Final

COASTAL HAZARDS, VULNERABILITY, AND RISK ASSESSMENT

Del Mar, CA

Prepared for
The City of Del Mar

April 2016 - Updated August 2018

ESA

July 13, 2016 bluff collapse at 10th Street

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Table of Acronyms

ALERT	Automated Local Evaluation in Real Time
CCC	California Coastal Commission
CDIP	Coastal Data Information Program
CIMIS	California Irrigation Management Information System
CMIP	Climate Model Intercomparison Project Phase
CoSMoS	Coastal Storm Modeling System
ESA	Environmental Science Associates
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
GEV	Generalized Extreme Value
IDF	Intensity Duration Frequency
IPCC	Intergovernmental Panel on Climate Change
LCPA	Local Coastal Program Amendment
LIDAR	Light Detection and Ranging
NAVD	North American Vertical Datum
NCTD	North County Transit District
NOAA	National Oceanic and Atmospheric Administration
PFDS	Precipitation Frequency Data Server
RCP	Representation Concentration Pathways
SANDAG	San Diego Association of Governments
SCE	Southern California Edison
SDCWA	San Diego County Water Authority
SIO	Scripps Institute of Oceanography
SLR	Sea-level rise
SWL	Still Water Level
TAW	Technische Adviescommissie voor de Waterkeringen (Dutch)
TWL	Total Water Level
USGS	United State Geological Survey

EXECUTIVE SUMMARY

The City of Del Mar is preparing a Local Coastal Program Amendment (LCPA) to address sea level rise, storm surge, and coastal flooding. This Coastal Hazards Vulnerability Assessment answers the following questions to assess the future vulnerability of the City of Del Mar and the Del Mar Fairgrounds to projected sea level rise, flooding and erosion:

- What will flood and erosion hazards be in the future?
- How vulnerable is the City of Del Mar to future hazards?
- What are the potential risks or consequences of future hazards and vulnerabilities?

In the next step of the LCPA preparation process, this Coastal Hazards Vulnerability Assessment will be used to inform the development of an Adaptation Plan and LCP policies to answer the question:

- How can the City adapt to reduce these hazards and vulnerabilities?

This assessment considers the key processes that drive hazards and influence vulnerability, which include:

- Beach erosion and coastal flooding
- San Dieguito River flooding
- Bluff erosion and retreat.

The City of Del Mar is currently vulnerable to river and coastal flooding and erosion, with significant damages in the recent past (late 1970s to present, Figures ES-1 and ES-2). Along the Del Mar bluffs (Figure ES-3), the cliff top has retreated to a point where it is a safety concern for the LOSSAN (Los Angeles-San Diego-San Luis Obispo) railroad along the bluff top and the San Diego Association of Governments (SANDAG) and North County Transit District (NCTD) have responded by installing multiple bluff stabilization projects.

Sea level rise. The rate of sea level rise is projected to accelerate in the future (Table ES-1).

TABLE ES-1
PROJECTED FUTURE SEA LEVEL RISE RELATIVE TO YEAR 2000

Sea Level Rise Scenario	2030	2050	2070	2100
Mid-range	5 in	12 in	20 in (1.7 ft)	37 in (3.1 ft)
High-range	12 in	24 in (2 ft)	38 in (3.2 ft)	66 in (5.5 ft)

Source: National Research Council 2012

Figure ES-1

Flooded North Beach Streets 1980

Source: Fletcher, 1983

Figure ES-2

Coastal Damage following 1983 Storm

Source: Fletcher, 1983

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Figure ES-3

Railway on Top of Bluff

The mid-range sea level rise scenario is based on reducing fossil fuel use, with a balance between fossil fuels and alternative energy sources, whereas the high-range sea level rise scenario assumes intensive fossil fuel use will continue in the future.

Flooding and erosion with sea level rise. With future climate change and sea level rise, the City of Del Mar's current vulnerabilities are projected to increase in both frequency and intensity, resulting in increased damage risk to most of Del Mar:

- The beach above high tide will be lost to erosion between 2030 and 2060, at which point beach erosion and coastal storms will threaten sea wall integrity, affecting the City's North Beach District.
- Bluffs will erode and impact the LOSSAN railroad as well as the South Beach and South Bluff Districts; or, if the railroad is armored with a seawall, little to no beach will exist.
- San Dieguito River flooding will inundate the City's North Beach and Valley Districts and the Del Mar Fairgrounds more frequently and with greater depths.

To quantify the increase in damage risk in the future, this assessment analyzes damaging storm that have occurred in the past and estimates the increase in the chance of occurrence of these damaging events in the future. This approach uses information about historic damages and forecasts the frequency of these damages for a range of climate change scenarios. Table ES-2 lists historic events, their estimated chance of occurrence in a given year at present, and the increased chance of occurrence in the future. These estimates are approximate upper end projections for a high sea level rise and climate change scenario developed for the purposes of identifying vulnerabilities and potential risks.

TABLE ES-2
APPROXIMATE ANNUAL CHANCE OF OCCURRENCE THROUGH 2100 WITH HIGH SEA LEVEL RISE AND CLIMATE CHANGE FOR TWO HISTORIC DAMAGING FLOOD EVENTS

Event	Description	Annual Chance of Occurrence				
		Present	2030	2050	2070	2100
1983 Ocean	• January storm caused high water levels and waves during the 1982/83 El Nino, during which the beach eroded • Caused flooding and structural damage to North Beach District properties	1%	5%	15%	50%	100%
1980 River	• February 20 storm caused high rainfall and San Dieguito River flow when upstream reservoirs filled and overtopped • Caused flooding and damage to North Beach and Valley Districts and Del Mar Fairgrounds	5%	15%	25%	50%	100%

Note that the 1983 event was an extreme event and there are higher chances of less extreme – but significant – flooding and damage. Also, this assessment of San Dieguito River flooding considers both the effects of sea level rise, projected changes in precipitation with climate change, and recent changes in Lake Hodges Reservoir operations. Current Lake Hodges operations have the potential to reduce the chances of river flooding, but there is still a risk of the reservoir overtopping as it did in the 1980 event.

Vulnerability and risks. The increased future sea level rise and hazards will impact coastal resources and assets in Del Mar (Figure ES-4), including properties, roads and bridges, infrastructure, emergency services, coastal access, and San Dieguito River lagoon wetland habitats. "Low, moderate, and high" vulnerabilities and risks are discussed below, which are defined for the purposes of this assessment as follows:

- Low: 0% - 5% chance of occurrence in a given year
- Moderate: 5% - 30% chance
- High: 30% - 100% chance

North Beach District vulnerability to coastal erosion, flooding, and damage. Public access along the beach (horizontal access) will be lost due to beach erosion by 2030 to 2070. Beach erosion and coastal storms will threaten sea wall integrity and increase flooding and storm damage. For properties west of Camino Del Mar, including the City's 17th St Beach Safety Center, the present low to moderate vulnerability to coastal flooding and wave damage will become a high vulnerability by about 2050. Ocean Front and Camino Del Mar/Coast Blvd. roads and properties west of Camino Del Mar will also be highly vulnerable to coastal flooding. Note that the blocks between Ocean Front and Camino Del Mar/Coast Blvd. and these roads will be increasingly vulnerable to both coastal and river flooding (discussed below).

Del Mar Fairgrounds, Valley District, and North Beach District vulnerability to San Dieguito River flooding and damage. The present low exposure of the Fairgrounds to significant flooding will become highly exposed by 2070; however, the vulnerability of the Fairground's land uses to flooding may be less than for other public and private development due to the reduced consequences of the flooding. Moderate exposure of the Fire Station to flooding will make emergency services highly vulnerable by 2030 because the Fire Station will be impacted when flooding is occurring and emergency response is needed, as occurred in the 1980 flood. Roads and bridges, including Camino Del Mar, Jimmy Durante Blvd. and bridge, the east ends of North Beach District streets, and San Dieguito Drive, will be highly vulnerable by about 2070. Low-lying central portions of the North Beach District (blocks bounded by Camino Del Mar, 28th St, and Railroad; general vicinity of Coast Blvd. and Santa Fe between 17th St. and 23rd St.), which currently have low vulnerability to River flooding, would be highly vulnerable in 2070. The sewer lift station along San Dieguito Drive would be increasingly exposed to flooding and risk of failure. Other water and sewer infrastructure in these areas would also be exposed to both River and coastal flooding, but is not highly vulnerable to flooding.

North Beach storm drain vulnerability. Local rainfall runoff from North Beach drains to the San Dieguito River via ditches and culverts, which are currently fitted with flap gates and pumps. Over time with sea level rise, gravity drainage through culverts will not be possible with sea level rise and additional pumping will be required.

Source: Del Mar Sandpiper

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Figure ES-4

1941 Train Wreck

South Beach, South Bluffs, and North Bluffs vulnerability to bluff erosion. The current localized vulnerability of the LOSSAN railroad to bluff erosion will increase in extent in the near-term and extend along almost the entire bluff before 2030 (Figure ES-5). By this timeframe, the railroad would need to be moved inland or armored with a seawall to reduce the risk of the railroad collapsing (as a section of railroad collapsed and cause a train wreck in 1940 as shown in Figure ES-4). If a seawall is constructed, the beach will erode back to the seawall over time until little to no beach exists. If the railroad is moved inland and bluff erosion is allowed to continue, bluff top property and sewer infrastructure in the South Beach and South Bluff Districts would be vulnerable to erosion by 2050. North Bluffs properties would be similarly vulnerable to erosion.

San Dieguito River Lagoon wetland habitat vulnerability. With sea level rise, existing wetland habitats will be inundated more frequently and vegetated wetland habitats will be “drowned out” and convert to intertidal mudflats and subtidal habitat. Existing pickleweed marsh habitat could drown out and be lost by 2070. Cordgrass low marsh habitat could be lost by 2090, such that almost all of the San Dieguito Lagoon Wetland Restoration would be converted to intertidal mudflat and subtidal open water. Salt marsh habitats are expected to migrate upstream along the San Dieguito River with sea level rise; however, the River corridor is relatively narrow and the overall vegetated marsh acreage will be greatly reduced.

Table ES-3 summarizes the timeframe when coastal resources and assets will be highly vulnerable and associated risks will be high (e.g., greater than 30% chance of occurrence of flooding and damage in a given year). Moderate vulnerability and risks before these timeframes may be acceptable; however, implementation of adaptation measures will likely be required in the near term (e.g., 2020 to 2050) prior to these timeframes to reduce these high vulnerabilities to within an acceptable level of risk. Adaptation measures will be considered and developed into an Adaptation Plan in the next phase of the LCPA process.

TABLE ES-3
SUMMARY OF HIGH VULNERABILITY COASTAL RESOURCES AND ASSETS

Vulnerability	Coastal Resources and Assets	High Vulnerability Timeframe
Beach erosion and loss	• Beach access	2030 to 2070
North Beach District coastal flooding and damage	• Beach front and adjacent properties including the City’s 17th St Beach Safety Center, roads, and amenities	2050
Del Mar Fairgrounds, Valley District, and North Beach District San Dieguito River flooding and damage	• Fire Station	2030
	• Sewer lift station on San Dieguito Drive	2050
	• Fairgrounds • Roads and bridges, including Camino Del Mar, Jimmy Durante Blvd. and bridge, east ends of North Beach District streets, and San Dieguito Drive • Low-lying central portions of the North Beach District (blocks bounded by Camino Del Mar, 28th St, and Railroad; general vicinity of Coast Blvd. and Santa Fe between 17th St. and 23rd St.)	2070

Vulnerability	Coastal Resources and Assets	High Vulnerability Timeframe
South Beach, South Bluffs, and North Bluffs bluff erosion	• Railroad	2030 or earlier
	• Bluff top property in South Beach, South Bluffs, and North Bluffs • Sewer infrastructure in South Beach and South Bluffs	2050
San Dieguito River Lagoon wetland habitat conversion and loss	• Vegetated wetland habitat	2070

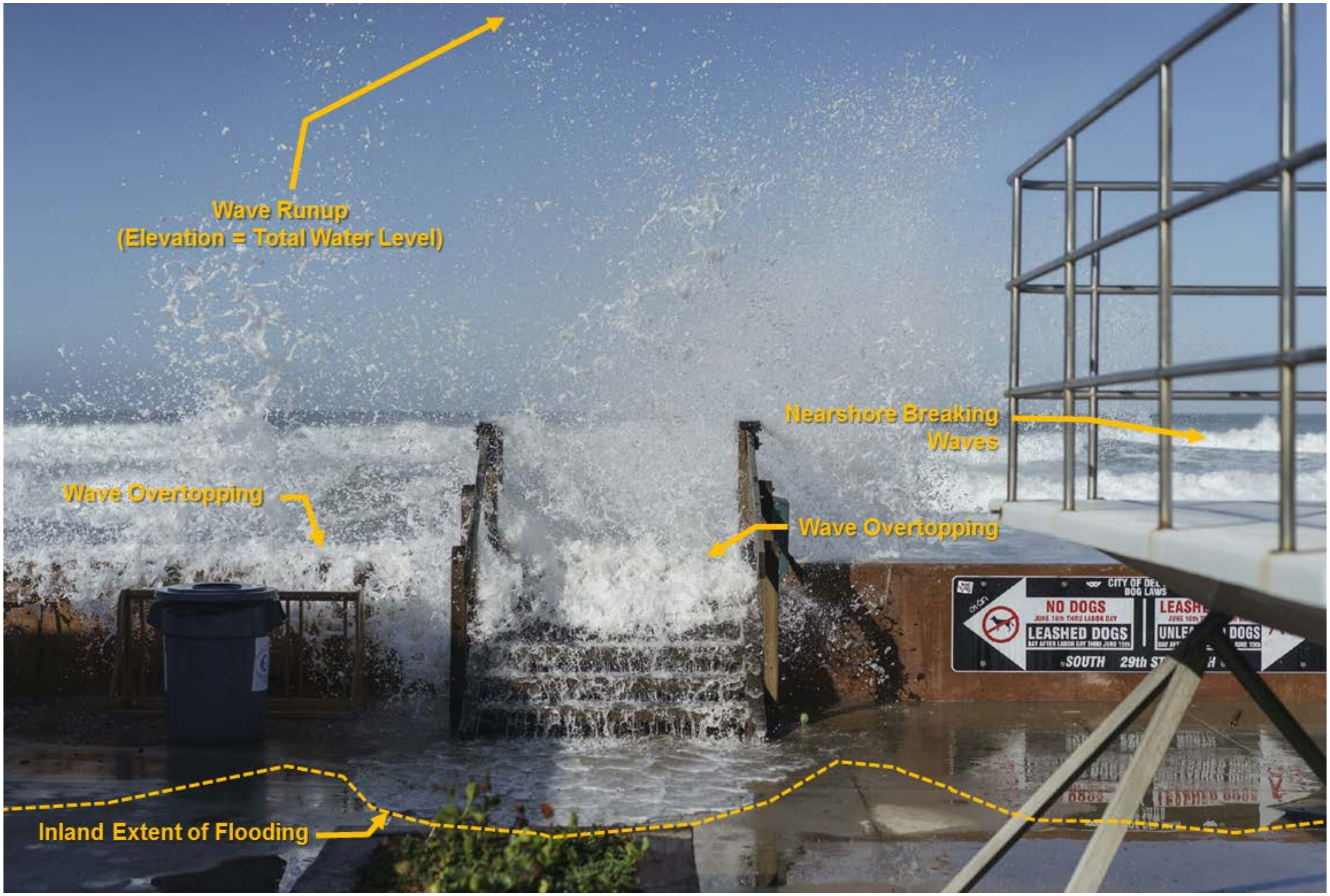
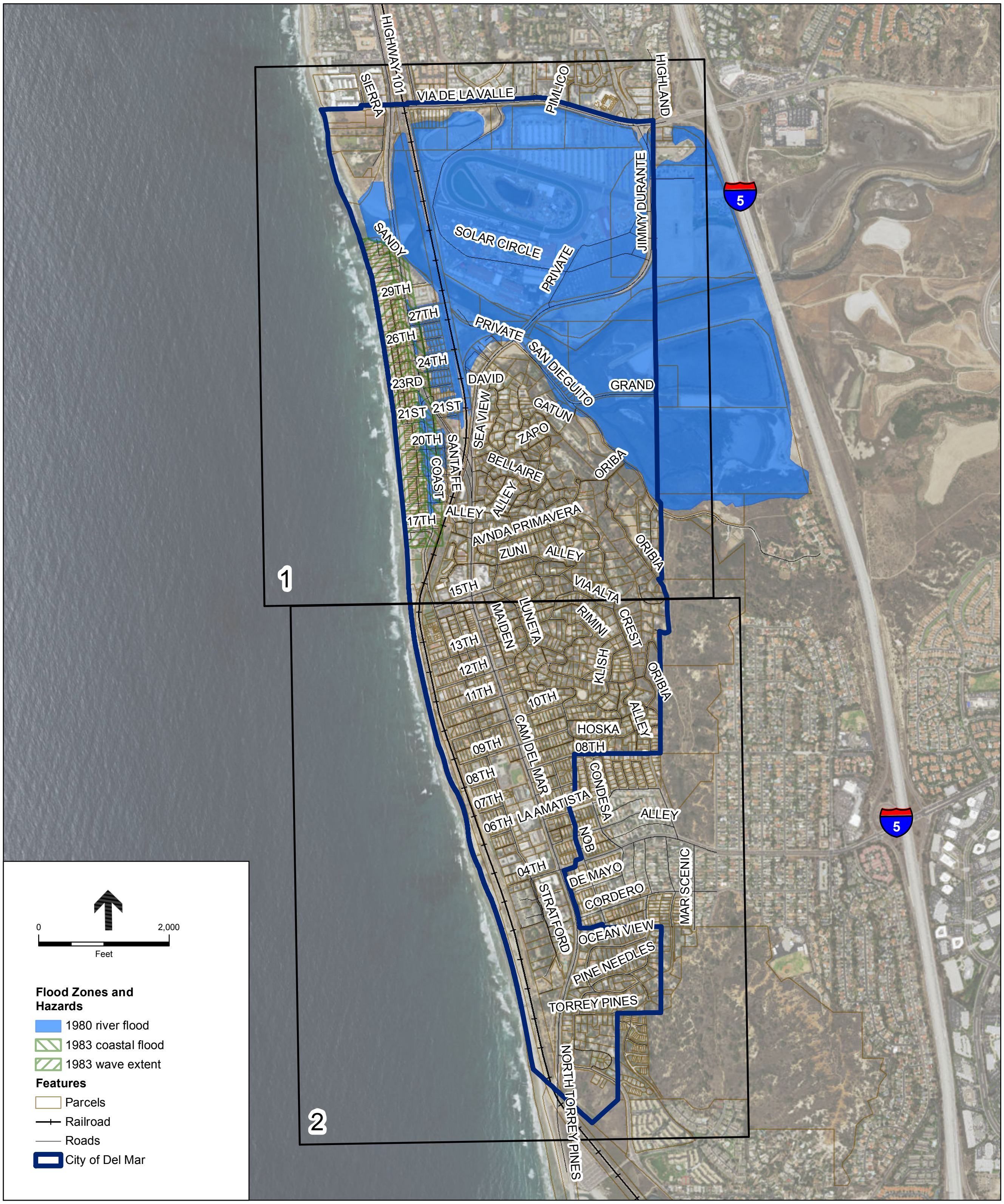
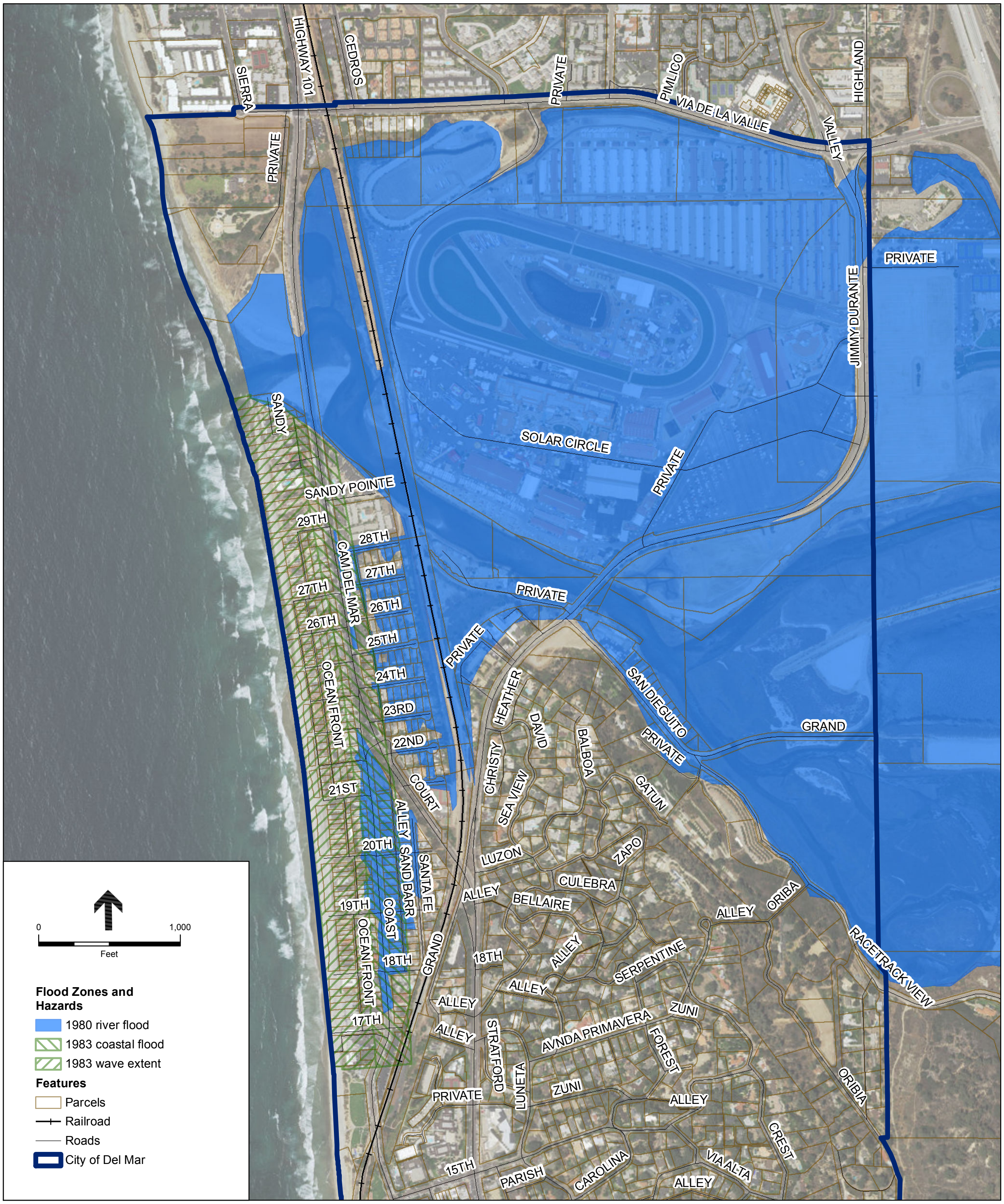


Figure ES-5
Schematic of Coastal Flooding Terms
Photo from March 8th, 2016 – Del Mar



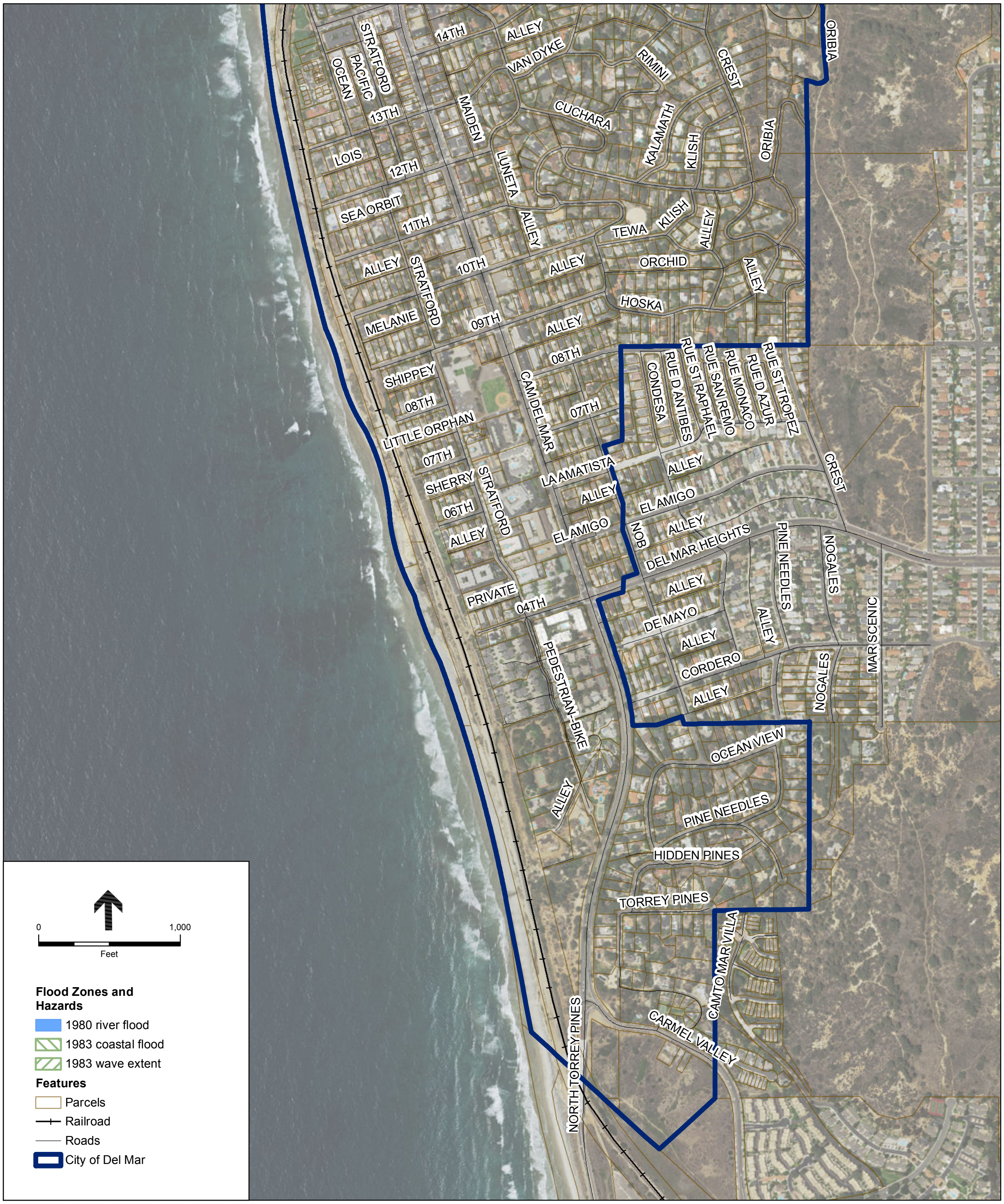
SOURCE: SanGIS 2016, FEMA

Figure ES-6- Map Grid Overview
1980 and 1983 Events
Property and Road Vulnerability



SOURCE: SanGIS 2016, FEMA

Figure ES-6.1
1980 and 1983 Events
Property and Road Vulnerability



SOURCE: SanGIS 2016, FEMA

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Figure ES-6.2
1980 and 1983 Events
Property and Road Vulnerability

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1 INTRODUCTION

1.1 Background

The City of Del Mar is preparing a Local Coastal Program Amendment (LCPA) to address sea level rise, storm surge, and coastal flooding. ESA, with team members Dr. Adam Young, Scripps Institute of Oceanography, and Argos Analytics, LLC performed this Coastal Hazards Vulnerability Assessment to assess the future vulnerability of the City of Del Mar and the Del Mar Fairgrounds to projected sea level rise, coastal flooding and erosion, and San Dieguito River flooding, considering both the effects of sea level rise and projected changes in precipitation with climate change.

The City of Del Mar is currently vulnerable to river and coastal flooding and erosion. In the recent past (late 1970s to present), extreme San Dieguito River flooding and coastal flooding and erosion have caused significant damages. In certain locations along the Del Mar bluffs, the cliff top has retreated to a point where it is a safety concern for the LOSSAN railroad along the bluff top and SANDAG and NCTD have responded by installing multiple bluff stabilization projects. These existing vulnerabilities are projected to increase in intensity and frequency in the future due to sea level rise and climate change.

Given that Del Mar is already vulnerable to coastal hazards, this vulnerability assessment focuses on how the frequency of damaging flood events is projected to increase in the future, rather than analyzing how the intensity and extent of infrequent extreme events may increase. In other words, this assessment analyzes how much more frequently historic flood events are likely to occur, rather than how much worse these events will be. For example, this assessment projects how the annual-chance-of-occurrence of historic flood events and the Federal Emergency Management Agency (FEMA) 1%-annual-chance (100-year return period) event will increase in the future (e.g., the FEMA 1% chance event may become a 10% chance event in the future). Since Del Mar is already vulnerably to coastal hazards, this approach provides useful information on future change in the frequency of vulnerability for use in adaptation planning, whereas the alternative approach of analyzing how the extent of extreme hazards may increase in the future is more useful for areas that are not currently vulnerable.

ESA's coastal hazard analysis and vulnerability assessment is a planning-level assessment for the purposes of informing the development of an Adaptation Plan and LCP policies in the next phases of the LCPA preparation process. This assessment considers the key processes that drive hazards and influence vulnerability, which include:

- The compounding effects of projected beach erosion on coastal flooding,

- The potential effects of projected changes in extreme precipitation and recent changes in Lake Hodges Reservoir operations on San Dieguito River flooding,
- Beach erosion and bluff retreat over the timeframe through 2100.

Many of these processes are inherently complex and detailed analyses of certain processes are beyond the scope of this assessment and the level of information needed for the LCPA. This assessment therefore relies on reasonable assumptions and engineering judgement to simplify the analysis and assessment of certain processes.

This assessment also utilizes preliminary results from the initial release of the U.S. Geological Survey's (USGS') Coastal Storm Modeling System (CoSMoS) 3.0, which provide an indication of the intensity of extreme coastal flooding (1% chance or 100-year event), without considering the effects of future beach erosion. The CoSMoS results also provide future projections of beach width and cliff retreat in 2100 for a range of sea level rise (SLR) scenarios. Final CoSMoS results, planned for release in the summer of 2016, are expected to provide additional information on flooding and beach and bluff erosion for the timeframe before 2100 (e.g., 2030, 2050, and 2070).

2 DATA COLLECTION AND PROCESSING

ESA collected publically available data on physical processes impacting coastal and riverine flooding in Del Mar. The locations of various gages and measurement stations described in this section are shown in Figure 1. Note that the vertical datum used in this project is the North American Vertical Datum of 1988 (NAVD).

2.1 Sea Level Rise

The rate of sea level rise is projected to accelerate in the future. Table 1 includes projected future sea level rise from the National Research Council study *Sea-Level Rise for the Coasts of California, Oregon, and Washington* (NRC 2012) for the mid-range sea level rise scenario and the high-range scenario. The mid-range sea level rise scenario is based on reducing fossil fuel use, with a balance between fossil fuels and alternative energy sources, whereas the high-range sea level rise scenario assumes intensive fossil fuel use will continue in the future. The NRC sea level rise projections are considered “best available science” for/by the State of California.

TABLE 1
SEA LEVEL RISE (SLR) PROJECTIONS

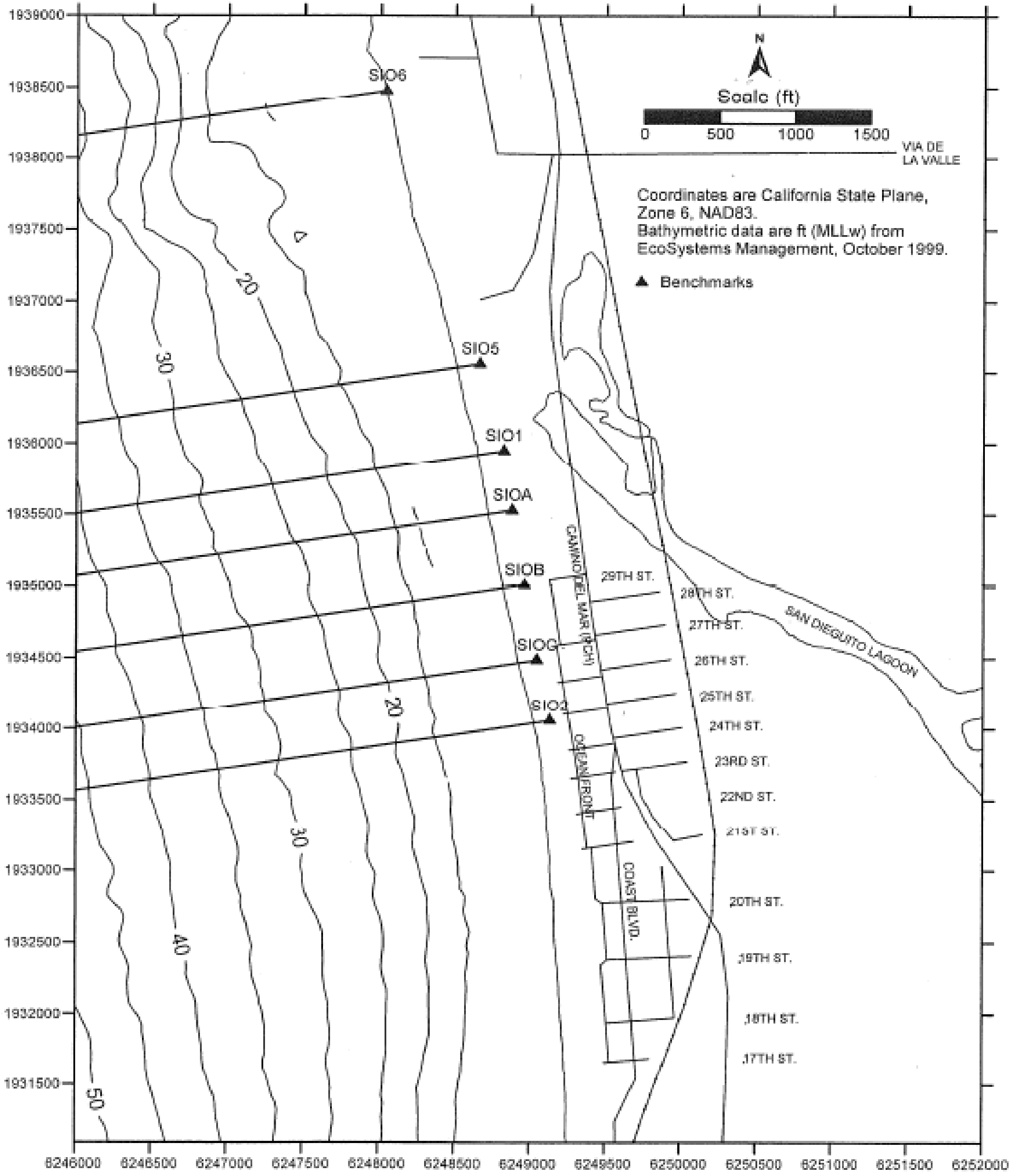
	2030	2050	2070	2100
Mid SLR	5 in	12 in	20 in (1.7 ft)	37 in (3.1 ft)
High SLR	12 in	24 in	38 in (3.2 ft)	66 in (5.5 ft)

2.2 Beach Elevations

Nearshore bathymetric and topographic information near Del Mar was used to determine beach slopes and shoreline response to sea level rise. Beach profiles along Del Mar Beach have been collected quarterly by Coastal Environments and were downloaded from the Coastal Environments website (Coastal Environments 2010-2016). Figure 2 shows the geographic extent of Coastal Environment profiles. Profiles are named with the prefix SIO for Scripps Institute of Oceanography). A digital elevation model from Coastal CA Data Merge Project (CCDMP) (USGS, 2015) was also used to compare beach slopes and widths.

Various beach slopes were calculated for Del Mar Beach along Ocean Front. The overall Bruun slope was determined to be approximately 1:40, and was calculated between the beach toe and the depth of closure. The depth of closure (the depth beyond which the beach profile is stable) was estimated to be approximately -23 ft NAVD (North American Vertical Datum of 1988) using a point near Del Mar from the Depth of Closure Tool provided by the U.S. Army Corps of

Figure 1
Gage Locations



Source: Coastal Environments

Figure 2

Beach Profile and Benchmark Locations

Engineers (Brutsché and McFall, undated.). A representative wintertime beach face slope of 1:20 and a revetment slope of 1:4 were selected by assessing beach profiles.

2.3 Still Water Levels

Still water levels (SWL) measured at La Jolla Scripps Institution Warf (NOAA NOS#9410230) were used as representative SWL for the project site. Hourly SWL data was downloaded from January 1974 to March 2016. The record at La Jolla contains several data gaps, some of which occurred during historical flood events at Del Mar. Data from Los Angeles Outer Harbor (NOAA NOS#9410660) was used to fill these gaps. The filled data from Los Angeles is shown in red in Figure 3.

2.4 Waves

Significant wave height, peak period, and peak direction were downloaded from Torrey Pines Outer CDIP Buoy #100. Though the buoy is located in an intermediate water depth of 1800 feet, ESA assumed that the buoy provides approximate nearshore waves near Del Mar Beach.

The Torrey Pines buoy has a relatively short record dating back only to February 2001. To assess wave conditions during historic coastal flooding events prior to 2001, wave conditions at other nearby buoys were substituted. The Begg Rock buoy (CDIP #138) record was substituted to assess wave conditions during the 1983 coastal event. The Begg Rock buoy is located approximately 140 miles from Del Mar and is within the shadow of the Channel Islands. However, wave data from the Begg Rock buoy during the 1983 storm is consistent with estimated wave parameters near Del Mar during the same event (Seymour 1983, Walker et al. 1984, Seymour 1984). For the 1998 event, wave data from the Oceanside Offshore Buoy (CDIP #045) was substituted after scaling the wave heights down by 17%. Nearshore transformation matrices indicate that Oceanside wave heights are approximately 17% larger than Del Mar wave heights for peak periods observed during the 1998 event.

2.4.1 Cumulative Wave Power

A seasonal cumulative wave power index was calculated from September 1 through May 31 from 2001 to 2016 (Figure 4). Wave power index was represented as the product of peak wave period and the square of significant wave height. This index is a proxy for actual wave power. As shown in Figure 4, high cumulative wave power does not only occur during years with large extreme events (such as in 2015-2016). High cumulative wave power can instead be caused by frequent or repeated small waves (see year 2009-2010). Also note that the 2015-2016 index was calculated through the beginning of March 2016.

Quarterly beach elevation was tabulated at the toe of a revetment along a typical North Del Mar Beach profile (Coastal Environment Profile named SIOB). The cumulative wave power from September 1 to the survey date of each observation was calculated and plotted against the respective beach elevation. Figure 5 indicates that as cumulative wave power increases, beach elevation drops. In general, this means that fall elevations are the highest and spring/early

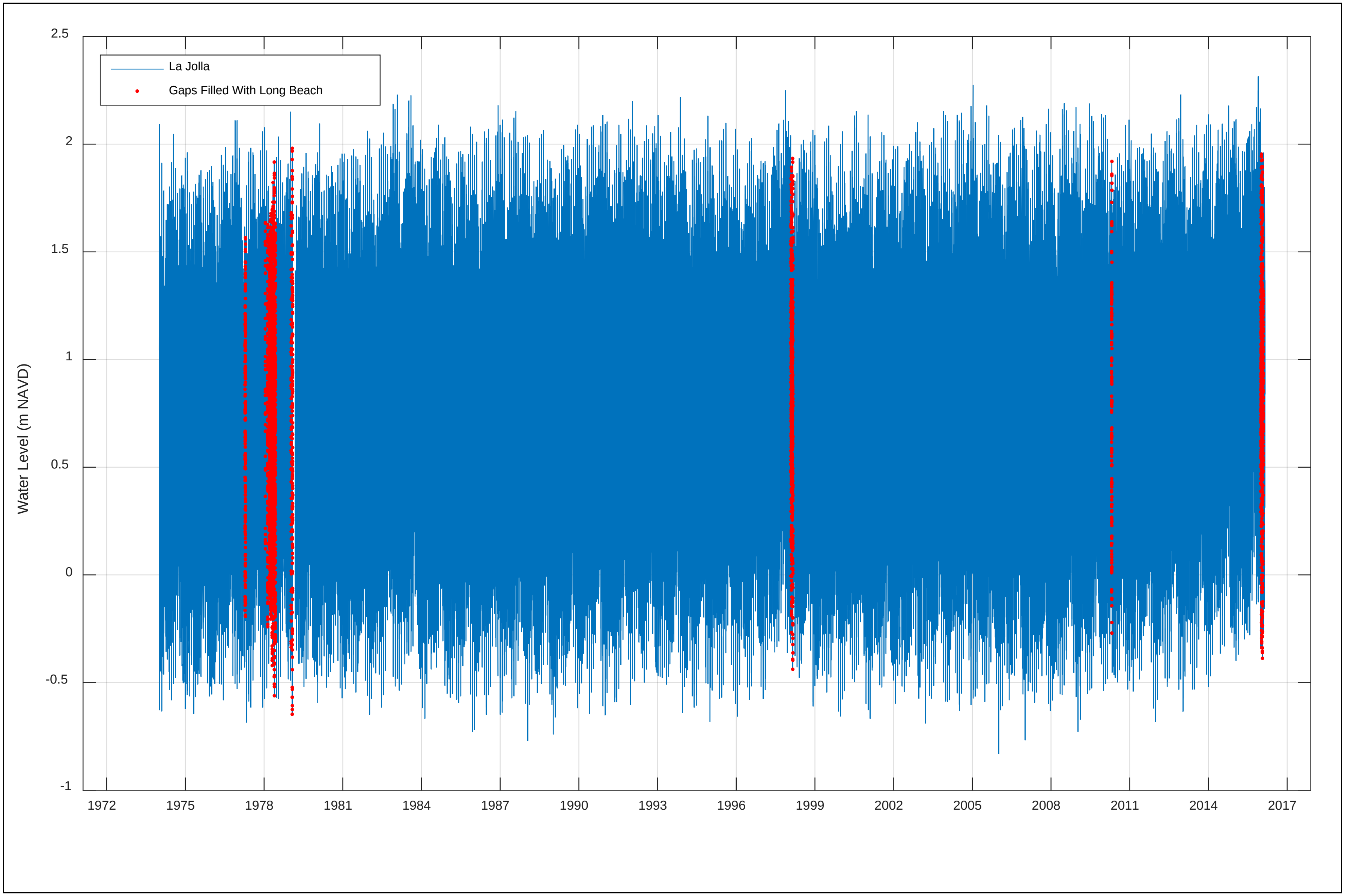
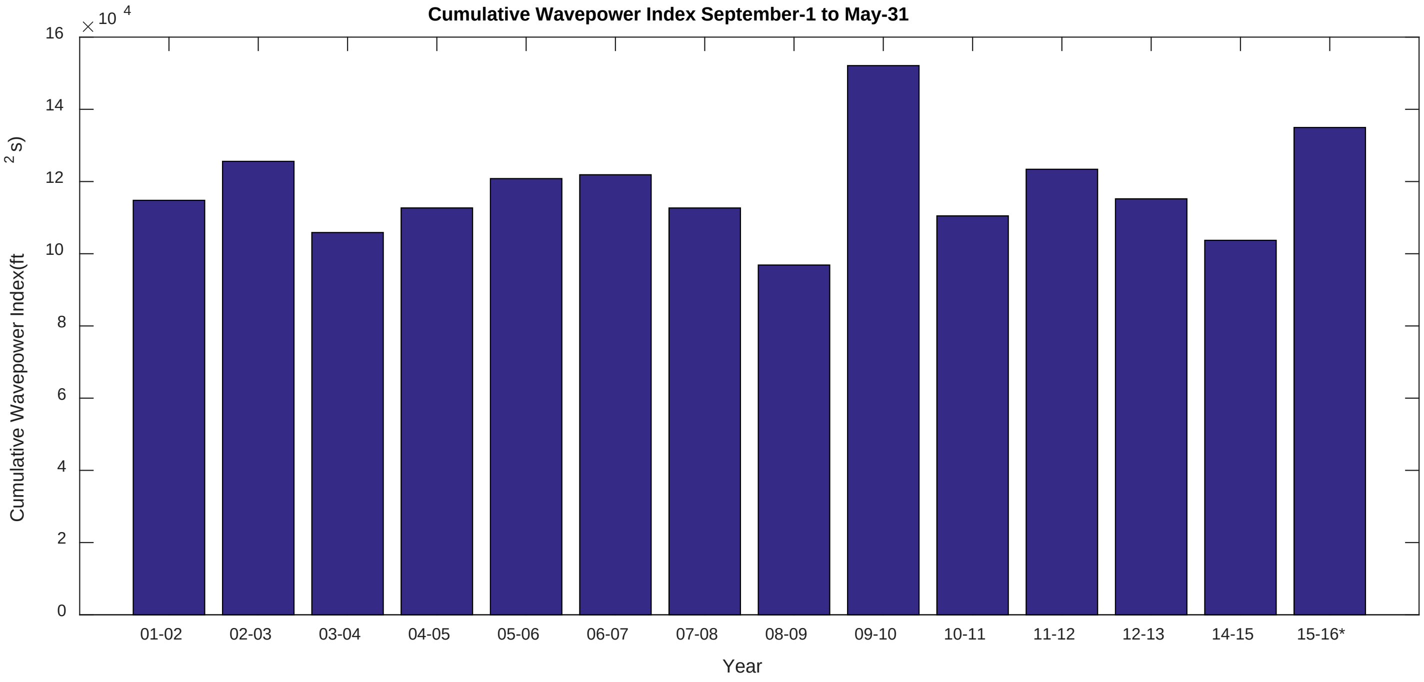


Figure 3

Still Water Level Record from La Jolla Gaps filled with Los Angeles Outer Harbor Data



Del Mar Vulnerability Assessment. D150347.00

Figure 4

Cumulative Seasonal Wave Power Index

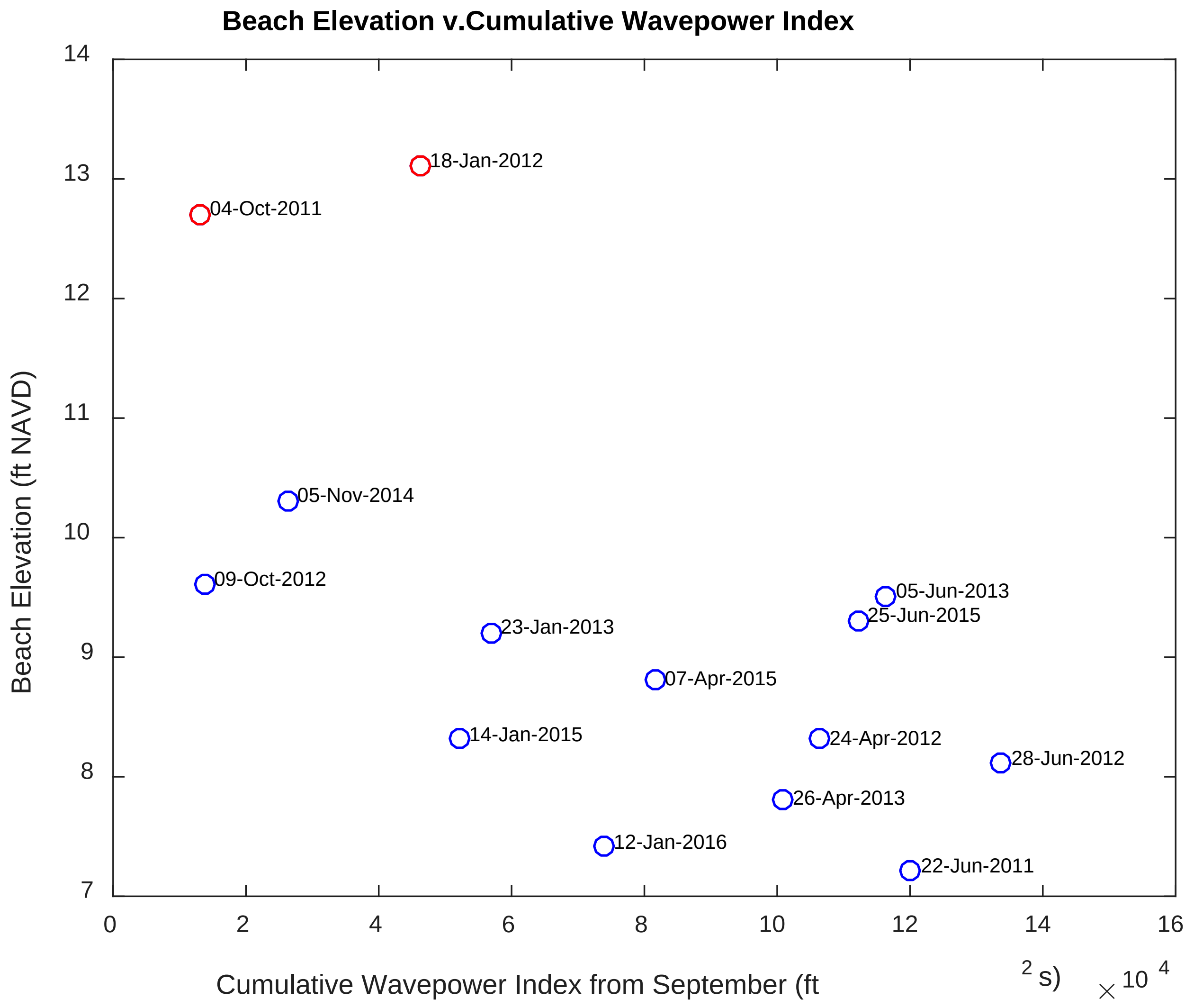


Figure 5

Beach Elevation vs. Cumulative Wavepower Index summer elevations are lowest. Note that two observations were taken following a beach nourishment and are indicated by red circles (October 4, 2011 and January 18, 2011).

2.5 Precipitation & River Flow

Three rain gages provided precipitation data for this analysis. The Ramona ALERT and Encinitas ALERT stations are run by the County of San Diego and both have data available from 1963 to 2008. The Ramona station is in the center of the watershed and was chosen to represent the watershed precipitation that causes high flows in the San Dieguito River for the analysis of fluvial events. The Encinitas station is not in the same watershed but is close in proximity and rainfall pattern to the City of Del Mar. More recent precipitation data from 2000 to 2016 was downloaded from the Torrey Pines precipitation gage (CIMIS Station #173).

Precipitation data is represented as precipitation intensity (inches of rainfall per hour) and is used in this analysis as a substitute for detailed river flow data near Del Mar. No river gages exist on the San Dieguito River. Extreme river discharge estimates were developed for the FEMA Flood Insurance study by modeling extreme precipitation and flow routing within a watershed hydrology and routing model (see Section 2.5.2 below).

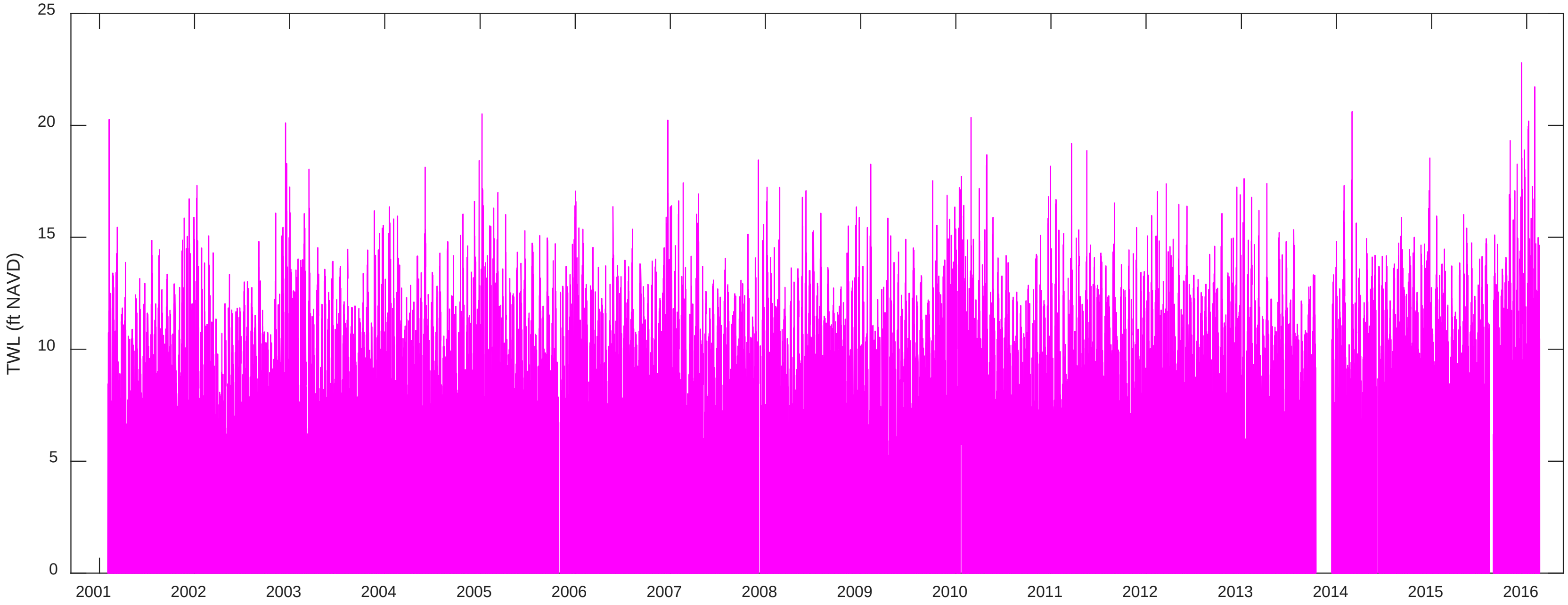
Note that flows in the San Dieguito River are controlled by two water supply storage reservoirs, with the larger downstream Lake Hodges Reservoir capturing discharge from the majority of the watershed; however, the reservoirs are not operated for flood control and have historically filled and overtopped, with river flows spilling over the often in the past (see Section 4.4.4).

2.6 Extreme Value Analysis

2.6.1 Runup and Total Water Level

Wave runup and Total Water Levels (TWL) are important parameters to investigate when assessing the vulnerability of coastal structures. Wave runup is measured as the vertical extent of wave wash along a structure or shoreline. Total Water Level represents the maximum elevation of the water surface, accounting for still water level (tides) and wave runup. Wave runup and Total Water Levels for Del Mar were calculated using a TAW (Technische Adviescommissie voor de Waterkeringen) equation (FEMA 2005) modified with a composite slope methodology for the Torrey Pines wave record (Figure 6). TWLs were also calculated during the peak wave conditions for the 1983 and 1998 events. As discussed in Section 2.1, a beach face slope of 1:20 and a revetment slope of 1:4 were used in the modified TAW computation.

The modified TAW method provides an approximation of TWL along a simplified, averaged profile. As a result, the TWLs predicted are approximate and may overestimate TWLs.



Del Mar Vulnerability Assessment. D150347.00

Figure 6

Del Mar TWL Timeseries from 2001 to 2016

1983 Hazard Zones

For the 1983 event, a more detail analysis of the inland extent of coastal flood waters was modeled using the 1-D numerical model Xbeach (Smit et al, 2010). The peak wave height, average period, and hourly SWL from the 1983 event were modeled over three hours along a representative profile in North Beach. The profile was composed of upland and offshore elevations from the CCDMP elevation model, with an eroded beach profile from Coastal Environment's Profile SIOB.

Water elevation and velocity was calculated along the representative profile. Using the profile-based wave parameters, hazard zones were first classified into three zones described in FEMA, 2015: the VE Zone (wave heights >3 feet), the Coastal VA Zone (wave heights between 3 and 1.5 feet), and the VA Zone (wave heights between 1.5 and 1 feet).

Following the guidelines described in FEMA, 2005, an alternate VE hazard zone was calculated based on a momentum-force index of 200 feet^3/second. For the Del Mar project, the Wave Hazard Zone was defined as the midway-point between the VE Zone calculated using the FEMA 2015 definition and the VE Zone calculated using the FEMA 2005 definition. The Wave Hazard Zone corresponds to a zone where structural damage due to wave action may occur. The Flood Hazard Zone, corresponding to an area where damage due to inundation may occur, was extended from the edge of the Wave Hazard Zone to the VA Zone as defined by FEMA 2015. The inland extent of these zones are mapped in Figures 40.1-40.4.

Discussion hazard zone changes with SLR is presented in Section 4. The intersection of hazard zones with existing land uses is discussed in Section 5 and 6.

2.6.2 Precipitation & River Flow

NOAA's Hydrometeorological Design Studies Center has estimated precipitation frequencies for different areas of the US. The Intensity-Duration-Frequency (IDF) analysis found in the Precipitation Frequency Data Server (PFDS) in NOAA ATLAS 14, Volume 6, Version 2 for the Ramona station (Table 2) provided values for the extreme precipitation frequency analysis (Section 4.4.2).

River discharge return periods provided by FEMA were used to characterize events with known discharge (Table 3). The FEMA discharges are based on a prior watershed hydrology analysis, which considered Lake Hodges Reservoir (prior to recent changes in reservoir operations). These discharges are based on an analysis of historic rainfall and river discharge.

TABLE 2
RAMONA INUNDATION-DURATION-FREQUENCY (IDF) VALUES FROM NOAA PFDS

by duration for ARI:	1	2	5	10	25	50	100	200	500	1000 years
5-min:	1.54	1.94	2.51	2.99	3.66	4.21	4.79	5.41	6.3	7.02
10-min:	1.1	1.39	1.79	2.14	2.63	3.02	3.43	3.88	4.51	5.03
15-min:	0.88	1.12	1.45	1.72	2.12	2.43	2.77	3.13	3.64	4.06
30-min:	0.62	0.79	1.02	1.22	1.49	1.72	1.95	2.21	2.57	2.86
60-min:	0.46	0.58	0.74	0.89	1.09	1.25	1.42	1.61	1.87	2.09
2-hr:	0.31	0.4	0.51	0.61	0.75	0.86	0.98	1.11	1.29	1.44
3-hr:	0.25	0.32	0.41	0.49	0.6	0.69	0.79	0.89	1.03	1.15
6-hr:	0.17	0.22	0.28	0.33	0.41	0.47	0.54	0.6	0.7	0.78
12-hr:	0.11	0.15	0.19	0.22	0.28	0.32	0.36	0.41	0.47	0.53
24-hr:	0.08	0.1	0.13	0.15	0.18	0.21	0.24	0.27	0.32	0.35
2-day:	0.05	0.06	0.08	0.1	0.12	0.14	0.16	0.18	0.21	0.23
3-day:	0.04	0.05	0.06	0.07	0.09	0.11	0.12	0.14	0.16	0.18
4-day:	0.03	0.04	0.05	0.06	0.08	0.09	0.1	0.12	0.14	0.16
7-day:	0.02	0.03	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.11
10-day:	0.02	0.02	0.03	0.03	0.04	0.05	0.06	0.06	0.08	0.09
20-day:	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.06
30-day:	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.04	0.05
45-day:	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.04
60-day:	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03

TABLE 3
RIVER DISCHARGE RETURN PERIOD

Return Period or Annual-chance-of-occurrence	River Discharge (cfs)
5-year or 20%-chance	2,120
10-year or 10%-chance	5,700
25-year or 4%-chance	16,510
50-year or 2%-chance	31,400
100-year or 1%-chance	41,800
500-year or 0.2%-chance	90,000

SOURCE: FEMA 2012, Leedshill-Herkenhoff 1985

3 HISTORIC EXTREME FLOOD EVENTS

Historic extreme events were characterized by ESA through community surveys, news and technical reports, and time series analyses. This section describes the physical processes that contributed to events in 1978, 1980, 1983, 1998, and 2015 and provides a discussion of associated damages. In addition, these events are classified by their approximate return period.

3.1 Riverine Flood of 1978

In January and February of 1978, there were a number of significant rain events that increased water level in the Lake Hodges reservoir. In early March 1978, there was additional rainfall that led to the overtopping of Lake Hodges dam and downstream flooding (Figure 7). Along the San Dieguito River in Rancho Santa Fe, portions of Chino Farm were eroded into the river. The Whispering Palms maintenance shed nearby was washed away.

Figure 8 shows the SWLs and precipitation at the Ramona and Encinitas stations from February 24, 1978 to March 16, 1978. The precipitation data shows two notable events in this time period. The Encinitas station recorded 0.3 in/hr for two consecutive hours in the morning of March 1. Precipitation at the Ramona station peaked at 0.55 inches on March 6 at 3am.

3.2 Riverine Flood of 1980

There was a significant amount of rainfall in February of 1980. Lake Hodges Dam overtopped and low-lying areas of Del Mar flooded, including the newly built racetrack, as seen in Figures 9–11. River discharge reached 22,000 cfs, corresponding to a 35-year return period event (Chang Consultants 2014). The 24-hr precipitation on February 20, 1980 corresponds to a 25-year event for the watershed. The maximum hourly rainfall for this storm was 0.9 in on February 20th at 8pm (Figure 12). The maximum 6 hr rainfall for this event was 0.45 in/hr corresponding to a 42-yr event (Appendix D).

3.3 Coastal/Riverine Flood of 1983

A series of intense storms during the1982-1983 El Niño season caused serious coastal damage throughout California (Figures 13-14). Economic losses exceeded $2 billion along the California coastline. $100 million of this damage occurred in January alone: 3000 homes and 900 businesses were damaged and 11 of the 15 coastal counties were declared state and federal disasters. Numerous coastal structures such as piers and jetties were damaged, and sediment was washed away from most beaches, exposing the underlying cobble and rock.

