW Damage to assets minimal. Indirect consequences should be considered.	MODERATE unlikely to occur until 2050 time horizon	LOW-MODERATE
Walls	Flooding	MODERATE Significant cost to repair walls	MODERATE Impacts possible at 2050 High SLR scenario	MODERATE
Pedestrian Trails	Flooding and Inundation	LOW Low cost to repair trails / loss of function not critical	LOW Unlikely to occur until 2050 time horizon	LOW
Transportation (Roads)	Flooding	HIGH Loss of service (traffic, emergency service delays), loss of evacuation routes, higher maintenance & repair cost	LOW Unlikely to occur until 2100 time horizon	MODERATE
			Overall Planning Area Risk Rating	**MODERATE**

Based on these results, this planning area is considered to have a moderate overall risk. Findings of the vulnerability assessment are as follows:

- **Beaches** in this planning area are at high risk of impacts from SLR. Increased beach erosion from rising sea levels will reduce the natural barrier to storm waves provided by the sandy beach. There may also be a “soft” economic cost associated with a loss of recreational beach. These impacts are expected for small to moderate rates of SLR and become severe for projected SLR values by 2050 and 2100.
- **Residential Buildings, Bike Trails, Parking Lots and Walls** face a moderate risk from impacts related to storm waves and SLR. Model results indicate these assets are not at risk to flooding and inundation at year 2050 under the high SLR projections, so they were assigned a moderate probability of occurrence. Consequences are moderate for even small amounts of flooding for these assets, resulting in a moderate overall risk to these assets.
- **Industrial Buildings** in the planning area are at high risk of impacts from SLR due to their high sensitivity and low adaptive capacity. Model results indicate these assets are not at risk to flooding until 2100 under the high SLR projections, so they were assigned a relatively low probability of occurrence.
- **City & State Buildings** were determined to have a low to moderate risk of impact from SLR. The consequences associated with these impacts were considered moderate due to the relatively high cost to repair or replace these structures. Model results indicate these assets are not at risk to flooding until year 2050 under the high SLR projections, so they were assigned a moderate probability of occurrence. Consequences are high due to the significant cost to repair or replace these facilities, which resulted in a moderate to high overall risk to these assets.

- **Storm Drains and Pedestrian Trails** were determined to have a moderate risk. The consequences associated with direct impacts of SLR were considered low in that inundation would likely not result in direct damage to these structures. However, indirect impacts to storm drains in the form of tail water backups in upland areas should be considered. Model results indicate that storm drains and pedestrian trails will become vulnerable to flooding in the 2050 high SLR scenario and will be vulnerable to flooding and inundation in the 2100 high SLR scenario. Thus, they were assigned a moderate probability of occurrence.
- **Transportation (Roads)** were assigned a high vulnerability owing to its high sensitivity and low adaptive capacity. Even minor amounts of flooding on the roads can cause significant traffic delays and potentially disrupt emergency service vehicles and evacuation routes. Maintenance and repair requirements would also increase after significant flooding, but the primary impact is disruption of service. These assets become exposed to flooding in year 2100 under the high SLR scenario, giving them a low overall exposure rating.



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moffatt & nichol

0 185 370 740 Feet

Coastal Inundation (MHHW Shoreline Position)
- Low SLR
- Projected SLR
- High SLR
- 2010 Shoreline Position (MHHW)

Coastal Flooding (Wave Run-up)
- Wave Run-up (Low to High SLR)
- Wave Run-up (Projected SLR)

XBeach Transects

Job No.: 8286
Date: 04/23/2014

FIGURE 16
IMPACTED ASSETS IN HUNTINGTON BEACH PLANNING AREA – YEAR 2100

8. Inland Waterway Vulnerability Assessment

8.1. Huntington Harbour & Bolsa Chica Planning Areas

The Huntington Harbour and Bolsa Chica planning areas are highly vulnerable to tidal flooding if sea levels rise as projected. Overtopping at several locations around Huntington Harbour in Sunset Beach occurs presently during King Tides. Projected SLR will significantly increase the frequency, duration, and extent of this flooding and lead to flooding in other areas. Extreme rainfall events combined with SLR will further increase the risk of flooding for areas adjacent to Bolsa Chica Channel and its tributaries.

8.1.1. Tidal Flooding

This analysis was based on a 2-year water level (essentially a high “King Tide”) combined with the highest SLR predictions for given timeframes. There are no probabilities associated with the highest SLR predictions for the timeframes used in this study, so they may actually occur farther out in the future than indicated herein. The potential for tidal inundation of low-lying communities around Huntington Harbour and Bolsa Chica are mapped in Figure 17 to Figure 19. As expected, areas along Sunset Beach where King Tides currently overtop the Huntington Harbour seawalls will experience the most significant increase in tidal flooding due to SLR. SLR projections by 2050 and 2100 will result in expanded areas of tidal flooding inland of Huntington Harbour and Bolsa Chica.

<u>2030 High Sea Level Rise (1.0 ft)</u>

- As expected, areas along Sunset Beach where King Tides currently overtop the Huntington Harbour seawalls will experience the most significant increase in flooding due to SLR.
- PCH would experience tidal flooding for about one mile between Anderson Street and Warner Ave. Tidal flooding would also be expected along low lying portions of PCH along Bolsa Chica State Beach. This flooding would likely result in traffic delays and/or road closures along PCH and portions of Huntington Harbour. Access for emergency service vehicles to the affected areas would be impacted.
- Residential areas along PCH through Sunset Beach and sections of Huntington Harbour would experience tidal flooding.

<u>2050 High Sea Level Rise (2.0 ft)</u>

- SLR projections by 2050 result in expanded areas of tidal flooding inland of Huntington Harbour and Bolsa Chica. High water levels would likely overtop large sections of the seawalls/bulkheads lining Huntington Harbour.
- Significant tidal flooding of residential and commercial properties in and around Huntington Harbour and Sunset Beach would be expected. Based on 2013 LIDAR topography, tidal flooding would extend inland to Algonquin Street between Edinger Avenue and Heil Avenue.

- PCH would be almost completely tidally-flooded from Anderson Street to the main entrance to Bolsa Chica State Beach. Most roads in Huntington Harbour would be periodically under water, as well as portions of Warner Avenue between PCH and Brightwater Drive.
- Based on 2013 LIDAR topography, tidal flooding could overtop the existing levee between the EGGWC and Bolsa Bluffs. The potential tidal flooding zone is shown with a cross-hatch. Construction planned for the Shea Homes Parkside project includes an improved levee that would eliminate the potential for tidal flooding in this area.

2100 High Sea Level Rise (5.5 ft)

- Water levels under this scenario would overtop all of the existing seawalls/bulkheads around Huntington Harbour and the existing levees around the Bolsa Chica full tidal basin. Major roads, utilities, and residential, commercial, and public properties would be vulnerable.
- East of the Harbour, tidal flooding would extend beyond Graham Street between Edinger Avenue and Heil Avenue.
- East of Bolsa Chica, tidal flooding would approach Gothard Street between the EGGWC levees to the north and higher ground along the Huntington Mesa to the south.
- PCH would be completely tidally-flooded from the northern City limit to just south of the south jetty of Bolsa Chica at the south end of Bolsa Chica State Beach.
- Areas shown with a cross hatch would be removed from the 2100 tidal flooding zone with construction of the levee proposed for the Shea Homes Parkside project.

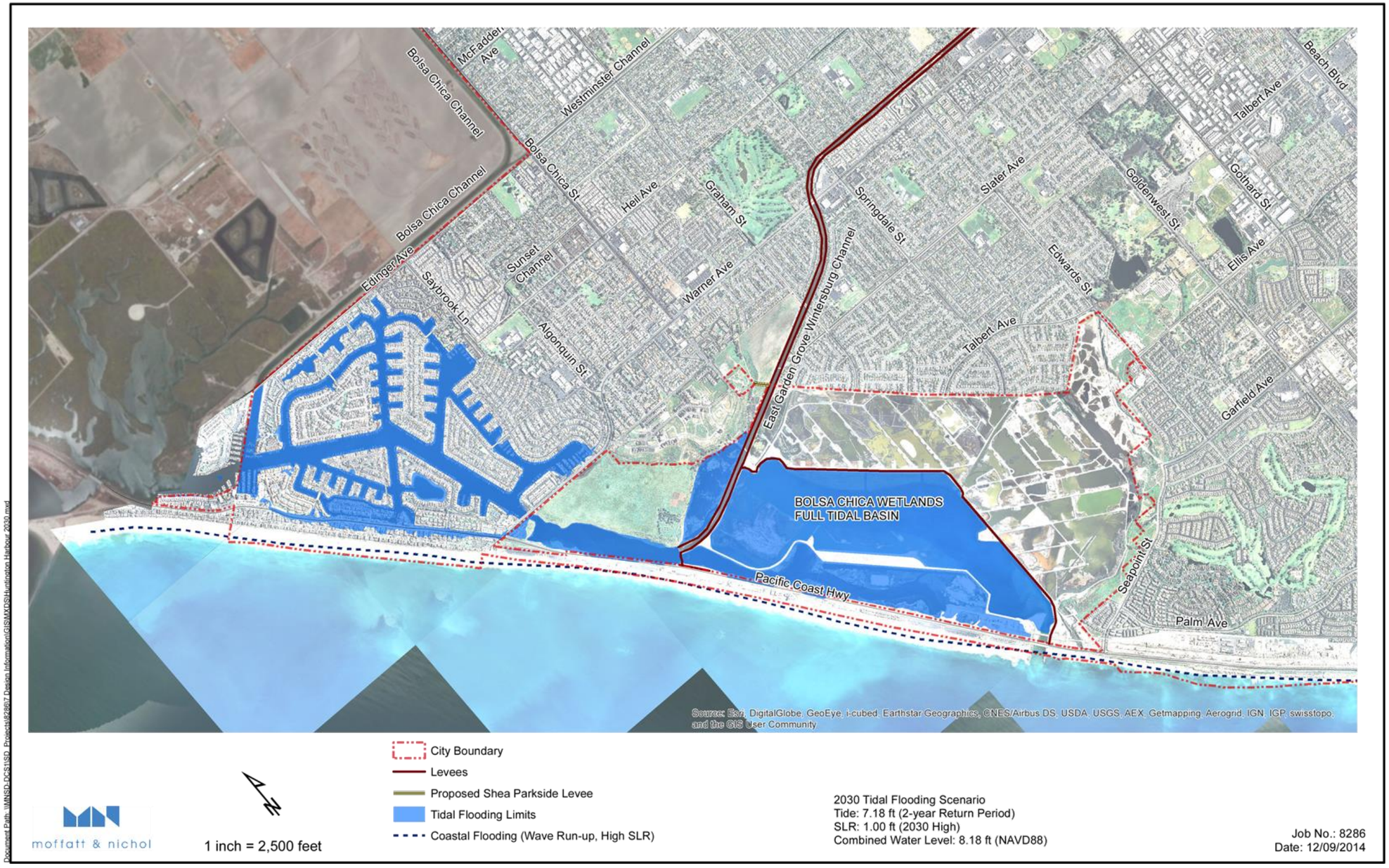


FIGURE 17
TIDAL FLOODING AT HUNTINGTON HARBOUR AREA – YEAR 2030 SLR (HIGH)

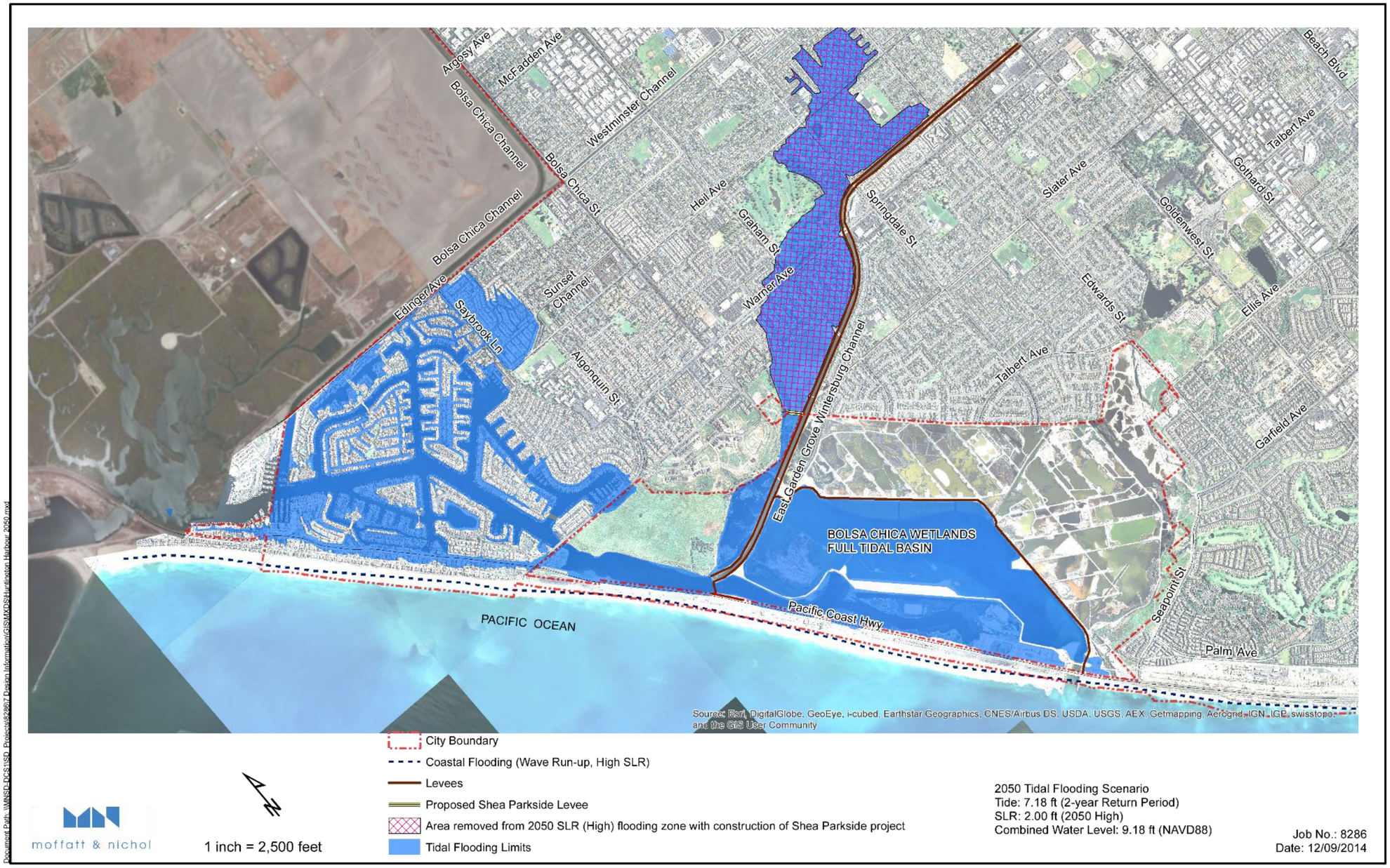


FIGURE 18
TIDAL FLOODING AT HUNTINGTON HARBOUR AREA – YEAR 2050 SLR (HIGH)

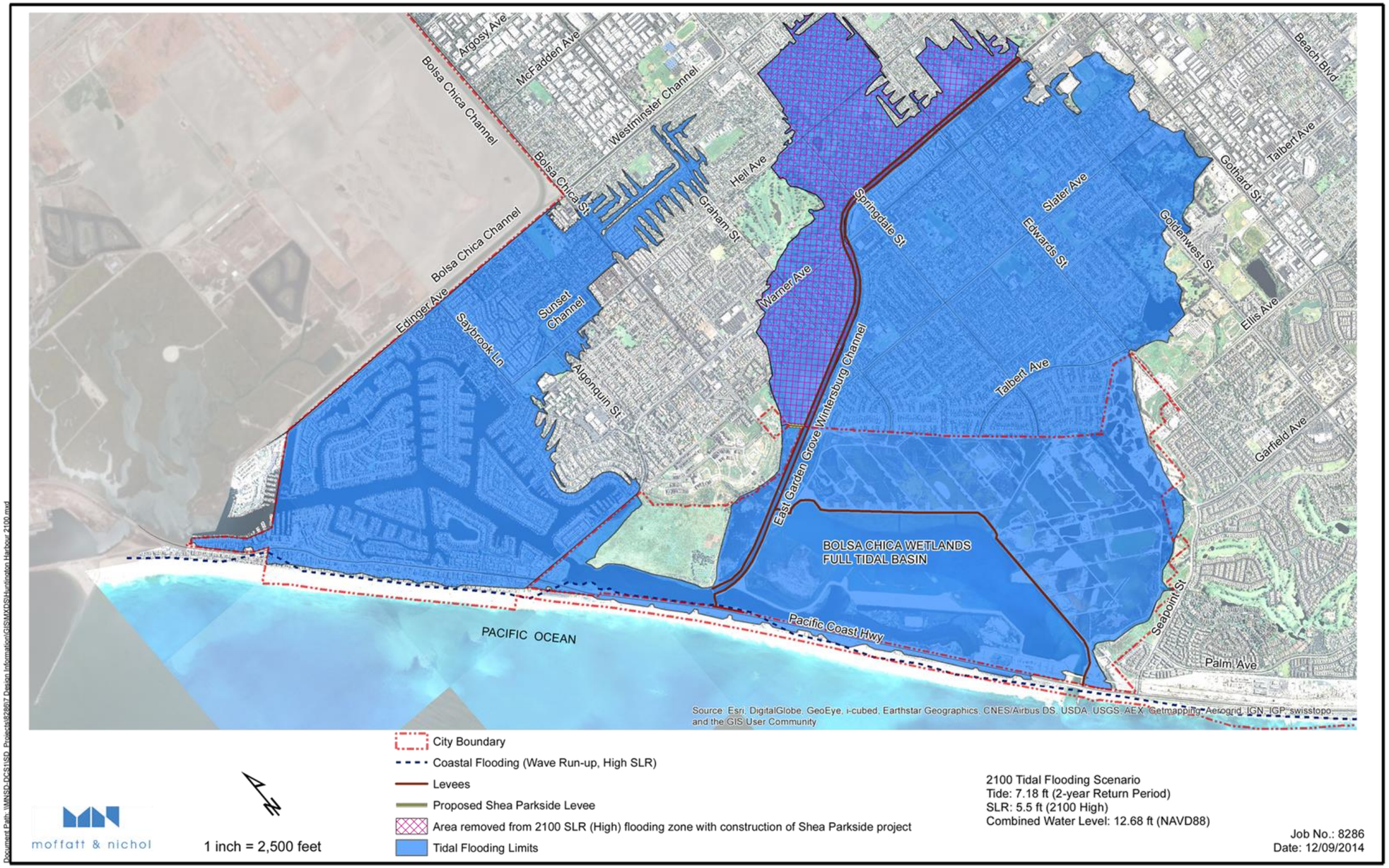


FIGURE 19
TIDAL FLOODING AT HUNTINGTON HARBOUR AREA – YEAR 2100 SLR (HIGH)

8.1.2. Flooding from Extreme Rainfall Events

In general, rising sea levels will increase the downstream controlling water surface elevation of flood control channels that discharge into tidally-influenced waterways. The effect of a higher downstream water level will be an increase in the water surface profile for a certain distance upstream. Channel reaches influenced by the downstream boundary can expect the risk of flooding to increase with projected SLR. The effect of rising sea levels on Bolsa Chica Channel (C02) and EGGWC (C05) were simulated using numerical models with results discussed below.

Bolsa Chica Channel (C02):

Bolsa Chica Channel (C02) follows an alignment along Bolsa Chica Street and Edinger Avenue between the City of Huntington Beach and the Naval Weapons Station, Seal Beach. The channel is an earthen trapezoidal channel with some rock slope protection, a relatively flat longitudinal slope and low invert elevations. Adjacent ground is typically at or slightly below the top of channel. Huntington Harbour and Bolsa Chica Channel were modeled using a 2-D unsteady state model (RMA-2) to simulate the combined effects of a 100-yr storm hydrograph and tidal exchange through the marsh and channel system during an average spring high tide. The limits of the RMA-2 model are shown in Figure 20.

FIGURE 20
HUNTINGTON HARBOUR RMA-2 MODEL BOUNDARY

In general the results indicate the lower channel reach that parallels Edinger Avenue (downstream of the C04 confluence) would be most vulnerable to increased flood profiles for projected SLR of 2 feet or less. SLR greater than 2 feet would increase water surface elevation further upstream in Bolsa Chica Channel (C02) and in Westminster Channel (C04).

The estimated water surface elevations upstream of major road crossings are listed in Table 24 for each SLR scenario for Bolsa Chica Channel. More detailed model results are provided on maps in Appendix B. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by FEMA and should not be used for purposes of floodplain mapping.

The model results indicate that 1 ft of SLR (2030 High) would increase water surface elevations in the downstream ~1,500 foot of channel. The increases taper from about 1 foot at the outlet into Huntington Harbour down to about 0.1 feet near the intersection of Edinger Avenue and Saybrook Lane. Upstream of this location no significant increases in water surface elevations would be expected for the 2030 high SLR projection.

A 2-ft rise in sea levels, which corresponds to the high SLR projection in 2050, would increase the 100-year water surface profile from Huntington Harbour to the Westminster Channel (C04) confluence near the intersection of Edinger Avenue and Bolsa Chica Street. An increase in 100-year water surface elevation of about 2 feet at the outlet into Huntington Harbour tapers to about

0.4 feet near the intersection of Saybrook Lane and Edinger Avenue. Upstream of the C02/C04 confluence no significant increases in water surface elevation would be expected for the 2050 high SLR projection.

The projected 2100 high SLR value of 5.5 ft would significantly reduce the conveyance capacity of the existing Bolsa Chica Channel. An increase in 100-year water surface elevation of over 5.5 feet at the outlet into Huntington Harbour tapers to 2.5 foot increase near the intersection of Saybrook Lane and Edinger Avenue. Model results indicate a 1 foot increase in water surface elevation from the C02/C04 confluence upstream to the C02/C03 confluence for the 2100 high SLR projection.

TABLE 24
BOLSA CHICA CHANNEL FLOOD RESULTS FOR EACH SLR SCENARIO

Bolsa Chica Channel (C02) Location	Adjacent Road	Top of Channel Elevation (ft, NAVD 88)	100-yr Water Surface Elevations (ft, NAVD 88)			
			2010 no SLR*	2030 High SLR	2050 High SLR	2100 High SLR
Outlet to Harbour	N/A	9.5	6.3	7.4	8.4	**11.9**
3200 ft U/S of outlet	Edinger Ave	12.7	8.5	8.8	9.3	12.0
6700 ft U/S of outlet	Edinger Ave	14.3	11.8	11.8	12.0	13.4
C04 Confluence	Edinger Ave	14.5	13.6	13.7	13.8	**14.7**
2200 ft U/S of C04	Bolsa Chica St	15.8	14	14.1	14.2	15.1
4700 ft U/S of C04	Bolsa Chica St	17	14.4	14.5	14.5	15.4
C03 Confluence	Bolsa Chica St	19	15.7	15.7	15.8	16.3

EGGWC (C05):

A Water Surface Pressure Gradient (WSPG) model, developed by Orange County Public Works, of the ultimate channel configuration was used to evaluate the changes in 100-year flood profiles for various SLR scenarios. The estimated water surface elevations upstream of major road crossings are listed in Table 25 for each SLR scenario. More detailed model results are provided on maps in Appendix B.

The purpose of this modeling was to estimate the relative impact of SLR on flood profiles. The results indicate that 1 foot of SLR (2030 High) would increase water surface elevations within C05 by about 0.5 feet near the Graham Street crossing. The changes to the water surface profile taper off to 0.1 feet upstream of the C05 culvert at Goldenwest Street.

A 2-foot increase in water surface elevation at the downstream tide gates corresponds to high SLR projections by 2050. This scenario has a more significant impact on the flood profile with increases on 1.0 feet at Graham Street and 0.5 feet at Edwards Street. The flood profile increases taper off to 0.1 feet upstream of Gothard Street.

The projected high SLR value of 5.5 ft in 2100 results has a significant impact to the EGGWC flood profiles. The 100-year flood profile increases by over 3 ft downstream of Goldenwest Street under the 2100 high SLR scenario. Upstream of Goldenwest Street, the flood profile

increases by over 5 ft due to head loss through the culvert. Under this scenario, a 100-year storm event would exceed the channel capacity as far upstream as Gothard Street.

In general, the EGGWC modeling results suggest that SLR projections of 2 ft or less would result in a higher flood profile downstream of Gothard Street and less freeboard available above the 100-year water surface elevations. A 2-ft rise in sea level would result in about a 1-ft increase in water surface elevations between Graham Street and Gothard Street.

Higher SLR projections will have significant impacts on the 100-year flood profile in the EGGWC. For the high SLR projection of 5.5 ft in 2100, there would be insufficient capacity to convey the 100-year flood for most of the channel reach downstream of Beach Blvd. Under this SLR scenario additional improvements would be required in the future to convey the 100-year flood within the EGGWC.

TABLE 25
EGGWC FLOOD RESULTS FOR EACH SLR SCENARIO

EGGWC (C05) Location	Top of Channel Elevation (ft, NAVD 88)	100-yr Water Surface Elevations (ft, NAVD 88)			
		2010 no SLR*	2030 High SLR	2050 High SLR	2100 High SLR
Tide Gates	11.1	6.4	7.4	8.4	**11.9**
U/S Graham St	13.5	9.4	9.9	10.4	13.0
U/S Warner Ave	13.9	10.7	11.1	11.6	**14.2**
U/S Springdale St	14.3	11.6	12.0	12.5	**15.3**
U/S Edwards St	14.5	12.3	12.6	13.1	**15.6**
U/S Goldenwest St	16.8	14.6	14.7	14.9	**19.1**
U/S Gothard St	18.7	15.2	15.3	15.4	**20.9**
U/S Beach Blvd	25.6	22.6	22.6	22.6	23.3
D/S 405 Fwy	29.9	26.4	26.4	26.4	26.4

**The model represents the ultimate EGGWC configuration in which several reaches of the channel are improved from their existing condition. Therefore, water surface elevations are not representative of the existing flood risk along the EGGWC.*

8.1.3. Huntington Harbour Planning Area - Vulnerability & Risk Assessments

A vulnerability assessment of assets in the Huntington Harbour planning area from inundation during high tides with SLR was performed following the methodology outlined in Section 5 and summarized in Table 26. The “impact threshold” refers to the approximate SLR scenario and time horizon at which impacts to each asset become significant. The type of impact and quantity of impact at this threshold are also provided. This planning area has an early impact threshold with major impacts for the 2030 high SLR projection. Beyond this threshold impacts for 2050 and 2100 projections increase significantly.

Sensitivity was assigned qualitatively (low/moderate/high) based on the SLR impacts to each asset. If an asset was impacted by SLR projections by 2030, it was considered highly sensitive. If an asset was impacted by SLR projections by 2050, it was considered moderately sensitive. If an asset was not impacted until the 2100 high SLR projection, it was assigned a low sensitivity.

Adaptive capacity was also assigned qualitatively, as follows, based on the ability of each asset to accommodate a rise in sea level while maintaining its function or service.

- Seawalls around the Harbour were assigned a low adaptive capacity. Most seawalls in this planning area are privately owned and vary in type, condition, and elevation. In general, most have a relatively low crest and limited ability to accommodate SLR without significant structural improvements.

- Buildings were assigned a low adaptive capacity for this vulnerability assessment. In reality, the adaptive capacity of buildings varies from parcel to parcel. Some lots have their finished floor at or close to grade, while others are elevated on a building pad, or above a garage. Low lying homes have some adaptive capacity in the form of low cost flood barriers (i.e., sandbags, plywood, or other temporary material) to limit damage from minor flooding. However, reliance on temporary measures may not be adequate to accommodate significant inundation, and only a few inches of standing water could render a building unusable.

- Transportation infrastructure was assigned a low adaptive capacity. Even minor amounts of flooding on the roads can cause significant traffic delays, impacting emergency service response times and evacuation routes. Maintenance and repair requirements would also increase after significant flooding, but the primary impact is disruption of service.

- Stormwater Infrastructure was assigned a low adaptive capacity. Storm drains that gravity flow to the Harbour will have limited ability to accommodate SLR without some reduction in capacity due to higher downstream water levels. Underground storage vaults may also be subject to increased buoyancy forces with higher groundwater levels.

- Wastewater Infrastructure was assigned a low adaptive capacity. The primary impact to wastewater infrastructure in this planning area is from inundation of City-owned and Sunset Beach Sanitary District lift stations and high groundwater levels causing increased inflow and infiltration (I&I) into the collection system and potentially reducing capacity at lift stations or treatment facilities. Underground storage vaults may also be subject to increased buoyancy forces with higher groundwater levels.

TABLE 26
HUNTINGTON HARBOUR PLANNING AREA – VULNERABILITY ASSESSMENT

Asset	Impact Threshold	Type of Impact	Max. No. Assets Impacted	Sensitivity to SLR	Adaptive Capacity	Vulnerability
Flood Protection – seawalls or levees	2030 - High	Overtopping from high tides	Not Available	HIGH	LOW	HIGH
Buildings (Public & Private)	2030 - High	Inundation from high tides	1100 Buildings	HIGH	LOW	HIGH
Transportation (Streets)	2030 - High	Inundation from high tides	4.5 miles (1 mile of PCH)	HIGH	LOW	HIGH
Stormwater Infrastructure*	2030 - High	Inundation/ High groundwater	Unknown	HIGH	LOW	HIGH
Wastewater Infrastructure*	~2050	Inundation/ High groundwater	Unknown	MODERATE	LOW	MODERATE

**Additional analysis of stormwater and wastewater infrastructure required to verify vulnerability and risk.*

Based on the high sensitivity and low adaptive capacity, most assets in the Huntington Harbour planning area are vulnerable to SLR as early as 2030. Impacts listed in Table 26 are based on the 2030 high scenario (1.0 ft of SLR), but these same impacts can be expected to a lesser degree from lower SLR projections.

For SLR projections higher than 1 ft, these impacts will increase significantly, extending inland to Algonquin Street for the 2050 high SLR projection and to Graham Street for the 2100 high SLR projection, as shown in Figure 17 to Figure 19.

Due to the high consequence of impacts from relatively small SLR projections, there is a high probability of these impacts occurring, and the current overall risk for this planning area is high. A summary of the risk assessment for the Huntington Harbour planning area is shown in Table 27. The vulnerability and risk assessments were based on the potential for inundation during a high tide combined with SLR.

Discharge from an extreme rainfall event combined with SLR would result in more significant impacts with potential for flooding from Bolsa Chica Channel (C02) and tributary flood control channels. Impacts from this flooding source was not quantified but would be similar to impacts from tidal inundation except that communities further inland along Edinger Avenue and Bolsa Chica Street are also at risk.

TABLE 27
HUNTINGTON HARBOUR PLANNING AREA – RISK ASSESSMENT

Asset	Impact	Consequence of Impact	Probability of Impact	Overall Risk to Asset
Flood Protection – Seawalls & Levees	Overtopping from high tides	HIGH Significant inundation of surrounding communities	HIGH Low crested seawalls will likely overtop during high tides with projected SLR	HIGH
Buildings (Public & Private)	Inundation from high tides	HIGH Significant cost to repair buildings / loss of function	HIGH Inundation likely during high tides with projected SLR	HIGH
Transportation (Streets)	Inundation from high tides	HIGH Loss of service/ impacts to traffic, emergency service, evacuation routes/ higher maintenance & repair cost	HIGH Inundation likely during high tides with projected SLR by 2030	HIGH
Stormwater Infrastructure*	Inundation/ High groundwater	HIGH Loss of capacity in gravity flow systems	HIGH Increased flooding from rainfall events	HIGH
Wastewater Infrastructure*	Inundation/ High groundwater	HIGH Reduced Capacity (I&I), Potential for overflows of untreated sewage	MODERATE More likely for high SLR projections by 2050 and 2100	HIGH
			Overall Planning Area Risk Rating	**HIGH**

**Additional analysis of stormwater and wastewater infrastructure required to verify vulnerability and risk.*

8.1.4. Bolsa Chica Planning Area - Vulnerability & Risk Assessments

A vulnerability assessment of assets in the Bolsa Chica planning area from flooding during high tides with SLR was performed following the methodology outlined in Section 5 and summarized in Table 28. The impact threshold varies for assets within this planning area. Transportation infrastructure (PCH) has an early impact threshold with potential for inundation for the 2030 high SLR projection. Other critical assets are protected by levees around Bolsa Chica and along the EGGWC with inundation unlikely until the 2100 high SLR projection.

TABLE 28
BOLSA CHICA PLANNING AREA – VULNERABILITY ASSESSMENT

Asset	Impact Threshold	Type of Impact	Max. No. Assets Impacted	Sensitivity to SLR	Adaptive Capacity	Vulnerability
Flood Protection – seawalls or levees	2100 - High	Overtopping from high tides	10,000 linear feet	Low	Moderate	Low
Buildings (Public & Private)	2100 - High	Flooding from high tides	6,700 Buildings	Low	Low	MODERATE
Transportation (Streets)	2030 - High	Flooding from high tides	0.7 miles (PCH)	High	Low	High
Stormwater Infrastructure*	~2100	Flooding / High groundwater	Unknown	Low	Low	MODERATE
Wastewater Infrastructure*	~2100	Flooding / High groundwater	Unknown	Low	Low	MODERATE

**Additional analysis of stormwater and wastewater infrastructure required to verify vulnerability and risk.*

Adaptive capacity was assigned qualitatively, as follows, based on the ability of assets in the planning area to accommodate a rise in sea level while maintaining function or service.

- Levees around Bolsa Chica wetlands and EGGWC were assigned a moderate adaptive capacity. Levees around the Bolsa Chica wetlands and along the EGGWC have relatively high crest elevations and would be able to accommodate increases in sea level up to about 4 ft. The levee crest elevations are above the projected SLR value in 2100 but less than the projected "high" SLR value in 2100.

- Buildings were assigned a low adaptive capacity for this planning area. Due to the low and flat topography of this area, there are a significant number of buildings reliant on levees for flood protection. Most buildings have their finished floor at or close to grade with limited adaptive capacity in the form of low cost flood barriers (i.e., sandbags, plywood, or other temporary material). However, reliance on temporary measures may not be adequate to accommodate significant inundation and only a few inches of standing water could render a building unusable.

- Transportation infrastructure was assigned a low adaptive capacity. Even minor amounts of flooding on the roads can cause significant traffic delays, impacting emergency service response times and evacuation routes. Maintenance and repair requirements would also increase after significant flooding, but the primary impact is disruption of service.

- Stormwater Infrastructure was assigned a low adaptive capacity. The primary impact to stormwater infrastructure in this planning area is from high groundwater levels. The low lying storm drain/flood control network draining to Slater pump station may experience reduced capacity with a significant rise in groundwater levels due increased I&I. Underground storage vaults may also be subject to increased buoyancy forces with higher groundwater levels.

- Wastewater Infrastructure was assigned a low adaptive capacity. Increased groundwater levels may also result in more I&I into the collection system and potentially reducing capacity of pipes, lift stations, or treatment facilities. Underground storage vaults may also be subject to increased buoyancy forces with higher groundwater levels.

Many assets in the Bolsa Chica planning area have low sensitivity to SLR because they are protected by levees that can accommodate a significant rise in sea level. PCH is considered to be highly vulnerable from tidal flooding based on the 2030 high SLR projection (1.0 ft) combined with high tide. Most other assets in this planning area are not considered vulnerable until groundwater levels rise significantly (~2100), or the combination of SLR and high tide exceeds the capacity of the levee system.

There is high consequence of impacts from high SLR projections but relatively low probability of these impacts occurring. The current overall risk for this planning area is considered moderate. A summary of the risk assessment for the Bolsa Chica planning area is shown in Table 29. The vulnerability and risk assessments were based on the potential for flooding during a high tide combined with SLR. Discharge from an extreme rainfall event combined with the 2100 high SLR projection may result in more significant impacts due to additional flooding from the downstream reach of EGGWC. Impacts from this flooding source were not quantified but would likely impact the same areas subject to tidal flooding for the 2100 high SLR projection.

TABLE 29
BOLSA CHICA PLANNING AREA – RISK ASSESSMENT

Asset	Impact	Consequence of Impact	Probability of Impact	Overall Risk to Asset
Flood Protection – Seawalls & Levees	Overtopping from high tides	HIGH Significant inundation of surrounding communities	LOW Not likely to occur until 2100 high SLR projection	MODERATE
Buildings (Public & Private)	Flooding from levee overtopping	HIGH Significant cost to repair buildings / loss of function	LOW Not likely to occur until 2100 high SLR projection	MODERATE
Transportation (Streets)	Flooding from high tides	HIGH Loss of service/ impacts to traffic, emergency service, evacuation routes/ higher maintenance & repair cost	HIGH Inundation likely during high tides with projected SLR by 2030	HIGH
Stormwater Infrastructure*	Flooding / High groundwater	HIGH Loss of capacity, reduced flood protection	LOW More likely for SLR projections in 2100	MODERATE

Asset	Impact	Consequence of Impact	Probability of Impact	Overall Risk to Asset
Wastewater Infrastructure*	Flooding / High groundwater	HIGH Reduced Capacity (I&I), Potential for overflows of untreated sewage	MODERATE More likely for SLR projections in 2100	MODERATE
			Overall Planning Area Risk Rating	**MODERATE**

**Additional analysis of stormwater and wastewater infrastructure required to verify vulnerability and risk.*

8.2. Huntington Beach Wetlands Planning Area

The Huntington Beach Wetlands planning area is reliant on a system of levees to protect developed areas from tides and stormwater runoff. The area is predominantly residential and commercial with several high priority facilities including the OCSD Wastewater Treatment Plant and the AES Power Plant.

For low to moderate projections of SLR (less than 2 ft,) the vulnerability of this planning area is relatively low due to the protection offered by the existing levees. For higher projections of SLR (more than 2 ft), the impacts from SLR are significant with overtopping of the existing levee system expected for the high SLR projection in 2100. Extreme rainfall events combined with SLR will reduce available freeboard and increase the risk of flooding from the regional flood control channels.

8.2.1. Tidal Flooding

The potential for tidal flooding of the Huntington Beach Wetlands planning area is mapped in Figure 21 to Figure 23. The potential impacts under each scenario are listed below:

<u>2030 High Sea Level Rise (1.0 ft)</u>

- Low-lying sections of Brookhurst Street could experience tidal flooding adjacent to the wetlands. (Consistent with Figure 21)
- Tidal inundation under this scenario is mostly confined to the wetlands and flood control channels.
- Potential for direct flooding of public/private infrastructure and property is relatively low.
- Potential impact to storm water pump station infrastructure warrants further evaluation. A facility-specific investigation would be necessary to determine:
  - Performance impact on pumps due to higher tail water elevation;
  - Potential for flow-reversals due to higher tail water elevation; and
  - Buoyancy effects on underground vaults due to higher groundwater levels.

2050 High Sea Level Rise (2.0 ft)

- Low-lying sections of Brookhurst Street could experience tidal flooding adjacent to the wetlands.
- Majority of planning area remains protected from tidal flooding by existing levee system.
- Potential impact to storm water pump station infrastructure warrants further evaluation. A facility specific investigation would be necessary to determine:
  - Performance impact on pumps due to higher tail water elevation;
  - Potential for flow-reversals due to higher tail water elevation; and
  - Buoyancy effects on underground vaults due to higher groundwater levels.

2100 High Sea Level Rise (5.5 ft)

- High SLR projections in 2100 will result in overtopping of the existing levee system along the downstream reaches of Talbert Channel and Huntington Beach Channel.
- The existing levee between Talbert Marsh and the OCSD Huntington Beach Treatment Plant would be overtopped, causing significant flooding of the facility.
- A long reach of PCH (from Brookhurst Street to Beach Blvd) will experience flooding from the wetlands. PCH becomes the main flow path for flooding impacting the AES Power Plant, mobile home community, and residential communities along Newland Street.
- Overtopping of the existing Talbert Channel levees downstream of Hamilton Ave would result in widespread flooding impacting roads, utilities, and residential, commercial, and public properties. See discussion below regarding extent of potential flooding.
- Potential impact to storm water pump station infrastructure warrants further evaluation. A facility specific investigation would be necessary to determine:
  - Performance impact on pumps due to higher tail water elevation;
  - Potential for flow-reversals due to higher tail water elevation; and
  - Buoyancy effects on underground vaults due to higher groundwater levels.

The potential tidal flooding limits shown in Figure 23 reflects the extent of the planning area that lies below the water level of 12.68 feet (NAVD 88) evaluated for the 2100 high SLR projection. Since the area below this projected water level is so large, the volume of water (not ground elevation) may be the limiting factor of potential flooding.

Theoretically, if there was an endless volume of floodwater due to a levee breach, a higher water level or a combination of the two, this entire area would be subject to flooding. However, if

the existing levees remain intact (at their current crest elevation) the duration of overtopping would be relatively short and the extent of flooding would be significantly less.

A color banded elevation map, shown in Figure 24, provides an indicator of the general topography of this planning area. Low-lying land along the marshes and lower reaches of Huntington Beach Channel and Talbert Channel would be most vulnerable to tidal flooding for the 2100 high SLR projection. The extents of flooding would progress inland following local topography until the water level subsided or the levees were repaired.

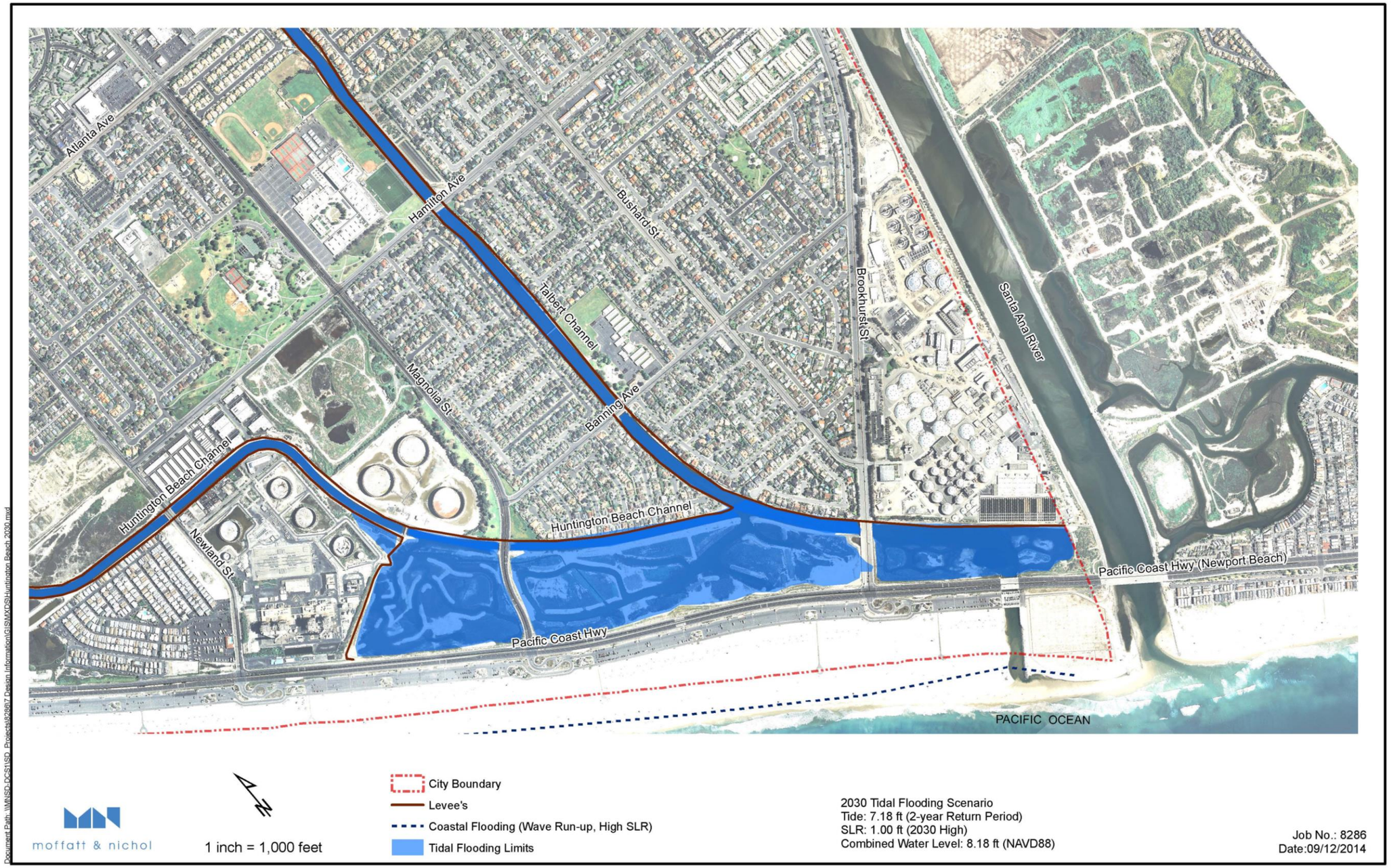


FIGURE 21
TIDAL FLOODING AT HUNTINGTON BEACH WETLANDS AREA – YEAR 2030 SLR (HIGH)

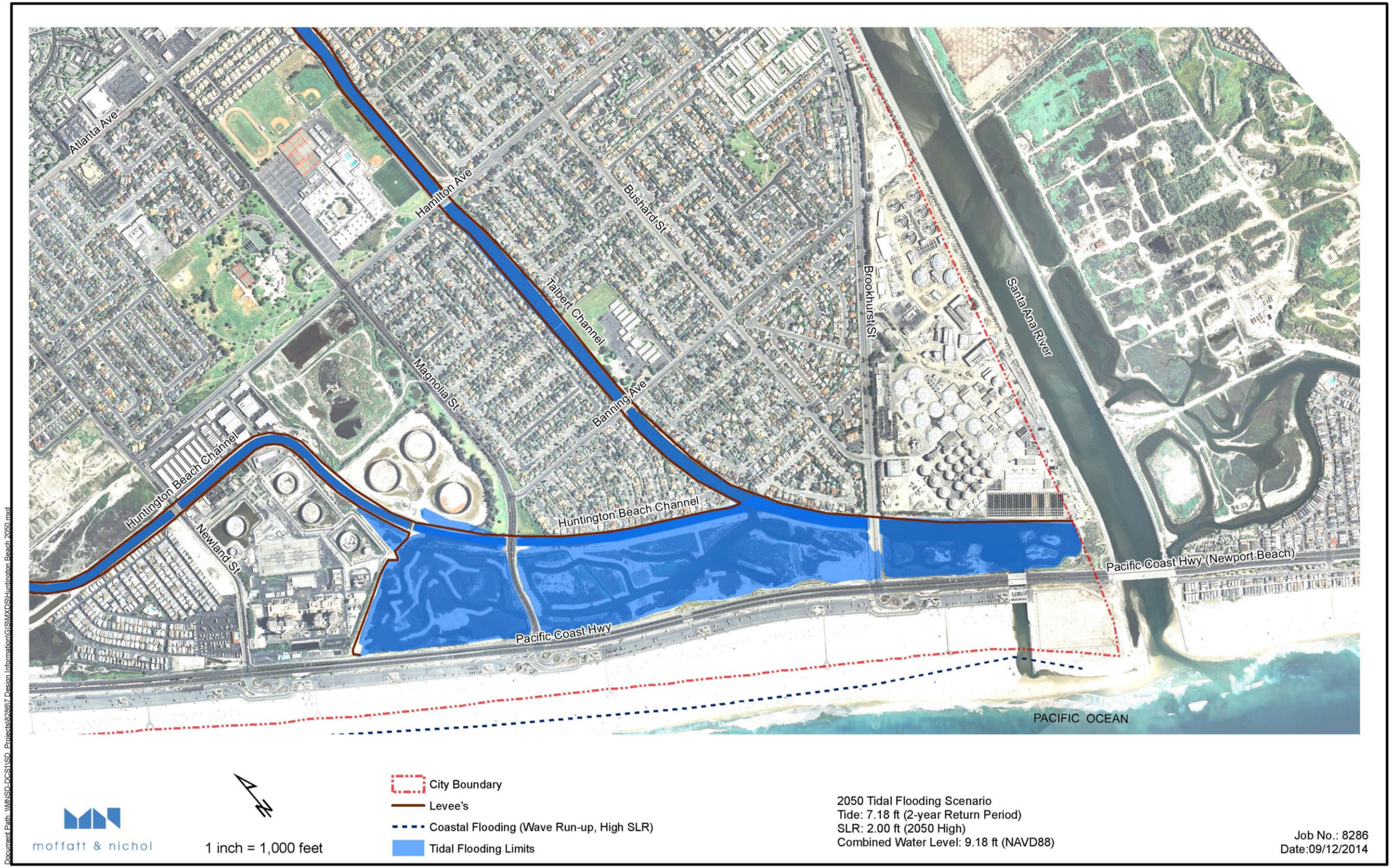
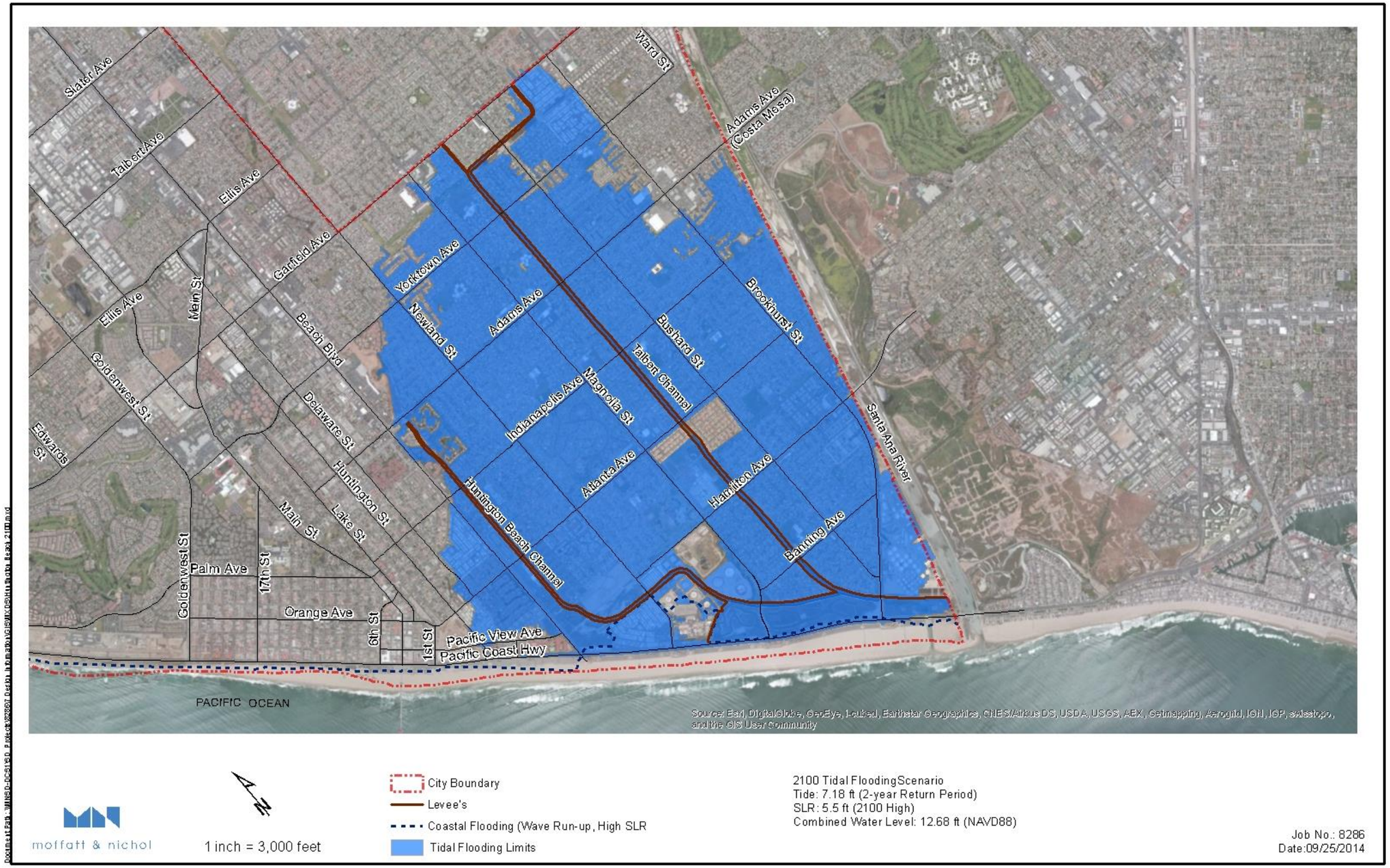


FIGURE 22
TIDAL FLOODING AT HUNTINGTON BEACH WETLANDS AREA – YEAR 2050 SLR (HIGH)



moffatt & nichol

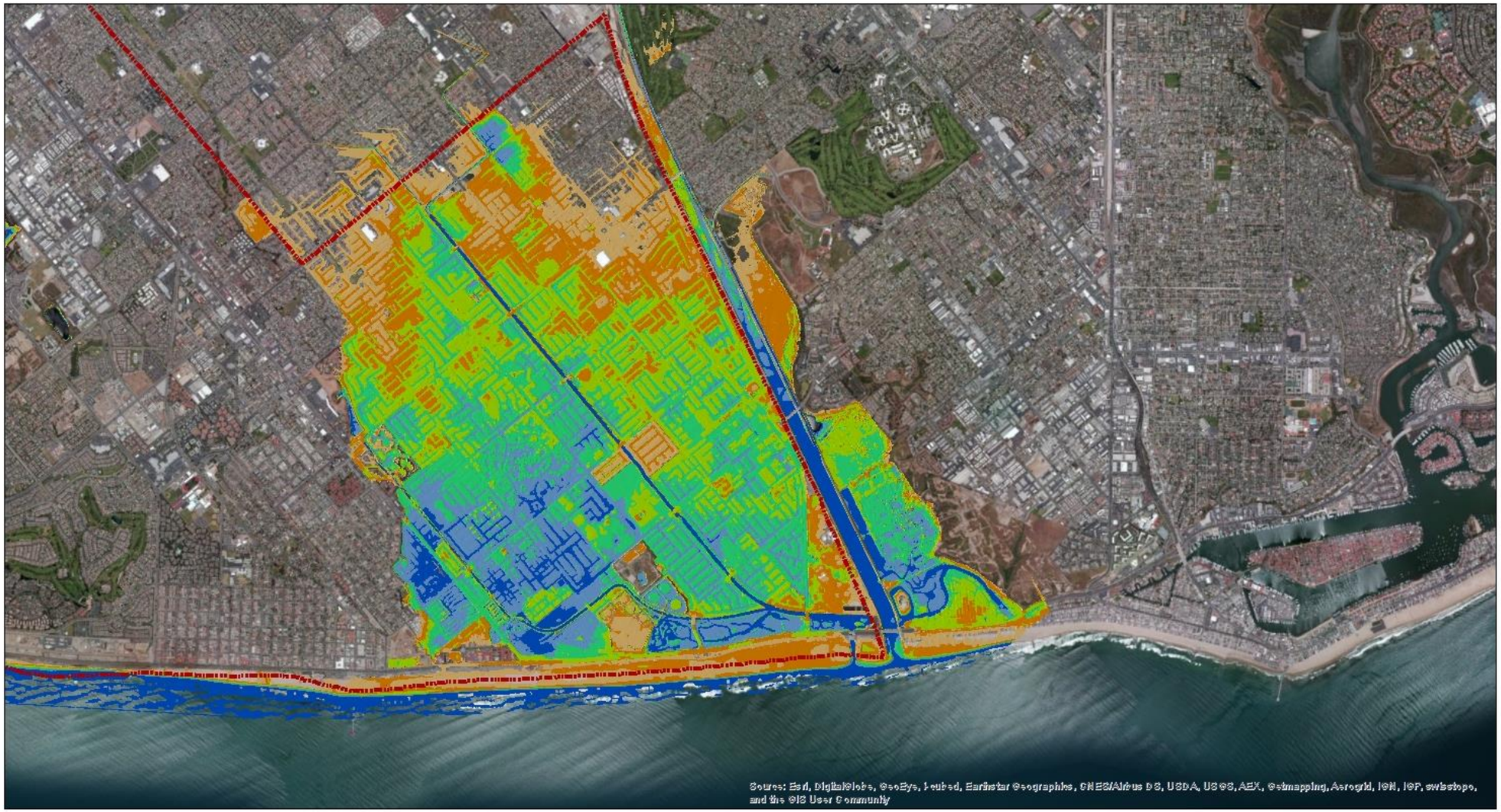
1 inch = 3,000 feet

City Boundary
Levee's
Coastal Flooding (Wave Run-up, High SLR
Tidal Flooding Limits

2100 Tidal Flooding Scenario
Tide: 7.18 ft (2-year Return Period)
SLR: 5.5 ft (2100 High)
Combined Water Level: 12.68 ft (NAVD88)

Job No.: 8286
Date:09/25/2014

FIGURE 23
TIDAL FLOODING AT HUNTINGTON BEACH WETLANDS AREA – YEAR 2100 SLR (HIGH)



moffatt & nichol

1 inch = 3,000 feet

City Boundary
Elevation shown in color bands
Ground Elevation (Feet, NAVD 88)
12 - 14
10 - 12
8 - 10
6 - 8
4 - 6
2 - 4

Job No.: 8286
Date: 09/26/2014

FIGURE 24
GROUND ELEVATION MAP OF HUNTINGTON BEACH WETLANDS PLANNING AREA

8.2.2. Flooding from Extreme Rainfall Events

The Huntington Beach Channel (D01) and Talbert Channel (D02) are recently improved flood control channels that consist of sheetpile walls and a natural bottom. Both channels have a relatively flat longitudinal slope and low invert elevations. Adjacent ground is typically lower than the flood levels, resulting in a levee condition for most of this planning area.

Rising sea levels will increase the downstream controlling water surface elevation, resulting in a higher water surface profile for a certain distance upstream. The upstream extent of these impacts was evaluated for several SLR scenarios, as discussed below.

Huntington Beach Channel (D01)

The D01 channel was modeled using a 2-D unsteady state model (RMA-2) to simulate the combined effects of a 100-yr storm hydrograph and tidal exchange through the marsh and channel system during an average spring high tide. The estimated water surface elevations upstream of major road crossings are listed in Table 30 for each SLR scenario. More detailed model results are provided in Appendix B.

The purpose of this model was to evaluate changes in the 100-year flood profiles for various SLR scenarios. The RMA-2 model assumes a uniform rectangular open channel upstream of Magnolia Marsh to Adams Avenue.

The model does not account for the culverts and bridge decks at each road crossing, which can significantly influence water surface profiles, especially for high projections of SLR. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by FEMA and should not be used for purposes of floodplain mapping.

The results indicate that 1 ft of SLR (2030 High) would increase water surface elevations by about 0.6 foot at Magnolia Street and 0.4 foot at Adams Avenue. The reach averaged increase in water surface elevation is about 0.5 foot. Model results of this scenario indicate the 100-year flood would be conveyed within the channel, but with less freeboard.

A 2 foot rise in sea level (2050 High) has a more significant impact on the flood profile with a reach averaged increase of about 1 ft compared to the 2010 (no SLR) results. Results indicate the 100-year flood profile remains below the top of channel with freeboard ranging from 2-3 ft upstream of Magnolia Street to Adams Avenue.

The projected high SLR value of 5.5 ft in 2100 would significantly reduce the conveyance capacity of the existing Huntington Beach channel. The flood profile upstream of Magnolia Street to Adams Avenue would increase by an average of nearly 4 ft compared to the 2010 (no SLR) results. Model results indicate overtopping of the channel would occur downstream of Atlanta Avenue during a 100-year flood with 5.5 ft of SLR. Under this SLR scenario, additional improvements would be required to convey the 100-year flood within the channel walls.

TABLE 30
HUNTINGTON BEACH CHANNEL FLOOD RESULTS FOR EACH SLR SCENARIO

Huntington Beach Channel (D01) Location	Top of Channel Elevation (ft, NAVD 88)	100-yr Water Surface Elevations (ft, NAVD 88)*			
		2010 no SLR	2030 High SLR	2050 High SLR	2100 High SLR
Brookhurst Marsh	12.2	8.1	8.7	9.5	**12.6**
Magnolia St	12.4	8.5	9.1	9.8	**12.9**
Newland St	13.1	9.6	10.1	10.7	**13.5**
Atlanta Ave	13.6	10.0	10.4	11.0	13.6
Indianapolis Ave	14.1	10.1	10.6	11.2	13.7
Adams Ave	14.5	10.3	10.7	11.2	13.7

**The results of this analysis should not be used for estimating base flood elevations or floodplain mapping. Because of the different models, methods, and assumptions used in this analysis the results are not comparable to base flood elevations determined by FEMA.*

Talbert Channel (D02) and East Valley-Fountain Valley Channel (D05)

These channels were modeled using a 2-D unsteady state model (RMA-2) to simulate the combined effects of a 100-year storm hydrograph and tidal exchange through the marsh and channel system during an average spring high tide. The estimated water surface elevations upstream of major road crossings are listed in Table 31 for each SLR scenario. More detailed model results are provided in Appendix B.

The purpose of this model was to evaluate changes in the 100-year flood profiles for various SLR scenarios. The RMA-2 model assumes a uniform rectangular open channel upstream of Magnolia Marsh to Garfield Avenue. The model does not account for the culverts and bridge decks at each road crossing, which can significantly influence water surface profiles, especially for high projections of SLR. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by FEMA and should not be used for purposes of floodplain mapping.

The results indicate that 1 ft of SLR (2030 High) would increase water surface elevations by about 1 ft at Brookhurst Street and about 0.7 ft at the confluence of D01 and D02 when compared to the 2010 (no SLR) water surface profile. The water surface profile increase tapers to 0.5 ft at Hamilton Avenue and 0.1 ft at Adams Avenue. Model results of this scenario indicate the 100-year flood would be conveyed within the channel, but with reduced freeboard in the downstream reach.

A 2-ft rise in sea level (2050 High) results in an increased water surface profile extending further upstream. A 2 ft rise in water surface elevation in the marsh area tapers to an increase of 1.5 ft at the D01/D02 confluence when compared to 2010 (no SLR) results. Water surface profile increases of greater than 1 ft can be expected downstream of Atlanta Avenue for the 2050 High SLR projection. Model results indicate the 100-year flood would be conveyed within the channel but with less than 2 ft of freeboard along sections of the downstream channel reach.

The projected high SLR value of 5.5 ft in 2100 would significantly impact the conveyance capacity of the existing Talbert (D02) and East Valley-Fountain Valley Channels (D05). The flood profile downstream of Hamilton Avenue would increase by more than 4 ft compared to the 2010 (no SLR) results. With 5.5 ft of SLR, overtopping of the channel would occur downstream of Atlanta Avenue during a 100-year flood. Under this SLR scenario additional improvements would be required to convey the 100-year flood within the channel walls.

TABLE 31
TALBERT CHANNEL FLOOD RESULTS FOR EACH SLR SCENARIO

Channel	Location	Top of Channel Elevation (ft, NAVD 88)	100-yr Water Surface Elevations (ft, NAVD 88)*			
			2010 no SLR	2030 High SLR	2050 High SLR	2100 High SLR
Marsh	Near OCSD	12.2	6.6	7.7	8.7	12.1
Marsh	Brookhurst St	12.2	6.9	7.8	8.7	12.1
Talbert (D02)	D01 Confluence	11.2	8.1	8.7	9.5	**12.7**
Talbert (D02)	Banning Ave	11.9	8.2	8.8	9.6	**12.7**
Talbert (D02)	Hamilton Ave	12.3	8.8	9.2	9.9	**12.8**
Talbert (D02)	Atlanta Ave	13.9	9.4	9.7	10.3	12.9
Talbert (D02)	Indianapolis Ave	15.2	10.3	10.5	10.9	13.2
Talbert (D02)	Adams Ave	15.7	11.1	11.2	11.5	13.5
Talbert (D02)	Yorktown Ave	16.3	11.8	11.9	12.1	13.8
Talbert (D02)	D05 Confluence	15.7	12.1	12.1	12.3	13.9
Talbert (D02)	Garfield Ave	15.1	12.5	12.6	12.7	14.2
FV (D05)	Bushard St	15.3	12.5	12.5	12.7	14.1
FV (D05)	Garfield Ave	16.7	13.4	13.4	13.5	14.5

**The results of this analysis should not be used for estimating base flood elevations or floodplain mapping. Because of the different models, methods and assumptions used in this analysis the results are not comparable to base flood elevations determined by FEMA.*

8.2.3. Huntington Beach Wetlands Planning Area - Vulnerability & Risk Assessments

A vulnerability and risk assessment of assets in the south Huntington Beach area was performed following the methodology outlined in Section 5 and summarized in Table 32. The impact threshold varies for assets within this planning area. Transportation infrastructure (PCH) will likely be impacted by SLR first with flooding of portions of the road from high tides combined with the 2050 high SLR projection. Other critical assets are protected by levees along the wetlands and flood control channels with impacts unlikely until the SLR projections in 2100.

TABLE 32
HUNTINGTON BEACH WETLANDS PLANNING AREA – VULNERABILITY ASSESSMENT

Asset	Impact Threshold	Type of Impact	Max. No. Assets Impacted	Sensitivity to SLR	Adaptive Capacity	Vulnerability
Flood Protection – seawalls or levees	2100 - High	Overtopping from high tides	14,700 linear feet	Low	Moderate	Low
Buildings (Public & Private)	2100 - High	Flooding from high tides	5,000 – 15,000 buildings	Low	Low	MODERATE
Transportation (Streets)	2100	Flooding from high tides	2.6 miles (PCH)	Low	Low	MODERATE
Energy Facilities*	2100 - High	Flooding from high tides	1 (AES Plant)	Low	Low	MODERATE
Stormwater Infrastructure**	~2100	High groundwater/ Flooding	Unknown	Low	Low	MODERATE
Wastewater Infrastructure**	~2100	High groundwater/ Flooding	OCSD Plant & more	Low	Low	MODERATE

**Additional information is required to verify vulnerability and risk of energy infrastructure.*
***Additional analysis required to verify vulnerability and risk of stormwater infrastructure.*

Adaptive capacity was assigned qualitatively, as follows, based on the ability of assets in the planning area to accommodate a rise in sea level while maintaining function or service.

- Levees along the Talbert Channel, Huntington Beach Channel, and marsh were assigned a moderate adaptive capacity. These levees consist mostly of sheetpile walls with relatively high crest elevations and would be able to accommodate increases in sea level up to about 4 ft. This amount of SLR is less than the projected high SLR value in 2100.

- Buildings were assigned a low adaptive capacity for this planning area. Due to the low and flat topography of this area, there are a significant number of buildings reliant on levees for flood protection. Most buildings have their finished floor at or close to grade with limited adaptive capacity in the form of low cost flood barriers (i.e., sandbags, plywood, or other temporary material). However, reliance on temporary measures may not be adequate to accommodate significant inundation and only a few inches of standing water could render a building unusable.

- Transportation infrastructure was assigned a low adaptive capacity. Even minor amounts of flooding on the roads can cause significant traffic delays, impacting emergency service response times and evacuation routes. Maintenance and repair requirements would also increase after significant flooding, but the primary impact is disruption of service.

- Energy Facility (AES Power Plant) was assigned a low adaptive capacity. The adaptive capacity of the plant depends on the elevation of critical equipment, controls, or other components relative to the predicted flood levels. Sufficient information to make a

judgment of the plant's adaptive capacity was not available, so a low score was assumed in this analysis.

- Stormwater Infrastructure was assigned a low adaptive capacity. The primary impact to stormwater infrastructure in this planning area is from high groundwater levels. The low lying storm drain/flood control networks that drain to pump stations may experience reduced capacity with a significant rise in groundwater levels due to increased I&I. Underground storage vaults may also be subject to increased buoyancy forces with higher groundwater levels.

- Wastewater Infrastructure was assigned a low adaptive capacity. Increased groundwater levels may also result in more I&I into the collection system and potentially reducing capacity of pipes, lift stations or treatment facilities. Higher groundwater levels may also impact underground infrastructure at the OCSD Huntington Beach Treatment Plant.

Most assets in the Huntington Beach Wetlands planning area have low sensitivity to SLR because they are protected by levees that can accommodate a significant rise in sea level. PCH is more sensitive to SLR than other assets and will likely experience flooding for projected SLR values in 2100. Most other assets in this planning area are not considered vulnerable until groundwater levels rise significantly (~2100), or the combination of SLR and high tide exceeds the capacity of the levee system.

There is a high consequence of impacts for high SLR projections but relatively low probability of these impacts occurring. The current overall risk for this planning area is considered moderate. A summary of the risk assessment for the planning area is shown in Table 33. The vulnerability and risk assessments were based on the potential for flooding during a high tide combined with SLR. Discharge from an extreme rainfall event combined with the 2100 high SLR projection may result in more significant impacts due to additional flooding from Huntington Beach and Talbert Channels. Impacts from this flooding source were not quantified, but would likely impact the same areas subject to tidal inundation for the 2100 high SLR projection.

TABLE 33
HUNTINGTON BEACH WETLANDS PLANNING AREA – RISK ASSESSMENT

Asset	Impact	Consequence of Impact	Probability of Impact	Overall Risk to Asset
Flood Protection – Seawalls & Levees	Overtopping from high tides	HIGH Significant inundation of surrounding communities	LOW Not likely to occur until 2100 high SLR projection	MODERATE
Buildings (Public & Private)	Flooding from levee overtopping	HIGH Significant cost to repair buildings / loss of function	LOW Not likely to occur until 2100 high SLR projection	MODERATE
Transportation (Streets)	Flooding from high tides	HIGH Loss of service/ impacts to traffic, emergency service, evacuation routes/ higher maintenance & repair cost	LOW Not likely to occur until SLR projections in 2100	MODERATE

Asset	Impact	Consequence of Impact	Probability of Impact	Overall Risk to Asset
Energy Facilities*	Flooding from high tides	HIGH Loss of service/ higher maintenance & repair cost	LOW Not likely to occur until SLR projections in 2100	MODERATE
Stormwater Infrastructure**	Flooding / High groundwater	HIGH Loss of capacity, reduced flood protection	LOW More likely for SLR projections in 2100	MODERATE
Wastewater Infrastructure**	Flooding / High groundwater	HIGH Damage to OCSD Treatment Plant/ Potential for overflows of untreated sewage	LOW More likely for SLR projections in 2100	MODERATE
			Overall Planning Area Risk Rating	MODERATE

**Additional information is required to verify vulnerability and risk of energy infrastructure.*
***Additional analysis of stormwater and wastewater infrastructure required to verify vulnerability and risk.*

9. Adaptation

Managing the impacts of SLR will require the adaptation of human activities in the coming decades through various policies and actions such that both human systems (communities, economies, and emergency management systems) and natural systems (wetlands and coastal ecosystems) can continue to function effectively and be resilient in the face of climate change. There are a number of effective policy tools local governments already have available to help their communities adapt to SLR, including:

- Local comprehensive land use plans
- Coastal management and beach preservation authority
- Ecosystem conservation policies
- Major public facility and infrastructure investments
- Post-disaster redevelopment planning

The California Coastal Commission (CCC) Draft Sea Level Rise Policy Guidance calls for adaptation policies that address SLR. Once the General Plan is updated, the next step will be to amend the City's Local Coastal Program (LCP) with SLR adaptation measures. The guidance identifies two major types of LCP updates likely to be needed to address SLR:

- New or revised policies/ordinances that apply to all development in the planning area, e.g., "all new development should be sited and designed to minimize risks from SLR over the life of the structure."
- Updated land use and zoning designations to reduce risks to specific coastal resources, such as modified zoning of undeveloped land located upland of wetlands from residential to open space in order to provide the opportunity of wetlands to migrate inland.

In Huntington Beach, one adaptive policy could be to create a SLR Hazard Overlay Zone – The overlay zone could set new development or redevelopment provisions such as building heights, foundation requirements, setbacks, etc. Alternatively, the projects proposed within the overlay could trigger future analysis of potential impacts due to SLR. This provision would be consistent with the CCC SLR Policy Guidance.

10. Conclusions and Recommendations

The purpose of the vulnerability and risk assessment was to identify priority planning areas within the City of Huntington Beach. Sea level rise impacts were considered along shoreline planning areas and inland waterway planning areas. The study considered the potential for flooding and inundation due to 1) very high tides with SLR, 2) 100-year wave event with SLR; and 3) 100-year stormwater discharge with SLR.

The vulnerability of assets with each planning area was evaluated as a function of exposure to SLR impacts, sensitivity to SLR impacts, and adaptive capacity. Information collected from the vulnerability assessment was used to estimate the consequence, probability, and resulting risk associated with a specific impact at a specific time horizon. Each planning area was assigned an overall risk rating based on the number and type of assets at risk. The shoreline planning areas facing the highest risk to impacts from SLR are listed below in order of priority:

1. Huntington Beach
2. Sunset Beach
3. Huntington Bluffs
4. Bolsa Chica

The inland waterway planning areas facing the highest risk to impacts from SLR are listed below in order of priority:

1. **Huntington Harbour** – high risk to transportation (PCH) & buildings which are vulnerable by 2030 or sooner. Significant impacts to all assets by 2050 and 2100.
2. **Bolsa Chica** – high risk to transportation assets (PCH) by 2050 time horizon. Other significant impacts not likely until the 2100 high SLR projection.
3. **Huntington Beach Wetlands** – most significant impacts not likely until the 2100 high SLR projection.

Based on the study efforts to this point, the following recommendations are presented:

- Additional investigation into seawall/bulkhead infrastructure around Huntington Harbour is recommended to improve accuracy of potential hazard zones.

- Input from Southern California Edison (SCE) during development of the coastal resiliency plan will help assess the vulnerability of energy infrastructure in each planning area.

- Input from the Sunset Beach Sanitary District during development of the Coastal Resiliency Plan will help assess the vulnerability of specific lift stations and other infrastructure most vulnerable in the Huntington Harbour planning area.

- Huntington Beach Bluffs Revetment – For the purposes of the analysis, the revetment or rip rap protection was assumed to sufficiently fortify the bluffs along this reach. Inspection of this structure identified gaps and areas of potential weakness. Thus, this assumption may be overestimating the structural integrity of the structure and the protection of the bluffs. More detailed investigation of this structure and potential erosional response of the bluffs in this reach is needed to get a better sense of the shoreline response to future changes in SLR.

- Modeling of proposed adaptation strategies – Strategies such as the Sunset Beach winter dike could be modeled to evaluate the effectiveness of these methods to offset future combined water levels.

- Pacific Coast Highway overtopping – More detailed analysis of run-up overtopping at Bolsa Chica and Huntington Beach Planning Subareas should be evaluated to characterize local topography and hot spots vulnerable to overtopping.

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Technical Appendix A

Sea-Level Rise Vulnerability Assessment Methods
and Results for the Shoreline Planning Areas

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1. Introduction

This appendix provides the technical background information (data review, methods, and results) that supports the sea level rise (SLR) vulnerability assessment of the Shoreline Planning Areas. It is organized in the following sections:

- Section 2 summarizes existing regional planning model results that serve as a starting point for this more focused vulnerability assessment.

- Section 3 describes the relevant oceanographic site conditions (water levels, waves, and tsunamis), including a summary of the projected SLR scenarios to be investigated in this assessment.

- Section 4 presents the detailed vulnerability assessment modeling approach for this effort. A process-based, two-dimensional (2D) numerical model called XBeach was used in combination with the *Bruun Rule*[1] (Bruun 1962) to model future SLR impact within the Shoreline Planning Areas. A separate Technical Appendix is attached that addresses the Inland Waterways Planning Areas.

[1] *The Bruun Rule hypothesizes that as the sea level rises, the shoreface will respond by moving landward. This rule is described in greater detail in subsequent sections of the report.*

2. Review of Existing SLR Modeling Efforts

Existing modeling efforts conducted by National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS) were reviewed as a first-order evaluation of vulnerabilities in the City of Huntington Beach. These modeling results are summarized in this section.

2.1. Sea-Level Rise and Coastal Flooding Impacts Viewer

The NOAA model applied to support the SLR Viewer can be described as a modified "bathtub approach" that attempts to account for local and regional tidal variability and hydraulic connectivity (http://www.csc.noaa.gov/digitalcoast/tools/slrviewer). The model uses best available elevation data at the time of the study relative to mean higher-high water (MHHW) tidal datum (i.e., 5.5 ft, [mean lower-low water] MLLW). The model does not include a detailed pipe network analysis or engineering-grade hydrologic analysis; thus, hydrologically unconnected areas of inundation are displayed and symbolized differently (i.e., as green areas) than hydrologically connected inundation areas (i.e., blue areas). Model results for the study area under a 6-ft SLR scenario are shown in Figures 1 through 3. This scenario was choosen because it represents approximately the highest SLR projection for year 2100 used in the vulnerability assessment (i.e. 5.5 feet). The modeling effort used a generalized elevation model and it is unclear what inland waterway assumptions were made (e.g. EGGWC, Parkside Project).