Source:

Figure 7

1978 Flooded River Mouth

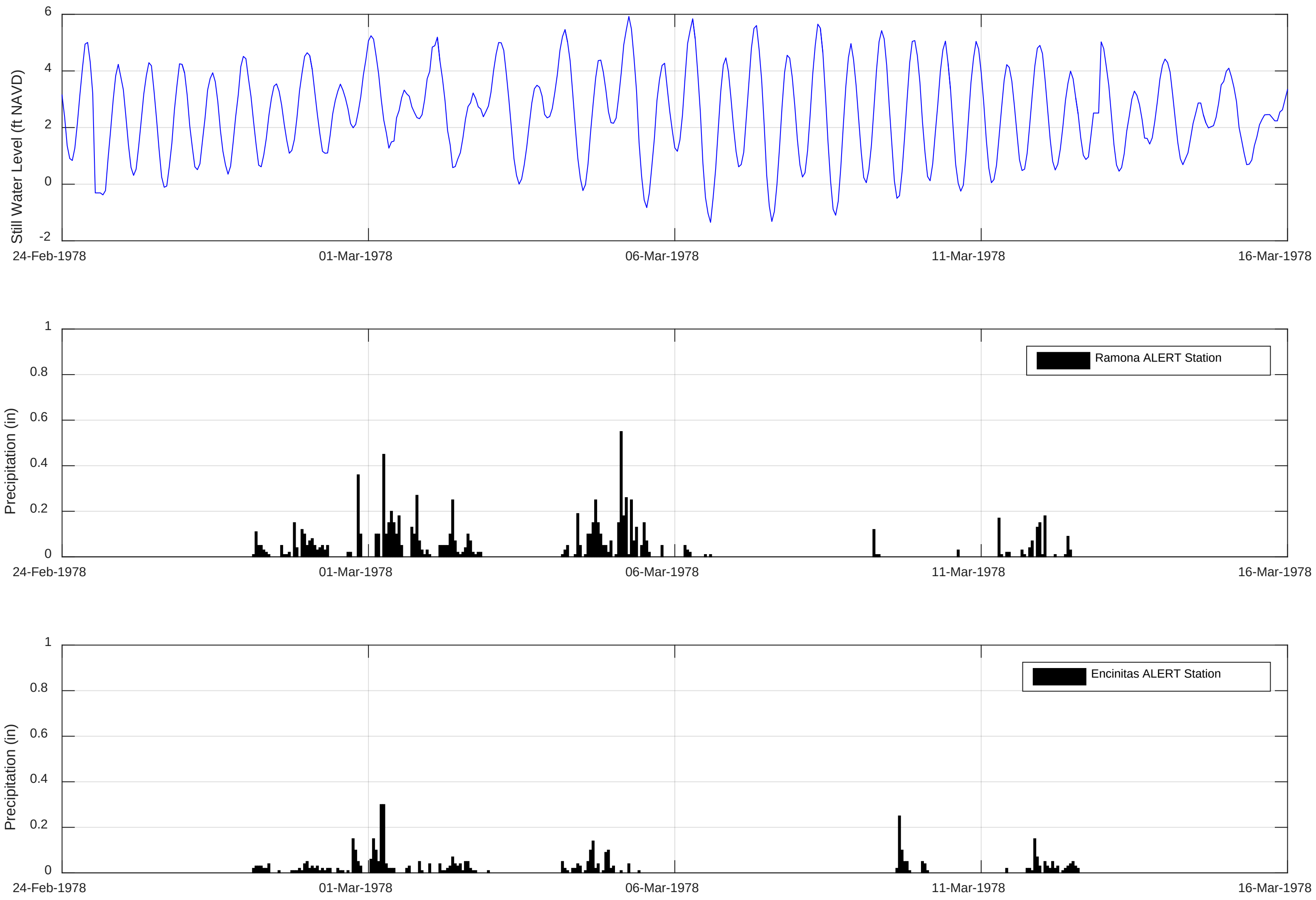


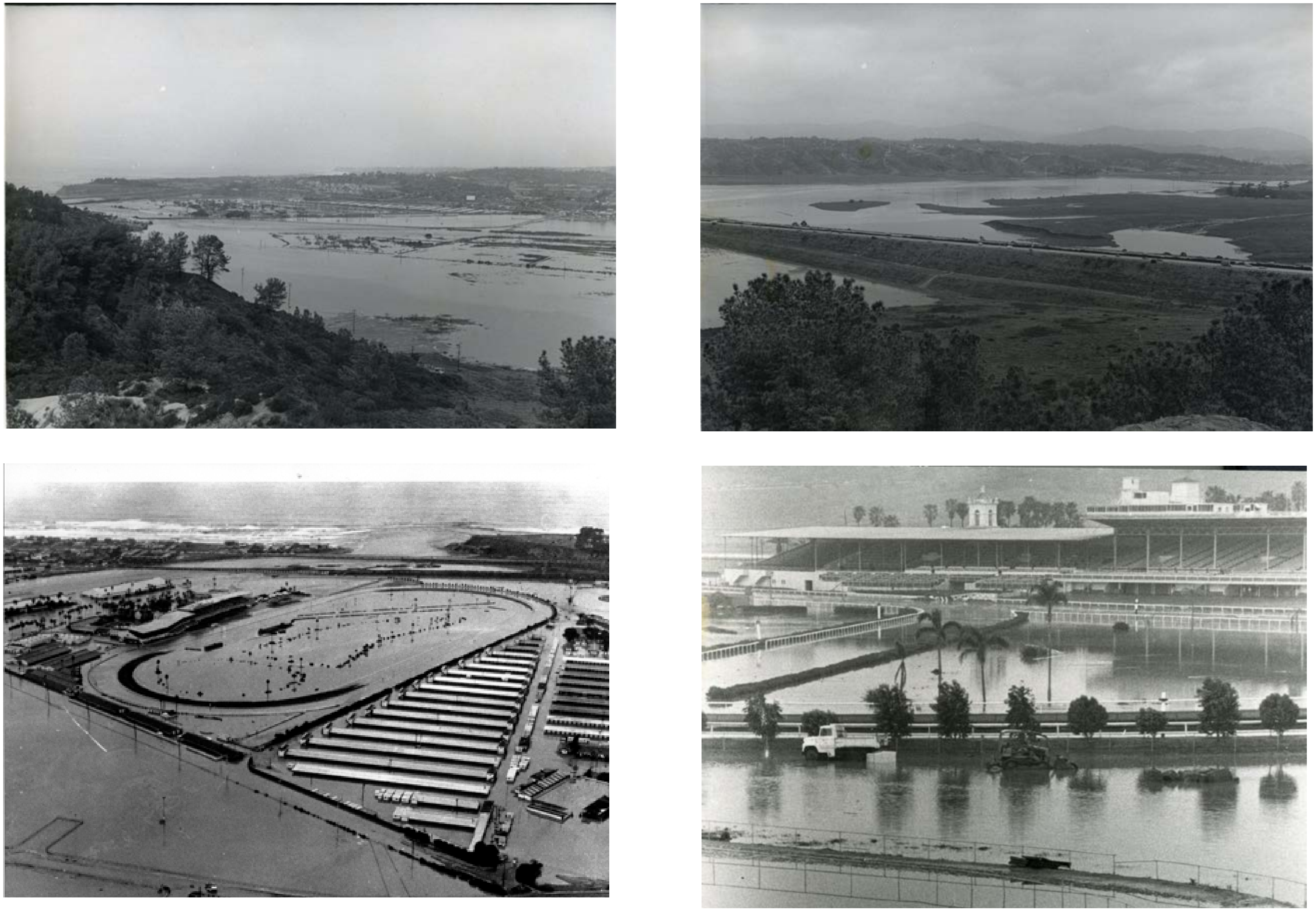
Figure 8

SWL and Precipitation – Flood 1978

Source:

Figure 9

View of San Dieguito River Mouth February 21, 1980



Source: Dustin Fuller

Figure 10

1980 Flooded River Mouth and Racetrack

Source: Bruce Bekkar

Figure 11

Flooded North Beach Streets, 1980

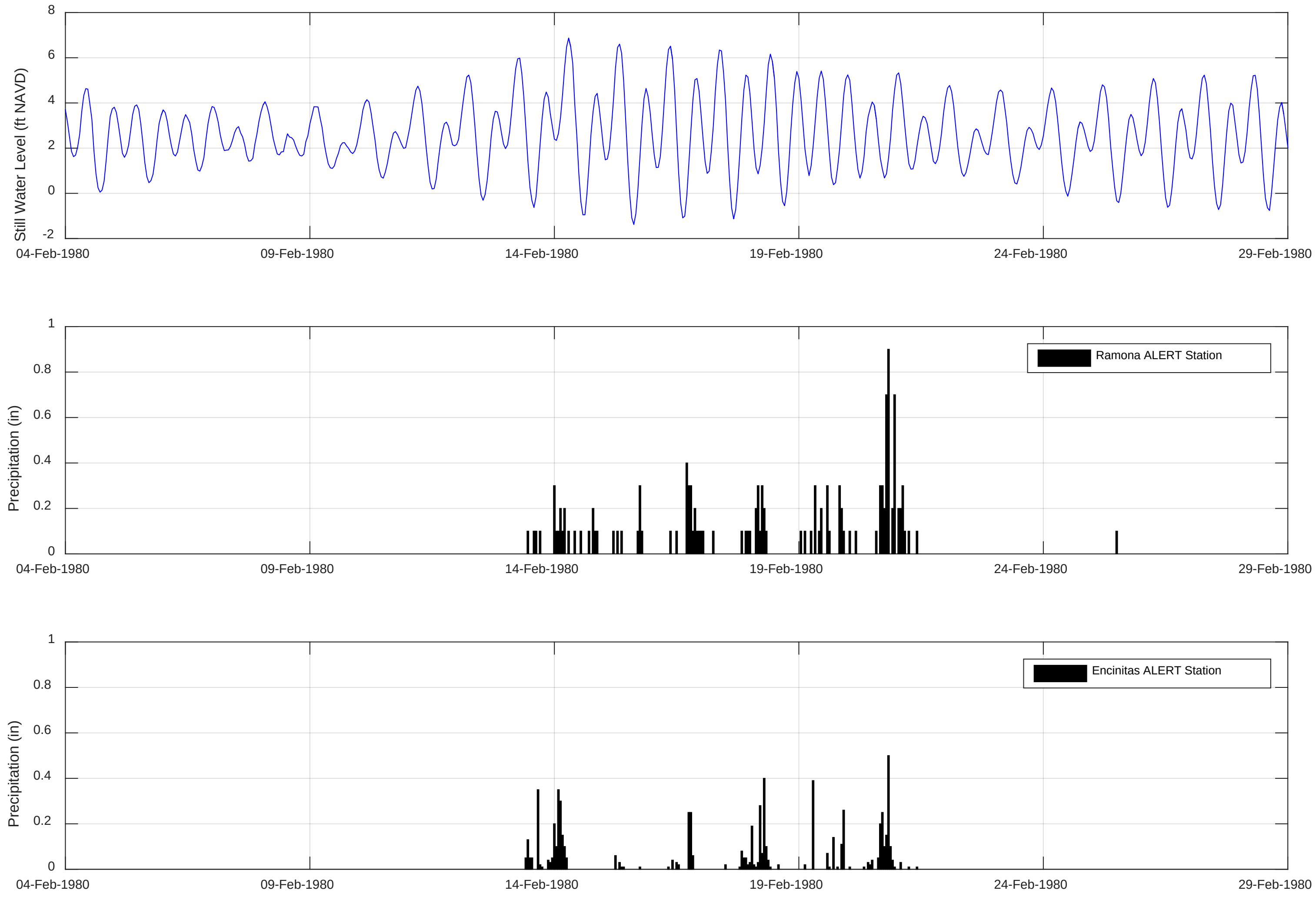


Figure 12

SWL and Precipitation – Flood 1980

Source: Fletcher, 1983

Figure 13

Coastal Damage following 1983 Storm

Source: Fletcher, 1983

Figure 14
Large Waves during 1983 Storm

On January 27, 1983, a state of emergency was declared in the City of Del Mar due to a coastal storm. Coast Boulevard was cleared and beaches were ordered off-limits to the public. The storm affected businesses and residents in close proximity to the beach. In some cases, waves smashed windows of buildings along the beach including those of Poseidon Restaurant near Coast Boulevard and 17th street. Tom Ranglas, owner of the establishment, received approval to build a seawall after this event.

Figure 15 shows the SWLs and precipitation at the Ramona and Encinitas stations from January 15, 1983 to February 15, 1983. Figure 16 indicates that there was a large spike in wave power index on the 27th, with wave heights reaching approximately 25 feet. TWLs (not plotted) peaked at approximately 27 feet NAVD, which would have resulted in significant overtopping of the seawalls and revetments located at approximately 16 feet NAVD. This TWL corresponds to a severe event with a recurrence of at least 100-years, which is the most extreme event analyzed for this project.

3.4 Coastal Storm of 1998

At the end of January 1998, one of the largest coastal storms on record for California hit Del Mar. Eighteen-foot waves and winds up to 80 miles per hour uprooted trees, left people without power, and threatened beachside homes. In San Diego, Amtrak cancelled all north-south trains because of flooded tracks. Waves scoured much of the sand from North County beaches, including those in Del Mar, closed Highway 101 several times, and damaged the Ocean Beach pier. Lifeguards were busy with numerous rescues. In Solana Beach a lifeguard was injured while rescuing a drowning teen (NOAA, 1998).

Figures 17 and 18 show SWLs, precipitation, and wave parameters during the 1998 event, which occurred on February 4. Wave heights from Torrey Pines exceeded 10 feet, though the event occurred during a neap tide. TWLs for the 1998 event (not plotted) reached 18.2 feet NAVD during peak wave conditions on February 4, corresponding to approximately a 7-year event. The coastal event was precluded by several notable rainstorms, which likely exacerbated flooding in Del Mar on the 4th. The TWL analysis does not consider transformed nearshore waves, local wind waves, or the impact of rainfall, which would likely act to increase the return period of this event.

3.5 Coastal Storms of 2015 and 2016

In mid-December, 2015, a large storm impacted much of the City of Del Mar. By January 7, 2016, the City of Del Mar declared a local emergency in response to damages, including a landslide and road closures (Figures 19 and 20). The storm damaged a portion of Camino del Mar, which runs north and south along the coast, and destroyed a storm drain and utility lines that run under the roadway. After the storm, much of the fill under the street slid down the canyon, exposing a communication conduit containing fiber optic cables, two gravity main sewer lines, and the Del Mar storm drain line and inlet. As Del Mar Times reports, "the city immediately closed all southbound lanes on Camino Del Mar" and "an estimated $1 million in repairs are still needed" (Del Mar Times 2016).

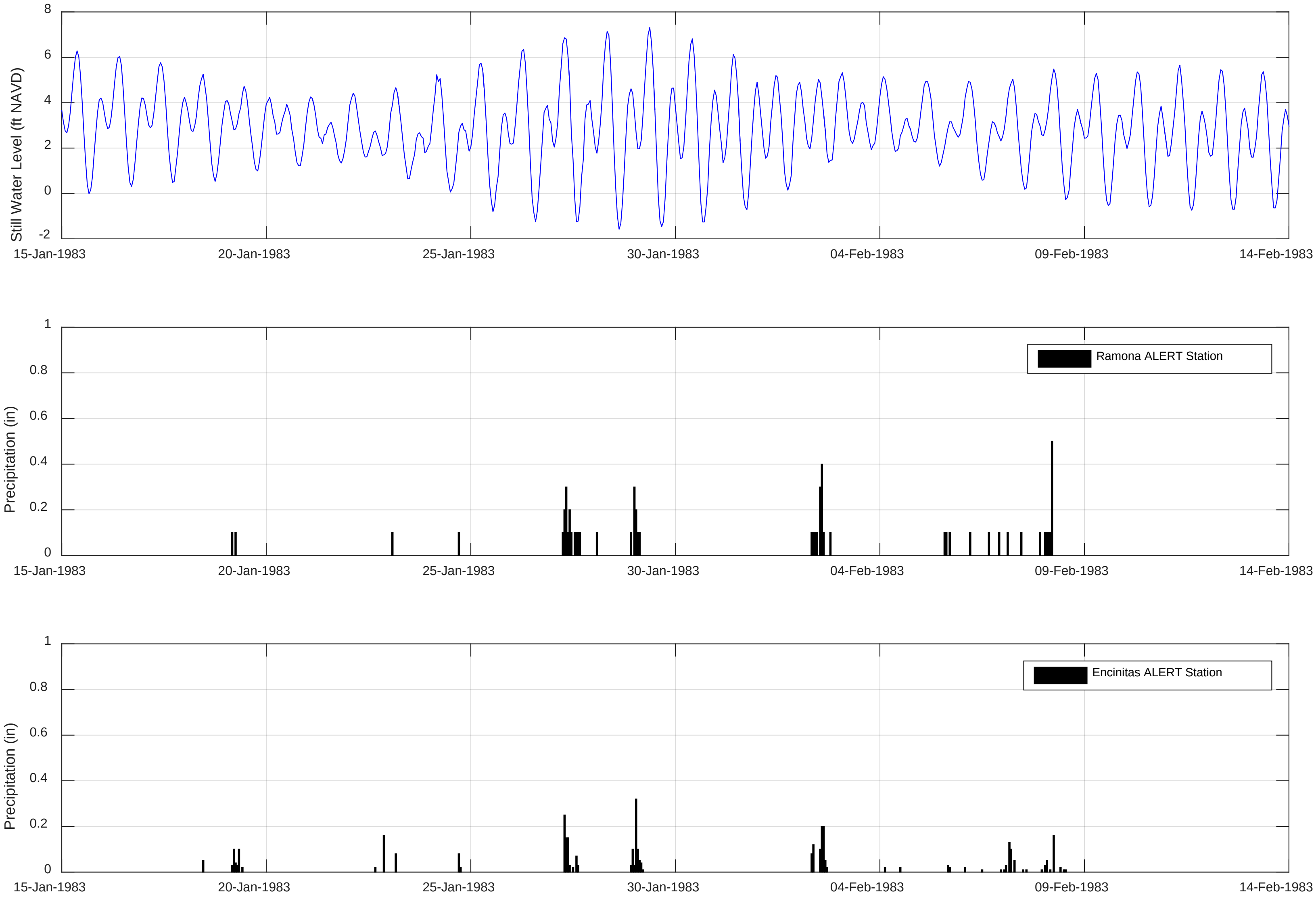


Figure 15

SWL and Precipitation – Flood 1983

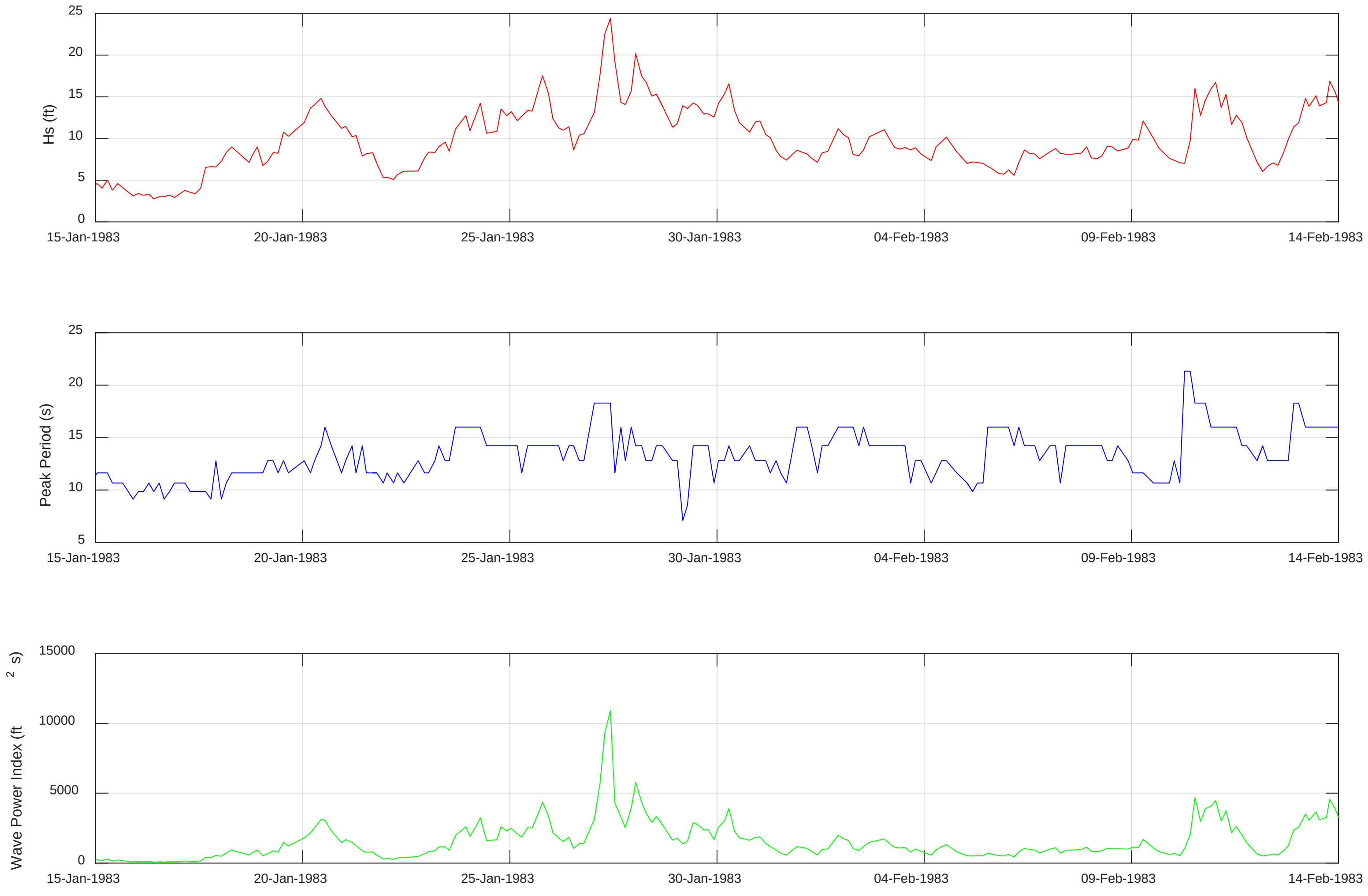


Figure 16

Wave Parameters from Begg Rock Station – Flood 1983

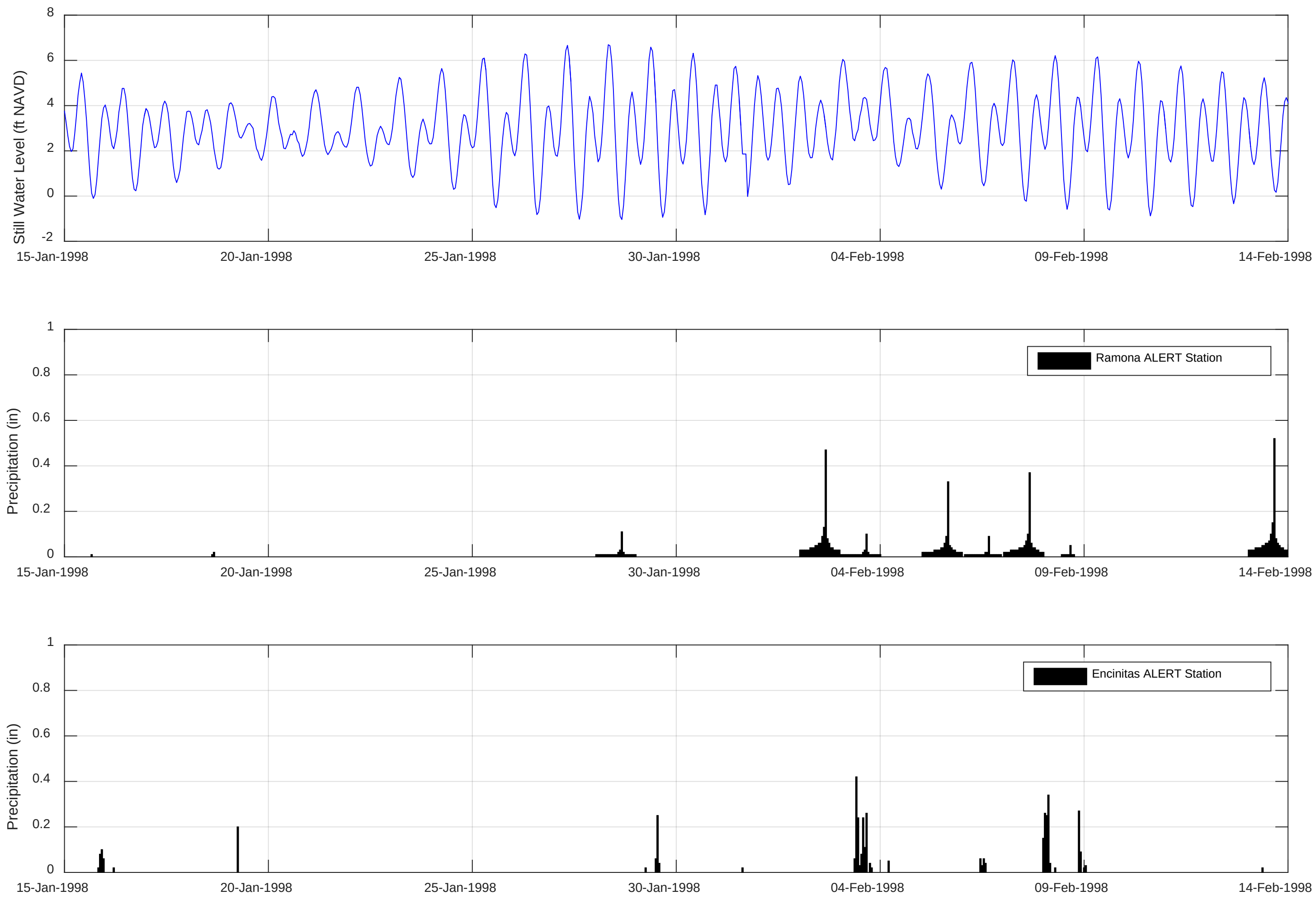


Figure 17

SWL and Precipitation – Flood 1998

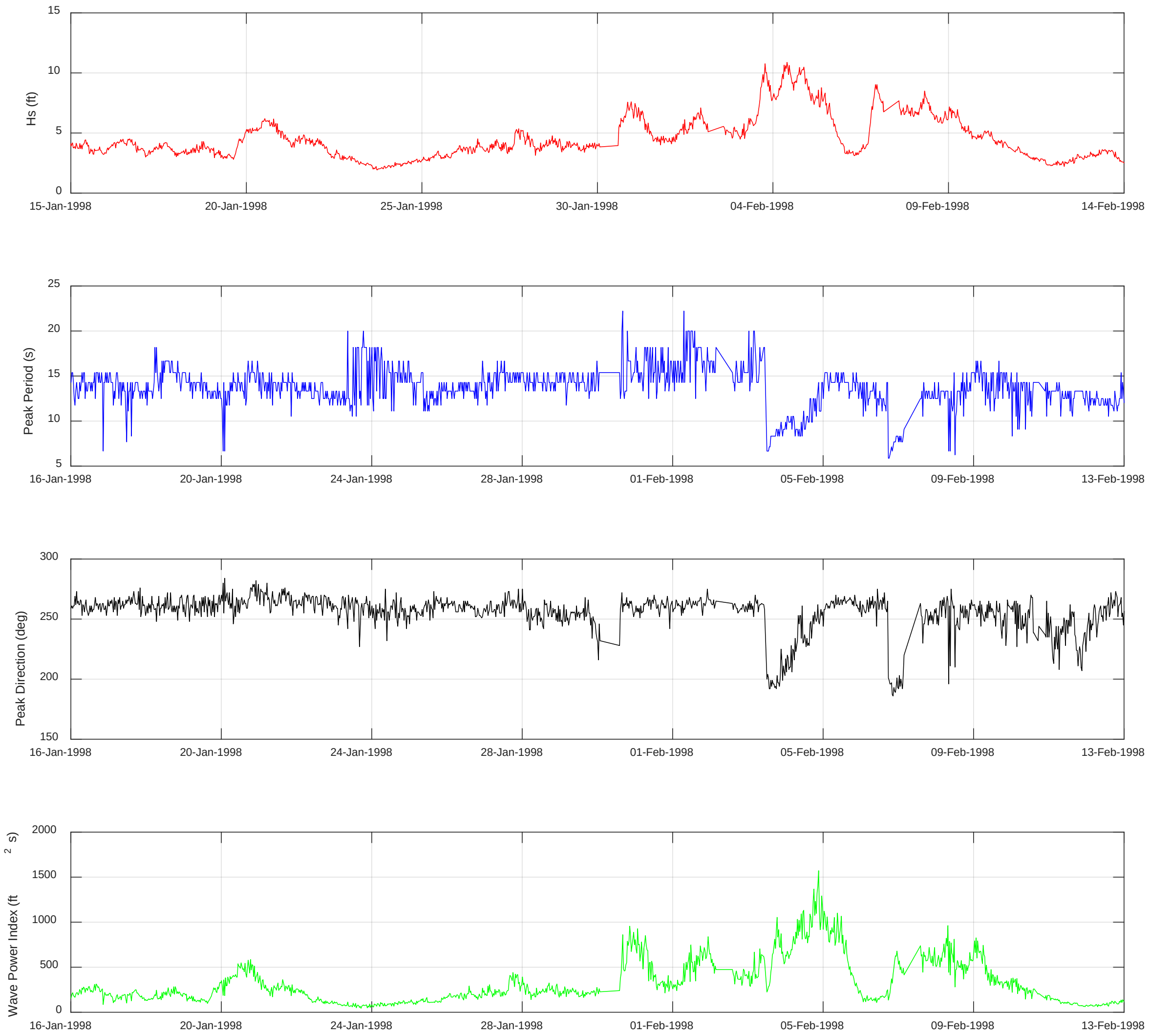


Figure 18

Wave Parameters – Flood 1998

Figure 19

Large Waves and Runup at La Jolla- December 11, 2015

Source: NBC 7, 2015

Figure 20

Large Waves at Torrey Pines – Dec. 11, 2015

In addition to rainfall occurring throughout December and January, a large TWL event occurred on December 12, 2015 (Figures 19 and 20). The event occurred during a spring tide, coinciding with a large northwesterly swell, with wave heights exceeding 13 feet at Torrey Pines. TWLs exceeded 20 feet, and caused overtopping and flooding along the Del Mar waterfront. This event was calculated to be approximately a 17-year return period event. Figures 21 and 22 show SWLs, precipitation, and wave parameters during the 2015 event.

More notable storms followed in January through March of 2016. These later storms had nearshore waves made larger by the result of beach erosion and lowering that occurred during the December event. Flooding and overtopping was reported in various locations along the Del Mar waterfront. Figure 23 and Figure 24 show elevated water levels and overtopping along the waterfront in February and March, respectively. Note that ESA's TWL analysis does not account for event erosion caused by large storms, such as the one in December, and therefore underestimates the TWL likely observed during storm events in early 2016.

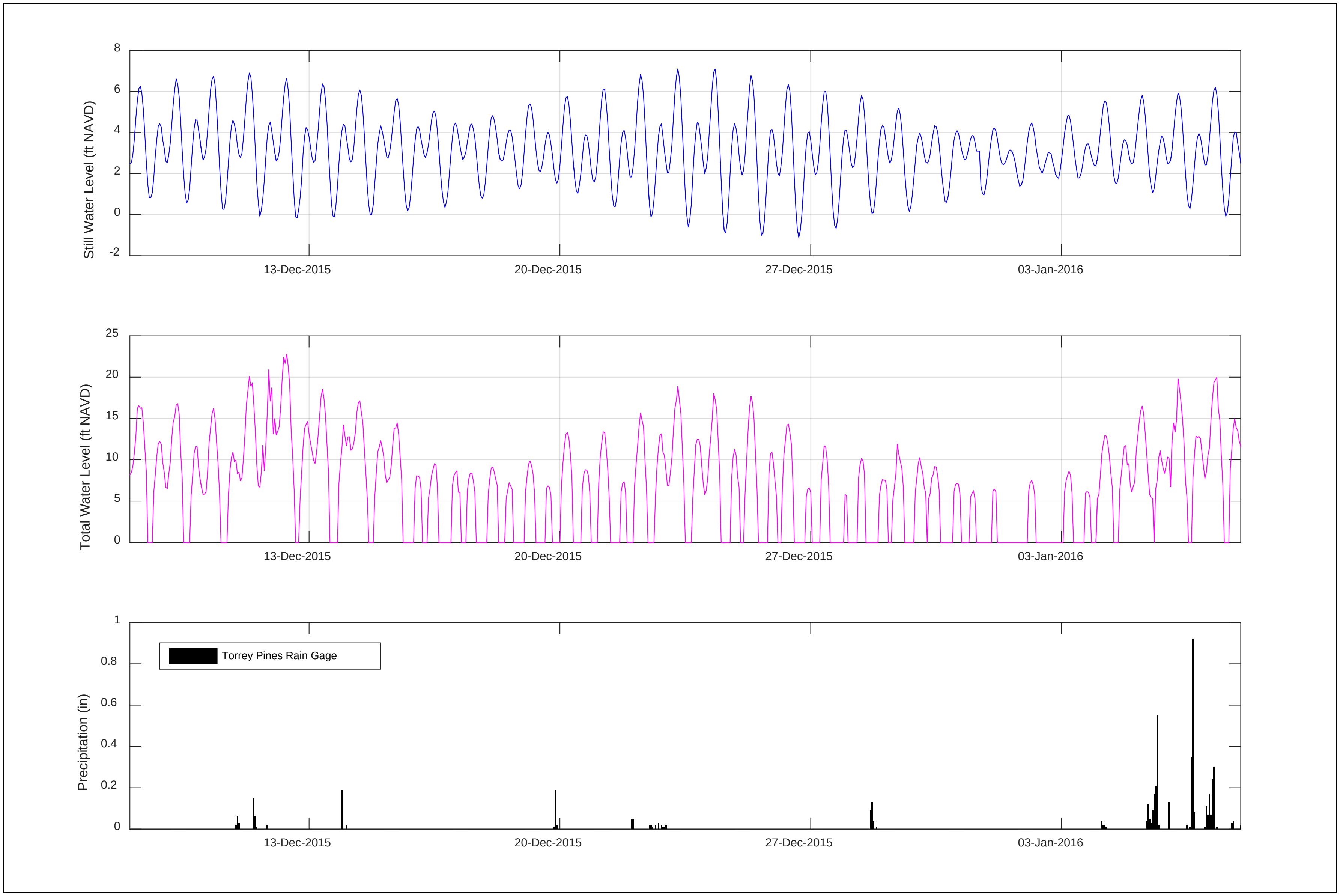


Figure 21

SWL, TWL, and Precipitation – Flood 2015

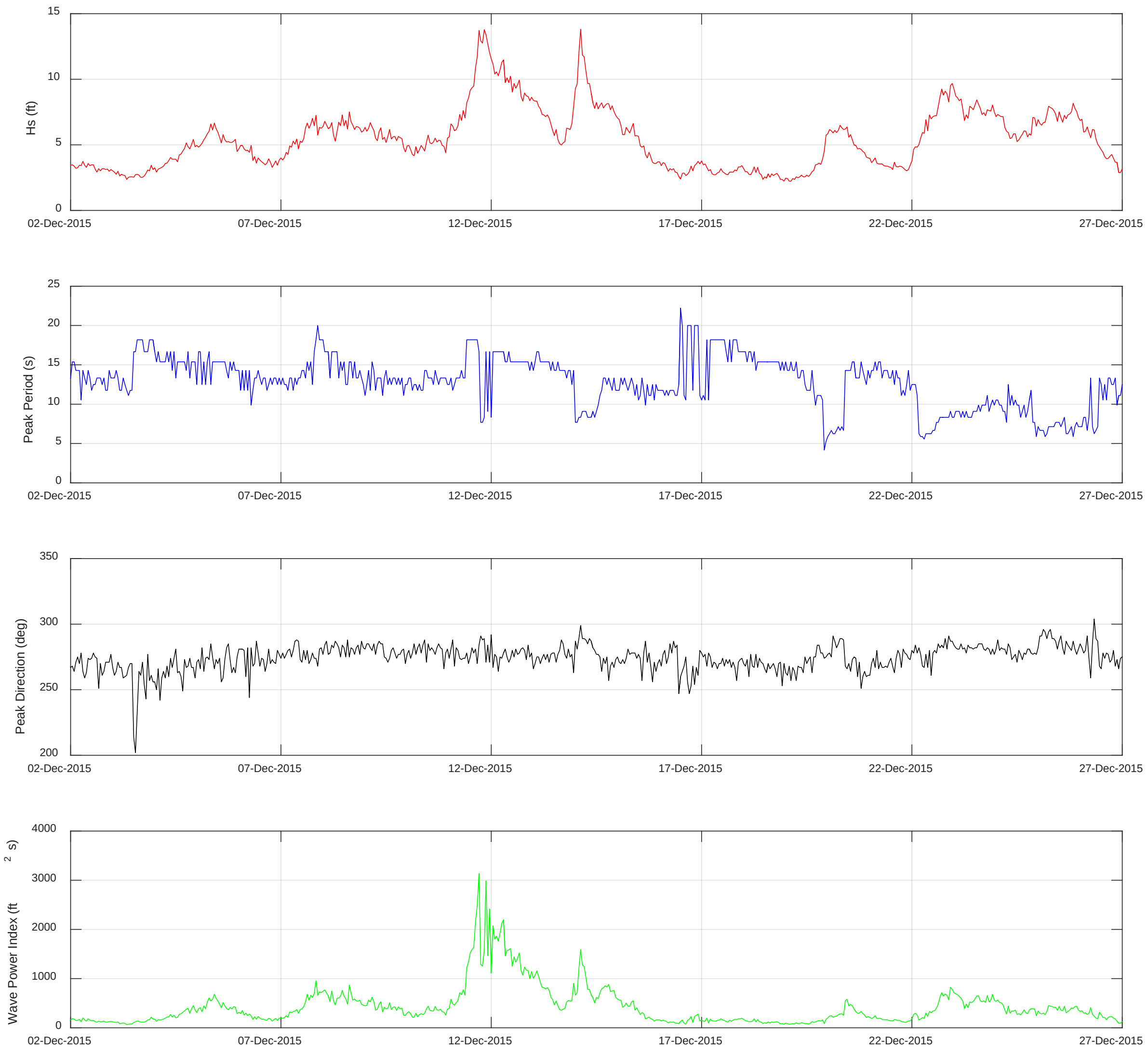


Figure 22

Wave Parameters – Flood 2015

Figure 23

Wave Runup in Del Mar, February 12th, 2016

Figure 24

Overtopping in Del Mar, March 8th, 2016

4 FUTURE EXTREME EVENTS

Extreme events are anticipated to occur more frequently in future as SLR and climate change increase flooding risks. In this section, the impact of SLR on beach widths and TWLs is investigated and the increase in extreme event frequency is discussed. The future frequency of several rainfall events is also summarized.

4.1 Beach Widths

Future beach widths were calculated for a range of sea level rise curves (CCC, 2015) using the Bruun rule with a slope of approximately 1:40. Figure 25 is a schematic indicating the change in beach width following the Bruun Rule, where W_o is current beach width, W_f is future beach width, MHW_o is current mean high water, and MHW_f is mean high water in the future with SLR.

Natural background erosion is present along Del Mar, which reduces beach widths in addition to the narrowing of the beach following the Bruun Rule (Figure 25). An average beach erosion rate within the Del Mar City limits is estimated as 2.5 feet/year, based on USGS short term erosion rates. The beach also receives sediment inflows from periodic nourishments and bluff sources, which increase beach widths. The rate of sand accretion due to nourishment and bluff contributions is not known and was not estimated for this study. However, given the historical stability of the beach, ESA assumes that the rate of background erosion is roughly equal to the rate of beach accretion when averaged over a long period of time. Thus, the beach width calculation presented in this section assumes an average net erosion rate of 0 feet/year. The actual effective erosion rate (erosion rate minus accretion rate) may vary from year to year depending on many factors (such as number of nourishments, storm conditions, etc.). However, assuming a zero net long-term erosion rate allows for a simplified analysis of sea level rise versus beach width.

A representative mean starting beach width was estimated to be approximately 95 feet in 2010 and was used as the baseline for this analysis. The width of 95 feet was calculated as an approximate annual mean beach width at MHW along a representative North Beach profile (Profile SIOB). The annual mean was calculated across surveys taken from January 2011 and January 2016, as shown in Figure 26. Profiles that were highly eroded likely as a result of storm event erosion were removed from the mean calculation for annual average width. A beach width analysis was also conducted for Profile SIOB using only winter beach profiles and only summer beach profiles. The average winter profile width at SIOB is approximately 70 feet, while the average summer width at SIOB is approximately 120 feet. Thus, future beach widths tabulated below represent an annual average beach width, which is typically 25 feet greater than winter beach widths and 25 feet less than summer beach widths.

Beach widths were assumed to not change significantly between 2010 and 2016. The annual average width of 95 feet calculated over years which survey data was available (2011 to 2016) was conservatively assigned to the baseline date of 2010.

The results, shown in Figure 27 and Table 2, indicate that the beach in Northern Del Mar will reach zero width as early as 2060. Though cross-shore widths vary North to South in Del Mar, no profiles are available from Coastal Environments south of 25th street. In general, beach widths are wider in North Beach than they are further south along the shore, and thus, beach widths will reach zero even sooner in areas with narrower beaches. Again, note that the annual mean beach width is tabulated in Table 4, which means that zero winter beach width with be reached sooner than 2060, and zero summer beach will be reached later than 2060.

Including the historic background erosion rate of 2.5 ft/year without including any sediment accretion due to nourishment or bluff sources will further decrease the time to zero beach width in North Beach to 2030.

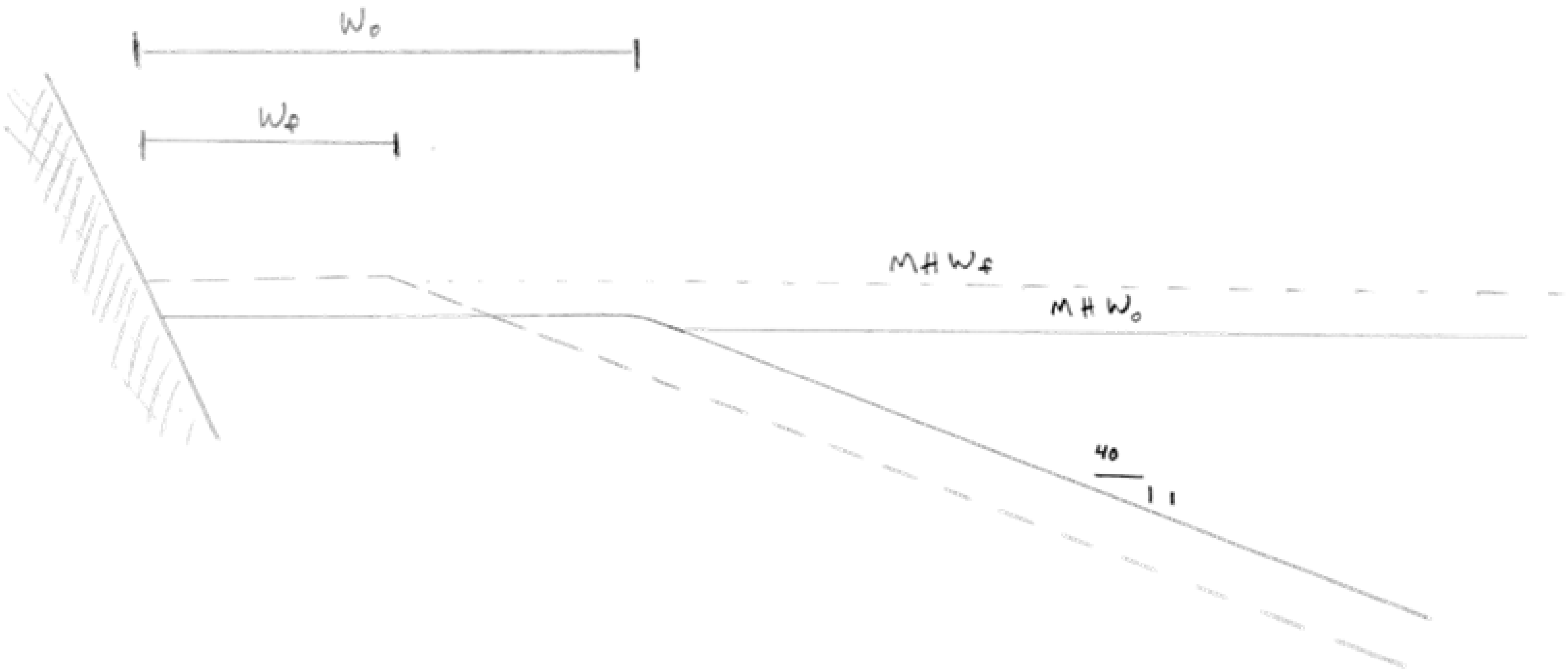


Figure 25
Beach Width Schematic (Not to Scale)

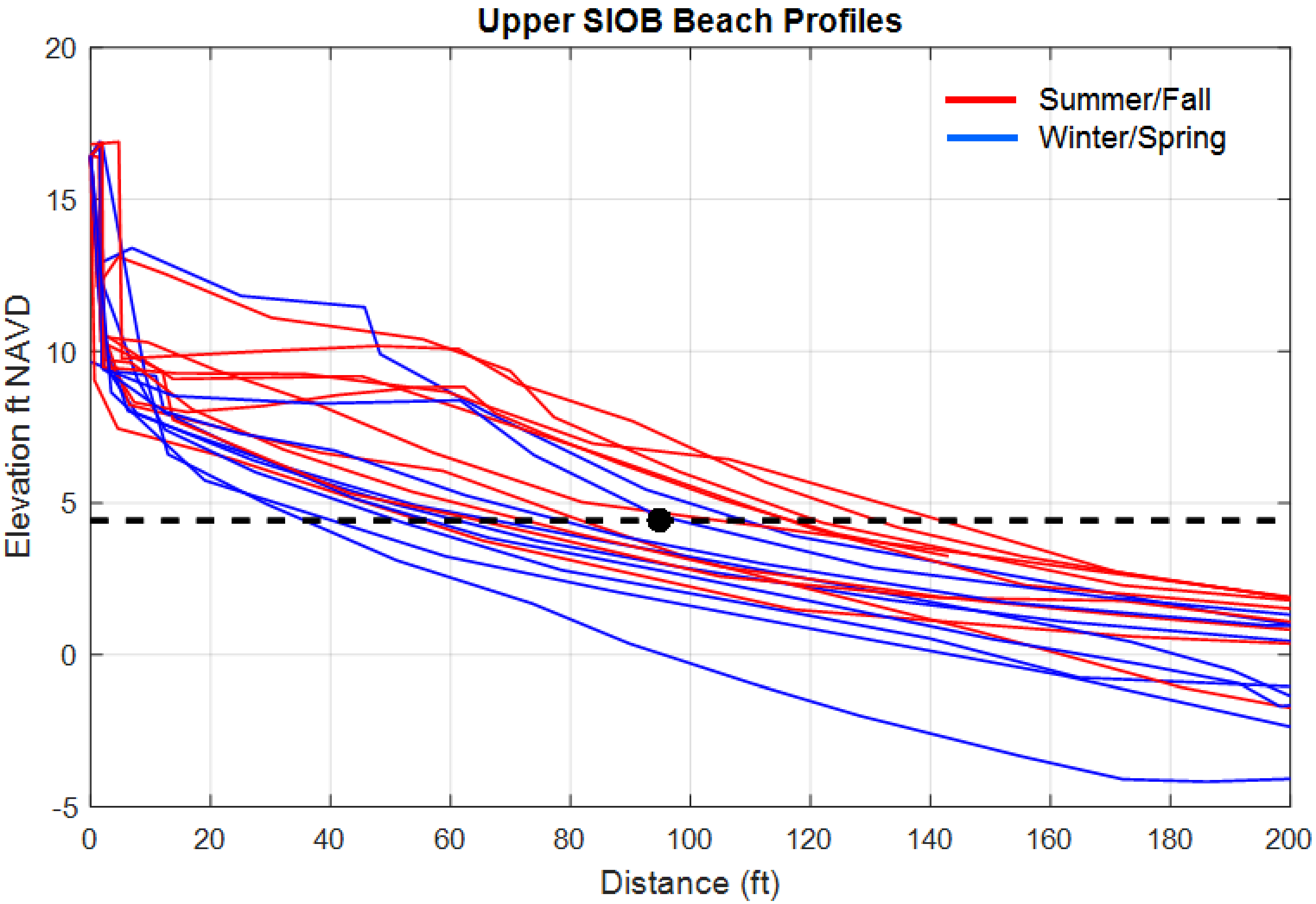


Figure 26
Upper SIOB Beach Profiles

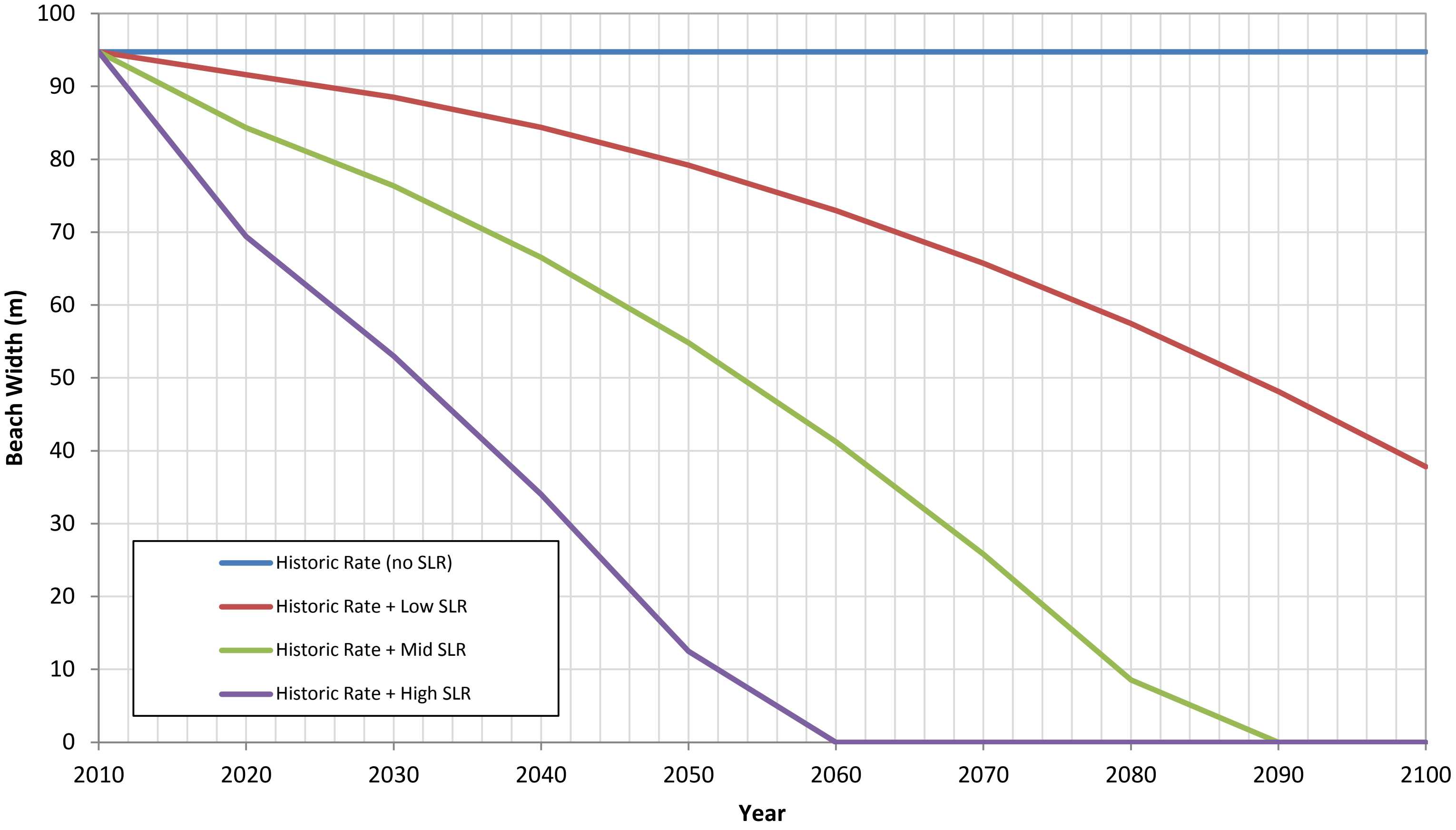


Figure 27

Beach Width Over Time with SLR

TABLE 4
BEACH WIDTHS OVER TIME WITH SLR

Beach Width (ft)	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Historic Rate (no SLR)	95	95	95	95	95	95	95	95	95	95
Historic Rate + Low SLR	95	92	88	84	79	73	66	57	48	38
Historic Rate + Mid SLR	95	84	76	67	55	41	26	9	0	0
Historic Rate + High SLR	95	69	53	34	12	0	0	0	0	0

The loss of beach has serious implications for shorefront homes and the City of Del Mar, as further discussed in Section 5 (Vulnerability Assessment) and Section 6 (Risk Assessment).

As sea level rises, beaches will lower and narrow as the beach moves inland along the Bruun Slope. When a beach is backed by a non-erodible structure, the beach cannot recess further inland, though it will continue to lower and narrow.

4.2 Bluff Retreat Analysis

The future acceleration of cliff retreat rates and future cliff top positions with sea level rise was assessed using results from the USGS CoSMoS 3.0 cliff retreat projections. Additionally, an analysis of historic cliff retreat for the Del Mar bluffs was performed for this assessment as a check of the CoSMoS results (Section 4.2.1). Future cliff retreat rates and cliff top positions with based on CoSMoS 3.0 results are described in Section 4.2.2.

4.2.1 Historic Bluff Retreat

Historic cliff retreat rates were estimated and projected into the future for comparison to the CoSMoS results. Historical cliff retreat was calculated with various methods using a 1934 (Hapke and Reid 2007) cliff top line and two airborne LIDAR data sets collected in 1998 and 2009. LIDAR data were processed into 0.5 m grid resolution digital elevation models using the second of two LIDAR returns (the most representative of the ground surface) and a “natural neighbors” interpolation. For cliff retreat analysis, the 7,500 ft (1.4 mi or 2,286 m) Del Mar cliff section was divided in to 762 ten-foot (three-meter) wide alongshore compartments.

As shown in Figure 28, long term historical cliff top edge retreat was estimated as the average compartment retreat between the 1934 cliff line and a cliff line digitized from the 2009 LIDAR digital elevation model. The same method was used to measure more recent cliff top retreat between 1998 and 2009 using digitized cliff lines from the LIDAR digital elevation models.

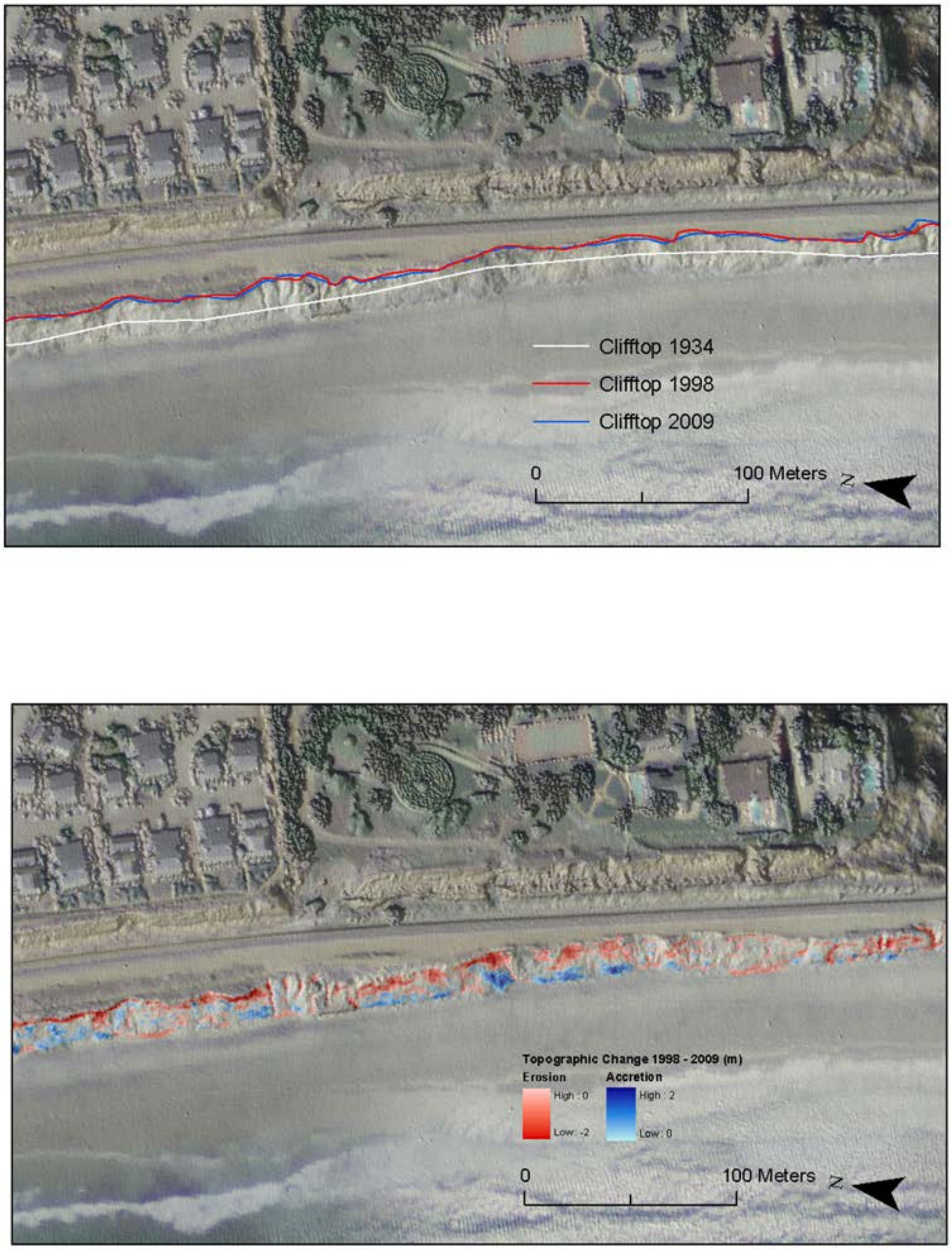


Figure 28

Clifftop edge retreat from 1934, 1998, and 2009 (top) and cliff face topographic change from 1998 to 2009 for a section of the Del Mar bluffs

Cliff retreat was also estimated for the 1998-2009 period using an average cliff face change method (Young et al., 2009). Digital change grids, estimated by differencing the 1998 and 2009 grids, show both negative (erosion) and positive (accretion, talus deposits on the cliff face or toe) changes. The digital change grids were filtered and edited to remove noise and erroneous data. First, all grid cells with vertical change less than 30 cm were neglected. Next, a minimum topographic footprint was imposed, requiring at least 8 connected cells of positive or negative change, thus enforcing a minimum change area of 2 m^2. This filtering identifies negative and positive individual topographic change areas with a minimum volume of about 0.6 m^3 (if all 10 cells had 38 cm of change). Finally, the filtered digital change grids data were edited visually to remove spurious changes caused by vegetation.

Cliff face changes were separated into negative (cliff and talus erosion) and positive (talus deposits) volumetric changes and then evaluated in 3 m wide (in the alongshore direction) cliff compartments. Dividing the volumetric compartment changes by the cliff height (extracted from the digital elevation model) and compartment width (3 m) yielded bulk negative and positive cliff face changes. The calculated change volumes underestimate the actual erosion because only relatively large volume (>0.6 m^3) and large footprint (>2 m^2) slides are detected. The neglected small events may play an important role in short-term seacliff evolution (Rosser et al., 2005; Young and Ashford, 2007), and their volume contribution for the study period is unknown. The net retreat was estimated as the differences between positive and negative cliff changes.

Table 5 summarizes the estimated historical retreat rates for the two periods analyzed. Note that while Table 5 includes average retreat rates, bluff retreat is episodic and variable over time. Little to no erosion can occur over a period of several years, and several feet of retreat can occur in a single year or event. The 1998 – 2009 period shows much less erosion than the 1934 – 2009 period. The rate of erosion from 1998 – 2009 may be less than the long term erosion rate because 1997 -98 was an erosive El Niño year that resulted in sediment release to the beaches and less erosion for the following years because winter wave and rain conditions from 1998-2009 were less severe than the long term average. There are also large uncertainties in the 1934 data with the actual rate of retreat from 1934 – 2009 resulting in an annual retreat uncertainty of 0.7 ft/year (Hapke and Reid, 2007). For the purposes of the Del Mar Vulnerability Assessment, the average historical retreat rate of 0.5 ft/yr from 1934 – 2009 is used as the best available estimate of long term retreat.

TABLE 5
HISTORICAL CLIFF RETREAT RATE ESTIMATES FROM 1934 – 2009 AND 1998 – 2009.

	1934–2009	1998–2009
Average (mean) retreat rate (ft/yr)	0.52 ft/yr	0.07 ft/yr
Standard deviation (ft/yr)	0.16 ft/yr	0.33 ft/yr
Maximum retreat (ft/yr)	1.3 ft/yr	2.7 ft/yr

Potential future cliff top positions were estimated at decadal intervals from 2020-2100 using the estimated mean Del Mar long term historical cliff retreat rate between 1934 and 2009 of 0.52 ft/yr (Appendix A, Figures A-1 to A-7). Future cliff line positions were generated by buffering the 2009 digitized cliff line for the specified retreat distance. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a potential measure of how much greater (or less) the retreat might be than the average projected retreat shown in Figures A-1 to A-7, however more research is needed to model the variability in cliff retreat with time. The influence of seawalls or other protection in the area (such as soldier piles) was not considered in these cliff line projections. Note that the potential extent of local erosion may be greater than the projected average cliff top position due to the occurrence of episodic localized landslides. Typically, ESA would use an offset from the average cliff top position shown in Figures A-1 to A-7 to define the extent of potential erosion, such as adding an additional 25 feet (two standard deviations) to the cliff retreat distances to shown in Figures A-1 to A-7. This approach has been used by ESA when mapping cliff erosion hazards in other locations; however, for this assessment, CoSMoS results are used and the cliff top projections in Figures A-1 to A-7 are provided for comparison only.

Figures A-1 to A-7 show the CoSMoS projected 2100 clifftop line and uncertainty for the 0.2 m SLR scenario, which is equivalent to projecting the historic rate of sea level and should therefore represent projecting the historic rate of retreat. For this scenario, CoSMoS applied retreat rates at 24 transects along the Del Mar bluffs that ranges from 0.4 ft/yr (0.13 m/yr) to 0.8 ft/yr (0.25 m/yr), with an average of 0.60 ft/yr (0.18 m/yr). The average retreat rate used in CoSMoS (0.60 ft/yr) is somewhat greater than the rate estimated per above (0.52 ft/yr). This difference would translate to projected CoSMoS 2100 clifftop lines that are approximately 7 ft beyond the 2100 clifftop projection for this study; however, Figures A-1 to A-7 show that the CoSMoS projection is up to 30 ft beyond the projection from this study. The discrepancy is likely in part from a smoothing filter applied to the CoSMoS cliff line projections. CoSMoS applies a filter to smooth predictions and "increase alongshore continuity and emphasize spatial trends in cliff retreat" (USGS 2016). As discussed above, ESA would typically add an offset to the average projected cliff top position to represent the potential extent of localized erosion. Given that the CoSMoS results are beyond the projections from this study, it is assumed that the CoSMoS high pass filtering method accounts somewhat for an offset that may represent the potential for localized erosion.

4.2.2. Future Bluff Retreat

CoSMoS 3.0 provides cliff top retreat rates and positions in 2100 for a range of SLR scenarios. The cliff 2100 retreat rates and positions for the 1.0 m (3.3 ft) SLR scenario was used as the mid SLR scenario for this assessment. For the high SLR scenario in this assessment (5.5 ft in 2100), ESA interpolated the 2100 cliff retreat rate and position from the CoSMoS 1.5 m (4.9 ft) SLR scenario and 2.0 m (6.6 ft) SLR scenario.

Starting with the 2100 cliff top positions based on CoSMoS 3.0, ESA projected backwards in time using the CoSMoS 3.0 cliff retreat rates to estimate cliff top positions in 2070, 2050, and

2030. Rather than assuming a constant retreat rate over time, ESA developed retreat rate curves where the retreat rate increases over time due to accelerating rates of sea level rise. The increase in retreat rates were assumed to be proportional to the increase in the rate of sea level rise based on the National Research Council (NRC 2012) sea level rise curves.

The average retreat rate along the south Del Mar bluffs from CoSMoS was used to project the 2030, 2050, and 2070 cliff top projections for the South Beach and South Bluffs Districts. The average rate along the North Bluffs was used for the North Bluffs projections.

The cliff top projections over time for the mid and high SLR scenarios are shown in Figures 29 and 30.

Figures 29 to 30 (and Figures A-1 to A-7) also show the railroad centerline with a 10 ft offset from the centerline to represent the minimum distance from the clifftop that may be acceptable for railroad safety. This 10 ft offset is based on the offset used in Leighton & Associates' (2010) geotechnical evaluation of the Del Mar Bluff Stabilization Project prepared for SANDAG. According to Leighton & Associates (2010), the 10 ft offset is the distance at which stabilization would be required following Caltrans criteria and that "NCTD has indicated that a failure within 10 feet of the track would be a serious concern that would likely 'shut down' the rail line." Note that the distance of 10 ft from the railroad centerline, which is "approximately 6 ft beyond the end of a typical railroad tie" (Leighton & Associates 2010), is small relative to the uncertainty associated with cliff erosion predictions (i.e., this offset is within the uncertainty distance of 25 feet (2 standard deviations) and 30 feet (USGS apparent smoothing) over the forecast period).

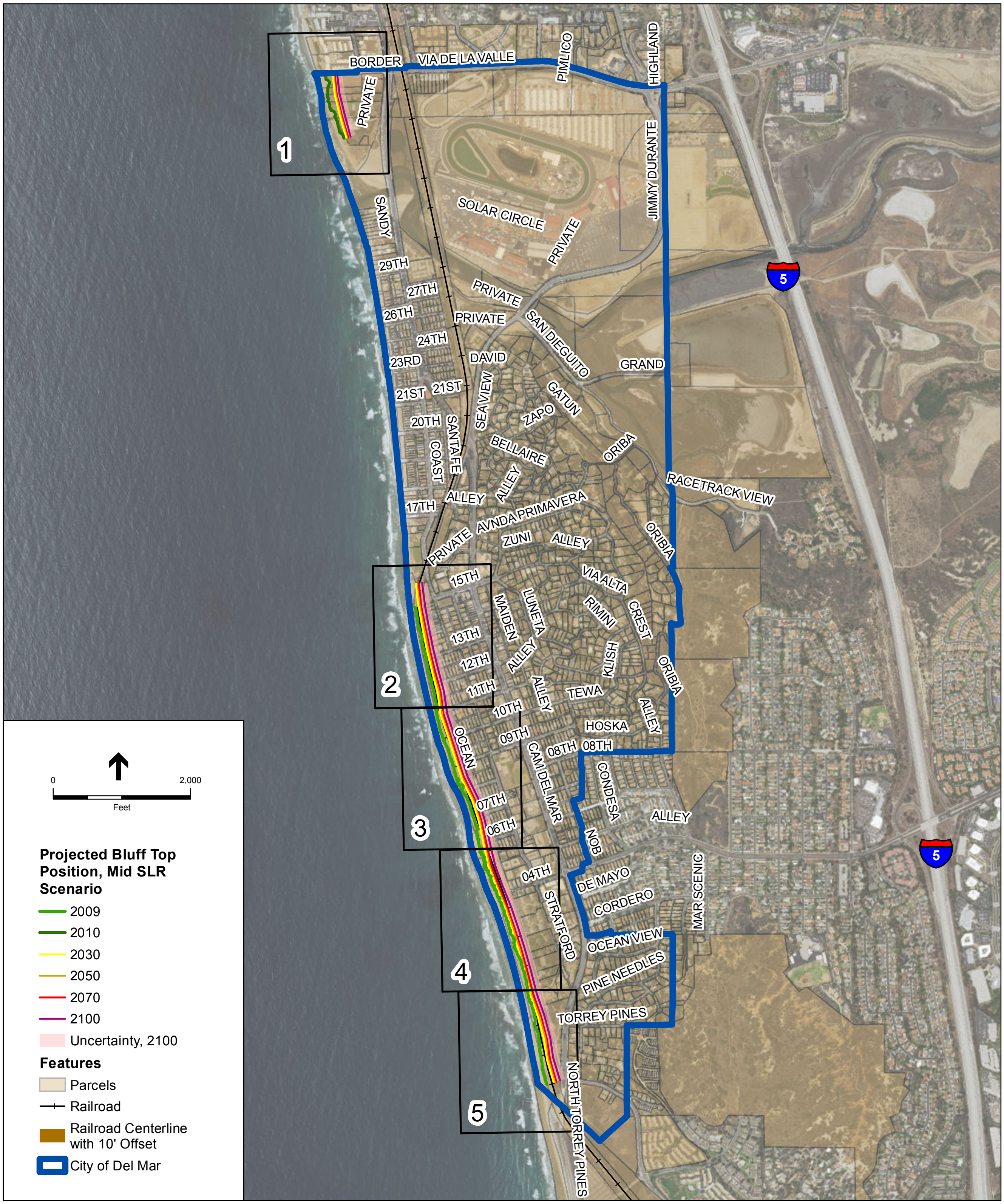
The results of the bluff retreat analysis and vulnerabilities are discussed in Section 5.