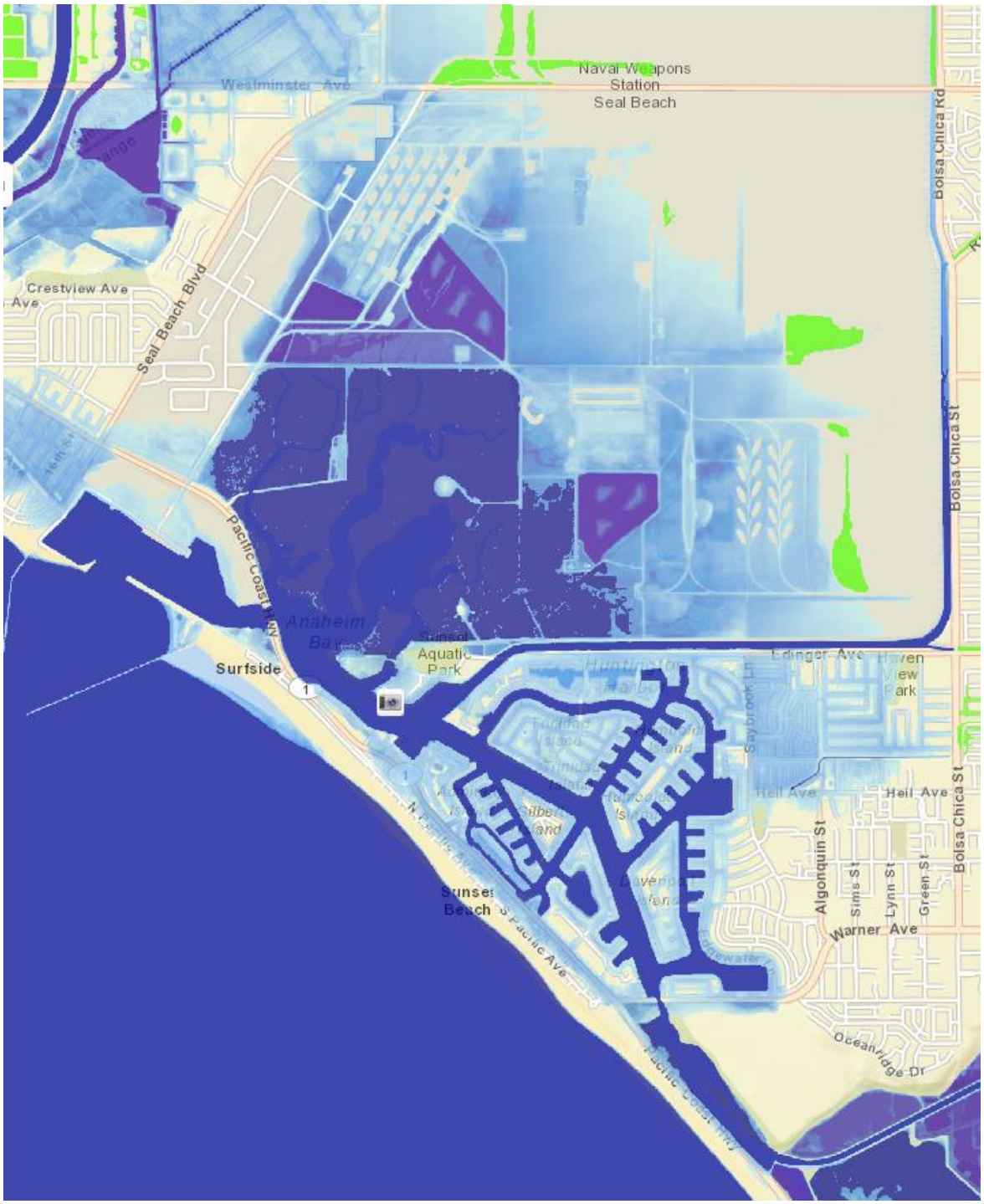

FIGURE 1
NOAA COASTAL FLOODING MODEL RESULTS (6 FT OF SLR) – SUNSET BEACH/HUNTINGTON HARBOUR PLANNING AREA

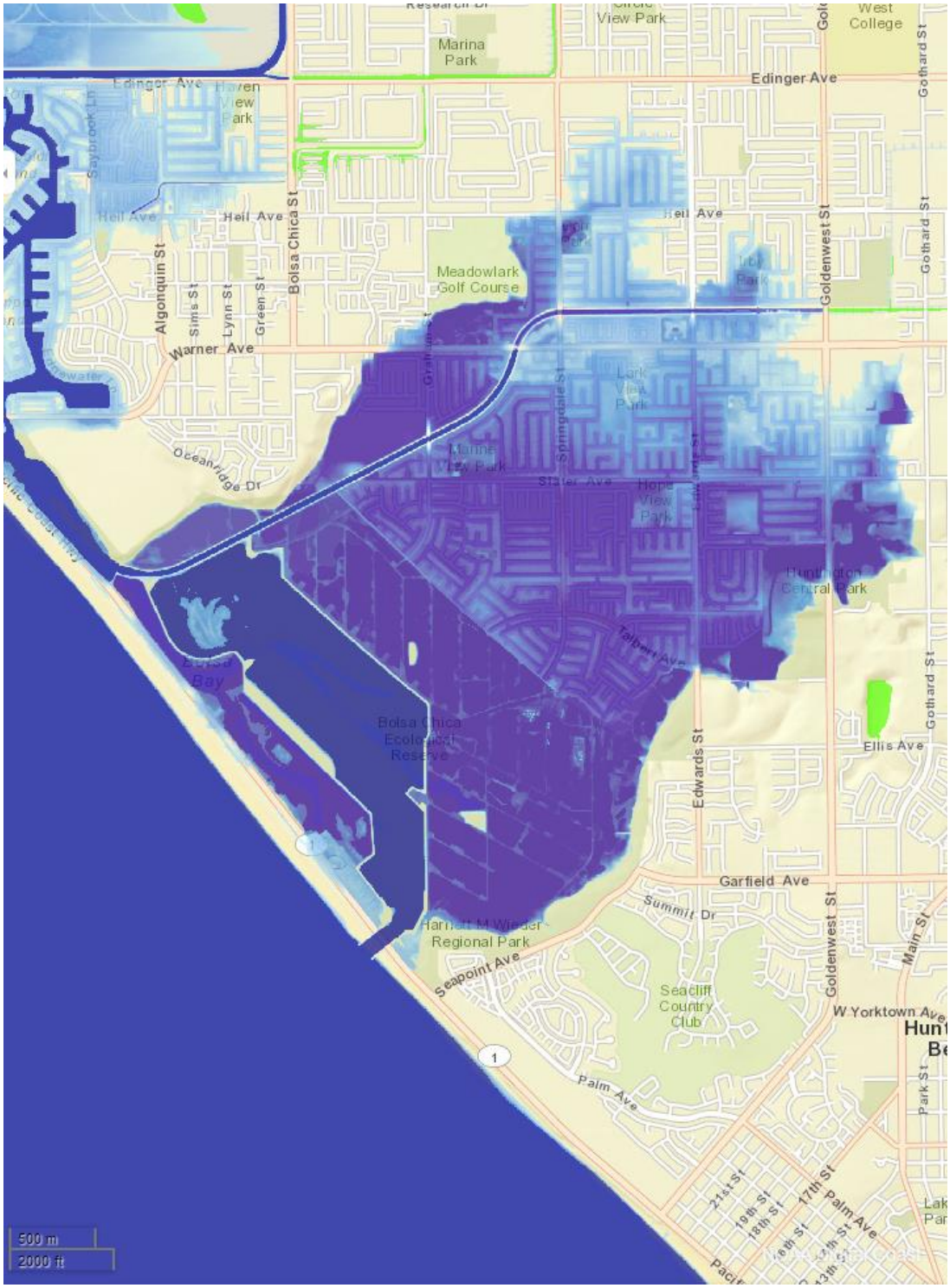

FIGURE 2
NOAA COASTAL FLOODING MODEL RESULTS (6 FT OF SLR) – BOLSA CHICA PLANNING AREA

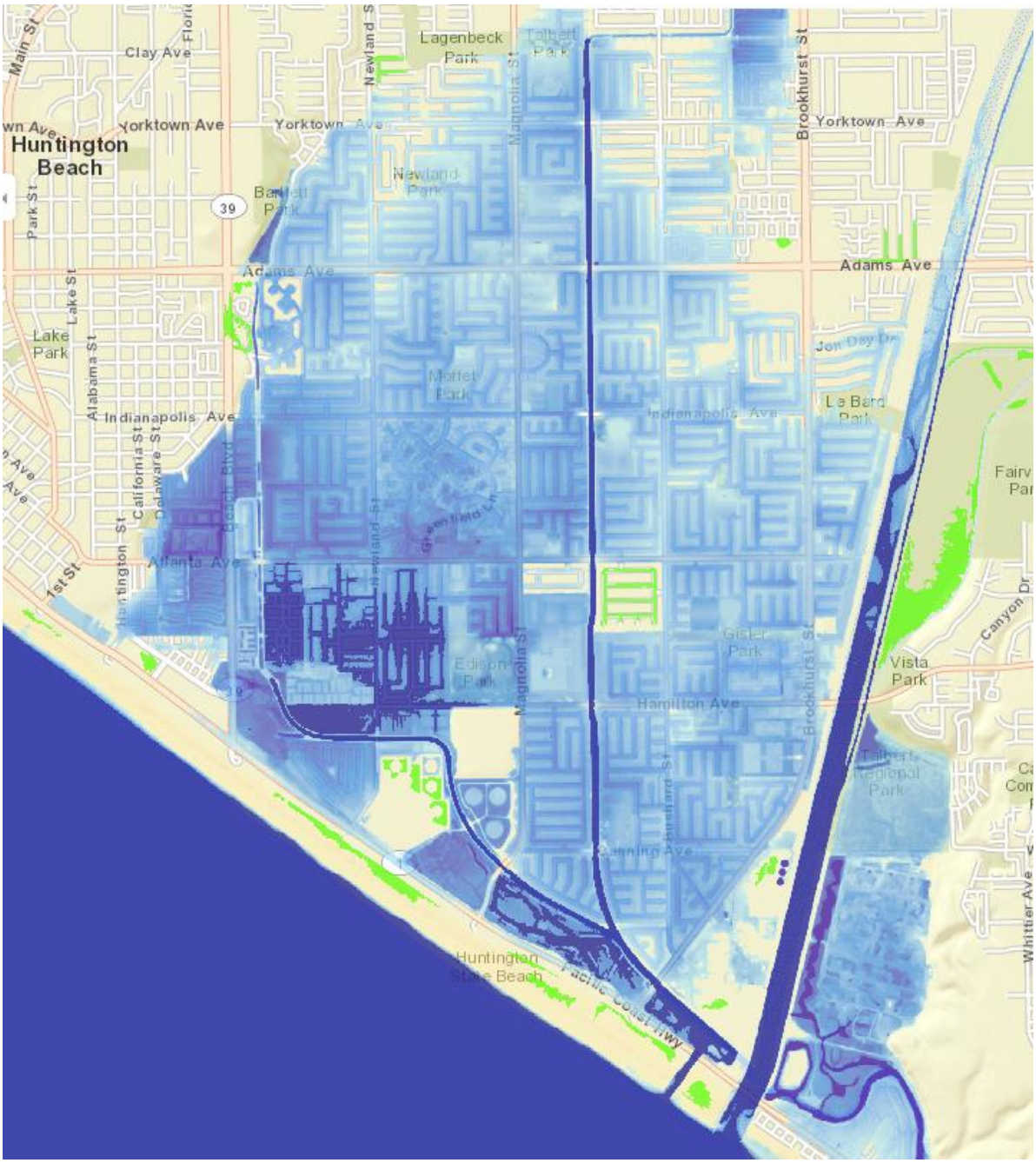

FIGURE 3
NOAA COASTAL FLOODING MODEL RESULTS (6 FT OF SLR) – SOUTH HUNTINGTON BEACH

2.2. CAL-ADAPT – THREATENED AREAS MAP

The Cal-Adapt Threatened Areas Map displays areas that may be in threat of inundation during an extreme flood event (100-year storm) during various SLR scenarios (19, 39, and 55 inches). These data were developed by scientists from the USGS and the Pacific Institute. Areas in blue indicate areas already in threat today, while lighter shades are areas projected to be in threat

given expected SLR. Currently, these maps do not take into account protective structures, such as levees. Threatened areas in the study area are shown in Figure 4 and Figure 5.

Details on the methodology used for this mapping effort area are not available on their website (http://cal-adapt.org/sealevel/).

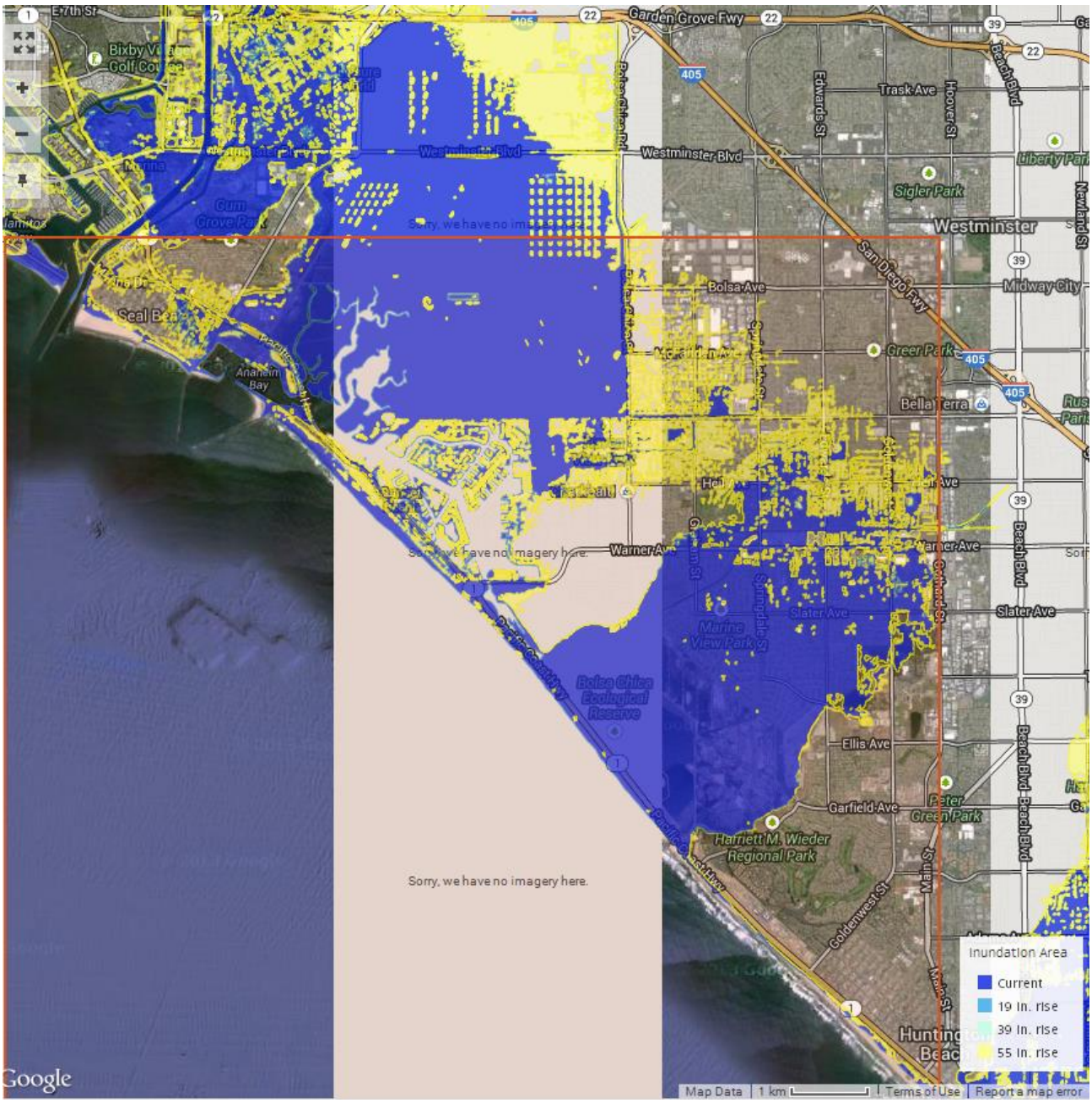

FIGURE 4
CAL-ADAPT MODEL INUNDATION RESULTS – NORTH HUNTINGTON BEACH

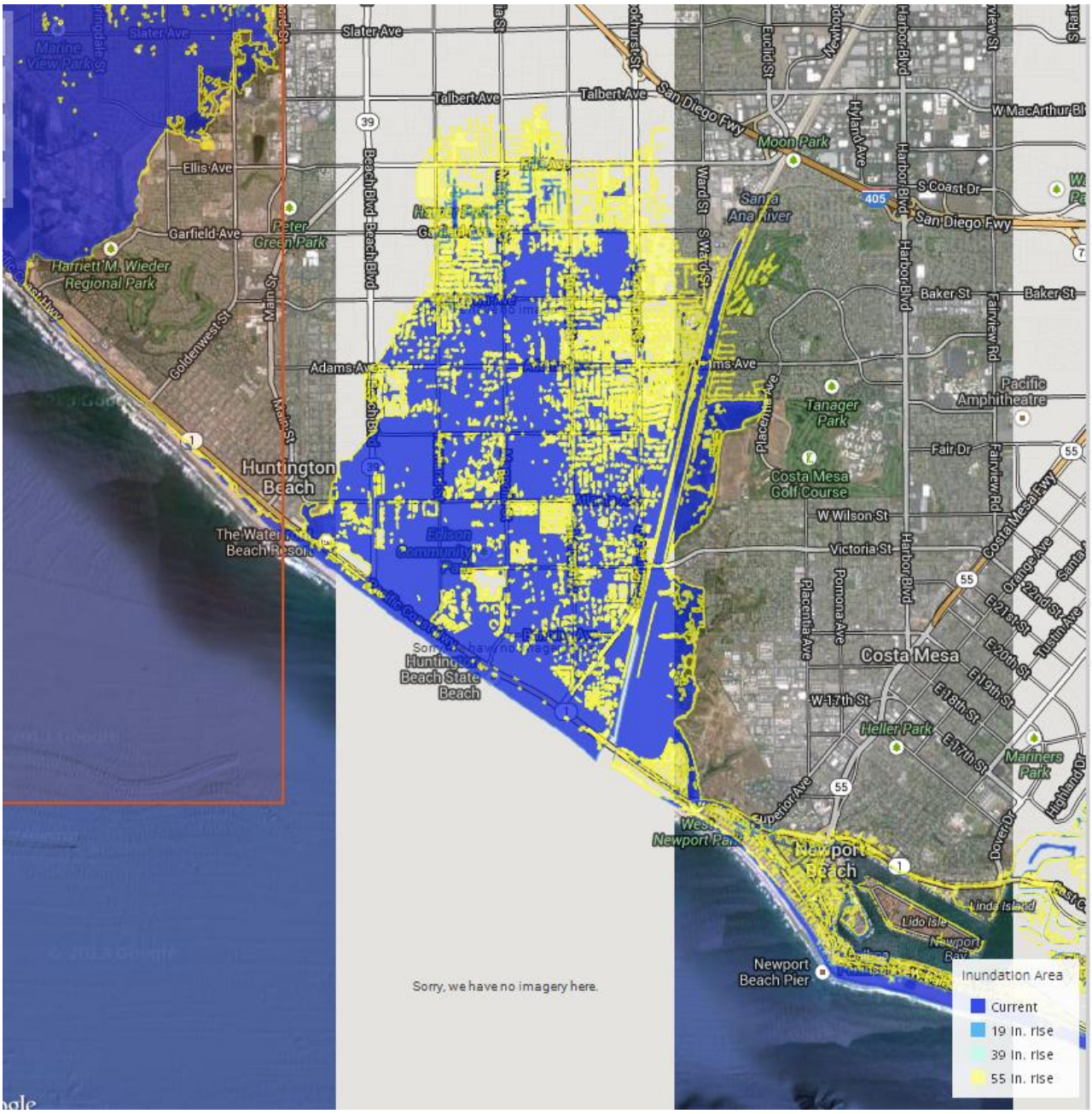

FIGURE 5
CAL-ADAPT MODEL INUNDATION RESULTS – SOUTH HUNTINGTON BEACH

2.3. COASTAL STORM MODELING SYSTEM

The Coastal Storm Modeling System (CoSMoS) for southern California (also known as CosMos1.0) was developed and released by USGS and Deltares in 2009 with the intent to provide real time predictions of hazards along the Southern California coast (Barnard et al. 2009). The model framework consist of a regional wave and flow model that feeds results to one-dimensional XBeach models. Output from the model is limited to hydrodynamic parameters which include

wave height, maximum water level, extreme run-up and flow velocities since the existing CoSMoS framework neglects the underlying morphological response of the coastline.

Initial evaluations of the CoSMoS model were performed simulating a synthetic 100 year storm along the coast and analyzing the response. Since its development however, the model has been extended to provide sea level rise predictions for specific segments of the coastline. Publically available results from these SLR scenarios are based upon the January 2010 El Nino event. A large swell, in combination with high tides, occurred on January 12 and 13, 2010 that resulted in coastal flooding and erosion in many parts of the state. Waves were reported at 8 to 12 ft at Los Angeles County beaches. The USGS compared known flooding occurrences associated with this event to calibrate their numerical models and then added 1.7 ft (0.5 m) and 4.6 ft (1.4 m) SLR projections on top of these measured water levels. Model results are shown in Figure 6 through Figure 8.

Results from the CoSMoS model however, neglect the coastal response of the system. This makes it difficult to gain a holistic understanding southern California's short and long term morphological development based upon the best available science.

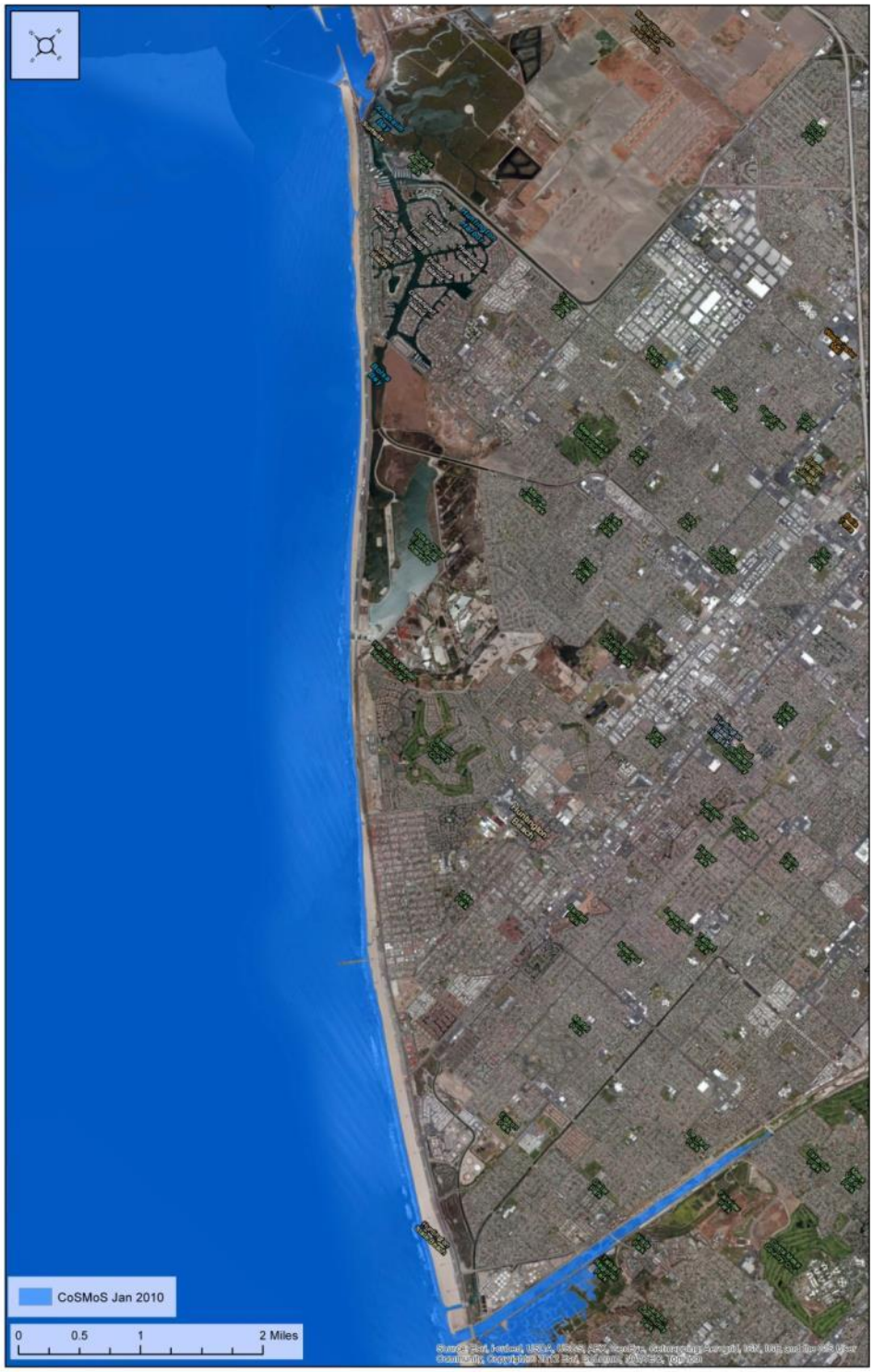

FIGURE 6
USGS EXTREME EVENT MODELING – JANUARY 2010 EVENT (NO SLR)

FIGURE 7
USGS EXTREME EVENT MODELING – JANUARY 2010 EVENT WITH 1.7 FT (0.5 M) OF SLR

FIGURE 8
USGS EXTREME EVENT MODELING – JANUARY 2010 EVENT WITH 4.6 FT (1.4 M) OF SLR

3. Oceanographic Site Conditions

The worst SLR impacts will occur as a result of higher sea levels in addition to storm surge associated with extreme wave events. Thus, understanding how these water level components work in isolation helps us understand how they could work in combination to make parts of the City vulnerable. Oceanographic conditions along the City shoreline are described in this section. Tide and wave data were extracted from NOAA and Wave Information System (WIS) stations in the vicinity of the Study Area. These stations are shown in Figure 9.

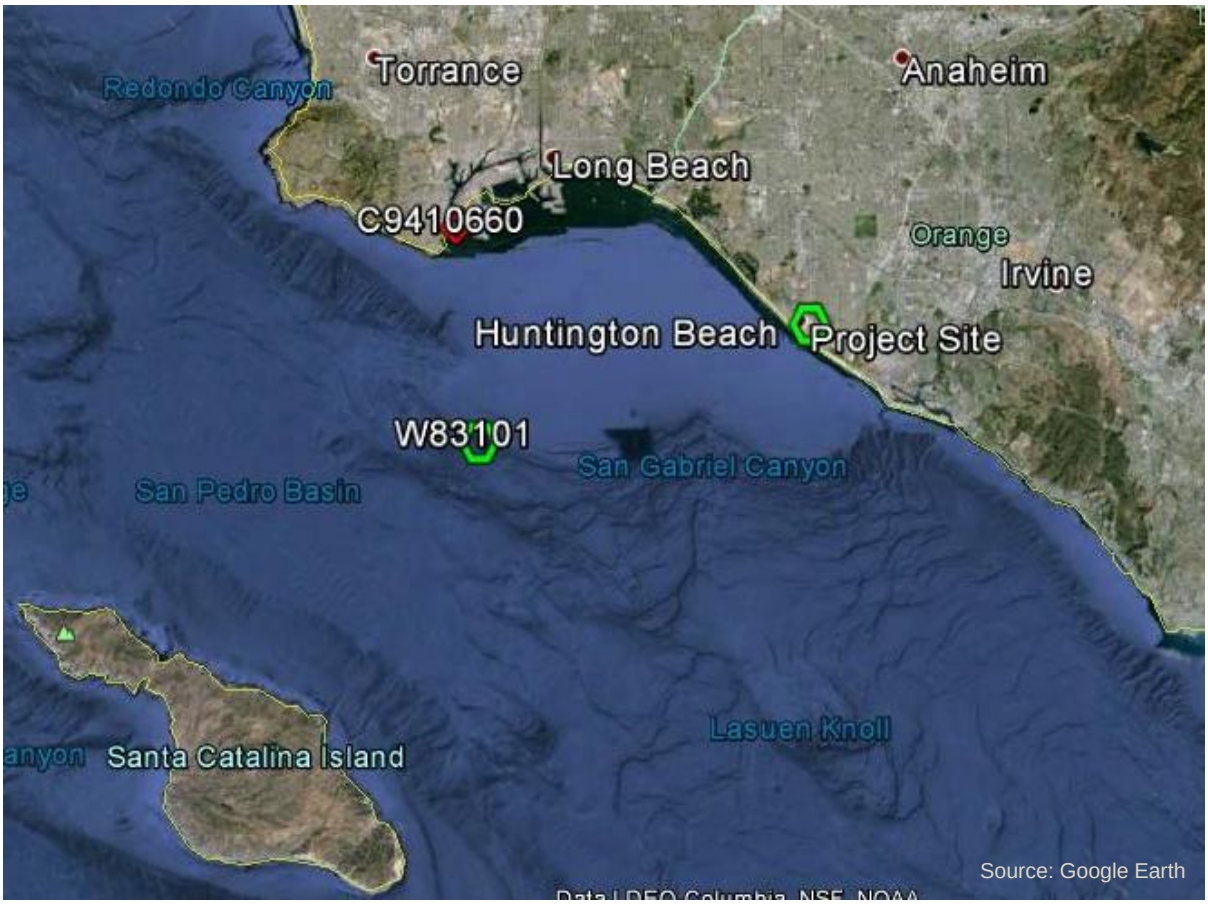

Figure 9
Water Level and Wave Data Extraction Locations
(Station C9410660=NOAA CO-OPs, Station W83101=WIS)

3.1. Tidal Datum

Tides in Huntington Beach are semidiurnal in nature: two highs and two lows per day. Water level datums measured by the NOAA were estimated for the project site using data from Station 9410660 – Los Angeles, CA. Tidal datum estimates from 1983-2001(the current tidal epoch) are summarized in Table 1.This is the closest, long-term tidal record to the City.

TABLE 1
TIDAL DATUMS FOR STATION 9410660 FROM THE 1983-2001 TIDAL EPOCH

Description	Datum	Elevation (feet MLLW)
Highest Observed Water Level	HOWL	7.9
Highest Astronomical Tide	HAT	7.3
Mean Higher-High Water	MHHW	5.5
Mean High Water	MHW	4.8
Mean Tide Level	MTL	2.8
Mean Sea Level	MSL	2.8
Mean Diurnal Tide Level	DTL	2.7
Mean Low Water	MLW	0.9
Mean Lower-Low Water	MLLW	0.0
North American Vertical Datum of 1988	NAVD88	0.2
Station Datum	STND	-3.8
Lowest Astronomical Tide	LAT	-2.0
Lowest Observed Water Level	LOWL	-2.7

3.2. WATER LEVELS

3.2.1. Storm Surge

Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide. Storm surges are a result of water being pushed toward the shore by winds moving cyclonically around a storm; thus, most significant examples are generally associated with hurricanes. Storm surge has been found to be comprised of only a small fraction of the total water levels along Southern California, and is commonly referenced as being less than a foot (CCC 2013). Storm surge is commonly confused with wave-runup, which is described in more detail below.

3.2.2. Wave Run-up

Wave setup and runup can contribute significantly to the damage potential of severe waves along the Pacific Coast (FEMA 2005). Total runup includes the combination of static wave setup, dynamic wave setup, and incident wave runup, as shown conceptually in Figure 10. Wave runup is governed by wave height, period, and beach slope. High wave runup values correspond with larger, more energetic waves and steeper beach slopes. *XBeach* was used to calculate wave runup in this study.

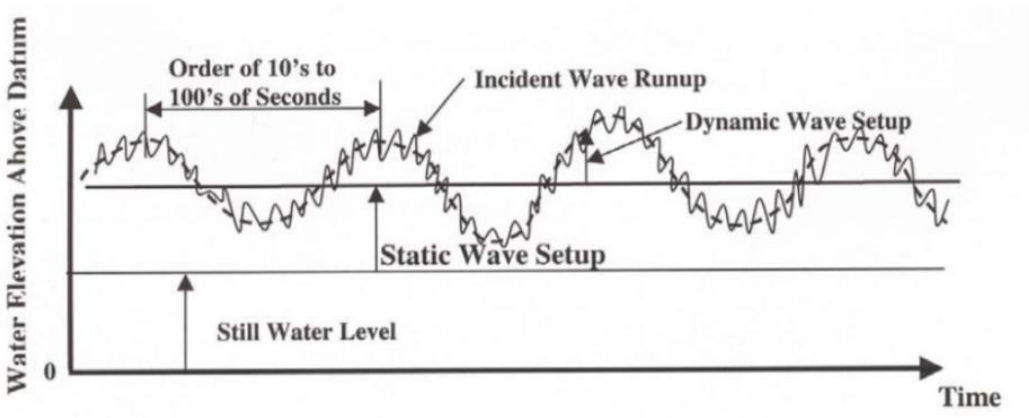

FIGURE 10
STATIC AND DYNAMIC WAVE SETUP AND INCIDENT WAVE RUN-UP
(FEMA 2005)

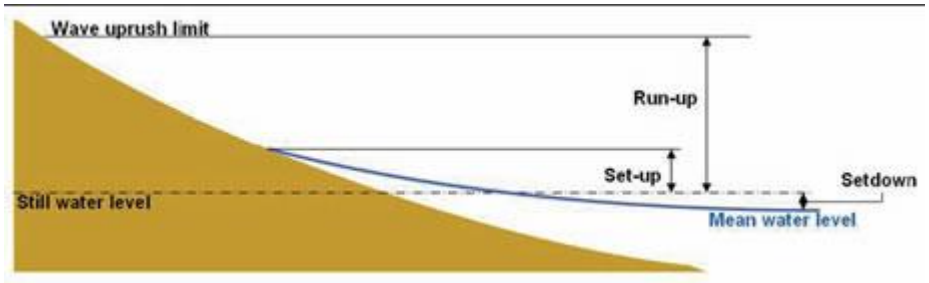

FIGURE 11
COMPONENTS OF SHORELINE WATER LEVELS (HTTP://WWW.MFE.GOVT.NZ/)

3.3. SEA LEVEL RISE

The nearest, long-term sea level record in the study area is the Los Angeles tidal datum. The buoy has been operational for over 90 years. Historical rates of SLR at this location are shown in Figure 12. The mean trend is a 0.83 mm/year (0.03 in./year) rise with a 95% confidence interval of +/- 0.27 mm/year based on monthly mean sea level data from 1923 to 2006. This is equivalent to a change of 0.27 ft in 100 years.

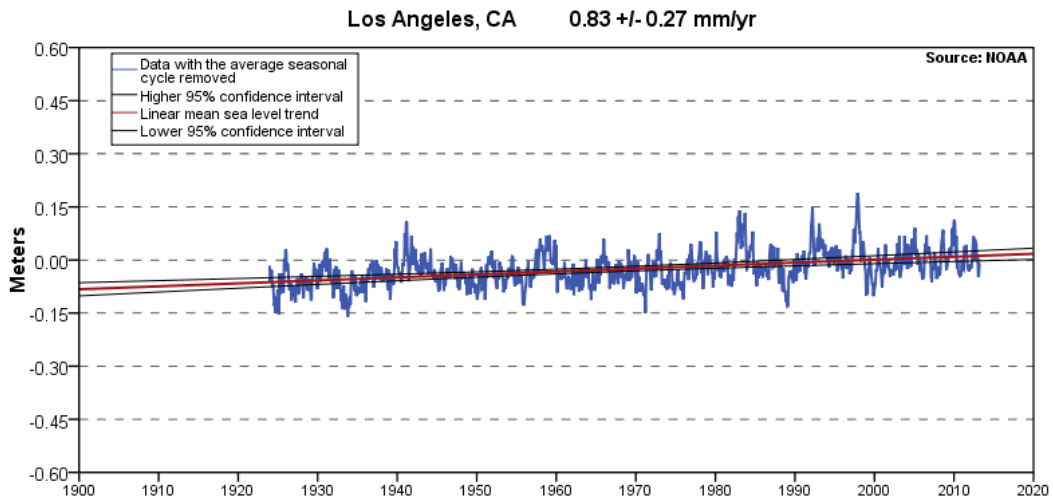

FIGURE 12
LOS ANGELES SEA-LEVEL RECORD
(NOAA 2014)

SLR is projected over the next century under a wide range of scenarios; the range of the projections is due to uncertainty associated with future emissions that feed into global circulation models aggregated by the Intergovernmental Panel on Climate Change (IPCC). Based on this uncertainty, SLR estimates are typically separated into low, medium, and high values based on a variety of assumptions that quantify the uncertainty in the projections, which increase with time.

National Research Council (2012) has the best available SLR projections for the State of California (CCC 2013, CO-CAT 2013). NRC's estimates take into account regional effects (such as land subsidence or isostatic rebound) to derive relative SLR projections for areas on the West Coast of the continental United States north and south of Cape Mendocino. An estimate for future SLR scenarios along Huntington Beach is shown in Figure 13. This area is referenced as south of Cape Mendocino in the NRC 2012 study.

TABLE 2
SEA LEVEL RISE SCENARIOS (NRC 2012)

Time Horizon	Low (ft)	Medium (ft)	High (ft)
2010	0.00	0.00	0.00
2030	0.15	0.50	1.00
2050	0.40	0.90	2.00
2100	1.40	3.10	5.50

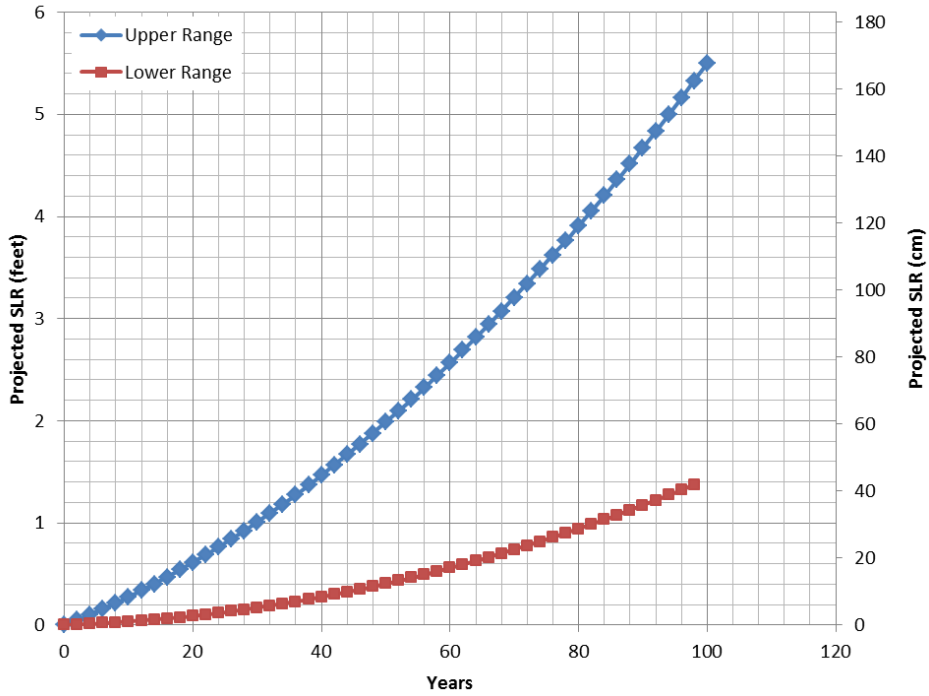

FIGURE 13
SEA LEVEL RISE PROJECTIONS FOR STUDY AREA RELATIVE TO YEAR 2000 (NRC 2012)

3.4. WAVES

The WIS project developed by the U.S. Army Corps of Engineers (USACE) produced 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 by offshore wave buoys. The hindcast data provide a valuable source of decades-long wave information needed in coastal engineering design; however, it is representative of offshore conditions only. Wave data was analyzed offshore for Huntington Beach from WIS station 83101.

3.4.1. Wave Climate

Results from the climatic wave analysis are shown in Figure 14, Figure 15 and Figure 16. The data indicated the 50%, and 10% wave height exceedance probabilities are 2.1 ft and 4.2 ft, respectively. Joint histogram data suggest the site is characterized by long period swell that propagates from the Eastern Pacific, through the Channel Islands, to the project site.

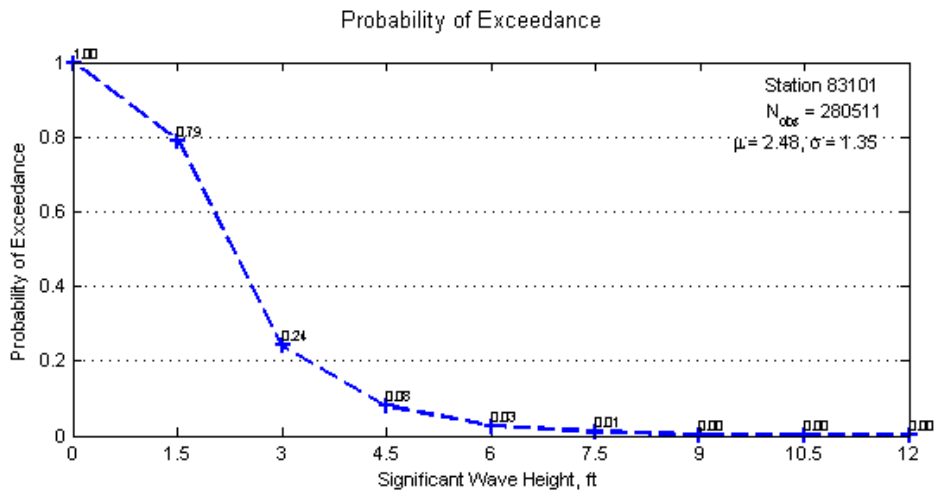

FIGURE 14
WAVE HEIGHT EXCEEDANCE CURVE FOR WIS 83101

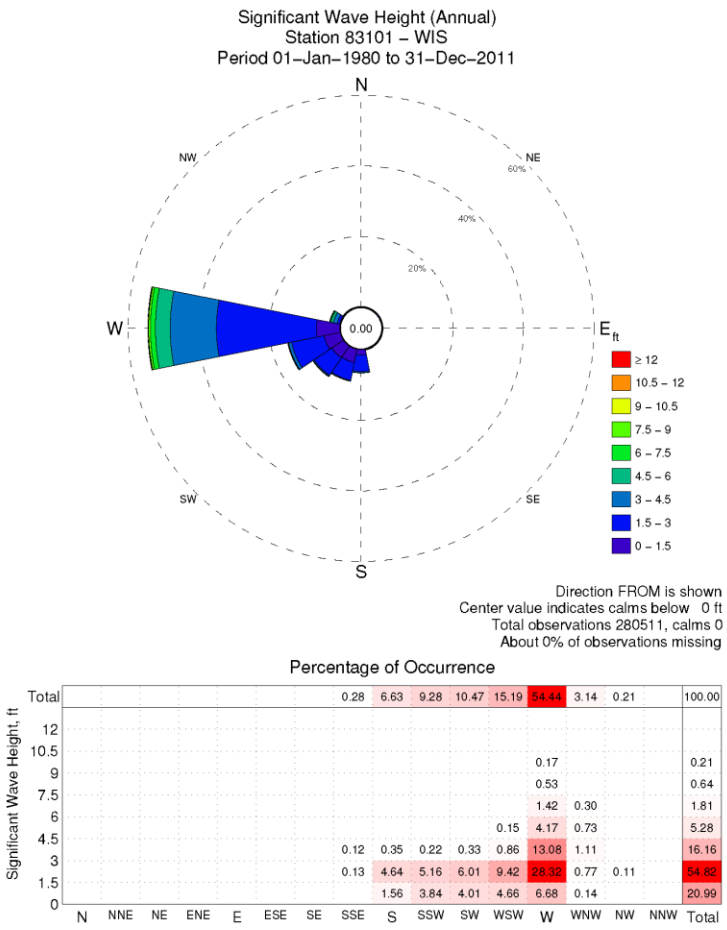

FIGURE 15
ANNUAL WAVE ROSE FOR WIS 83101

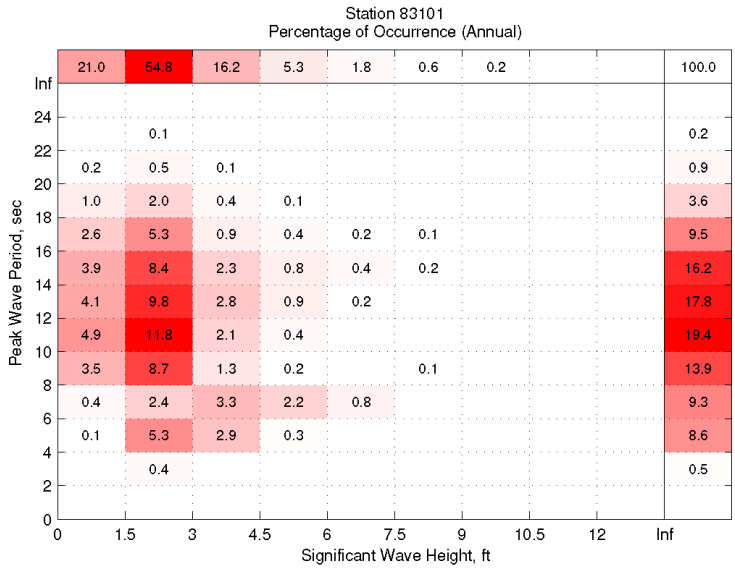

FIGURE 16
SIGNIFICANT WAVE HEIGHT VS. PEAK WAVE PERIOD JOINT HISTOGRAM FOR WIS 83101

3.4.2. Extreme Waves

In order to evaluate the probability of occurrence of extreme wave events, a peak-over-threshold analysis was performed to isolate extreme events and determine return periods. Numerous probability density functions (Fisher-Tippett Type I, Fisher-Tippett Type II, and Weibull) were tested to determine the probability density function that provides the best fit. Return interval statistics are adjusted for record length and sample interval. A selection was made based on the probability density function with the highest correlation.

Extreme value analysis results are summarized in Table 3 and shown in Figure 17. The data indicate the 50- and 100-year significant wave heights are 16.3 ft and 18.2 ft, respectively. The top 15 extreme, historical wave events within the study area are shown in
Table 4.

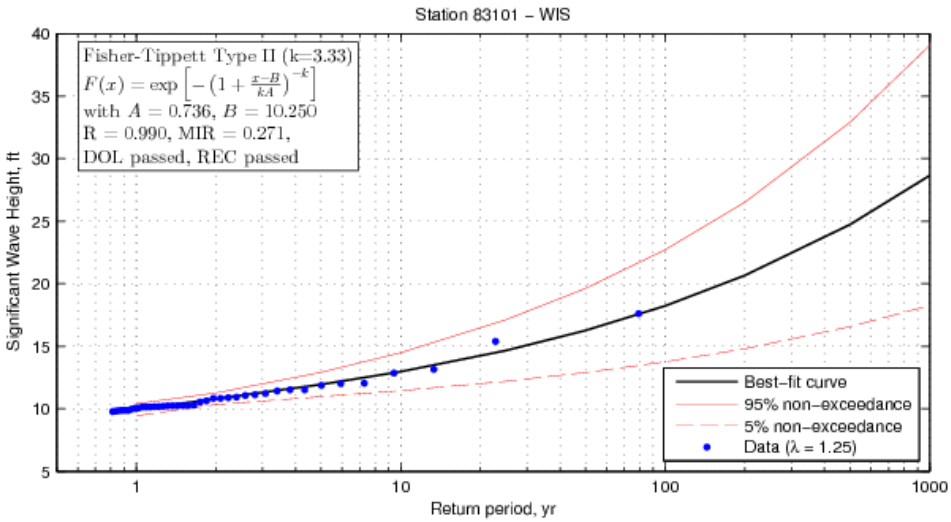

FIGURE 17
SIGNIFICANT WAVE HEIGHT EXTREME VALUE CURVE

TABLE 3
EXTREME SIGNIFICANT WAVE HEIGHT RETURN PERIODS (WIS 83101)

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 4
DEEP WATER EXTREME EXTRATROPICAL STORM EVENTS

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

(Source: USACE 2002)

3.5. TSUNAMIS

A tsunami is a series of ocean waves generated by a sudden displacement(s) in the sea floor, landslides, or volcanic activity (NOAA 2014). In the deep ocean, the tsunami wave may only be a few inches high. The tsunami wave may come gently ashore or may increase in height to become a fast moving wall of turbulent water.

Tsunamis occur periodically within the region and have the potential of to cause coastal flooding. The tsunami generated by the Miyagi earthquake in Japan on April 7, 2011 reached Southern California, where a tsunami of less than 2.5 ft was observed within Huntington Harbor (NGDC/WDS 2014). Another tsunami wave was observed after the Chile earthquake on February 27, 2010, where waves of approximately 1.5 ft were observed within Huntington Harbour (measured waves were on the order of 2.0 ft at the Santa Monica tide gauge) (NGDC/WDS 2014). A number of references were reviewed to assess the tsunami inundation potential within the study area.

3.5.1. State of California Tsunami Inundation Maps (2009)

The “Tsunami Inundation Maps for Emergency Planning” were published on June 1, 2009 through a joint effort by the State of California Office of Emergency Services, the California Geologic Survey, the University of Southern California Tsunami Research Center, and NOAA. The maps present the impacts of both local and distant sources of tsunamis to the California coastline. Tsunami inundation areas were depicted in these maps relative to a MHW topographic /

bathymetric surface. The maps represent the maximum tsunami run-up from a number of credible, extreme tsunami sources. Therefore, the maps do not represent inundation from a single event; rather, they display the maximum tsunami generated from either a local or a distant source event affecting a given region. This combination of a MHW surface and a worst case scenario tsunami event was used to create a “credible upper bound” for each region of the coastline.

Within the Seal Beach quadrangle, model results indicate that Surfside, Sunset Beach, Huntington Harbour, and Bolsa Chica Wetlands are vulnerable to tsunami inundation. The Huntington Beach wetlands are also vulnerable according to the inundation maps. The maps also indicate Pacific Coast Highway is at risk of tsunami damage. Landward inundation limits depend strongly on the local topography and roughness, therefore, reference is made to Figure 18 and Figure 19 for further information.

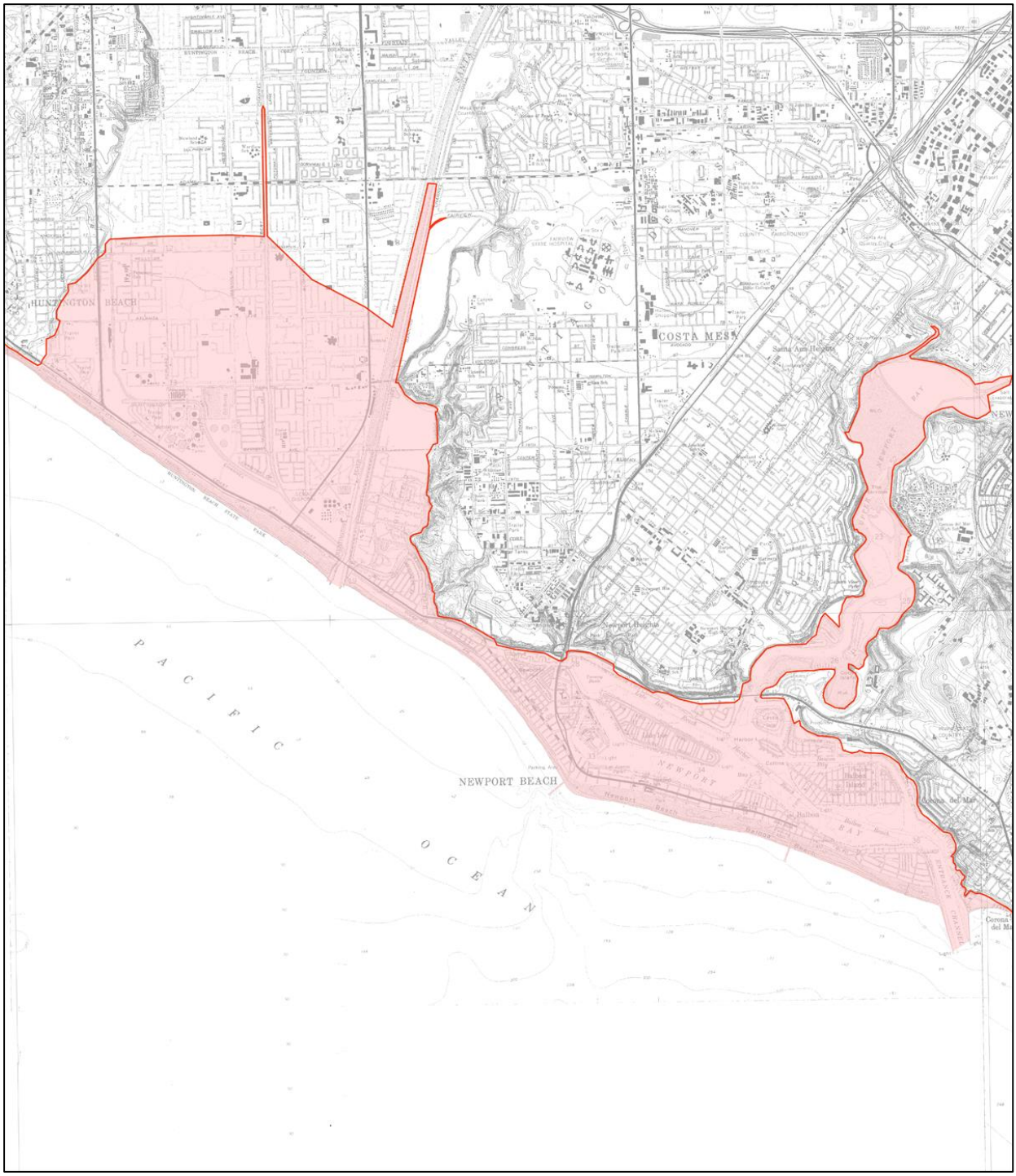

FIGURE 18
TSUNAMI INUNDATION MAP FOR NEWPORT BEACH QUADRANGLE (CALEMA, 2009)

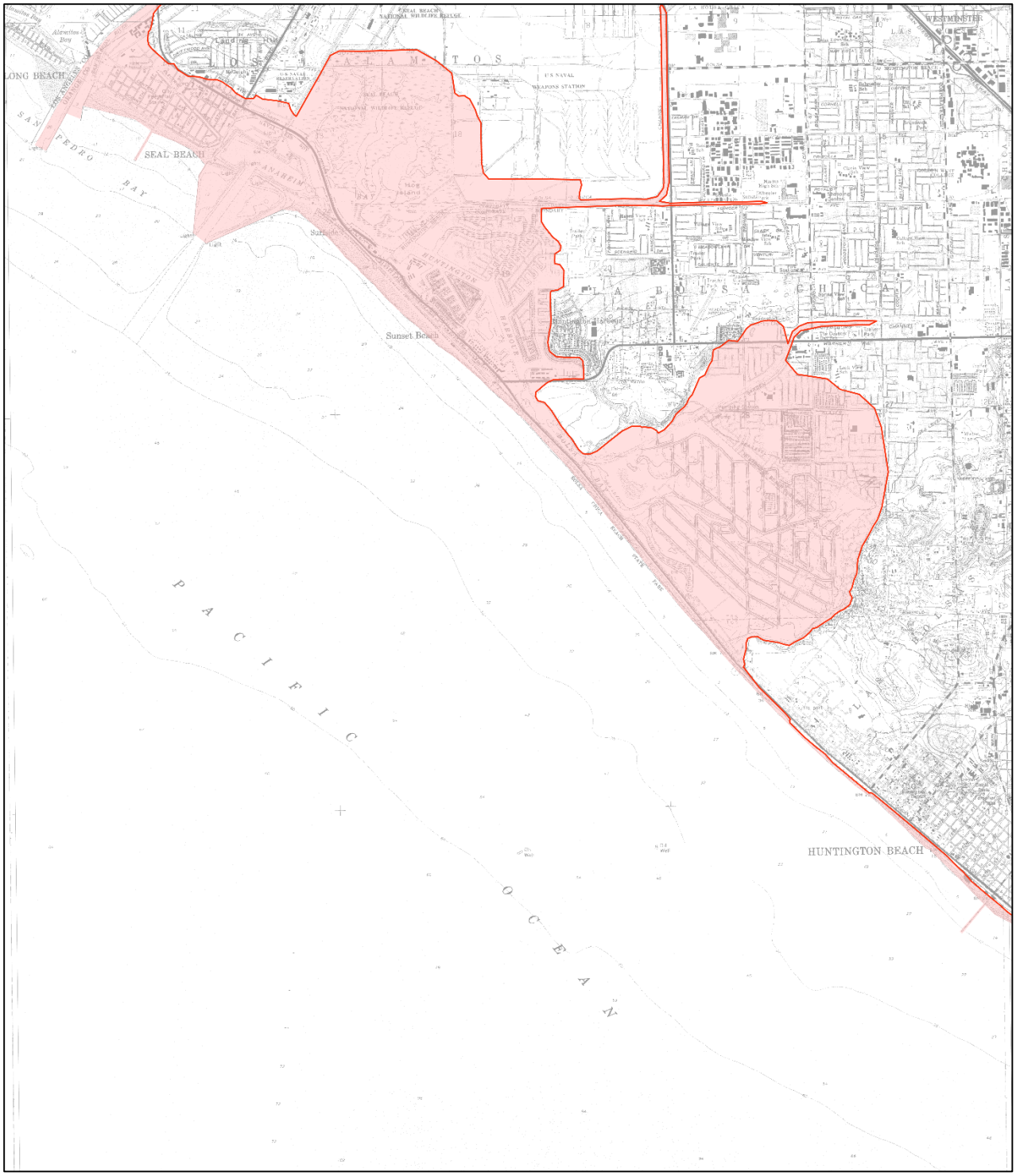

FIGURE 19
TSUNAMI INUNDATION MAP FOR SEAL BEACH QUADRANGLE (CALEMA, 2009)

3.5.2. Ports of Long Beach and Los Angeles Tsunami Study (2007)

The Ports of Long Beach and Los Angeles completed a study in 2007 of potential exposure to tsunamis (Moffatt & Nichol 2007). The study utilized a Boussinesq wave model to simulate tsunami wave propagation into the Ports of Long Beach and Los Angeles (POLA/POLB). Seven potential tsunami sources were modeled, which included four local tectonic scenarios, two local submarine landslide scenarios, and one distant tsunami source scenario. Model results suggest the worst case scenario tsunami for the region would be from a landslide in the vicinity of Palos Verdes. The report found that based on the seismicity, geodetics, and geology of the region, a large, locally generated tsunami from either local seismic activity or a local submarine landslide would likely not occur more than once every 10,000 years.

Analysis of wave height distribution of historical tsunamis was also analyzed. The data indicate the region may have experienced the maximum far-field tsunamis from Chile with a magnitude of 9.5 in 1960 and from Alaska with a magnitude of 9.2 in 1964. The data indicate that the POLA/POLB area may experience waves up to 2 to 3 ft from these events.

The close proximity of Huntington Beach to the POLA/POLB means the same generalizations of return period and wave height can also be applied to the project area. Thus, the results from both of these studies are applicable to the study area.

4. Vulnerability Assessment Modeling

Structures and developments along the coast are more vulnerable to episodic storms rather than to long-term rates of recession (CCC 2013). Therefore, numerical modeling was used to assess storm scale beach response during a storm event under a number of future, worst-case combined water levels.

XBeach was used to assess future vulnerabilities along the Shoreline Planning Areas. The model was used to simulate shoreline erosion and wave runup during extreme storm events over relatively short durations (72 hours). The approach for the vulnerability assessment was to compile the best available topographic and bathymetric data for the region to develop the computational grid. Once the grid was developed, the Bruun Rule was used to augment the computational surface to account for long-term changes in the profile as a result of SLR. The adjusted profile was then run through *XBeach* to simulate the beach response and wave runup during a 100-year wave event. The modeling approach is discussed in detail in this section.

4.1. Model Development

XBeach is a 2D model for wave propagation, long waves and mean flow, sediment transport and morphological changes of the nearshore area (Roelvink, et. al. 2010). It is a public-domain model that has been developed with funding and support by the USACE, by a consortium of UNESCO-IHE, Deltares, Delft University of Technology, and the University of Miami.

XBeach is intended as a tool to compute the coastal response of the nearshore area, beaches, dunes and back-barrier during storms. The model uses formulations for short wave envelope propagation based on the time-dependent wave action balance solver. The time-dependent averages over the short wave motions while resolving the long wave motions that are particularly important for swash motions. Flow is resolved by the non-stationary shallow water equations. The Generalized Lagrangean Mean (GLM) approach was implemented to represent the depth averaged undertow. The two-dimensional horizontal (2DH) advection-diffusion equation was included using the Soulsby-Van Rijn transport formulations. The model also includes an avalanching routine with separate criteria for critical wet and dry slope to simulate slumping. The model has been validated with a number of analytical, laboratory, and field test cases (Roelvink, et. al. 2010).

Output from coupled long- and short-term models includes erosion distances and run-up levels. The 4.8 ft MLLW profile elevation is equal to the MHW contour in 2010. At each time horizon, this elevation was adjusted for SLR and tracked as the representative profile feature to characterize the erosion. In 2100, the same mean high water line is equal to 10.2 ft MLLW, which comes from the mean high water line plus the maximum SLR for 2100.

4.1.1. Bathymetry & Computational Grid

A number of topographic and bathymetric elevation data sets were utilized to establish the numerical model domain and to map impacted assets. Data sources used for the study are provided in Table 5.

TABLE 5
ELEVATION DATA SOURCES IN THE STUDY AREA

Elevation Data Type	Source	Year	Vertical Datum
Beach Profiles	USACE / Coastal Frontiers Corporation	2010	MLLW
Topographic Lidar	City of Huntington Beach	2013	NAVD88
Topo / Bathymetry	NOAA/California State Coastal Conservancy/USACE	2011	NAVD88
Digital Elevation Model	U.S. Geological Survey	2009	NAVD88

The numerical model domain for *XBeach* was developed using beach profile transects collected in 2010 by Coastal Frontiers Corporation. This bathymetric data was extended from approximately -60 ft (MLLW) to +14 ft (MLLW). The bathymetric data was augmented with topographic data extracted from a digital elevation model (DEM) developed by the USGS. The composite of these data sets formed the DEM for the Study Area. The location of each transect is given in Table 6 and shown on Figure 20.

TABLE 6
COASTAL FRONTIERS 2010 SURVEY TRANSECTS

Transect ID	Planning Area	CFC Transect No.	Northing (ft)*	Easting (ft)*	Transect Alignment (ft)
1	Sunset Beach	98+87	2214210.10	6003169.60	228
2		104+64	2213439.00	6003795.70	228
3		117+83	2212789.00	6004946.80	228
4		128+44	2211531.20	6005212.50	228
5		137+84	2211315.90	6006301.10	228
6		140+24	2210704.80	6006057.10	228
7		147+84	2210581.80	6006980.20	228
8		157+68	2209842.40	6007656.30	228
9		167+86	2209105.00	6008330.20	228
10		177+86	2208366.10	6009005.50	228
11		187+84	2207629.40	6009678.80	228
12	Bolsa Chica	192+76	2207196.20	6009993.90	228
13		211+92	2205752.80	6011266.90	228
14		227+87	2204675.60	6012380.30	228
15		237+83	2203937.10	6013055.40	228
16		257+88	2202338.80	6014258.20	228
17		267+88	2201539.80	6014859.50	228
18		277+48	2200740.50	6015460.60	228
19		287+88	2199740.40	6016063.20	228
20		297+88	2199143.70	6016666.50	228
21		337+85	2195995.90	6019125.40	228
22	Huntington Cliffs	365+28	2193888.70	6021016.20	228
23		393+92	2191889.90	6023075.80	228
24		411+98	2190813.90	6024416.40	228
25		458+84	2187538.20	6027938.50	228
26	Huntington Beach	488+47	2185437.40	6030031.30	228
27		517+91	2184005.30	6032513.20	228
28		545+66	2182404.30	6034779.30	213
29		566+04	2181031.50	6036491.30	213
30		588+04	2180031.40	6038277.40	213
31		603+81	2179038.30	6039698.40	213
32		619+66	2178218.40	6040853.70	213
33		626+19	2177425.40	6041111.80	213

**NAD83 State Plane Zone 5, ft*

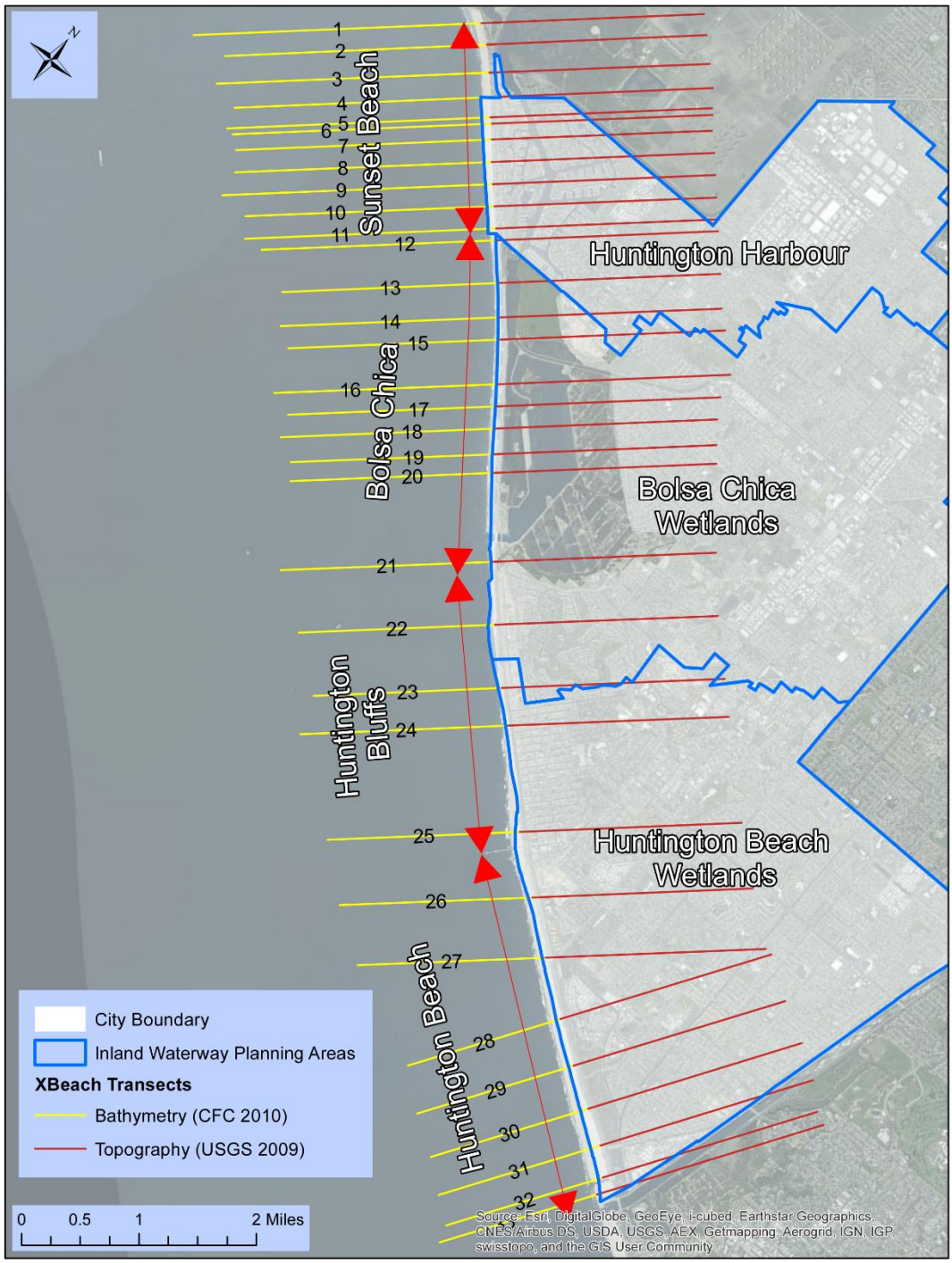

FIGURE 20
XBEACH TRANSECT LOCATIONS

Coastal Frontiers and USGS profiles were smoothed and merged to ensure a seamless model domain. The final lengths of each transect varied, but extended approximately 9,843 ft (3,000 m) beyond the most landward end of the Coastal Frontiers data set.

Grid resolution varied across the domain based upon a Courant–Friedrichs–Lewy (CLF) condition that did not exceed 8.2 ft (2.5 m).

4.1.2. Bruun Rule Profile Development

Sea level rise is expected to continue for time scales much longer than individual storms. Therefore, before running the XBeach model, the bathymetric profiles need to be adjusted to account for the long term morphodynamic development of the coastline.The Bruun rule is widely accepted as the approach to predict the effects of SLR on sandy shorelines (Masselink and Hughes 2003). It is based on three assumptions:

(1) The underlying geology does not play a role in determining the shoreface shape;
(2) Shoreface sediment is moved only by waves; and
(3) No significant movement of sediment beyond the depth of closure.

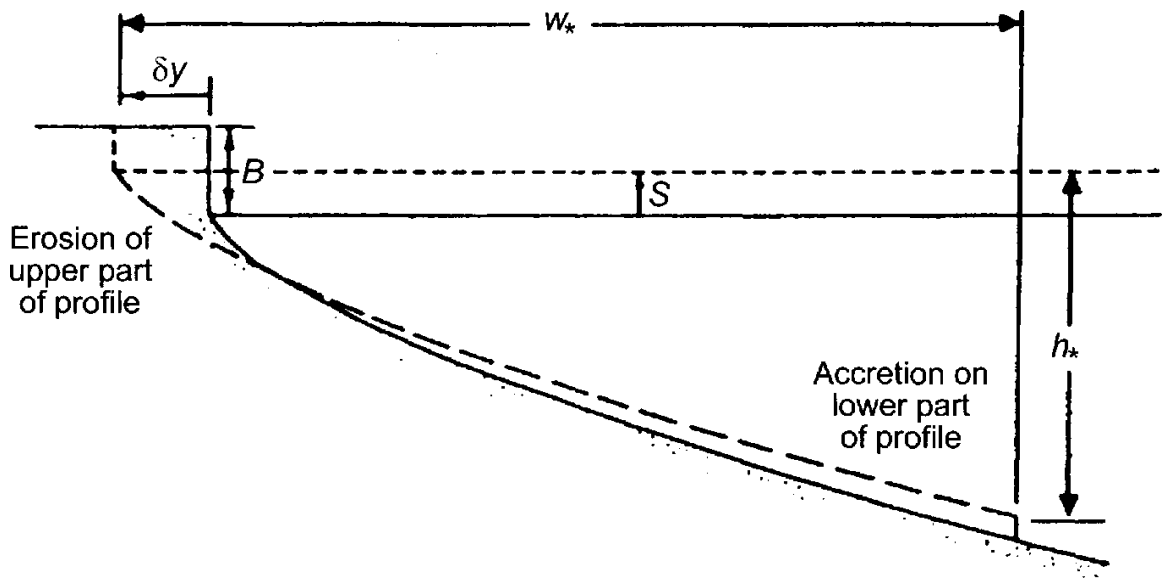

FIGURE 21
RESPONSE OF THE SHOREFACE PROFILE TO RISING SEA LEVEL (BRUUN RULE, MASSELINK & HUGHES, 2003)

The Bruun Rule hypothesizes that as the sea level rises, the shoreface will respond by moving landward. Using this equilibrium understanding, Bruun (1962) proposed that the retreat of the shoreline can be estimated by assuming that the amount of erosion on the upper part of the profile must equate to the amount of deposition on the lower part of the profile.

The amount of shoreline retreat (δy) can be estimated according to:

$$\delta y = S\frac{w}{h+B}$$

where S is the rise in sea level, w is the width of the shoreface, h is the depth of closure, and B is berm height.

The depth of closure is defined in the equation above as the depth at which there is no significant change in bottom elevation and no significant net exchange between the nearshore and the offshore. The depth of closure for the study area was defined using statistical methods by the USACE (2002). Estimates of the depth of closure for each profile were derived from Figure 22.

Berm height was estimated directly from the measured profile. This point was taken as the first point of local maxima above the mean sea level elevation. Profiles were shifted landward and up according to the Bruun estimates. Each profile was merged using a tapered cosine window at the upper end of the profile and an inverse weight function at the lower seaward end to ensure a smooth transition from one profile to the next.

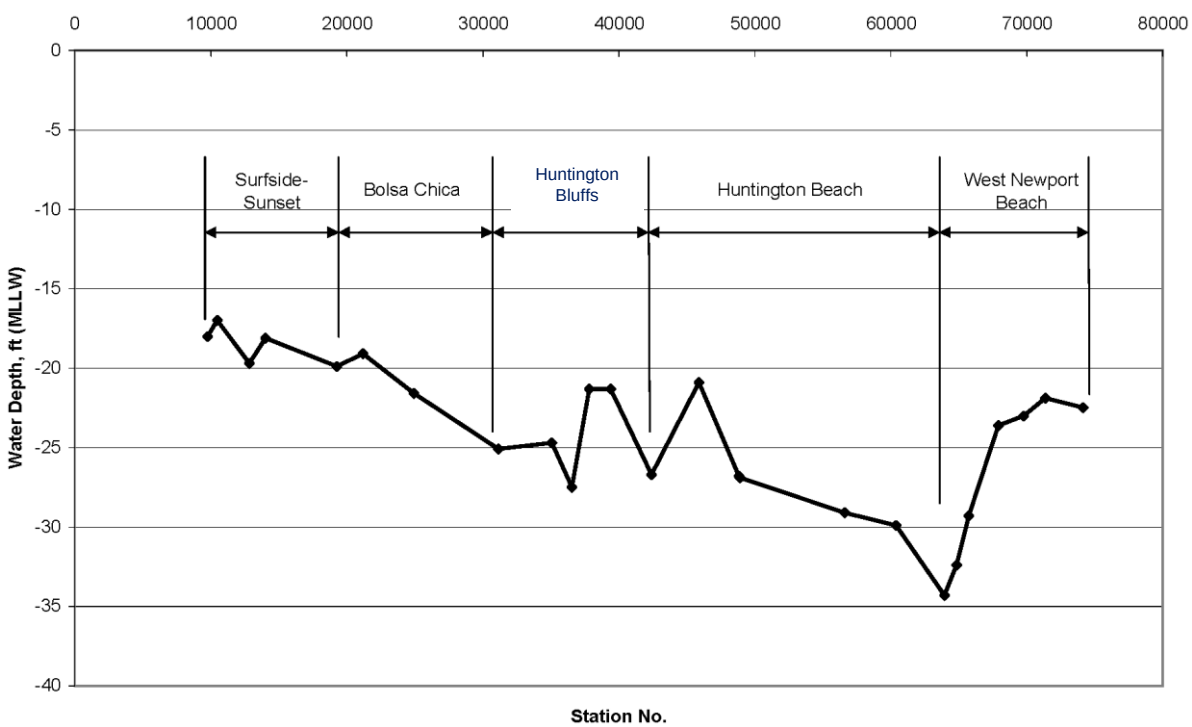

FIGURE 22
STATISTICAL DEPTH OF CLOSURE FOR THE HUNTINGTON BEACH LITTORAL CELL (USACE 2002)

An example profile shift in response to SLR according to the Bruun Rule is shown in Figure 23.

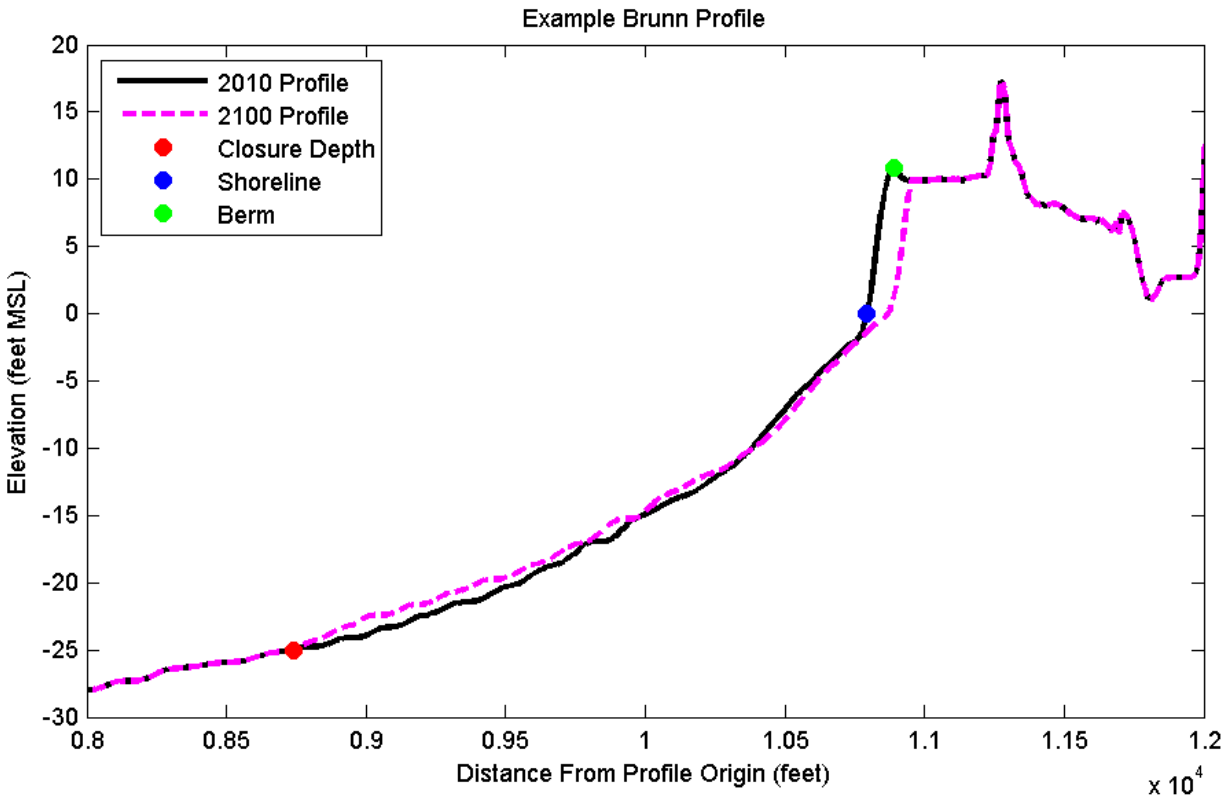

FIGURE 23
EXAMPLE BRUUN RULE PROFILE SHIFT

Recession distances for each of the 33 transects according Bruun Rule is shown in Table 7 on Page A-32.

TABLE 7
MEAN SEA LEVEL RECESSION DISTANCE ACCORDING TO BRUUN RULE

Transect ID	2010	2030			2050				2100	
		Low	Med	High	Low	Med	High	Low	Med	High
1	0.0	6.0	20.1	40.2	16.1	36.1	80.3	56.2	124.5	220.9
2	0.0	5.6	18.6	37.3	14.9	33.6	74.6	52.2	115.6	205.1
3	0.0	4.4	14.8	29.5	11.8	26.6	59.0	41.3	91.5	162.4
4	0.0	4.6	15.3	30.6	12.2	27.5	61.2	42.9	94.9	168.4
5	0.0	5.4	18.1	36.1	14.4	32.5	72.2	50.6	112.0	198.7
6	0.0	5.3	17.6	35.2	14.1	31.7	70.4	49.3	109.1	193.5
7	0.0	5.3	17.8	35.7	14.3	32.1	71.3	49.9	110.5	196.1
8	0.0	7.2	24.1	48.2	19.3	43.4	96.5	67.5	149.6	265.4
9	0.0	6.1	20.5	40.9	16.4	36.8	81.8	57.3	126.8	225.0
10	0.0	5.4	18.1	36.2	14.5	32.6	72.3	50.6	112.1	198.9
11	0.0	5.6	18.7	37.5	15.0	33.7	74.9	52.4	116.1	206.0
12	0.0	5.3	17.8	35.6	14.2	32.0	71.2	49.8	110.3	195.8
13	0.0	4.8	15.9	31.8	12.7	28.7	63.7	44.6	98.7	175.1
14	0.0	4.7	15.8	31.6	12.6	28.4	63.1	44.2	97.8	173.6
15	0.0	4.6	15.3	30.5	12.2	27.5	61.0	42.7	94.6	167.8
16	0.0	4.5	15.1	30.1	12.0	27.1	60.2	42.2	93.3	165.6
17	0.0	4.5	15.1	30.2	12.1	27.2	60.3	42.2	93.5	166.0
18	0.0	4.4	14.7	29.5	11.8	26.5	59.0	41.3	91.4	162.2
19	0.0	4.4	14.5	29.0	11.6	26.1	58.1	40.7	90.0	159.7
20	0.0	4.6	15.3	30.6	12.3	27.6	61.3	42.9	95.0	168.5
21	0.0	5.6	18.7	37.3	14.9	33.6	74.6	52.3	115.7	205.3
22	0.0	6.0	20.0	40.0	16.0	36.0	80.0	56.0	124.0	220.0
23	0.0	5.0	16.6	33.2	13.3	29.9	66.4	46.5	102.9	182.6
24	0.0	4.6	15.4	30.7	12.3	27.7	61.4	43.0	95.2	169.0
25	0.0	5.0	16.7	33.3	13.3	30.0	66.7	46.7	103.4	183.4
26	0.0	5.0	16.8	33.6	13.4	30.2	67.2	47.0	104.1	184.8
27	0.0	4.4	14.7	29.4	11.8	26.5	58.8	41.2	91.2	161.8
28	0.0	3.5	11.6	23.2	9.3	20.9	46.4	32.5	71.9	127.6
29	0.0	3.6	12.0	24.1	9.6	21.6	48.1	33.7	74.6	132.3
30	0.0	3.3	10.9	21.8	8.7	19.7	43.7	30.6	67.7	120.1
31	0.0	3.2	10.8	21.5	8.6	19.4	43.1	30.2	66.8	118.5
32	0.0	4.1	13.8	27.6	11.0	24.8	55.1	38.6	85.5	151.6
33	0.0	4.9	16.4	32.9	13.2	29.6	65.8	46.0	102.0	180.9
Average	0.0	4.9	16.3	32.6	13.0	29.3	65.1	45.6	101.0	179.2
Std. Dev. (+/-)	0.0	0.8	2.9	5.7	2.3	5.1	11.4	8.0	17.7	31.4

4.1.3. Erodible Boundary

Landward boundaries to erosion were set within the model to acknowledge the presence of hard structures such as parking lots, walls, revetments, and roads. The location of these features was estimated visually using georeferenced aerial images. This boundary set the landward limit of beach recession. Wave run-up was allowed to extend landward of this limit.

4.1.4. Boundary Conditions

Boundary conditions for the *XBeach* model are based on the January 1988 El Niño storm event. This storm event is the largest event on the WIS time series, representing approximately a 70-year storm event. According to the Coast of California Storm and Tidal Wave Study (CCSTWS), the January of 1988 storm caused $18.2 million worth of damages ($17.1 million in Los Angeles County and $1.1 million in Orange County) (USACE 2002). The storm hydrograph is shown in Figure 24.

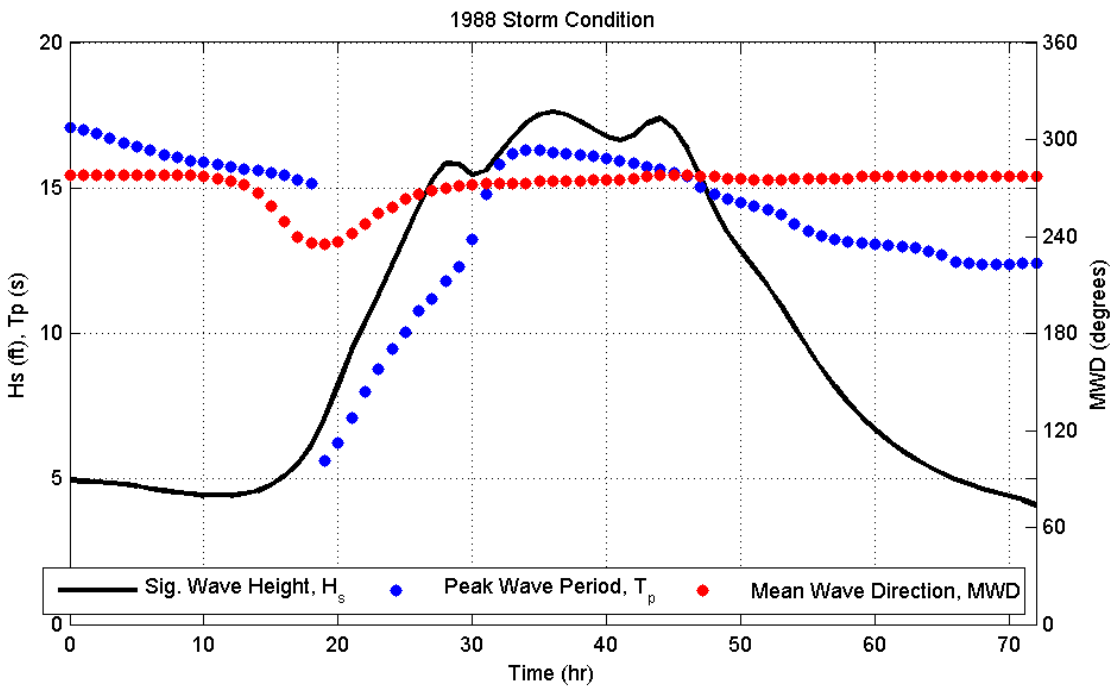

FIGURE 24
1988 STORM EVENT FROM WIS HINDCAST

The January 1988 storm was scaled up from a peak wave height of 17.6 ft to 18.2 ft to be representative of the 100-year storm event. Peak wave period and mean wave direction were left unchanged. The 100-year storm event is shown in Figure 25.