4.3 Coastal Flood Levels with SLR

As still water levels (SWLs) rise and beaches narrow and lower, coastal flood levels or total water levels (TWLs) increase non-linearly. The Total Water Level (TWL) is estimated by combining measured still water levels near the site (Still Water Level, SWL) with the wave runup, which is a function of the wave height, wave period and the slope of the shoreform (beach, marsh, embankment, etc.). ESA repeated the analysis described in Section 2.6 for a medium SLR scenario at 2050 and 2100 and performed an extreme value analysis on the TWL results.

Extreme TWLs are caused by combinations of high still water levels and/or large waves. Coastal storm systems can cause both high water levels due to low atmospheric pressure and large waves, resulting in high TWLs. El Niño may exacerbate coastal storms in California, causing periodic extreme TWLs. Additionally, TWL is dependent on the slope of the beach. Steeper beaches result in higher TWLs while flatter beaches lower TWLs. An extreme value analysis of TWL illustrates the statistical likelihood of extreme events based on historical data samples. This analysis method helps evaluate coastal flooding risk.

The TWL extreme value analysis is shown in Figure 31. The annual maximum TWL from 2001 through 2015 were fit with a Gumbel Least-Squares statistical fit. TWLs for return periods between 2 and 50 are shown in Table 6. Due to the short period of record, return periods beyond 50 years are highly uncertain and are not reported in Table 6. Note that existing seawalls and revetments along Del Mar Beach have a maximum elevation of between 14 and 17 feet NAVD. The computed TWLs exceed these structure elevations annually, while observations have not supported evidence of annual overtopping. This indicates that calculated TWLs may be biased high by up to five feet. This is within the accuracy of this analysis, which is sensitive to beach profile and surface conditions (e.g. rock and sand placement).



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Position in 2010 (north) and 2009 (south) is based on LiDAR elevation data.

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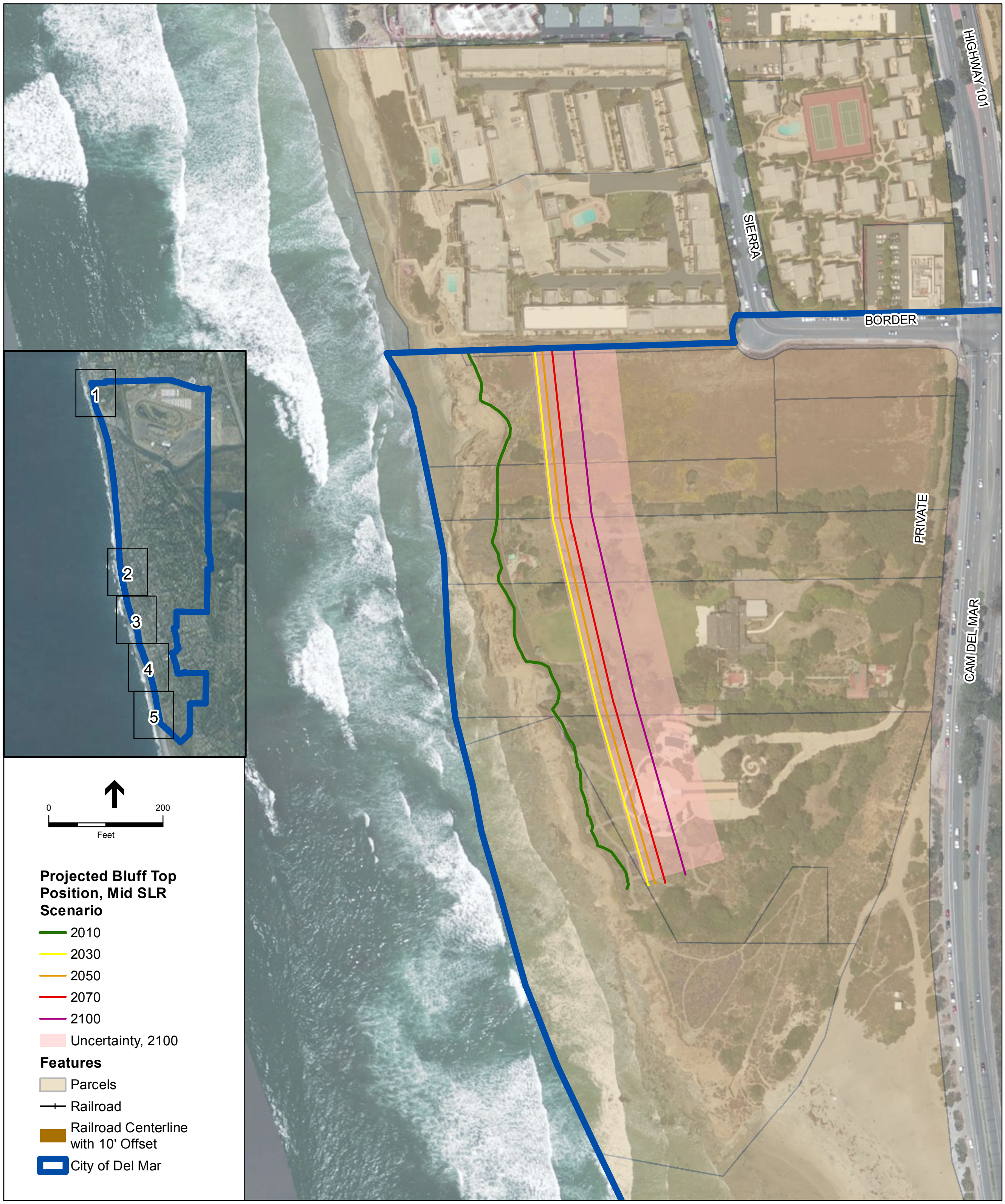
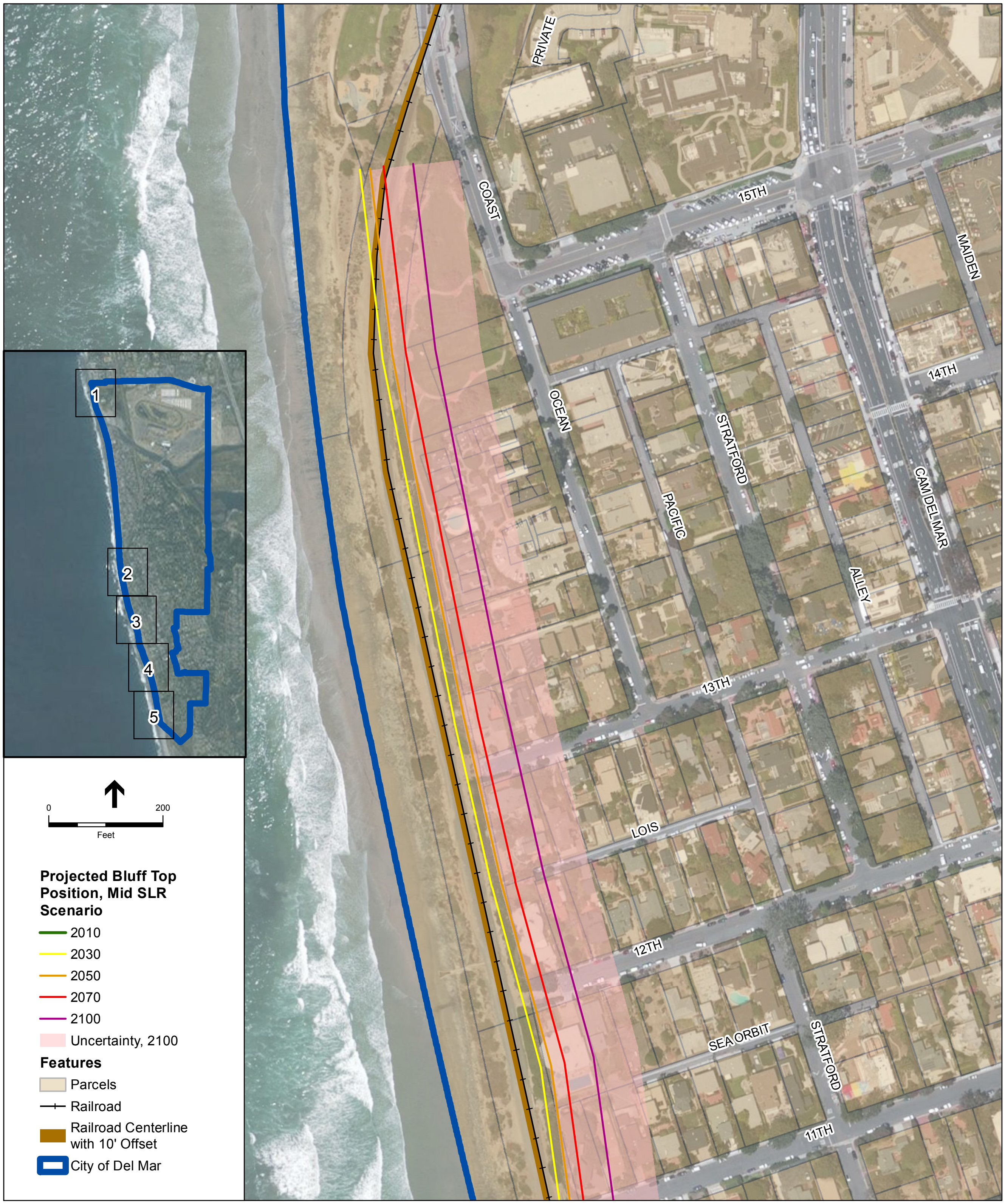
Figure 29- Map Grid Overview
Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 29.1
Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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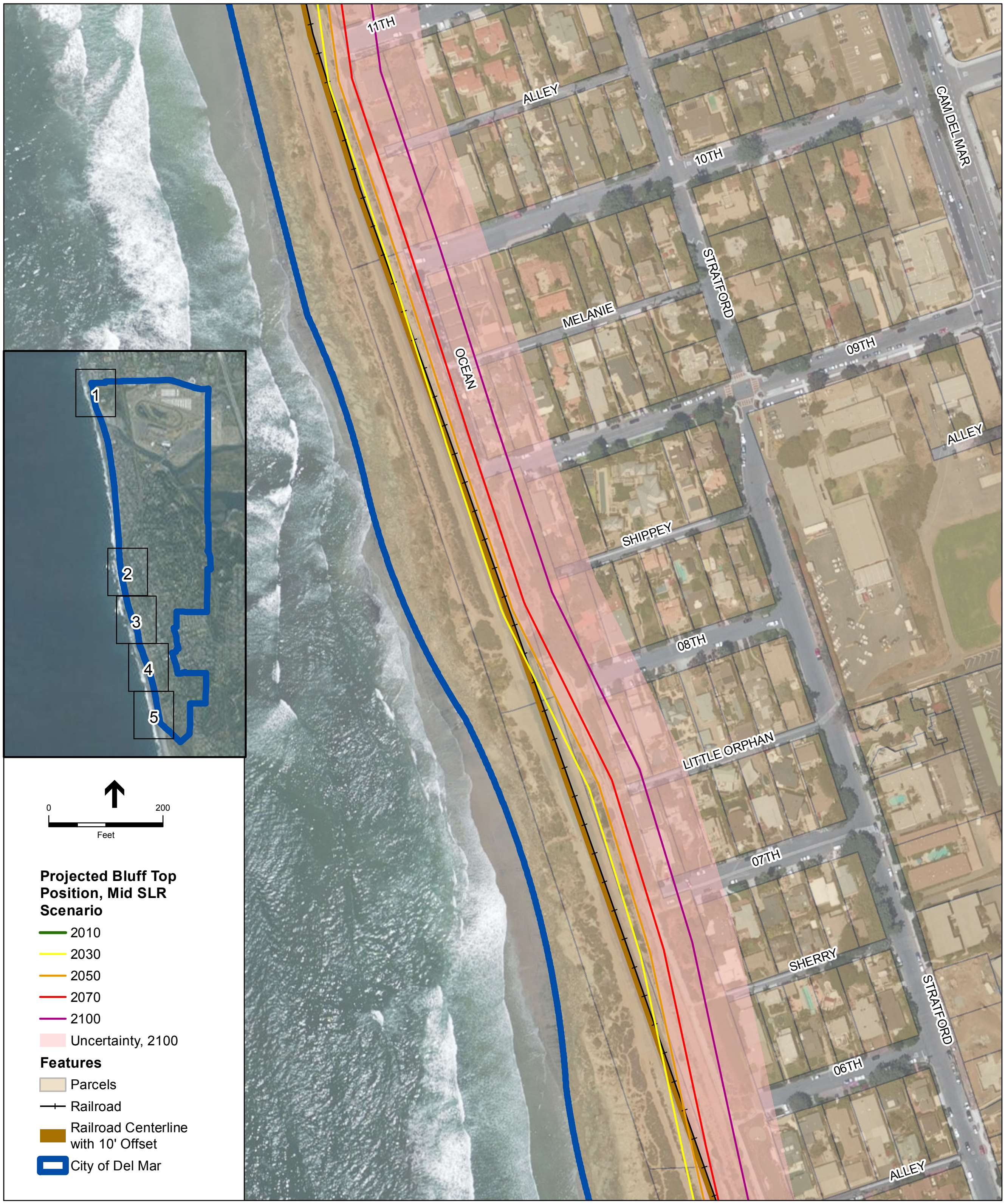
Figure 29.2

Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability

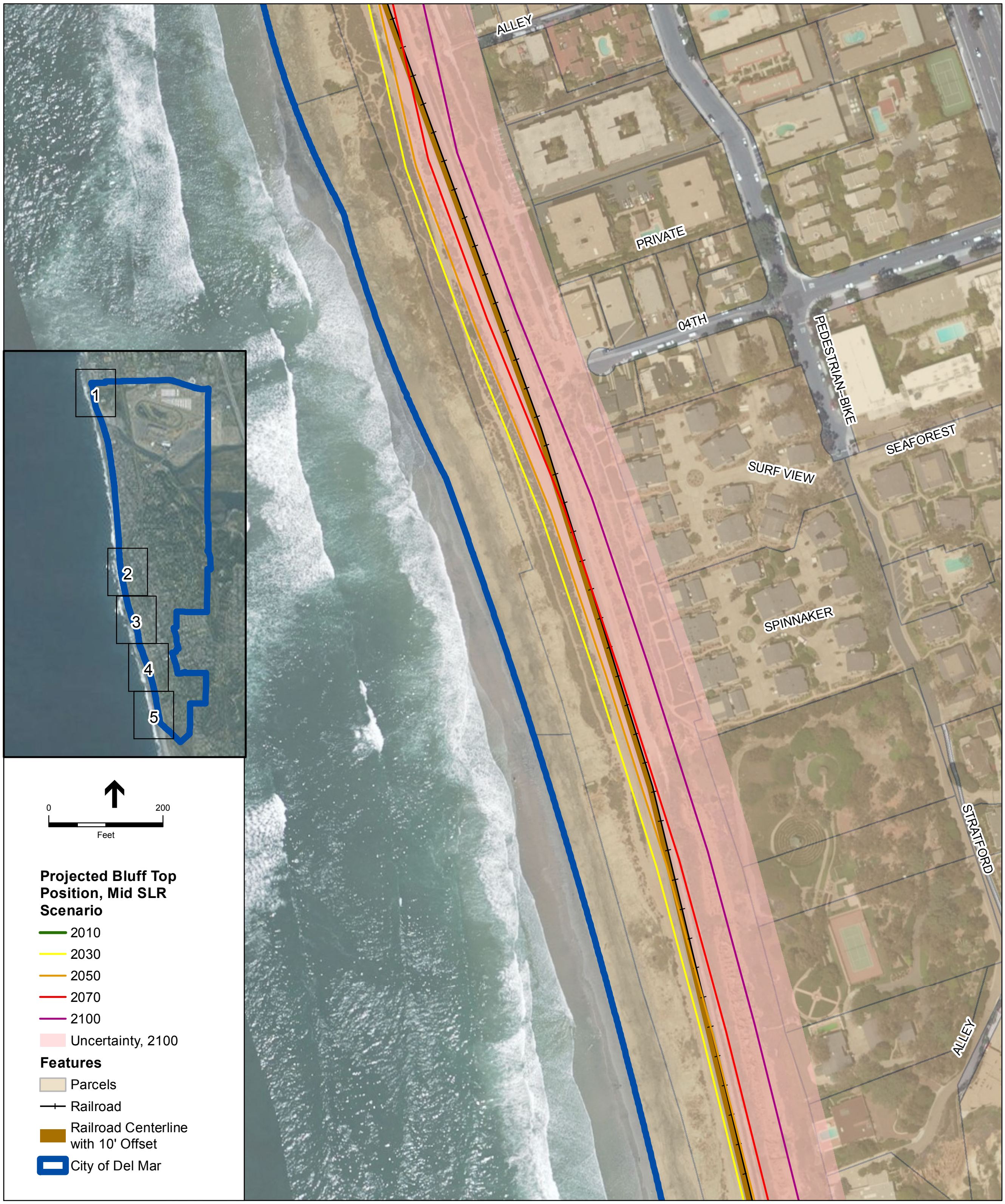


SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

Figure 29.3
Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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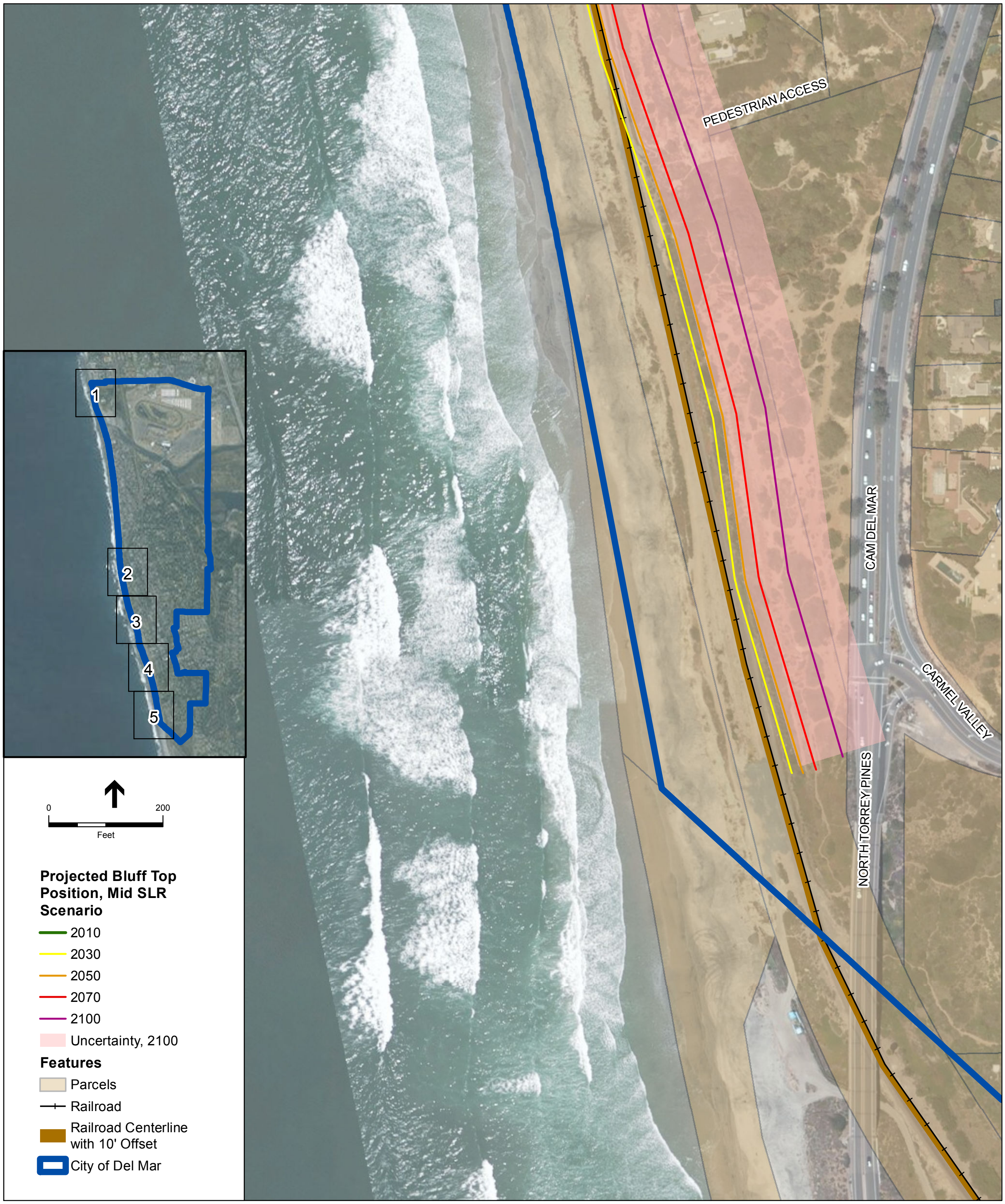
Figure 29.4

Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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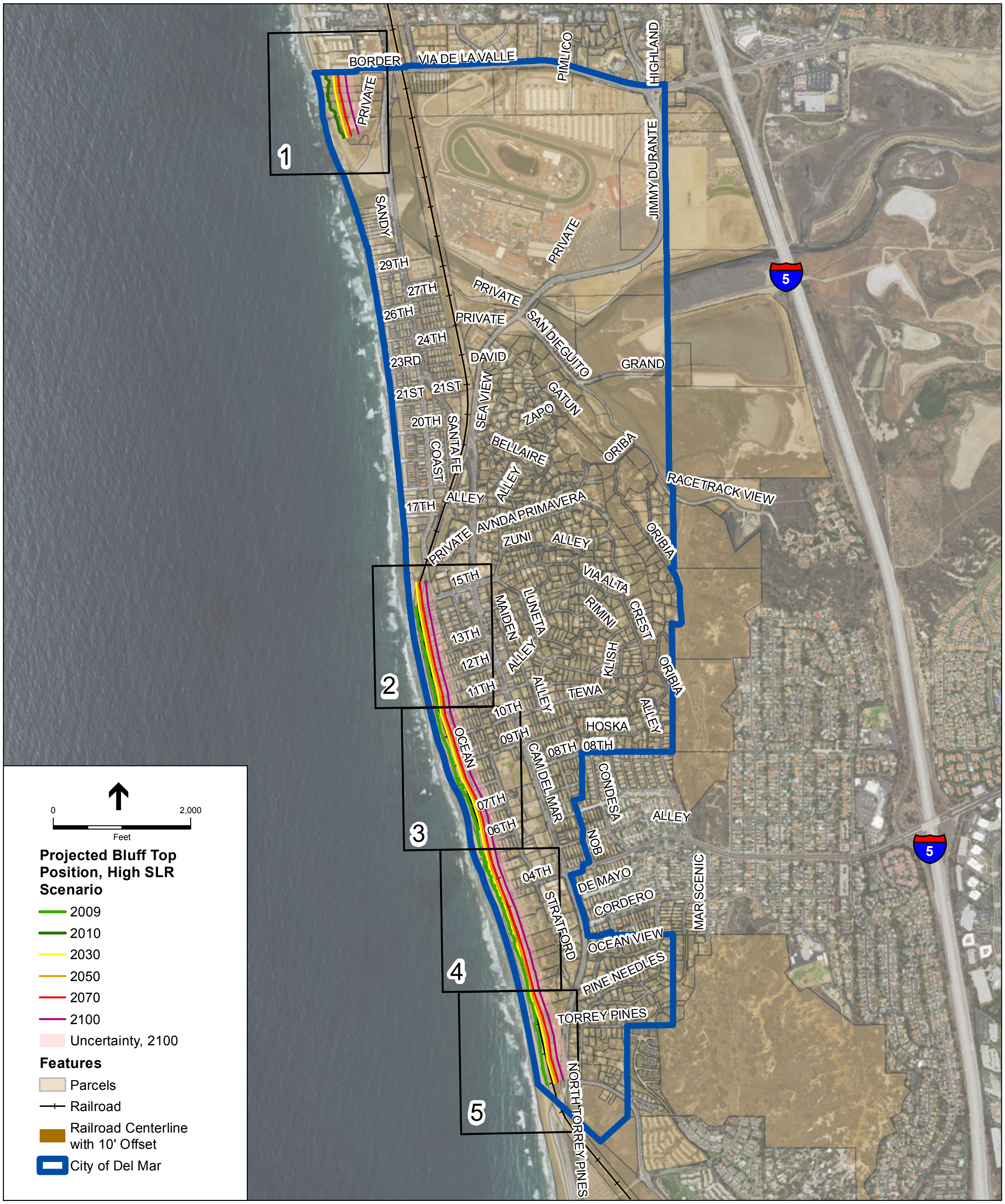
Figure 29.5

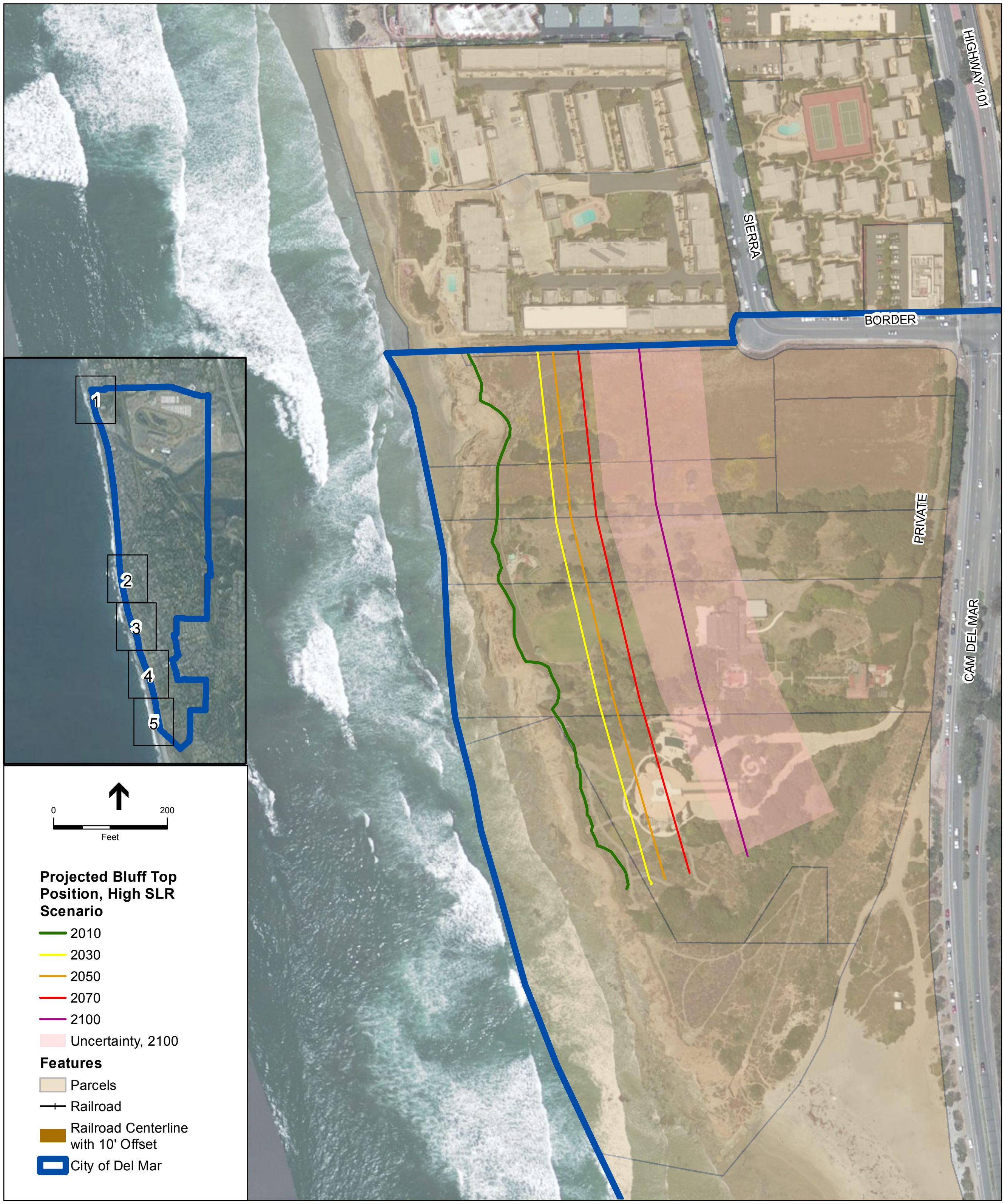
Mid Sea Level Rise in Del Mar Properties and Roads Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 30- Map Grid Overview
High Sea Level Rise in Del Mar
Properties and Roads Vulnerability

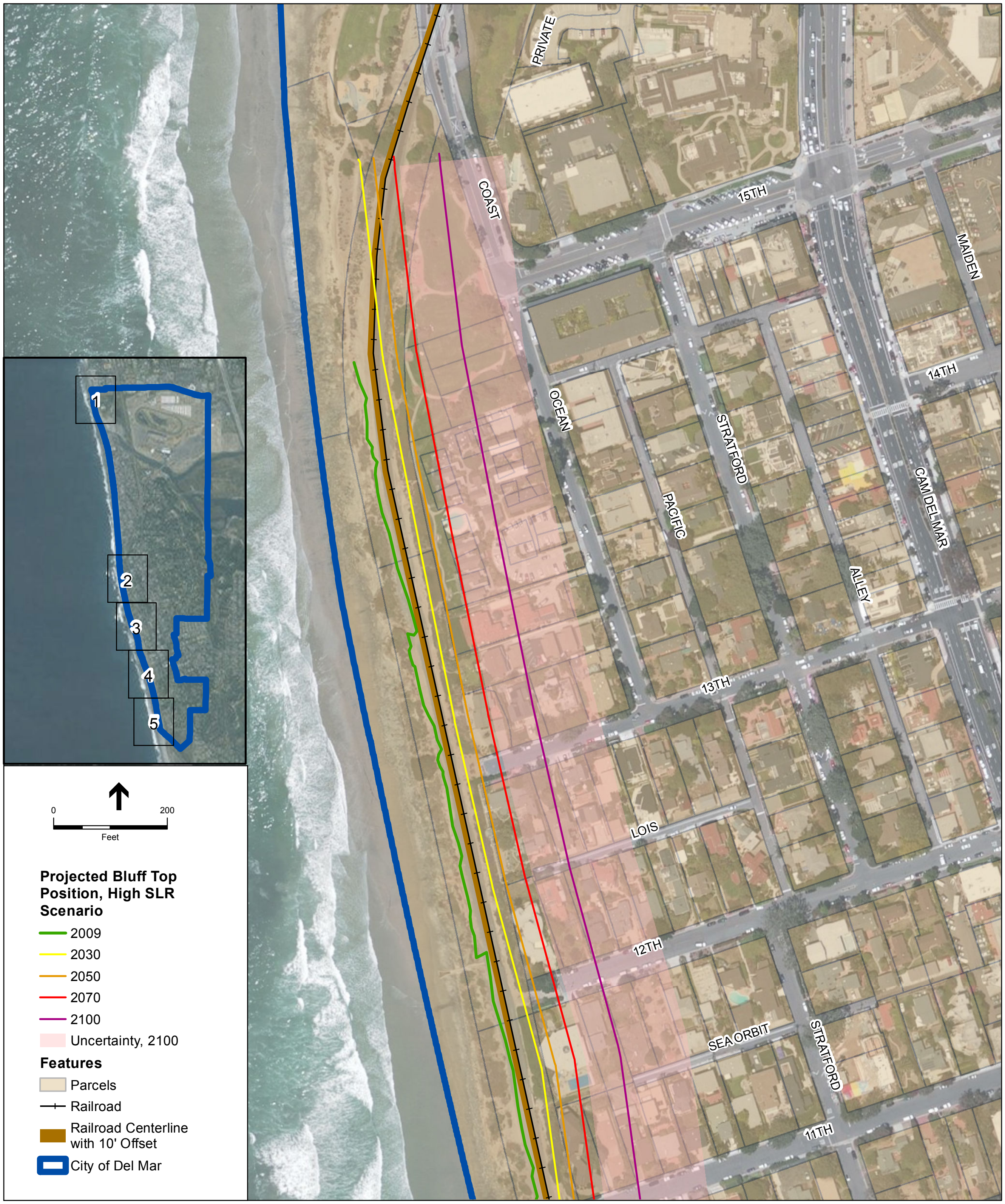


SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 30.1

High Sea Level Rise in Del Mar Properties and Roads Vulnerability

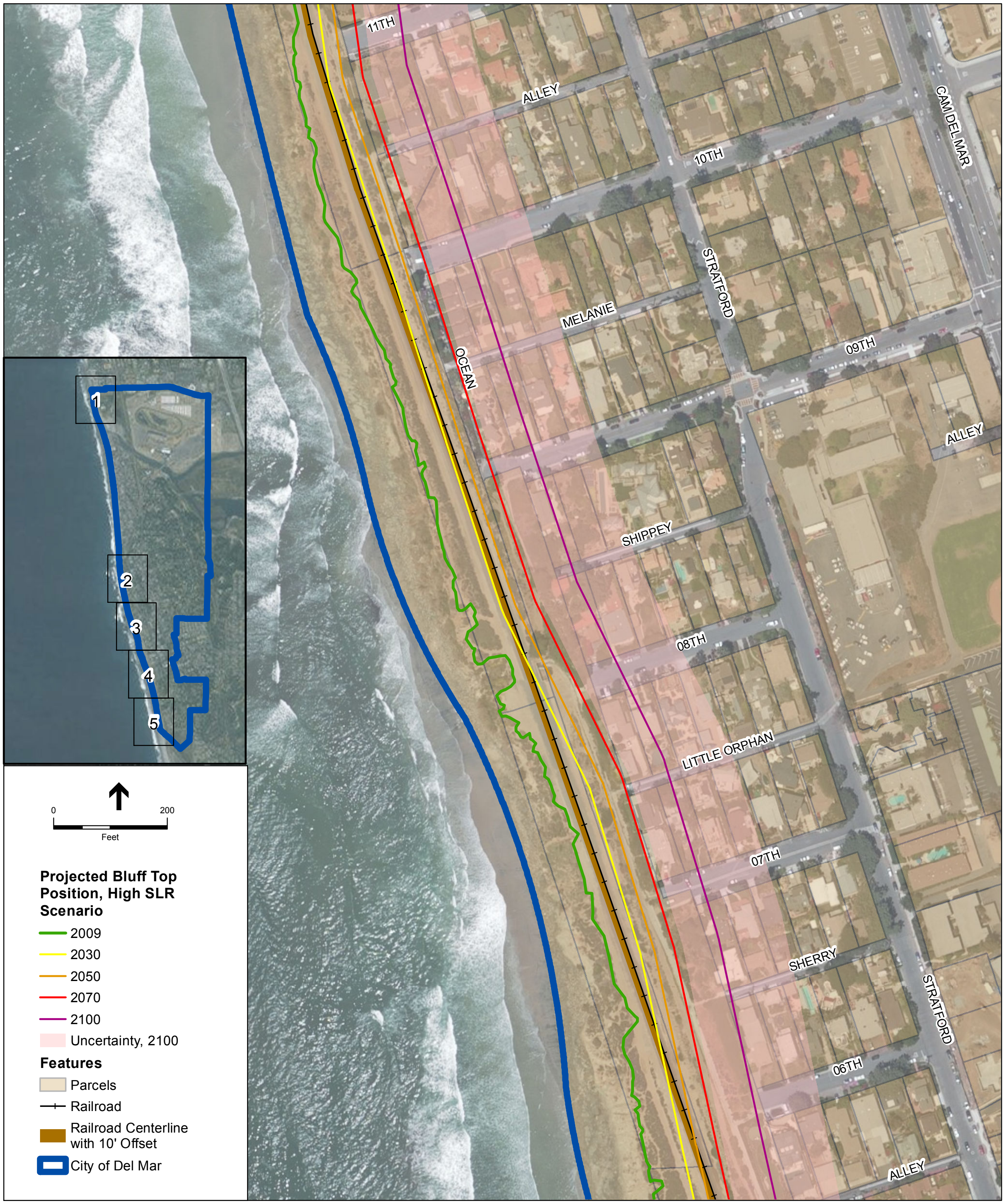


SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

Figure 30.2
High Sea Level Rise in Del Mar
Properties and Roads Vulnerability



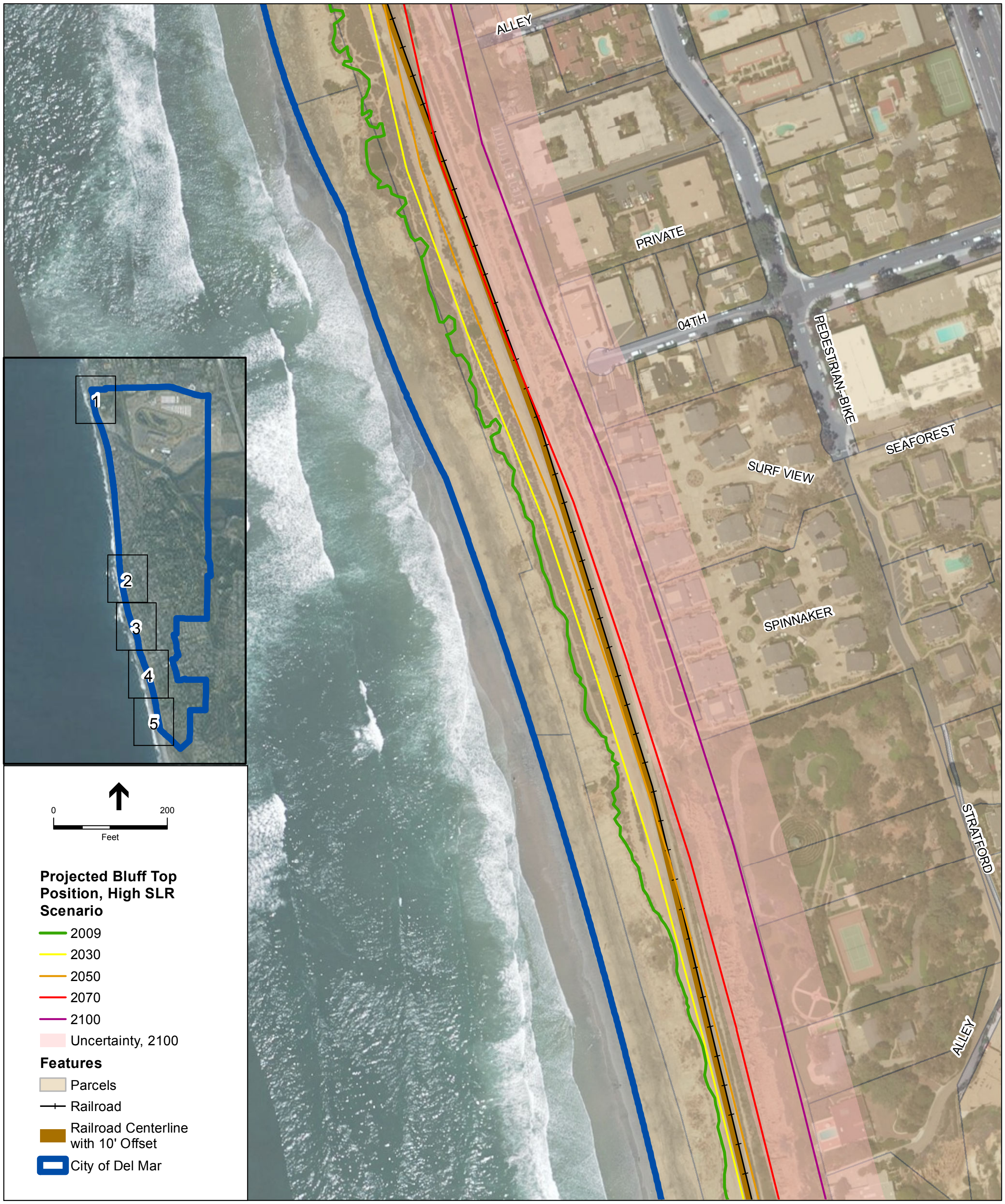
SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

Figure 30.3

High Sea Level Rise in Del Mar
Properties and Roads Vulnerability



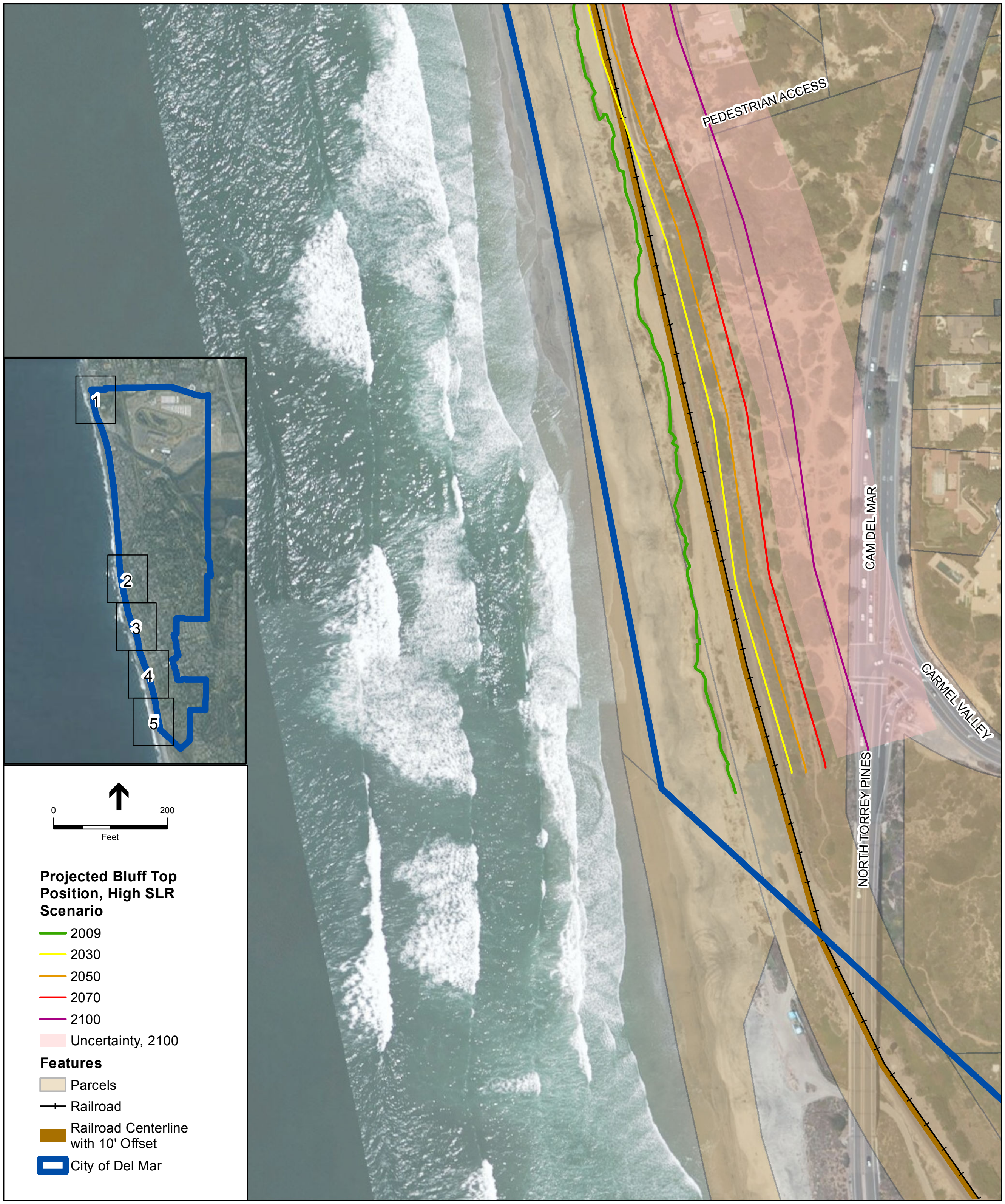
SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

Figure 30.4

High Sea Level Rise in Del Mar
Properties and Roads Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

Figure 30.5

High Sea Level Rise in Del Mar
Properties and Roads Vulnerability

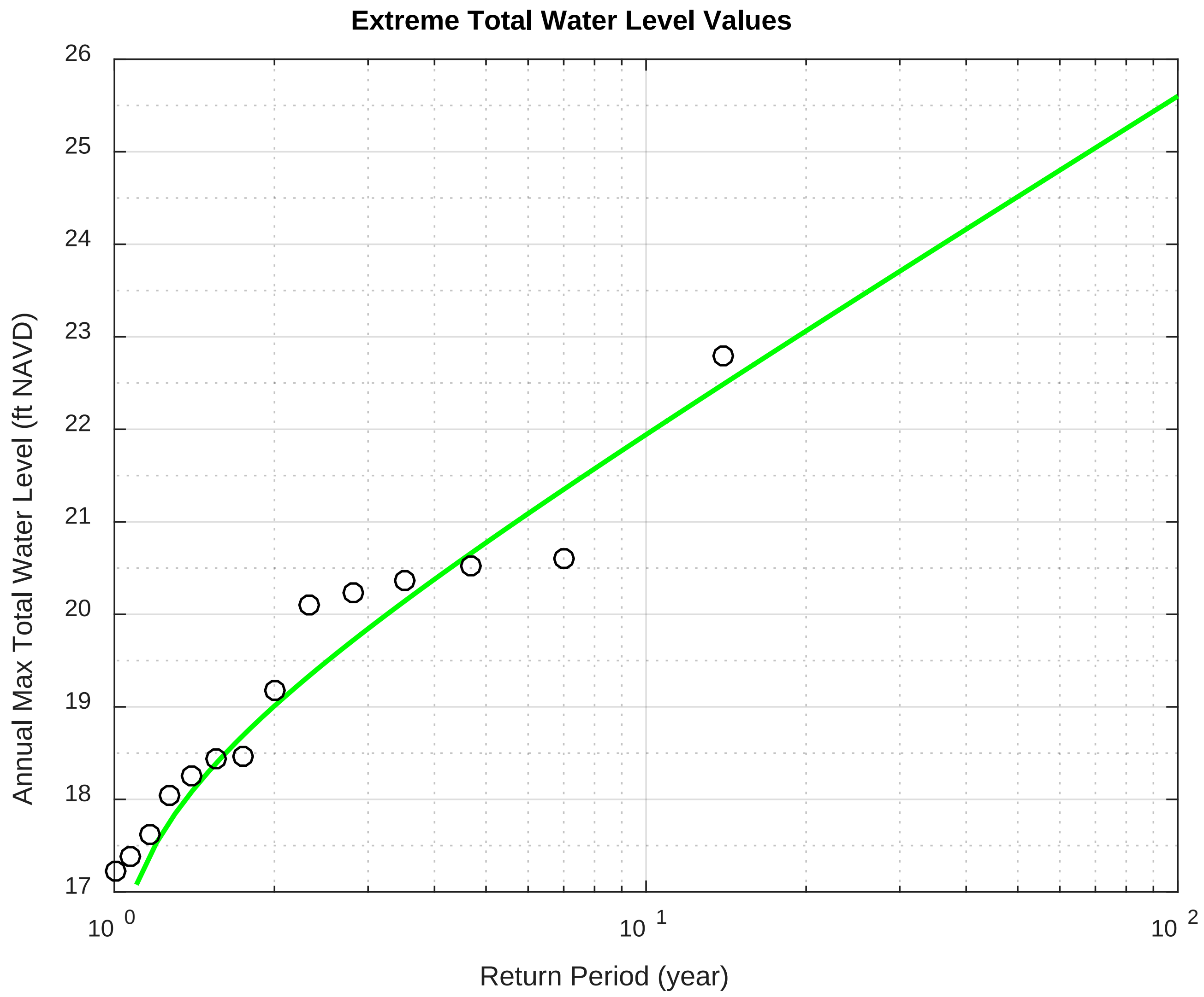


Figure 31

Extreme Value Analysis – Existing Conditions

TABLE 6
RETURN PERIODS – EXISTING CONDITIONS

Return Period	TWL (ft NAVD)
2	19.0
5	20.8
10	21.9
25	23.4
50	24.5

An extreme value analysis for TWL in 2050 and 2100 was calculated by adding sea level rise to the SWL record and accounting for beach lowering. Beach lowering was included by decreasing the bed elevation where waves break in the modified TAW analysis. Figure 32 shows the existing, 2050, and 2100 TWL extreme value analysis. The existing TWL for the 2015 and 1983 extreme events are plotted at their respective return periods for existing conditions and for 2050 conditions.

With SLR, the extreme events observed in 1983 and 2015 will become more frequent. The 1983 TWL will decrease from a >100-year event to an approximately 8-year event in 2050, and the 2015 event will decrease from a 12 year event, to an annual event in 2050. In 2100, both of these events will likely occur at least annually.

Note that this extreme value analysis results in extremely high water levels for 2050 and 2100. Due to the limited period of record and the limitations of the TWL calculations, these estimates are intended to show a range of possible future conditions and include significant uncertainty.

4.3.1 Comparison with FEMA Flood Maps

Current effective FEMA FIRM maps were last updated in the 1980’s. These maps show 100-year water levels around 10 feet NAVD along Del Mar Beach (Figure 33). This value is very low, and is well below existing revetment and seawall elevations (approximately 14 to 17 feet NAVD). It should be noted that ESA’s TWL analysis deviates significantly from the dated FIRM 100-year estimates. An update to the FIRM maps is underway for the greater San Diego Shoreline. Preliminary updated maps should be compared when released.

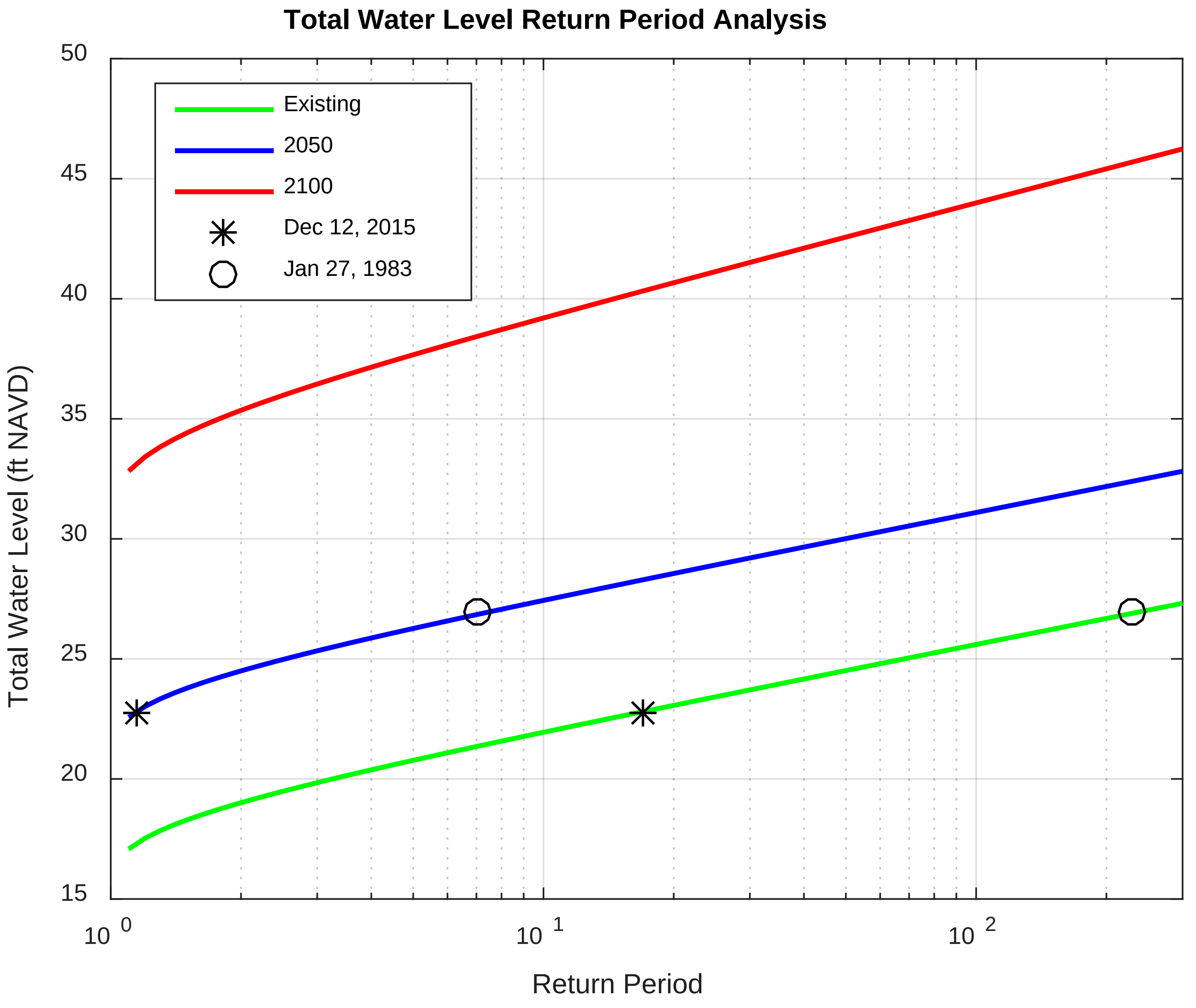
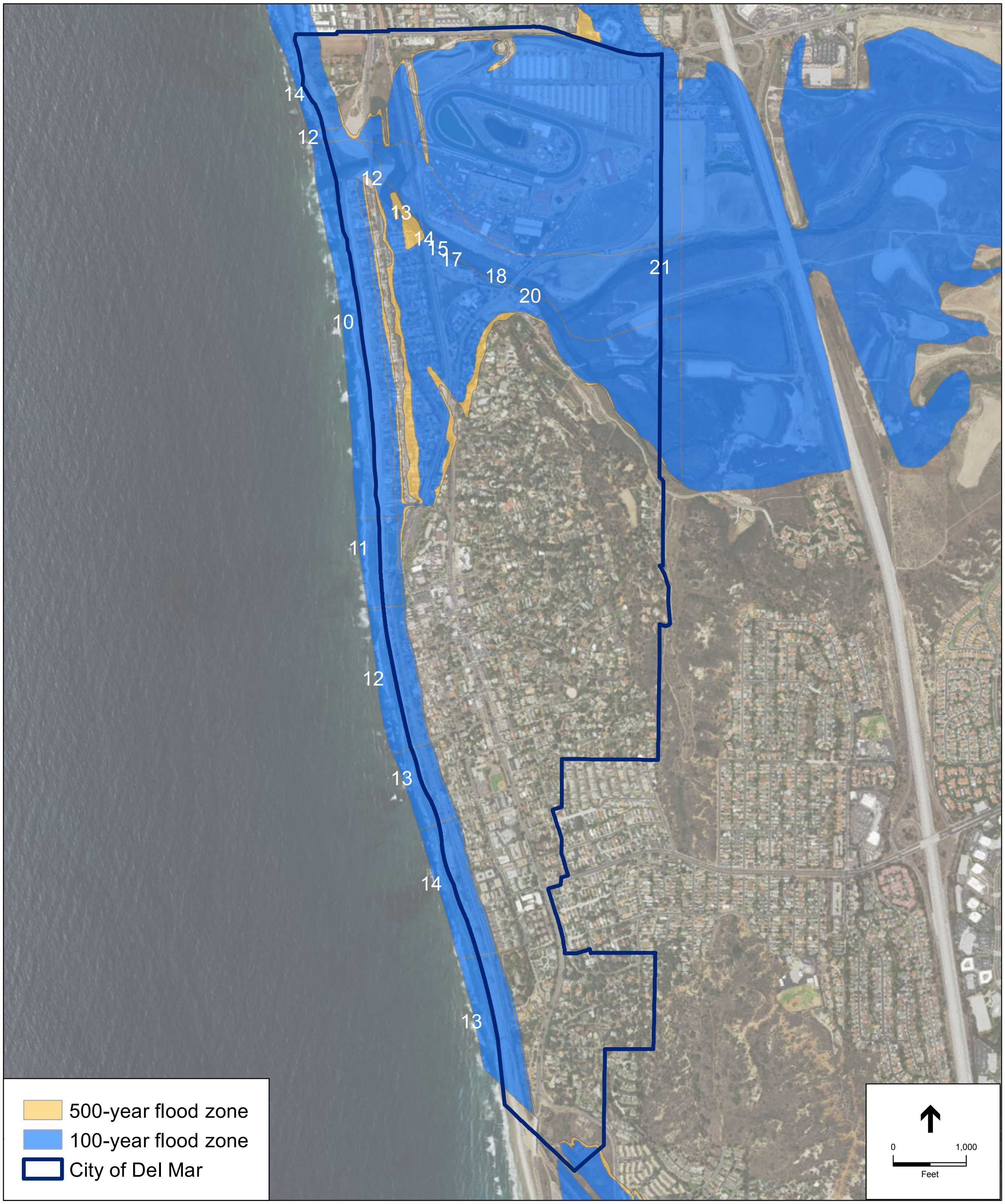


Figure 32

Extreme Value Analysis – Existing and Future Conditions



SOURCE: FEMA 2014

Del Mar LCP Update. 150347

Figure 33

FEMA Flood Zones in Del Mar

4.4 San Dieguito River Flooding with Climate Change and SLR

ESA analyzed the change in San Dieguito River flood frequency with sea level rise and considering both the effects of climate change on extreme precipitation and the potential for recent changes in upstream reservoir operations to provide improved flood management. The analysis was performed as follows:

1. Define a frequency distribution of extreme River food levels (river stage) using the FEMA Flood Insurance Study (Section 4.4.1)
2. Estimate the change in frequency of extreme River flood events based on projected future changes in precipitation (Section 4.4.2)
3. Apply an increase in the River flood level to the frequency distribution to account for the effects of sea level rise on both increasing flood levels and deposition in the River channel (Section 4.4.3)
4. Assess the potential for recent changes in upstream reservoir operations to decrease the frequency of River flooding (Section 4.4.4)

4.4.1 River Flood Levels

ESA defined a frequency distribution of San Dieguito River flood levels using the FEMA Flood Insurance Study (FIS) (FEMA 2012). River water surface elevations for the 0.2% chance (500-year), 1% chance (100-year), 2% chance (50-year) River flood events were taken from the modeled River flood profiles between Camino del Mar (Highway 1) and the Railroad Bridge. The River water surface elevation for the 10% chance (10-year) event was taken from the modeled River flood profile from Chang (2014). A point mid-way between Camino del Mar and the Railroad Bridge was chosen to represent the River flood level because the flood water surface profile is relatively flat in this reach, with water backing up behind Camino del Mar, and can drive flooding in both the City of Del Mar and the Del Mar Fairgrounds. Figure 34 shows the River flood level frequency distribution, which is based on the operations of the upstream Lake Hodges Reservoir prior to 2012 (see Section 4.4.5 for further discussion).

4.4.2 Extreme Precipitation with Climate Change

ESA and ESA's team member, Argos Analytics, projected the future frequency of six specific rainfall events to estimate the change in River flood event frequency under two different climate change scenarios. The precipitation events analyzed are listed in Table 7. Rainfall data for these events were collected by the Ramona ALERT station.

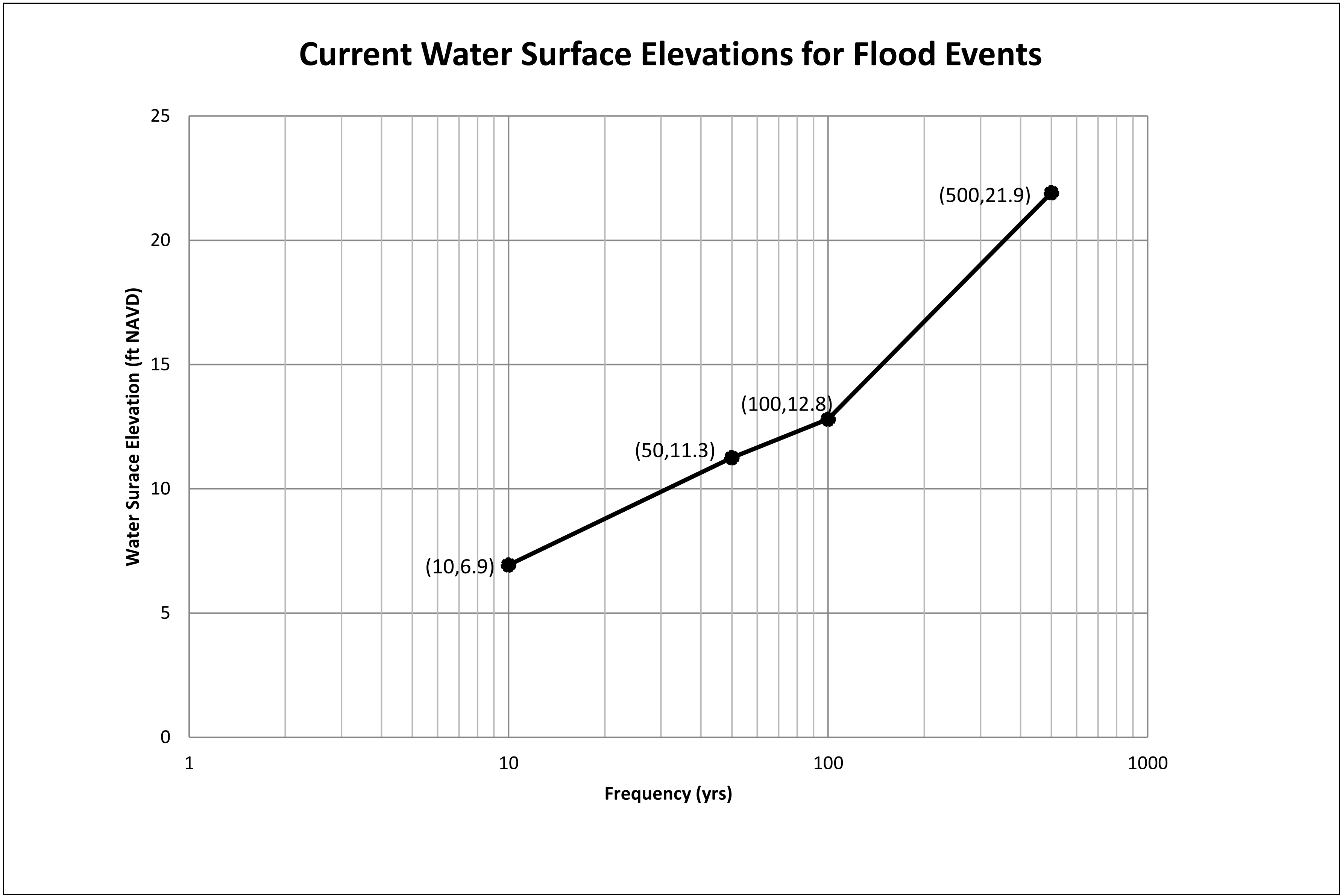


Figure 34

San Dieguito River Flood Level Frequency Distribution based on the FEMA Flood Insurance Study

TABLE 7
PRECIPITATION EVENTS, AMOUNTS, AND INTENSITIES ANALYZED

Event (Date/Time)	Total Precip (inches over 24 hrs)	Intensity (in/hr over 24 hrs)
FEMA 10-year Event (NOAA Atlas 14 – Ramona Gage)	3.6	0.150
5-Mar-78 (3/4/78 2 pm to 3/5/78 2 pm)	2.92	0.122
20-Feb-80 (2/20/80 2pm to 2/21/80 10am)	4.4 (2.7 inches over 6 hrs)	0.183 (0.45 in/hr over 6 hrs)
1-Mar-83 (3/1/1983 1pm to 3/2/83 5am)	1.9	0.079
FEMA 100-year Event (NOAA Atlas 14 – Ramona Gage)	5.86	0.244
FEMA 500-year Event (NOAA Atlas 14 – Ramona Gage)	7.69	0.320

This analysis uses the projected change in precipitation frequency as a surrogate for the change in frequency of River flood discharge and flood level. A precipitation runoff flow routing model of the watershed and Lake Hodges Reservoir is not available to translate changes in precipitation to changes in River flow (see ESA's 12/11/15 memorandum re: Del Mar LCP Amendment: Information and Data Summary and Gaps Analysis Data Gaps Assessment). The change in precipitation frequency may not directly correspond to the change in River flood level due to the complexities of runoff flow routing and River hydraulics; however, assuming a one-to-one correspondence provides a first order approximation of the change in River flood level appropriate for this planning-level LCPA study.

Method for Projecting Frequency of Precipitation Intensity

The analysis utilized Intensity-Duration-Frequency (IDF) projections derived from 3 hourly precipitation data for 2035 (2026-2045) and 2090 (2081-2099) produced by 20 global climate models that were part of the Climate Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al 2009) set of models run for the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment (IPCC 2014). The model projections were based on two emissions scenarios, referred to as Representative Concentration Pathways (RCP) (Moss et al 2008). RCP 4.5 represents moderately aggressive mitigation of greenhouse gas emissions (referred to as "decreasing emissions" in this report for shorthand), while RCP 8.5 is essentially business as usual (referred to as "increasing emissions" in this report). IDF projections for both scenarios were included in this analysis.

The frequency of rainfall intensity values for 3, 6, 12, 24, and 48 hour durations were tabulated for each of the models for the two future time periods and the baseline period of 1970-2000 and Generalized Extreme Value (GEV) distributions were fitted to the results for each duration and time period. Differences between the GEV intensity values for each future time period and the baseline period, referred to as intensity offsets, were calculated for each model for each combination of duration and return time. The return times used in this analysis were 2, 5, 10, 25, 50, 100, and 200 years.

Real rainfall intensity is inherently variable and hence there is not one value for a given duration and recurrence interval, but rather there is a distribution of values. For historical data, the median or 50th percentile is often used, although a risk-based analysis may consider a higher value, often the 90th or 95th percentile. The higher percentiles are emphasized when there is a low risk tolerance, which may be appropriate for an essential facility such as a power substation near a hospital. For future projections using global climate modeling of climate change, the distributions are also affected by "method uncertainty," which is associated with the sensitivities of models to different climate parameters, as well as other methodological differences. For hazard evaluation, a value associated with the 50th percentile, or larger to as high as the 95th percentile is often selected. This is a judgment as guidelines do not exist for this type of analysis. Use of the 50th percentile can indicate little or no change relative to historic conditions whereas the higher percentiles at higher RCP levels can indicate significant increases in precipitation and flooding.

The intensity offsets calculated for the 20 models for each duration/return time pair were sorted by magnitude and the values for the 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles calculated by interpolation. The offsets were then added to the corresponding intensity values based on historical data to generate projected intensities. In this analysis, only the 10th, 50th and 90th percentiles were considered. The 50th percentile represents the average projected offset or change in precipitation intensity from the 20 global climate models, while the 10th and 90th percentiles represent the range of change from 80% of the models (excluding outliers).

Since the intensity values for the six events considered do not, in general, fall exactly on the standard return times, the return times associated with them were calculated using interpolation, or extrapolation, assuming a piecewise power law relationship between intensity and return time of the form:

$$I = A + BR^n$$

Where I is intensity in in/hr, A, B and n are parameters, and R is return time in years. Since the standard return times range from 2 years to 200 years, return times less than a year and significantly greater than 200 years should be viewed with caution.

Only 8 of the 20 models provide 3 hourly precipitation data from throughout the 21st century. The other 12 provide it only for 2026-2045 and 2081-2099. IDF projections for intermediate time periods derived from the 8 models are not consistent with the 20 model projections so it was necessary to interpolate between them to generate results for 2050 and 2070. The interpolation assumed a piecewise linear relationship between annual frequency (inverse of return time) and time.

Precipitation Frequency Change Results

Appendix E includes the projected change in the frequency of the precipitation event analyzed for the decreasing emissions (RCP 4.5) and increasing emissions (RCP 8.5) climate scenarios. Future frequencies (return periods) at the 50th percentile are relatively unchanged or show a moderate decrease, while at the 10th percentile they are generally decreased (longer return periods). For the 90th percentile, however, frequencies increase (return times decrease) significantly for the higher intensity events, and these are the scenarios that are the most relevant from a vulnerability and risk perspective. The exception to this projected trend is the 24 hour 0.079 in/hr precipitation event, for which future frequencies are less than the historical frequency (return periods are greater than the historical return periods) in all cases.

Figures 35 to 38 show the projected future River flood level distribution in 2030, 2050, 2070, and 2100 estimated by applying the projected change in precipitation frequency to the FEMA River flood level distribution (from Section 4.4.1). Figures 35–38 also apply an increase in the River flood level to the frequency distribution to account for the effects of sea level rise, which is discussed in the following section.

4.4.3 River Flood Level with SLR

ESA applied an increase in the River flood level to the frequency distribution with climate change (from Section 4.4.2 above) to account for the effects of sea level rise on both increasing flood levels and deposition in the River channel.

Sea level rise will increase the downstream tide level or tail water elevation during River flood events. During extreme River discharge events such as the FEMA 1% chance (100-year) and 0.2% chance (500-year) events, the River discharge and flood water surface elevations back up behind the Camino del Mar and railroad bridges such that an increase in the downstream tide level with sea level rise would not increase the River flood level. For the FEMA 2% chance (50-year) River storm event, ESA's assessment of the River flood profile indicates that sea level rise would increase the water surface elevation downstream of the Camino del Mar bridge and would therefore increase the River flood level between the Camino del Mar and the railroad bridge, but may not have a significant effect upstream of the railroad bridge. For more frequent River storm events such as the 10% chance (10-year) event, storm events do not greatly increase the water level in the River and the increase in tide levels with SLR dominates the change in River water levels.

The potential in sediment (sand) deposition in the River channel with sea level rise has a much greater potential to increase River flood levels. The process of long-term channel deposition with sea level rise has not been analyzed or assessed previously (see ESA 12/11/15 Data Gaps Assessment). With sea level rise, sediment (sand) from both the beach and watershed is expected to deposit in the lower River channel. Assuming that deposition is not limited by sediment supply, both the River bed profile and flood profiles would increase in elevation with sea level rise, with a rate and amount of deposition equal to the rate and amount of sea level rise. Southern California Edison (SCE) dredges the River mouth for the San Dieguito Lagoon Restoration and is

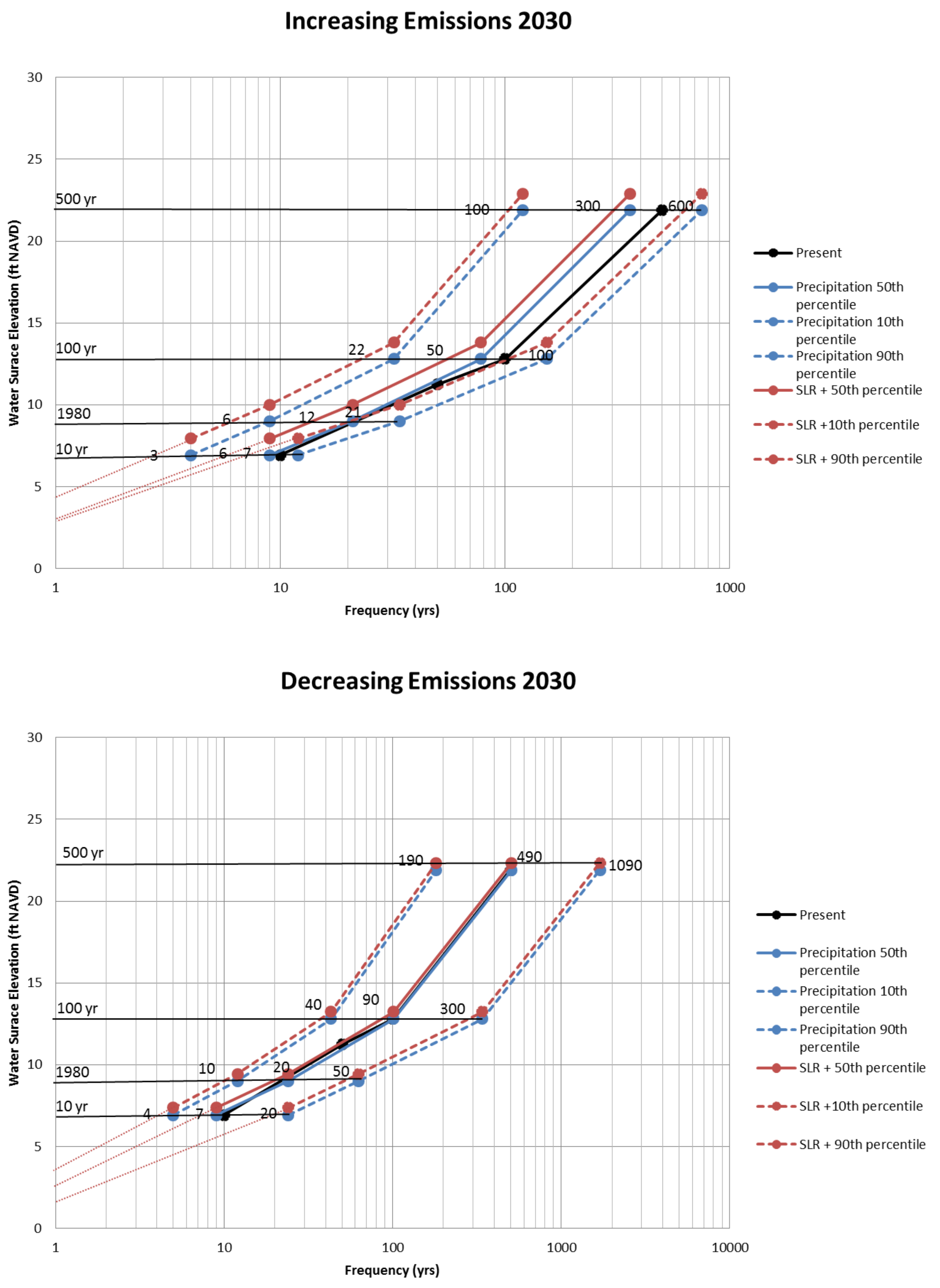


Figure 35

Projected Future River Flood Level Distribution for 2030 for RCP8.5 (top) and RCP4.5 (bottom) Scenario

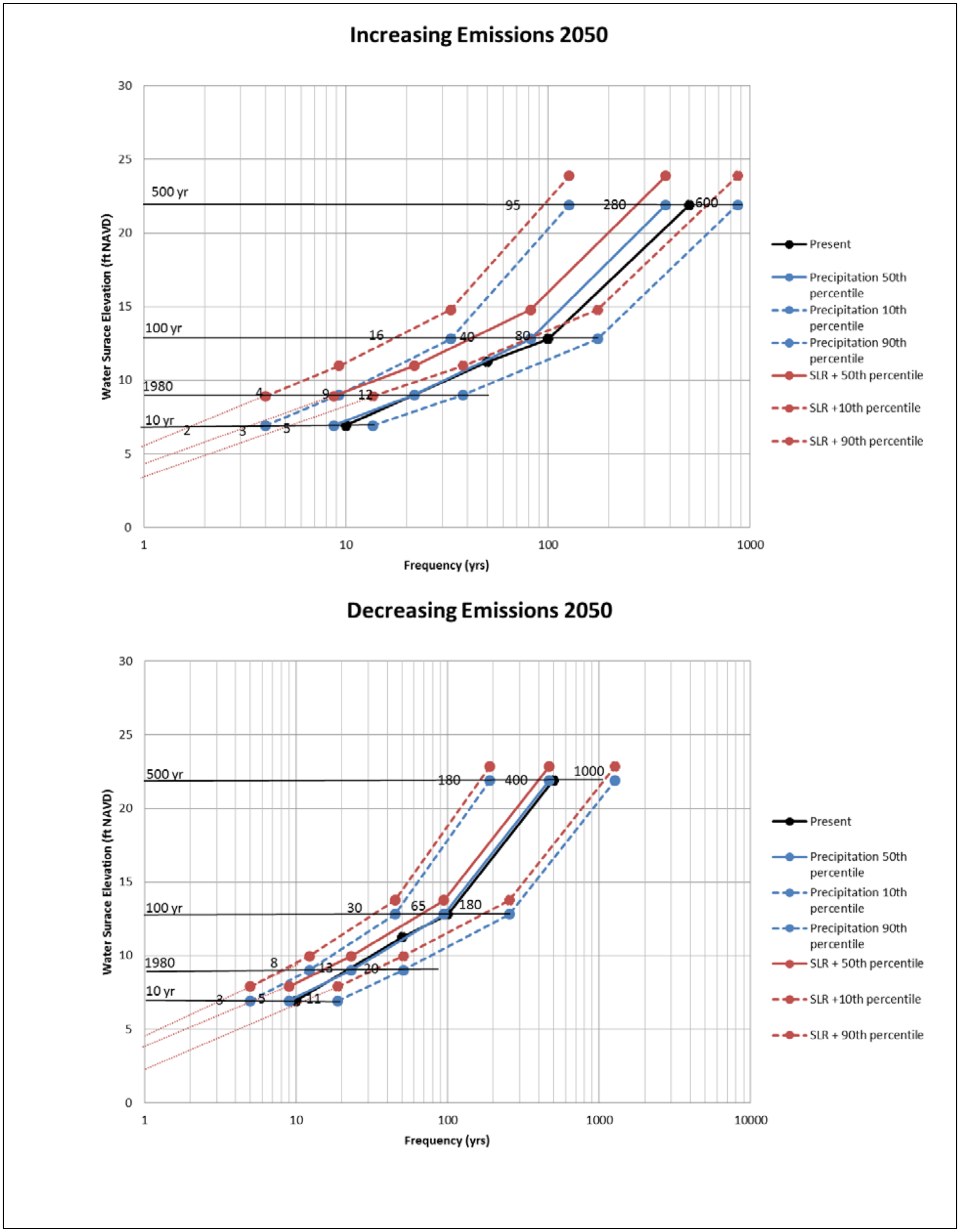


Figure 36

Projected Future River Flood Level Distribution for 2050 for RCP8.5 (top) and RCP4.5 (bottom) Scenarios

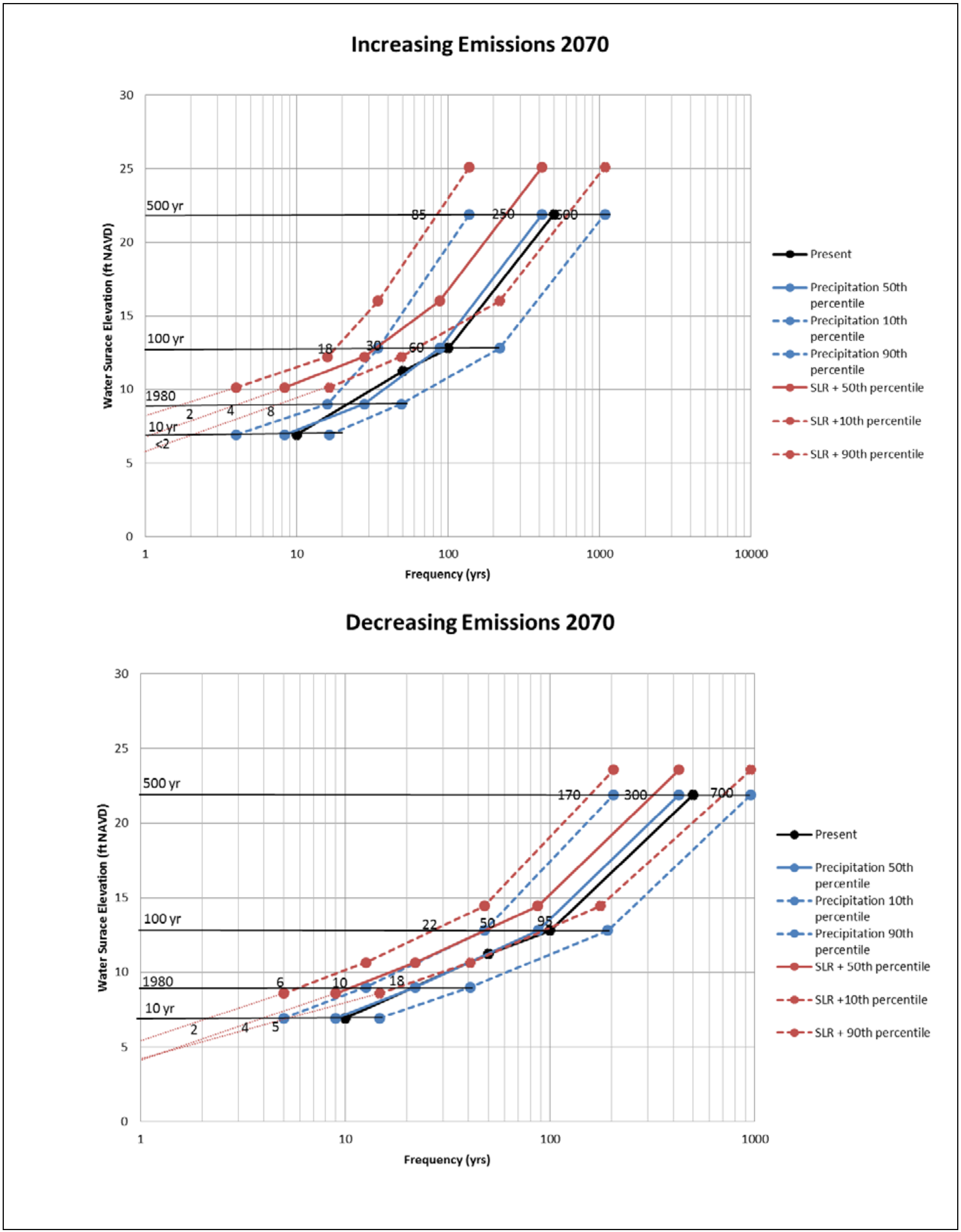


Figure 37
Projected Future River Flood Level Distribution for 2070 for RCP8.5 (top) and RCP4.5 (bottom) Scenarios

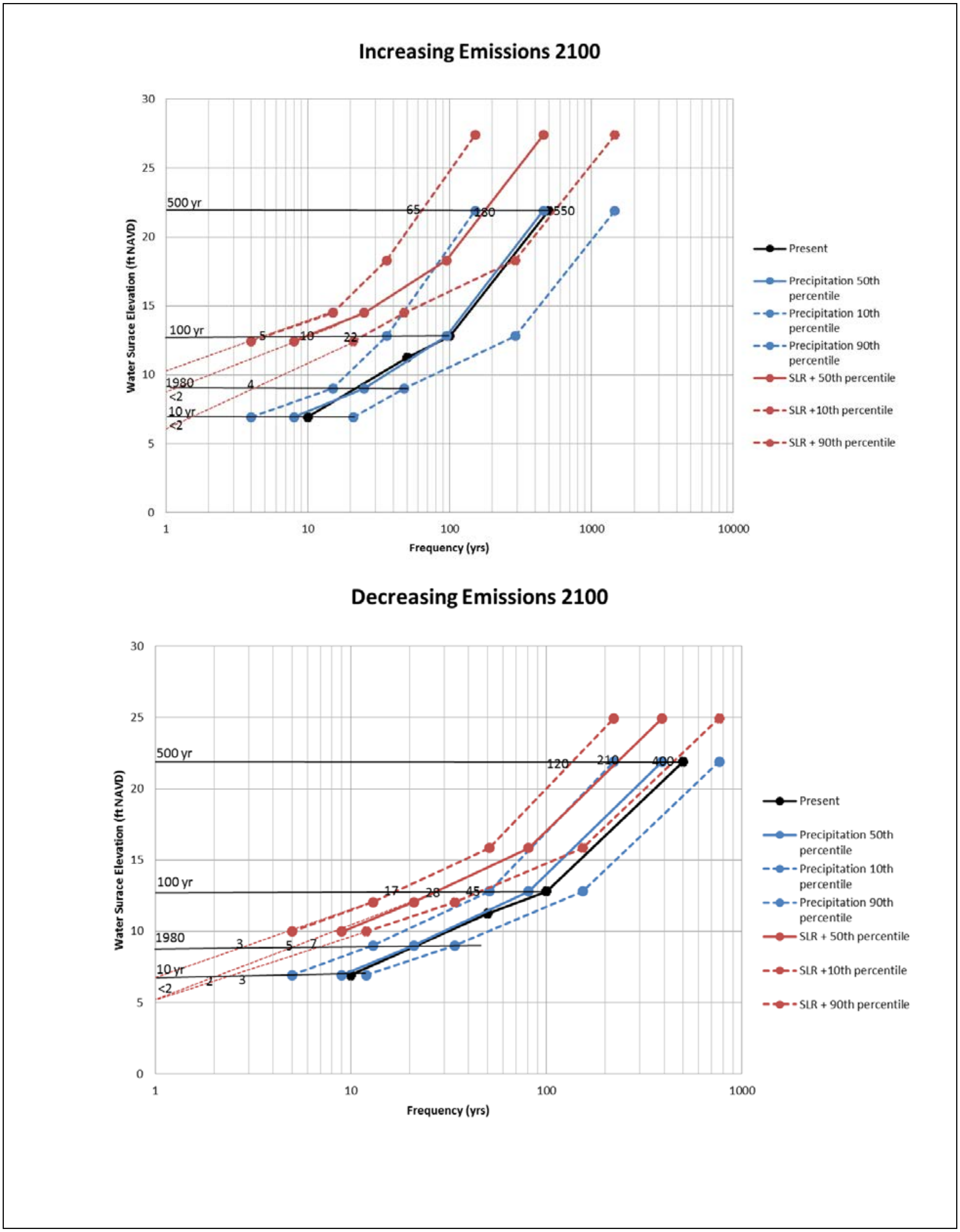


Figure 38

Projected Future River Flood Level Distribution for 2100 for RCP8.5 (top) and RCP4.5 (bottom) Scenarios

required to maintain a minimum cross-sectional area and tidal flow (tidal prism); however, SCE is not required to maintain a particular River bed elevation and River deposition could therefore occur while SCE maintains the required cross-section at a higher elevation.

As a simplifying assumption for this planning-level vulnerability analysis, ESA assumed that uniform channel deposition would raise the channel bed elevation by an amount equal to sea level rise. This assumes that the existing River cross-section is maintained at a higher elevation as discussed above. Based on this assumption of uniform bed deposition in the lower River, the flood profile in the lower River would also increase by an amount equal to sea level rise. ESA therefore added the height of sea level rise to the River flood levels to effectively "raise" the elevation of the River flood levels frequency distributions (Figures 35–38). Raising the flood level frequency distribution translates into an increase in the frequency of River flood events. For example, the FEMA 1% chance (100-year) event has a flood level of 12.8 ft NAVD. In 2100 with increasing emissions (RCP 8.5 and high SLR of 5.5 ft) (Figures 35–38), the projected frequency distribution with climate change (50th percentile) and SLR shows that a 12.8 ft NAVD flood level has a 10% chance of occurring (10-year return period frequency as labeled in Figures 35–38).

For sea level rise in 2030, 2050, 2100 and low, mid, and high SLR scenarios, sea level rise was calculated using methods described in the California Coastal Commission Sea Level Rise Policy Guidance (CCC 2015). The equations for SLR projections are based on values from the 2012 NRC 2012 Report. The upper and lower ranges of sea level rise projections were calculated using equations 1 and 2 respectively.

Equation 1: Upper Range

$$\text{Sea Level Change (cm)} = 0.0093t^2 + 0.7457t$$

Equation 2: Lower Range

$$\text{Sea Level Change (cm)} = 0.0038t^2 + 0.039t$$

Where t is the number of years after 2000.

ESA created a mid-range projection by a linear interpolation of the two coefficients (equation 3).

Equation 3: ESA Mid-Range

$$\text{Sea Level Change (cm)} = 0.0068t^2 + 0.256t$$

SLR projections for mid and upper range were calculated for the years 2030, 2050, 2070 and 2100. These values were added to the frequency distribution curve to account for the changes in water surface elevation due to flood levels and deposition changes from sea level rise as described above.

4.4.4 Lake Hodges Reservoir Operations

River flows from approximately 87% of the San Dieguito River watershed are controlled by the City of San Diego's Lake Hodges Reservoir. The primary purpose of the Lake Hodges Reservoir is water storage; however, the Reservoir can provide ancillary flood management benefits. In the past, extreme river flooding has occurred when the reservoir is full and extreme rainfall runoff events overtop the dam spillway and is conveyed downstream. The majority of the extreme river discharge at Del Mar has been contributed by the flow spilling over the dam spillway. Reservoir overflow occurred frequently in the past (with overflow in 26 of 78 years from 1926-2003 per Chang (2014)) and as recently as 2011.

In 2012, The San Diego County Water Authority (SDCWA) completed the Lake Hodges Projects that connected Lake Hodges to SDCWA's new Olivenhain Reservoir (City of San Diego 2016). Per SDCWA (San Diego County Water Authority 2016):

> *"The Lake Hodges Projects are part of the San Diego County Water Authority's Emergency Storage Project, a system of reservoirs, interconnected pipelines and pumping stations designed to make water available to the San Diego region in the event of an interruption in imported water deliveries. The Lake Hodges Projects connect the City of San Diego's Hodges Reservoir, also called Lake Hodges, to the Water Authority's Olivenhain Reservoir. The connection provides the ability to store 20,000 acre-feet of water in Hodges Reservoir for emergency use. The connection also allows water to be pumped back and forth between Hodges Reservoir and Olivenhain Reservoir. From Olivenhain Reservoir, water can be distributed throughout the region by the Water Authority's delivery system.*
>
> *The Lake Hodges Projects will also help keep Hodges Reservoir at a more constant level during dry seasons, capture runoff during rainy seasons and prevent spills over Hodges Dam."*

As in the past, the primary purpose of the recent Lake Hodges Projects is water storage; however, the improved reservoir system and operations could provide improved flood management. Additional information on operations and flood management benefits has been requested from SDCWA.

Leedshill-Herkenhoff (1985) evaluated options for using Lake Hodges to improve flood management for the City of Del Mar. Their study calculated the change in return frequency of discharges in the lower San Dieguito River for two scenarios in which reservoir storage is reserved for flood management (Table 8).

TABLE 8
RETURN FREQUENCY OF DISCHARGES IN SAN DIEGUITO RIVER FOR VARIOUS STORAGE CONDITIONS IN LAKE HODGES

Discharge (cfs)	Initial Lake Storage (37,700 AF)	Initial Lake Storage (16,800 AF)	Initial Lake Storage (6,000 AF)
41,800	100	167	390
31,500	50	126	288
16,500	25	67	144
5,700	10	27	27
2,100	5	5	5

SOURCE: Leedshill-Herkenhoff (1985)

4.4.5 Frequency Distribution Results

To assess the potential change in future river flooding frequency accounting for both climate change, sea level rise, and potential reservoir operations for flood management, ESA applied the estimated change in discharge frequency for the two reservoir flood management operations scenarios to the river flood level frequency distribution projected for future climate change and sea level rise with increasing emissions (RCP 8.5 and high SLR) (Figure 34 (from 4.4.1) and Tables 9 and 10). This assessment indicates a potential range in future river flood frequencies; however, additional information is needed on new reservoir operations from SDCWA to confirm if either of these scenarios is representative of expected reservoir operations.

4.5 CoSMoS Results

The results of the initial release of CoSMoS 3.0 made available on November 15, 2015 are included in Appendices B and C. The preliminary results include coastal flooding extents for 3 scenarios: the “100-year” (1% annual chance) coastal flood event storm with 0.5, 1, and 1.5 m of sea level rise (20, 39, and 59 inches or 1.6, 3.3, and 4.9 feet of sea level rise).

The beach erosion results showed that if Del Mar “holds the line” and maintains structures as they are, there will be a loss of beach by 2090 under a mid sea level rise scenario (1.0 m of sea level rise). The bluff retreat model results showed a likely loss of property along the bluffs.

ESA’s analysis indicates a more rapid narrowing of the beach, and therefore we recommend against using the CoSMoS projection until the USGS’ methods are better understood and the results are finalized.

For the beach erosion analysis, the model results include continuing the past rate of beach nourishment, but assume no failure of armoring. For the flood extent analysis, wave overtopping and coincident river flow were considered, but wave runup, flooding in conjunction with erosion, and hurricanes were not included. (See Appendix B and C for CoSMoS Beach and Bluff erosion)

TABLE 9
SUMMARY OF PROJECTED INCREASE IN RIVER FLOOD EVENT FREQUENCY DUE TO SEA LEVEL RISE AND POTENTIAL INCREASED EXTREME PRECIPITATION INTENSITY WITH CLIMATE CHANGE FOR MID-LEVEL PROJECTIONS

	RCP4.5		**2030**			**2050**			**2070**			**2100**		
		Present	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
Annual chance of occurrence	FEMA 10-year	10.0%	5.0%	14.3%	25.0%	9.1%	20.0%	33.3%	20.0%	25.0%	50.0%	33.3%	50.0%	>50%
	Feb-80	4.0%	2.0%	5.0%	10.0%	5.0%	7.7%	12.5%	5.6%	10.0%	16.7%	14.3%	20.0%	33.3%
	FEMA 100-year	1.0%	0.3%	1.1%	2.5%	0.6%	1.5%	3.3%	1.1%	2.0%	4.5%	2.2%	3.6%	5.9%
	FEMA 500-year	0.2%	0.1%	0.2%	0.5%	0.1%	0.3%	0.6%	0.1%	0.3%	0.6%	0.3%	0.5%	0.8%
Average frequency (years)	FEMA 10-year	10	20	7	4	11	5	3	5	4	2	3	2	<2
	Feb-80	25	50	20	10	20	13	8	18	10	6	7	5	3
	FEMA 100-year	100	300	90	40	180	65	30	95	50	22	45	28	17
	FEMA 500-year	500	1090	490	190	1000	400	180	700	300	170	400	210	

TABLE 10
SUMMARY OF PROJECTED INCREASE IN RIVER FLOOD EVENT FREQUENCY DUE TO SEA LEVEL RISE AND POTENTIAL INCREASED EXTREME PRECIPITATION INTENSITY WITH CLIMATE CHANGE FOR HIGH-LEVEL PROJECTIONS

	RCP8.5		**2030**			**2050**			**2070**			**2100**		
		Present	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
Annual chance of occurrence	FEMA 10-year	10.0%	14.3%	16.7%	33.3%	20.0%	33.3%	50.0%	>50%	100%	100%	>50%	100%	100%
	Feb-80	4.0%	4.8%	8.3%	16.7%	8.3%	11.1%	25.0%	12.5%	25.0%	50.0%	25.0%	>50%	100%
	FEMA 100-year	1.0%	1.0%	2.0%	4.5%	1.3%	2.5%	6.3%	1.7%	3.3%	5.6%	4.5%	10.0%	20.0%
	FEMA 500-year	0.2%	0.2%	0.3%	1.0%	0.2%	0.4%	1.1%	0.2%	4.0%	1.2%	0.2%	0.6%	1.5%
Average frequency (years)	FEMA 10-year	10	7	6	3	5	3	2	<2	<2	<2	<2	<2	<2
	Feb-80	25	21	12	6	12	9	4	8	4	2	2	<2	<2
	FEMA 100-year	100	100	50	22	80	40	16	60	30	18	22	10	5
	FEMA 500-year	500	600	300	100	600	280	95	600	25	85	550	180	65

The entire suite of 40 scenarios is expected to be released in June 2016 and will include:

- 0 to 2 m of sea level rise at 0.25 m increments, plus an additional 5 m “catastrophic” sea level rise scenario
- Inundation for daily tides and annual, “20-year” (5% annual chance), and “100-year” (1% annual chance) storm events

5 VULNERABILITY ASSESSMENT

The City of Del Mar is currently vulnerable to river and coastal flooding and erosion. In the recent past (late 1970s to present), river and coastal flooding and coastal beach and bluff erosion have caused significant damages. In certain locations along the Del Mar bluffs, the cliff top has retreated to a point where it is a safety concern for the LOSSAN railroad and SANDAG and NCTD have responded by installing multiple bluff stabilization projects consisting of soldier pile installation to allow for the construction of sea walls in the future.

These existing vulnerabilities are projected to increase in intensity and frequency in the future due to sea level rise and climate change. The USGS' preliminary CoSMoS 3.0 modeling results provide an indication of how the intensity of extreme coastal flooding (1% chance or 100-year event) and coincident river flooding could increase with sea level rise, without considering the effects of future beach erosion. CoSMoS results also provide future projections of beach width and cliff retreat in 2100 for a range of SLR scenarios. Final CoSMoS results are expected to provide information on flooding considering beach erosion and bluff erosion for the timeframe before 2100 (e.g., 2030, 2050, and 2070).

This City of Del Mar Coastal Vulnerability Assessment utilizes information from CoSMoS and includes additional analyses to assess future vulnerabilities due to:

- The increase in the frequency of extreme coastal and river flood events
- The compounding effects of projected beach erosion on coastal flooding
- The potential effects of projected changes in extreme precipitation and recent changes in Lake Hodges Reservoir operations on river flooding
- Beach erosion and bluff retreat for the timeframe before 2100.

5.1 Coastal Flooding and Damage

The City of Del Mar is currently vulnerable to damage caused by coastal flooding and wave runup, and the vulnerability is anticipated to increase significantly with SLR. Already, coastal storms damage waterfront structures and cause notable flooding.

As SWLs rise, nearshore wave heights will increase, moving beach sediment and driving a reduction in beach width and elevation. The lowered beach will further increase water depths, allowing for even larger waves. As a result, wave runup and overtopping at the seawalls and revetments along Del Mar Beach will increase. Seawalls and revetments are most susceptible to overtopping along Ocean Front in areas where the back-beach structure is low. Overtopped water will flood residences and buildings near the shore, and as sea level rises, the overtopped water will take longer to drain from flooded areas. Large waves impinging directly on seawalls and revetments may cause serious damage, especially when the structures are old or poorly maintained. The maintenance demand will increase over time, and therefore it is possible that the risk of structural failure will also increase with time. Coastal storm events with elevated TWLs will become more common in the future. By 2050, an event with TWLs similar to the 1983 storm will become a 7-year event, while an event with TWLs similar to the 2015 storm will occur yearly. By 2100, even an event similar to the 1983 storm will occur annually under high climate change scenarios. Note that climate change scenarios are projections based on future emissions and are therefore inherently uncertain. While the probability of these climate projection scenarios are unknown, the projections provide indications of potential future scenarios.

As beaches lower, seawalls may be susceptible to scour at the toe, which can infringe on their structural stability and cause public access concerns. Beach lowering and narrowing will also reduce the time that beaches are above water and are available for public use. Beach above high tide will be lost between 2030 and 2060, effectively eliminating all public access seaward of hardened backshores for much, if not all of the tide range. Areas without seawalls and revetments will experience erosion as the shoreline moves inland.

5.2 Bluff Erosion

Along the northern end of the southerly Del Mar bluffs, the railroad appears to be vulnerable to bluff erosion impacts under current conditions based on a safety criterion of maintaining a 10 ft offset between the bluff top edge and the railroad centerline (Leighton & Associates 2010). In a few locations in the central and southern portions of the bluff where the distance between the bluff edge and the railroad is greatest, bluff retreat would not be expected to reach within 10 ft of the railroad through 2100 based on the historic rate of erosion (i.e., without an increase in the rate of sea level rise). The uncertainty of historic erosion in terms of future distance is approximately 20 feet over the forecasting period: Application of this additional erosion substantially increases the length of railway at risk. The projection of future erosion does not include the effect of sea level rise and therefore under-predicts the risk. In these locations however, CoSMoS results show that the bluff would retreat to the railroad in 2100 in a “low” sea level rise scenario (i.e., with 1.6 ft or 0.5 m of SLR in 2100). Thus, the current localized vulnerability of the railroad to bluff retreat is expected to increase in extent in the near-term and extend along the entire bluff in the long-term (i.e., by 2100 in a low SLR scenario or sooner in a mid to high SLR scenario). Additional analyzes or additional data and information from CoSMoS are needed to estimate vulnerability timeframes (i.e., prior to 2100) for mid and high SLR scenarios.

Assuming that the bluff retreats past the railroad, CoSMoS results show that the first row of properties along the bluff may be impacted by 2100 in a low sea level rise scenario and that the fourth or fifth row of properties along the bluff may be impacted by 2100 in a high sea level rise scenario.

5.3 San Dieguito River Flooding

Portions of the City of Del Mar Beach Colony and the Del Mar Fairgrounds have been flooded by the San Dieguito River due to extreme rainfall and river discharge, such as the February 21, 1980 river flood event when the Lake Hodges Reservoir was full and a 3% to 4% chance rainfall and river discharge event (25- to 40-year event) occurred (with discharge from the upper watershed spilling over the Lake Hodges dam). The FEMA Flood Insurance Rate Map shows the 1% chance (100-year) River flood event inundating a large are of the Beach Colony and a greater extent of flooding for the 0.2% chance (500-year) event.

Projections of extreme precipitation with future climate change indicate that the frequency of extreme events is likely to increase. Without operating the Lake Hodges Reservoir for improved flood management, a similar increase in the frequency of River flood events can be expected. With sea level rise, sediment (sand) from both the beach and watershed is expected to deposit in the lower River channel. Assuming that deposition is not limited by sediment supply, both the River bed profile and flood profiles would increase in elevation with sea level rise, with a rate and amount of deposition equal to the rate and amount of sea level rise. Southern California Edison (SCE) dredges the River mouth for the San Dieguito Lagoon Restoration and is required to maintain a minimum cross-sectional area and tidal flow (tidal prism); however, SCE is not required to maintain a particular River bed elevation and River deposition could therefore occur while SCE maintains the required cross-section at a higher elevation. The increase in River bed elevations and flood levels due to sea level rise and channel deposition translates into an increase in the frequency of River flood events. Tables 11 summarizes the potential increase in River flood event frequencies due to both sea level rise and projected future precipitation with climate change as well as a scenario with reservoir flood management.

TABLE 11
PROJECTED RIVER FLOOD EVENT FREQUENCIES IN 2100 WITH INCREASING EMISSIONS (RCP 8.5 AND HIGH SLR OF 5.5 FT) FOR TWO FLOOD MANAGEMENT RESERVOIR OPERATIONS SCENARIOS

River flood event	Present	2050	2100	2100 with Reservoir Flood Management
FEMA 10% chance (10-year) event	10% chance (10-year)	20% to 50% chance (2- to 5-year)	50+% chance (<2 year)	Data not available
February 21, 1980	4% chance (25-year)	8% to 25% chance (4- to 13-year)	20% to 50+% (5- to <2-year)	Data not available
FEMA 1% chance (100-year) event	1% chance (100-year)	2% to 6% chance (16- to 65-year)	4% to 20% chance (5- to 25-year)	4% chance (25-year)
FEMA 0.2% chance (500-year) event	0.2% chance (500-year)	0.25% to 1% (95- to 400-year)	0.5% to 1.5% chance (65- to 210- year)	Data not available

The completion of SDCWA's Lake Hodges Projects in 2012 for the purpose of improving water supply and storage provide the ability for the Lake Hodges reservoir to be operated for improved flood management. ESA's assessment of two potential flood management scenarios indicates that these reservoir operations scenarios could partially offset the increase in the future frequency of River flooding, but that the frequency of River flooding could still increase compared to the frequency of flooding in the past.

5.4 San Dieguito River Lagoon Wetland Habitat Vulnerability Assessment

Salt marsh habitat zones can be defined for different areas based on the elevation of the area relative to tidal datums (i.e., as a surrogate for the frequency of tidal inundation). ESA calculated estimated habitat elevation ranges at San Dieguito Lagoon based on vegetation-inundation relationships measured at other reference sites and survey measurements at the site.

At the Ballona Wetlands in Los Angeles, inundation frequencies were determined for each habitat zone (ESA 2015). Table 12 presents the percent inundations and the corresponding elevations based on the NOAA La Jolla tide gage.

TABLE 12
HABITATS BY PERCENT INUNDATION

Habitat Transitions	% Inundation[1]	Habitat Elevations (ft NAVD)
Upland/Transition Zone	~3yr tidal inundation	7.38
Transition Zone/High Marsh	1%	6.05
High Marsh/Mid Marsh	5%	5.21
Mid Marsh/Low Marsh	26%	3.62
Low Marsh/Mudflat	51%	2.56
Mudflat/Subtidal	MLLW	-0.19

SOURCE: ESA 2015.

The habitat elevations in Table 12 were compared to elevations of pickleweed and cordgrass in the Lagoon for verification. At San Dieguito, average pickleweed elevations (± one standard deviation) ranged from 4.5-5.6 ft NAVD, which falls in the mid marsh to high marsh categories as expected. Average cordgrass elevations at San Dieguito (± one standard deviation) occurred from 3.5 to 3.9 ft NAVD, which falls in the low to mid marsh category.

Future habitat elevations were estimated using the NRC projection values for Los Angeles. The sea-level rise for each year was applied to the habitat elevations shown in Appendix F to estimate the future habitat elevations. Combined with an accretion rate of 4.6 mm/yr based off of measurements at the Los Peñasquitos Lagoon to the south (Cole and Wahl 1999), estimates of how quickly habitats could evolve at San Dieguito Lagoon were calculated.

Appendix F includes results showing the estimated habitat evolution/conversion over time. Because high marsh occupies a smaller range of elevations compared to mid and low marsh, the existing high marsh is expected to be lost the most quickly. Existing high marsh could be lost as soon as 2040 and up to 2100, based on the high or low sea-level rise estimates. Mid marsh occupies the largest range of elevations, so it would be maintained the longest. Under high rates of sea-level rise, the upper end of existing mid marsh could drown out by 2070. However, mid marsh is expected to migrate into areas that are currently occupied by high marsh as water levels rise, although due to the steep slopes at San Dieguito, this area is minimal. Existing low marsh is expected to convert to mudflat and be lost by 2090 or later.

Within the existing marsh basins in San Dieguito Lagoon, the salt marsh is expected to move upslope as water levels rise. However, the steep slopes will limit the amount of salt marsh in these areas. Salt marsh is also expected to move further upstream along the San Dieguito River to keep up with sea-level rise; however, the River corridor is relatively narrow and the overall vegetated marsh acreage will be greatly reduced.

6 RISK ASSESSMENT

The vulnerability of coastal resources and City assets and associated risks were assessed by overlaying hazards on resource and asset maps. Coastal and river flood and damage hazards were mapped and classified as follows:

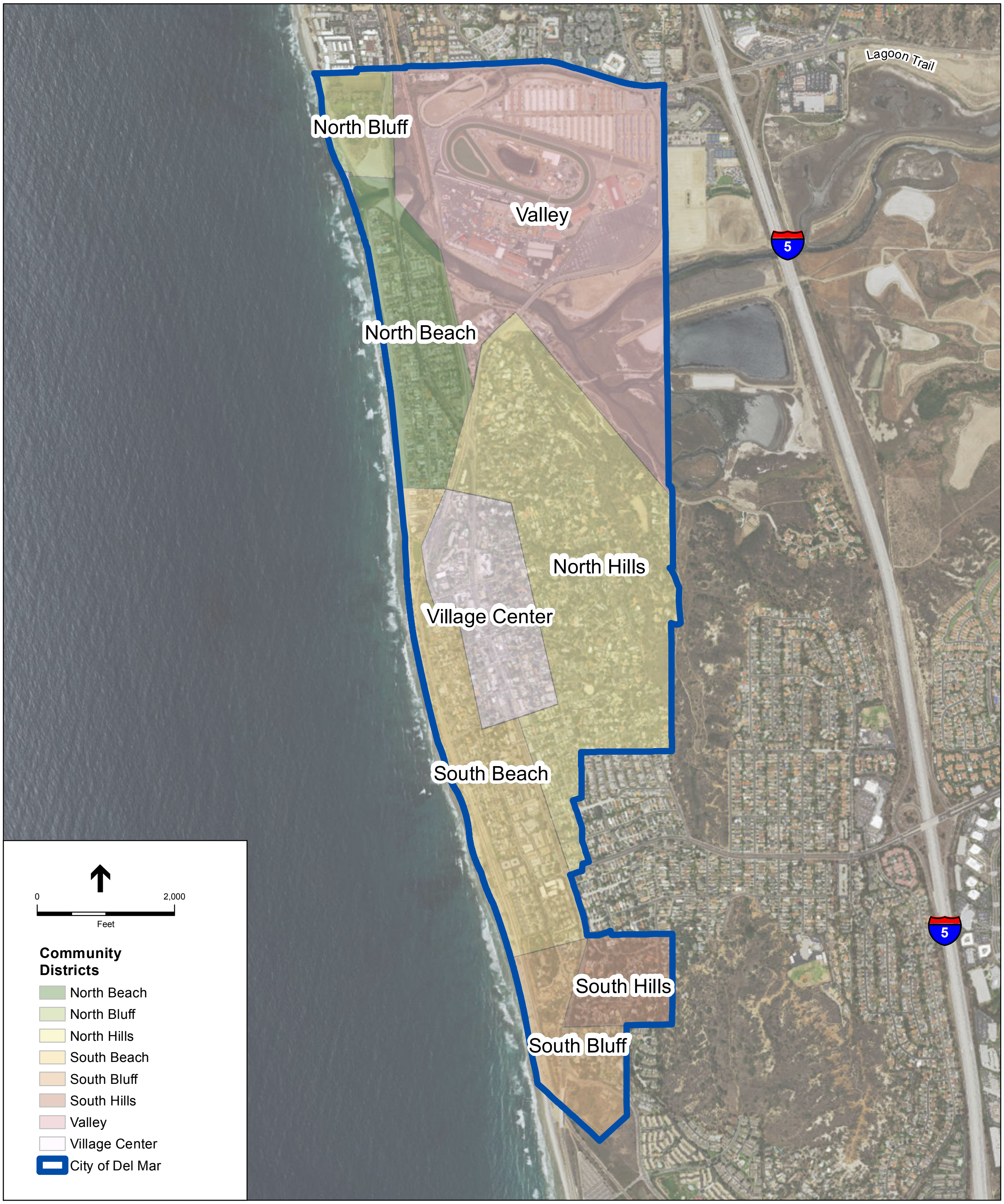
- Significant coastal flooding: the term “significant” flooding is used to refer to flood events that would cause significant flooding and damage, rather than nuisance flooding. To represent significant coastal flooding, the extent of flooding for the 2016 coastal storm events were mapped as the zone 10 ft landward of the seawalls.
- Extreme coastal flooding: the term “extreme” is used to refer to extensive flooding and damage that presently has a low (i.e., 1%) chance of occurrence (but is projected to increase in frequency in the future). The 1983 flood event was mapped as described in Section 2.5.1. In addition to the extent of extreme coastal flooding, the extent of extreme wave hazards was mapped. In the extreme wave hazards zone, wave heights and velocities are high enough to cause damage to structures.
- Significant river flooding: the 1980 river flood event was approximately mapped based on information from photos (aerial and ground photos) and City reports on flood damages.
- Extreme river flooding: the 1% chance river flood map from the FEMA Flood Insurance Rate Map was used to represent the extent of extreme river flooding.

The figures at the end of this section include maps of hazards by asset and resource category (Figures 39–46). The resources and asset maps include the following information available in GIS from the City and other sources:

- City Districts
- Property (parcels) and roads
- Water and sewer system
- Stormwater drainage system
- Other, including public access features and City (municipal) areas including the Fire Station.

The increased future sea level rise and hazards will impact coastal resources and assets in Del Mar, including properties, roads and bridges, infrastructure, emergency services, coastal access, and San Dieguito River lagoon wetland habitats. “Low, moderate, and high” vulnerabilities and risks are discussed below, which are defined for the purposes of this assessment as follows:

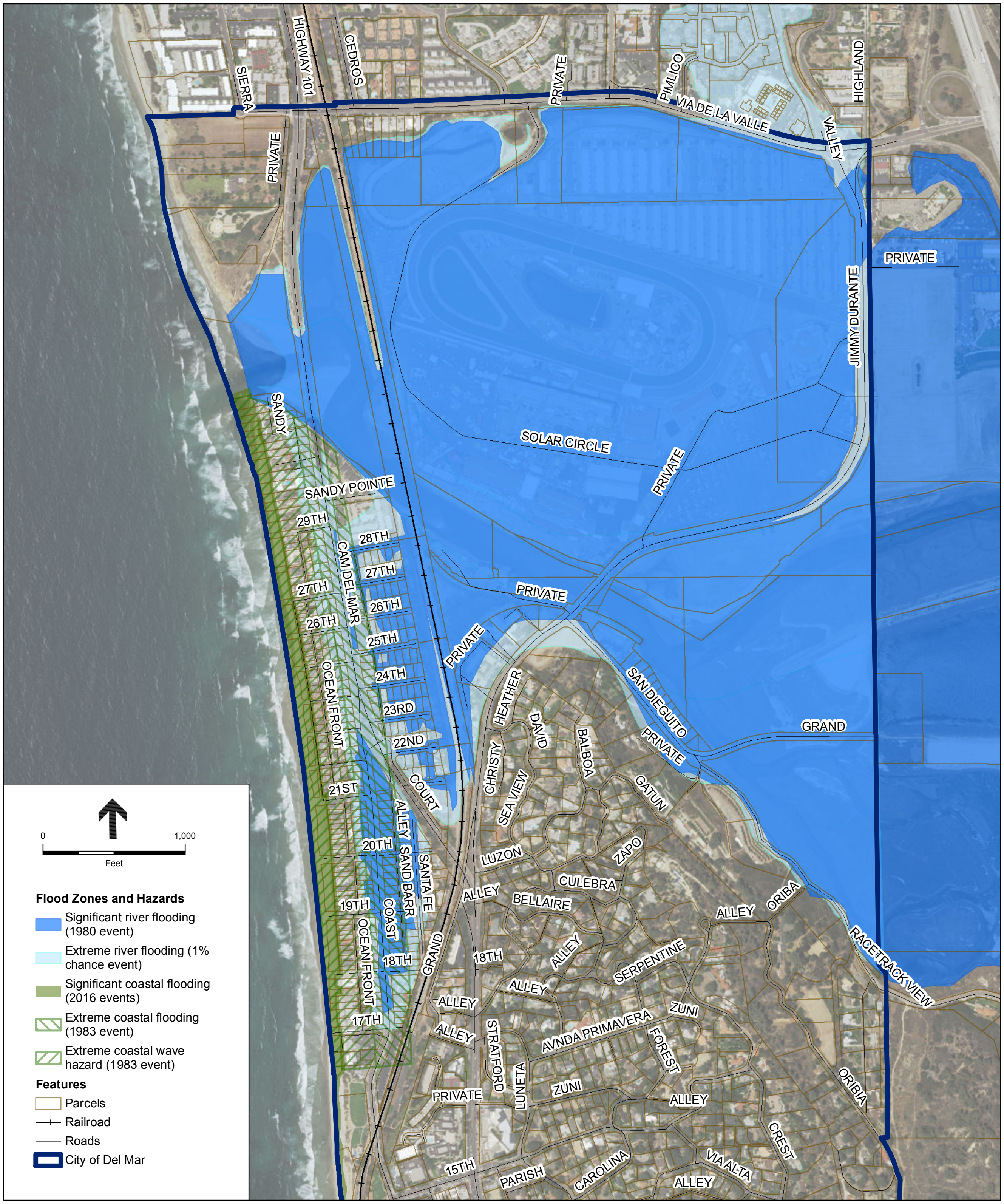
- Low: 0% - 5% chance of occurrence in a given year
- Moderate: 5% - 30% chance
- High: 30% - 100% chance



SOURCE: SanGIS 2016, USGS 2015

Figure 39

Community Districts in Del Mar



SOURCE: SanGIS 2016, FEMA

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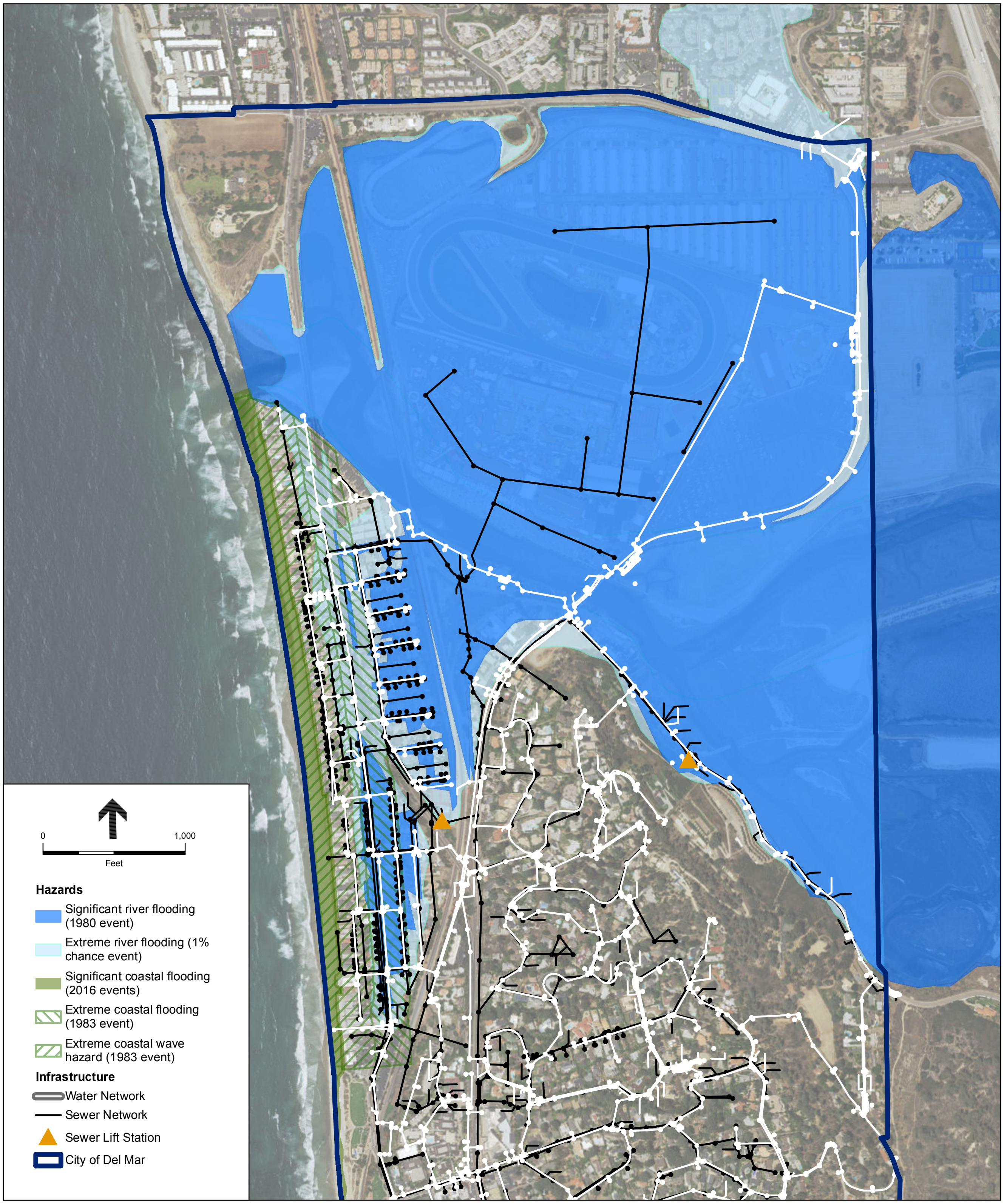
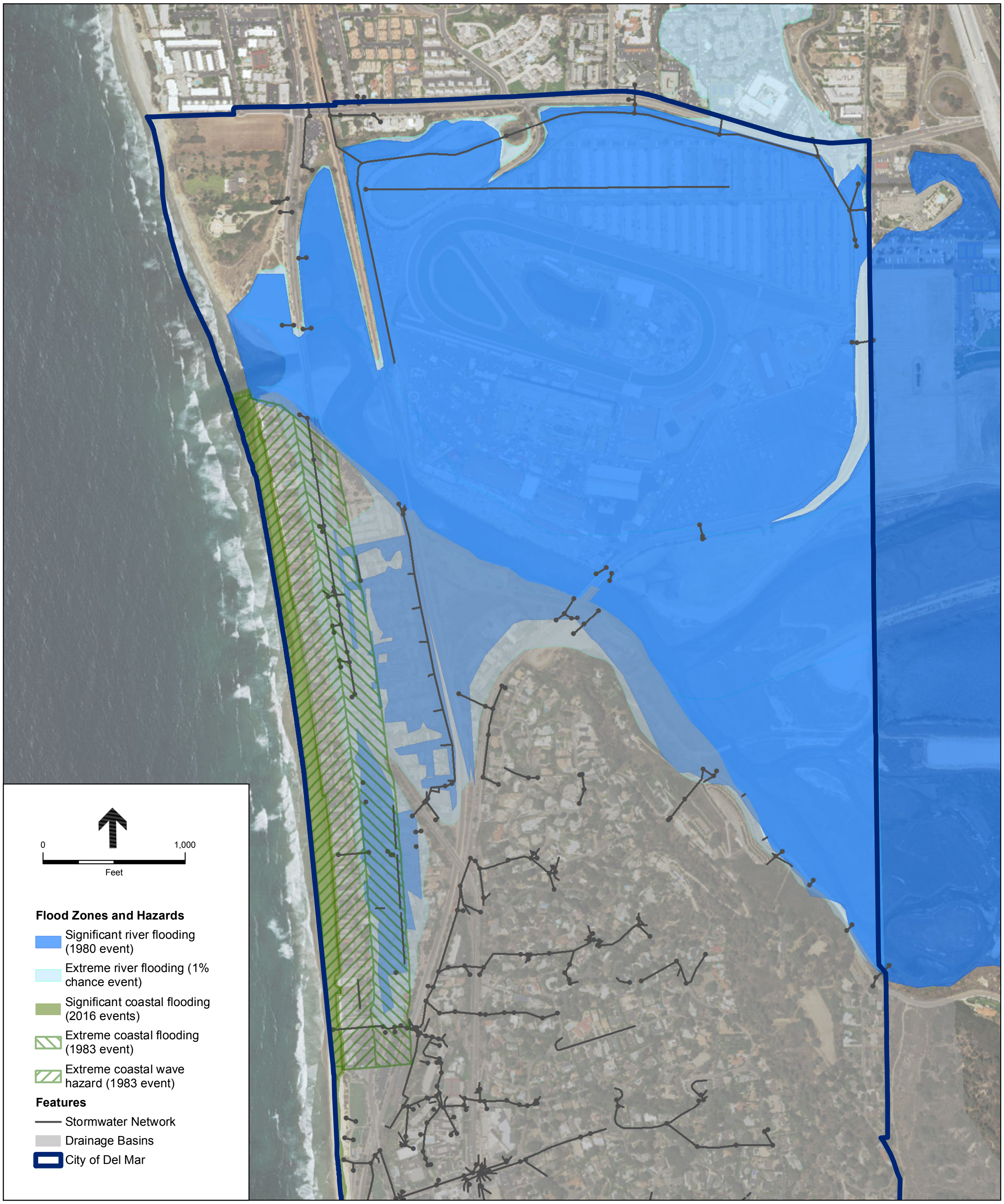
Figure 40.1

Flood Zones and Hazards
Properties and Roads Vulnerability



SOURCE: SanGIS 2016, FEMA

Figure 40.2
Flood Zones and Hazards
Water and Sewer Infrastructure Vulnerability



SOURCE: SanGIS 2016, FEMA

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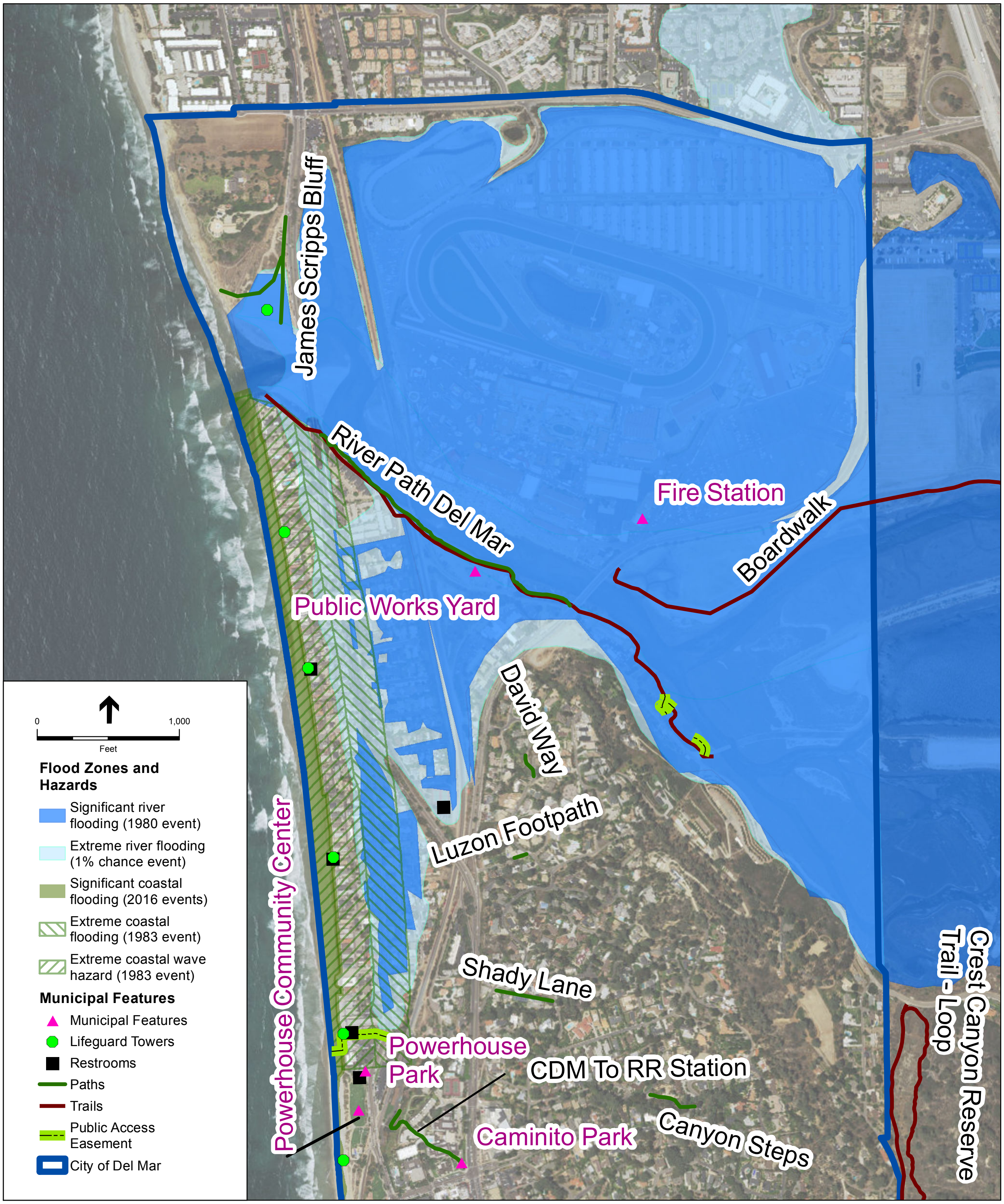
Figure 40.3

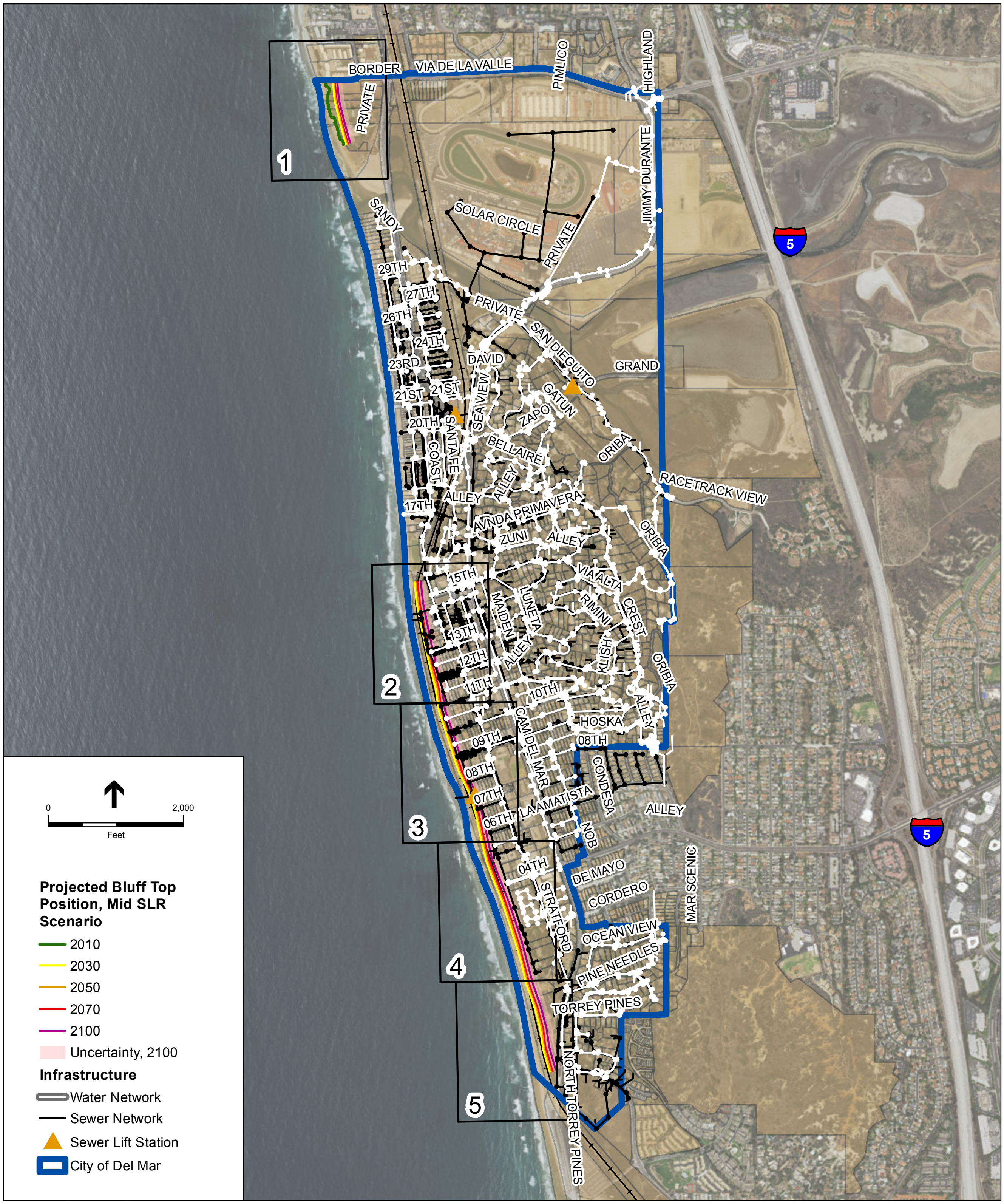
Flood Zones and Hazards
Stormwater Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Figure 40.4