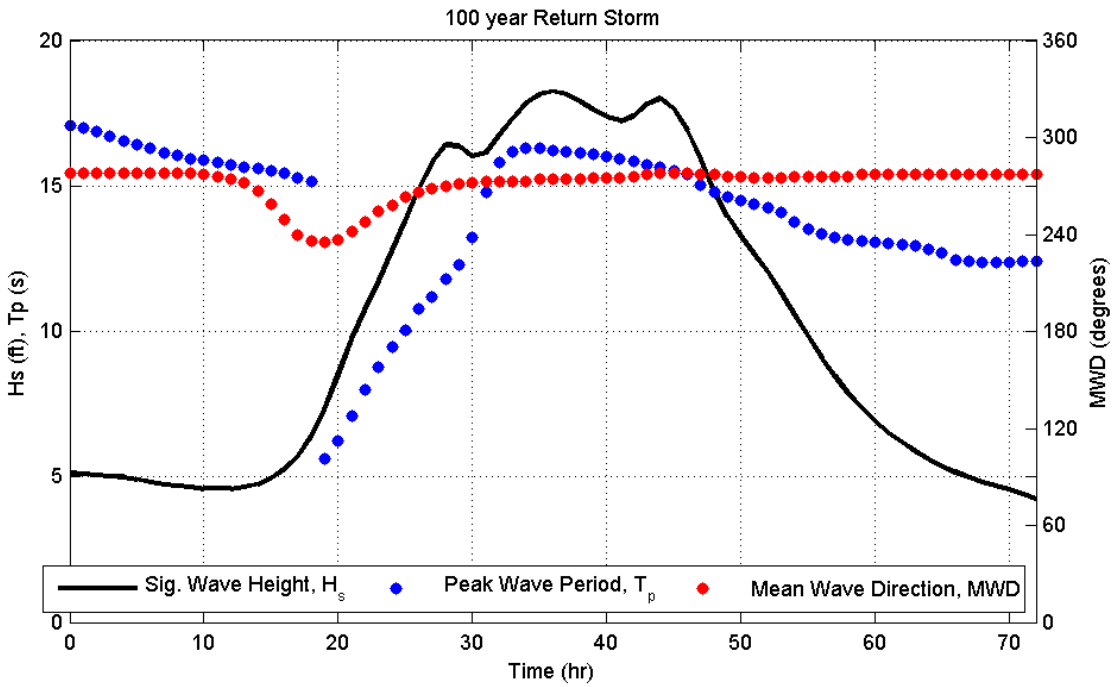

FIGURE 25
SCALED 100-YEAR STORM EVENT

Tide boundary conditions were taken from the NOAA CO-OPs tide gauge. The time series corresponds to the 1988 storm event shown on Figure 24.

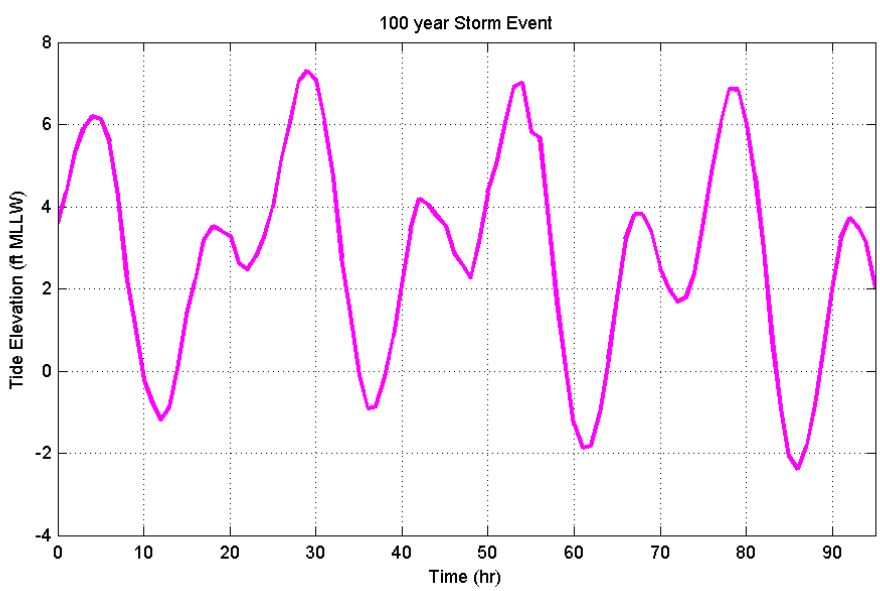

FIGURE 26
100-YEAR STORM EVENT WATER LEVEL TIME SERIES

The tidal value (6.48 ft, MLLW) represents the 10% exceedance water level based on an exceedance curved derived using daily maximum tide elevations, as extracted from the entire Los

Angeles tidal data records. This water level also includes storm surge, though a minor component of the overall water level.

4.1.5. Water Level Modeling Scenarios

For long-term planning, it is important to consider a range of potential future water level scenarios. A total of 10 events were simulated at each of the 33 profile locations. The events consist of various SLR scenarios combined with high tide and 100-year wave events. The combined water level events are detailed in Table 8.

TABLE 8
COMBINED MODELING SCENARIOS

Scenario	Time Horizon	Sea Level Scenario (NRC 2012)	Sea Level Rise Projection (feet)	Peak Tide Level (feet, MLLW)	Peak Sig. Wave Height (feet)
1	2010	---	0.00	6.48	18.2
2	2030	Low	0.15	6.48	18.2
3	2030	Medium	0.50	6.48	18.2
4	2030	High	1.00	6.48	18.2
5	2050	Low	0.40	6.48	18.2
6	2050	Medium	0.90	6.48	18.2
7	2050	High	2.00	6.48	18.2
8	2100	Low	1.40	6.48	18.2
9	2100	Medium	3.10	6.48	18.2
10	2100	High	5.50	6.48	18.2

4.2. MODEL CALIBRATION

4.2.1. Bathymetry & Computational Grid

Bathymetric and upper beach profiles were collected in 2007 by Coastal Frontiers immediately before (pre-storm) and following (post-storm) a coastal storm event. The pre-storm survey was performed on December 3, 2007, approximately one day before a series of closely spaced, forecasted wave events. The subsequent post-storm survey followed on December 10, 2007, shortly after the conclusion of the second storm event. The location of each profile is given in Table 9 and shown in Figure 27.

TABLE 9
PRE- AND POST-STORM SURVEY TRANSECTS

Transect No.	Northing (feet)	Easting (feet)	Transect Alignment (degree)
128+44 (CCSTWS 13)	2,211,939.47	6,005,661.18	228
423+89 (CCSTWS 23)	2,189,894.00	6,025,334.80	228
566+04 (SA 24)	2,181,031.55	6,036,491.29	213

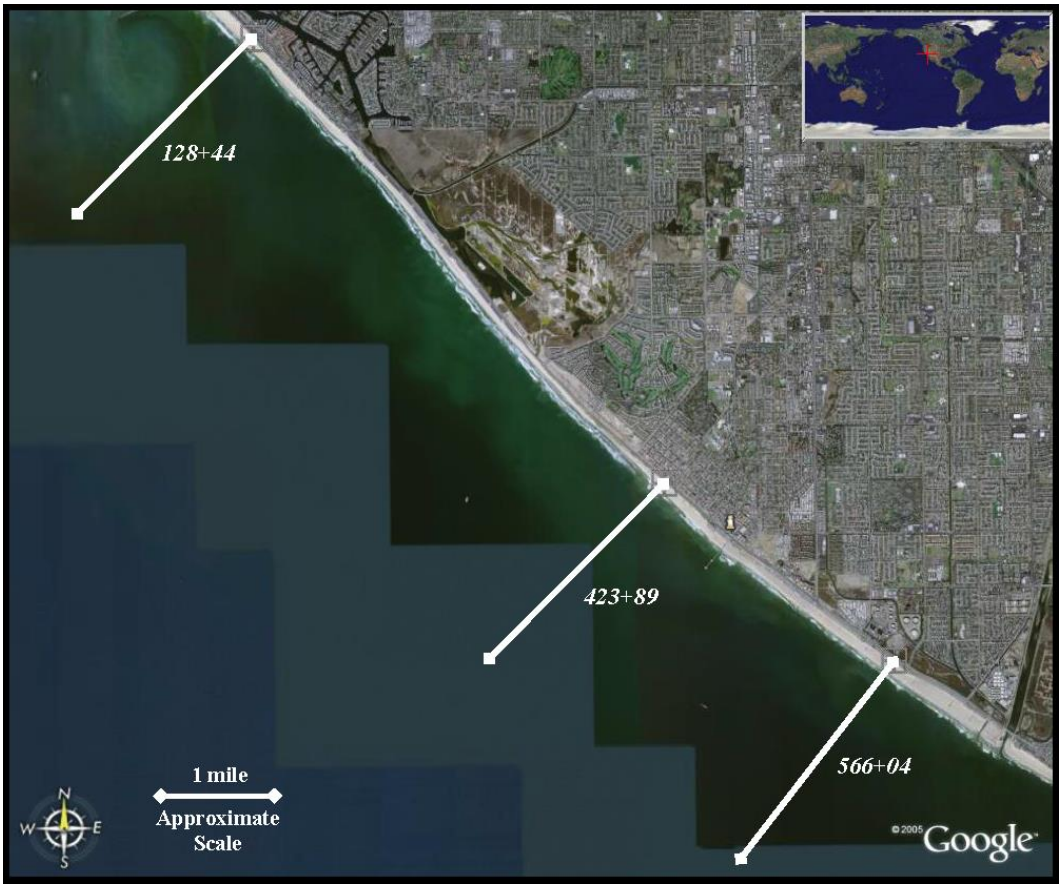

FIGURE 27
COASTAL FRONTIERS 2007 PRE- AND POST-STORM SURVEY LOCATIONS

4.2.2. Boundary Conditions

Wave boundary conditions were taken from the WIS hindcast between the date of the pre- and post-storm survey. The storm represents a small but significant extreme wave event. A summary of offshore wave conditions (direction, period and height) is shown in Figure 28.

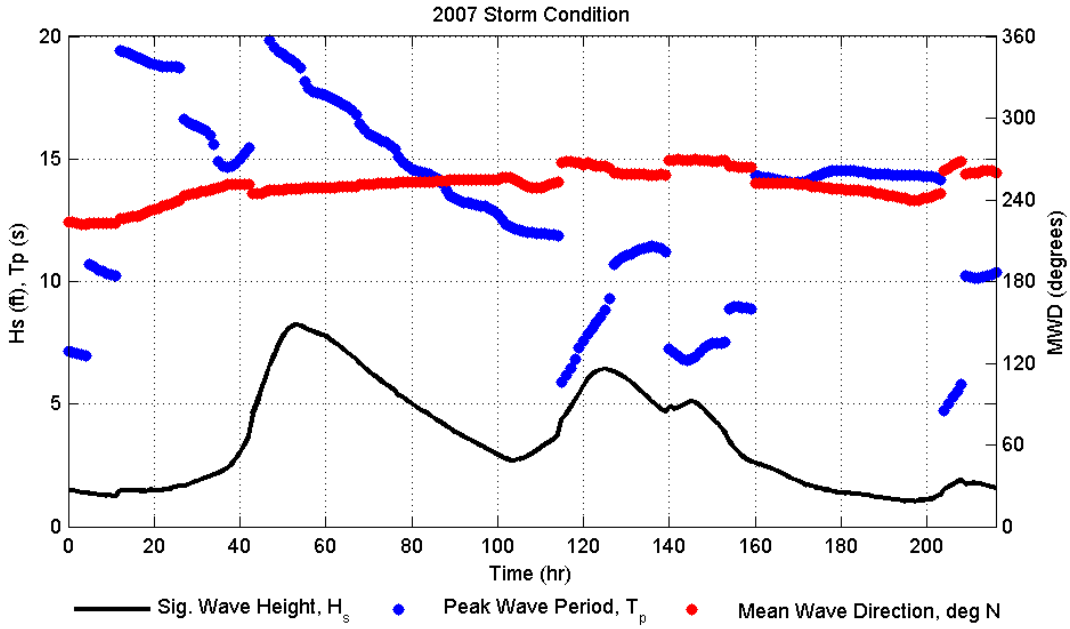

FIGURE 28
2007 STORM EVENT FROM WIS 83101

Tidal boundary conditions were taken from the NOAA CO-OPs tide gauge (Figure 29). The time series corresponds to a water level that coincides with the 2007 storm event wave time series.

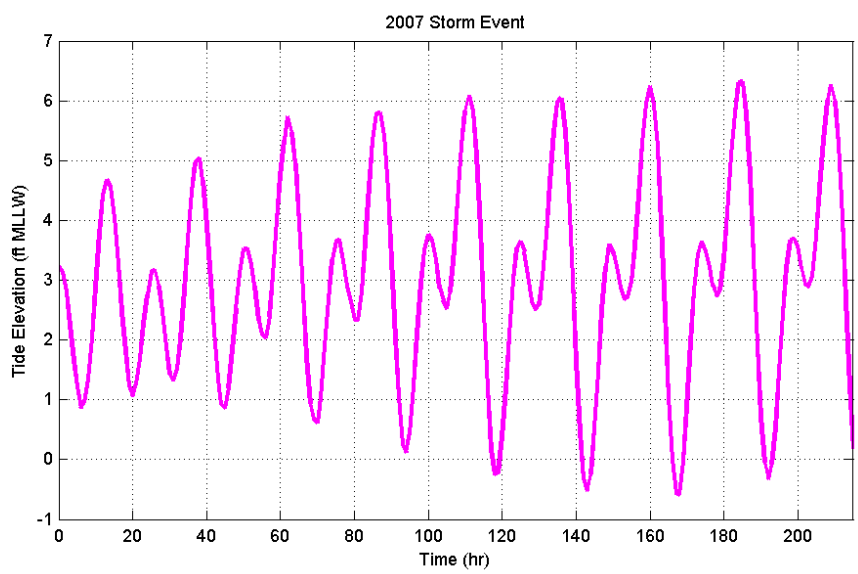

FIGURE 29
2007 STORM EVENT WATER LEVEL TIME SERIES

4.2.3. Model Parameters

XBeach model parameters are based on the relevant site-specific conditions and past model calibration in Southern California from the Coastal Storm Modeling System (CoSMoS) model. CoSMoS for Southern California (USGS 2012) was developed by the USGS in collaboration with Deltares to generate real-time forecasts of water levels, wave heights, and coastal erosion and flooding for up to 3 days in advance.

The following CoSMoS parameters (see Table 10) were used in the Huntington Beach *XBeach* model:

TABLE 10
COSMOS MODEL PARAMETERS

Description	Model Parameter	Value
Maximum courant number	CFL	0.8
Threshold depth for drying and flooding	eps	0.01
Breaker slope coefficient in roller model	break	1
Option roller model	roller	1
Breaker slope coefficient	beta	0.1
Breaker parameter	gamma	0.45
Horizontal background viscosity	nuh	0.1
Viscosity coefficient for roller induced turbulent horizontal viscosity	nuhfac	1
Chezy coefficient	C	55
Threshold water depth for concentration and return flow	umin	0.01
Critical avalanching slope under water	wetslip	0.15

The following site-specific parameters (Table 11) are applied here to better characterize the site-specific pre- and post-storm surveys:

TABLE 11
HUNTINGTON BEACH SPECIFIC MODEL PARAMETERS

Description	Model Parameter	Value
Uniform D50 sediment diameter	d50	0.00037
Uniform D90 sediment diameter	d90	0.00090
Erosion limiter	smax	0.3

4.3. MODEL RESULTS

XBeach results were mapped by linearly connecting points between beach recession and run-up positions. In non-contiguous topographic sections of the shoreline or hinterland areas, the high

resolution topography collected by the City was used in combination with engineering judgment to locate the position of vulnerable areas.

4.3.1. Beach Erosion

Beach erosion results are shown in Table 12 per transect for each SLR scenario. Note that Transects 22 and 23 in the Huntington Cliffs area were considered non-erodible due to the presence of a revetment; thus, erosion values for this area reflect this assumption. Further study of this area is needed.

TABLE 12
BEACH EROSION DISTANCE (FEET, FROM 2010 BASELINE)

Transect ID	2010	2030			2050				2100	
		Low	Med	High	Low	Med	High	Low	Med	High
1	0	9	19	38	16	33	68	47	93	229
2	7	14	29	45	26	43	78	65	97	163
3	11	17	30	48	27	44	73	60	92	175
4	27	30	43	59	39	55	96	73	121	218
5	26	32	45	60	40	56	88	75	117	187
6	23	29	42	64	35	54	90	74	111	166
7	27	33	46	67	39	60	92	74	109	182
8	27	37	51	75	45	70	117	91	153	234
9	19	25	35	61	36	58	96	77	119	188
10	16	23	36	55	36	48	86	69	109	171
11	24	26	38	59	36	54	92	70	128	215
12	23	31	44	62	39	58	102	79	130	157
13	15	20	32	49	29	46	90	66	133	379
14	22	28	41	60	37	56	100	76	117	360
15	15	21	32	51	28	49	87	66	120	458
16	22	27	38	58	35	53	91	72	134	245
17	46	51	62	79	59	75	112	92	151	296
18	38	42	54	69	51	66	104	84	137	218
19	43	47	59	76	55	71	105	86	129	211
20	40	43	55	71	48	68	101	83	135	200
21	6	12	24	41	21	38	63	49	79	108
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	23	29	42	58	38	56	75	66	90	122
25	24	32	45	61	40	56	96	73	163	356
26	14	19	25	46	27	43	74	58	102	243
27	16	19	32	46	31	41	77	57	113	180
28	16	22	31	48	32	45	76	59	109	542
29	17	26	36	46	32	51	73	56	111	311
30	46	53	62	75	55	73	105	89	139	300
31	28	29	39	51	33	49	83	63	127	460
32	134	145	148	168	147	164	203	180	256	473
33	49	57	58	70	59	64	85	77	121	403
Average	26	31	42	58	39	54	87	70	117	247
Std. Dev. (ft, +/-)	23.4	24.5	24.1	26.5	23.8	25.8	32.6	28.5	42.5	127

4.3.2. Wave Run-Up Elevation

Wave run-up along the beach was determined by taking the difference between the water surface elevation and topography from the model output. The run-up line is defined by the landward limit of grid points that are covered by 8 in. or more of water for 2% (approximately 86 minutes) of the model run time. The 2% definition is consistent with the community-accepted definition of run-up limits on a sandy beach. Wave run-up results were provided as water level elevations. Results are shown in Table 13 per transect for each SLR scenario.

TABLE 13
WAVE RUN-UP HEIGHT (FEET, MLLW)

Transect ID	2010	2030			2050				2100	
		Low	Med	High	Low	Med	High	Low	Med	High
1	14.5	15.5	16.4	16.3	16.1	16.2	15.5	15.6	15.6	17.4
2	15.0	15.2	15.8	15.8	15.8	15.8	16.2	15.8	16.1	16.8
3	17.1	16.0	17.9	19.0	17.3	19.1	18.9	19.5	16.9	15.2
4	15.5	15.7	16.7	17.6	16.7	17.1	18.7	18.0	18.6	13.6
5	16.0	16.5	17.9	17.6	17.4	17.7	16.9	17.2	17.2	19.4
6	16.2	17.1	17.5	16.8	17.4	16.8	15.8	16.4	16.6	18.4
7	16.3	16.3	16.2	15.1	16.0	15.1	15.7	14.9	16.6	19.1
8	14.8	15.7	16.6	17.2	16.6	17.1	16.7	17.1	16.7	19.3
9	15.0	16.5	16.9	16.9	16.8	16.9	16.6	16.8	17.0	18.2
10	15.5	16.0	16.8	17.1	16.6	17.1	16.1	16.6	16.1	19.8
11	15.0	15.3	16.7	17.1	16.1	17.1	15.6	16.2	16.7	18.3
12	15.0	15.1	15.8	16.4	15.8	16.4	16.8	16.4	17.5	19.3
13	16.5	17.1	17.5	17.7	17.4	17.7	18.0	17.7	17.9	16.4
14	18.1	18.2	19.1	19.3	18.8	19.3	18.7	19.2	16.3	16.7
15	16.1	16.6	17.6	19.0	17.6	18.6	19.2	19.2	18.3	16.6
16	16.5	16.7	17.4	18.8	17.1	18.4	19.2	19.1	19.3	16.2
17	13.9	14.1	15.9	16.9	15.2	16.6	19.3	17.8	19.6	15.9
18	16.2	16.3	16.6	17.2	16.3	17.0	17.9	17.6	18.6	19.1
19	15.4	15.6	16.4	16.9	16.0	17.2	17.9	17.4	18.5	17.1
20	14.4	14.5	15.3	15.7	15.2	15.7	16.1	15.8	17.3	18.7
21	17.4	18.1	18.6	18.7	18.4	18.7	18.7	18.6	20.4	21.5
22	7.5	7.7	9.2	10.4	8.7	10.2	11.6	11.1	13.3	14.9
23	6.6	7.0	7.9	10.5	7.7	10.2	12.2	11.2	14.6	17.3
24	16.2	17.4	17.8	18.4	17.5	18.4	18.2	18.3	18.1	18.0
25	14.4	14.4	14.1	14.2	14.2	14.2	38.2	14.8	15.6	20.8
26	13.5	13.4	13.6	14.6	13.8	14.8	16.8	15.9	14.8	18.0
27	14.8	15.3	15.8	16.5	15.6	16.4	16.8	16.6	17.2	18.8
28	14.3	14.7	15.4	16.0	15.1	16.0	16.3	16.1	17.2	19.6
29	14.6	14.7	14.1	13.9	14.2	14.1	14.3	14.1	16.2	17.0
30	12.9	12.7	13.5	14.1	13.5	14.0	14.9	14.4	15.4	16.1
31	13.3	13.6	14.3	14.8	14.5	14.8	14.2	14.5	14.2	15.2
32	11.8	12.0	12.2	12.4	12.2	12.6	13.7	13.3	14.7	16.3
33	12.5	13.2	13.3	13.7	13.4	13.7	15.2	14.2	15.0	16.6
Average	14.6	15.0	15.7	16.1	15.5	16.1	17.2	16.3	16.8	17.6
Std. Dev. (+/-)	2.4	2.4	2.4	2.2	2.4	2.2	4.2	2.1	1.6	1.8

4.4. VULNERABILITY ASSESSMENT

A georeferenced shoreline asset inventory was created in GIS of impacted and potentially impacted resources within the City. Assets included in the geodatabase include beaches, roads, pedestrian paths, bike paths, parking lots, buildings, walls, revetments, storm drains and sensitive habitats. Asset classes were populated with appropriate attribute information such as critical elevations, structure types, year built, replacement cost, and condition.

SLR impacts within the planning areas are discussed in terms of shoreline erosion and areas of potential flooding as a result of wave run-up. Beach erosion is discussed relative to the 2010 shoreline position. Run-up areas were shown as a blue, transparent overlays and bracket the predicted low and high SLR positions. Note that the run-up location is relative to the predicted shoreline position for each scenario.

Results of the modeling and analysis for the various SLR scenarios are shown in Figure 30 through Figure 41. Note that wave runup values are shown as a light blue polygon between the low and high SLR scenarios. Wave runup in earlier planning horizon years (2030 and 2050) are minimal; thus, appear as a polyline during these timeframes.