Flood Zones and Hazards
Public Access and City Services Vulnerability



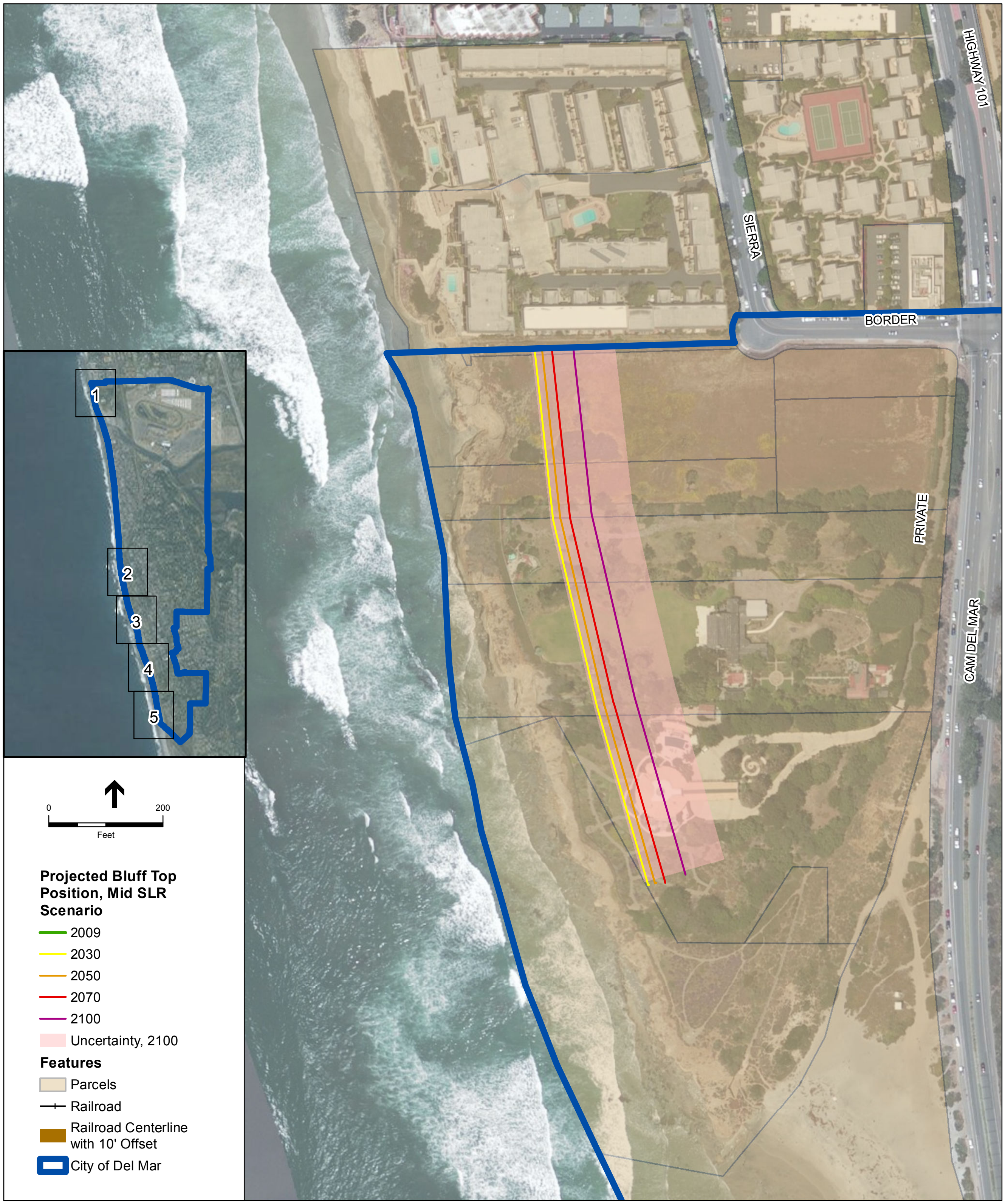
SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 41- Map Grid Overview

Mid Sea Level Rise in Del Mar

Water and Sewer Infrastructure Vulnerability

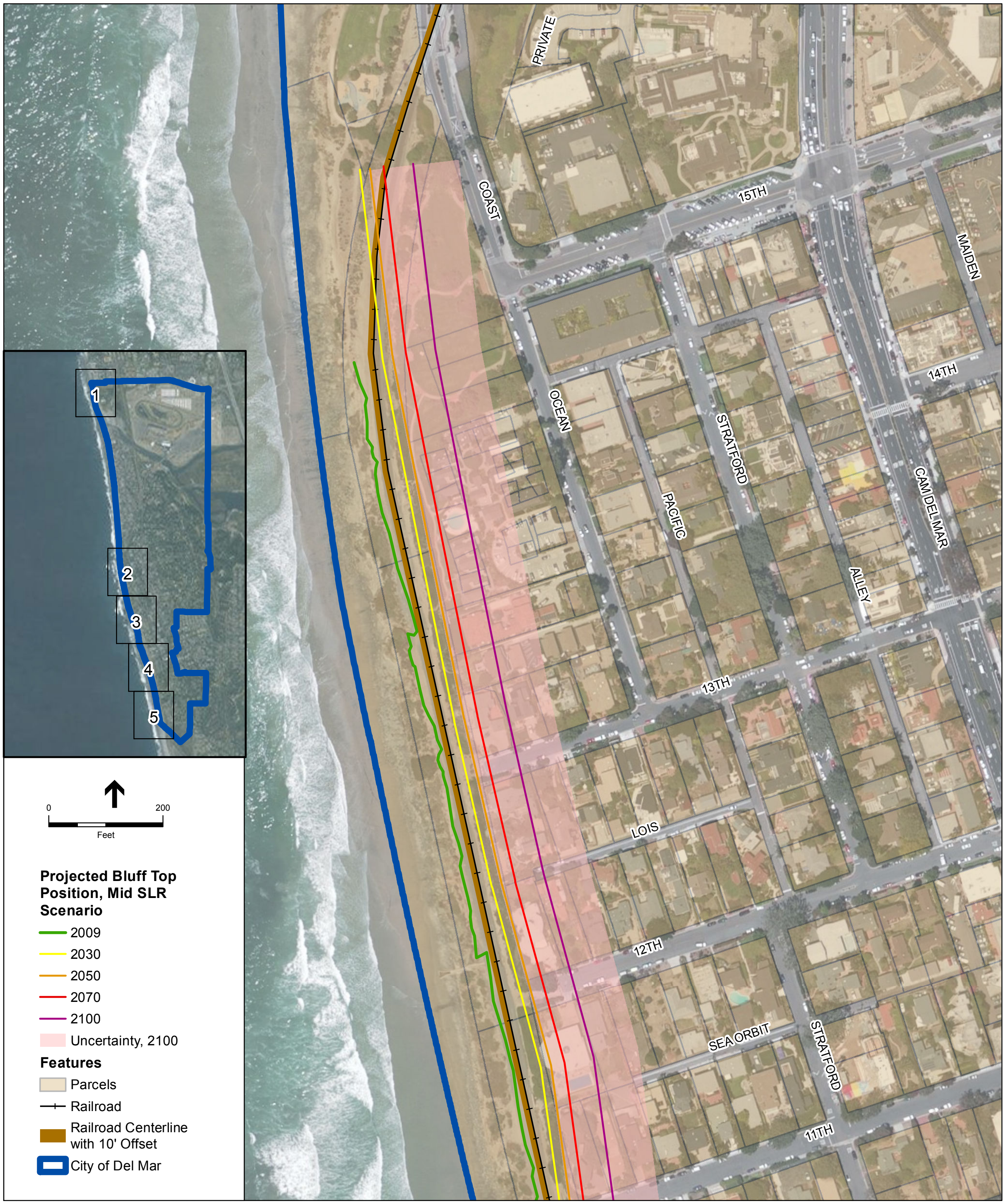


SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 41.1

Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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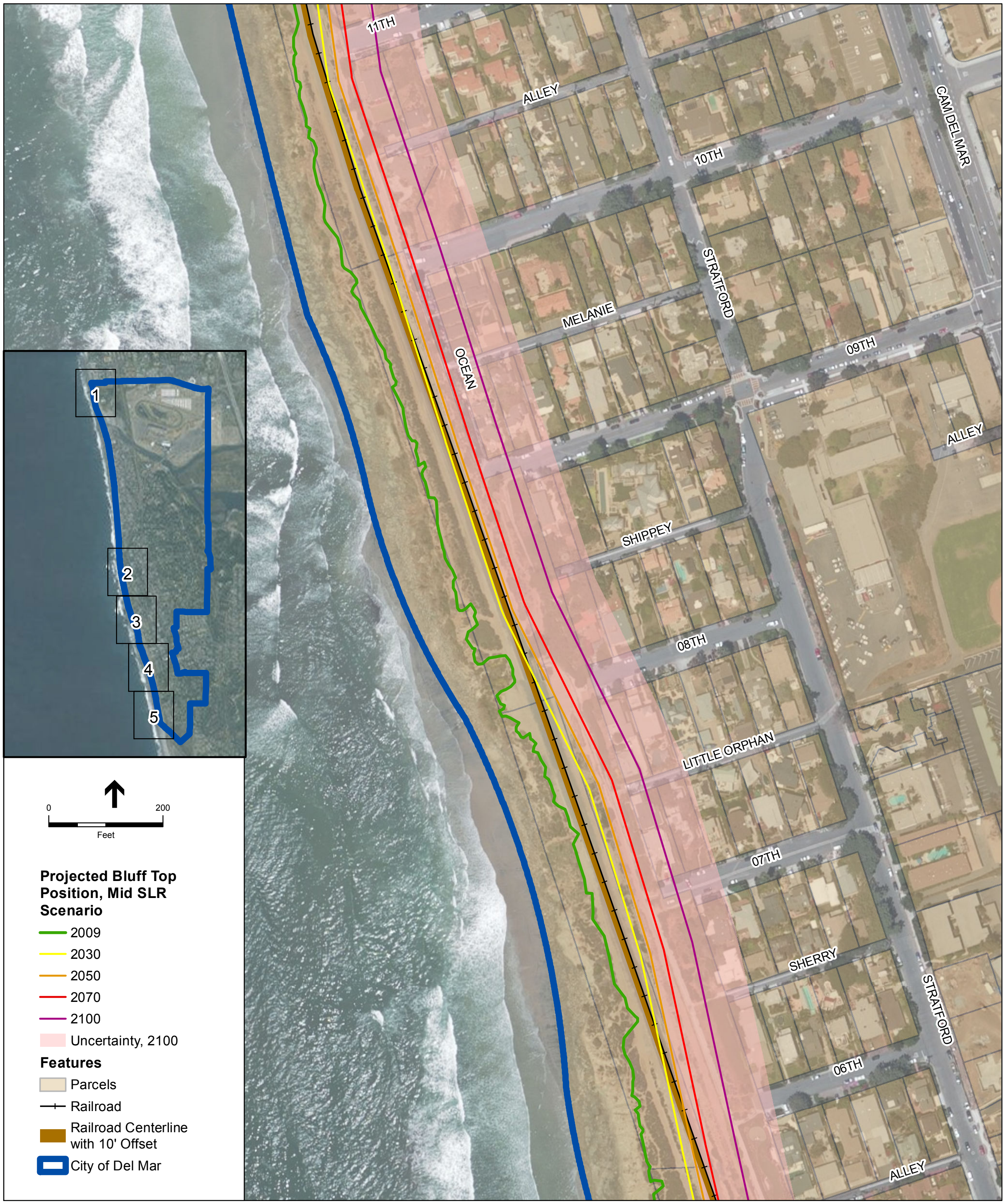
Figure 41.2

Mid Sea Level Rise in Del Mar Properties and Roads Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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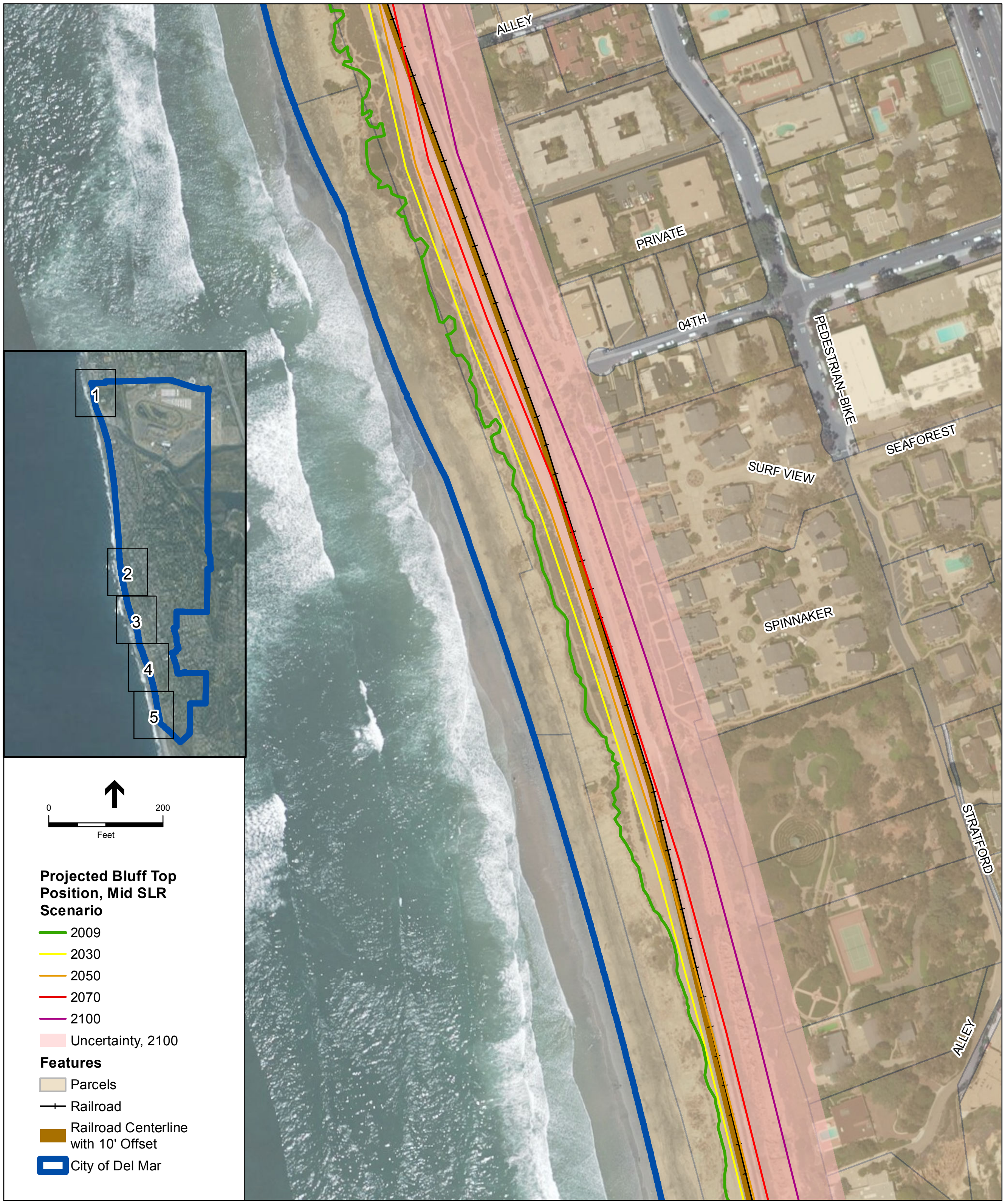
Figure 41.3
Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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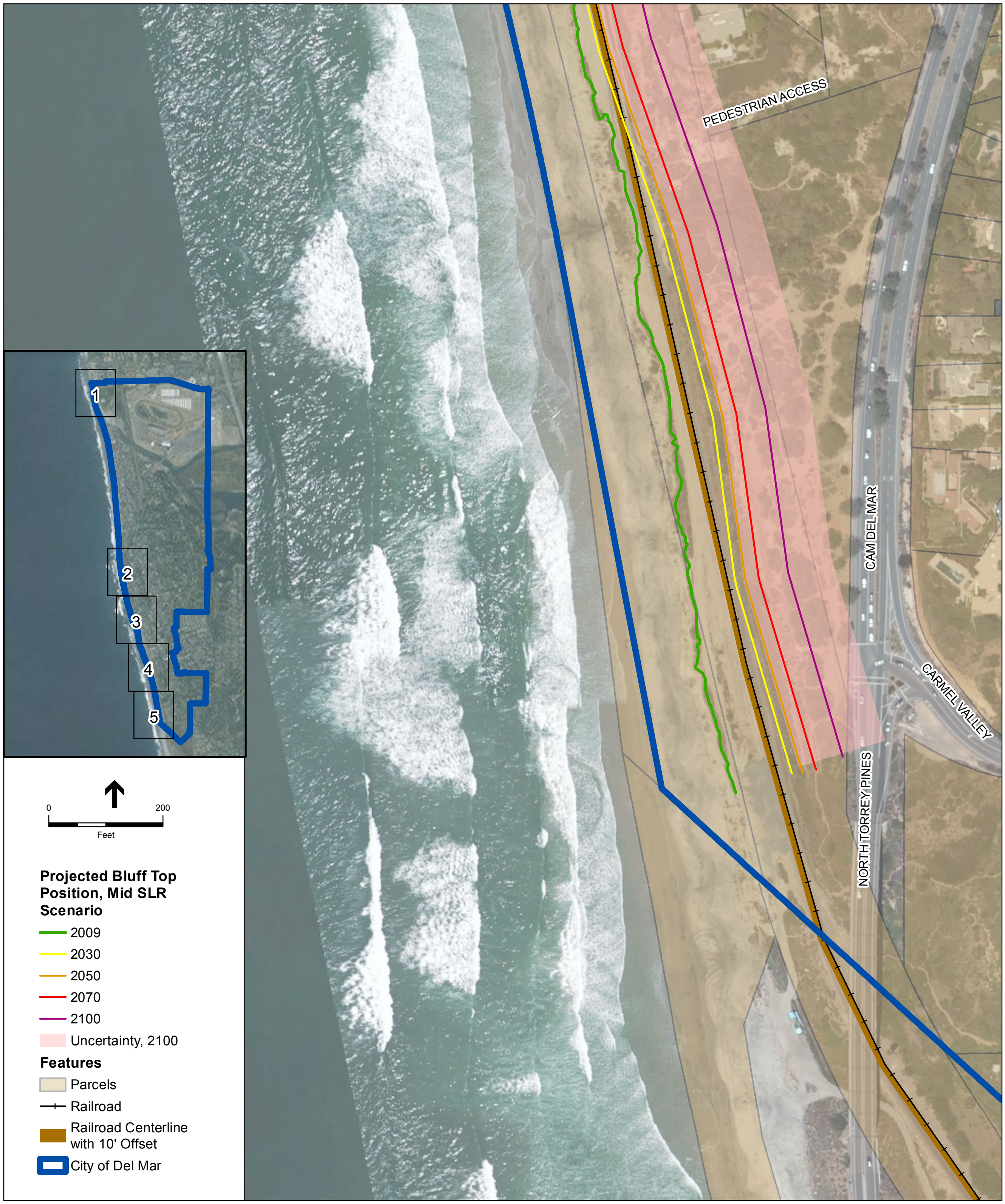
Figure 41.4

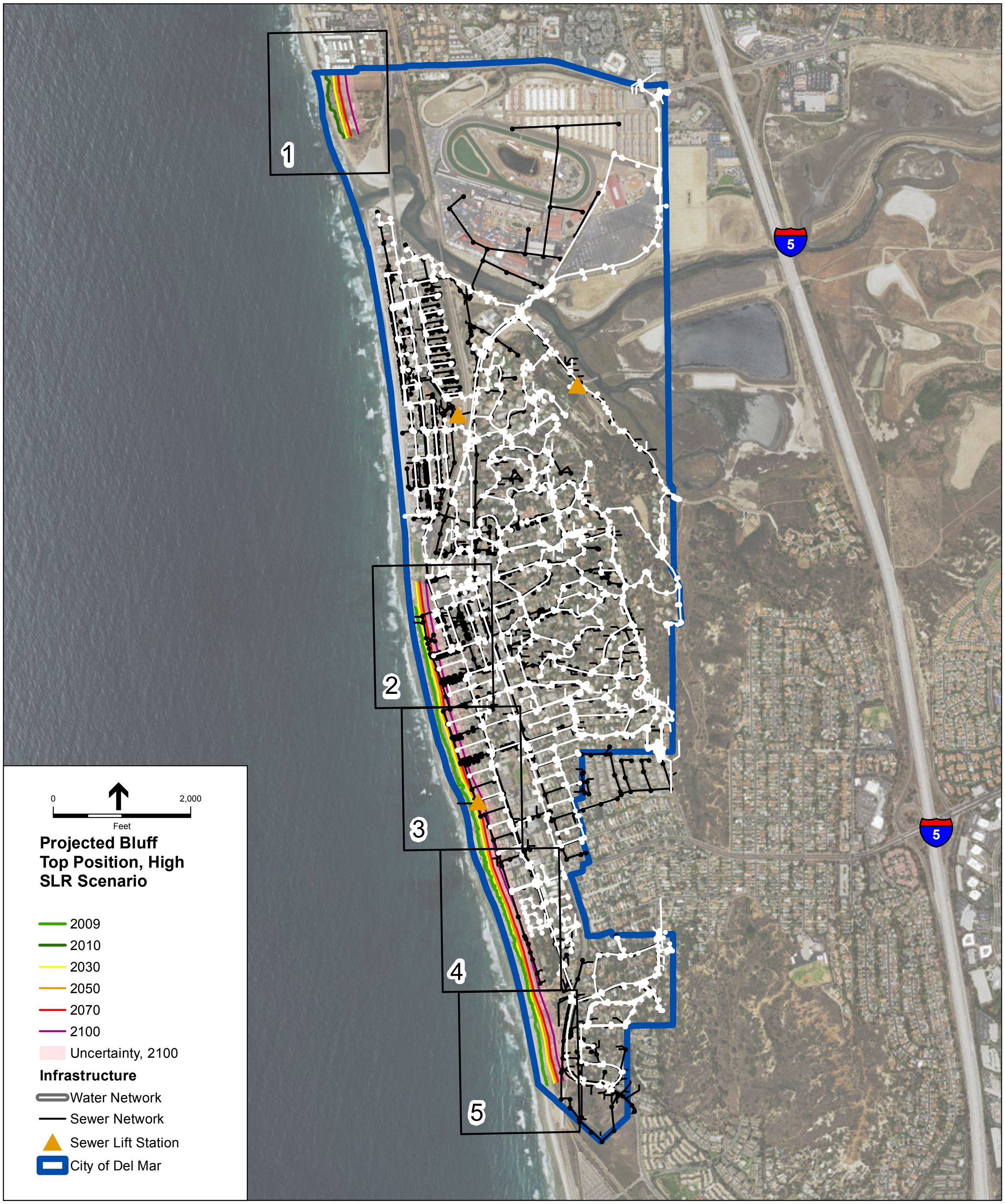
Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 41.5
Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability



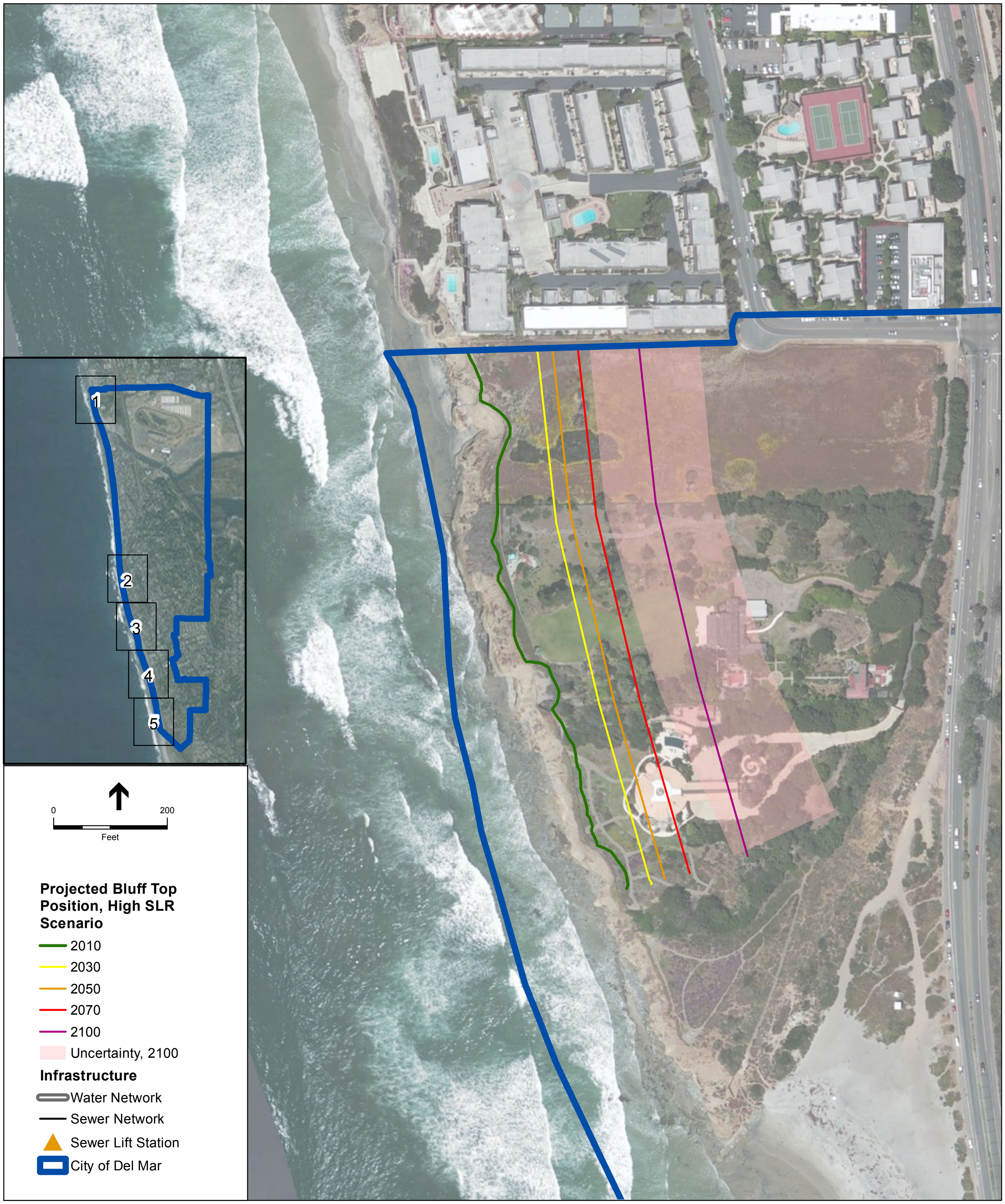
SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 42- Map Grid Overview

High Sea Level Rise in Del Mar

Water and Sewer Infrastructure Vulnerability



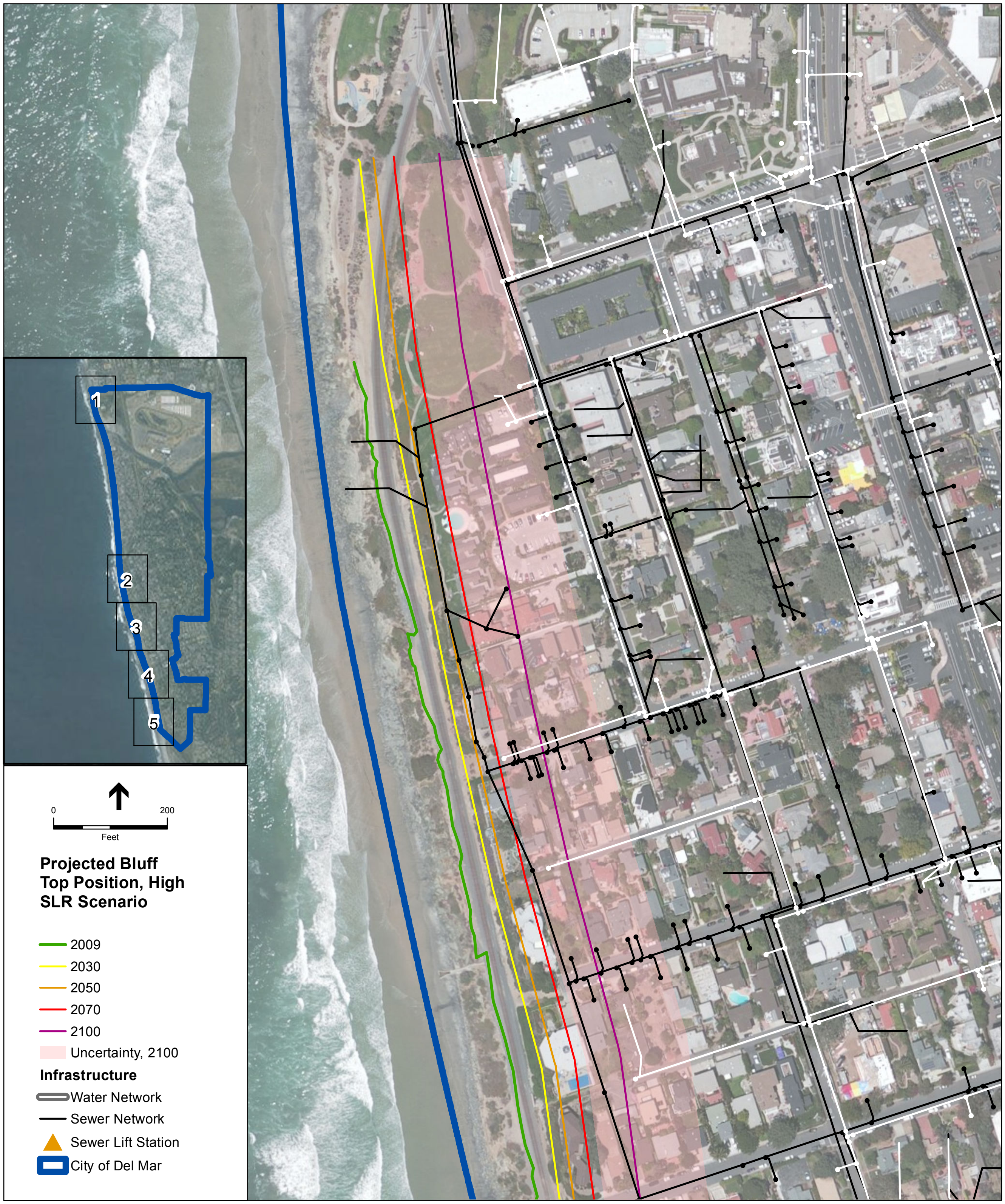
SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 42.1

High Sea Level Rise in Del Mar

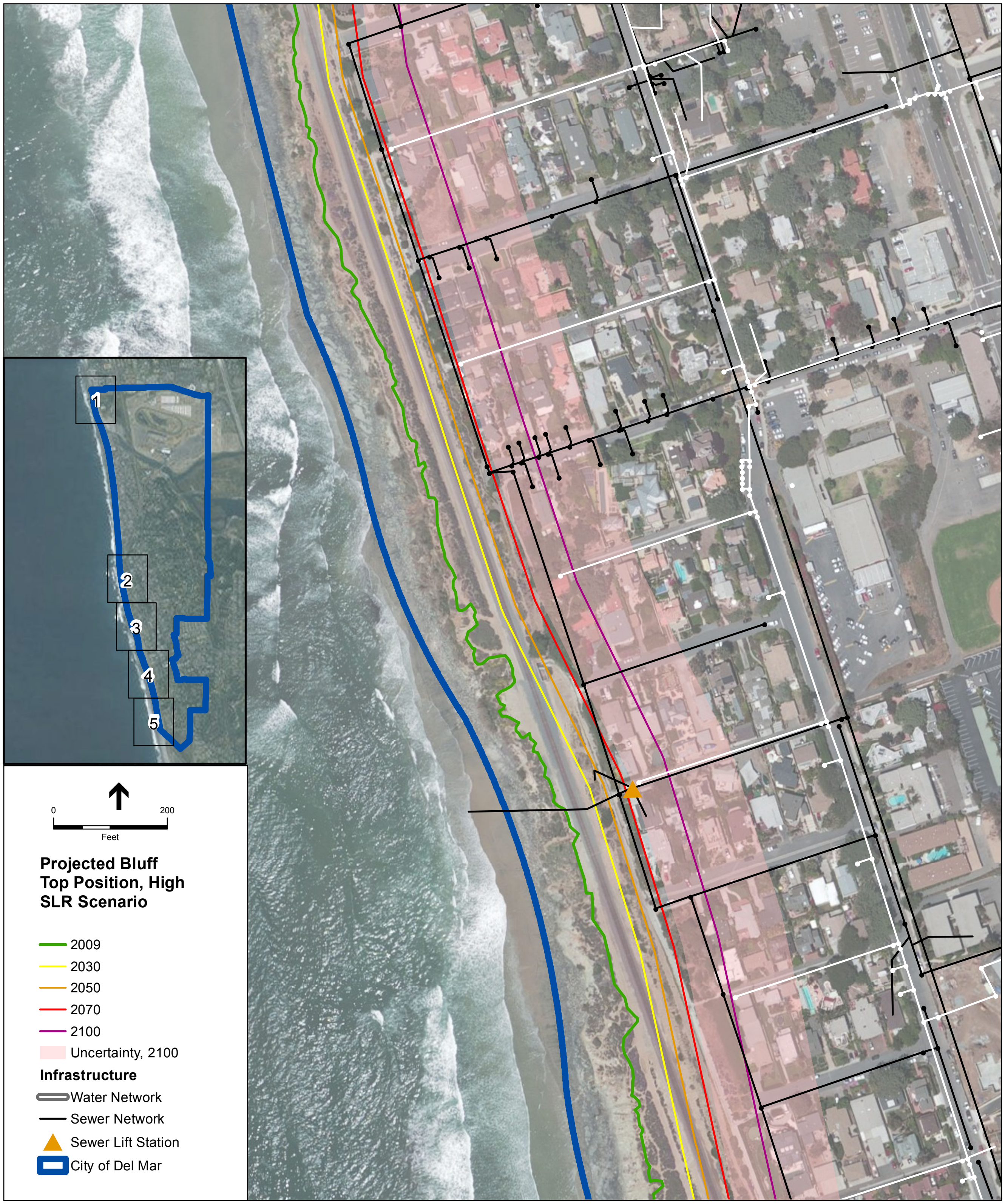
Water and Sewer Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 42.2
High Sea Level Rise in Del Mar
Water and Sewer Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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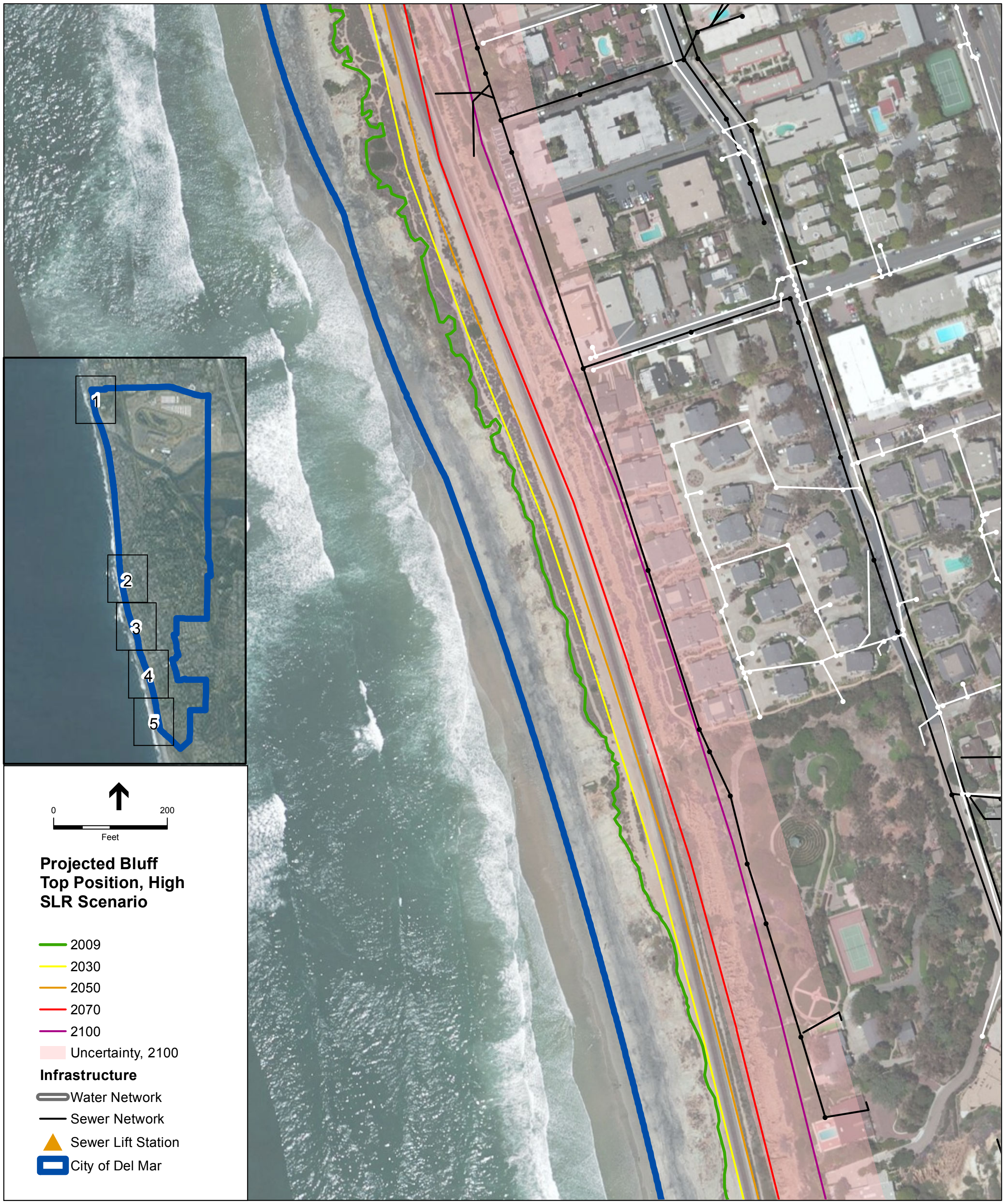
Figure 42.3

High Sea Level Rise in Del Mar

Water and Sewer Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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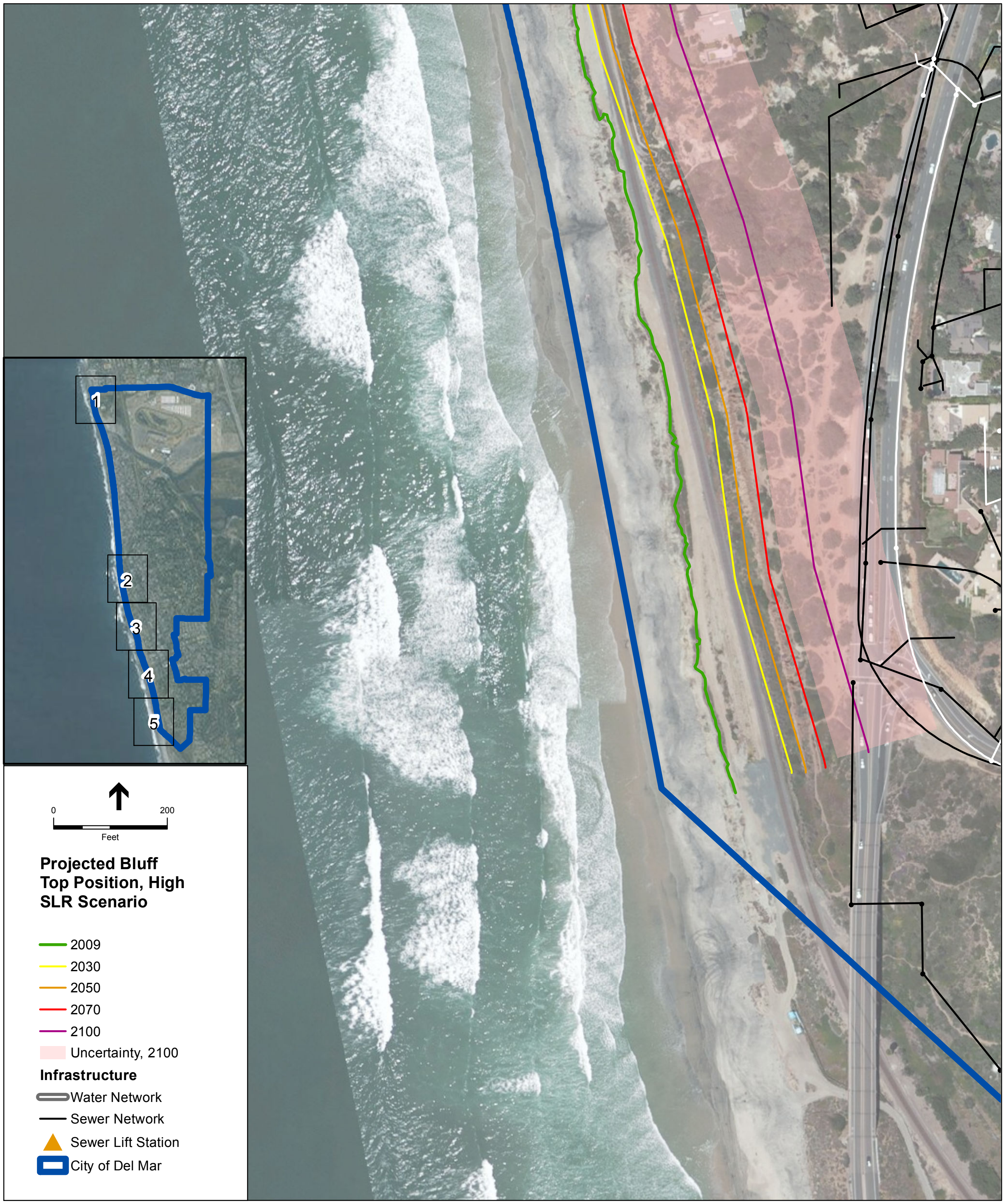
Figure 42.4

High Sea Level Rise in Del Mar

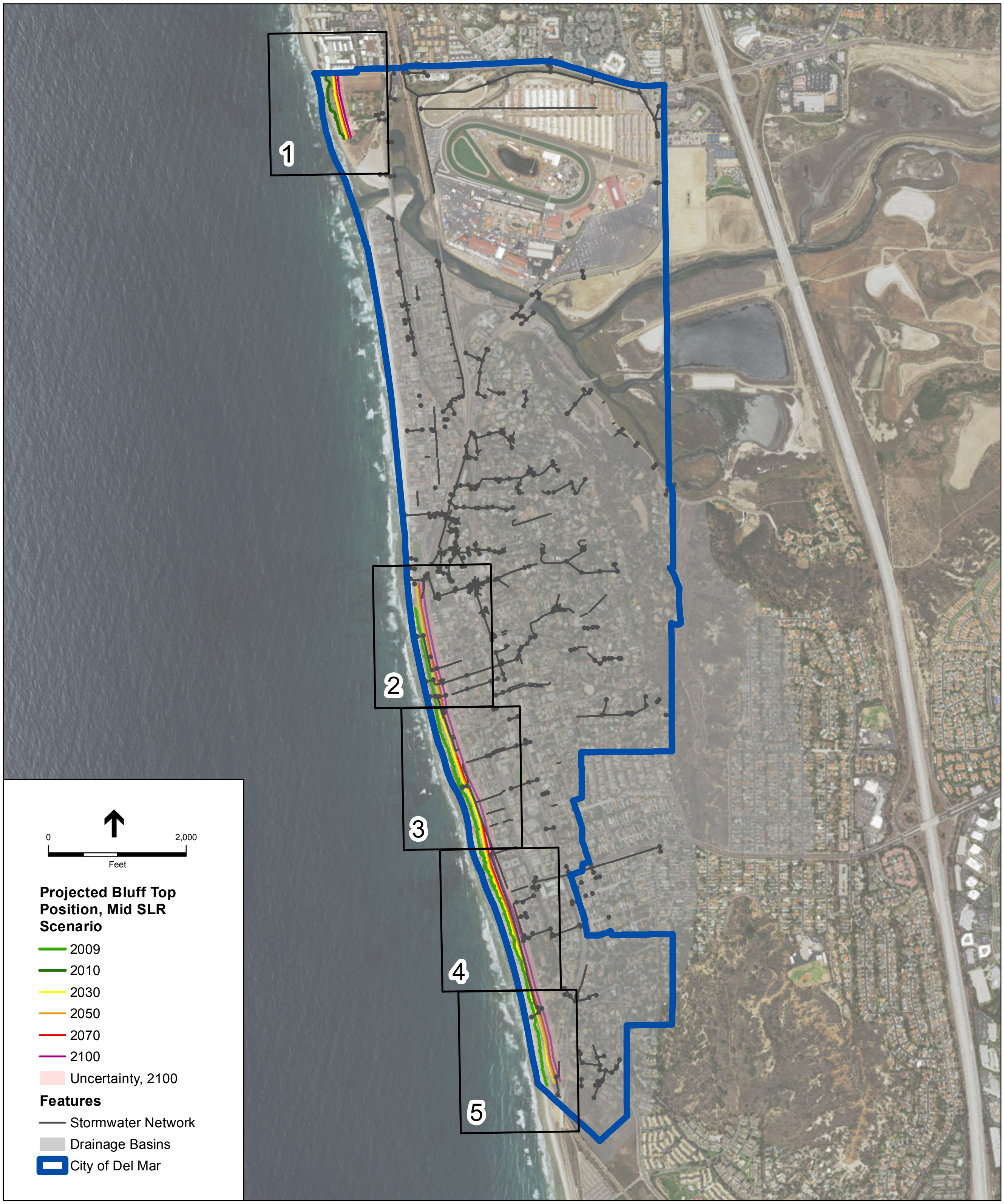
Water and Sewer Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 42.5
High Sea Level Rise in Del Mar
Water and Sewer Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

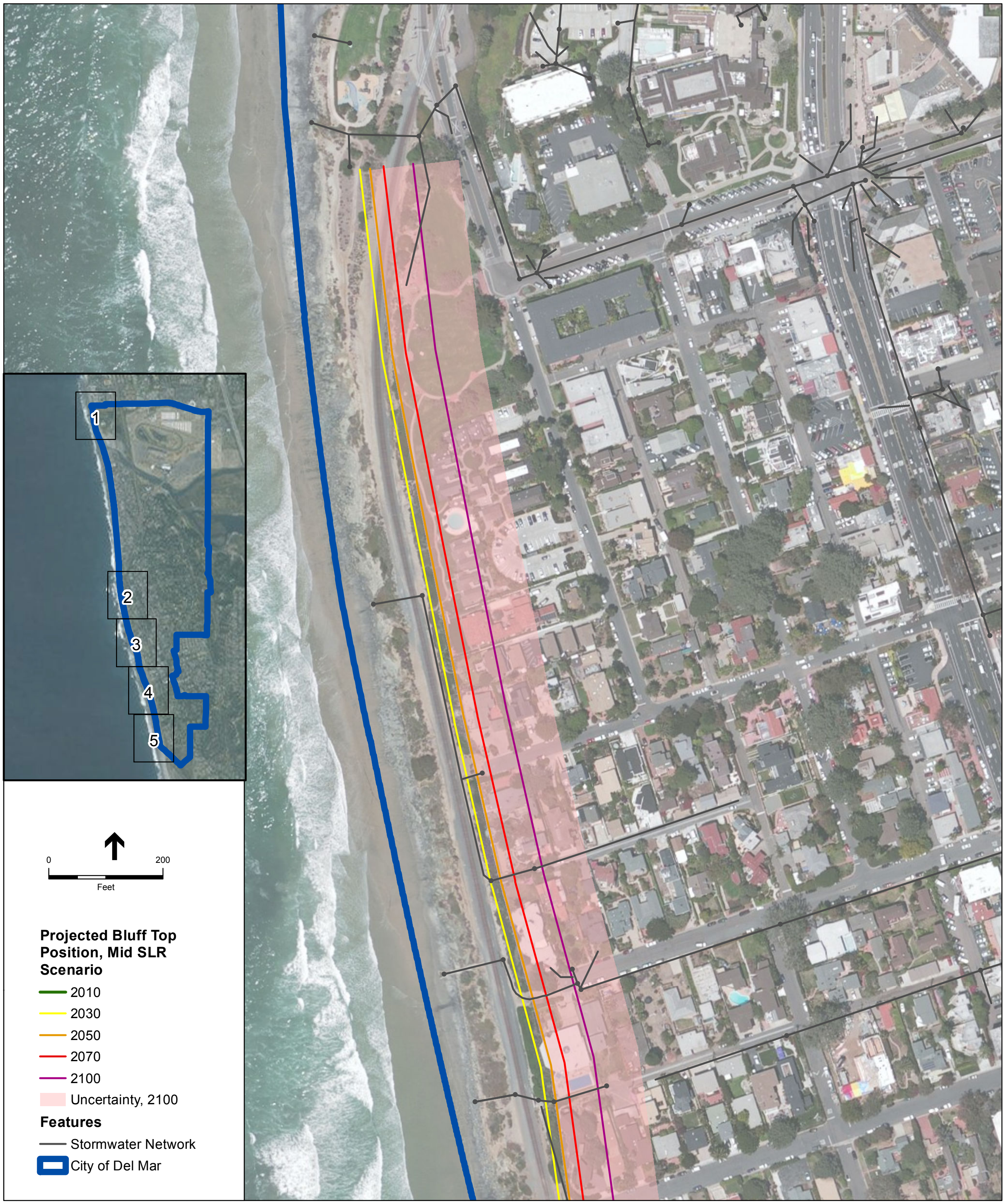
Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 43- Map Grid Overview
Mid Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability

SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 43.1
Mid Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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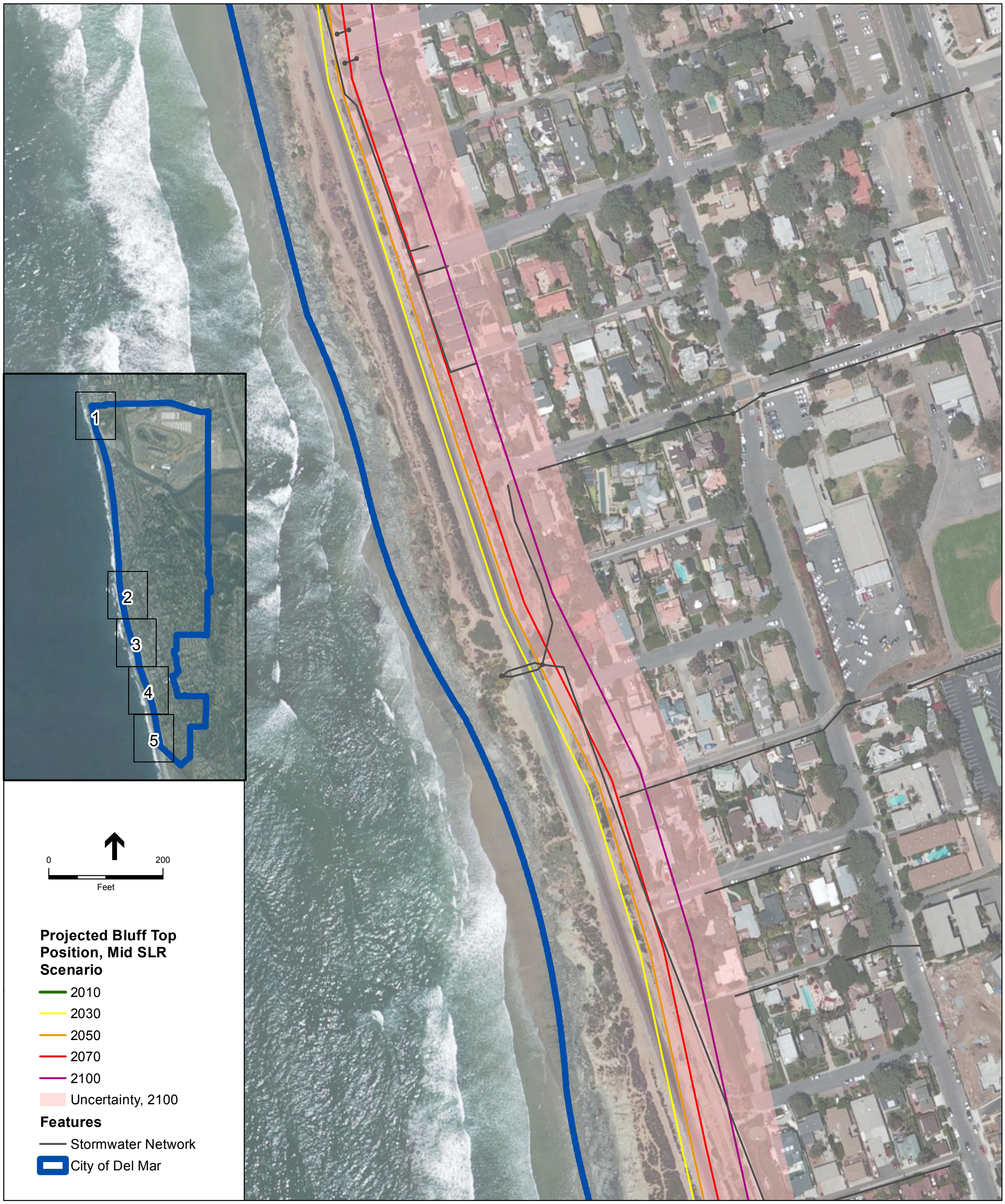
Figure 43.2

Mid Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 43.3
Mid Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability

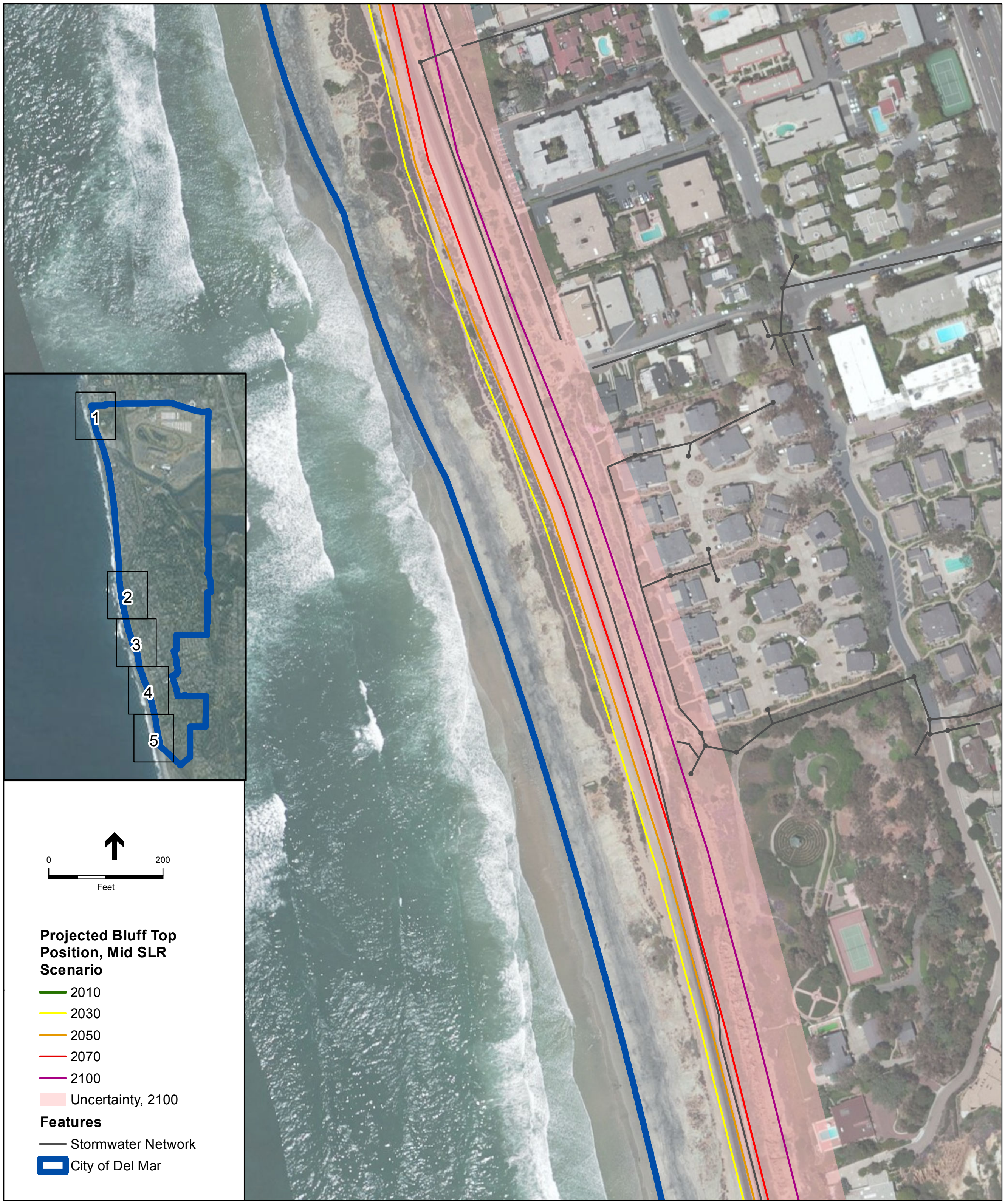


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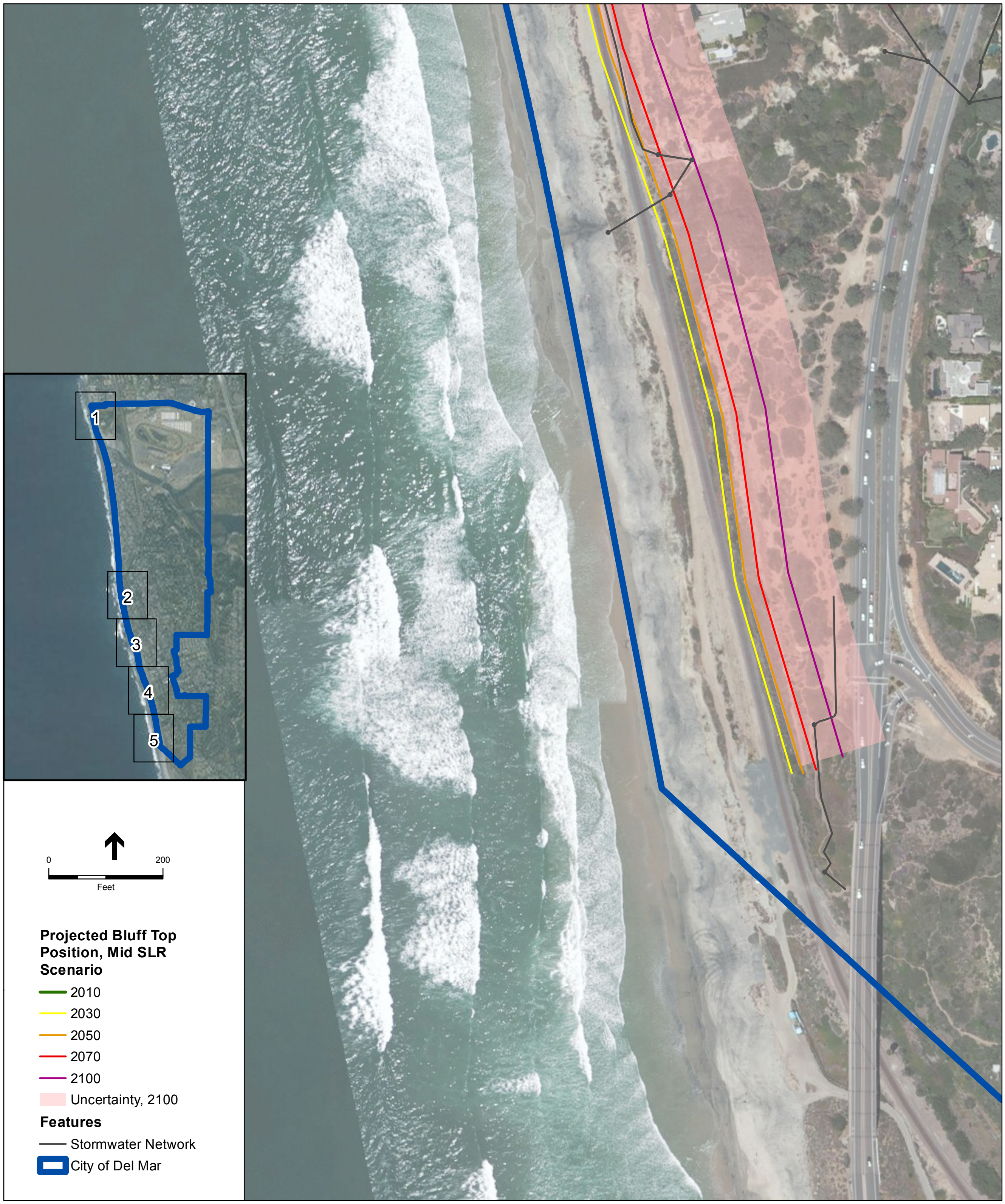
Figure 43.4

Mid Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability

SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.



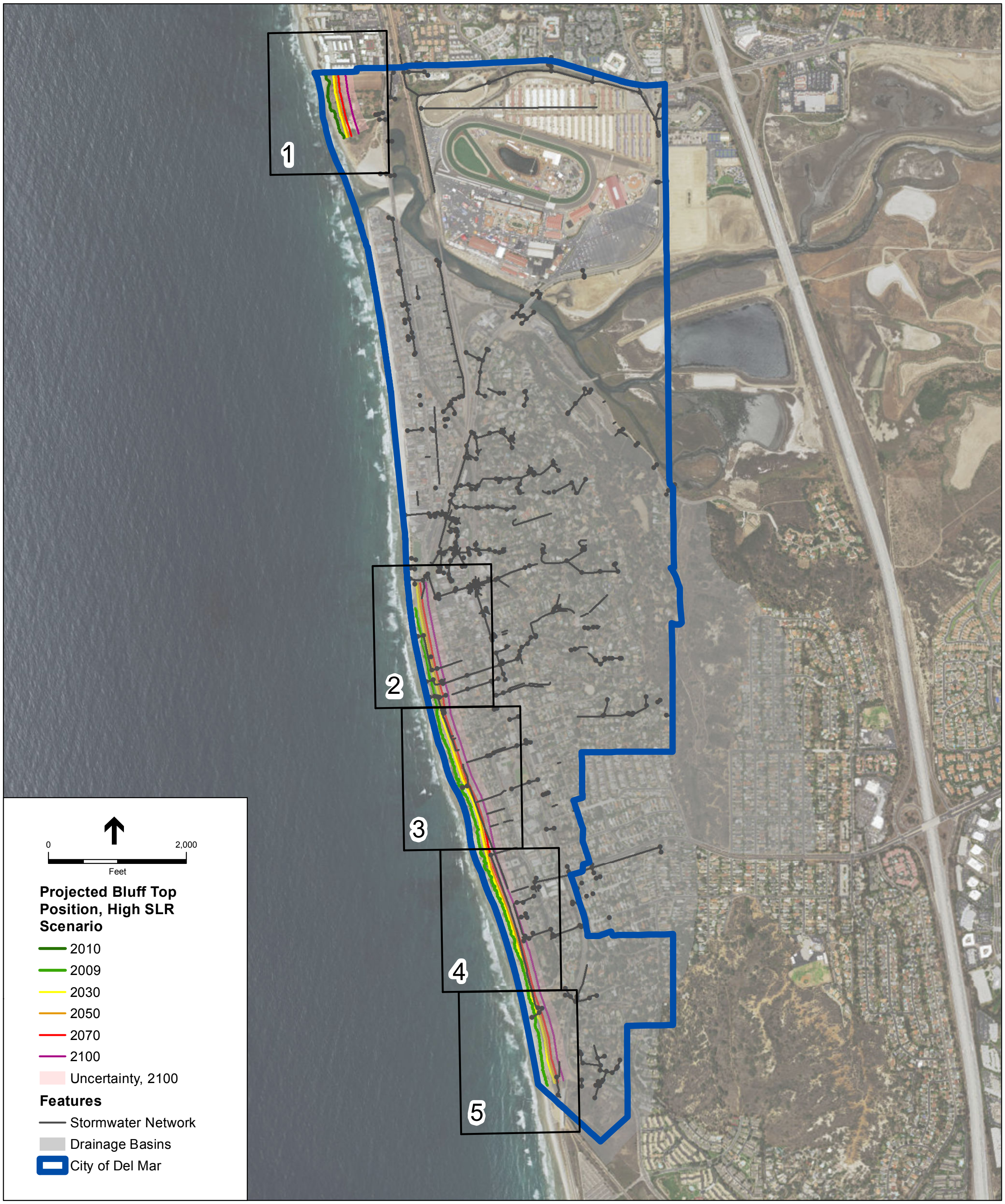
SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 43.5

Mid Sea Level Rise in Del Mar

Stormwater Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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Figure 44- Map Grid Overview
High Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability

SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 44.1
High Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability

SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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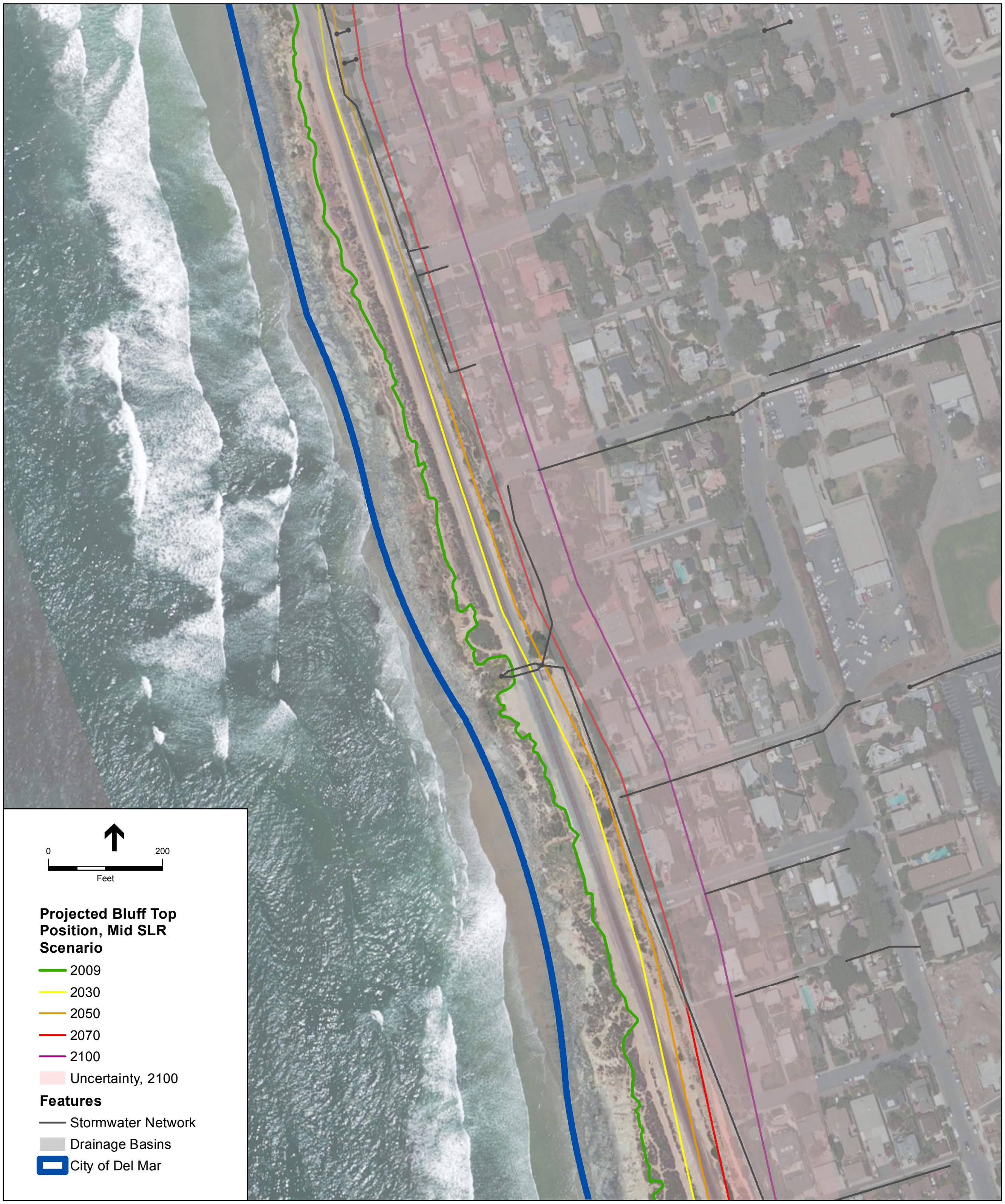
Figure 44.2

High Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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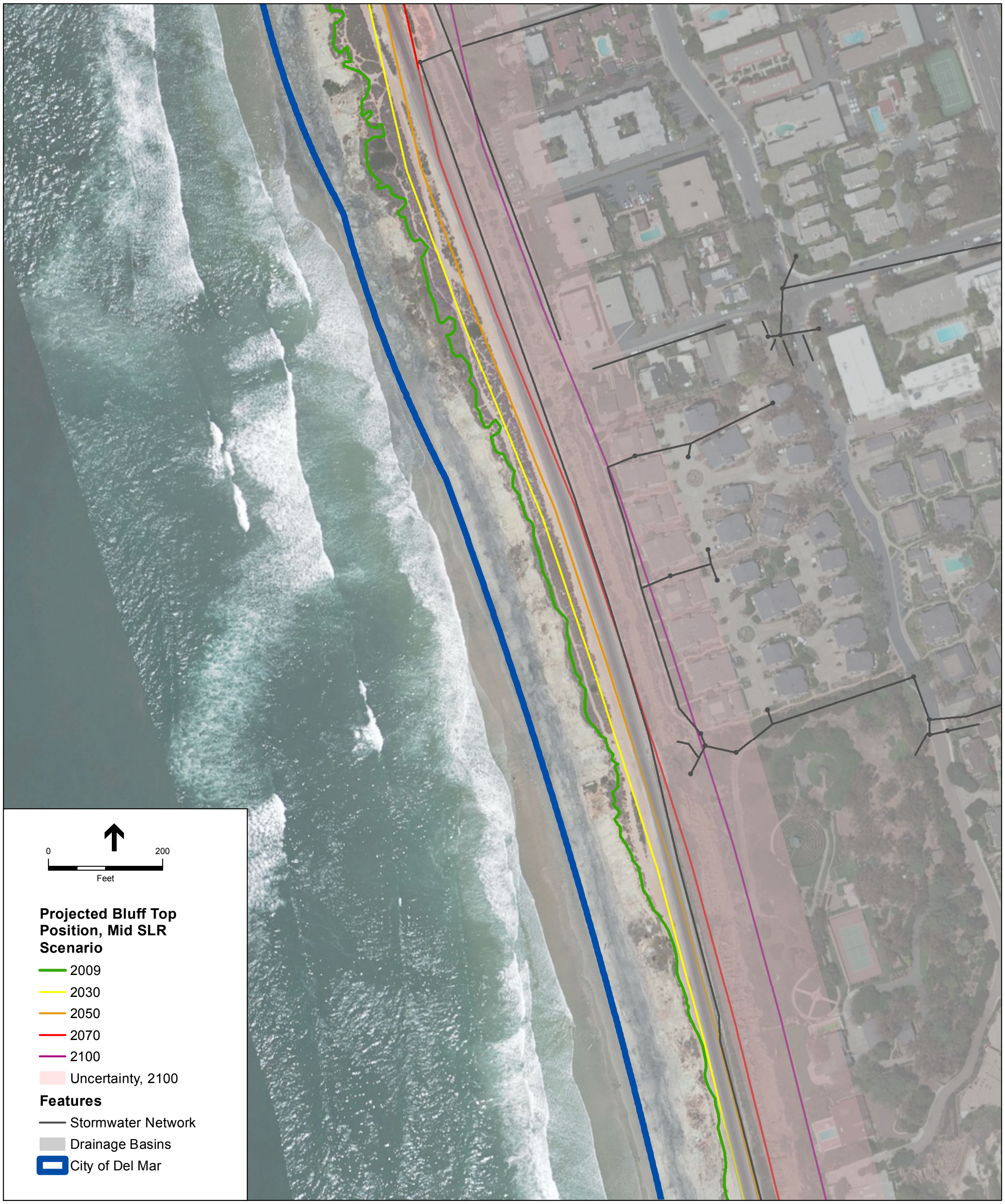
Figure 44.3

High Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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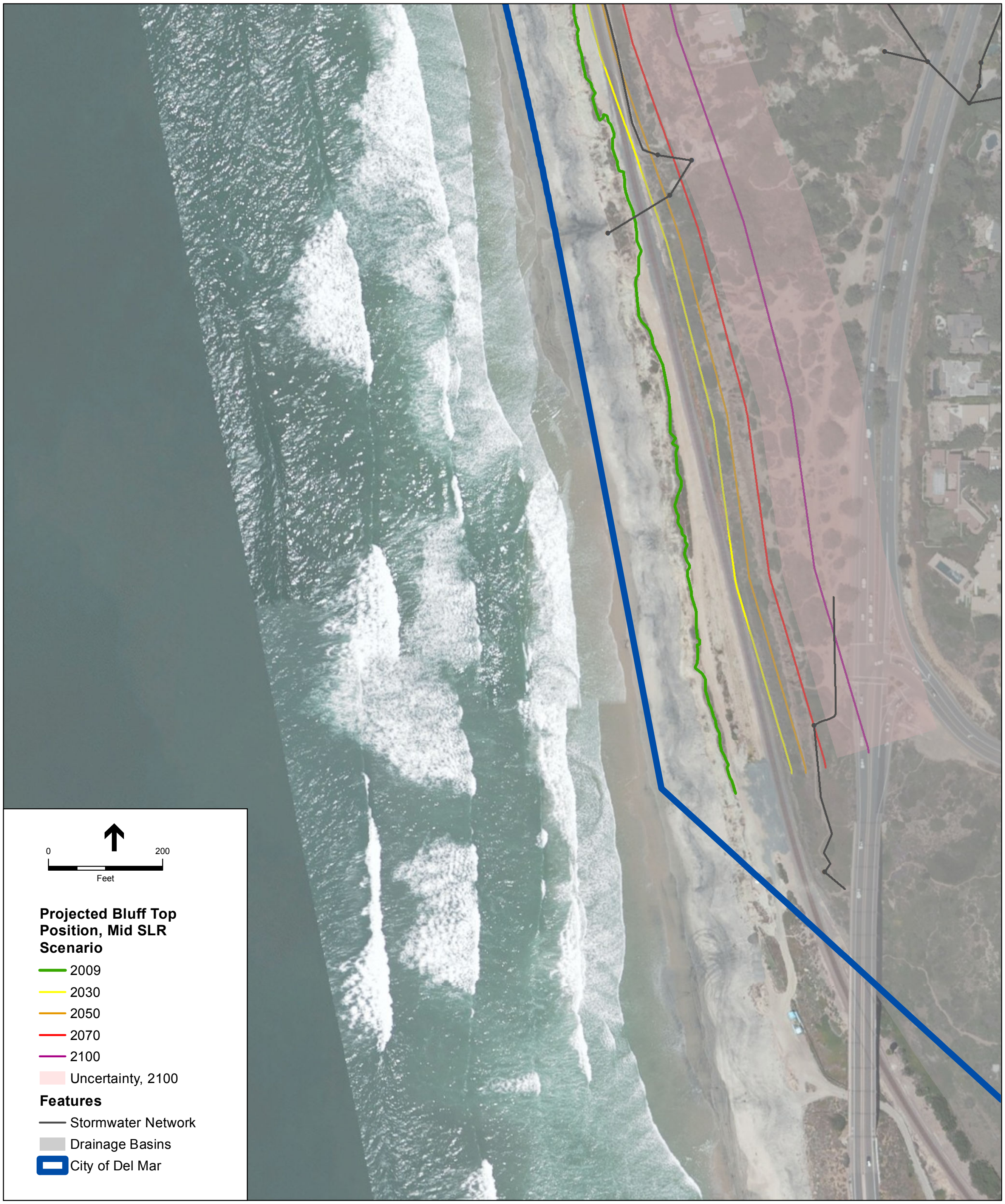
Figure 44.4

High Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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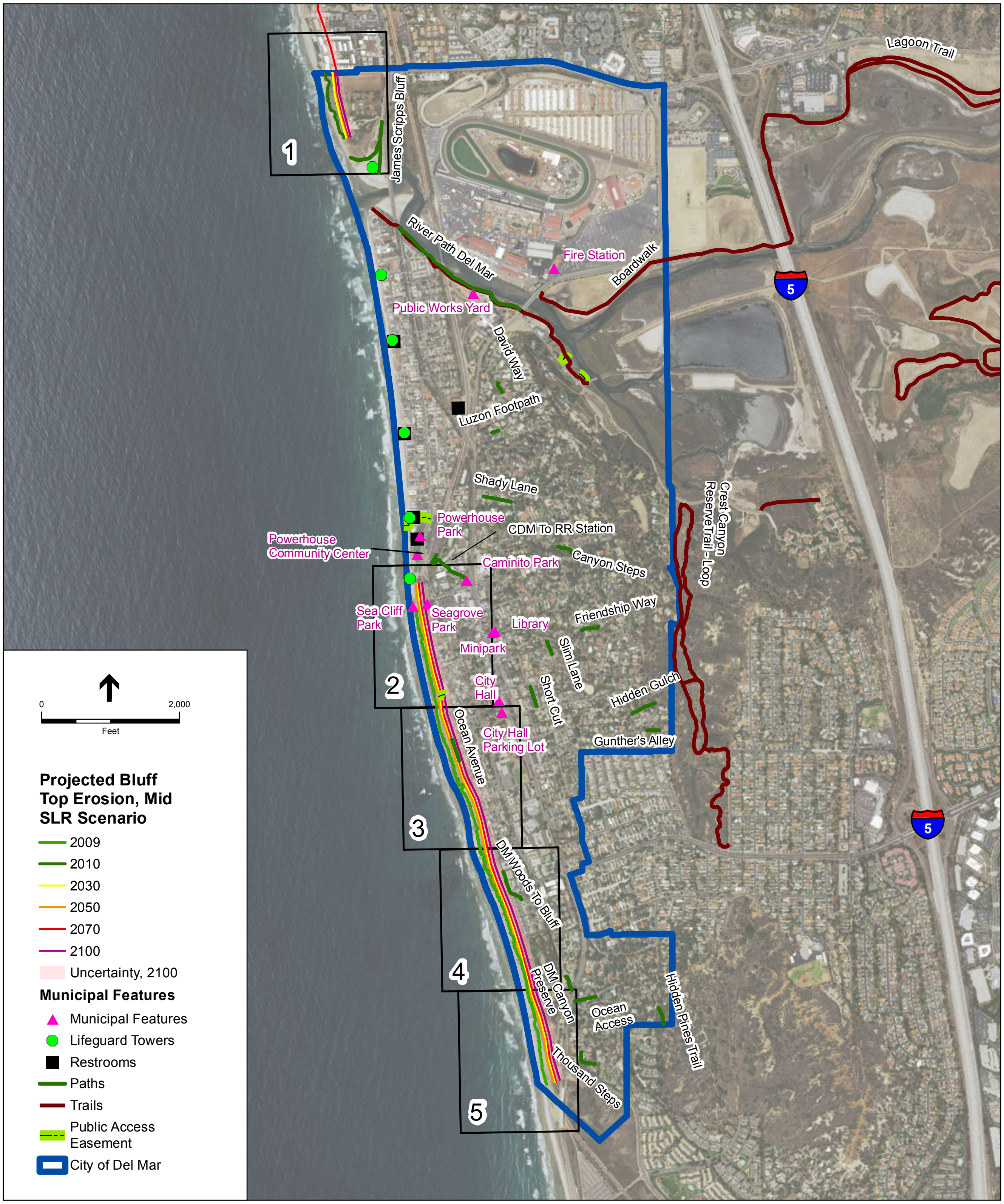
Figure 44.5

High Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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Figure 45- Map Grid Overview

Mid Sea Level Rise in Del Mar

Public Access and City Services Vulnerability

SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 45.1
Mid Sea Level Rise in Del Mar
Public Access and City Services Vulnerability

SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 45.2
Mid Sea Level Rise in Del Mar
Public Access and City Services Vulnerability

SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 45.3

Mid Sea Level Rise in Del Mar

Public Access and City Services Vulnerability

SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 45.4
Mid Sea Level Rise in Del Mar
Public Access and City Services Vulnerability

SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top positions are based on CoSMoS 3.0 results for 2100 with 1.0 meter SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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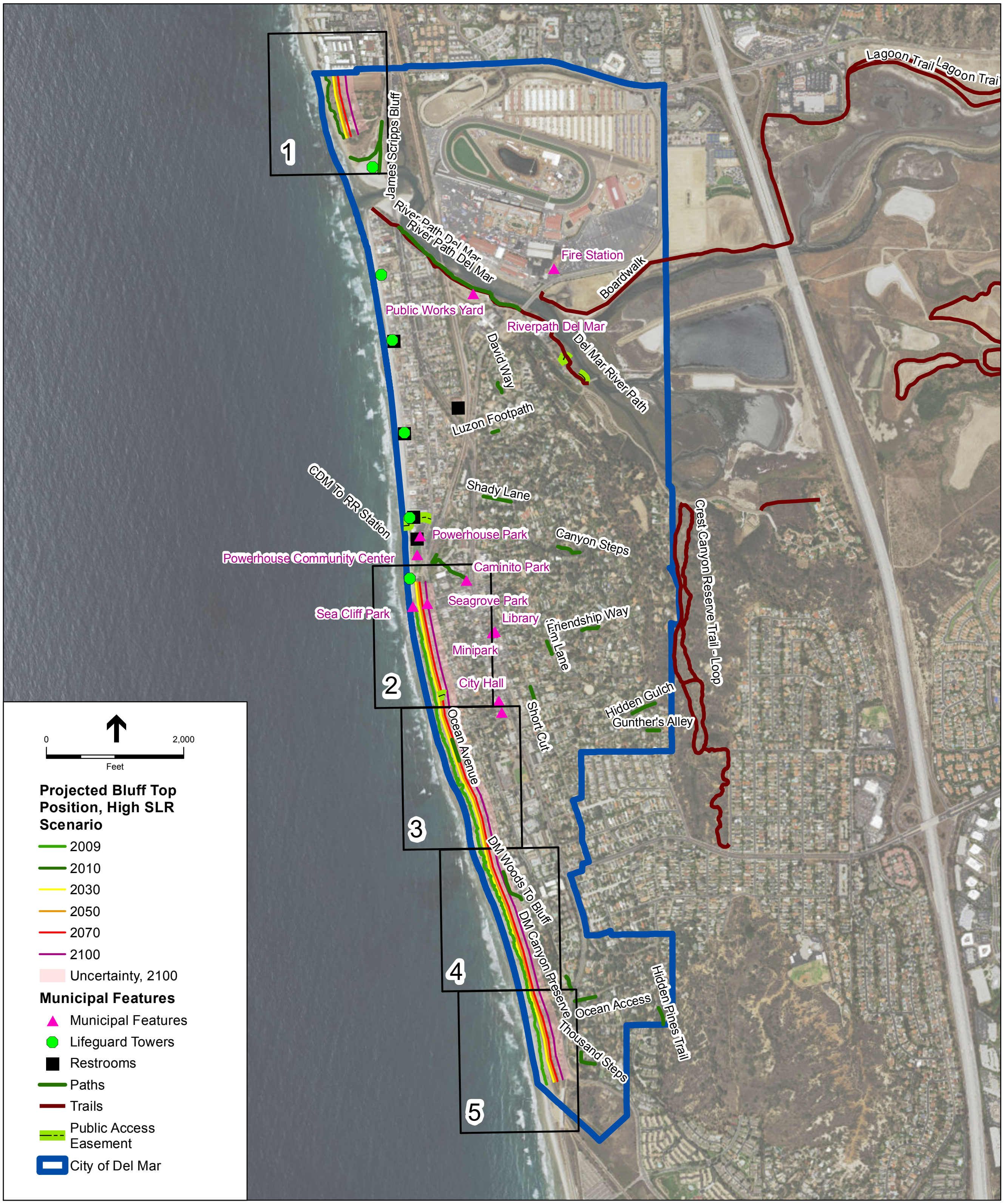
Figure 45.5
Mid Sea Level Rise in Del Mar
Public Access and City Services Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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Figure 46- Map Grid Overview

High Sea Level Rise in Del Mar

Public Access and City Services Vulnerability

SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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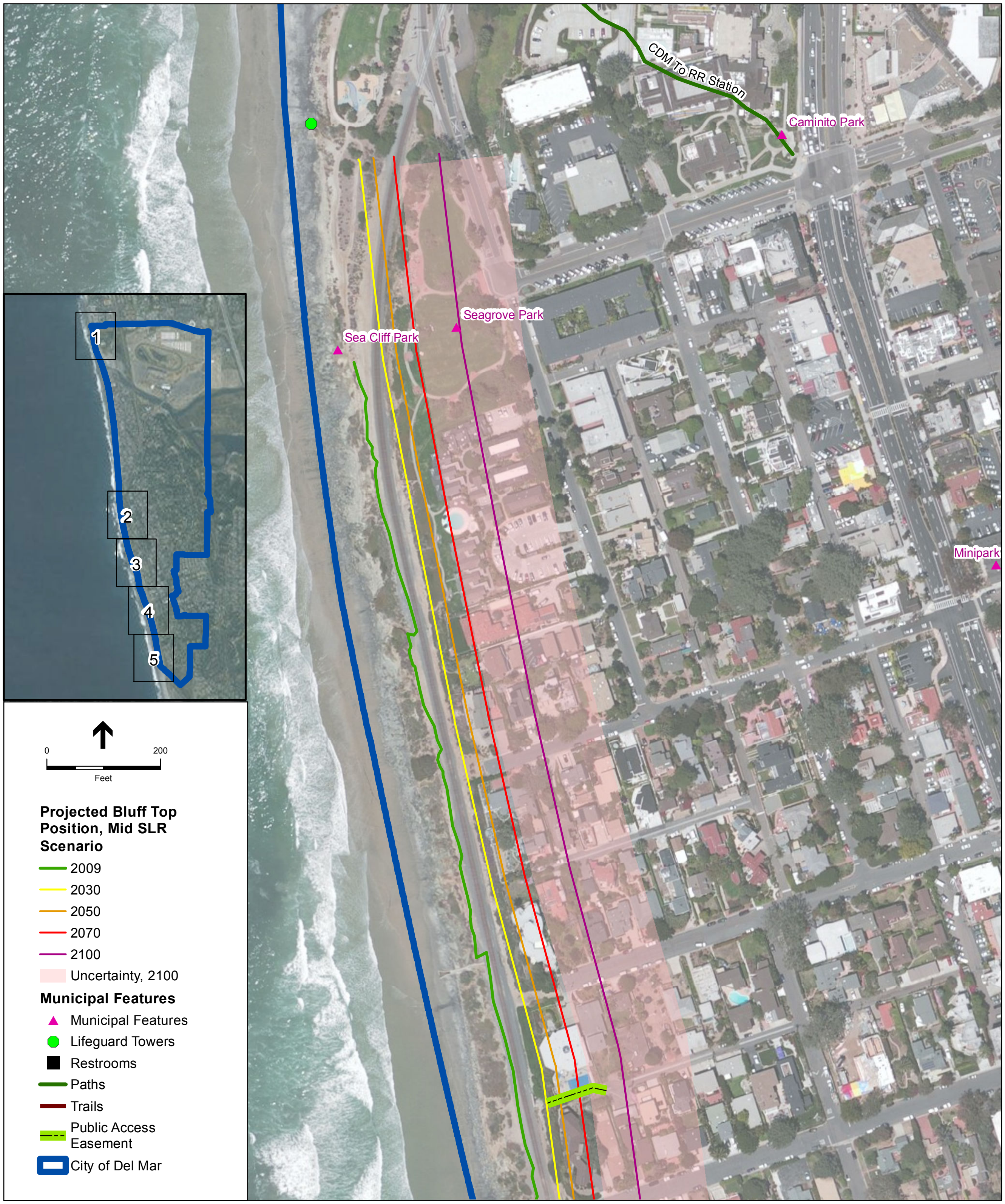
Figure 46.1

High Sea Level Rise in Del Mar
Public Access and City Services Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 46.2
High Sea Level Rise in Del Mar
Public Access and City Services Vulnerability

SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 46.3
High Sea Level Rise in Del Mar
Public Access and City Services Vulnerability

SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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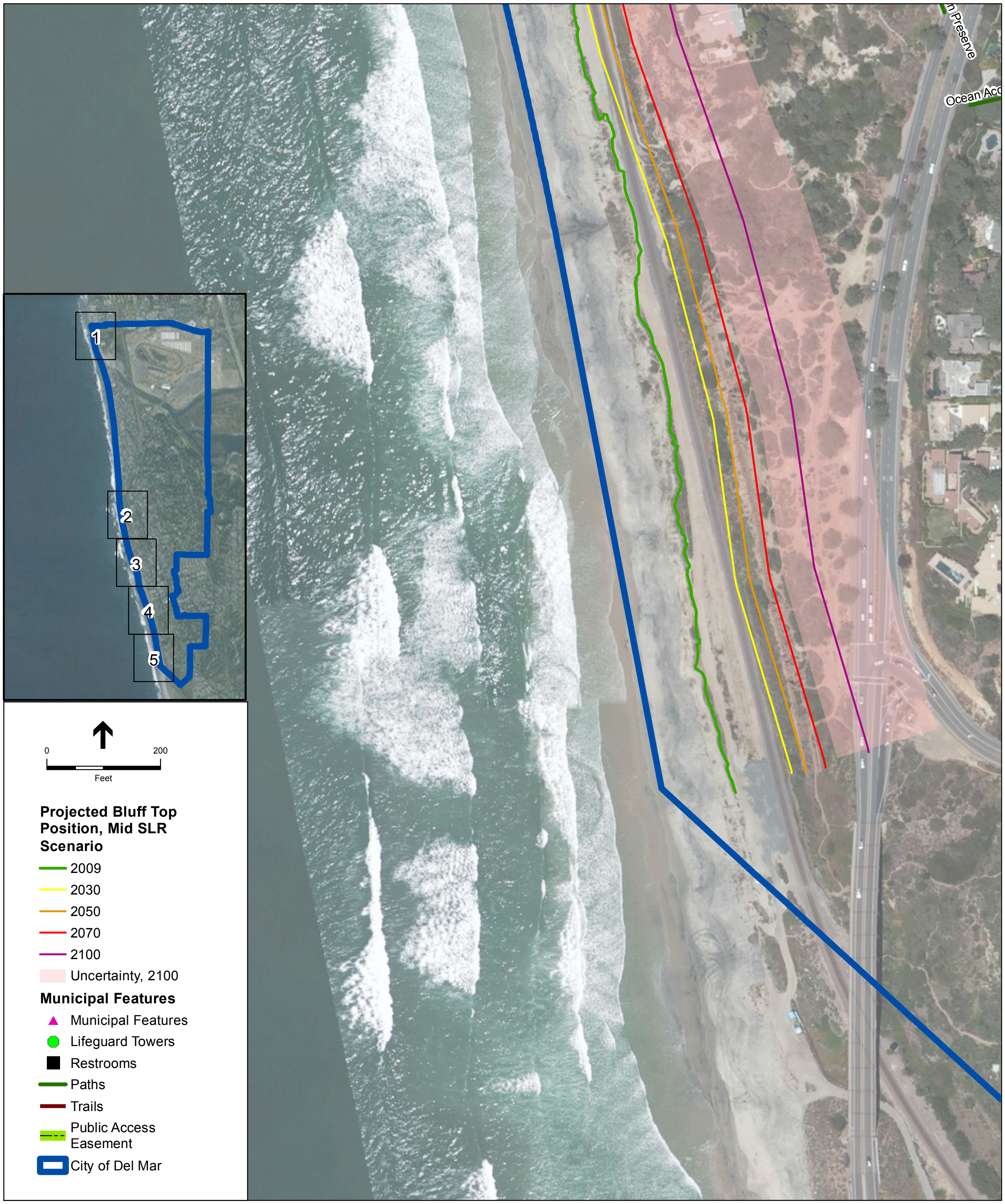
Figure 46.4

High Sea Level Rise in Del Mar

Public Access and City Services Vulnerability



SOURCE: SanGIS 2016, USGS 2015

Note: Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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Figure 46.5

High Sea Level Rise in Del Mar
Public Access and City Services Vulnerability

Vulnerabilities and risks are identified and discussed below by area (City District) and type of vulnerability and risk.

North Beach District vulnerability to coastal erosion, flooding, and damage. Public access along the beach (horizontal access) will be lost due to beach erosion by 2030 to 2060. Beach erosion and coastal storms will threaten sea wall integrity and increase flooding and storm damage. For properties west of Camino Del Mar, including the City's 17th St Beach Safety Center, the present low to moderate vulnerability to coastal flooding and wave damage will become a high vulnerability by about 2050. Ocean Front and Camino Del Mar/Coast Blvd. roads and properties west of Camino Del Mar will also be highly vulnerable to coastal flooding. Note that the blocks between Ocean Front and Camino Del Mar/Coast Blvd. and these roads will be increasingly vulnerable to both coastal and river flooding (discussed below).

Del Mar Fairgrounds, Valley District, and North Beach District vulnerability to San Dieguito River flooding and damage. The present low exposure of the Fairgrounds to significant flooding will become highly exposed by 2070; however, the vulnerability of the Fairground's land uses to flooding may be less than for other public and private development due to the reduced consequences of the flooding. Moderate exposure of the Fire Station to flooding will make emergency services highly vulnerable by 2030 because the Fire Station will be impacted when flooding is occurring and emergency response is needed, as occurred in the 1980 flood. Roads and bridges, including Camino Del Mar, Jimmy Durante Blvd. and bridge, the east ends of North Beach District streets, and San Dieguito Drive, will be highly vulnerable by about 2070. Low-lying central portions of the North Beach District (blocks bounded by Camino Del Mar, 28th St, and Railroad; general vicinity of Coast Blvd. and Santa Fe between 17th St. and 23rd St.), which currently have low vulnerability to River flooding, would be highly vulnerable in 2070. The sewer lift station along San Dieguito Drive would be increasingly exposed to flooding and risk of failure. Other water and sewer infrastructure in these areas would also be exposed to both River and coastal flooding, but is not highly vulnerable to flooding.

North Beach storm drain vulnerability. Local rainfall runoff from North Beach drains to the San Dieguito River via ditches and culverts, which are currently fitted with flap gates and pumps. Over time with sea level rise, gravity drainage through culverts will not be possible with sea level rise and additional pumping will be required.

South Beach, South Bluffs, and North Bluffs vulnerability to bluff erosion. The current localized vulnerability of the LOSSAN railroad to bluff erosion will increase in extent in the near-term and extend along almost the entire bluff before 2030. By this timeframe, the railroad would need to be moved inland or armored with a seawall to reduce the risk of the railroad collapsing (as a section of railroad collapsed and cause a train wreck in 1940 as shown in Figure ES-4). If a seawall is constructed, the beach will erode back to the seawall over time until little to no beach exists. If the railroad is moved inland and bluff erosion is allowed to continue, blufftop property and sewer infrastructure in the South Beach and South Bluff Districts would be vulnerable to erosion by 2050. North Bluffs properties would be similarly vulnerable to erosion.

San Dieguito River Lagoon wetland habitat vulnerability. With sea level rise, existing wetland habitats will be inundated more frequently and vegetated wetland habitats will be "drowned out" and convert to intertidal mudflats and subtidal habitat. Existing pickleweed marsh habitat could drown out and be lost by 2070. Cordgrass low marsh habitat could be lost by 2090, such that almost all of the San Dieguito Lagoon Wetland Restoration would be converted to intertidal mudflat and subtidal open water. Salt marsh habitats are expected to migrate upstream along the San Dieguito River with sea level rise; however, the River corridor is relatively narrow and the overall vegetated marsh acreage will be greatly reduced.

Table 13 summarizes the timeframe when coastal resources and assets will be highly vulnerable and associated risks will be high (e.g., greater than 30% chance of occurrence of flooding and damage in a given year). Moderate vulnerability and risks before these timeframes may be acceptable; however, implementation of adaptation measures will likely be required in the near term (e.g., 2020 to 2050) prior to these timeframes to reduce these high vulnerabilities to within an acceptable level of risk. Adaptation measures will be considered and developed into an Adaptation Plan in the next phase of the LCPA process.

Table 13 summarizes these vulnerabilities and risk and identifies the sensitivity to exposure for different resources and assets based on "high-range" projections from Section 5. Sensitivities are defined as follows:

- Low sensitivity: resources and assets, such as property and roads, with lower exposure for which hazards have lower consequences, such as more minor flooding and damage.
- Medium sensitivity: resources and assets, such as the Fire Station, for which low exposure presents more of a risk, and properties with medium exposure and greater frequency of flooding and damage.
- High sensitivity: resources and assets with high exposure and high consequences, such as regular flooding and damage of property and roads.

Adaptive capacity is low for assets with medium to high sensitivity. Table 14 summarizes the timeframe for which key assets and resources could become highly vulnerable and sensitive. Consideration of adaptation strategies in the near term (e.g., 2030 to 2050) are recommended to address high exposure and sensitivities to beach front properties and streets

TABLE 13
SUMMARY OF NORTH BEACH ASSET VULNERABILITY TO FLOODING AND DAMAGE

Type and degree of flooding and damage		**Assets**			**Exposure**				
		Properties in North Beach	**Roads & Bridges**	**Emergency, City, and Public Facilities**	**Present**	**2030**	**2050**	**2070**	**2100**
Coastal	Significant (e.g., 2016 storms)	- Beach front	- West ends of 17th to 29th Streets		Moderate 10%	High 50%	High 100%		
	Extreme (e.g., 1983 storm)	- West of Sand Barr Ln.	- Ocean Front - Camino Del Mar/Coast Blvd.	- 17th St Beach Safety Center	Low 1%	Mod. 5%	Mod. 15%	High 50%	High 100%
River	Significant (e.g., 1980 flood)	- Blocks bounded by Camino Del Mar, 28th St, and RR - General vicinity of Coast Blvd. and Santa Fe between 17th St. and 23rd St.	- San Dieguito Drive - Jimmy Durante Bridge - East ends of 17th to 29th Streets	- Fire Station - Public Works Yard - Riverpath Del Mar	Low 4%	Mod. 15%	Mod. 25%	High 50%	High 100%
	Extreme (e.g., FEMA 1% chance flood)	- Majority of North Beach west of Ocean Front	- Jimmy Durante Blvd. - Camino Del Mar		Low 1%	Mod. 5%	Mod. 6%	Mod. 6%	Mod. 20%
Sensitivity to Exposure	Low Exposure	Low Sensitivity	Low Sensitivity	Medium Sensitivity	Adaptation: adaptive capacity is low for assets listed with medium to high sensitivity. Consideration of adaptation strategies in the near term (e.g., 2030 to 2050) are recommended.				
	Medium Exposure	Medium Sensitivity	High Sensitivity	High Sensitivity					
	High Exposure	High Sensitivity							

TABLE 14
SUMMARY OF HIGH VULNERABILITY COASTAL RESOURCES AND ASSETS

Vulnerability	Coastal Resources and Assets	High Vulnerability Timeframe
Beach erosion and loss	• Beach access	2030 to 2060
North Beach District coastal flooding and damage	• Beach front and adjacent properties including the City's 17th St Beach Safety Center, roads, and amenities	2050
Del Mar Fairgrounds, Valley District, and North Beach District San Dieguito River flooding and damage	• Fire Station	2030
	• Sewer lift station on San Dieguito Drive	2050
	• Fairgrounds • Roads and bridges, including Camino Del Mar, Jimmy Durante Blvd. and bridge, east ends of North Beach District streets, and San Dieguito Drive • Low-lying central portions of the North Beach District (blocks bounded by Camino Del Mar, 28th St, and Railroad; general vicinity of Coast Blvd. and Santa Fe between 17th St. and 23rd St.)	2070
South Beach, South Bluffs, and North Bluffs bluff erosion	• Railroad	2030 or earlier
	• Bluff top property in South Beach, South Bluffs, and North Bluffs • Sewer infrastructure in South Beach and South Bluffs	2050
San Dieguito River Lagoon wetland habitat conversion and loss	• Vegetated wetland habitat	2070

7 CONCLUSIONS AND NEXT STEPS

With future sea level rise, the City of Del Mar's current vulnerabilities to coastal flooding and erosion are projected to increase in both frequency and intensity. The beach above high tide will be lost to erosion between 2030 and 2060, at which point beach erosion and coastal storms will threaten sea wall integrity. Coastal storm events that cause coastal flooding and damage, which currently have a 10% chance of occurring in a given year (i.e., a 10-year event) are projected to occur annually between 2050 and 2070. Extreme events such as the damaging January 1983 El Nino coastal flood event, which is currently a < 1% chance events (>100-year event), are projected to have a 14% chance of occurring (7-year event) in 2050 and may occur annually by 2100.

Public access along the beach (horizontal access) will be lost due to beach erosion by 2030 to 2060. Beach erosion and coastal storms will threaten sea wall integrity and increase flooding and storm damage. For properties west of Camino Del Mar, including the City's 17th St Beach Safety Center, the present low to moderate vulnerability to coastal flooding and wave damage will become a high vulnerability by about 2050. Ocean Front and Camino Del Mar/Coast Blvd. roads and properties west of Camino Del Mar will also be highly vulnerable to coastal flooding. Note that the blocks between Ocean Front and Camino Del Mar/Coast Blvd. and these roads will be increasingly vulnerable to both coastal and river flooding (discussed below).

Local rainfall runoff from North Beach drains to the San Dieguito River via ditches and culverts, which are currently fitted with flap gates and pumps. Over time with sea level rise, gravity drainage through culverts will not be possible with sea level rise and additional pumping will be required.

The current localized vulnerability of the LOSSAN railroad to bluff erosion will increase in extent in the near-term and extend along almost the entire bluff before 2030. By this timeframe, the railroad would need to be moved inland or armored with a seawall to reduce the risk of the railroad collapsing (as a section of railroad collapsed and cause a train wreck in 1940). If a seawall is constructed, the beach will erode back to the seawall over time until little to no beach exists. If the railroad is moved inland and bluff erosion is allowed to continue, blufftop property and sewer infrastructure in the South Beach and South Bluff Districts would be vulnerable to erosion by 2050. North Bluffs properties would be similarly vulnerable to erosion.

The past and current vulnerability of the City of Del Mar and the Del Mar Fairgrounds to flooding from the San Dieguito River also has the potential to increase in frequency and intensity due to sea level rise, deposition of sand in the River channel in response to sea level rise, and projected future changes in extreme rainfall with climate change. For example, the February 21, 1980 River flood event, which flooded portions of the City and Fairgrounds and was approximately a 4% chance (25-year event), is projected to become an 8% to 25% chance (4- to

13-year) event in 2050 and a 20% to 50% or greater chance event (2- to 5-year or more frequent event) in 2100. Recent improvements to the upstream Lake Hodges Reservoir and changes to reservoir operations for water supply purposes could partially offset the increase in the future frequency of River flooding, but the frequency of River flooding could still increase compared to the frequency of flooding in the past. For example, the FEMA 1% chance (100-year) River flood event is projected to become a 4% to 20% chance (5- to 25-year) event in 2100 due to sea level rise and climate change, but reservoir operations for flood control could limit the frequency of this event in 2100 to a 4% chance (25-year) event.

The present low exposure of the Fairgrounds to significant flooding will become highly exposed by 2070; however, the vulnerability of the Fairground's land uses to flooding may be less than for other public and private development due to the reduced consequences of the flooding. Moderate exposure of the Fire Station to flooding will make emergency services highly vulnerable by 2030 because the Fire Station will be impacted when flooding is occurring and emergency response is needed, as occurred in the 1980 flood. Roads and bridges, including Camino Del Mar, Jimmy Durante Blvd. and bridge, the east ends of North Beach District streets, and San Dieguito Drive, will be highly vulnerable by about 2070. Low-lying central portions of the North Beach District (blocks bounded by Camino Del Mar, 28th St, and Railroad; general vicinity of Coast Blvd. and Santa Fe between 17th St. and 23rd St.), which currently have low vulnerability to River flooding, would be highly vulnerable in 2070. The sewer lift station along San Dieguito Drive would be increasingly exposed to flooding and risk of failure. Other water and sewer infrastructure in these areas would also be exposed to both River and coastal flooding, but is not highly vulnerable to flooding.

With sea level rise, existing and restored wetland habitats in the San Dieguito River Lagoon will be inundated more frequently and vegetated wetland habitats will be "drowned out" and convert to intertidal mudflats and subtidal habitat. Existing pickleweed marsh habitat could drown out and be lost by 2070. Cordgrass low marsh habitat could be lost by 2090, such that almost all of the San Dieguito Lagoon Wetland Restoration would be converted to intertidal mudflat and subtidal open water. Salt marsh habitats are expected to migrate upstream along the San Dieguito River with sea level rise; however, the River corridor is relatively narrow and the overall vegetated marsh acreage will be greatly reduced.

These planning-level analyses and results are approximate and intended solely for the purpose of assessing potential future coastal vulnerabilities and informing the development of an Adaptation Plan and LCPA policies. Additional information is needed from SDCWA to confirm how recent changes in reservoir operations improve River flood management. Also, as discussed above, additional analyses or additional data and information from CoSMoS are needed to estimate the vulnerability of the Del Mar Bluffs prior to 2100 for sea level rise scenarios.

In the next steps of the LCPA preparation process, additional information will be used to confirm and finalize this coastal vulnerability assessment. Adaptation measures to reduce future vulnerabilities will then be identified and assessed and an Adaptation Plan will be developed. This vulnerability assessment indicates the potential for adaptation measures such as future beach nourishment, River channel dredging, and operating the Lake Hodges Reservoir for flood management to reduce future vulnerabilities. The Adaptation Plan will likely consider these potential measures as well as a range of accommodation, protection, and retreat adaptation strategies.

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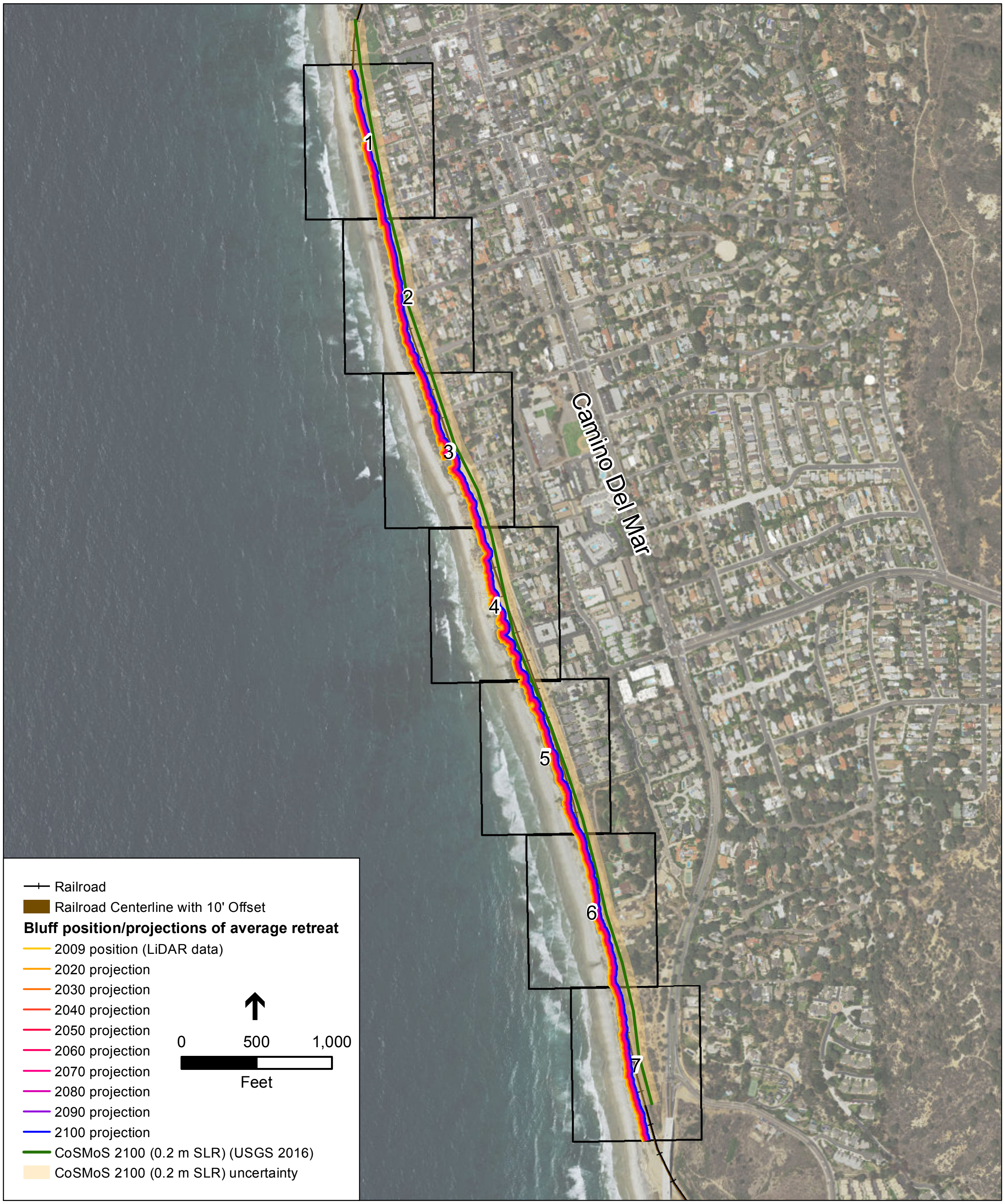
APPENDIX A

Bluff Erosion Maps

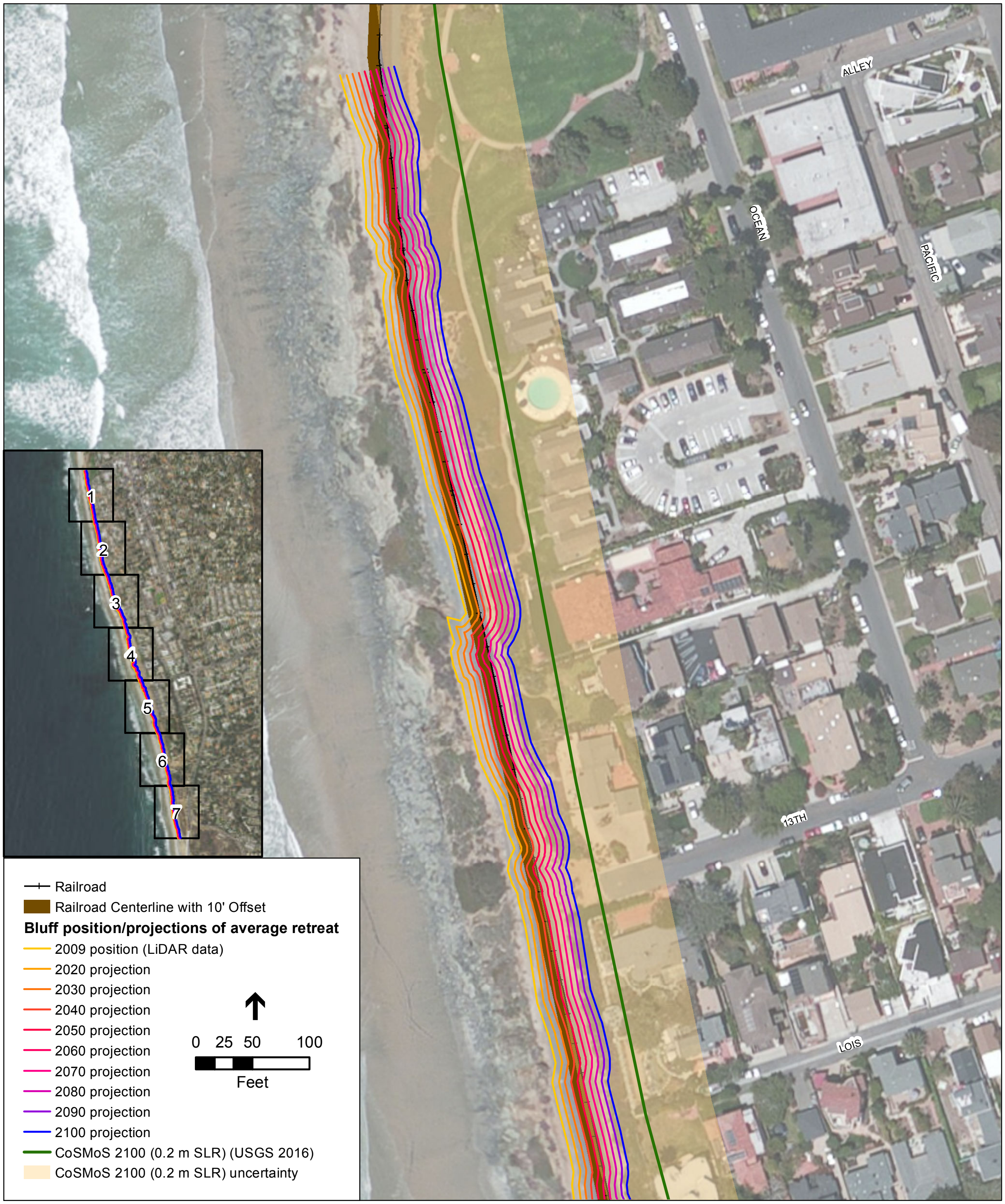


SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

Del Mar LCP Update . D150347

Figure A- Map Grid Overview
Bluff Retreat Projections for Historic Rates of Retreat and Sea Level Rise (2 mm/yr)



SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

Del Mar LCP Update . D150347

Figure A1

Bluff Retreat Projections for Historic Rates of Retreat and Sea Level Rise (2 mm/yr)

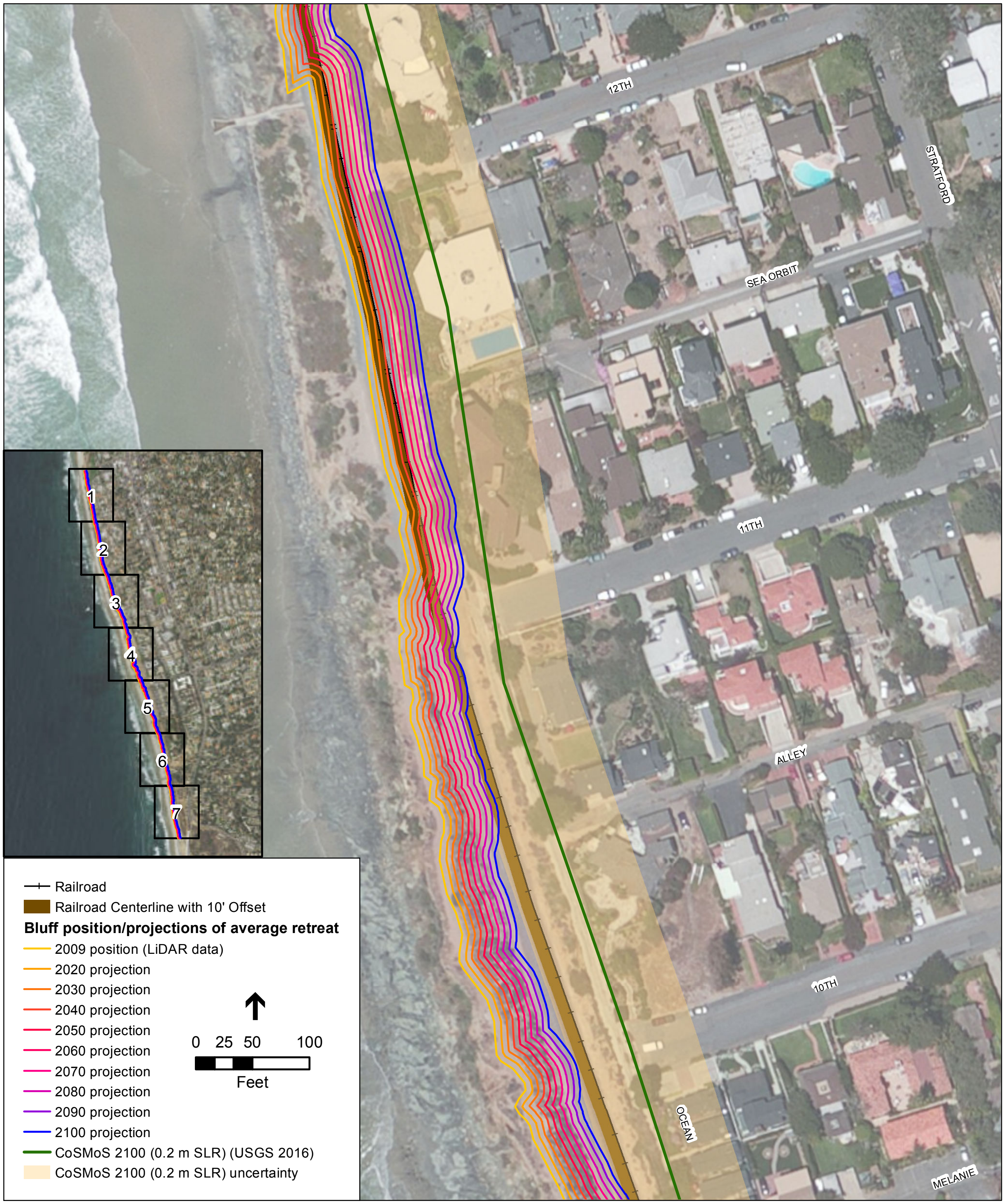
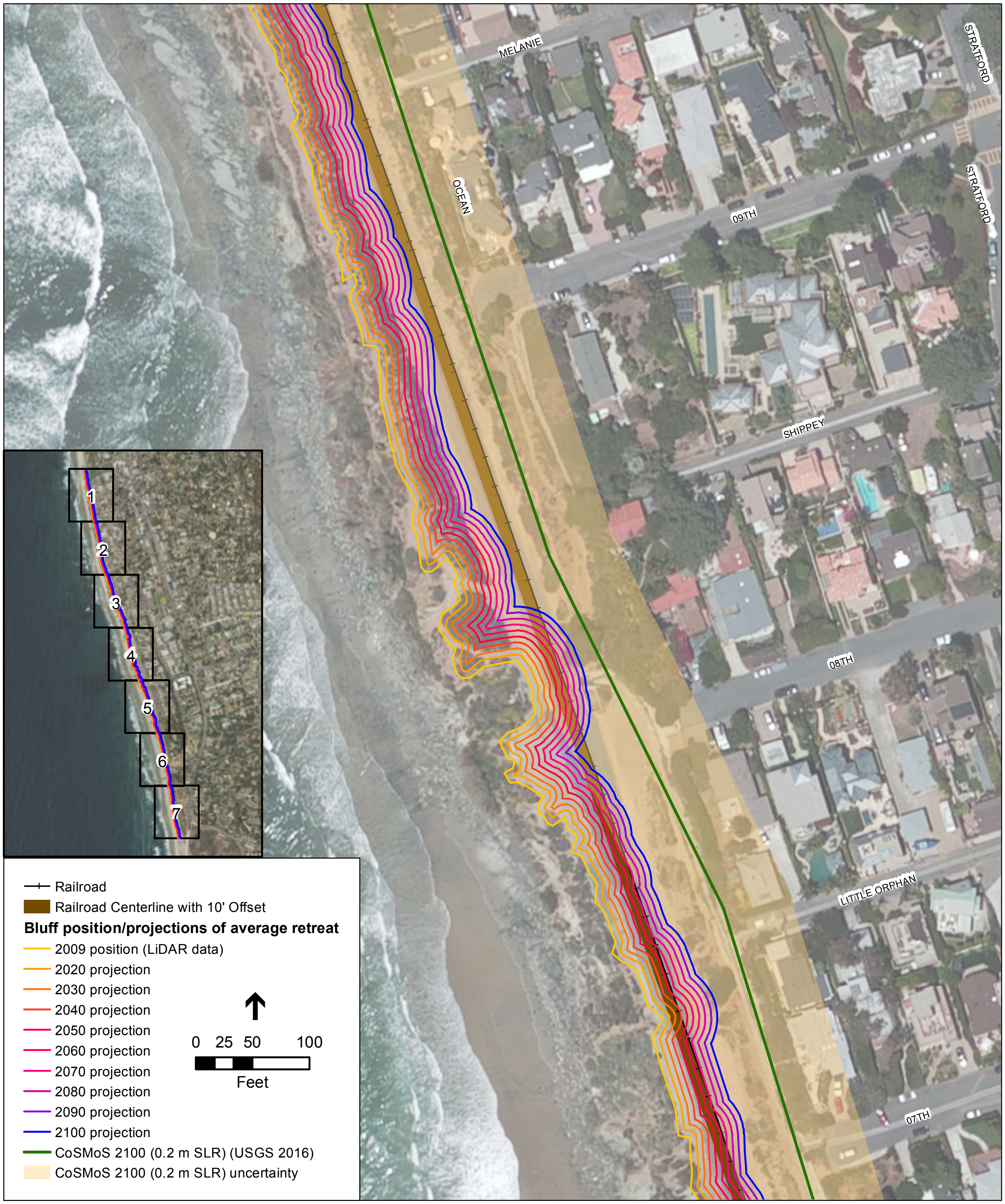


Figure A2
Bluff Retreat Projections for Historic Rates of Retreat and Sea Level Rise (2 mm/yr)

SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.



SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

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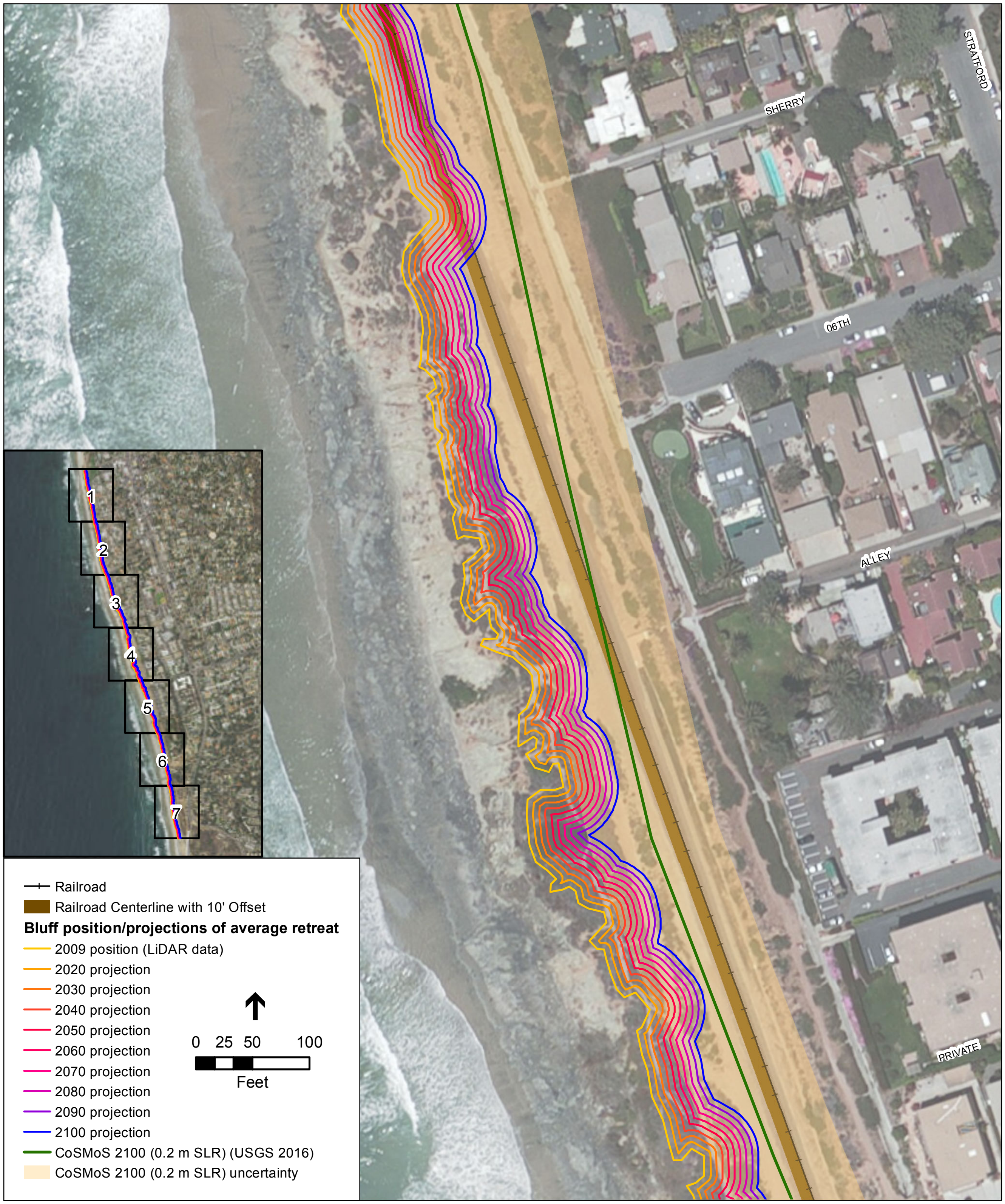
Figure A3

Bluff Retreat Projections for Historic Rates of Retreat and Sea Level Rise (2 mm/yr)

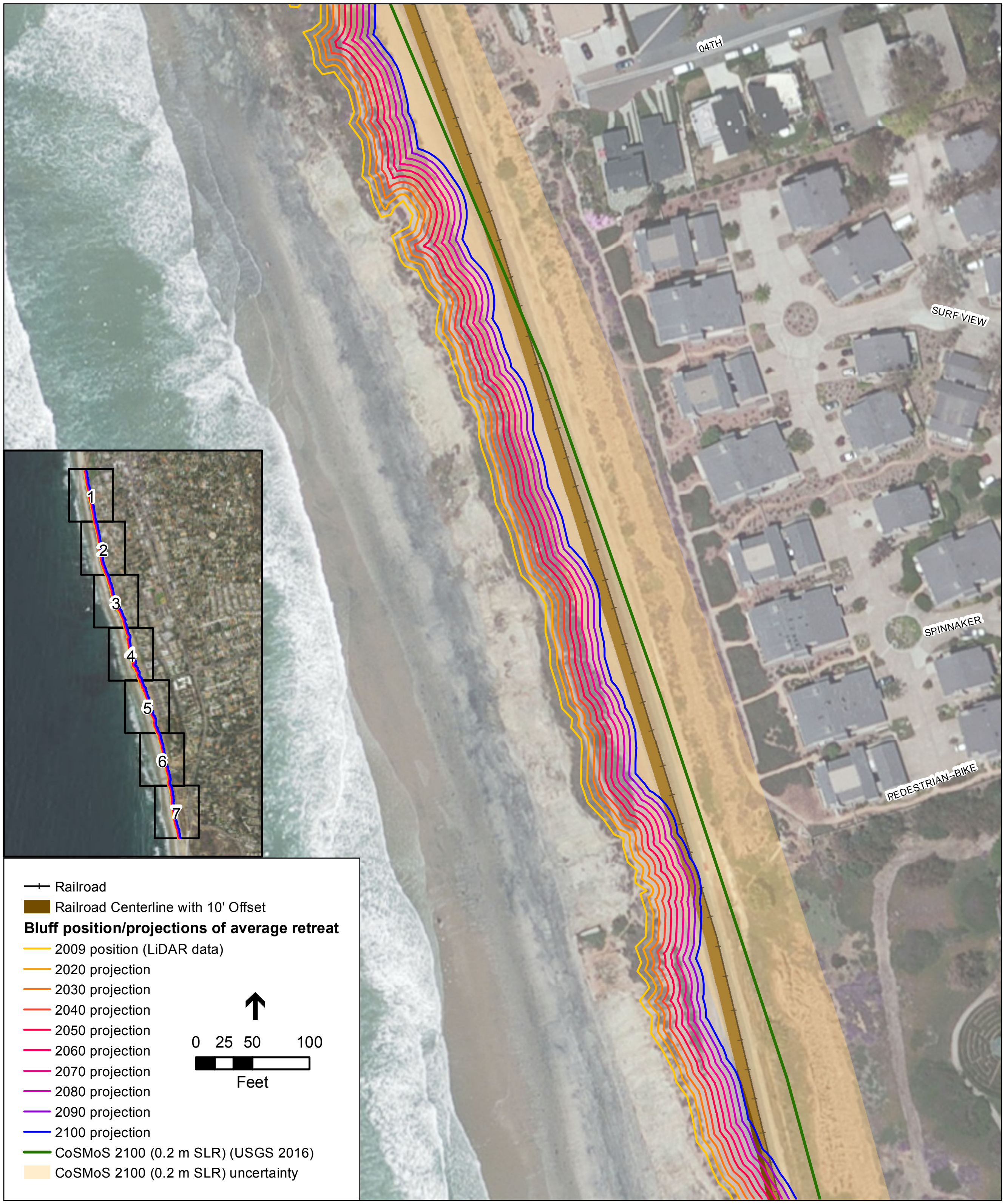


SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

Figure A4

Bluff Retreat Projections for Historic Rates of Retreat and Sea Level Rise (2 mm/yr)



SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

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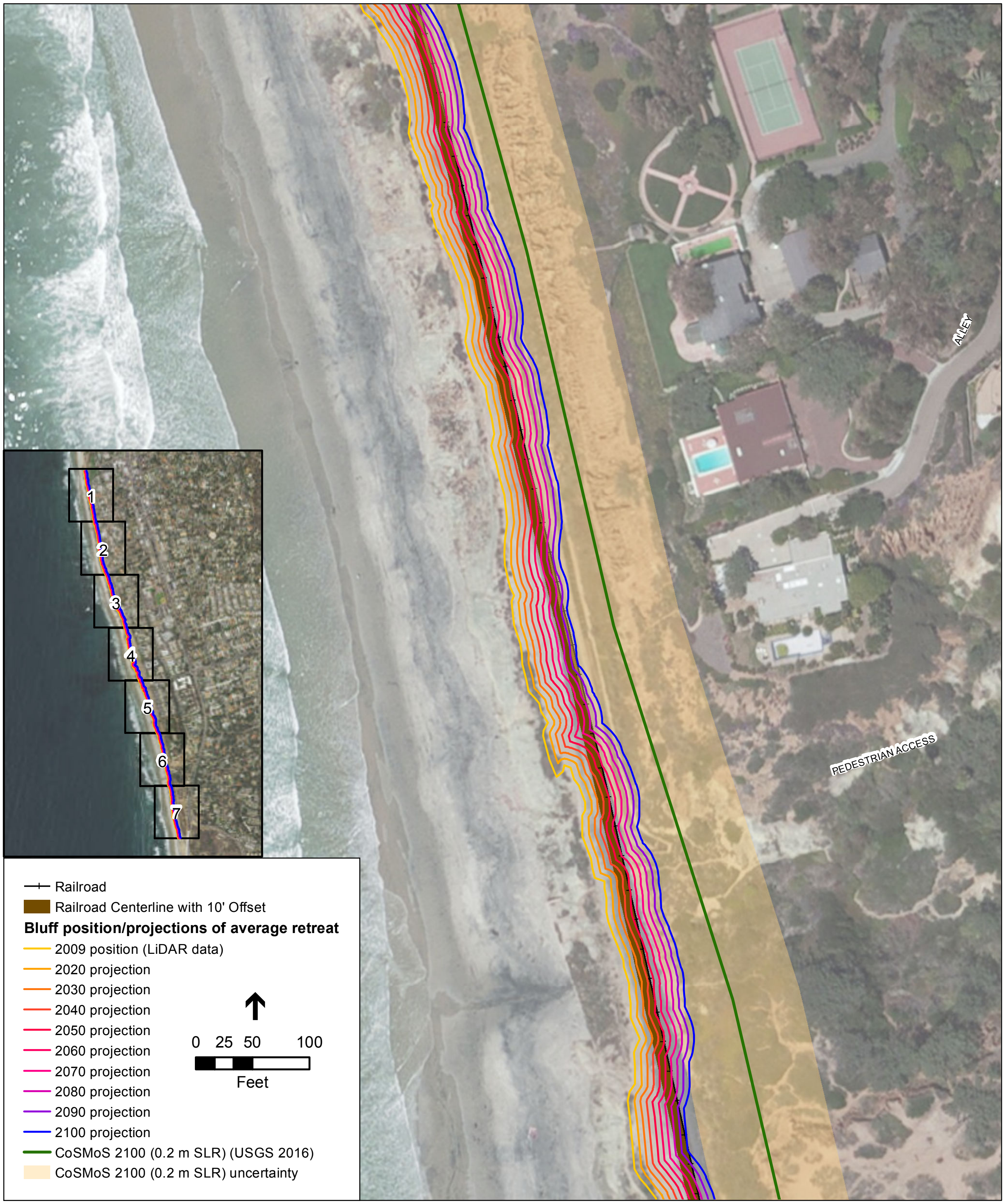
Figure A5

Bluff Retreat Projections for Historic Rates of Retreat and Sea Level Rise (2 mm/yr)



SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

Figure A6

Bluff Retreat Projections for Historic Rates of Retreat and Sea Level Rise (2 mm/yr)

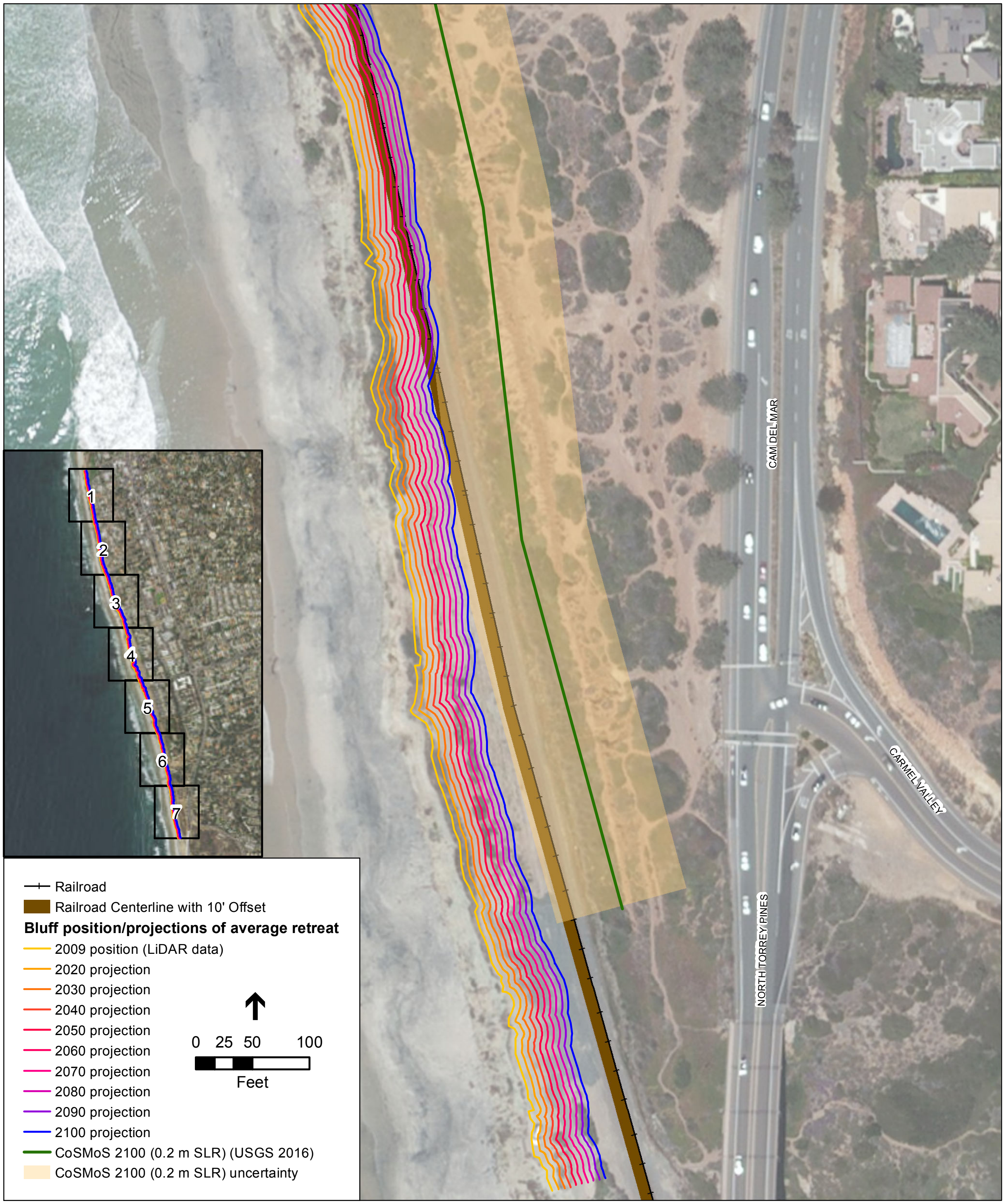


Figure A7

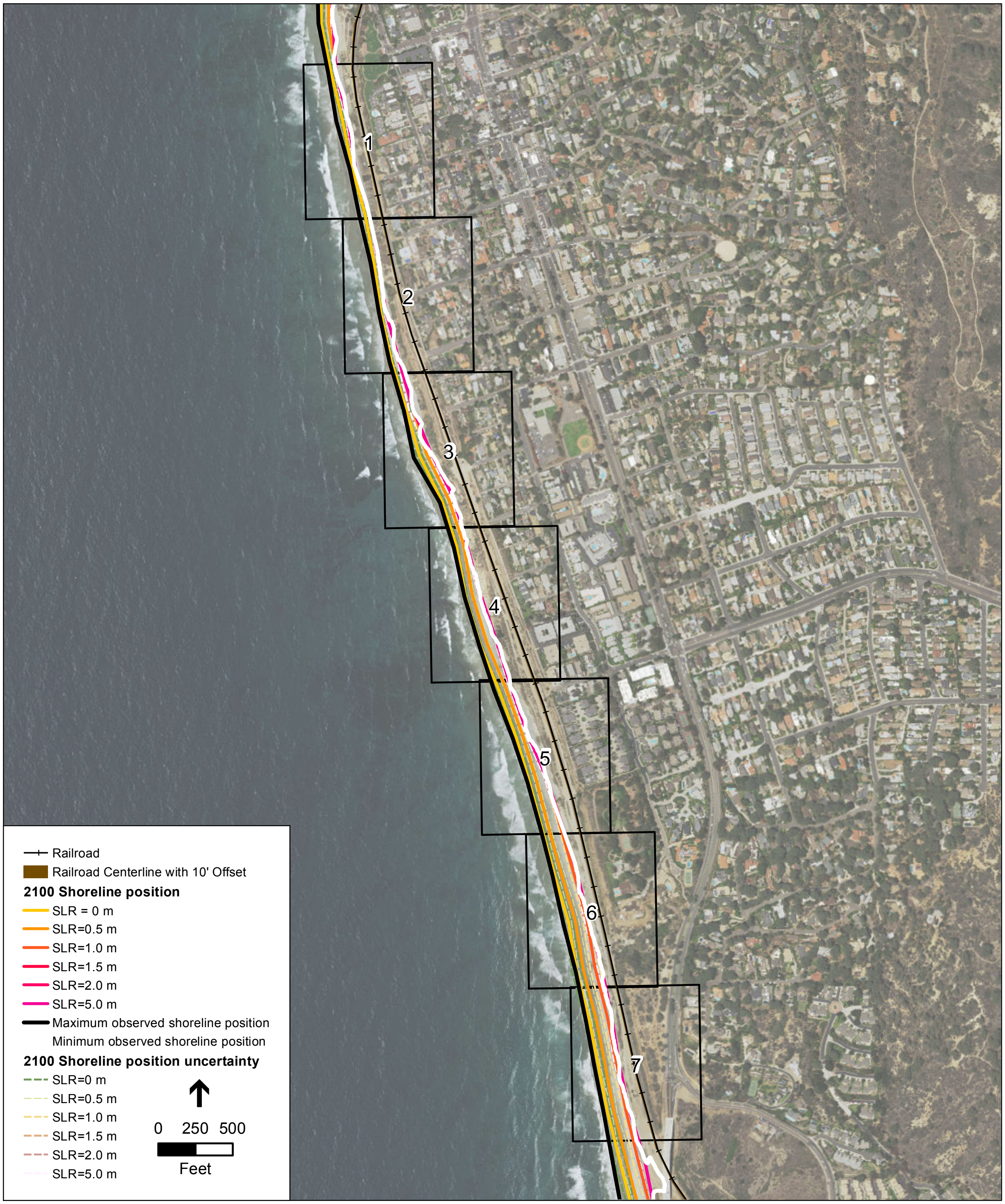
Bluff Retreat Projections for Historic Rates of Retreat and Sea Level Rise (2 mm/yr)

SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

APPENDIX B

CoSMoS Beach Erosion Maps



SOURCE: USGS 2016

Figure B- Map Grid Overview

CoSMoS Beach Erosion- Shoreline Change by 2100

SOURCE: USGS 2016

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Figure B1

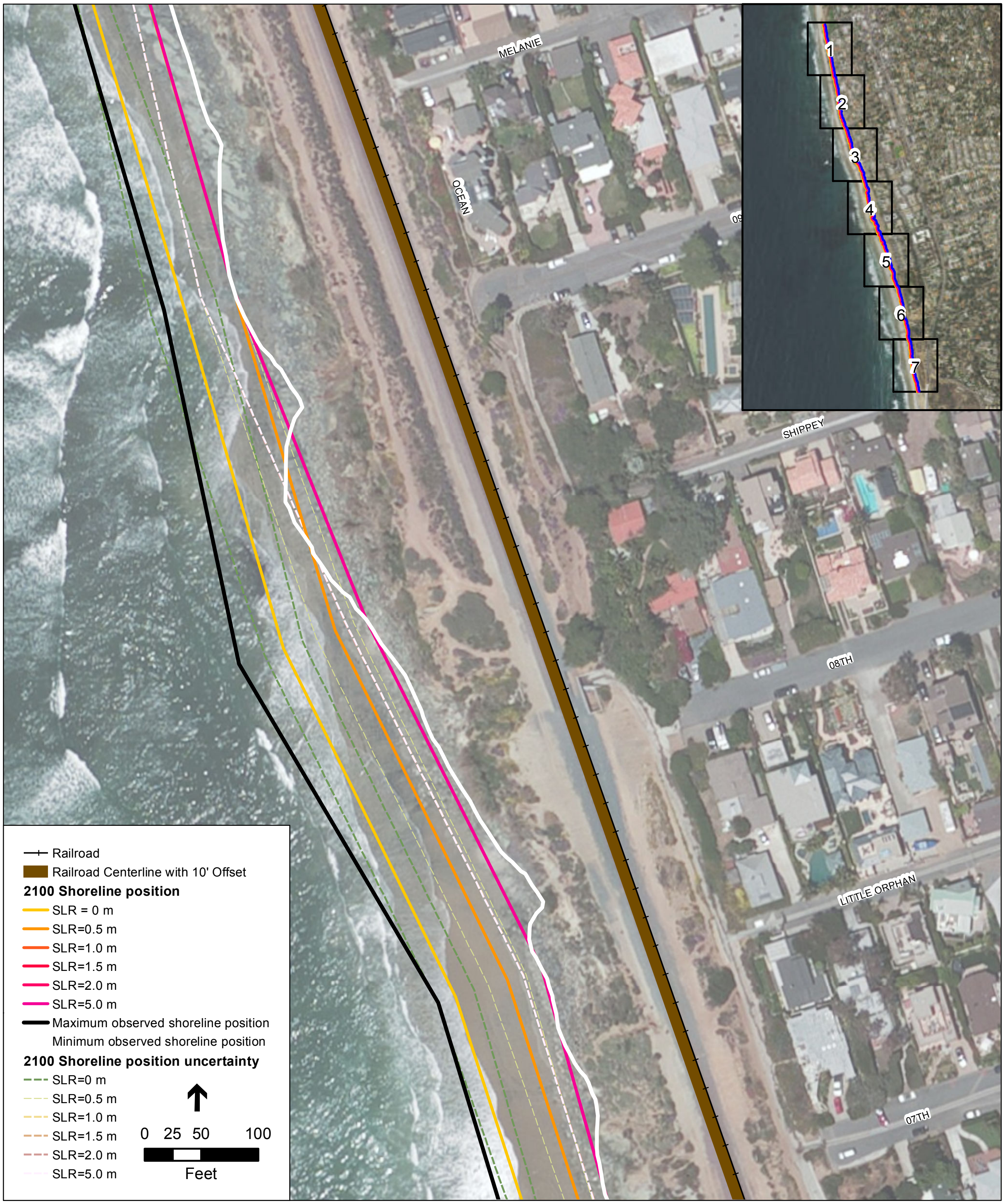
CoSMoS Beach Erosion- Shoreline Change by 2100

SOURCE: USGS 2016

Del Mar LCP Update . D150347

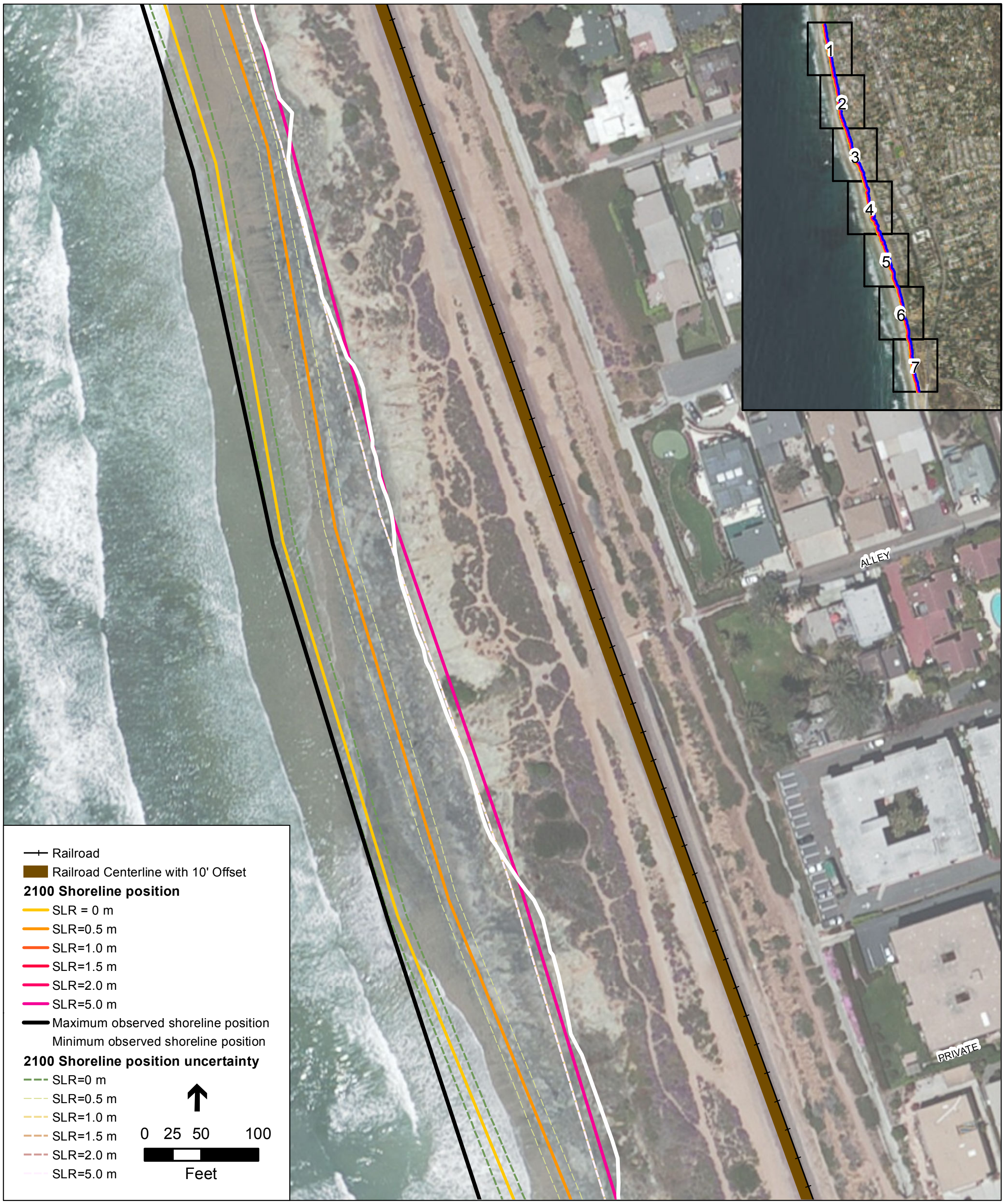
Figure B2

CoSMoS Beach Erosion- Shoreline Change by 2100



SOURCE: USGS 2016

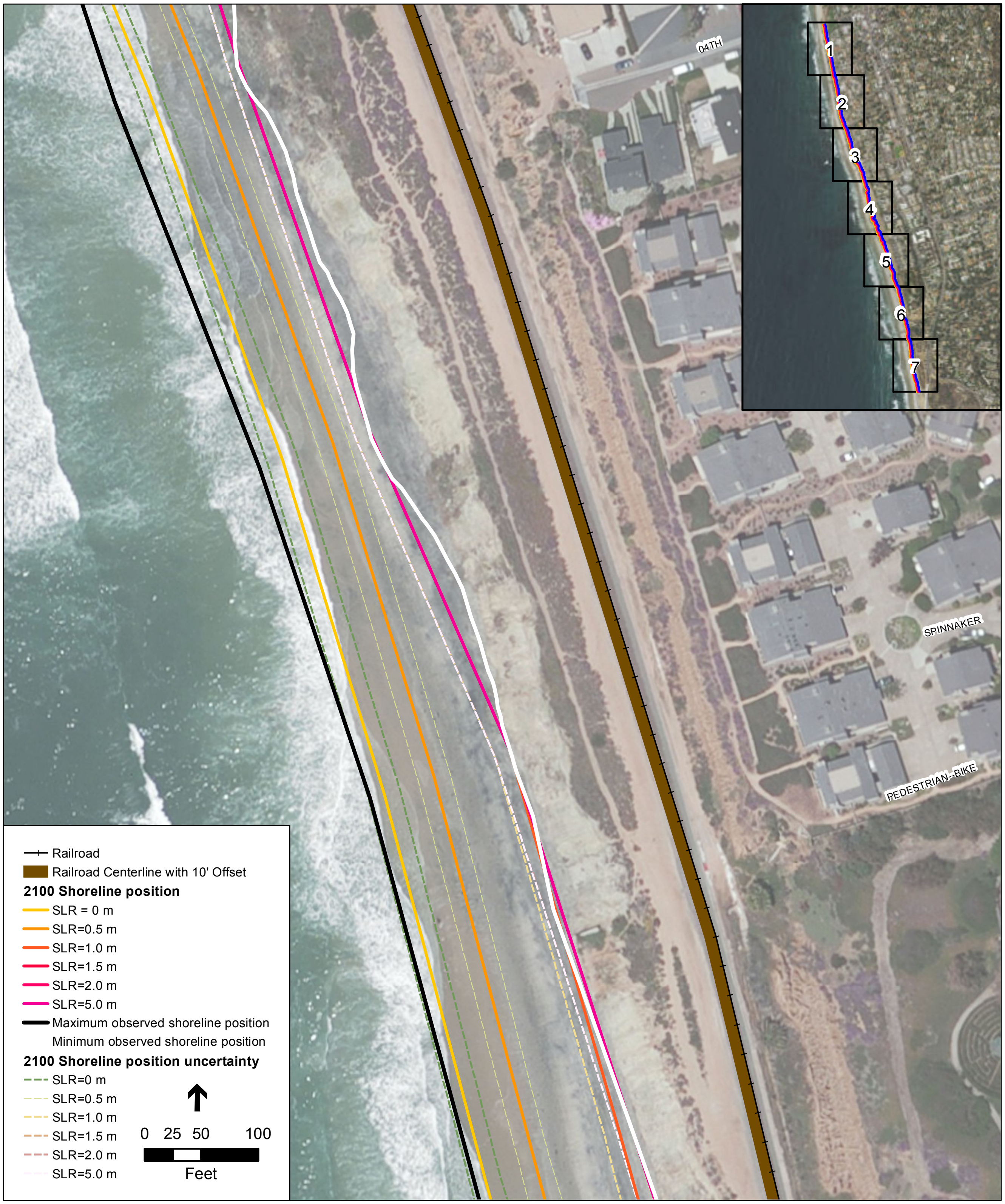
Figure B3
CoSMoS Beach Erosion- Shoreline Change by 2100



SOURCE: USGS 2016

Figure B4

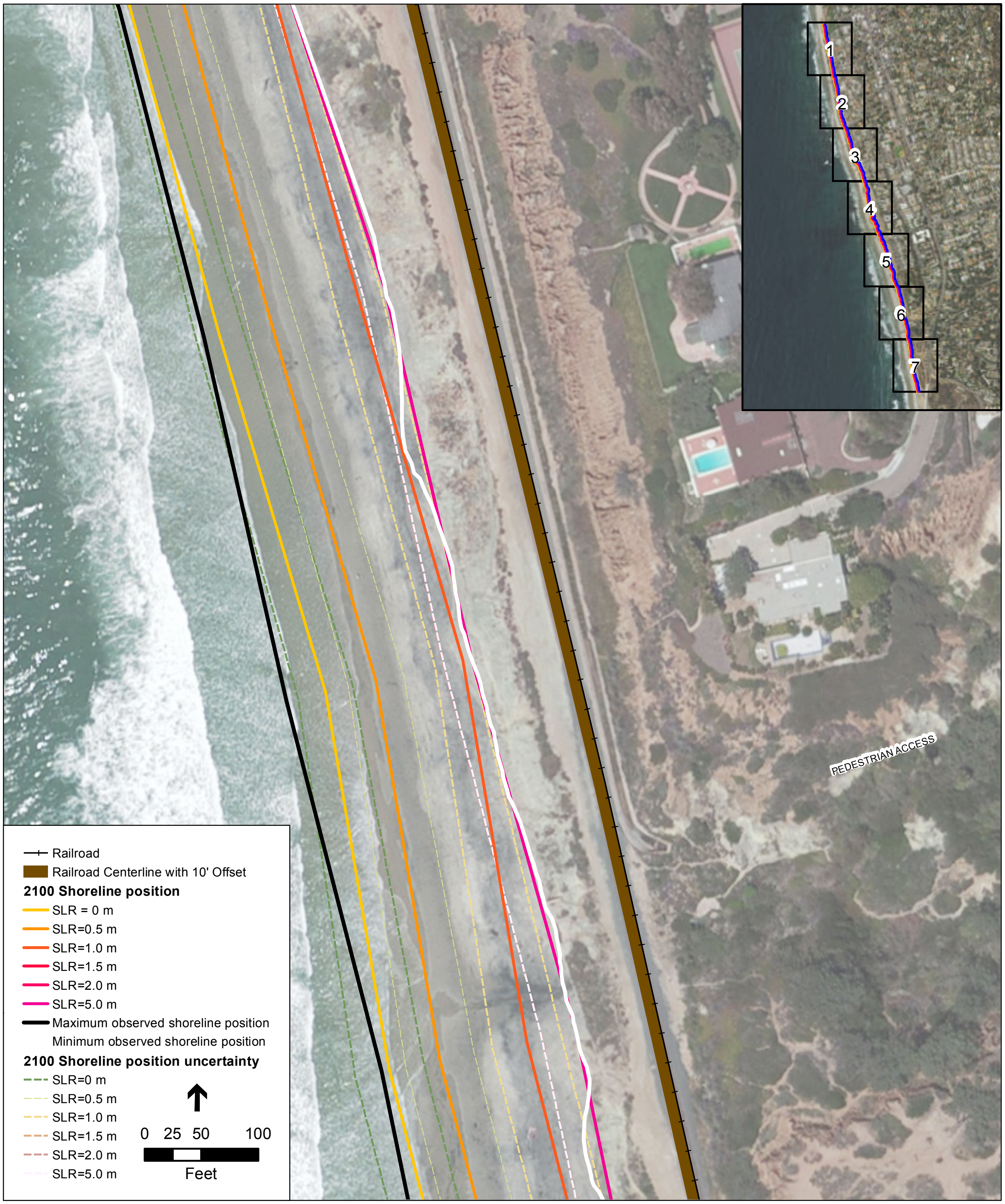
CoSMoS Beach Erosion- Shoreline Change by 2100



SOURCE: USGS 2016

Figure B5

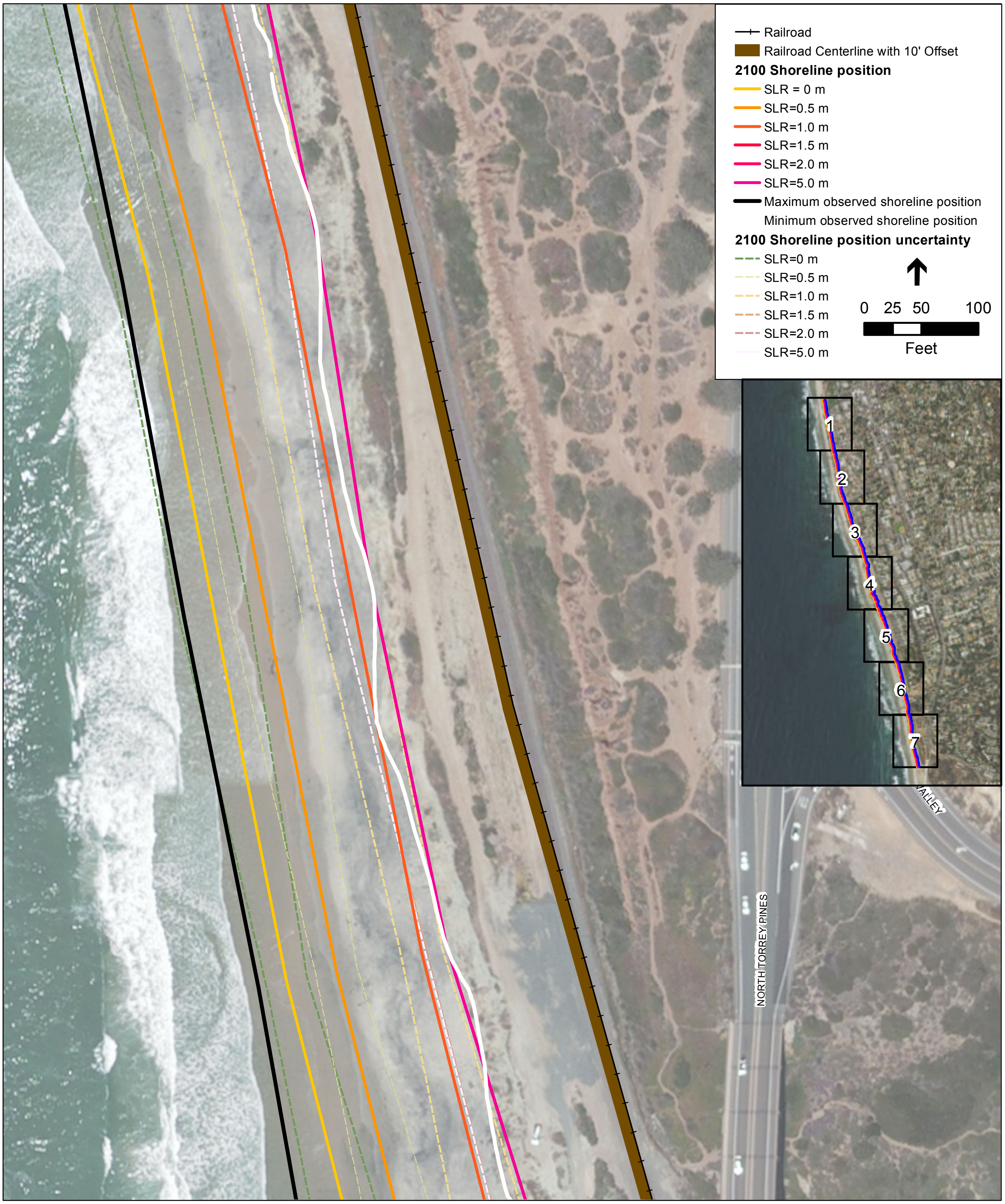
CoSMoS Beach Erosion- Shoreline Change by 2100



SOURCE: USGS 2016

Figure B6

CoSMoS Beach Erosion- Shoreline Change by 2100



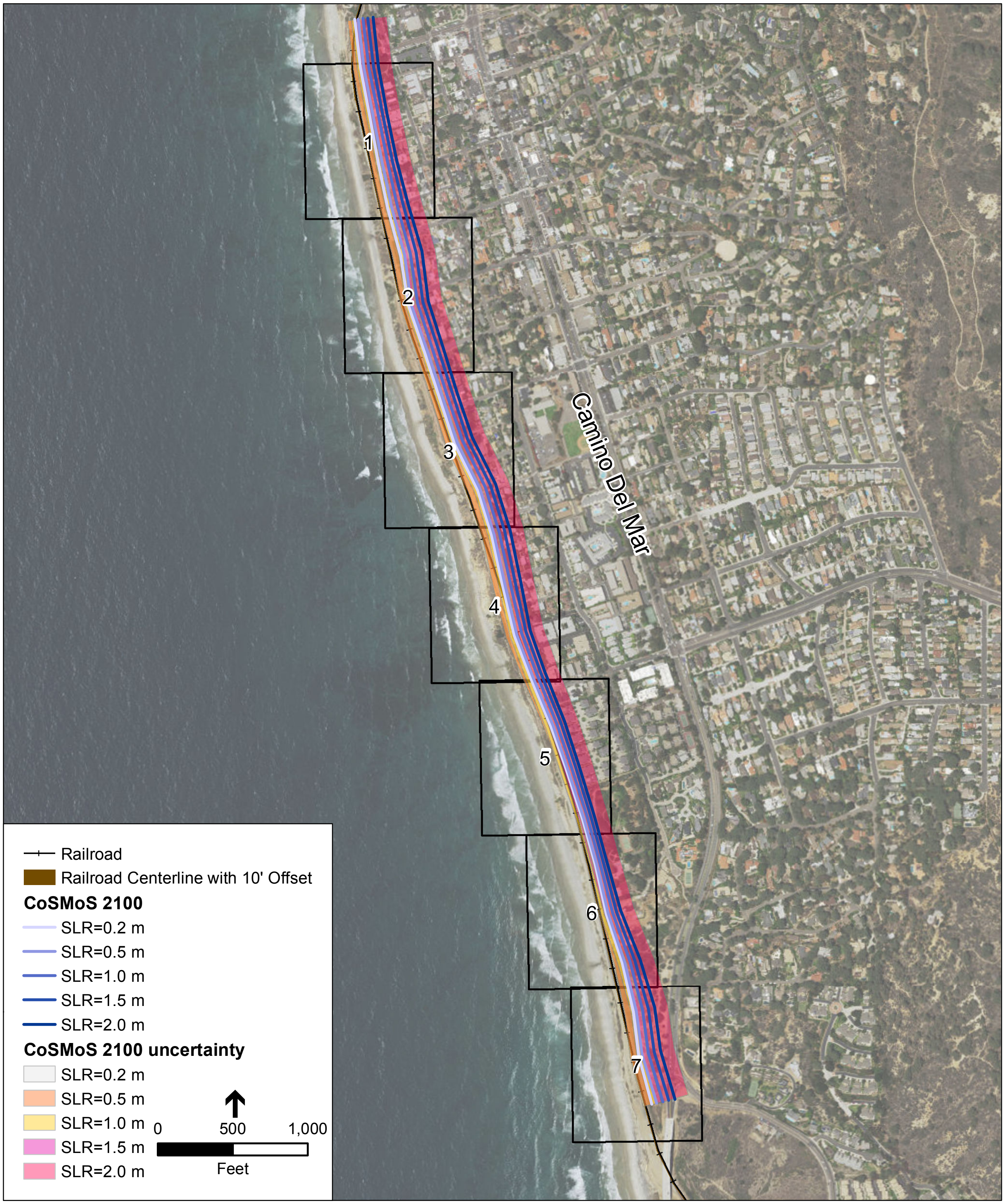
SOURCE: USGS 2016

Figure B7

CoSMoS Beach Erosion- Shoreline Change by 2100

APPENDIX C

CoSMoS Bluff Erosion Maps



SOURCE: USGS 2016

Figure C- Map Grid Overview

CoSMoS Bluff Erosion- Cliff Retreat by 2100

SOURCE: USGS 2016

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Figure C1

CoSMoS Bluff Erosion- Cliff Retreat by 2100

SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure C2

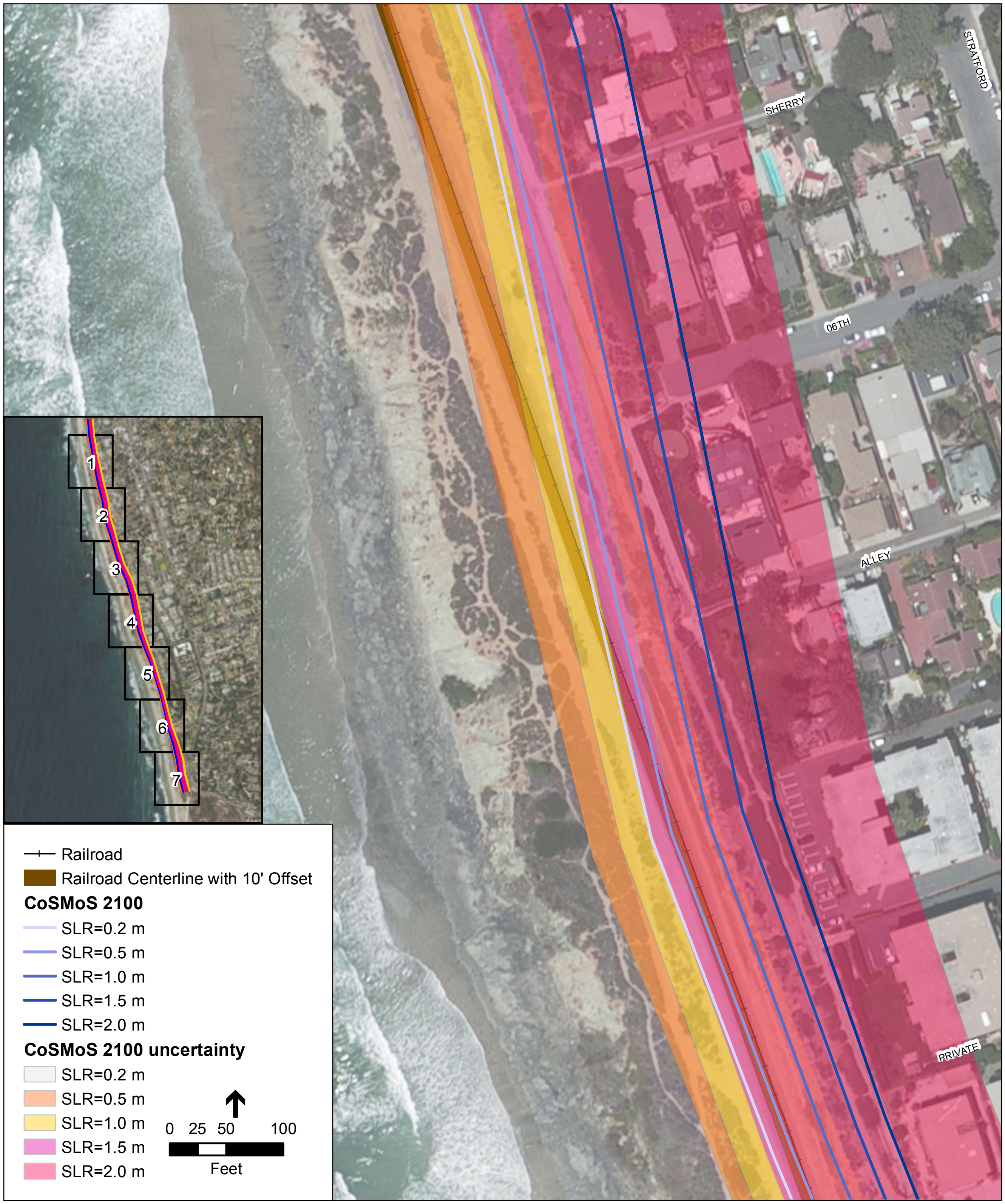
CoSMoS Bluff Erosion- Cliff Retreat by 2100

SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure C3

CoSMoS Bluff Erosion- Cliff Retreat by 2100



SOURCE: USGS 2016

Figure C4

CoSMoS Bluff Erosion- Cliff Retreat by 2100

SOURCE: USGS 2016

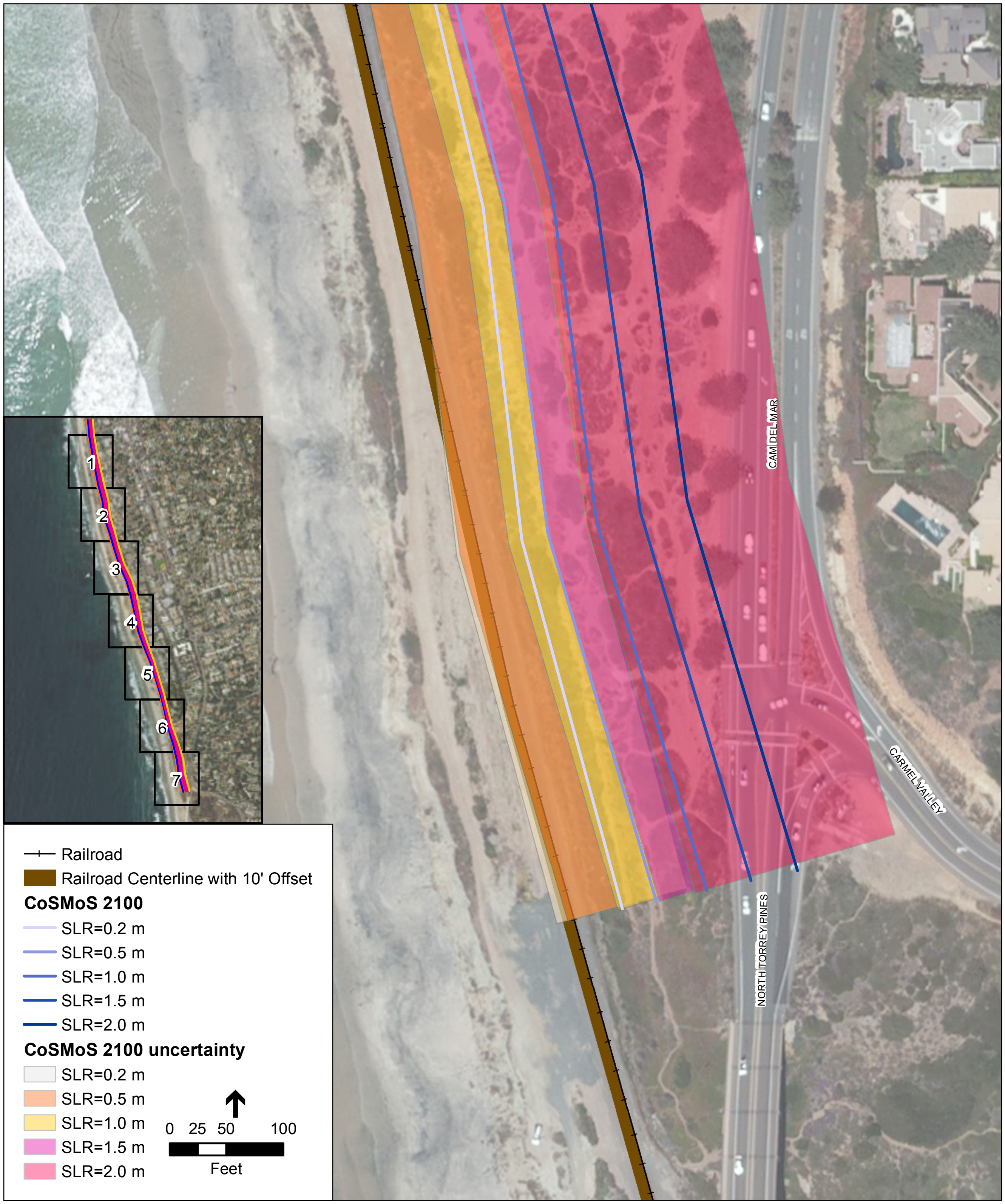
Figure C5

CoSMoS Bluff Erosion- Cliff Retreat by 2100

SOURCE: USGS 2016

Figure C6

CoSMoS Bluff Erosion- Cliff Retreat by 2100



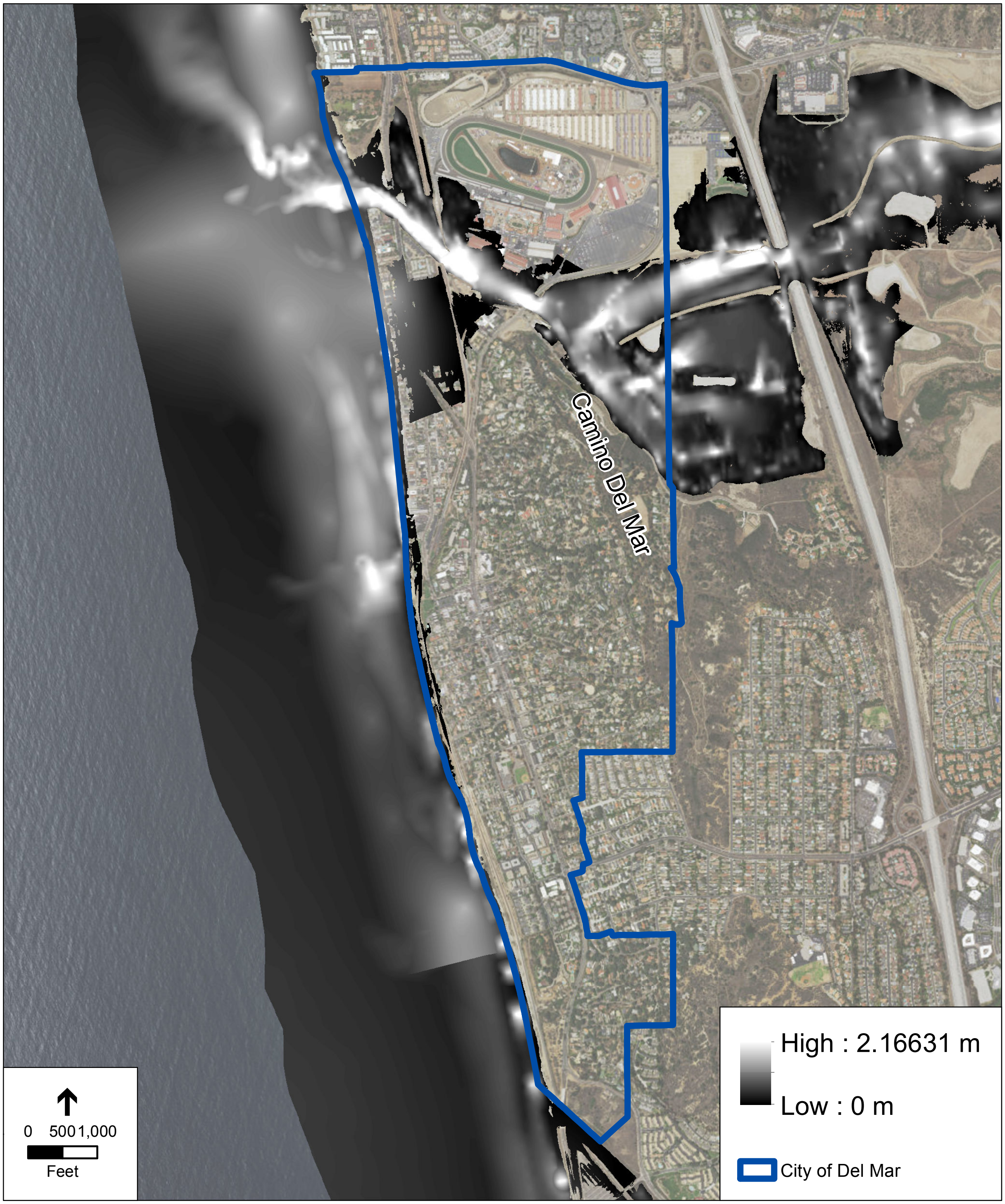
SOURCE: USGS 2016

Figure C7

CoSMoS Bluff Erosion- Cliff Retreat by 2100

APPENDIX D

Precipitation Event Frequency Analysis



SOURCE: USGS 2016

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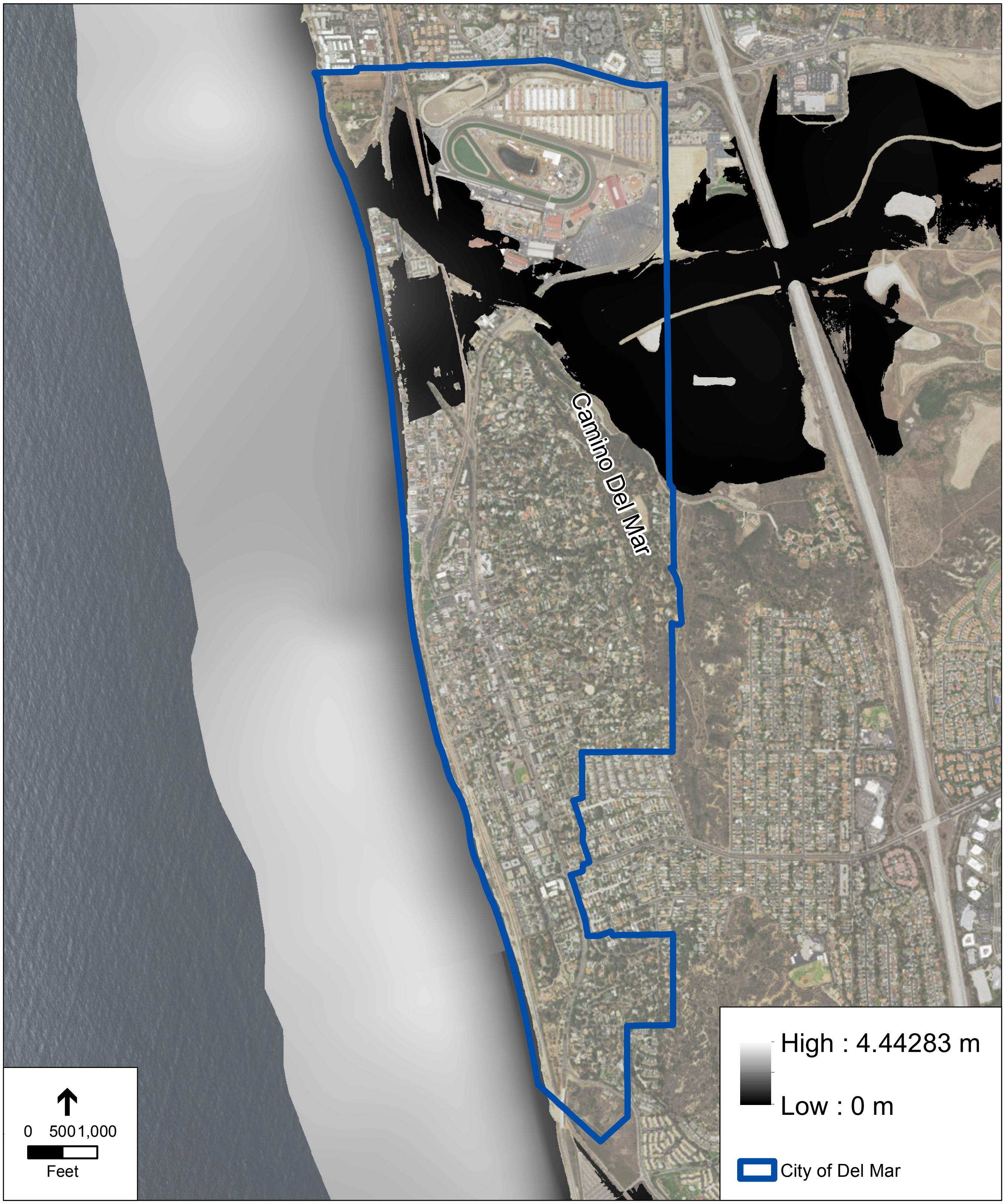
Figure D1

Wave Hazards, 0 cm SLR

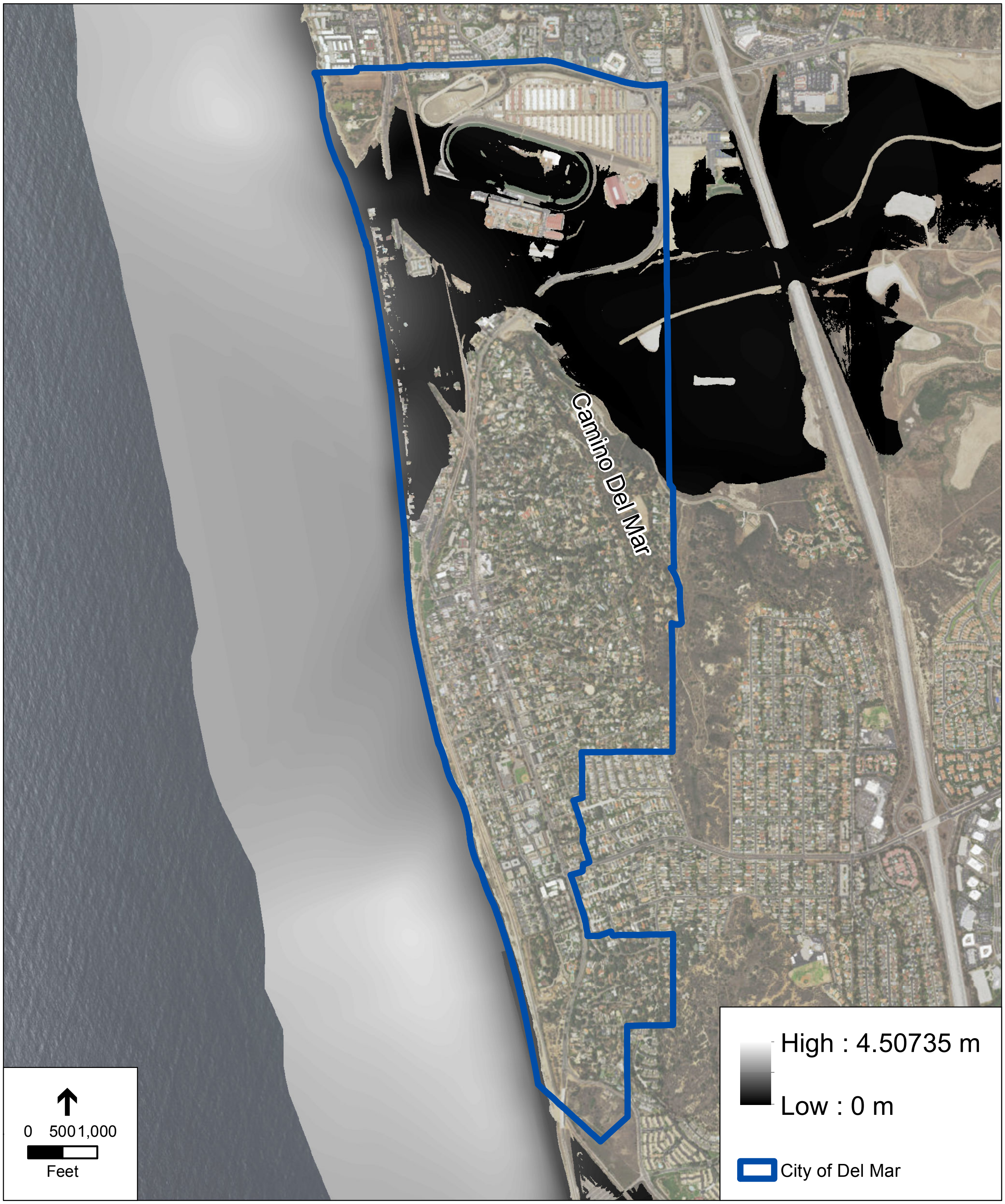


SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure D2

Wave Hazards, 50 cm SLR

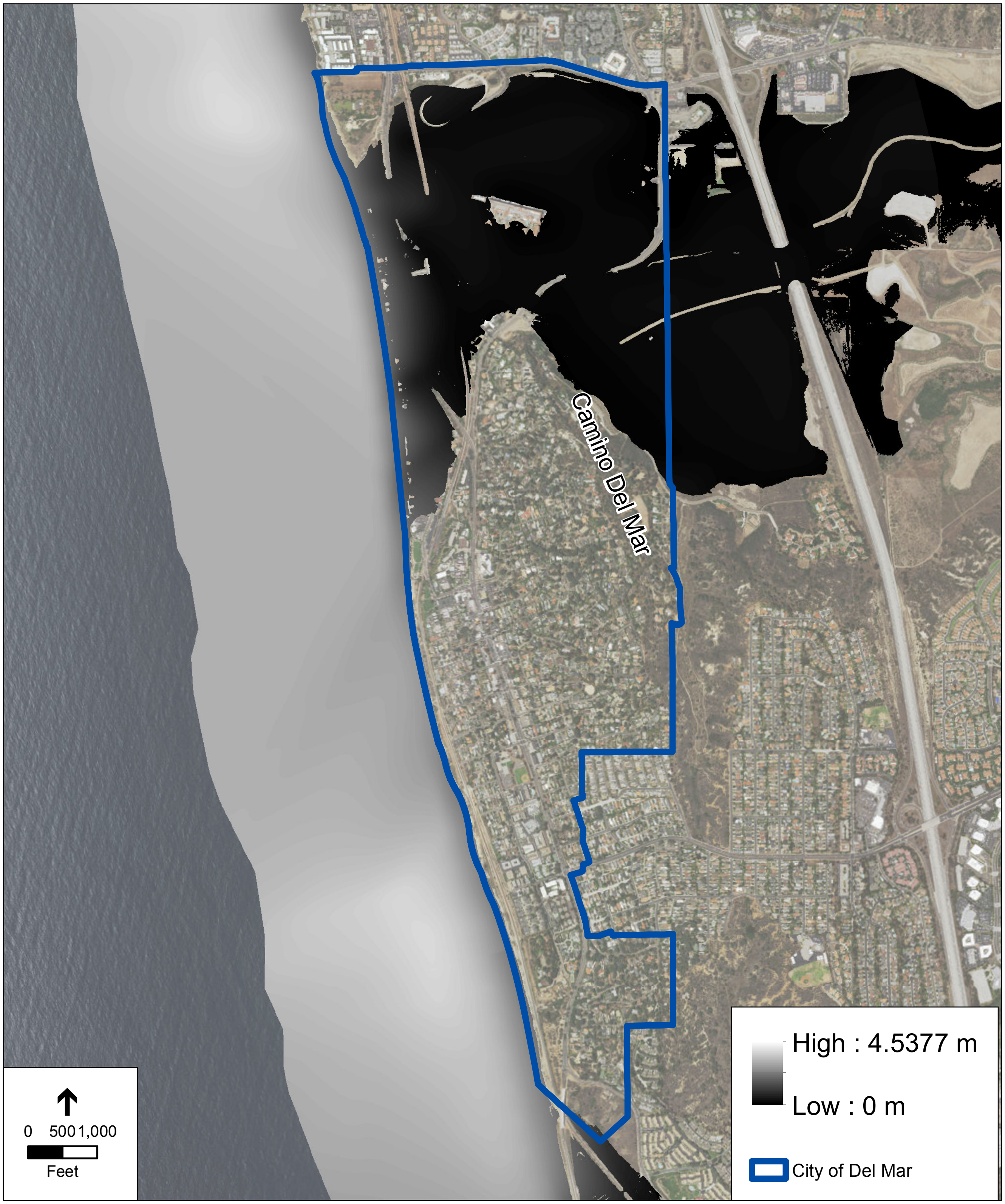


SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure D3

Wave Hazards, 100 cm SLR

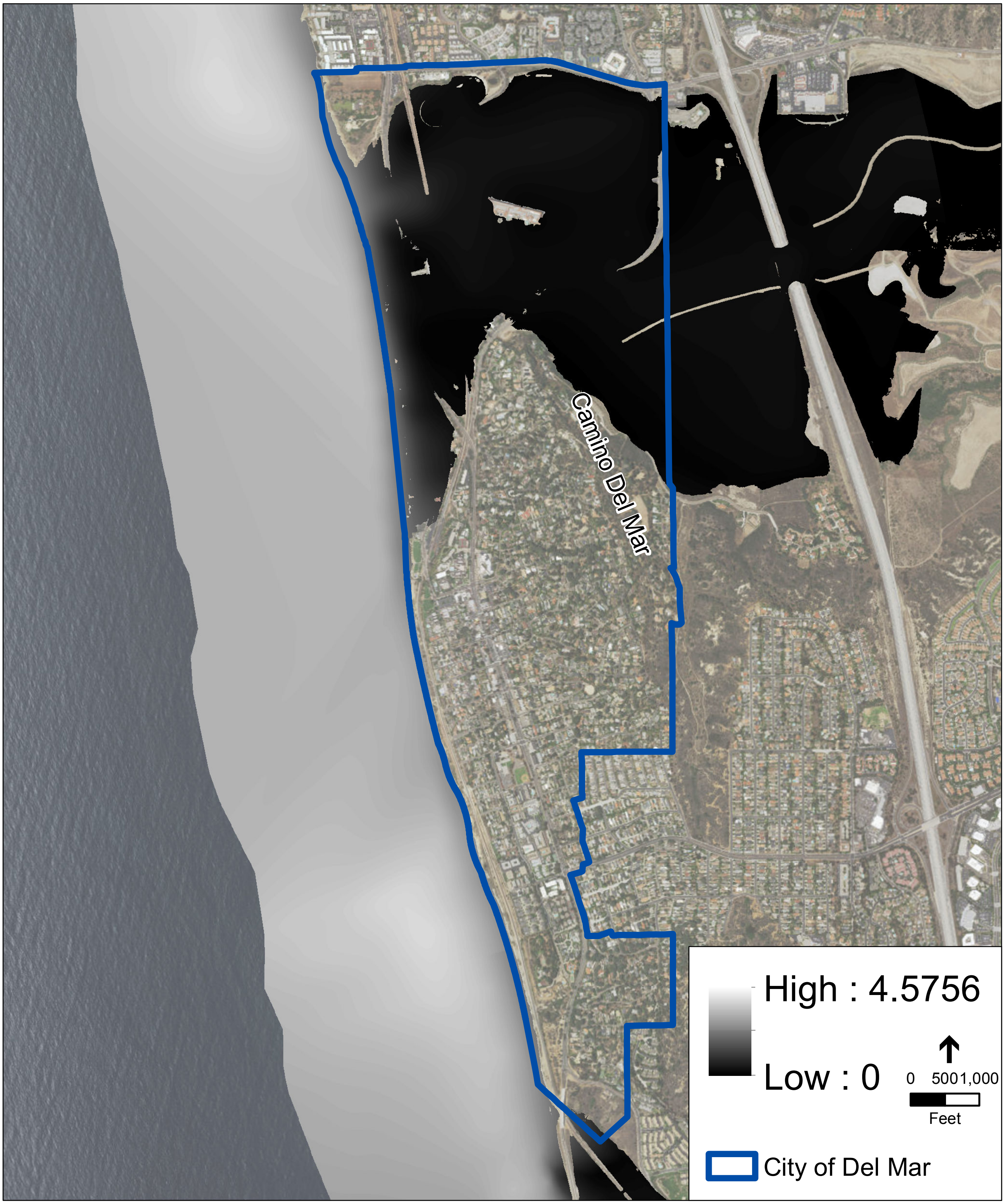


SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure D4

Wave Hazards, 150 cm SLR



SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure D5

Wave Hazards, 200 cm SLR

APPENDIX E

Argos Results

6 HR 0.45 IN/HR

RCP 4.5	1990	2015	2035	2050	2070	2090
10TH			58	55	50	47
50TH	42	40	38	36	33	31
90TH			20	19	18	17
RCP 8.5	1990	2015	2035	2050	2070	2090
10TH			49	48	48	47
50TH	42	38	35	30	25	22
90TH			17	16	16	15

24 HR 0.079 IN/HR

RCP 4.5	1990	2015	2035	2050	2070	2090
10TH			1.1	1.07	1.03	1
50TH	0.45	0.64	0.9	0.90	0.89	0.89
90TH			0.74	0.70	0.64	0.6
RCP 8.5	1990	2015	2035	2050	2070	2090
10TH			1.1	1.10	1.10	1.1
50TH	0.45	0.59	0.75	0.78	0.82	0.86
90TH			0.7	0.68	0.66	0.64

24 HR 0.122 IN/HR

RCP 4.5	1990	2015	2035	2050	2070	2090
10TH			7	5.8	4.7	4
50TH	4	4.0	4	3.9	3.9	3.8
90TH			3	2.9	2.7	2.6
RCP 8.5	1990	2015	2035	2050	2070	2090
10TH			5	5.2	5.4	5.6
50TH	4	4.0	4	3.9	3.7	3.6
90TH			3	2.8	2.6	2.4

24 HR 0.15 IN/HR

RCP 4.5	1990	2015	2035	2050	2070	2090
10TH			24	18.9	14.7	12
50TH	10	9.4	9	9.0	9.0	9
90TH			5	5.0	5.0	5
RCP 8.5	1990	2015	2035	2050	2070	2090
10TH			12	13.6	16.5	21
50TH	10	9.4	9	8.7	8.3	8
90TH			4	4.0	4.0	4

24 HR 0.183 IN/HR

RCP 4.5	1990	2015	2035	2050	2070	2090
10TH			63	51	41	34
50TH	27	25	24	23	22	21
90TH			12	12	13	13
RCP 8.5	1990	2015	2035	2050	2070	2090
10TH			34	38	45	55
50TH	27	23	21	22	23	24
90TH			9	9.3	9.6	10

Table E

Argos Results

24 HR 0.244 IN/HR

RCP 4.5	1990	2015	2035	2050	2070	2090
10TH			341	255	191	153
50TH	110	104	101	95	87	81
90TH			43	45	48	51
RCP 8.5	1990	2015	2035	2050	2070	2090
10TH			153	176	219	290
50TH	110	88	78	82	88	95
90TH			32	33	34	36

24 HR 0.32 IN/HR

RCP 4.5	1990	2015	2035	2050	2070	2090
10TH			1699	1275	956	765
50TH	500	504	507	469	426	390
90TH			181	190	205	221
RCP 8.5	1990	2015	2035	2050	2070	2090
10TH			752	867	1088	1460
50TH	500	405	360	382	417	458
90TH			120	127	138	151

Table E

Argos Results

APPENDIX F

San Dieguito River Lagoon Wetland Habitat

Habitat Percentages Based on Inundation

Habitat based on % inundation	**Low**	**High**	**Based on surveys at San Dieguito**	Low (- 1 stdv)	High (+ 1 stdv)
Upland	7.376				
Transition Zone	6.05	7.376			
High Marsh	5.21	6.05			
Mid Marsh	3.62	5.21	Pickleweed	4.5	5.6
Low Marsh	2.56	3.62	Cordgrass	3.5	3.9
Mudflat	-0.19	2.56			
Subtidal		-0.19			

NRC 2012 Sea-Level Rise (cm)

	Emission level	**baseline year**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Los Angeles Ranges **(cm)** (in Table 5.3)	low end of range	2000	0.8	2.3	4.6	7.6	11.5	16.0	21.4	27.4	34.3	41.9
	projection		3.1	7.7	13.5	20.8	29.4	39.4	50.7	63.4	77.5	93.0
	high end of range		8.4	18.6	30.7	44.7	60.5	78.2	97.8	119.2	142.4	167.6

Ground Elevation

Ground Elevation* in 2010 (ft NAVD)	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00
11.84	11.84	11.84	11.84	11.84	11.84	11.84	11.84	11.84	11.84
6.56	6.56	6.56	6.56	6.56	6.56	6.56	6.56	6.56	6.56
5.75	5.90	6.05	6.20	6.35	6.50	6.56	6.56	6.56	6.56
4.14	4.29	4.44	4.59	4.74	4.89	5.05	5.20	5.35	5.50
2.94	3.09	3.24	3.39	3.54	3.69	3.85	4.00	4.15	4.30

Low Habitat Limits for Low, Mid, and High SLR Scenarios

Low SLR

Low Habitat Limit in ~2010 (ft NAVD)	2020	2030	2040	2050	2060	2070	2080	2090	2100
7.376	7.5	7.5	7.6	7.8	7.9	8.1	8.3	8.5	8.8
6.05	6.1	6.2	6.3	6.4	6.6	6.8	7.0	7.2	7.4
5.21	5.3	5.4	5.5	5.6	5.7	5.9	6.1	6.3	6.6
3.62	3.7	3.8	3.9	4.0	4.1	4.3	4.5	4.7	5.0
2.56	2.6	2.7	2.8	2.9	3.1	3.3	3.5	3.7	3.9
-0.19	-0.1	0.0	0.1	0.2	0.3	0.5	0.7	0.9	1.2

Mid SLR

Low Habitat Limit in ~2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
7.376	7.6	7.8	8.1	8.3	8.7	9.0	9.5	9.9	10.4
6.05	6.3	6.5	6.7	7.0	7.3	7.7	8.1	8.6	9.1
5.21	5.5	5.7	5.9	6.2	6.5	6.9	7.3	7.8	8.3
3.62	3.9	4.1	4.3	4.6	4.9	5.3	5.7	6.2	6.7
2.56	2.8	3.0	3.2	3.5	3.9	4.2	4.6	5.1	5.6
-0.19	0.1	0.3	0.5	0.8	1.1	1.5	1.9	2.4	2.9

High SLR

Low Habitat Limit in ~2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
7.376	8.0	8.4	8.8	9.4	9.9	10.6	11.3	12.0	12.9
6.05	6.7	7.1	7.5	8.0	8.6	9.3	10.0	10.7	11.5
5.21	5.8	6.2	6.7	7.2	7.8	8.4	9.1	9.9	10.7
3.62	4.2	4.6	5.1	5.6	6.2	6.8	7.5	8.3	9.1
2.56	3.2	3.6	4.0	4.5	5.1	5.8	6.5	7.2	8.1
-0.19	0.4	0.8	1.3	1.8	2.4	3.0	3.7	4.5	5.3

Habitats in Low, Mid and High SLR Scenarios

Low SLR

Habitat in ~2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Upland	Upland	Upland	Upland	Upland	Upland	Upland	Upland	Upland	Upland
Transition	Transition	Transition	Transition	Transition	Transition	Transition	Transition	Transition	Transition
High Marsh	High Marsh	High Marsh	High Marsh	High Marsh	High Marsh	High Marsh	High Marsh	High Marsh	Mid Marsh
Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh
Low Marsh	Low Marsh	Low Marsh	Low Marsh	Low Marsh	Low Marsh	Low Marsh	Low Marsh	Low Marsh	Low Marsh
Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat

Mid SLR

Habitat in ~2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Upland	Upland	Upland	Upland	Upland	Upland	Upland	Upland	Upland	Upland
Transition	Transition	Transition	Transition	Transition	Transition	Transition	Transition	Transition	Transition
High Marsh	High Marsh	High Marsh	High Marsh	High Marsh	High Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Low Marsh
Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Low Marsh
Low Marsh	Low Marsh	Low Marsh	Low Marsh	Low Marsh	Low Marsh	Low Marsh	Low Marsh	Low Marsh	Mudflat
Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat

High SLR

Habitat in ~2010	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Upland	Upland	Upland	Upland	Upland	Upland	Upland	Upland	Upland	Upland
Transition	Transition	Transition	Transition	Transition	Transition	Transition	Transition	Transition	Transition
High Marsh	High Marsh	High Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Low Marsh	Low Marsh	Mudflat	Mudflat
Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Mid Marsh	Low Marsh	Low Marsh	Mudflat	Mudflat
Low Marsh	Low Marsh	Low Marsh	Low Marsh	Low Marsh	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat
Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Mudflat	Subtidal	Subtidal

ADDENDUM 1

Comparison of CHVRA, CoSMoS, and FEMA for Beach Erosion and Coastal Storm Flood Hazards

Addendum 1

Comparison of CHVRA, CoSMoS, and FEMA for Beach Erosion, Bluff Erosion, and Coastal Storm Flood Hazards

EXECUTIVE SUMMARY

This addendum to the Del Mar Coastal Hazards, Vulnerability, and Risk Assessment (CHVRA, ESA 2016) provides a comparison of beach erosion, bluff erosion, and coastal flood risk assessments performed for the CHVRA to the U.S. Geological Survey's latest Coastal Storm Modeling System 3.0 results (CoSMoS 3.0 Phase 2, USGS 2017) and the Federal Emergency Management Agency (FEMA 2017) Flood Insurance Study (FIS) and Flood Insurance Rate Map (FIRM). The conclusion and recommendations of this comparison are as follows:

Beach Erosion

The beach erosion and shoreline projections in the CHVRA and most recent CoSMoS results generally agree. Both the CHVRA and CoSMoS results project the potential for the loss of the Del Mar Beach with about 2.6 feet of sea-level rise (SLR), which is projected to occur by about 2060 in the high SLR scenario used for the CHVRA.[1] ESA concludes that:

- The CHVRA shoreline erosion projections are appropriate for the purposes of adaptation planning and coastal policy development.
- CoSMoS projections should not be used in place of the CHVRA results without a comparison to CHVRA results and an independent, third-party review by a qualified coastal engineer and/or geologist.