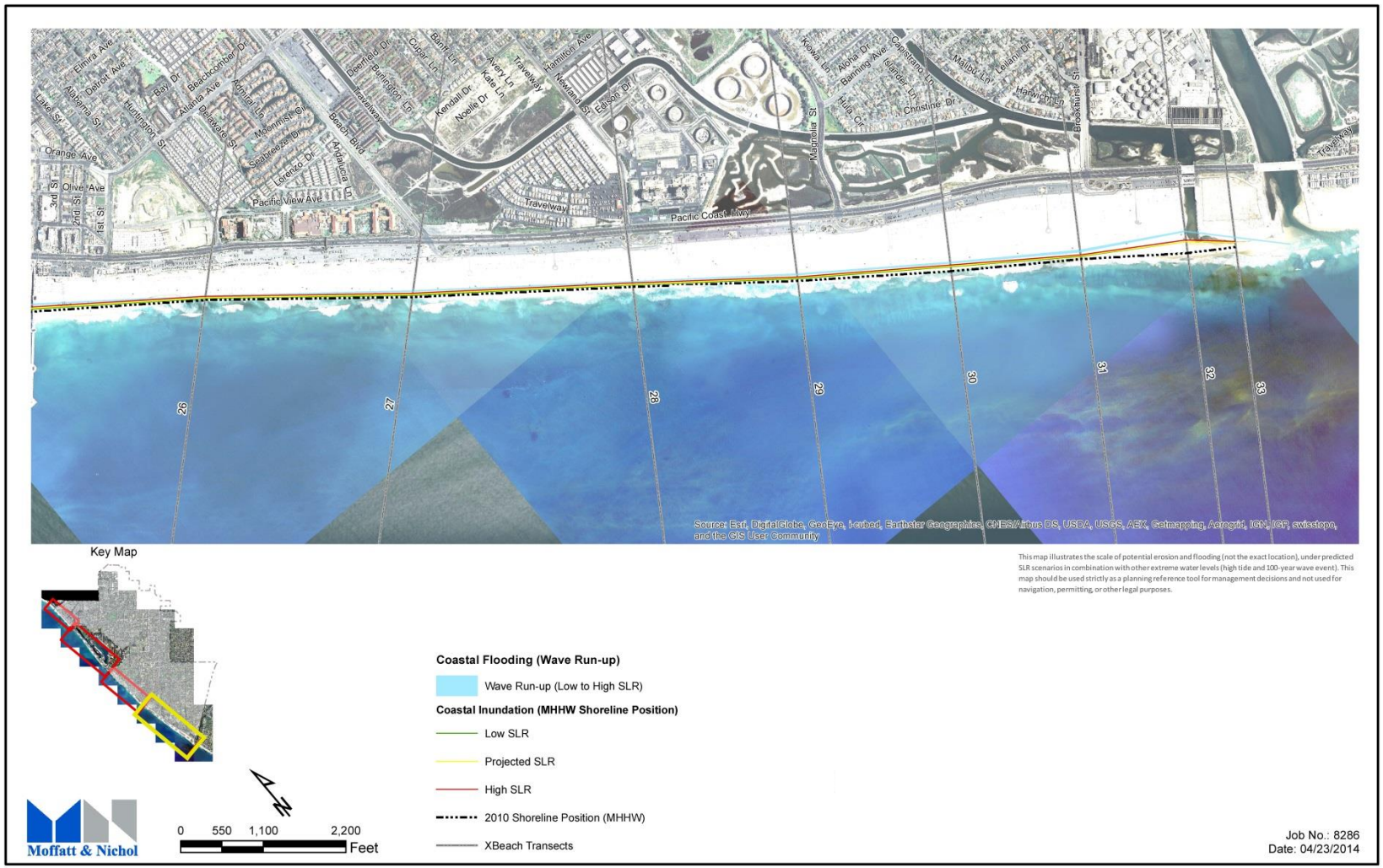

FIGURE 30
PROJECTED COASTAL EROSION AND RUN-UP RESULTS – YEAR 2030, HUNTINGTON BEACH PLANNING AREA

FIGURE 31
PROJECTED COASTAL EROSION AND RUN-UP RESULTS – YEAR 2030, HUNTINGTON BLUFFS PLANNING AREA

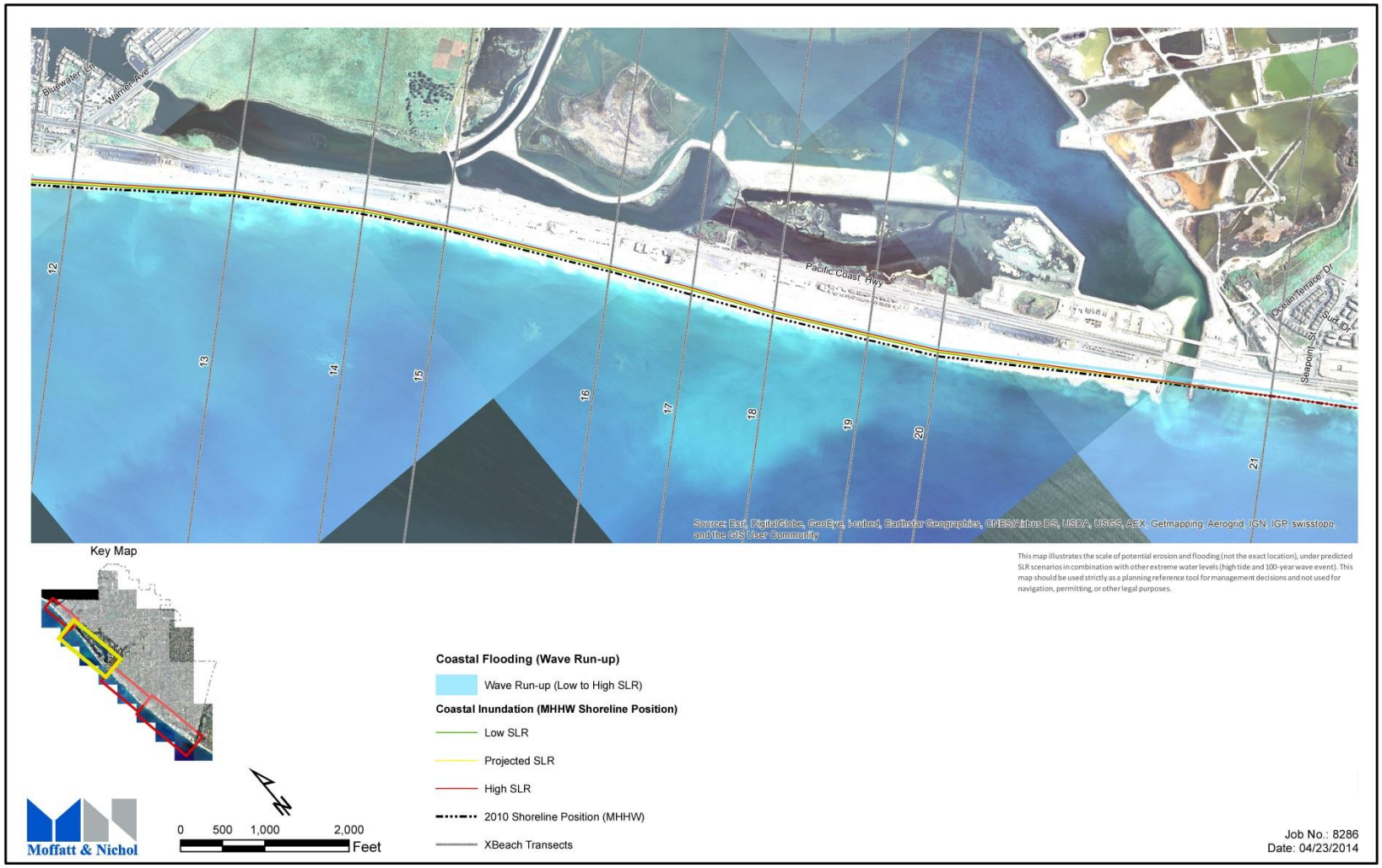

FIGURE 32
PROJECTED COASTAL EROSION AND RUN-UP RESULTS – YEAR 2030, BOLSA CHICA PLANNING AREA

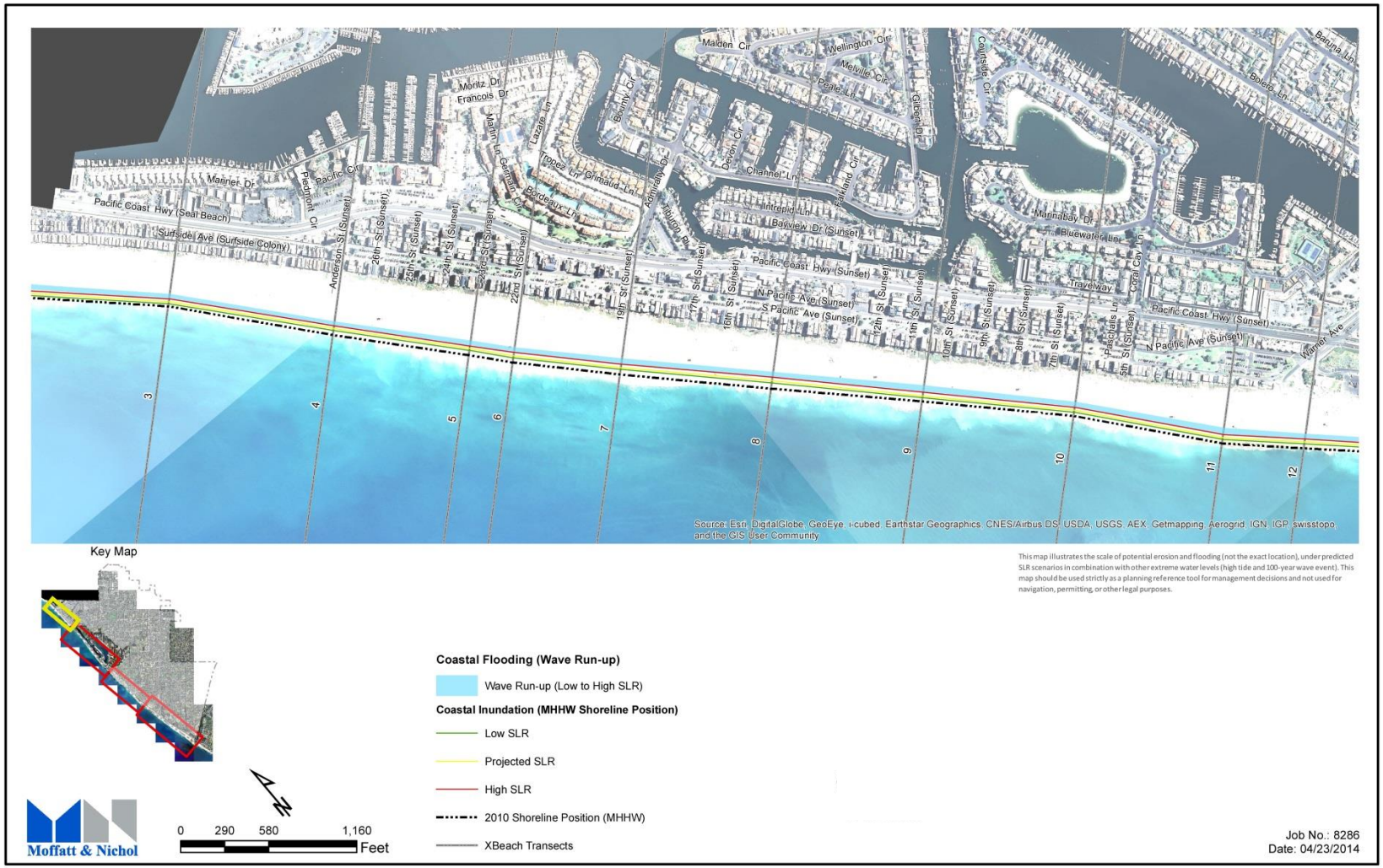

FIGURE 33
PROJECTED COASTAL EROSION AND RUN-UP RESULTS – YEAR 2030, SUNSET BEACH PLANNING AREA

FIGURE 34
PROJECTED COASTAL EROSION AND RUN-UP RESULTS – YEAR 2050, HUNTINGTON BEACH PLANNING AREA

FIGURE 35
PROJECTED COASTAL EROSION AND RUN-UP RESULTS – YEAR 2050, HUNTINGTON BLUFFS PLANNING AREA

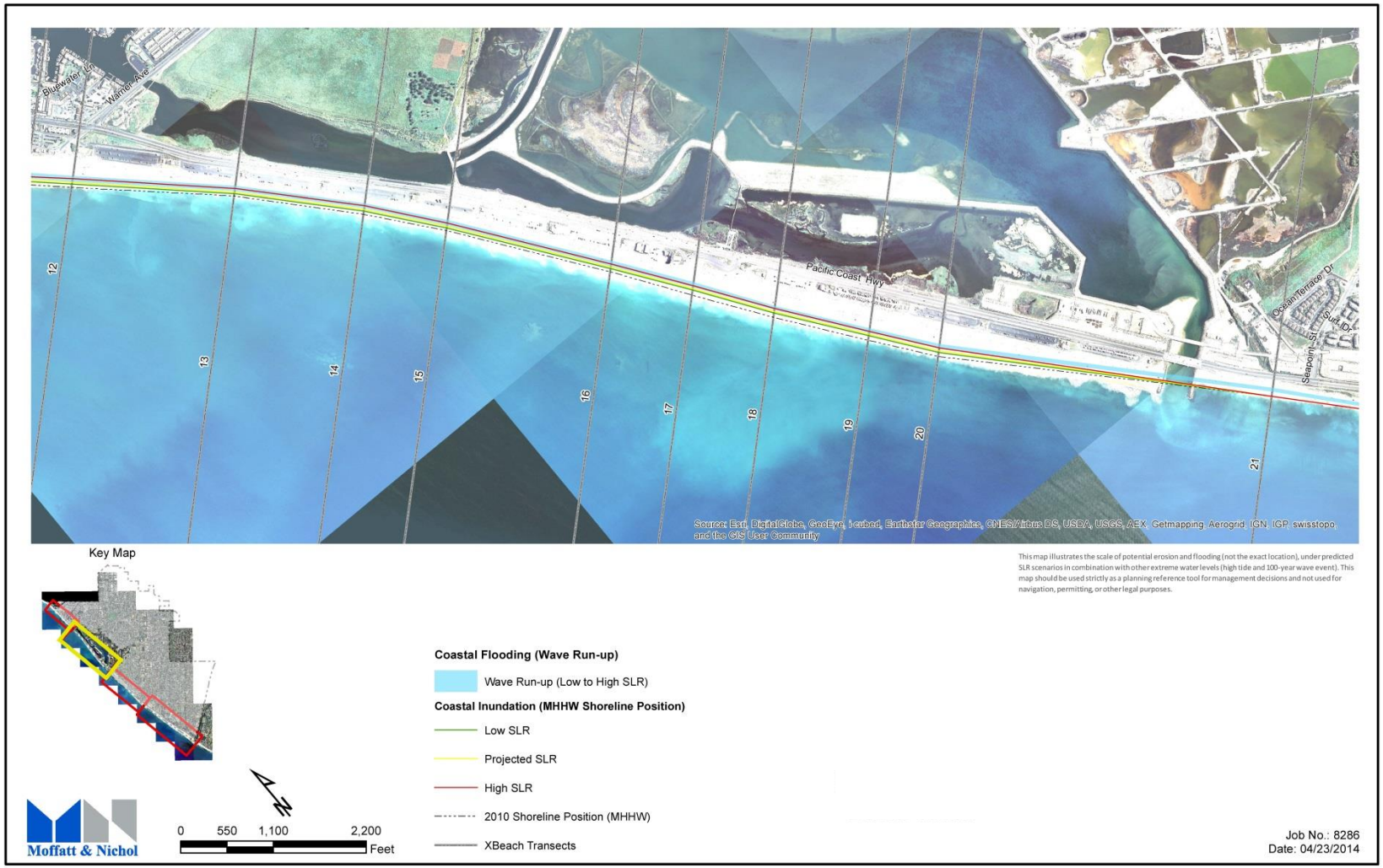

FIGURE 36
PROJECTED COASTAL EROSION AND RUN-UP RESULTS – YEAR 2050, BOLSA CHICA PLANNING AREA

FIGURE 37
PROJECTED COASTAL EROSION AND RUN-UP RESULTS – YEAR 2050, SUNSET BEACH PLANNING AREA

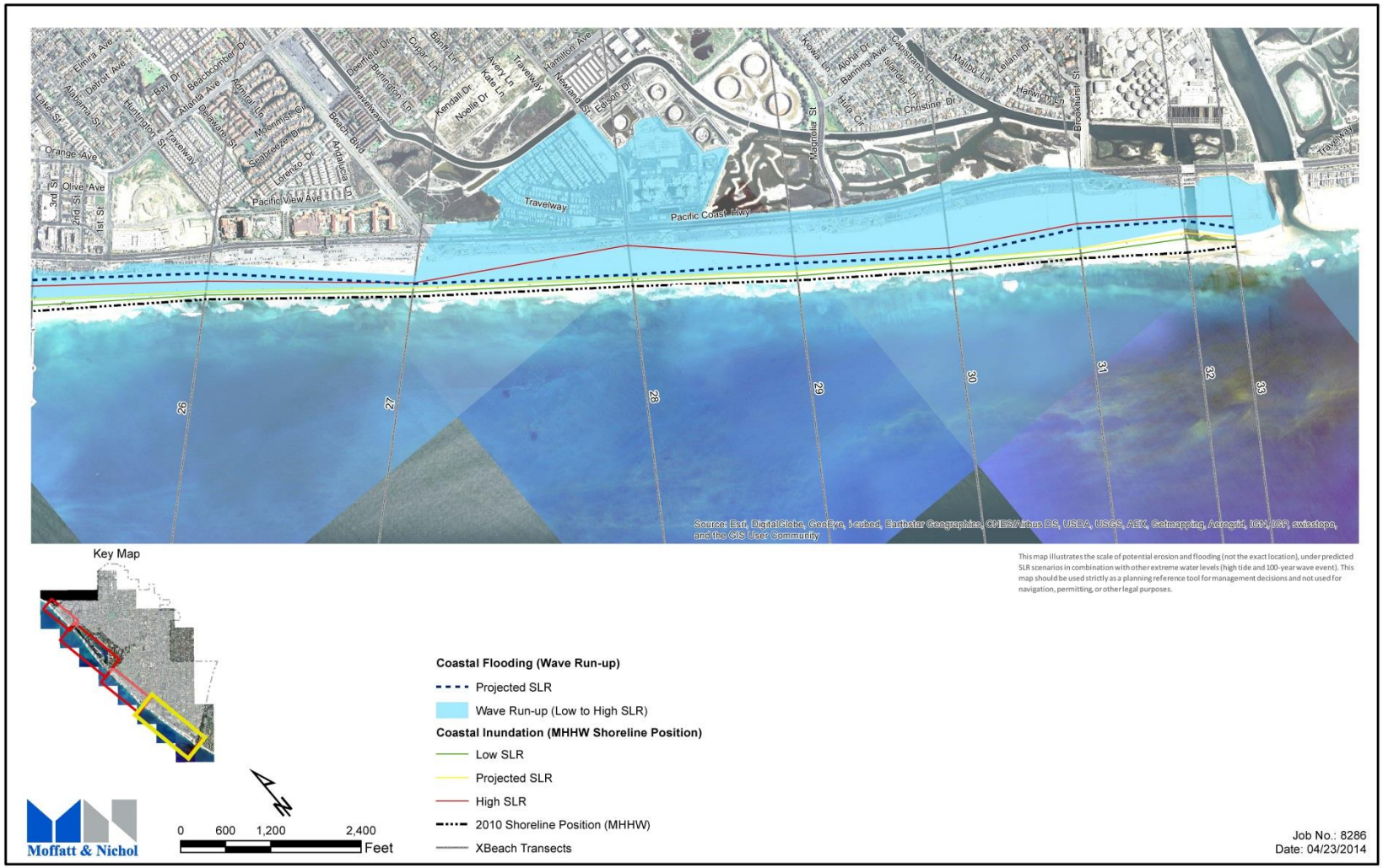

FIGURE 38
PROJECTED COASTAL EROSION AND RUN-UP RESULTS – YEAR 2100, HUNTINGTON BEACH PLANNING AREA

FIGURE 39
PROJECTED COASTAL EROSION AND RUN-UP RESULTS – YEAR 2100, HUNTINGTON BLUFFS PLANNING AREA

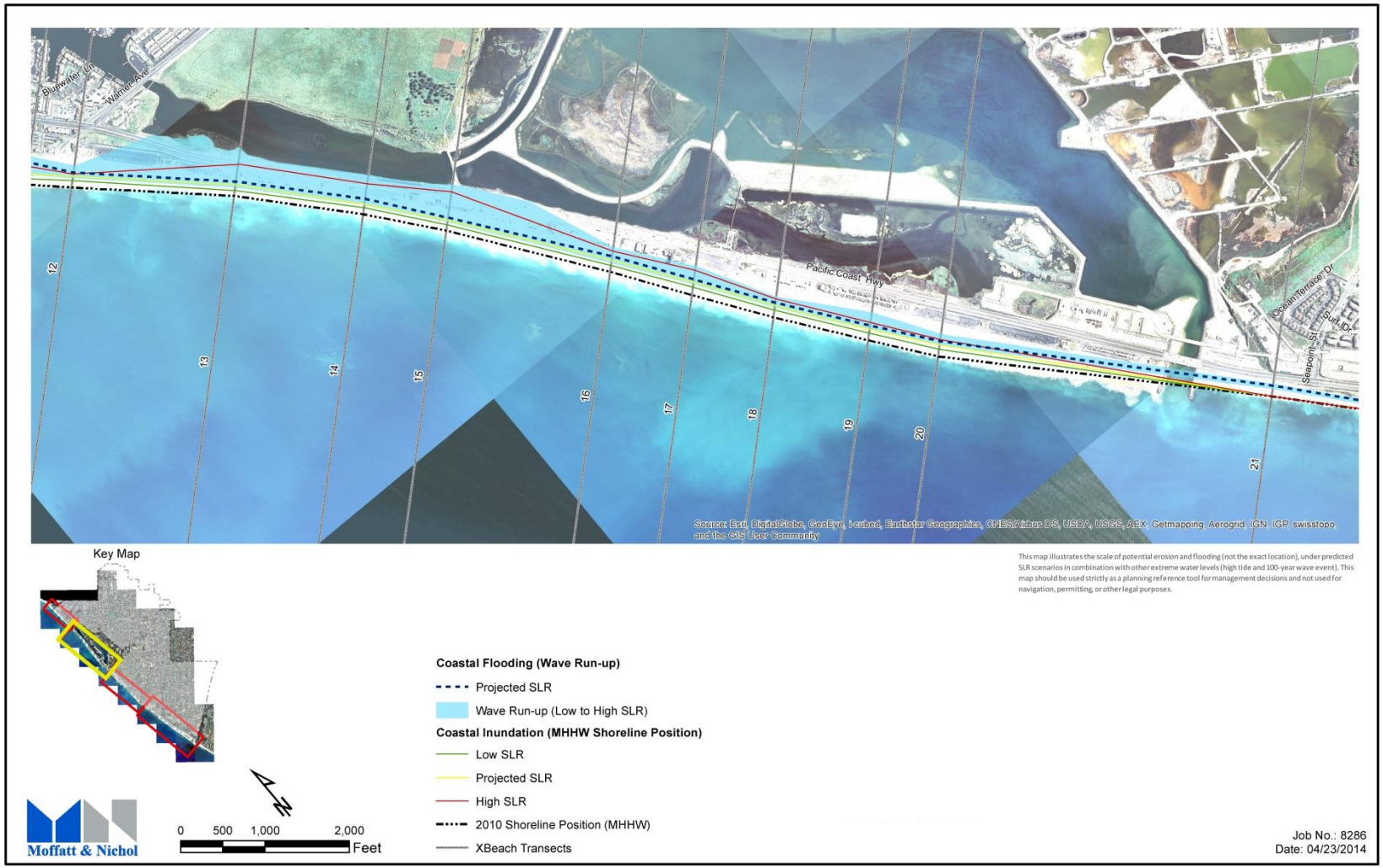

FIGURE 40
PROJECTED COASTAL EROSION AND RUN-UP RESULTS – YEAR 2100, BOLSA CHICA PLANNING AREA

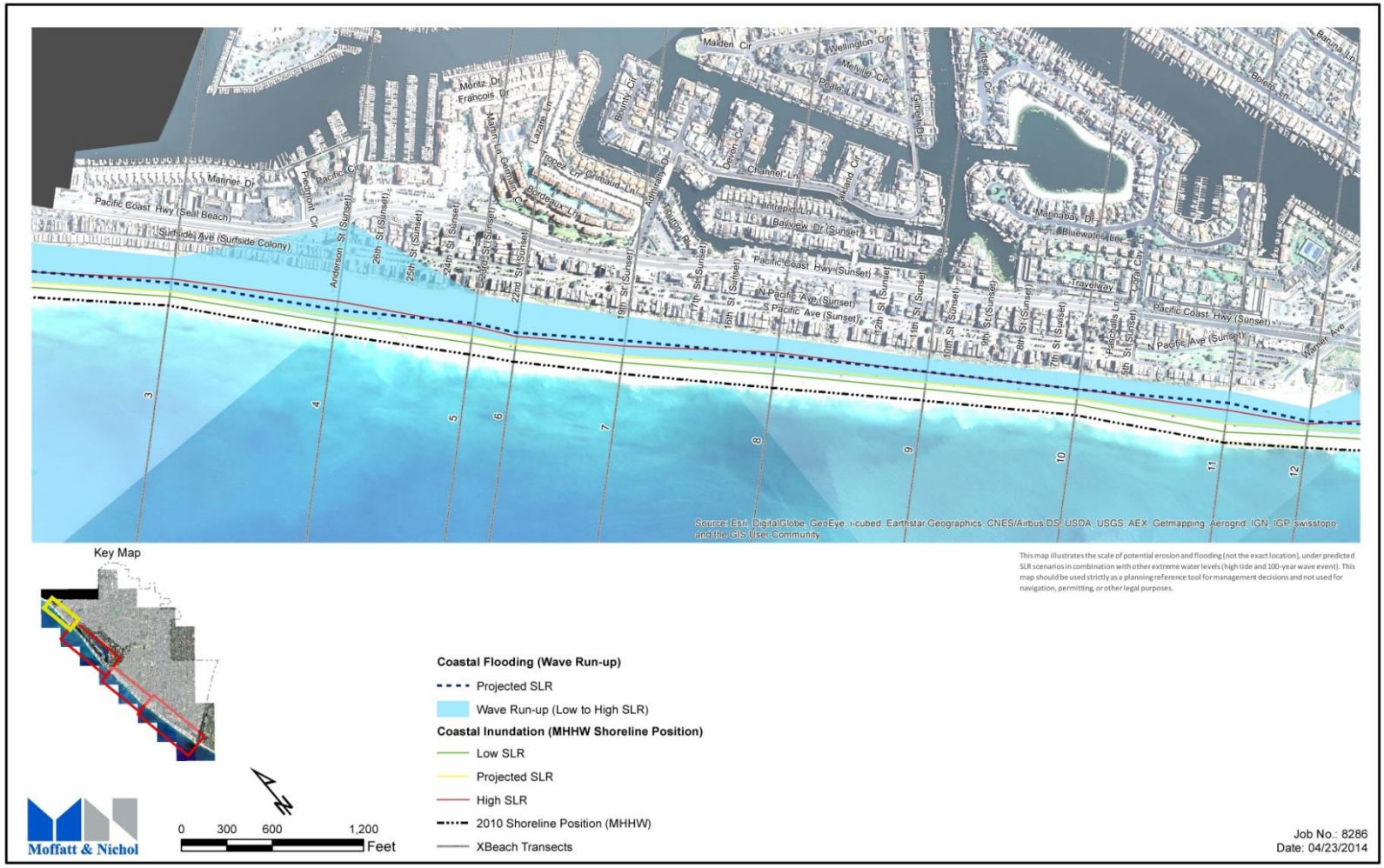

FIGURE 41
PROJECTED COASTAL EROSION AND RUN-UP RESULTS – YEAR 2100, SUNSET BEACH PLANNING AREA

4.4.1. Impacted Assets

Asset impacts were quantified by querrying assets within predicted flooded or inundated areas and applying replacement costs (a conservative measure). Replacement costs were derived from City GIS data (i.e. total building costs) and construction replacement values (based on 2014 dollars) where GIS data was not available (e.g. State Park Beach facilities). These values did not include design and permitting costs. Repalcement costs by asset type used for the vulnerability assesment are provided in Table 14.

TABLE 14
REPLACEMENT COST BY ASSET TYPE

Asset Type	Source	Cost*
City Building and Residential Structures	City GIS building data (Total Value column). Value represents replacement value (USD / sq.ft) times the building area (sq.ft.) times the number of stories.	Varies
Other Buildings	Replacement Construction Estimate	Varied
Bike Trails	Replacement Construction Estimate	$10/sq.ft.
Pedestrian Paths	Replacement Construction Estimate	$10/sq.ft.
Walls	Replacement Construction Estimate	$50/ft. (multiply by average wall height).
Parking Lots	Replacement Construction Estimate	$3/sq.ft.
Roads	Replacement Construction Estimate	$3/sq.ft.

** Engineer's estimate based on unit cost for recent comparable projects*

Impacted assets in the Study Area under the year 2100 high scenario are shown in Table 15 through Table 18.

TABLE 15
IMPACTED ASSETS IN THE SUNSET BEACH PLANNING AREA

Assets	ID	No. of Impacted Assets	Common Name	Flooded Area (sq. ft)	Replacement Cost (USD)*	Replacement Value ($)
Buildings**	Multiple	30		NA	$250,000 ea	$7,500,000
Roads**	1		Anderson St.	10,560	$3 / sq.ft	$32,000
	2		N Pacific Ave.	12,672		$38,000
	3		S Pacific Ave.	31,680		$95,000
	4		26th St.	4,224		$13,000
	5		25th St.	4,224		$13,000
	6		24th St.	4,224		$13,000
	Total	**6**		**67,584**		**$204,000**
					Total Impact	$7,704,000

**Estimates based on 2014 dollars.*
*** Engineer's estimate based on unit cost for recent comparable projects.*
**** Replacement values rounded to the nearest thousand.*

TABLE 16
IMPACTED ASSETS IN THE BOLSA CHICA PLANNING AREA

Assets	ID	Common Name	Number of Assets	Elevation (ft, NAVD88)	Flooded Area	Replacement Cost *	Replacement Value ($)***
Parking Lots	1	Bolsa Chica State Beach Parking Lot		13	85,611 sq. ft.	$3 / sq. ft.	$257,000
	2			13	75,044 sq. ft.		$225,000
	3			13	94,311 sq. ft.		$283,000
	4			12	100,160 sq. ft.		$300,000
	5			12	727,487 sq. ft.		$2,182,000
	6			12	100,427 sq. ft.		$301,000
	7			12	45,917 sq. ft.		$138,000
Totals			**7**		**1,228,957 sq.ft**		**$3,687,000**
Bike Trails	1			12	10, 794 sq. ft.	$10 / sq. ft.	$108,000
	2			12	14,490 sq. ft.		$145,000
	3			12	19, 524 sq. ft.		$195,000
	4			12	2,952 sq. ft.		$30,000
Totals			**4**		**47,760 sq. ft.**		**$478,000**
Pedestrian Trails	1			15	804 sq. ft.	$10 / sq. ft.	$8,000
	2			16	534 sq. ft.		$5,000
Totals			**2**		**1,338 sq. ft.**		**$13,000**
Buildings**	1	Bolsa Chica State Beach Restrooms and Facilities	**9**		N/A	$150,000 ea.	**$1,350,000**
Roads	2	PCH	**1**		**211,200 sq. ft.**	$3 / sq. ft.	**$634,000**
						Total Impact	**$6,162,000**

**Estimates based on 2014 dollars. Engineer's estimate based on unit cost for recent comparable projects.*
*** Total Replacement Cost per City building GIS data*
**** Replacement values rounded to the nearest thousand.*

TABLE 17
IMPACTED ASSETS IN THE HUNTINGTON BLUFFS PLANNING AREA

Assets	ID	Common Name	Number of Assets	Elevation (ft, NAVD88)	Flooded Area	Replacement Cost*	Replacement Value ($)**
Parking Lots	1			29	12,033 sq.ft.	$3 / sq.ft.t	$36,000
	2			28	17,348 sq.ft		$52,000
Totals			2		29,381 sq.ft.		$88,000
Bike Trails	1			12	12,120 sq.ft	$10 / sq.ft.	$121,000
Totals			1		12,120 sq.ft.		$121,000
Pedestrian Trails	1			15	1314 sq.ft.	$10 / sq.ft.	$13,000
	2			14	876 sq.ft.		$9,000
Totals					2,190 sq.ft.		$22,000
Walls* **	1			13-15	629 ft.	$150 /ft.	$94,000
	2			15-16	239 ft.		$36,000
	3			15-16	252 ft.		$38,000
Totals			3		1,120 ft.		$168,000
Buildings	1	Beach Facility	1		NA	$150,000 ea	$150,000
	2	Huntington Beach Condos	90		NA	$346,000 ea	$31,140,000
Totals			91				$31,290,000
						Total Impact	**$31,689,000**

**Estimates based on 2014 dollars. Based on engineering estimate in conjunction with City GIS data, where available. Engineer's estimate based on unit cost for recent comparable projects.*
*** Replacement values rounded to the nearest thousand.*
****Assumed average wall height of 3 feet.*

TABLE 18
IMPACTED ASSETS IN THE HUNTINGTON BEACH PLANNING AREA

Assets	ID	Common Name	Number of Assets	Elevation (ft, NAVD88)	Flooded Area	Replacement Cost	Replacement Value ($)****
Parking Lots**	1			27	15,767 sq.ft.	$3 /sq.ft.	$47,000
	2			29	8,749 sq.ft.		$26,000
	3			15	75,460 sq.ft.		$226,000
	4			13	242,063 sq.ft.		$726,000
	5			13	240,068 sq.ft.		$720,000
	6			13	324,913 sq.ft.		$975,000
	7			13	29,630 sq.ft.		$89,000
Total			**7**		**936,650**		**$2,810,000**
Bike Trails**	1			12	4,626 sq.ft.	$10 / sq.ft.	$46,000
	2			12	8,496 sq.ft.		$85,000
	3			12	3,408 sq.ft.		$34,000
	4			12	10,866 sq.ft.		$109,000
	5			12	21,540 sq.ft.		$215,000
	6			12	28,650 sq.ft.		$287,000
Total			**6**		77,586 sq.ft.		**$776,000**
Pedestrian Paths**	1			14	1,524	$10 / sq.ft.	$15,000
	2			13	1,368		$14,000
	3			13	1,704		$17,000
	4			13	2,076		$21,000
	5			12	3,096		$31,000
	6			12	2,748		$27,000
Total			**6**		12,516		**$125,000**

Assets	ID	Common Name	Number of Assets	Elevation (ft, NAVD88)	Flooded Area	Replacement Cost	Replacement Value ($)****
Walls, *****	1			15-16	264	$150 / ft.	$40,000
	2			11.5-13.5	117	$150 / ft.	$18,000
	3			11.5-13.5	199	$150 / ft.	$30,000
	4			12-14.5	736	$150 / ft.	$110,000
Total			**4**		**1,316**	**$50** / ft.	**$197,000**
Buildings	1	City Beach Facilities (estimated)**	23	Varies	NA	$150,000 ea.	$3,450,000
	2	City Beach Facilities***	11	Varies	NA	$11,328,000	$11,328,000
	3	State Beach Facilities***	1	Varies	NA	$2,331,000	$2,331,000
	4	Manufactured Homes***	352	Varies	NA	$63,884,000	$63,884,000
	5	Industrial (AES)***	12	Varies	NA	$82,658,000	$82,658,000
	6	Commercial***	4	Varies	NA	$6,436,000	$6,436,000
Total			**393**				**$170,087,000**
Roads**	1	Beach Blvd			10,560	$3 / sq.ft.	$32,000
	2	PCH			211,200	$3 / sq.ft.	$634,000
	3	Newland St			63,360	$3 / sq.ft.	$190,000
	4	Travelways			422,400	$3 / sq.ft.	$1,267,000
Total			**4**		**707,520**		**$2,123,000**
						Total Impact	**$176,118,000**

**Estimates based on 2014 dollars.*
***Engineer's estimate based on unit cost for recent comparable projects.*
**** Total Replacement cost per City GIS data*
***** Replacement values rounded to the nearest thousand.*
******Assumed average wall height of 3 feet.*

4.4.2. Shoreline Vulnerabilities

Predicted shoreline erosion for the Study Area is shown in Table 19. Shoreline erosion estimates were made relative to May 2010 MSL shoreline position. The most vulnerable planning area to shoreline erosion is Huntington Beach.

TABLE 19
SHORELINE EROSION PER PLANNING AREA

Year	SLR Scenario	Sunset Beach Eroded Area (acre)	Bolsa Chica Eroded Area (acre)	Huntington Bluffs Eroded Area (acre)	Huntington Beach Eroded Area (acre)	Average	Standard Deviation
2030	Low	4.2	10.2	4.3	12.6	7.8	3.7
	Medium	6.1	14.3	6.0	15.8	10.6	4.5
	High	9.1	20.3	8.5	21.2	14.8	6.0
2050	Low	5.6	12.9	5.4	15.2	9.8	4.3
	Medium	15.2	19.1	8.0	20.5	15.7	4.9
	High	13.9	31.6	12.3	31.8	22.4	9.3
2100	Low	11.0	24.7	9.9	25.4	17.8	7.3
	Medium	17.7	42.0	19.2	45.2	31.0	12.6
	High	28.2	87.3	36.0	122.0	68.4	38.4

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Technical Appendix B

Sea-level Rise Modeling Approach
and Results for the Inland Waterway Planning Areas

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1. Introduction

This appendix provides the technical background information (modeling approach, assumptions, and results) that supports the sea level rise (SLR) vulnerability assessment of the Inland Waterway Planning Areas for the Huntington Beach General Plan Update. Flooding from high tides and stormwater discharge in regional flood control channels was evaluated to develop several SLR projections. The three inland waterway planning areas are described below and illustrated in Figure 1.

1. Huntington Harbour Area: This residential, commercial, and marina development harbor is primarily residential and lined with bulkhead structures that vary in crest elevation. Huntington Harbour is tidally influenced and receives stormwater runoff from major regional flood control channels such as Bolsa Chica Channel, Westminster Channel, Sunset Channel, and Anaheim-Barber City Channel.
2. Bolsa Chica Wetlands Area: Most of this low-lying area is protected by levees from the tidally influenced Bolsa Chica wetlands and stormwater runoff conveyed by the East Garden Grove Wintersburg Channel (EGGWC).
3. Huntington Beach Wetlands Area: This low-lying planning area is protected by a system of levees along the tidally influenced Huntington Beach wetlands and along regional flood control channels, including the Huntington Beach Channel, Talbert Channel, and East Valley-Fountain Valley Channel.

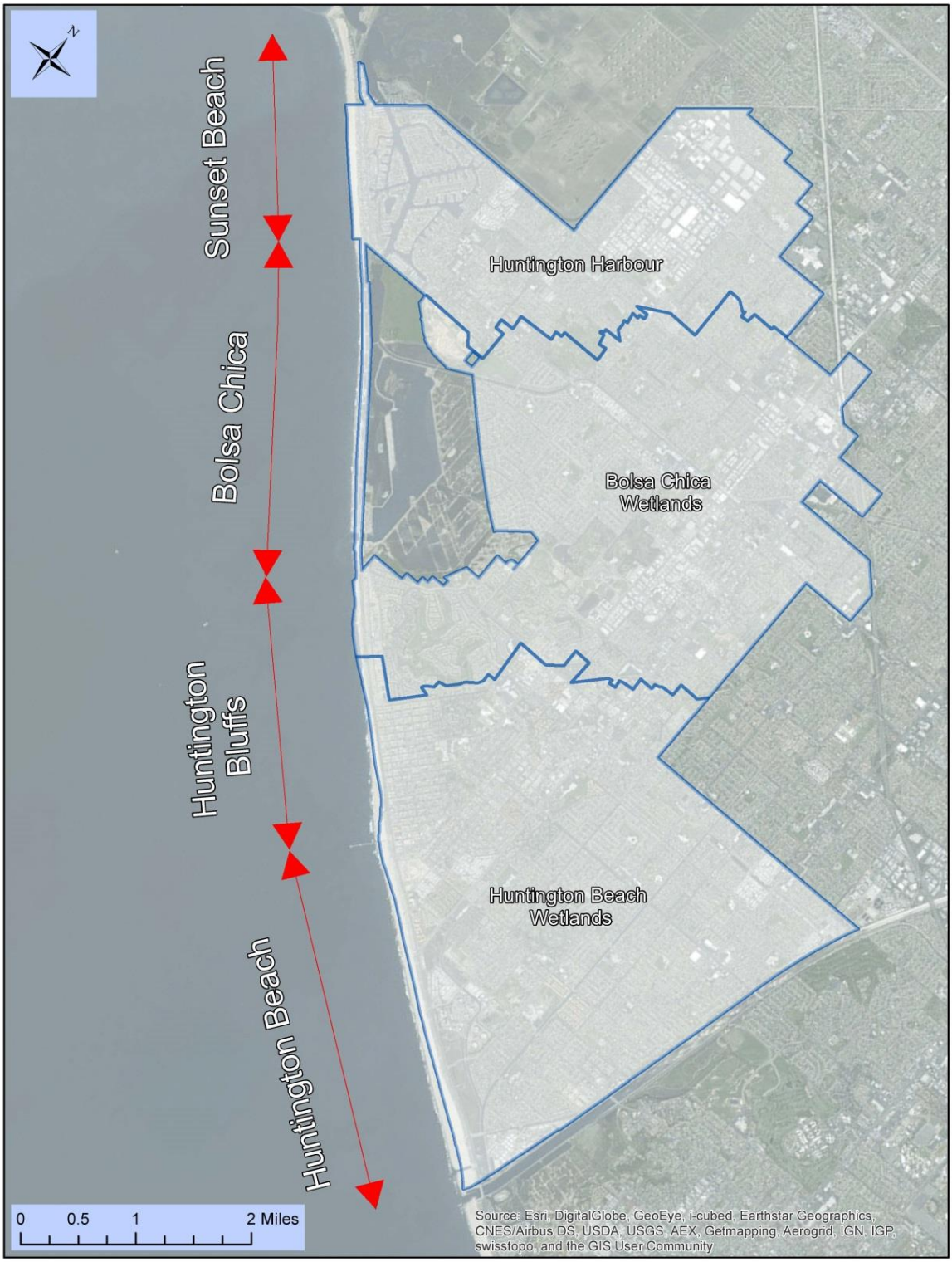


FIGURE 1
INLAND WATERWAY PLANNING AREAS

2. Tidal Flooding Approach

The most direct impact of rising sea levels on the inland waterway planning areas will be the increased potential for tidal flooding from high water levels. Most communities along the inland waterways are currently protected from tidal flooding by seawalls, bulkheads, or levees. The crest elevation and condition of these structures are controlling factors in the potential for flooding under various SLR projections. A three-step approach was used to evaluate the potential for flooding due to high water levels and is summarized below.

1. Determine specific water levels for each SLR scenario
2. Compare the specified water level with the crest elevation of the flood barrier (levee/bulkhead/seawall) to determine if overtopping may occur.
3. Estimate limits of flooding using topography generated from light detection and ranging (LiDAR) data captured in October 2013 if water levels overtop the flood barriers.

These steps are described in more detail in Section 2.1.

2.1. Water Levels

Water level information was extracted from NOAA station 9410660, which is located at the Port of Los Angeles for use in establishing water level statistics in the vicinity of Huntington Beach. Because tides occur on a large spatial scale, the tidal characteristics are similar at coastal locations throughout Southern California. The Los Angeles tide gage data provided a 90-plus-year record of water levels, providing more reliable water level statistics than a closer Newport Beach station with a shorter record of data. Extreme water levels associated with a range of exceedance probabilities are shown in Table 1 and Figure 2.

The baseline water level (without SLR) selected for the tidal flooding analysis was +7.18 (feet, NAVD 88), which is slightly higher than a typical King Tide water level. This water level has a 50% annual exceedance probability (2-year return period) based on analysis of data from the Los Angeles tide gage (NOAA Tides and Currents, Station 9410660, Data from 1923 to 2006). These high ocean water levels include the effects of astronomical tide, storm surge, and short-term climatic variations such as El Niño Southern Oscillation (ENSO) cycles, which are described below.

This analysis used a higher water level than the coastal erosion and inundation analysis because this analysis only considered high water levels and not storm waves. A water level of 6.48 feet, NAVD 88 combined with a 100-year wave event, was used in the coastal erosion and inundation analysis.

Table 1
Exceedance Probability Water Levels at Los Angeles Station 9410660

Annual Exceedance Probability	Return Interval	Elevation (feet NAVD 88)
99%	1-year	6.79
50%	**2-year**	**7.18**
10%	10-year	7.45
1%	100-year	7.68

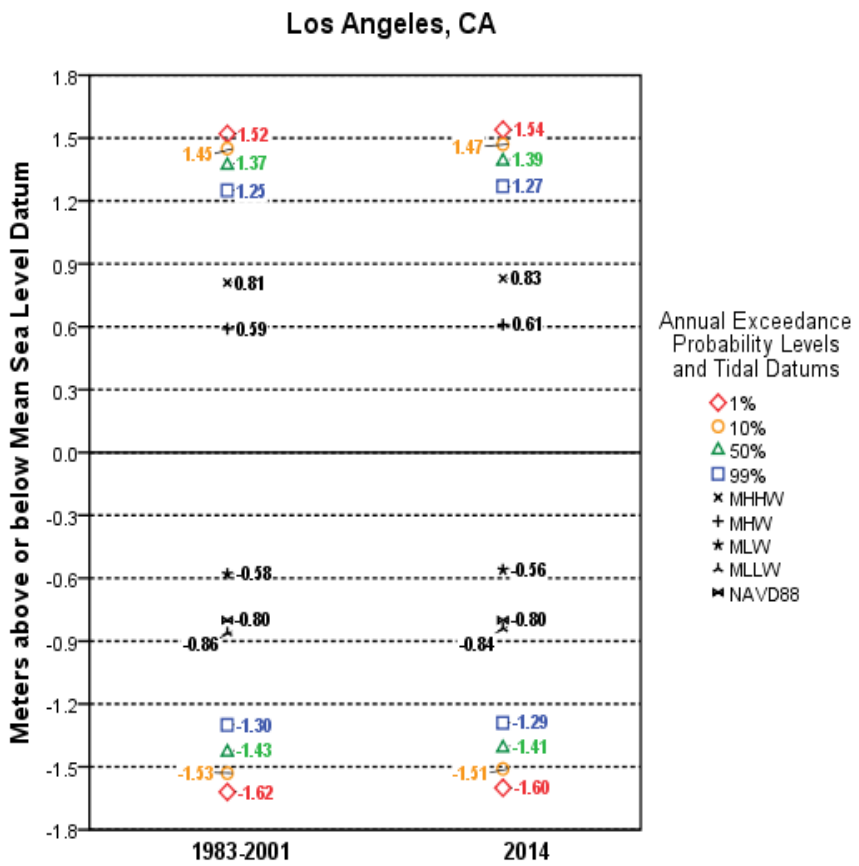


FIGURE 2
EXCEEDANCE PROBABILITY WATER LEVELS AT LOS ANGELES STATION 9410660
(NOAA CO-OPS, 2014)

2.1.1. Tides

Tides in Huntington Beach are semidiurnal in nature: two highs and two lows occur per day. Astronomical tides make up the most significant amount of the total water level. Typical daily tides range from mean lower low water (MLLW) to mean higher high water (MHHW), a tidal range of about 5.5 feet. Spring high tides occur twice per lunar month and result in higher high tides and lower low tides. The average spring high tide elevation is about +6.44 (feet, NAVD 88) based on data from the Los Angeles gage. The highest annual tides (King Tides) can reach elevations of +7 (feet, NAVD 88) and typically occur in or near December, January, or July.

2.1.2. Storm Surge

Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide. Storm surges are a result of water being pushed toward the shore by winds moving cyclonically around a storm; thus, most significant examples are generally associated with hurricanes. Storm surge has been found to comprise only a small fraction of the total water levels along the Southern California coast, and is commonly referenced as being less than a foot. During the winter storm of January 17-18, 1988 the measured water level at the Los Angeles gage was 0.7 feet above the predicted astronomical tide (USACE, 2002).

2.1.3. Short-Term Climatic Variations

ENSO events are global-scale climatic variations with a duration of one to several years. These variations result in a decreased atmospheric pressure in the eastern tropical Pacific Ocean, a decrease in easterly trade winds, and an increase in sea level on the west coast of North America and South America. During the major ENSO of 1997-1998, monthly mean sea levels in Southern California were increased by up to one foot (USACE, 2002).

2.1.4. Historic Sea Level Rise

The nearest, long-term sea level record in the study area is from the Los Angeles tidal datum, which has been reported for more than 90 years. Historical rates of SLR at this location are shown in Figure 3. The mean trend is a 0.83 millimeter/year (0.03 inch/year) rise with a 95% confidence interval of +/- 0.27 millimeter/year based on monthly mean sea level data from 1923 to 2006. This is equivalent to a change of 0.27 feet in 100 years.

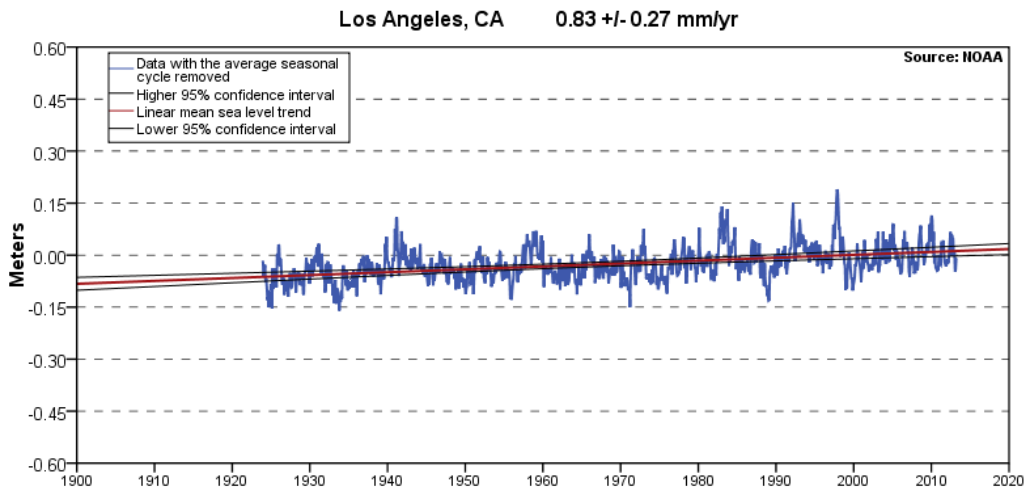


FIGURE 3
LOS ANGELES SEA-LEVEL RECORD (NOAA 2014)

2.1.5. Future Sea Level Rise Projections

Sea levels are projected to rise in coming decades as a result of increased global temperatures associated with climate change (IPCC 2014). The amount of SLR projected over the next century varies for each time horizon due to the uncertainty associated with future emissions, which feed into global circulation models produced by the Intergovernmental Panel on Climate Change (IPCC). The most recent and best available science for regional SLR projections is the National Research Council (2012) report, titled *SLR for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. Guidance documents from the California Coastal Commision (CCC 2013) and State of Califorina (CO-CAT 2013) recommended using values shown in Table 2 from the NRC 2012 report for the region south of Cape Mendocino. These projections were combined with the baseline 2-year water level identifed in Section 2.1 to map tidal flooding potential as a result of rising sea levels.

TABLE 2
SEA LEVEL RISE SCENARIOS (NRC 2012)

Time Horizon	Low (ft)	Medium (ft)	High (ft)
2010	0.00	0.00	0.00
2030	0.15	0.50	1.00
2050	0.40	0.90	2.00
2100	1.40	3.10	5.50

2.1.6. Combined Water Levels

The baseline water level was combined with the high SLR projections in the years 2030, 2050, and 2100 to evaluate the potential for flooding due to high water levels and SLR. The scenarios evaluated are listed in Table 3 and represent possible worst-case scenarios for future planning purposes, rather than a probable future condition.

TABLE 3
WATER LEVELS FOR TIDAL FLOODING MAPPING

SLR Scenario	SLR (ft)	Baseline Water Level 2-year Return Period (ft, NAVD 88)	Combined Water Level (ft, NAVD 88)
2030 High	1.0	7.18	8.18
2050 High	2.0	7.18	9.18
2100 High	5.5	7.18	12.68

2.2. CREST ELEVATION OF EXISTING FLOOD BARRIERS

The inland waterway planning areas are characterized by low-lying development protected by flood barriers. The crest elevation and condition of these structures is a controlling factor when assessing the potential for flooding due to rising sea levels. As-built plans, LIDAR topography, and survey data were used to estimate the crest elevations of existing flood barriers (levees/seawalls/bulkheads) in each planning area.

2.2.1. Huntington Harbour Planning Area

Huntington Harbour is lined with seawalls/bulkheads of varying type, condition and crest elevation. Limited as-built data indicate seawalls/bulkheads around Huntington Harbour had a crest elevation ranging from +9 to +10 (feet, NAVD 88). However, subsidence has been reported in the Huntington Harbour area due to historic oil production activities. Seawalls and bulkheads around Huntington Harbour are the primary defense to rising sea levels and subsidence can directly impact the ability to accommodate SLR.

A survey of the bulkhead wall at Sunset Aquatic Marina found the top-of-wall elevation to range from +8 to +8.2 feet above MLLW (7.8 to 8.0 feet, NAVD 88), whereas the as-built elevation was +9 feet MLLW (8.8 feet, NAVD 88). This disparity is attributed to historic underground oil extraction activities in the region. Subsidence from these activities has since been slowed by way of underground water injection (Moffatt & Nichol, 2013). Since accurate seawall crest elevations

were not available and as-built information varies, mapping of tidal flooding in the Huntington Harbour area was based on LIDAR topography. This method assumes the crest of the seawall/bulkhead is equivalent to adjacent ground elevations.

2.2.2. Bolsa Chica Planning Area

Reasonably accurate crest elevations (± 0.5 feet) could be determined from LIDAR topography for earthen levees around the Bolsa Chica full tidal basin and along the lower reach of the East Garden Grove Wintersburg Channel (C05). LIDAR topography indicates the crest elevations along these levees to be approximately +12 (feet, NAVD 88), which is consistent with the as-built cross-sections of the Bolsa Chica north levee shown in Figure 4. Please note, the elevations shown in Figure 4 are in meters relative to the North American Vertical Datum of 1988 (NAVD 88).

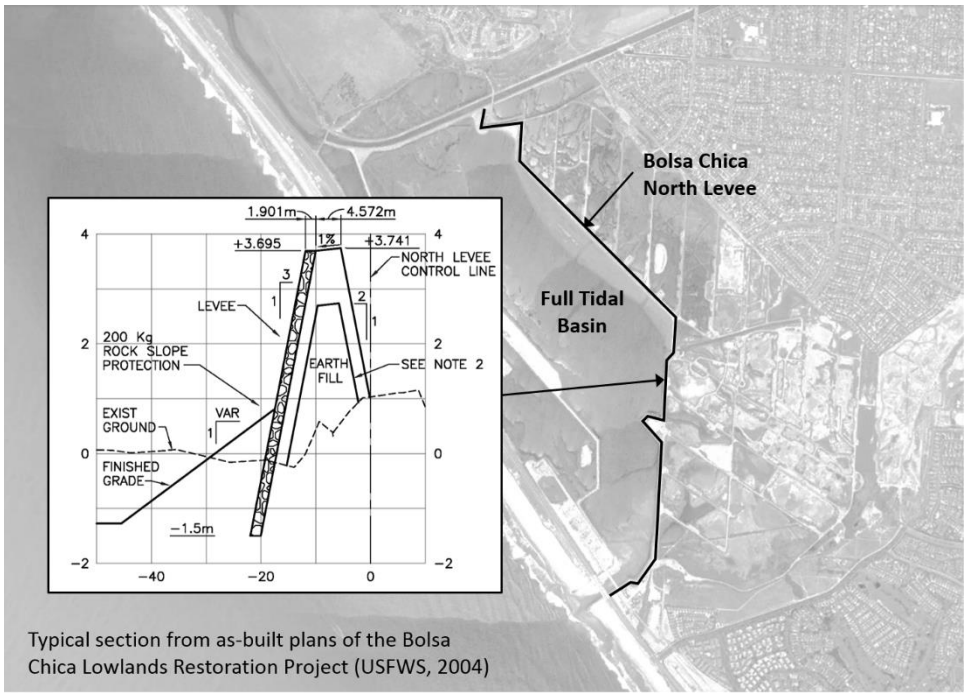


FIGURE 4
TYPICAL LEVEE SECTION – BOLSA CHICA FULL TIDAL BASIN (USFWS 2004)

2.2.3. Huntington Beach Wetlands Planning Area

The inland waterways of the Huntington Beach Wetlands Planning area are confined between vertical walls that line the regional flood control channels and earthen levees along the lower Huntington Beach Wetlands. The county-owned flood control channels in the planning area include the following: Huntington Beach Channel (D01), Talbert Channel (D02) and East Valley-Fountain Valley Channel (D05). These channels are wide and low, with a relatively flat longitudinal gradient. D01 and D02 are lined with sheet pile walls on both sides of the channel upstream of the wetlands. The top of channel wall elevations were estimated from as-built plans obtained from Orange County Public Works (OCPW) and are listed in Table 4 and Table 5.

TABLE 4
HUNTINGTON BEACH CHANNEL (D01) – TOP OF WALL ELEVATIONS

Channel	Station	Location	As-Built Plan	Date	As-built Datum	Elevation (As-built)	Elevation (NAVD 88)*
D01	16092	D/S Adams Ave	D01-101-12	2004	NGVD 29 (HB-197-71)	12.2	14.50
D01	14978	U/S Sea Bridge Ln	D01-101-12	2004	NGVD 29 (HB-197-71)	12.2	14.50
D01	14710	D/S Sea Bridge Ln	D01-101-12	2004	NGVD 29 (HB-197-71)	12	14.30
D01	13891	U/S Indianapolis Ave	D01-101-12	2004	NGVD 29 (HB-197-71)	12	14.30
D01	13600	D/S Indianapolis Ave	D01-101-10R	2003	NGVD 29 (HB-196-71)	11.75	14.05
D01	11292	U/S Atlanta Ave	D01-101-10R	2003	NGVD 29 (HB-196-71)	11.75	14.05
D01	10970.79	D/S Atlanta Ave	D01-101-8	2000	NGVD 29 (HB-196-71)	11.25	13.55
D01	10200	900' D/S of Atlanta Ave	D01-101-8	2000	NGVD 29 (HB-196-71)	11.25	13.55
D01	10199	900' D/S of Atlanta Ave	D01-101-8	2000	NGVD 29 (HB-196-71)	11	13.30
D01	6547	U/S Newland St	D01-101-11R	2002	NGVD 29 (HB-196-71)	11	13.30
D01	6305	D/S Newland St	D01-101-11R	2002	NGVD 29 (HB-196-71)	10.80	13.10
D01	5801	Wall Ht Transition	D01-101-11R	2002	NGVD 29 (HB-196-71)	10.80	13.10
D01	5800	Wall Ht Transition	D01-101-11R	2002	NGVD 29 (HB-196-71)	10.60	12.90
D01	5301	Wall Ht Transition	D01-101-11R	2002	NGVD 29 (HB-196-71)	10.60	12.90
D01	5300	Wall Ht Transition	D01-101-11R	2002	NGVD 29 (HB-196-71)	10.50	12.80
D01	4601	Wall Ht Transition	D01-101-11R	2002	NGVD 29 (HB-196-71)	10.50	12.80
D01	4600	Wall Ht Transition	D01-101-11R	2002	NGVD 29 (HB-196-71)	10.4	12.70
D01	3752	U/S Access Bridge	D01-101-11R	2002	NGVD 29 (HB-196-71)	10.4	12.70
D01	3540	D/S Access Bridge	D01-101-11R	2002	NGVD 29 (HB-196-71)	10.1	12.40
D01	3400	Magnolia Marsh	D01-101-11R	2002	NGVD 29 (HB-196-71)	10.1	12.40
D01	2500	D/S Magnolia St	D02-101-7R	1993	NGVD 29 (BM IJ-67-89)	10.1	12.40
D01	405.47	U/S D02 Confluence	D02-101-7R	1993	NGVD 29 (BM IJ-67-89)	9.68	11.98
D02	4500	D02 Confluence	D02-101-7R	1993	NGVD 29 (BM IJ-67-89)	8.85	11.15

* Adjustment from NGVD 29 to NAVD 88 (2.3') used average difference in Orange County (ocpublicworks.com). Actual datum conversions vary with location and adjustment year used on as-built plans.

TABLE 5
TALBERT CHANNEL (D02) – TOP OF WALL ELEVATIONS

Channel	Station	Location	As-Built Plan	Date	As-built Datum	Elevation (as-built)	Elevation (NAVD 88)*
D02	22104.79	Garfield	D02-701-3A	1976	NGVD 29 (OCS 1974	12.84	15.14
D02	21206.78	U/S D05 Confluence	D02-101-4A	1986	NGVD 29 (OCS 1974	12.44	14.74
D02	20950.78	D/S D05 Confluence	D02-101-4A	1986	NGVD 29 (OCS 1976	13.35	15.65
D02	19700.5	U/S Yorktown Ave	D02-101-4A	1986	NGVD 29 (OCS 1976	12.81	15.11
D02	19495.5	D/S Yorktown Ave	D02-101-15R	2002	NGVD 29 (BM IJ-67-89)	13.95	16.25
D02	17147	U/S Adams Ave	D02-101-15R	2002	NGVD 29 (BM IJ-67-89)	13.20	15.50
D02	16800	D/S Adams Ave	D02-101-14R	1999	NGVD 29 (BM IJ-67-89)	13.38	15.68
D02	14500	U/S Indianapolis Ave	D02-101-14R	1999	NGVD 29 (BM IJ-67-89)	12.87	15.17
D02	14200	D/S Indianapolis Ave	D02-101-13R	1997	NGVD 29 (BM IJ-67-89)	12.90	15.20
D02	11900	U/S Atlanta Ave	D02-101-13R	1997	NGVD 29 (BM IJ-67-89)	12.19	14.49
D02	11559	D/S Atlanta Ave	D02-101-12	1996	NGVD 29 (BM IJ-67-89)	11.57	13.87
D02	9216	U/S Hamilton Ave	D02-101-12	1996	NGVD 29 (BM IJ-67-89)	11.11	13.41
D02	8986.64	D/S Hamilton Ave	D02-101-9	1995	NGVD 29 (BM IJ-67-89)	9.99	12.29
D02	6402.71	U/S Banning Ave	D02-101-9	1995	NGVD 29 (BM IJ-67-89)	9.5	11.80
D02	6300	D/S Banning Ave	D02-101-7R	1993	NGVD 29 (BM IJ-67-89)	9.55	11.85
D02	5400	U/S D01 Confluence	D02-101-7R	1993	NGVD 29 (BM IJ-67-89)	9.1	11.40
D02	4500	D01 Confluence	D02-101-7R	1993	NGVD 29 (BM IJ-67-89)	8.85	11.15
D02	3791	U/S Brookhurst St	D02-101-7R	1993	NGVD 29 (BM IJ-67-89)	8.3	10.60

* Adjustment from NGVD 29 to NAVD 88 (2.3') used average difference in Orange County (ocpublicworks.com). Actual datum conversions vary with location and adjustment year used on as-built plans.

2.3. TIDAL FLOOD MAPPING RESULTS

The sensitivity of communities to tidal flooding was determined by comparing the extreme water level for each SLR projection with the existing top of levee/seawall/bulkhead elevation. If a projected water level exceeds the estimated top of levee elevation, then flooding can be expected. Flooding limits were mapped using 1-foot contours generated from LiDARdata captured in October 2013.

2.3.1. Huntington Harbour and Bolsa Chica Planning Areas

This analysis was based on a 2-year high water level (7.18 feet NAVD88) combined with the highest SLR predictions for given timeframes; therefore, results are conservative at the specific time horizons. The 2-year water level is slightly higher than a typical King Tide water level. There are no probabilities associated with the highest SLR predictions for the timeframes used in this study, so they may actually occur farther out in the future than indicated herein, if they occur at all. This document is showing possible worst-case scenarios for future planning purposes rather than a probable future condition. The potential for tidal inundation of low-lying communities around Huntington Harbour and Bolsa Chica are mapped in Figure 5 to Figure 7. As expected, areas along Sunset Beach where King Tides currently overtop the Huntington Harbour seawalls will experience the most significant increase in tidal flooding due to SLR. SLR projections in 2050 and 2100 will result in expanded areas of tidal flooding inland of Huntington Harbour and Bolsa Chica.

2030 High Sea Level Rise, 1.0 foot (Figure 5)

- As expected, areas along Sunset Beach where King Tides currently overtop the Huntington Harbour seawalls will experience the most significant increase in flooding due to SLR.
- The Pacific Coast Highway (PCH) would experience tidal flooding for about one mile between Anderson Street and Warner Ave. Tidal flooding would also be expected along low lying portions of PCH along Bolsa Chica State Beach. This flooding would likely result in traffic delays and/or road closures along PCH and portions of Huntington Harbour. Access for emergency service vehicles to the affected areas would be impacted.
- Residential areas along PCH through Sunset Beach and sections of Huntington Harbour would experience tidal flooding.

2050 High Sea Level Rise, 2.0 feet (Figure 6)

- SLR projections in 2050 result in expanded areas of tidal flooding inland of Huntington Harbour and Bolsa Chica Wetlands planning area. High water levels would likely overtop large sections of the seawalls/bulkheads lining Huntington Harbour.
- Significant tidal flooding of residential and commercial properties in and around Huntington Harbour and Sunset Beach would be expected. Based on 2013 LIDAR topography, tidal flooding would extend inland to Algonquin Street between Edinger Avenue and Heil Avenue.
- PCH would be almost completely tidally-flooded from Anderson Street to the main entrance to Bolsa Chica State Beach. Most roads in Huntington Harbour would be periodically under water, as well as portions of Warner Avenue between PCH and Brightwater Drive.
- Based on 2013 LIDAR topography, tidal flooding could overtop the existing levee between the EGGWC and Bolsa Bluffs. The potential tidal flooding zone is shown with a cross-hatch in

Figure 6. Construction planned for the Shea Homes Parkside project includes an improved levee that would eliminate the potential for tidal flooding in this area.

2100 High Sea Level Rise, 5.5 feet (Figure 7)

- Water levels under this scenario would overtop all of the existing seawalls/bulkheads around Huntington Harbour and the existing levees around the Bolsa Chica full tidal basin. Major roads, utilities, and residential, commercial, and public properties would be vulnerable.
- East of Huntington Harbour, tidal flooding would extend beyond Graham Street between Edinger Avenue and Heil Avenue.
- East of Bolsa Chica Wetlands, tidal flooding would approach Gothard Street between the EGGWC levees to the north and higher ground along the Huntington Mesa to the south.
- PCH would be completely tidally flooded from the northern city limit to just south of the south jetty of Bolsa Chica at the south end of Bolsa Chica State Beach.
- Areas shown with a cross hatch in Figure 7 would be removed from the 2100 tidal flooding zone with construction of the levee proposed for the Shea Homes Parkside project.

FIGURE 5
TIDAL FLOODING AT HUNTINGTON HARBOUR AREA – YEAR 2030 SLR (HIGH)

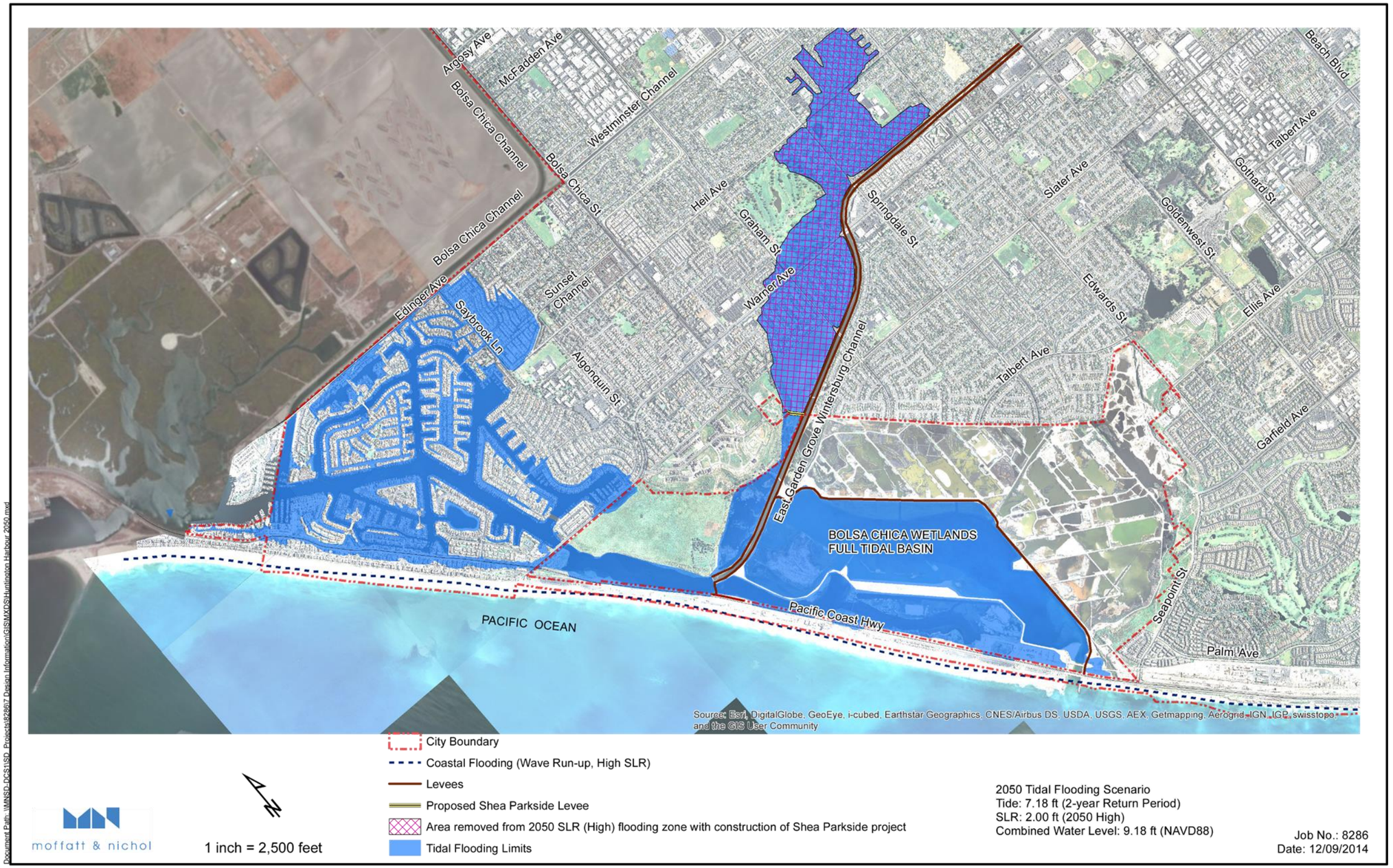


FIGURE 6
TIDAL FLOODING AT HUNTINGTON HARBOUR AREA – YEAR 2050 SLR (HIGH)

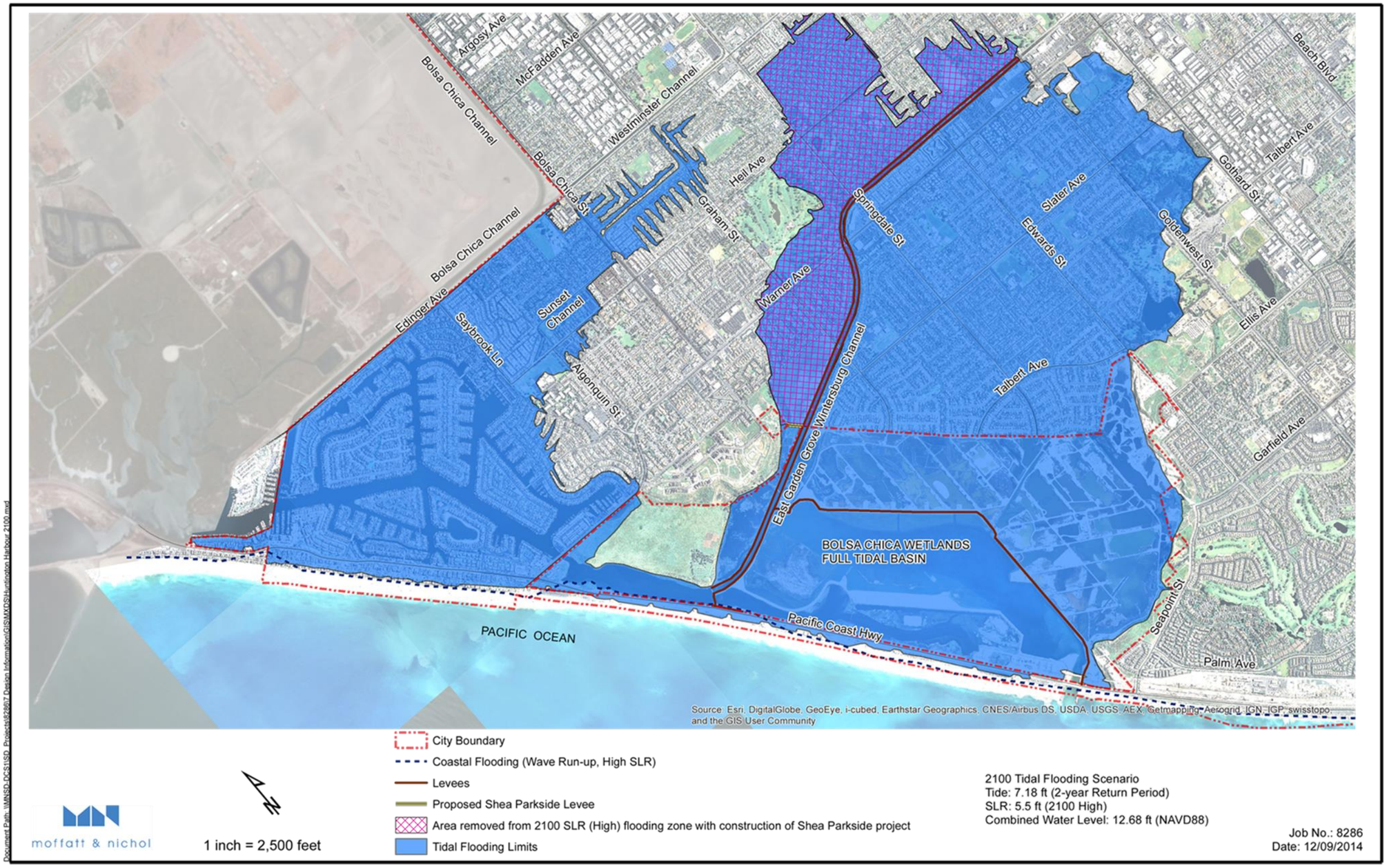


FIGURE 7
TIDAL FLOODING AT HUNTINGTON HARBOUR AREA – YEAR 2100 SLR (HIGH)

2.3.2. Huntington Beach Wetlands Planning Area

The Huntington Beach Wetlands planning area is reliant on a system of levees to protect developed areas from tides and stormwater runoff. The area is predominantly residential and commercial with several high priority facilities including the Orange County Sanitation District (OCSD) Wastewater Treatment Plant and the AES Power Plant.

The potential for tidal flooding of the Huntington Beach Wetlands planning area is mapped in Figure 8 to Figure 11. The potential impacts under each scenario are listed below:

2030 High Sea Level Rise, 1.0 feet (Figure 8)

- Low-lying sections of Brookhurst Street could experience tidal flooding adjacent to the wetlands.
- Tidal inundation under this scenario is mostly confined to the wetlands and flood control channels.
- Potential for direct flooding of public/private infrastructure and property is relatively low.
- Potential impact to pump station infrastructure warrants further evaluation. A facility-specific investigation would be necessary to determine:
    - Performance impact on pumps due to higher tail water elevation;
    - Potential for flow-reversals due to higher tail water elevation;
    - Effect of salt water (corrosion) on mechanical elements; and
    - Buoyancy effects on underground vaults due to higher groundwater levels.

2050 High Sea Level Rise, 2.0 feet (Figure 9)

- Low-lying sections of Brookhurst Street could experience tidal flooding adjacent to the wetlands.
- Majority of planning area remains protected from tidal flooding by existing levee system.
- Potential impact to pump station infrastructure warrants further evaluation. A facility specific investigation would be necessary to determine:
    - Performance impact on pumps due to higher tail water elevation;
    - Potential for flow-reversals due to higher tail water elevation;
    - Effect of salt water (corrosion) on mechanical elements; and
    - Buoyancy effects on underground vaults due to higher groundwater levels.

2100 High Sea Level Rise, 5.5 feet (Figure 11)

- High SLR projections in 2100 will result in overtopping of the existing levee system along the downstream reaches of Talbert Channel and Huntington Beach Channel.
- The existing levee between Talbert Marsh and the OCSD Treatment Plant would be overtopped, causing significant flooding of the facility.

- Overtopping of the existing Talbert Channel levees downstream of Hamilton Ave would result in widespread flooding impacting roads, utilities, and residential, commercial, and public properties. See discussion below regarding extent of potential flooding.

- Potential impact to storm water pump station infrastructure warrants further evaluation. A facility specific investigation would be necessary to determine:

    - Performance impact on pumps due to higher tail water elevation;

    - Potential for flow-reversals due to higher tail water elevation; and

    - Buoyancy effects on underground vaults due to higher groundwater levels.

The potential tidal flooding limits shown in Figure 10 reflects the extent of the planning area that lies below the water level of 12.68 feet (NAVD 88) evaluated for the 2100 high SLR projection. Since the area below this projected water level is so large, the volume of water (not ground elevation) may be the limiting factor of potential flooding.

Theoretically, if there was an endless volume of floodwater due to a levee breach, a higher water level or a combination of the two, this entire area would be subject to flooding. However, if the existing levees remain intact (at their current crest elevation) the duration of overtopping would be relatively short and the extent of flood would be significantly less.

A color banded elevation map, shown in Figure 11, provides an indicator of the general topography of this planning area. Low-lying land along the marshes and lower reaches of Huntington Beach Channel and Talbert Channel would be most vulnerable to tidal flooding for the 2100 high SLR projection. The extents of flooding would progress inland following local topography until the water level subsided or the levees were repaired.

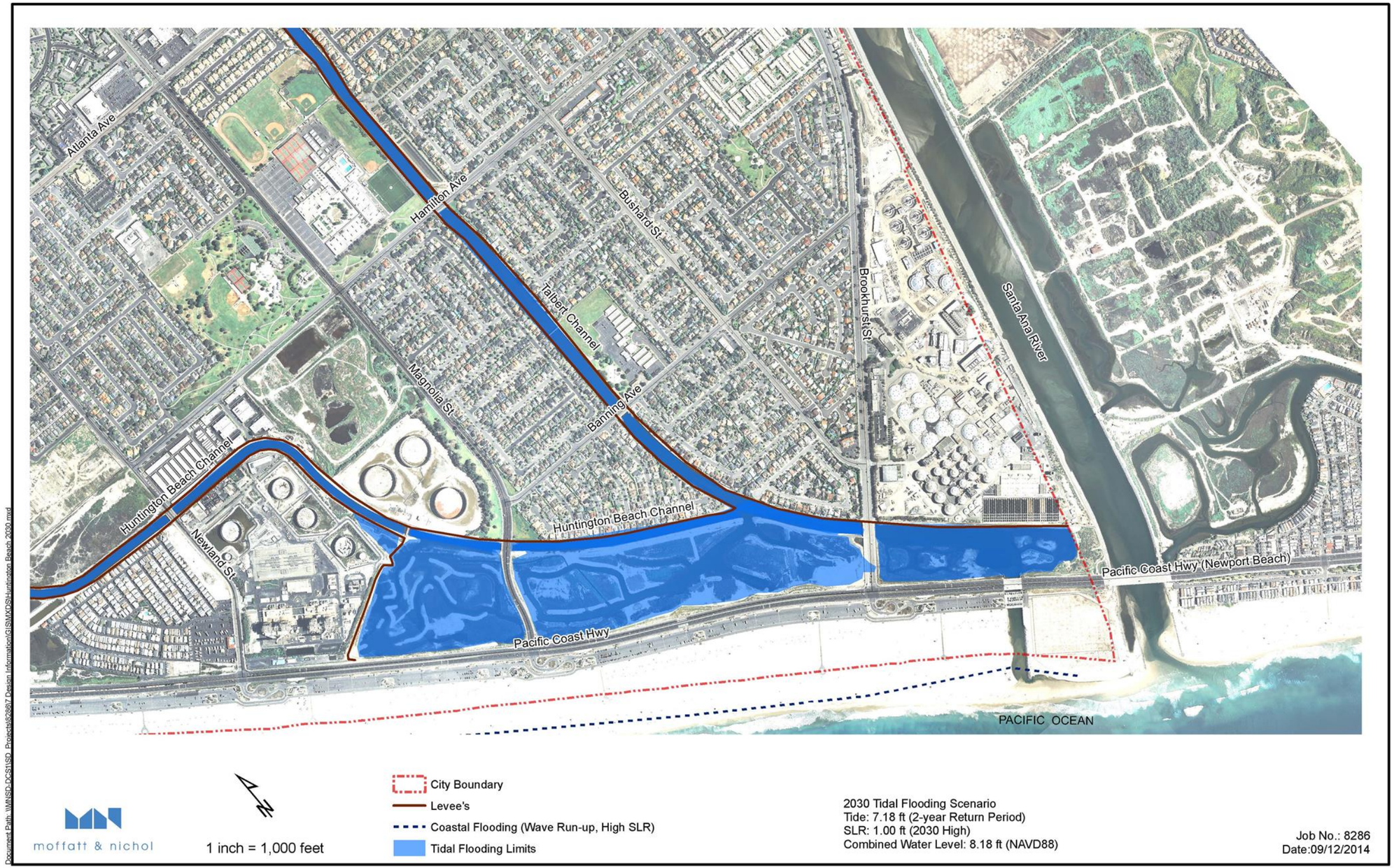


FIGURE 8
TIDAL FLOODING AT HUNTINGTON BEACH WETLANDS AREA – YEAR 2030 SLR (HIGH)

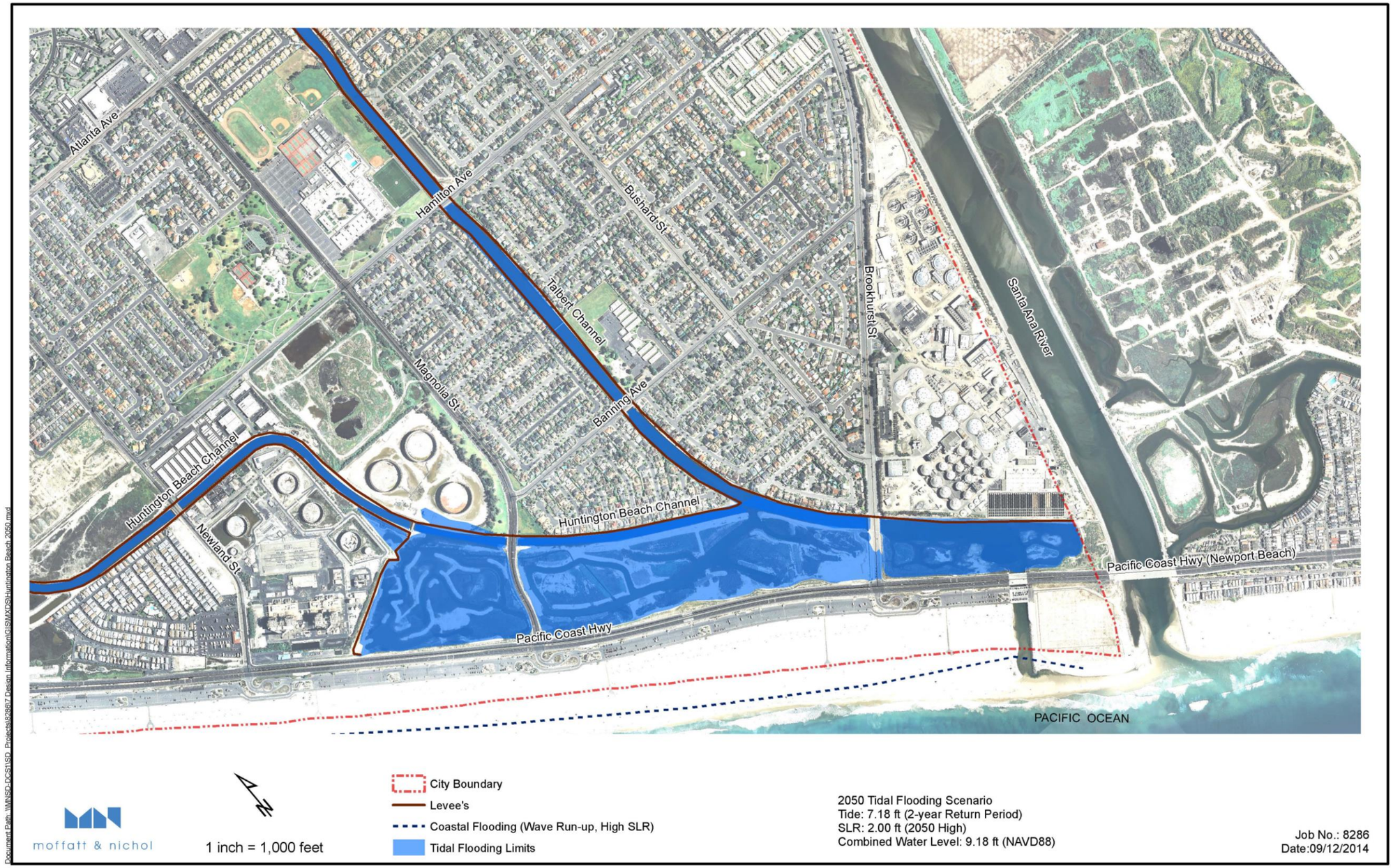


FIGURE 9
TIDAL FLOODING AT HUNTINGTON BEACH WETLANDS AREA – YEAR 2050 SLR (HIGH)

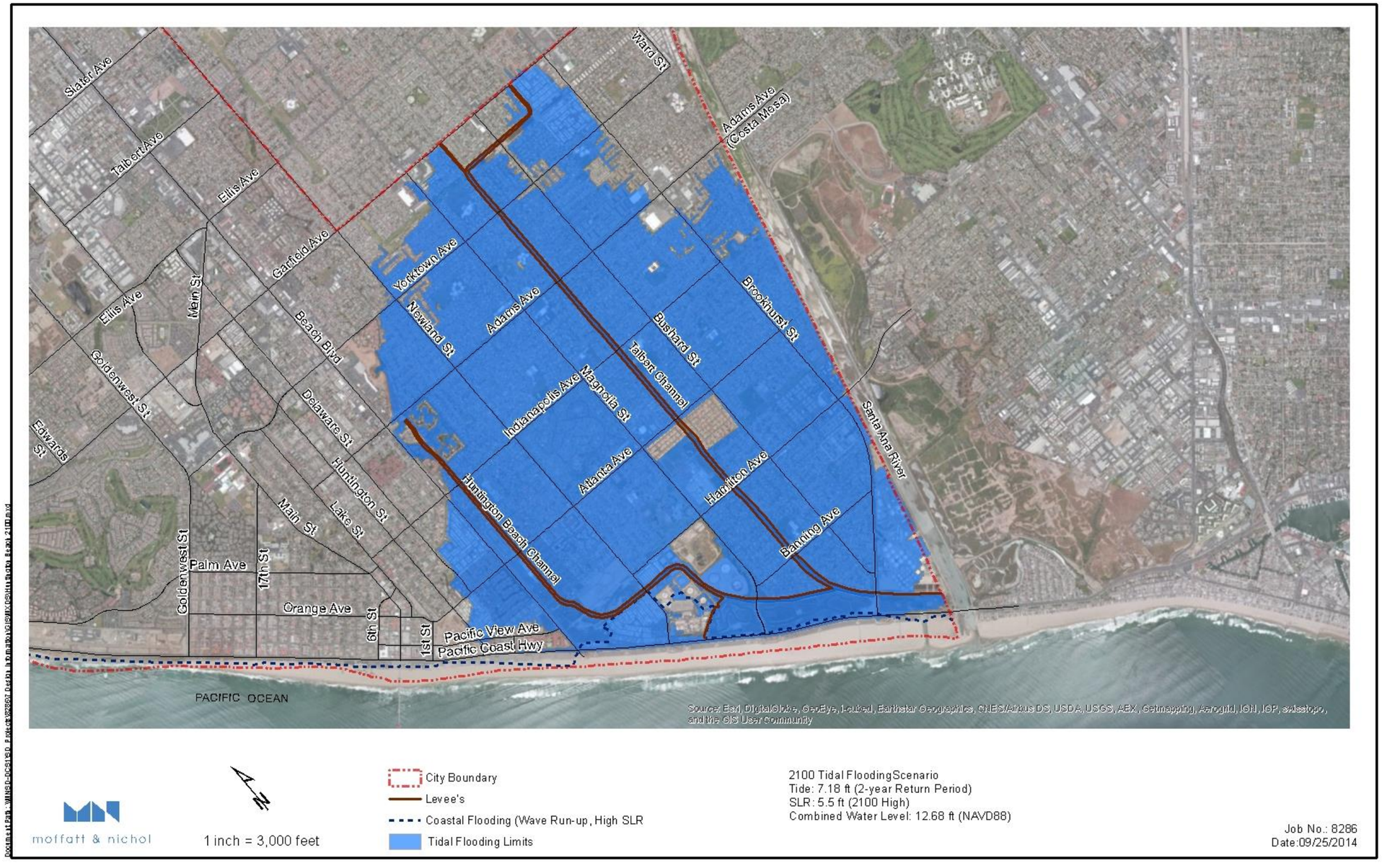
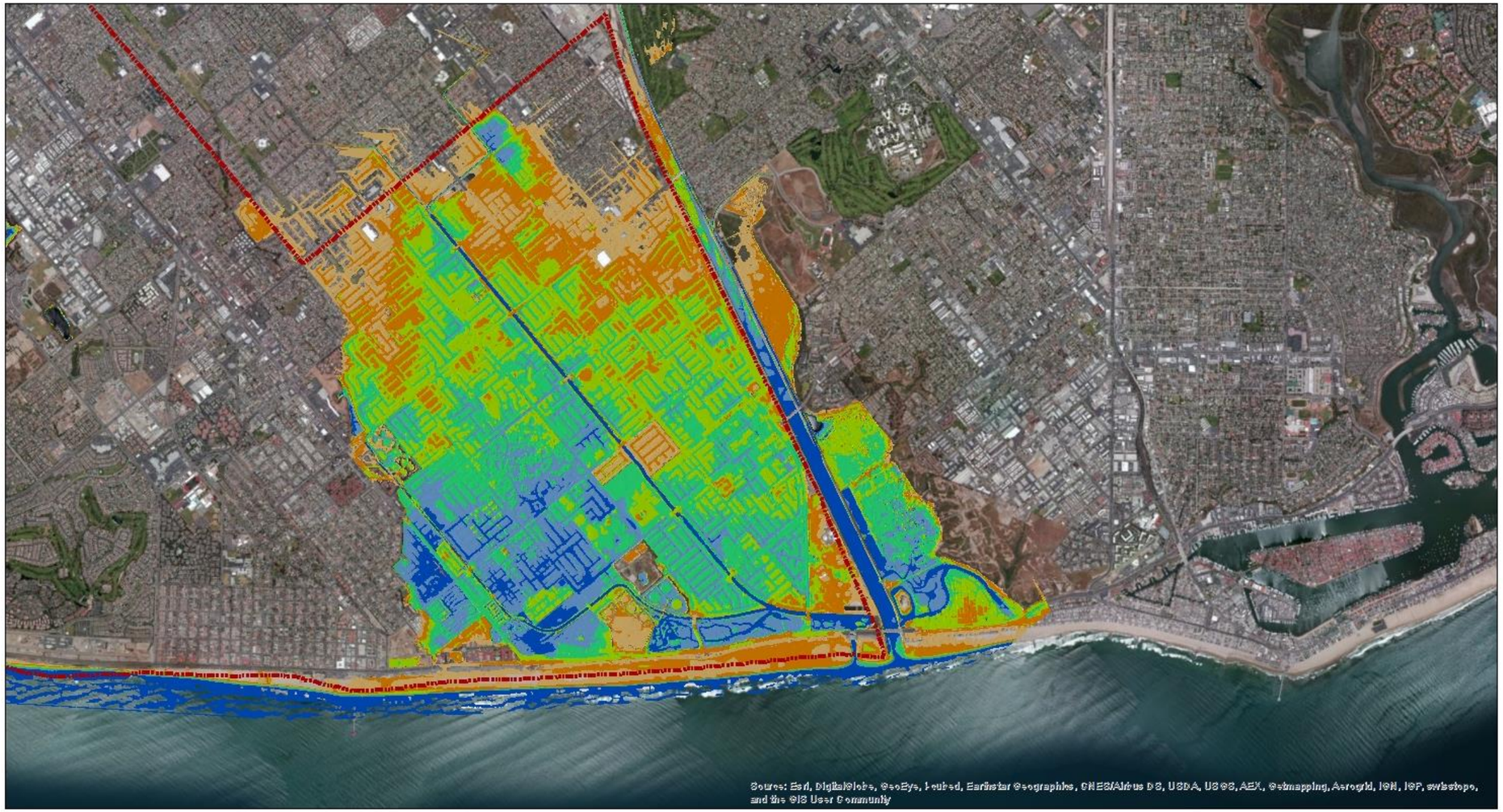


FIGURE 10
TIDAL FLOODING AT HUNTINGTON BEACH WETLANDS AREA – YEAR 2100 SLR (HIGH)



moffatt & nichol

1 inch = 3,000 feet

City Boundary
Elevation shown in color bands
Ground Elevation (Feet, NAVD 88)
- 12 - 14
- 10 - 12
- 8 - 10
- 6 - 8
- 4 - 6
- 2 - 4

Job No.: 8286
Date: 09/26/2014

FIGURE 11
GROUND ELEVATION MAP OF HUNTINGTON BEACH WETLANDS PLANNING AREA

2.4. LIMITATIONS OF TIDAL FLOODING ANALYSIS

The tidal flooding analysis was based on comparing a specific water level with the top elevation of a levee or seawall/bulkhead, where applicable. If the specific water level was higher than the top of the levee/wall, then flooding landward of the barrier was assumed. This method of analysis includes the following limitations:

- Actual top of levee/wall elevations vary: Actual top of wall elevations may vary from what is shown on the as-built plans due to subsidence, settlement, or other factors. Levee elevations determined from LIDAR are accurate to within about ±0.5 feet. Seawall/bulkhead information around Huntington Harbour indicates that the top-of-wall elevation varies from +8 to +10 feet above MLLW (7.8 to 9.8 feet, NAVD 88). Variations in actual top-of-wall elevations would influence both duration and extent of flooding for future SLR scenarios in which overtopping may occur.
- Duration of flooding not included: In some cases the extent of flooding will be limited by the volume of water, not the ground elevations. For example, in situations where the specific water level is only slightly higher than the top of levee/wall flooding will occur over a short period of time during peak high tide. The volume of water overtopping the structure over such a limited duration would likely control the extents of flooding. Since the duration of flooding was not accounted for in this analysis, the extents of flooding shown may be conservative.
- Flow reversal in storm drains not included: Flow reversal through storm drains was not accounted for in this analysis. In situations where sea levels rise significantly, there is potential for backflow through storm drains and catch basins to flood areas protected by levees or seawalls. This may result in flooding of inland areas even if water levels are lower than protecting levee/wall crest elevations.

3. Riverine Flood Modeling

SLR will increase the risk of flooding from extreme rainfall events. Many of the regional flood control channels have low invert elevations, relatively flat slopes, and are controlled at the downstream end by ocean water levels. Numerical modeling of tidal and flood hydraulics was performed to simulate the effects of SLR projections on flood profiles for several major flood control channels in Huntington Beach.

The purpose of this flood modeling was to assess the impact of rising sea levels on the conveyance capacity of the regional flood control channels. The results of this analysis should not be used for estimating base flood elevations or floodplain mapping. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by the Federal Emergency Management Agency (FEMA).

3.1. Model Selection

A 2-D, vertically averaged finite element hydrodynamics model (RMA-2) was used to simulate the tidal and flood hydrodynamics of the Huntington Harbour area and the Huntington Beach wetlands area. RMA-2 is a component of the TABS2 (McAnally and Thomas 1985) modeling system developed by the U.S. Army Corps of Engineers (USACE).

The Huntington Harbour RMA-2 model was based on a previous model developed and calibrated for the Bolsa Chica Restoration project. This model was updated with the most recent geometry, topographic, and bathymetric data available for the harbor area and Bolsa Chica Channel (C02).

The Huntington Beach wetlands RMA-2 model was initially developed to analyze wetland restoration alternatives planned for Magnolia and Brookhurst marshes in south Huntington Beach. This model was refined to reflect an as-built condition of the restored wetlands using data from the as-built plans and recent LIDAR topography (performed in 2013). The model area was expanded to include Huntington Beach Channel (D01), Talbert Channel (D02) and a portion of East Valley-Fountain Valley Channel (D05) within the City limits.

The EGGWC (C05) was modeled using a Water Surface Pressure Gradient (WSPG) model of the ultimate channel configuration developed by Orange County Public Works. WSPG is a steady state model run that assumes a static water surface elevation at the downstream boundary and a constant flow rate in the channel. Water levels from the RMA-2 model of Huntington Harbour were used to establish the downstream starting water surface elevation at the tide gates.

3.2. Boundary conditions

The RMA-2 simulations were run with variable boundary conditions to better represent actual flow conditions in the inland waterways of Huntington Harbour and Huntington Beach Wetlands.

3.2.1. Ocean Boundary

A tide series representative of an average spring high tide was applied at the ocean boundary of each model. The average spring high tide series occurs once to twice per month and, therefore, provides a conservative but reasonable downstream boundary for the flood simulations. The ocean water levels selected for flood modeling are lower than those used for tidal flood mapping because the probability of an extreme flood event coinciding with an extreme high tide event is

low. The peak high tide of the average spring tide series was 6.44 (feet, NAVD88). The entire tide series was increased for each SLR projection, as shown in Table 6.

TABLE 6
PEAK OCEAN WATER LEVELS FOR FLOOD MODELING

SLR Scenario	SLR (ft)	Maximum Water Level (ft, NAVD 88)	Combined Water Level (ft, NAVD 88)
2030 High	1.0	6.44	7.44
2050 High	2.0	6.44	8.44
2100 High	5.5	6.44	11.94

3.2.2. Flood Hydrographs

Flood hydrographs were provided by OCPW for the 100-year storm event for each flood control channel modeled. Hydrographs provided for Bolsa Chica Channel (C02) are from a draft study that has not been finalized, but provides a reasonable estimate of the 100-year discharge. Peak flow rates for the ultimate configuration of the EGGWC (C05) were provided in the WSPG model developed by OCPW. Hydrology for the Talbert Valley channel system was based on design flow rates used for the recent channel improvements that were published in Exhibit KK of the Fountain Valley Channel Diversion Feasibility Report (RBF 1990). The RBF (1990) report provides 100-year peak flow rates for the Huntington Beach Channel (D01), Talbert Channel (D02), and East Valley-Fountain Valley Channel (D05). Where complete hydrographs were not available, a 24-hour pattern hydrograph was scaled to match the peak flow rates.

TABLE 7
100-YEAR PEAK DISCHARGES FOR FLOOD MODELING

Channel	OC Facility ID	100-yr Peak Flow (cfs)	Downstream Boundary Location
Bolsa Chica Channel	C02	11,917	Downstream of C04
EGGWC	C05	9,290	Tide Gates
Huntington Beach Channel	D01	2,315	U/S of D02 Confluence
Talbert Channel	D02	3,325	U/S of D01 Confluence
East Valley-Fountain Valley Channel	D05	1,515	U/S of D02 Confluence

3.3. 100-YEAR STORM EVENT FLOOD MODELING RESULTS

In general, rising sea levels will increase the downstream controlling water surface elevation of flood control channels that discharge into tidally influenced waterways. The effect of a higher downstream water level will be an increase in the water surface profile for a certain distance upstream. Channel reaches influenced by the downstream boundary can expect the risk of flooding to increase with projected SLR. The modeling results for each planning area are provided in the following sections.

3.3.1. Huntington Harbour Planning Area

Bolsa Chica Channel (C02) follows an alignment along Bolsa Chica Street and Edinger Avenue between the City of Huntington Beach and the Naval Weapons Station, Seal Beach. The channel is an earthen trapezoidal channel with some rock slope protection, a relatively flat longitudinal slope and low invert elevations. Adjacent ground is typically at or slightly below the top of channel.

Rising sea levels will increase the downstream controlling water surface elevation, resulting in a higher water surface profile for a certain distance upstream. Huntington Harbour and Bolsa Chica Channel were modeled using a 2-D unsteady state model (RMA-2) to simulate the combined effects of a 100-year storm hydrograph and tidal exchange through the marsh and channel system during an average spring high tide. The limits of the RMA-2 model are shown in Figure 12. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by FEMA and should not be used for purposes of floodplain mapping.

FIGURE 12
HUNTINGTON HARBOUR RMA-2 MODEL BOUNDARY

In general, the results indicate the lower channel reach that parallels Edinger Avenue (downstream of the C04 conflluence) would be most vulnerable to increased flood profiles if sea levels rise as projected through 2050. The model results for the 100-year water surface elevations without SLR (2010) are shown in Figure 13. Model results for high SLR projections in 2030, 2050, and 2100 are shown in Figure 14 through Figure 16.

The model results indicate that 1 foot of SLR (2030 High) would increase water surface elevations in the downstream ~1,500 foot of Bolsa Chica Channel. The increases taper from about 1 foot at the outlet into Huntington Harbour down to about 0.1 foot near the intersection of Edinger Avenue and Saybrook Lane. Upstream of this location no significant increases in water surface elevations would be expected for the 2030 high SLR projection.

A 2-foot rise in sea levels, which corresponds to the high SLR projection in 2050, would increase the 100-year water surface profile from Huntington Harbour to the Westminster Channel (C04) confluence near the intersection of Edinger Avenue and Bolsa Chica Street. An increase in 100-year water surface elevation of about 2 feet at the outlet into Huntington Harbour tapers to about 0.4 foot near the intersection of Saybrook Lane and Edinger Avenue. Upstream of the C02/C04 confluence no significant increases in water surface elevation would be expected for the 2050 high SLR projection.

The projected 2100 high SLR value of 5.5 feet would significantly reduce the conveyance capacity of the existing Bolsa Chica Channel. An increase in 100-year water surface elevation of over 5.5 feet at the outlet into Huntington Harbour tapers to 2.5-foot increase near the intersection of Saybrook Lane and Edinger Avenue. Model results indicate a 1 foot increase in water surface elevation from the C02/C04 confluence upstream to the C02/C03 confluence for the 2100 high SLR projection.

3.3.2. Bolsa Chica Planning Area

A Water Surface Pressure Gradient (WSPG) model of the ultimate EGGWC channel configuration, developed by OCPW, was used to evaluate the changes in 100-year flood profiles for various SLR scenarios. The model represents the ultimate EGGWC configuration, in which several reaches of the channel are improved from their existing conditions. Therefore, water surface elevations are not representative of the existing flood risk along the EGGWC. The model results of the ultimate channel configuration without SLR (2010) are shown in Figure 13. Model results for high SLR projections in 2030, 2050 and 2100 are shown in Figure 14 through Figure 16.

The results indicate that 1 foot of SLR (2030 High) would increase water surface elevations at Graham Street by about 0.5 ft. The changes to the water surface profile taper off to 0.1 foot upstream of Goldenwest Street.

A 2-foot increase in water surface elevation at the downstream tide gates corresponds to high SLR projections in 2050. This scenario has a more significant impact on the flood profile with increases on 1 foot at Graham Street and 0.5 ft at Edwards Street. The flood profile increases taper off to 0.1 foot upstream of Gothard Street.

The projected 2100 high SLR value of 5.5 feet results has a significant impact to the EGGWC flood profiles. The 100-year flood profile increases by more than 3 feet downstream of Goldenwest Street under the 2100 high SLR scenario. Upstream of Goldenwest Street, the flood profile

increases by more than 5 feet due to head loss through the culvert. Under this scenario, a 100-year storm event would exceed the channel capacity as far upstream as Gothard Street.

In general, the EGGWC modeling results suggest that SLR projections of 2 feet or less would result in a higher flood profile downstream of Gothard Street and less freeboard available above the 100-year water surface elevations. A 2-foot rise in sea level would result in about a 1-foot increase in water surface elevations between Graham Street and Gothard Street.

Higher SLR projections will have significant impacts on the 100-year flood profile in the EGGWC. For the high SLR projection of 5.5 feet in 2100, there would be insufficient capacity to convey the 100-year flood for most of the channel reach downstream of Beach Blvd. Under this SLR scenario additional improvements would be required in the future to convey the 100-year flood within the EGGWC or some potential for overtopping will exist along portions of the channel.

Bolsa Chica Channel (4-16)			
Station #	Top of Levee Elev (ft NAVD 88)	100 yr WSE (2010 no SLR)	Freeboard (ft)
4	9.5	6.33	3.17
5	13.75	5.89	7.86
6	12.7	8.52	4.18
7	12.9	9.99	2.91
8	14.25	11.75	2.50
9	15	12.63	2.37
10	14.5	13.62	0.88
11	15.25	13.90	1.35
12	15.75	14.03	1.72
13	16.4	14.23	2.17
14	17	14.41	2.59
15	19	14.82	4.18
16	19	15.72	3.28

Top of levee elevations based on LiDAR topography along levee adjacent to Bolsa Chica Street and Edinger Avenue.

East Garden Grove Wintersburg Channel-C05 (1-40)			
Station #	Top of Wall Elev (ft NAVD 88)	100 yr WSE (2010 no SLR)	Freeboard (ft)
1	11.05	6.44	4.61
2	12.89	8.26	4.64
3	13.90	9.36	4.54
4	13.52	9.36	4.15
5	13.80	10.42	3.39
6	13.90	10.73	3.17
7	13.94	11.13	2.81
8	14.33	11.31	3.02
9	14.33	11.22	3.11
10	14.34	11.57	2.77
11	14.44	12.13	2.32
12	14.51	12.27	2.25
13	15.77	12.68	3.09
14	15.84	12.07	3.77
15	16.72	11.67	5.05
16	16.72	12.10	4.62
17	16.74	12.77	3.97
18	16.79	14.56	2.23
19	18.20	15.29	2.92
20	18.23	14.57	3.66
21	18.31	15.13	3.18
22	18.31	14.98	3.33
23	18.66	15.20	3.46
24	18.66	14.88	3.78
25	19.53	14.79	4.73
26	19.53	12.40	7.13
27	20.01	14.25	5.76
28	20.02	16.18	3.84
29	20.02	14.74	5.27
30	20.60	17.89	2.71
31	26.91	20.00	6.92
32	26.91	18.71	8.21
33	25.64	21.65	3.99
34	25.64	22.63	3.01
35	28.15	24.35	3.80
36	28.47	23.45	5.03
37	28.47	22.13	6.34
38	28.51	25.38	3.14
39	28.51	24.27	4.24
40	29.88	26.39	3.49

moffatt & nichol

1 inch = 3,500 feet

C02 Output Location (No SLR)
C05 Output Location (No SLR)
Orange County Flood Control Channels
Channel Drainage Area Boundary
City Boundary

Note: The purpose of this flood modeling was to assess the impact of rising sea levels on the conveyance capacity of the regional flood control channels. The results of this analysis should not be used for estimating base flood elevations or floodplain mapping. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by the Federal Emergency Management Agency (FEMA).

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FIGURE 13
BOLSA CHICA CHANNEL & EGGWC MODEL RESULTS – 100-YEAR FLOOD WITHOUT SLR

Bolsa Chica Channel (4-16)			
Station #	Top of Levee Elev (ft NAVD 88)	100-yr WSE (2030 high SLR)	Freeboard (ft)
4	9.5	7.36	2.14
5	13.75	6.93	6.82
6	12.7	8.78	3.92
7	12.9	10.13	2.77
8	14.25	11.83	2.42
9	15	12.69	2.31
10	14.5	13.67	0.83
11	15.25	13.95	1.30
12	15.75	14.08	1.67
13	16.4	14.27	2.13
14	17	14.45	2.55
15	19	14.85	4.15
16	19	15.74	3.26

Top of levee elevations based on LiDAR topography along levee adjacent to Bolsa Chica Street and Edinger Avenue.

East Garden Grove Wintersburg Channel-C05 (1-40)			
Station #	Top of Wall Elev (ft NAVD 88)	100 yr WSE (2030 High SLR)	Freeboard (ft)
1	11.05	7.44	3.61
2	12.89	8.84	4.05
3	13.90	9.78	4.12
4	13.52	13.14	0.38
5	13.80	10.73	3.08
6	13.90	11.12	2.79
7	13.94	11.48	2.47
8	14.33	11.61	2.72
9	14.33	11.77	2.56
10	14.34	12.01	2.33
11	14.44	12.50	1.94
12	14.51	12.64	1.88
13	15.77	13.02	2.75
14	15.84	12.45	3.39
15	16.72	12.45	4.26
16	16.72	12.14	4.58
17	16.74	13.01	3.73
18	16.79	14.68	2.11
19	18.20	15.39	2.82
20	18.23	14.69	3.54
21	18.31	15.22	3.09
22	18.31	15.08	3.23
23	18.66	15.30	3.36
24	18.66	14.99	3.67
25	19.53	14.87	4.73
26	19.53	12.46	7.13
27	20.01	14.25	5.76
28	20.02	16.18	3.84
29	20.02	14.74	5.27
30	20.60	17.89	2.71
31	26.91	20.00	6.92
32	26.91	18.71	8.21
33	25.64	22.63	3.01
34	25.64	21.65	3.99
35	28.15	24.35	3.80
36	28.47	23.45	5.03
37	28.47	22.13	6.34
38	28.51	25.38	3.14
39	28.51	24.27	4.24
40	29.88	26.39	3.49

moffatt & nichol

1 inch = 3,500 feet

C02 Ouput Location (High SLR 2030)
C05 Output Location (High SLR 2030)
Orange County Flood Control Channels
Channel Drainage Area Boundary
City Boundary

Note: The purpose of this flood modeling was to assess the impact of rising sea levels on the conveyance capacity of the regional flood control channels. The results of this analysis should not be used for estimating base flood elevations or floodplain mapping. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by the Federal Emergency Management Agency (FEMA).

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FIGURE 14
BOLSA CHICA CHANNEL & EGGWC MODEL RESULTS – 100-YEAR FLOOD WITH 2030 HIGH SLR

Bolsa Chica Channel (4-16)			
Station #	Top of Levee Elev (ft NAVD 88)	100-yr WSE (2050 High SLR)	Freeboard (ft)
4	9.5	8.38	1.12
5	13.75	7.97	5.78
6	12.7	9.26	3.44
7	12.9	10.39	2.51
8	14.25	11.98	2.28
9	15	12.81	2.19
10	14.5	13.76	0.74
11	15.25	14.04	1.21
12	15.75	14.16	1.59
13	16.4	14.36	2.04
14	17	14.53	2.47
15	19	14.92	4.08
16	19	15.79	3.21

Top of levee elevations based on LiDAR topography along levee adjacent to Bolsa Chica Street and Edinger Avenue.

East Garden Grove Wintersburg Channel-C05 (1-40)			
Station #	Top of Wall Elev (ft NAVD 88)	100 yr WSE (2050 High SLR)	Freeboard (ft)
1	11.05	8.44	2.61
2	12.89	9.54	3.36
3	13.90	13.67	0.23
4	13.52	13.67	-0.15
5	13.80	14.14	-0.33
6	13.90	11.61	2.29
7	13.94	11.93	2.01
8	14.33	12.32	2.02
9	14.33	12.07	2.27
10	14.34	12.53	1.80
11	14.44	12.96	1.48
12	14.51	15.38	-0.86
13	15.77	14.47	1.30
14	15.84	13.88	1.96
15	16.72	12.65	4.07
16	16.72	12.89	3.83
17	16.74	13.35	3.40
18	16.79	14.87	1.92
19	18.20	15.55	2.66
20	18.23	14.88	3.35
21	18.31	15.15	3.16
22	18.31	15.24	3.07
23	18.66	15.44	3.22
24	18.66	15.15	3.51
25	19.71	15.00	4.71
26	19.71	12.56	7.15
27	20.01	14.25	5.76
28	20.02	16.18	3.84
29	20.02	14.74	5.27
30	20.60	17.89	2.71
31	26.91	20.00	6.92
32	26.91	18.71	8.21
33	25.64	22.63	3.01
34	25.64	21.65	3.99
35	28.15	24.35	3.80
36	28.47	23.45	5.03
37	28.47	22.13	6.34
38	28.51	25.38	3.14
39	28.51	24.27	4.24
40	29.88	26.39	3.49

moffatt & nichol

1 inch = 3,500 feet

C02 Output Location (High SLR 2050)
C05 Output Location (High SLR 2050)
Orange County Flood Control Channels
Channel Drainage Area Boundary
City Boundary

Note: The purpose of this flood modeling was to assess the impact of rising sea levels on the conveyance capacity of the regional flood control channels. The results of this analysis should not be used for estimating base flood elevations or floodplain mapping. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by the Federal Emergency Management Agency (FEMA).

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FIGURE 15
BOLSA CHICA CHANNEL & EGGWC MODEL RESULTS – 100-YEAR FLOOD WITH 2050 HIGH SLR

Bolsa Chica Channel (4-16)			
Station #	Top of Levee Elev (ft NAVD 88)	100-yr WSE (2100 High SLR)	Freeboard (ft)
4	9.5	11.94	-2.44
5	13.75	11.60	2.15
6	12.7	12.02	0.68
7	12.9	12.48	0.42
8	14.25	13.38	0.87
9	15	13.95	1.05
10	14.5	14.73	-0.23
11	15.25	14.97	0.28
12	15.75	15.06	0.69
13	16.4	15.22	1.18
14	17	15.35	1.65
15	19	15.65	3.35
16	19	16.33	2.67

Top of levee elevations based on LiDAR topography along levee adjacent to Bolsa Chica Street and Edinger Avenue.

East Garden Grove Wintersburg Channel-C05 (1-38)			
Station #	Top of Wall Elev (ft NAVD 88)	100 yr WSE (2100 High SLR)	Freeboard (ft)
1	11.05	11.94	-0.89
2	12.89	12.44	0.45
3	13.90	12.82	1.08
4	13.52	13.04	0.48
5	13.80	13.45	0.36
6	13.90	14.23	-0.33
7	13.94	14.41	-0.47
8	14.33	15.13	-0.79
9	14.33	14.55	-0.21
10	14.34	15.26	-0.93
11	14.44	15.49	-1.05
12	14.51	15.59	-1.07
13	15.77	15.81	-0.04
14	15.84	15.46	0.38
15	16.72	15.39	1.33
16	16.72	15.39	1.33
17	16.74	18.49	-1.75
18	16.79	19.06	-2.27
19	18.20	19.34	-1.14
20	18.23	19.02	-0.80
21	18.31	19.18	-0.87
22	18.31	19.18	-0.87
23	18.66	20.89	-2.24
24	18.66	19.29	-0.63
25	20.01	20.82	-0.81
26	20.02	21.71	-1.70
27	20.02	20.84	-0.82
28	20.60	22.29	-1.69
29	26.91	22.23	4.68
30	26.91	22.54	4.37
31	25.64	23.31	2.33
32	25.64	22.69	2.95
33	28.15	24.60	3.55
34	28.47	24.07	4.40
35	28.47	24.84	3.63
36	28.51	25.47	3.04
37	28.51	24.47	4.04
38	29.88	26.45	3.43

moffatt & nichol

1 inch = 3,500 feet

- C02 Output Location (High SLR 2100)
- C05 Output Location (High SLR 2100)
- Orange County Flood Control Channels
- Channel Drainage Area Boundary
- City Boundary

Note: The purpose of this flood modeling was to assess the impact of rising sea levels on the conveyance capacity of the regional flood control channels. The results of this analysis should not be used for estimating base flood elevations or floodplain mapping. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by the Federal Emergency Management Agency (FEMA).

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FIGURE 16
BOLSA CHICA CHANNEL & EGGWC MODEL RESULTS – 100-YEAR FLOOD WITH 2100 HIGH SLR

3.3.3. Huntington Beach Wetlands Planning Area

The Huntington Beach Channel (D01) and Talbert Channel (D02) are recently improved flood control channels that consist of sheetpile walls and a natural bottom along the lower channel reaches. Both channels have a relatively flat longitudinal slope and low invert elevations. Adjacent ground is typically lower than the flood levels, resulting in a levee condition for most of this planning area. Rising sea levels will increase the downstream controlling water surface elevation, resulting in a higher water surface profile for a certain distance upstream. The upstream extent of these impacts was evaluated for high SLR projections in 2030, 2050 and 2100. These channels were modeled using a 2-D unsteady state model (RMA-2) to simulate the combined effects of a 100-year storm hydrograph and tidal exchange through the marsh and D01 and D02 channel systems (Figure 18) during an average spring high tide. The limits of the RMA-2 model are shown in Figure 17. The model bathymetry used to represent the Huntington Beach wetlands is shown in Figure 18.

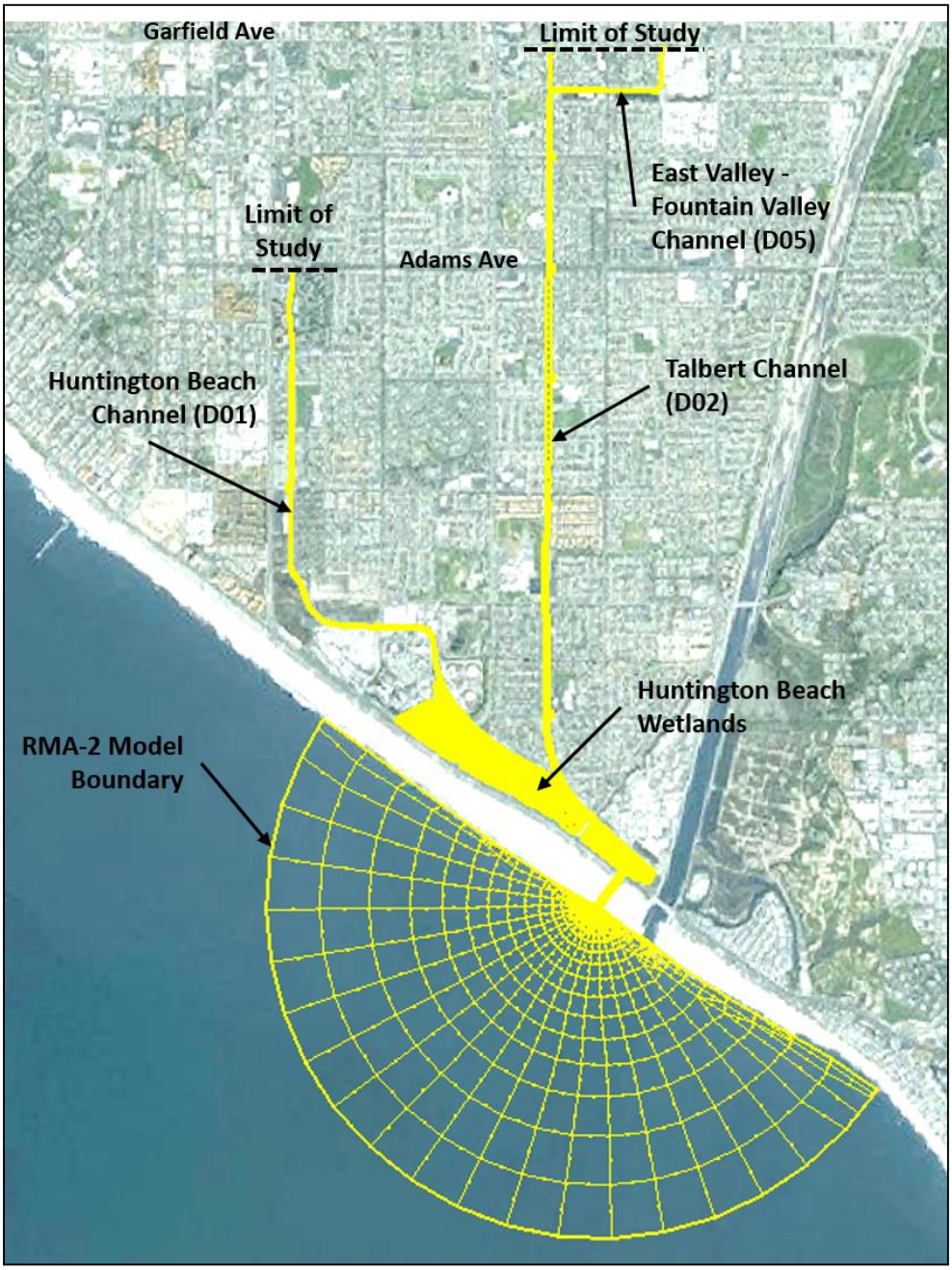


FIGURE 17
HUNTINGTON BEACH WETLANDS RMA-2 MODEL BOUNDARY

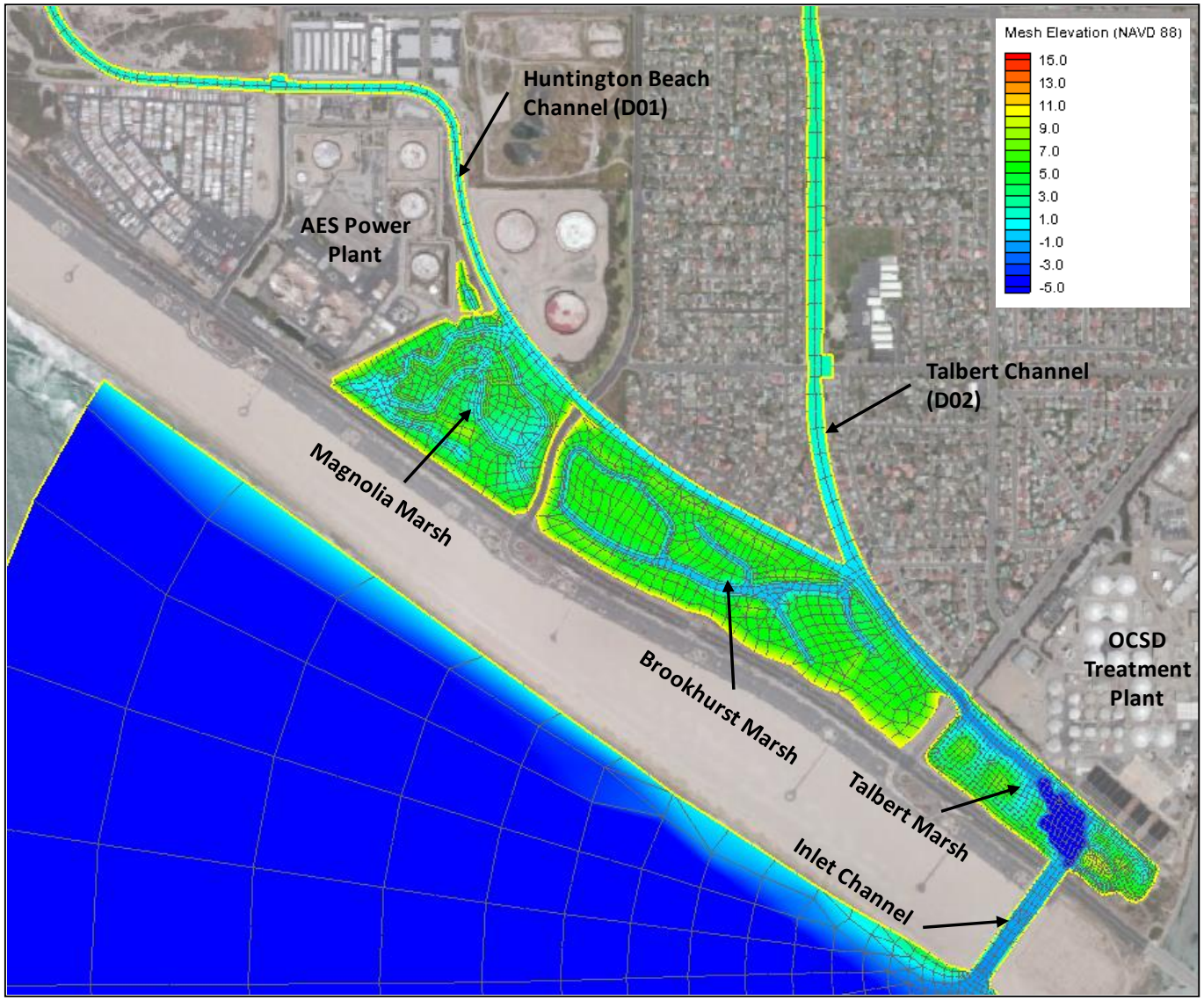


FIGURE 18
HUNTINGTON BEACH WETLANDS – RMA-2 MODEL BATHYMETRY

Huntington Beach Channel (D01)

The RMA-2 model assumes a uniform rectangular open channel upstream of Magnolia Marsh to Adams Avenue. The model does not account for the culverts and bridge decks at each road crossing, which can significantly influence water surface profiles, especially at Indianapolis and Atlanta Avenues where the soffit is 5 to 6 feet lower than the top of channel wall. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by FEMA and should not be used for purposes of floodplain mapping.

The model results for the current time horizon (without SLR) are shown in Figure 18. The water surface elevations are higher than existing soffit elevations at Newland Street and each road crossing upstream even without consideration for SLR. Pressure flow will result in additional head loss through these culverts resulting in higher water surface elevations than shown in Figure 18.

The model results for the 2030 high SLR projection (1 foot of SLR) and the 100-year discharge for D01 indicate that water surface elevations would increase by about 0.6 foot at Magnolia Street and 0.4 foot at Adams Avenue. The reach-averaged increase in water surface elevation is about 0.5 foot. Model results of this scenario indicate the 100-year flood would be conveyed within the channel, but with less freeboard. Results for the 2030 high SLR projection are shown in Figure 20. If the culverts remain in their existing condition, the water surface elevations will be higher than shown in Figure 20 due to additional head loss through the road crossings.

A 2-foot rise in sea level (2050 High) has a more significant impact on the flood profile with a reach-averaged increase of about 1 foot compared to the 2010 (no SLR) results. Results indicate the 100-year flood profile remains below the top of channel with freeboard ranging from 2-3 feet upstream of Magnolia Street to Adams Avenue. Results for the 2050 high SLR projection are shown in Figure 21. If the culverts remain in their existing condition, the water surface elevations will be higher than shown in Figure 21 due to additional head loss through the road crossings.

The projected 2100 high SLR value of 5.5 feet would significantly reduce the conveyance capacity of the existing Huntington Beach channel. The flood profile upstream of Magnolia Street to Adams Avenue would increase by an average of nearly 4 feet compared to the 2010 (no SLR) results. Model results indicate overtopping of the channel would occur downstream of Atlanta Avenue during a 100-year flood with 5.5 feet of SLR. Under this SLR scenario, additional improvements would be required to convey the 100-year flood within the channel walls. Results for the 2100 high SLR projection are shown in Figure 22. If the culverts remain in their existing condition, the water surface elevations will be higher than shown in Figure 22 due to additional head loss through the road crossings.

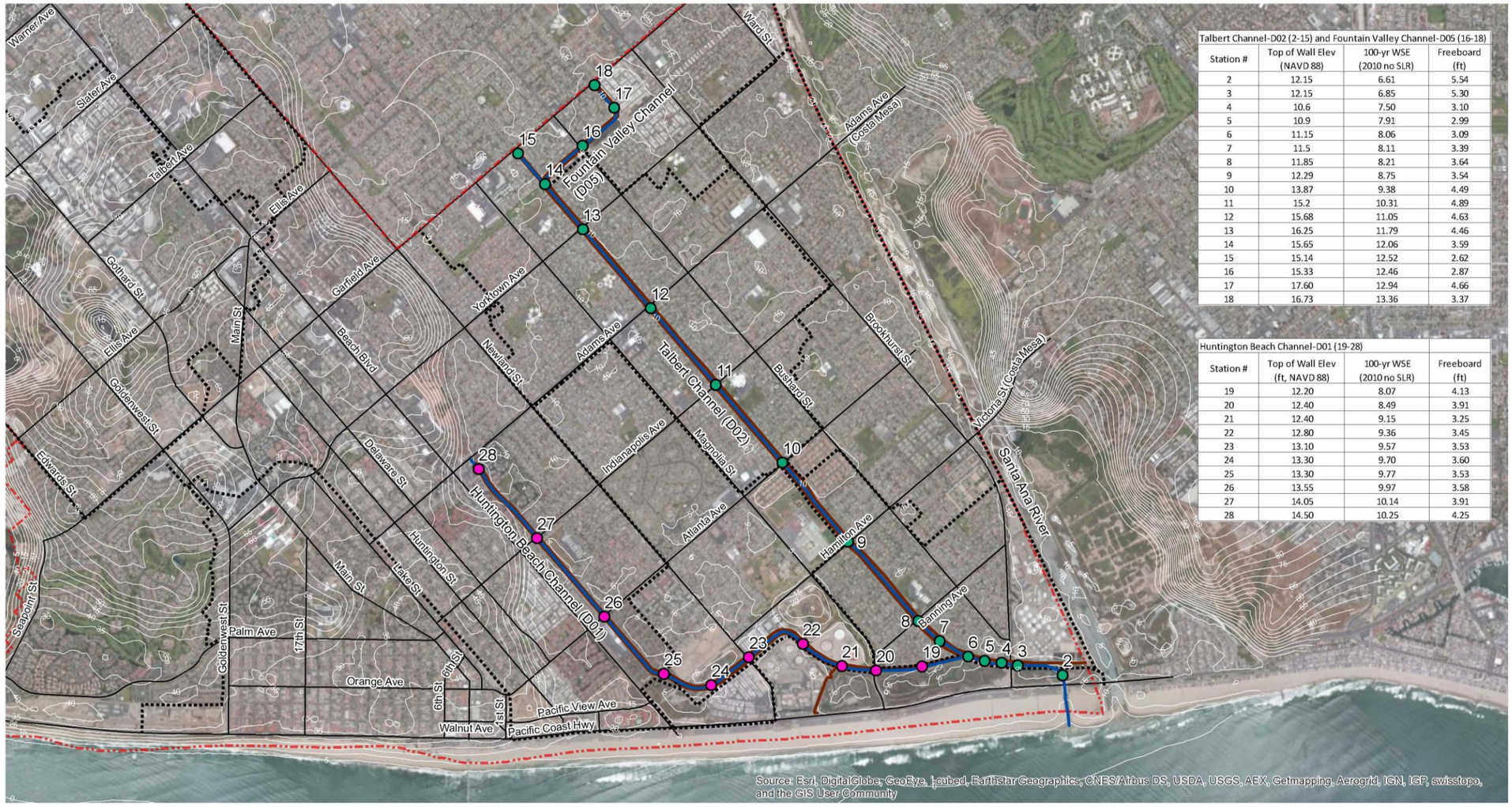
Talbert Channel (D02) and East Valley-Fountain Valley Channel (D05)

The RMA-2 model assumes a uniform rectangular open channel upstream of Brookhurst Marsh to Garfield Avenue. The model results for the current time horizon (without SLR) are shown in Figure 19. The model does not account for the culverts and bridge decks at each road crossing, which can significantly influence water surface profiles, especially for high projections of SLR. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by FEMA and should not be used for purposes of floodplain mapping.

The model results for the 2030 high SLR projection (1 foot of SLR) indicate that water surface elevations would increase by about 1 feet at Brookhurst Street and about 0.7 foot at the confluence of D01 and D02 when compared to the 2010 (no SLR) water surface profile. The water surface profile increase tapers to 0.5 foot at Hamilton Avenue and 0.1 foot at Adams Avenue. Model results of this scenario indicate the 100-year flood would be conveyed within the channel, but with reduced freeboard in the downstream reach. Results for the 2030 high SLR projection are shown in Figure 20. The water surface profile is slightly below the existing soffit elevations at each culvert under this scenario.

A 2-foot rise in sea level (2050 High) results in an increased water surface profile extending further upstream. A 2-foot rise in water surface elevation in the marsh area tapers to an increase of 1.5 feet at the D01/D02 confluence when compared to 2010 (no SLR) results. Water surface profile increases of greater than 1 foot can be expected downstream of Atlanta Avenue for the 2050 High SLR projection. Model results indicate the 100-year flood would be conveyed within the channel but with less than 2 feet of freeboard along sections of the downstream channel. Results for the 2050 high SLR projection are shown in Figure 21. Under this scenario the water surface elevations are higher than most existing soffit elevations upstream of Banning Avenue. Pressure flow may develop resulting in additional head loss through these culverts and higher water surface elevations than shown in Figure 21.

The projected high SLR value of 5.5 feet in 2100 would significantly impact the conveyance capacity of the existing Talbert Channel (D02) and East Valley-Fountain Valley Channel (D05). The flood profile downstream of Hamilton Avenue would increase by more than 4 feet compared to the 2010 (no SLR) results. With 5.5 feet of SLR, overtopping of the channel would occur downstream of Atlanta Avenue during a 100-year flood. Under this SLR scenario, additional improvements would be required to convey the 100-year flood within the channel walls. Results for the 2100 high SLR projection are shown in Figure 22. Under this scenario the water surface elevations are higher than most existing soffit elevations upstream of Brookhurst Street. Pressure flow will result in additional head loss through these culverts and higher water surface elevations than shown in Figure 22.



Talbert Channel-D02 (2-15) and Fountain Valley Channel-D05 (16-18)			
Station #	Top of Wall Elev (NAVD 88)	100-yr WSE (2010 no SLR)	Freeboard (ft)
2	12.15	6.61	5.54
3	12.15	6.85	5.30
4	10.6	7.50	3.10
5	10.9	7.91	2.99
6	11.15	8.06	3.09
7	11.5	8.11	3.39
8	11.85	8.21	3.64
9	12.29	8.75	3.54
10	13.87	9.38	4.49
11	15.2	10.31	4.89
12	15.68	11.05	4.63
13	16.25	11.79	4.46
14	15.65	12.06	3.59
15	15.14	12.52	2.62
16	15.33	12.46	2.87
17	17.60	12.94	4.66
18	16.73	13.36	3.37

Huntington Beach Channel-D01 (19-28)			
Station #	Top of Wall Elev (ft, NAVD 88)	100-yr WSE (2010 no SLR)	Freeboard (ft)
19	12.20	8.07	4.13
20	12.40	8.49	3.91
21	12.40	9.15	3.25
22	12.80	9.36	3.45
23	13.10	9.57	3.53
24	13.30	9.70	3.60
25	13.30	9.77	3.53
26	13.55	9.97	3.58
27	14.05	10.14	3.91
28	14.50	10.25	4.25

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1 inch = 3,000 feet

D01 Output Location
D02/D05 Output Location
Orange County Flood Control Channels
Channel Drainage Area Boundary
Levee's
City Boundary

Note: The purpose of this flood modeling was to assess the impact of rising sea levels on the conveyance capacity of the regional flood control channels. The results of this analysis should not be used for estimating base flood elevations or floodplain mapping. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by the Federal Emergency Management Agency (FEMA).

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FIGURE 19
HUNTINGTON BEACH WETLANDS MODEL RESULTS – 100-YEAR FLOOD WITHOUT SLR

FIGURE 20
HUNTINGTON BEACH WETLANDS MODEL RESULTS – 100-YEAR FLOOD WITH 2030 HIGH SLR

Talbert Channel-D02 (2-15) and Fountain Valley Channel-D05 (16-18)			
Station #	Top of Wall Elev (NAVD 88)	100-yr WSE (2050 High SLR)	Freeboard (ft)
2	12.15	8.69	3.46
3	12.15	8.73	3.42
4	10.6	9.13	1.47
5	10.9	9.43	1.47
6	11.15	9.51	1.64
7	11.5	9.53	1.97
8	11.85	9.58	2.27
9	12.29	9.89	2.40
10	13.87	10.25	3.62
11	15.2	10.90	4.30
12	15.68	11.48	4.20
13	16.25	12.10	4.15
14	15.65	12.33	3.32
15	15.14	12.74	2.40
16	15.33	12.69	2.64
17	17.60	13.11	4.49
18	16.73	13.48	3.25

Huntington Beach Channel-D01 (19-28)			
Station #	Top of Wall Elev (ft, NAVD 88)	100-yr WSE (2050 High SLR)	Freeboard (ft)
19	12.20	9.49	2.71
20	12.40	9.83	2.58
21	12.40	10.39	2.02
22	12.80	10.55	2.25
23	13.10	10.71	2.39
24	13.30	10.81	2.49
25	13.30	10.86	2.44
26	13.55	11.01	2.54
27	14.05	11.15	2.90
28	14.50	11.22	3.28

moffatt & nichol

1 inch = 3,000 feet

- D01 Output Location
- D02/D05 Output Location
- Orange County Flood Control Channel
- Channel Drainage Area Boundary
- Levee's
- City Boundary

Note: The purpose of this flood modeling was to assess the impact of rising sea levels on the conveyance capacity of the regional flood control channels. The results of this analysis should not be used for estimating base flood elevations or floodplain mapping. Because of the different models, methods, and assumptions used in this analysis, the results are not comparable to base flood elevations determined by the Federal Emergency Management Agency (FEMA).

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FIGURE 21
HUNTINGTON BEACH WETLANDS MODEL RESULTS – 100-YEAR FLOOD WITH 2050 HIGH SLR

FIGURE 22
HUNTINGTON BEACH WETLANDS MODEL RESULTS – 100-YEAR FLOOD WITH 2100 HIGH SLR

3.4. LIMITATIONS OF FLOOD MODELING

The purpose of flood modeling was to determine the relative impact of SLR on the conveyance capacity of regional flood control channels. The numerical models used and methods applied include the following limitations:

- Culverts not included in RMA-2 models: The models developed for the Huntington Beach Wetlands area did not account for bridge crossings over the Huntington Beach Channel (D01), Talbert Channel (D02), and East Valley-Fountain Valley Channel (D05). These channels were assumed to be open rectangular channels in which the water surface elevations are not obstructed by the bridge decks. If water surface elevations are higher than existing soffit elevations, pressure flow may result in additional head loss through the culverts and higher water surface elevations. Because of this limitation, the model results may underestimate water surface elevations along these channels.
- EGGWC (C05) model run in steady state: Due to WSPG model limitations, the EGGWC was modeled with a fixed downstream boundary and fixed flow rate. In reality, the downstream boundary water surface elevation and flow rate in the channel will vary and the actual water surface profile may also vary. The results are conservative in comparison to unsteady model results from RMA-2 model.
- EGGWC modeled using future conditions: The model provided by OCPW includes the ultimate configuration of the channel. The time horizon at which the ultimate channel configuration will be in place is uncertain and portions of the channel that remain in their existing condition will significantly impact channel capacity.
- Flood hydrographs: The existing 100-year flow rates were used for each time horizon. The impact of a changing climate on regional hydrology was not accounted for in this analysis.

4. REFERENCES

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