Bluff Erosion

The latest CoSMoS Phase 2 bluff erosion projections show less erosion than the previously released CoSMoS Phase 1 results. The CHVRA bluff erosion projections were based on the previously released CoSMoS Phase 1 results and the CHVRA, therefore, projects more bluff erosion than the latest CoSMoS results. ESA further assessed and compared the bluff erosion projections from the CHVRA and CoSMoS Phase 1 and 2 and concluded that the CoSMoS Phase 2 results may under-predict future erosion with SLR. Based on this review, ESA recommends:

- An independent bluff erosion analysis to provide additional information for the basis of refining the City's coastal bluff overlay.
- If the City does not choose to do an independent analysis, ESA recommends using the CHVRA bluff erosion projections (which are based on the CoSMoS Phase 1 results) to inform the coastal bluff overlay. ESA also recommends the option for the City to sub-divide the overlay into subareas with different levels of risk (e.g., one or more transitional subareas) based on both the CHVRA/CoSMoS Phase 1 results and the CoSMoS Phase 2 results.

ESA does not recommend using the CHVRA's bluff erosion projection without increased SLR, which ESA and Dr. Adam Young performed solely for the purpose of comparison to the CoSMoS

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[1] The high SLR scenario used in the CHVRA projects 5.5 feet of SLR in 2100.

results. Note that the bluff erosion projections from the CHVRA and CoSMoS do not consider existing bluff armoring or stabilization measures because the existing armoring and stabilization may not limit or prevent bluff erosion over the long-term. Also note that the bluff erosion hazard and vulnerability assessments from the CHVRA and CoSMoS assume that the bluffs would erode past the railroad; this approach provides the baseline “no action” scenario for the purposes of adaptation planning and policy development.

Flooding

The flood hazards from the CHVRA and the most recent CoSMoS release both consider SLR and generally agree. The updated FEMA flood maps do not consider SLR and show a limited coastal flood risk compared to the CHVRA, which does include SLR. Note that while the CHVRA, CoSMoS, and FEMA use different methods to assess coastal flooding, all consider the existing seawalls and revetments and all show that beachfront properties are currently vulnerable to coastal flooding. Based on ESA’s analysis and comparison, ESA concludes that the CHVRA coastal flooding and wave hazard maps and analysis are the best available and most appropriate mapping for the purposes of the City’s adaptation planning and coastal policy development.

1 INTRODUCTION

This addendum to the Del Mar Coastal Hazards, Vulnerability, and Risk Assessment (CHVRA, ESA 2016) provides a comparison of beach erosion, bluff erosion, and coastal flood risk assessments performed for the CHVRA to the latest U.S. Geological Survey Coastal Storm Modeling System 3.0 results (CoSMoS, USGS 2017) and the Federal Emergency Management Agency (FEMA, 2017) Flood Insurance Study (FIS) and Flood Insurance Rate Map (FIRM). The CHVRA was prepared in 2016 when only partial initial CoSMoS results were available and before the updated FEMA FIS and FIRM were available. This addendum to the CHVRA compares the results of the CHVRA to the latest CoSMoS results and FEMA products. The conclusion of this comparison (Section 5) is that CHVRA results are appropriate for SLR adaptation planning and informing policy development.

The CHVRA analyzed the increase in coastal hazard exposure and vulnerability with SLR in the City of Del Mar for the following four hazards:

1. Beach Erosion (Section 4.1 in CHVRA)
2. Coastal Flooding (Sections 4.3 and 5.1 in CHVRA)
3. Bluff Erosion (Sections 4.2 and 5.2 in CHVRA)
4. River Flooding (Sections 4.4 and 5.3 in CHVRA)

At the time that the CHVRA was prepared and completed in 2016, only the following partial initial results for CoSMoS 3.0 were available (published November 15, 2015).

1. Beach erosion: Initial CoSMoS results included beach erosion or shoreline positions in 2100 under CoSMoS' "hold the line and continued nourishment" scenario. ESA therefore performed a supplemental analysis of beach erosion from 2030 to 2100 for the CHVRA.
2. Coastal flooding: Initial CoSMoS results included coastal flood extents, but these flood extents excluded the contribution of wave runup and beach erosion. For the CHVRA, ESA therefore performed an independent wave runup analysis and coastal flood hazard assessment.
3. Bluff erosion: Initial CoSMoS results included bluff erosion (also referred to as cliff retreat rates) and positions in 2100. ESA applied the CoSMoS cliff retreat rates and interpolated cliff positions from the CoSMoS results for the CHRVA.

4. River flooding: CoSMoS results include only extreme coastal flooding with inclusion of the coincident river discharge and flooding estimated to occur during an extreme coastal flood event. ESA assessed extreme San Dieguito River flooding for the CHVRA. CHVRA results for extreme river flooding are not compared to CoSMoS results because the CHRVRA considers extreme river flood hazards, whereas CoSMoS does not.

Since publication of the CHVRA, additional CoSMoS erosion and flooding data have become available through the USGS. This addendum compares the results of the CHVRA and the latest CoSMoS results (CoSMoS 3.0, Phase 2, published October 2016) for beach erosion, bluff erosion, and coastal flooding. Compared to the initial CoSMoS release, the latest CoSMoS results show different hazard extents than the initial outputs and provide additional results and scenarios. Sections 2.2, 3.2, and 4.2 of this addendum provide overviews of the updated CoSMoS modeling, and sections 2.3, 3.3, and 4.4 compare the results of the CHVRA with the updated CoSMoS shoreline and flood modeling within the City of Del Mar.

At the time that the CHVRA was prepared and completed in 2016, the available and effective FEMA FIS and FIRM were based on analyses performed in the 1980s (see CHVRA Section 4.4.2). FEMA subsequently released an updated FIS for San Diego County and FIRMs, including for the City, in April 2016. The FEMA update includes new analyses and mapping of current extreme coastal flood hazards. FEMA does not consider or analyze future flood hazards with SLR or coastal erosion. This addendum compares the updated FEMA and CHVRA results for current extreme coastal flood hazards. FEMA did not update or include new analyses of extreme river hazards for the San Dieguito River. The CHRVA results for extreme river flood hazards are based on the prior FEMA results and mapping of river flood hazards, which FEMA has not updated. A comparison of CHRVA and FEMA river flood hazards results is therefore not necessary or included in this addendum. For information on how the river flooding hazards were evaluated, refer to CHVRA Sections 4.4 and 5.3.

2 COMPARISON OF BEACH EROSION ASSESSMENT

The following sections summarize the beach erosion assessment methods used in the CHVRA (Section 2.1) and CoSMoS (Section 2.2) and compare the results (Section 2.3).

2.1 CHVRA

As described further in CHVRA Section 4.1, ESA calculated future beach widths for a range of SLR curves (CCC 2015) using the Bruun rule, assuming no background erosion (0 feet/year). A representative mean starting beach width was estimated to be approximately 95 feet in 2010 and was used as the baseline for this analysis. The width of 95 feet was calculated as an approximate annual mean beach width at Mean High Water along a representative North Beach profile (Profile SIOB). The annual mean was calculated across surveys taken from January 2011 and January 2016, as shown in Figure 26 in Section 4-1 of the CHVRA. A beach width analysis was also conducted for Profile SIOB using only winter beach profiles and only summer beach profiles.

Figure 27 and Table 2 in the CHVRA show the beach widths over time under existing conditions and three future SLR scenarios. Under the high SLR scenario, ESA's analysis shows beach widths reaching zero as early as 2060. For the mid SLR scenario, ESA's analysis shows beach loss by 2090. Note that Figure 27 and Table 2 represent average beach widths, which is typically 25 feet greater than winter beach widths and 25 feet less than summer beach widths.

2.2 CoSMoS

Figure 1 below shows the results of the most recent CoSMoS 3.0 shoreline erosion projections for various SLR amounts. CoSMoS uses past shoreline position data to estimate the historic "background" rate of shoreline. This background rate is then included in the projection model, which assumes a Bruun-type geomorphic response to SLR and incorporates historical trends in shoreline position, longshore transport, and cross shore transport to provide a line indicating the inland extent of shoreline erosion. The CoSMoS shoreline erosion model evaluates the beach width on January 1 of each simulation year under two management scenarios ("hold-the-line" and "let it go") and two nourishment scenarios ("nourishment" and "no nourishment"). The model is then run to simulate historic erosion, and if the model results show a shoreline position that is farther seaward than past shoreline position data, the model estimates the amount of beach nourishment (or other sand sources/sinks) that would have needed to occur for the model to match past shoreline position data. For the beach nourishment model scenarios, the model includes this estimate of past beach nourishment as part of the shoreline erosion projections. For the "no beach nourishment" model scenarios, the model does not include this adjustment. Note that for Del Mar beach, the CoSMoS results for their "nourishment" and "no nourishment" scenarios are the same because CoSMoS uses historic shoreline transect data from 1995 to present, which show erosion. Therefore, there is no nourishment term in CoSMoS for the Del Mar shoreline transects and no difference between the “nourishment” and “no nourishment” CoSMoS results for Del Mar (Sean Vitousek, USGS, pers. comm., April 12, 2017).

Figure 1 shows the CoSMoS results for the “let it go” scenario, in which shoreline erosion is not stopped at the existing developed edge. The CoSMoS shoreline erosion projections for the Del Mar beach shoreline appear to indicate oscillation between erosion and accretion over time as shown by the black arrows between successive shoreline positions in Figure 1. This is because the CoSMoS model simulates shoreline position on a daily or similar time step based on simulated ocean conditions and the results are output for January 1 of each year. In certain model output years (2033, 2063, and 2075), the model output shoreline shows positions on January 1 that are seaward of the shoreline position output for the preceding output year. This is due to the CoSMoS method of simulating daily and annual variations in the shoreline position (Sean Vitousek, USGS, pers. comm., April 12, 2017). The CoSMoS results do show overall progressive erosion over time as discussed further in following section.

2.3 Comparison

To compare the CHVRA and CoSMoS shoreline erosion projections, ESA measured the beach widths derived from the CoSMoS shoreline projections over time for 175 cm (5.7 ft) of SLR in 2100 (shown in Figure 1). **Figure 2** compares beach widths based on the CoSMoS results with the CHVRA’s beach width projections with 5.5 ft of SLR in 2100. To ensure consistency, the beach widths were measured at the same location as the representative transect used for ESA’s shoreline position analysis (SIOB). As shown in Figure 2 below, the shoreline projections from the CHVRA and CoSMoS generally agree, as they are both primarily based on application of the Bruun Rule. The CoSMoS shoreline outputs showed three positions (2033, 2063 and 2075) that showed shoreline accretion due to the fact that the CoSMoS results output shoreline position on January 1 as discussed in the above section. When these outputs for years when wider beach widths are simulated by CoSMoS on January 1 are excluded, the ESA CHVRA and CoSMoS beach widths are in close agreement as shown in Figure 2. This is because the CHVRA and CoSMoS shoreline projections are both based on the Bruun rule and the fact that future projected shoreline erosion projected with SLR based on the Bruun rule dominates the future projections more so than other coastal processes simulated by CoSMoS. Both the CHVRA and CoSMoS results project the potential for the loss of the Del Mar beach by about 2060 in the SLR scenario with about 5.5 ft of SLR in 2100. The CHVRA did not project the potential shoreline position landward of existing development, whereas CoSMoS results for the “let it go” scenario show the potential for shoreline erosion into developed areas after about 2060.

SOURCE: USGS, 2015

Figure 1
CoSMoS 3.0 Phase 2 Shoreline Projections Over Time with 175 cm (5.7 ft) of SLR in 2100

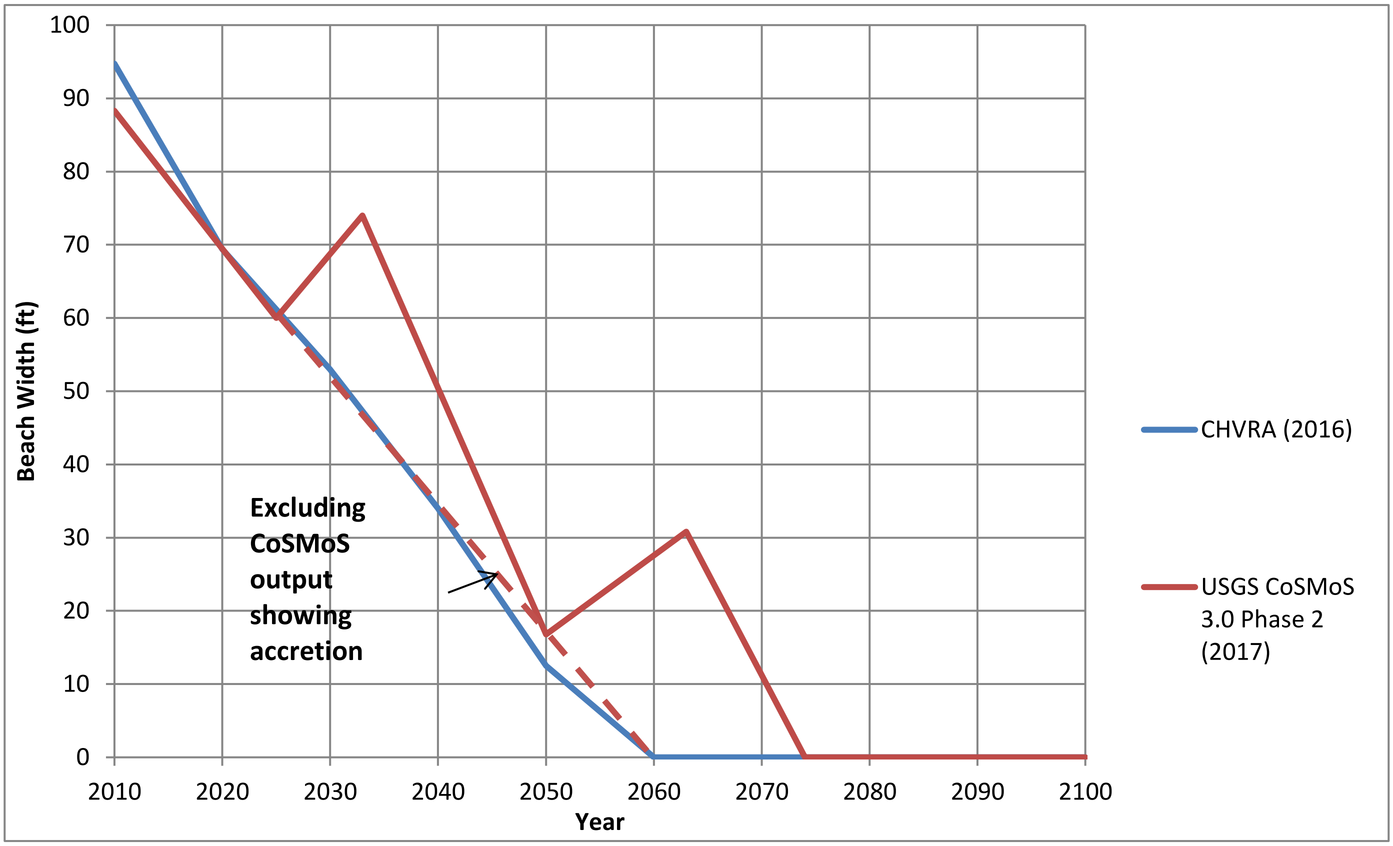


Figure 2. CHVRA and CoSMoS Beach Width Comparison with approximately 5.5 ft of SLR for Transect SIOB

3 COMPARISON OF BLUFF EROSION ASSESSMENT

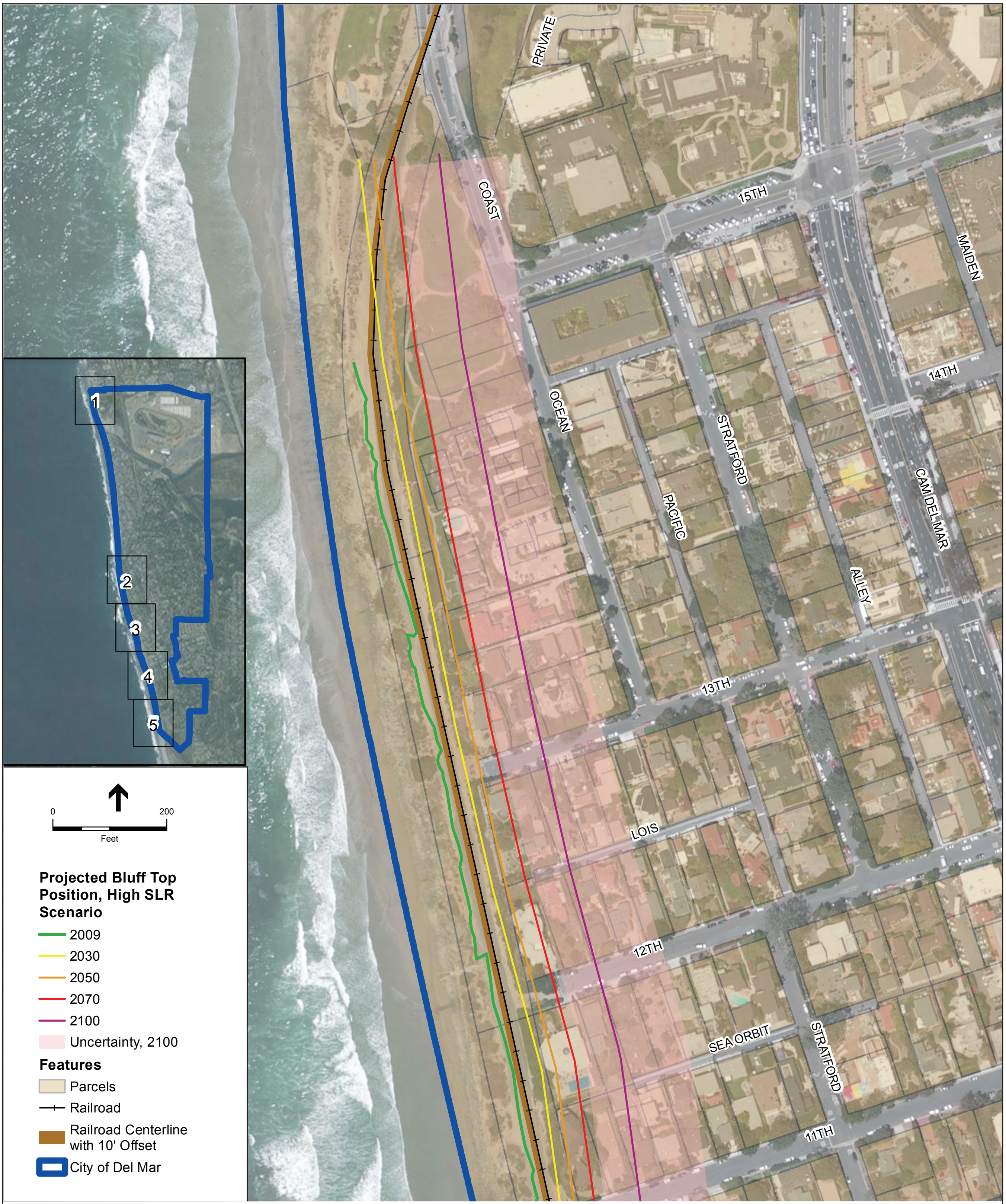
The following section summarizes the bluff erosion hazard assessment methods used in CHVRA (Section 3.1), and CoSMoS (Section 3.2). Section 3.2 also discusses the differences in bluff erosion projections between the initial 2015 CoSMoS 3.0 release and the subsequent 2016 CoSMoS 3.0 Phase 2. Section 3.3 compares the results of both the CHVRA and both CoSMoS projections, and discusses potential implications for the City of Del Mar.

3.1 CHVRA

Section 4.2 of the CHVRA provides a full description of the bluff retreat analysis performed as part of the CHVRA; this section includes a brief summary of the methods. The future acceleration of cliff retreat rates and future cliff top positions with SLR were assessed for the CHVRA using results from the initial USGS CoSMoS 3.0 cliff retreat projections. Additionally, an analysis of historic cliff retreat for the Del Mar bluffs was performed for the CHVRA as a check of CoSMoS. At the time of CHVRA publication, CoSMoS provided bluff edge projections for 1.0 m (3.3 ft), 1.5 m (4.9 ft), and 2.0 m (6.6 ft) SLR. ESA used the CoSMoS 1.0 m cliff retreat rate and position for the mid-SLR scenario for the CHVRA assessment. For the high SLR scenario, ESA interpolated the cliff retreat rates and positions between the CoSMoS 1.5 m and 2.0 m SLR scenario to estimate bluff erosion with 5.5 ft (1.68 m) of SLR in 2100.

Starting with the 2100 cliff top positions based on CoSMoS 3.0 Phase 1, ESA projected backwards in time using the CoSMoS 3.0 cliff retreat rates to estimate cliff top positions in 2070, 2050, and 2030. Rather than assuming a constant retreat rate over time, ESA developed retreat rate curves where the retreat rate increases over time due to accelerating rates of SLR. The increase in retreat rates was assumed to be proportional to the increase in the rate of SLR based on the National Research Council (NRC 2012) SLR curves. The average retreat rate along the south Del Mar bluffs from CoSMoS was used to project the 2030, 2050, and 2070 cliff top projections for the South Beach and South Bluffs Districts. The average rate along the North Bluffs was used for the North Bluffs projections. **Figure 3** below shows one panel of cliff top position projections from the CHVRA; Figures 30 – 30.5 in the CHVRA provide the bluff projection positions for all of Del Mar.

Additionally, as a check, ESA evaluated potential future cliff top positions at decadal intervals from 2020-2100 using the estimated mean Del Mar long-term historical cliff retreat rate between 1934 and 2009 of 0.52 ft/yr, shown in **Figure 4** below. Future cliff line positions were generated by buffering the 2009 digitized cliff line for the specified retreat distance. Actual future retreat is expected to be greater than this projection of the historic bluff erosion rate because increased SLR is expected to increase the rate and extent of bluff erosion. Figures A1-A7 in Appendix A of the CHVRA provide these projection maps for the entire City.



Note : Projected bluff top position for 2100 is interpolated from CoSMoS 3.0 results with 1.5 m SLR and 2.0 m SLR. Positions for 2030 – 2070 are interpolated based on CoSMoS 3.0 erosion rates. Positions in 2010 (north) and 2009 (south) are based on LiDAR elevation data.

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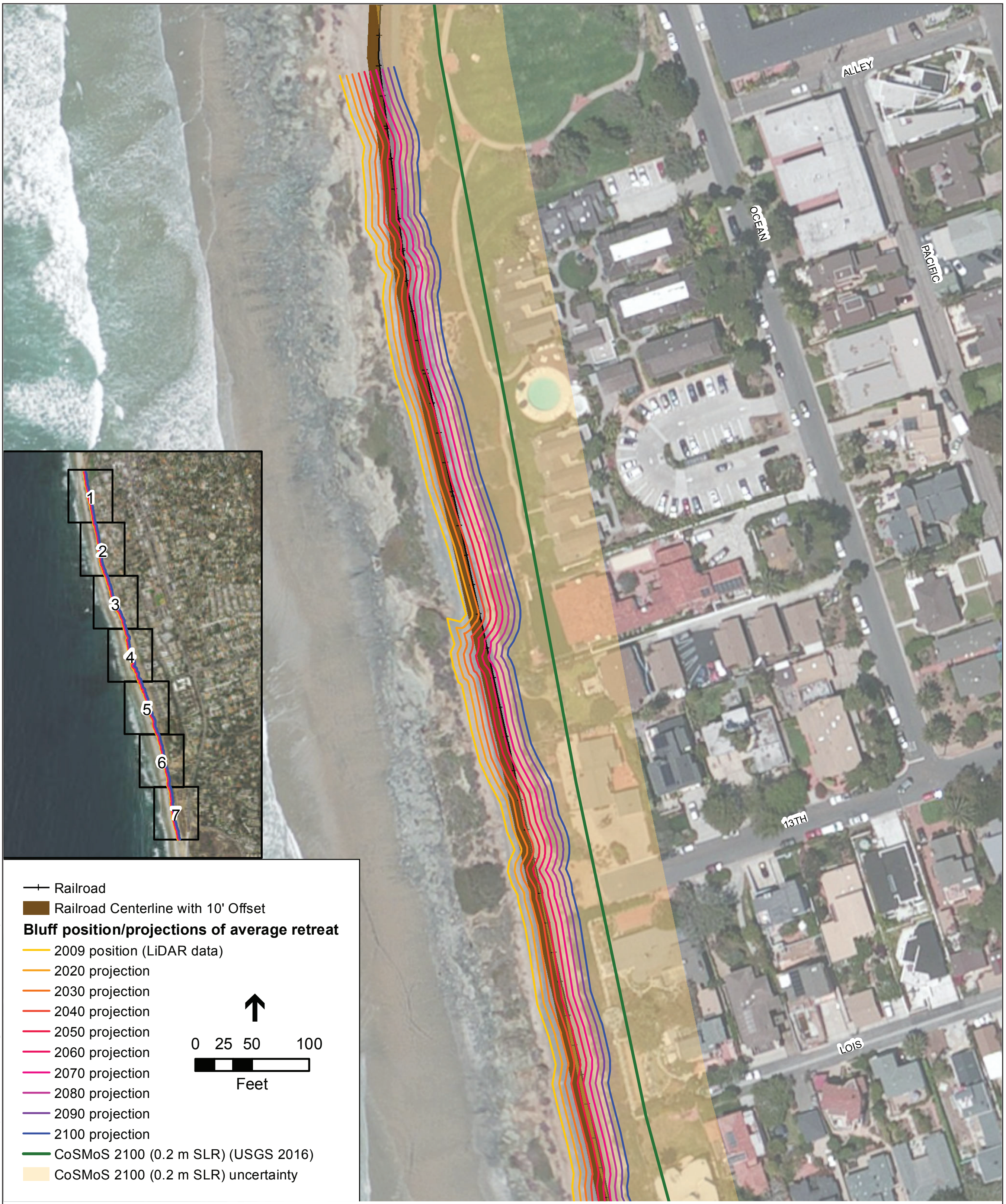
SOURCE: SanGIS 2016, USGS 2015

Del Mar Vulnerability Assessment

Figure 3
High SLR Bluff Projections from the CHVRA

ESA



Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

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SOURCE: USGS 2016

Del Mar Vulnerability Assessment

Figure 4
Bluff Retreat Projections for Historic Rates of Retreat
without Increased SLR

ESA

3.2 CoSMoS 3.0 Phase 1 and Phase 2

After publication of the CHVRA, the USGS released updated CoSMoS 3.0 Phase 2 results that superseded the initial CoSMoS 3.0 Phase 1 results. CoSMoS 3.0 Phase 2 included an updated set of bluff projections for the same SLR scenarios used for Phase 1 (1.0, 1.5, and 2.0 m SLR), as well as additional SLR scenarios (0.25, 0.5, 0.75, 1.25, 1.75, and 5.0 m SLR). According to the USGS, the bluff retreat modeling approach was refined significantly between the Phase 1 and Phase 2 release dates. The Phase 1 modeling approach used a single model, whereas the Phase 2 methods used a suite of projections from multiple models (Patrick Limber, USGS, pers. comm., 2018). As a result, the USGS significantly reduced the CoSMoS bluff erosion projections between the Phase 1 and Phase 2 releases. **Figure 5-1** through **Figure 5-8** below show the bluff erosion projections for the 1.0, 1.5, and 2.0 m SLR scenarios for both CoSMoS Phase 1 and Phase 2.

In addition to the difference in model ensemble, the historical retreat rates used for the modeling and projected bluffs differed between the Phase 1 and Phase 2 releases. For the 2015 projections, CoSMoS used the historic rates from the USGS National Assessment of Shoreline Change (Hapke and Reid 2007), which were developed from bluff edge positions between the mid 1930s and 1998. In the Phase 2 modeling, the USGS incorporated a more recent bluff end position from 2010, which generally lowered the historic rates calculated at each transect. **Table 1** below shows and compares the historic rates used in the bluff projection modeling for Phase 1 and Phase 2. In general, the Phase 2 historic rates were lower than the corresponding Phase 1 rates. The bluff erosion models are sensitive to background historical rates at each transect, and as a result both the projected bluff erosion rates and cliff edge location are generally lower, or more seaward, for the Phase 2 projections (Patrick Limber, USGS, pers. comm., 2018).

Note that CoSMoS applies the erosion rate estimated at each model transect location and projects bluff erosion at individual transects. The projected bluff top erosion line from CoSMoS is a straight line interpolation that connects the projected bluff top at each transect.

TABLE 1
HISTORIC AND PROJECTED BLUFF EROSION RATES

Transect ID	Projected Bluff Erosion Rates (m/yr)								
	Phase 1	Phase 2	Difference	Phase 1	Phase 2	Difference	Phase 1	Phase 2	Difference
	Historic Rate (m/yr)			1 m			2 m		
596	0.250	0.185	0.065	0.500	0.268	0.232	0.780	0.401	0.379
597	0.220	0.165	0.055	0.450	0.249	0.201	0.730	0.370	0.360
598	0.210	0.181	0.029	0.410	0.239	0.171	0.690	0.362	0.328
599	0.180	0.161	0.019	0.360	0.230	0.130	0.600	0.347	0.253
600	0.150	0.121	0.029	0.280	0.187	0.093	0.470	0.290	0.180
601	0.130	0.094	0.036	0.250	0.149	0.101	0.400	0.244	0.156
602	0.130	0.117	0.013	0.250	0.197	0.053	0.410	0.289	0.121
603	0.150	0.144	0.006	0.280	0.210	0.070	0.450	0.316	0.134
604	0.160	0.133	0.027	0.310	0.205	0.105	0.490	0.309	0.181
605	0.160	0.120	0.040	0.330	0.185	0.145	0.520	0.241	0.279
606	0.180	0.141	0.039	0.360	0.189	0.171	0.570	0.265	0.305
607	0.220	0.178	0.042	0.400	0.246	0.154	0.640	0.356	0.284
608	0.240	0.232	0.008	0.430	0.313	0.117	0.680	0.452	0.228
609	0.230	0.214	0.016	0.420	0.317	0.103	0.660	0.453	0.207
610	0.200	0.167	0.033	0.390	0.235	0.155	0.620	0.318	0.302
611	0.180	0.182	-0.002	0.380	0.291	0.089	0.600	0.403	0.197
612	0.180	0.142	0.038	0.380	0.199	0.181	0.620	0.293	0.327
613	0.180	0.178	0.002	0.390	0.268	0.122	0.650	0.390	0.260
614	0.180	0.160	0.020	0.400	0.225	0.175	0.670	0.314	0.356
615	0.180	0.151	0.029	0.400	0.209	0.191	0.640	0.304	0.336
616	0.170	0.166	0.004	0.380	0.222	0.158	0.600	0.311	0.289
617	0.170	0.154	0.016	0.360	0.253	0.107	0.570	0.353	0.217
618	0.170	0.153	0.017	0.360	0.233	0.127	0.570	0.334	0.236
619	0.170	0.153	0.017	0.350	0.218	0.132	0.580	0.218	0.362
Average (m/yr)	**0.183**	**0.158**		**0.368**	**0.231**		**0.592**	**0.331**	
Average (ft/yr)	**0.6**	**0.5**		**1.2**	**0.8**		**1.9**	**1.1**	

3.3 Comparison

The CHVRA was based on and is consistent with the initial USGS CoSMoS 3.0 Phase 1 results that were available at that time. The CoSMoS Phase 1 results projected an increase in erosion over the historic rate of erosion projected by ESA for the CHVRA, which is consistent with the expectation that erosion will increase with increasing rates of SLR. The updated CoSMoS 3.0 Phase 2 results projected less erosion than the Phase 1 results. The Phase 1 model projections that ESA used as the basis for the CHVRA are outside of the outer range of uncertainty from the CoSMoS 3.0 Phase 2 results (Figure 5). Therefore, CoSMoS Phase 2 results appear to suggest that the Phase 1 results over-predict projected erosion.

To further assess this change in the CoSMoS model results for this addendum, ESA compared the CoSMoS Phase 2 bluff erosion projections with 1.0 m SLR to the CHVRA's projection of the historic erosion rate (performed previously by ESA and Dr. Adam Young as described in Section 3.2), which is shown in **Figure 6-1** through **Figure 6-8.** ESA's comparison shows that the CoSMoS Phase 2 bluff erosion projections with 1.0 m SLR range from approximately 60 ft landward (at CoSMoS transect 609) to approximately 22 ft seaward (between CoSMoS transects 606 and 605) of the CHVRA's projection of the historic rate of erosion. CoSMoS Phase 2 bluff projections with 1.0 m of SLR are less than the CHVRA's projection of the historic rate of erosion at a number of locations south of 6th St (various locations interpolated between CoSMoS transects 607 and 599 and at transects 605 and 601). This indicates that the CoSMoS Phase 2 projections may underestimate future bluff erosion, since it is expected that future erosion rates will be higher than historic rates due to the projected increase in SLR.

CoSMoS Phase 2 and the CHVRA use similar historic rates of erosion (average historic erosion rates along the Del Mar southern bluffs of 0.5 ft/yr for both). The CoSMoS Phase 2 projections of limited erosion beyond or less erosion than the CHRVA historic erosion rate projection can be attributed to differences in modeling methodology. CoSMoS Phase 2 applies a suite of models to project the increase in the historic rate due to SLR at a particular transect. The CHVRA applies an average rate of historic erosion along the entire Del Mar southern bluffs. ESA's opinion is that CHVRA's approach of applying a spatially averaged rate of erosion to a representative section of bluff is an accepted practice of accounting for spatial and temporal variability in bluff erosion that is scientifically supported. For example, locations along a bluff that have not historically eroded as fast as adjacent locations could actually erode more rapidly in the future due to the long time scale and episodic nature of bluff erosion (Young et al. 2018).

Figure 7-1 through **7-8** compare the following bluff erosion projections for 2100 for the purposes of informing the City's planning and policy decisions and providing a basis for ESA's recommendations below:

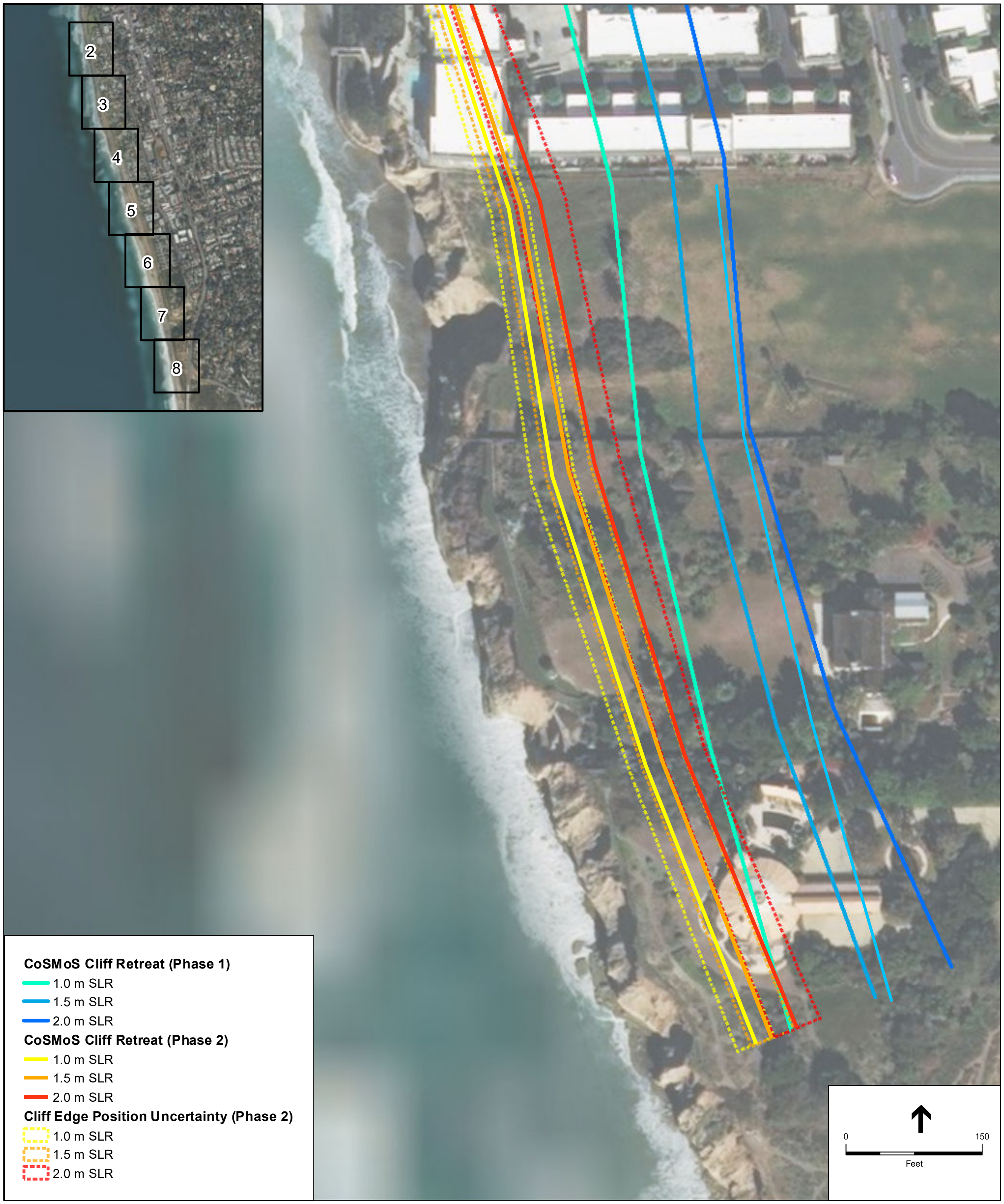
1. CHVRA bluff erosion projection with 5.5 ft of SLR in 2100 (high SLR scenario), based on CoSMoS 3.0 Phase 1.

2. CoSMoS 3.0 Phase 2 bluff erosion projection with 5.7 ft of SLR in 2100 (high SLR scenario). The outer or landward uncertainty limit of the CoSMoS 3.0 Phase 2 model results is shown, rather than the average model projection.

3. CHVRA projection of bluff erosion in 2100 without increased SLR performed by ESA and Dr. Adam Young. Note that this projection is only shown for comparison to the model projections above. As discussed further below, ESA does not recommend using this bluff erosion projection without increased SLR as a representation of future bluff erosion.

At this time, ESA does not recommend updating the CHVRA's projection of future bluff erosion with SLR (item 1 above, which is based on CoSMoS Phase 1 results) with the CoSMoS Phase 2 results (item 2) because ESA's comparison of the different models indicates that the CoSMoS Phase 2 results may under-predict future erosion with SLR. ESA recommends that ESA and Dr. Adam Young perform an independent, site-specific analysis with modeling of projected future bluff erosion with SLR for the Del Mar bluffs. Note that modeling independent from CoSMoS was not included in the City's work program for the CHVRA because the work program was based on using CoSMoS. ESA does not recommend using CoSMoS Phase 2 results to update bluff erosion overlay zones for the Local Coastal Program (LCP) Amendment or other planning purposes at this time. An independent bluff erosion analysis as recommended above would provide additional information for the basis of refining the LCP and planning. If an independent analysis is not performed, an alternative approach to refining the bluff erosion hazard overlay zone would be to sub-divide the bluff erosion hazard overlay zone into subareas with different levels of risk. If the City chooses to take this approach, ESA recommends using the CHVRA (i.e., CoSMoS 3.0 Phase 1) and the outer/landward uncertainty of the CoSMoS 3.0 Phase 2 model projections for the high sea-level rise scenario in 2100 (items 1 and 2 above). ESA does not recommend using the bluff erosion projection without increased SLR in 2100 (item 3 above), which ESA has included for comparison only.

Note that the bluff erosion projections from the CHVRA and CoSMoS do not consider existing bluff armoring or stabilization measures because the existing armoring and stabilization may not limit or prevent bluff erosion over the long-term. Also note that the bluff erosion hazard and vulnerability assessments from the CHVRA and CoSMoS assume that the bluffs would erode past the railroad; this approach provides the baseline “no action” scenario for the purposes of adaptation planning and policy development.

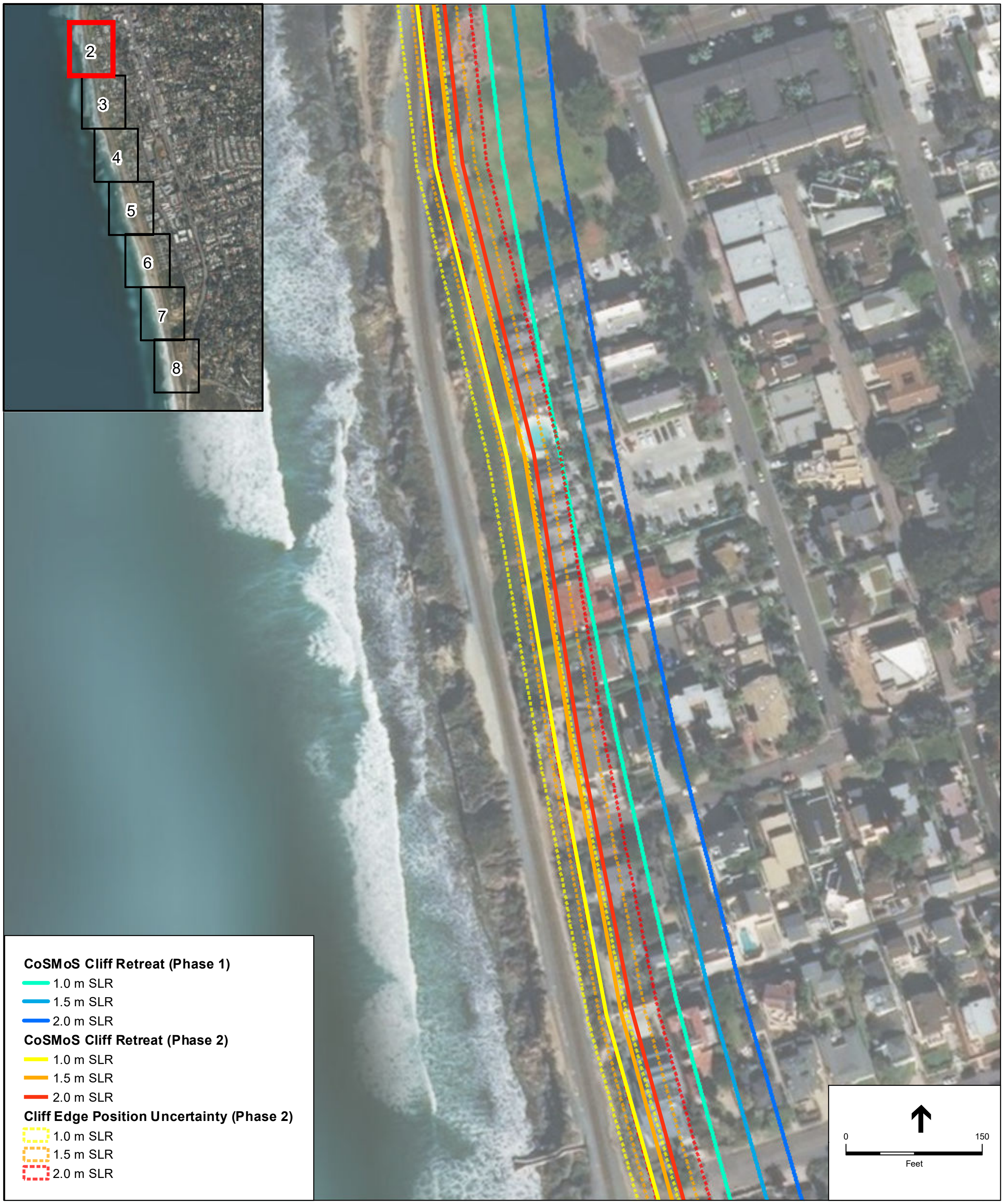


SOURCE: USGS 2015

Del Mar Vulnerability Assessment

Figure 5-1

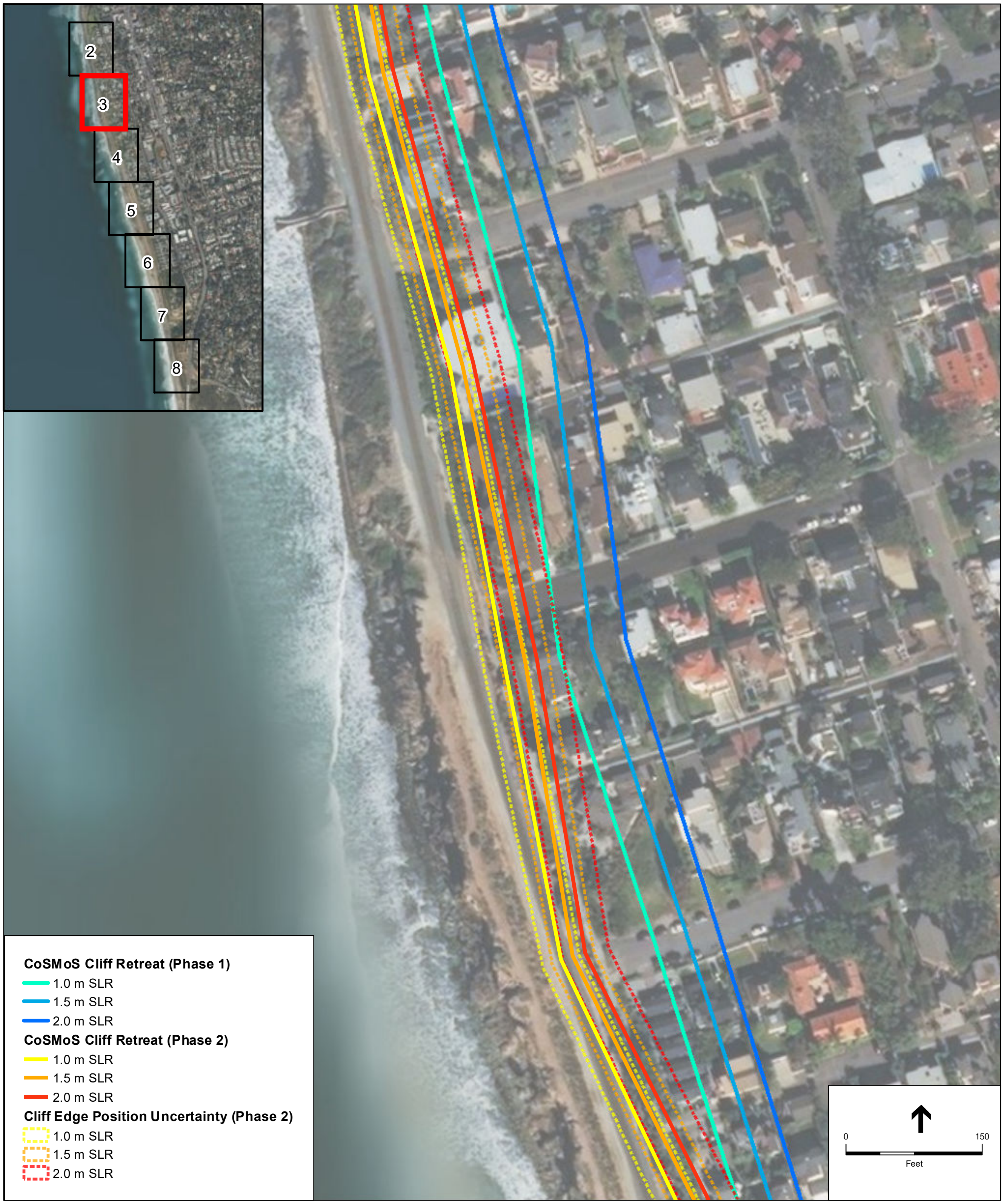
Bluff Retreat Comparison between CoSMoS 3.0 Phase 1 and Phase 2



SOURCE: USGS 2015

Figure 5-2

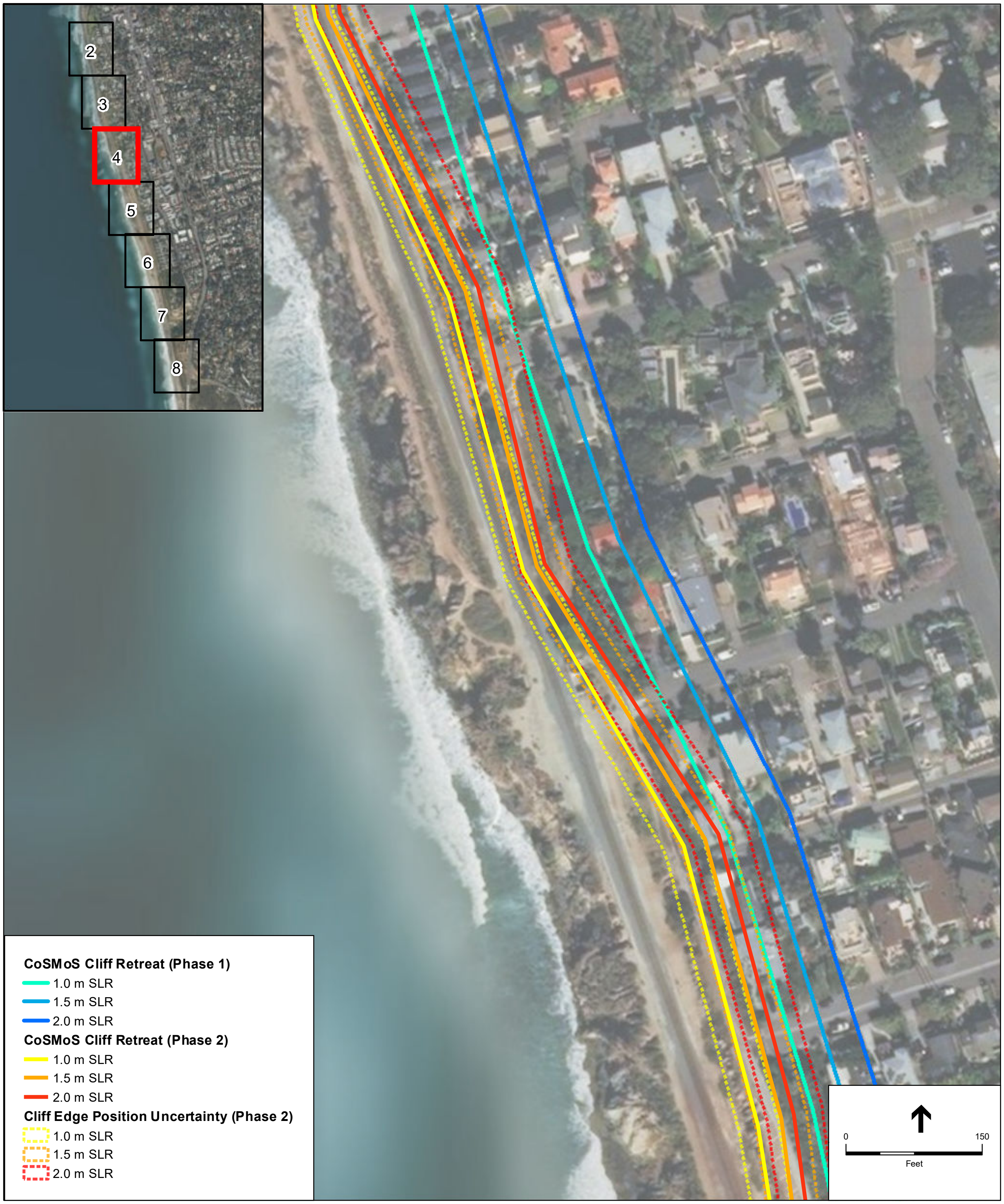
Bluff Retreat Comparison between CoSMoS 3.0 Phase 1 and Phase 2



SOURCE: USGS 2015

Figure 5-3

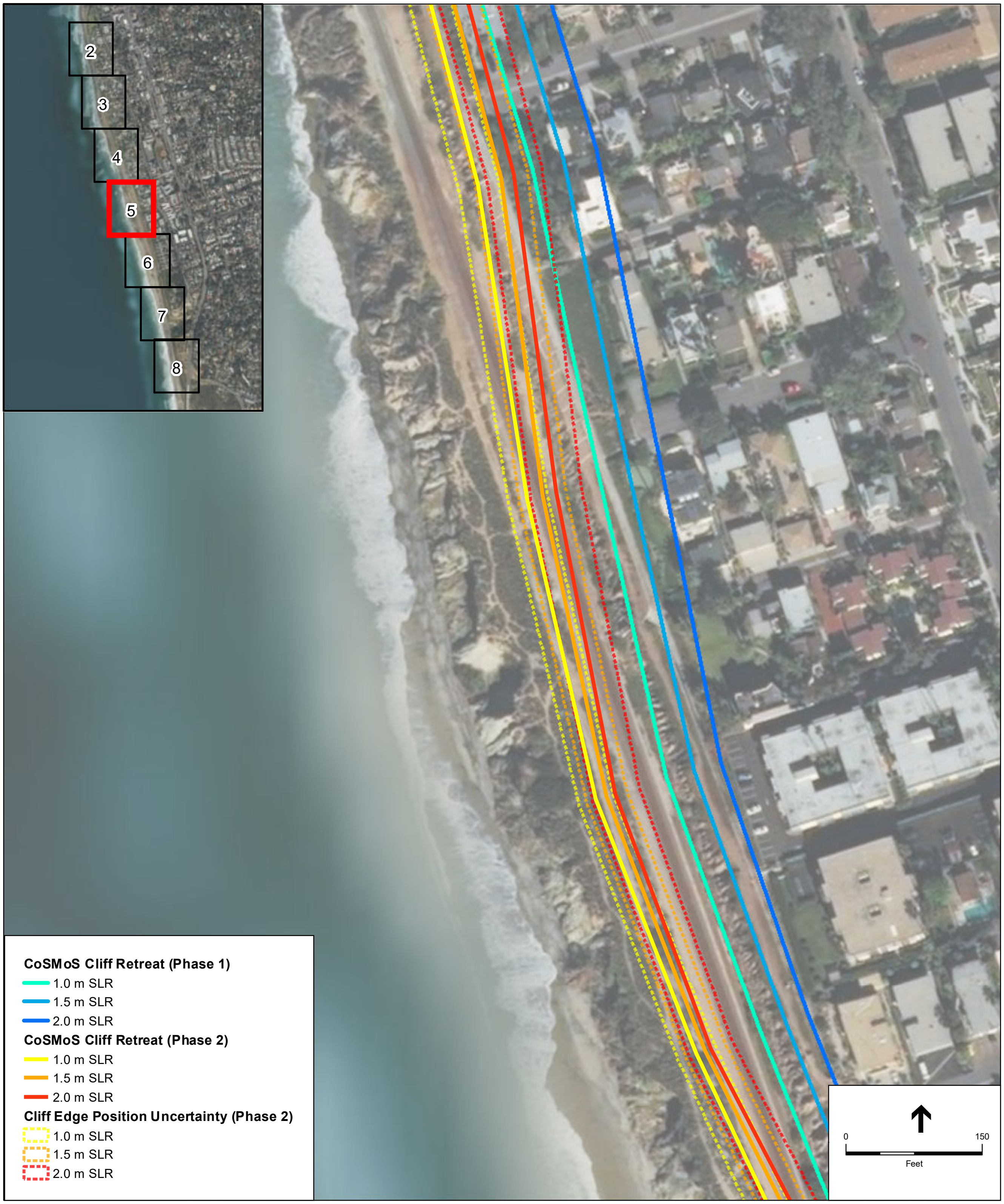
Bluff Retreat Comparison between CoSMoS 3.0 Phase 1 and Phase 2



SOURCE: USGS 2015

Figure 5-4

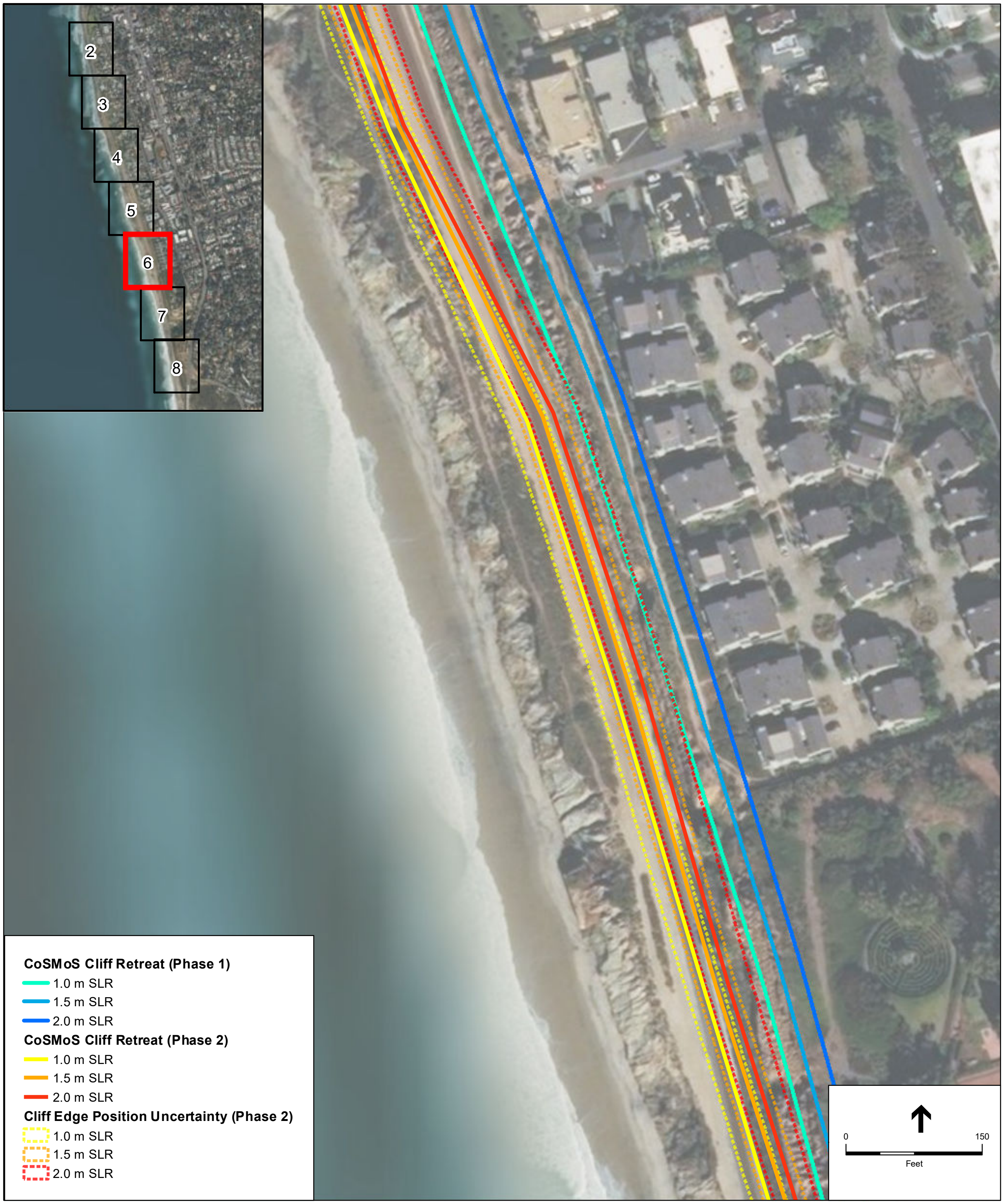
Bluff Retreat Comparison between CoSMoS 3.0 Phase 1 and Phase 2



SOURCE: USGS 2015

Figure 5-5

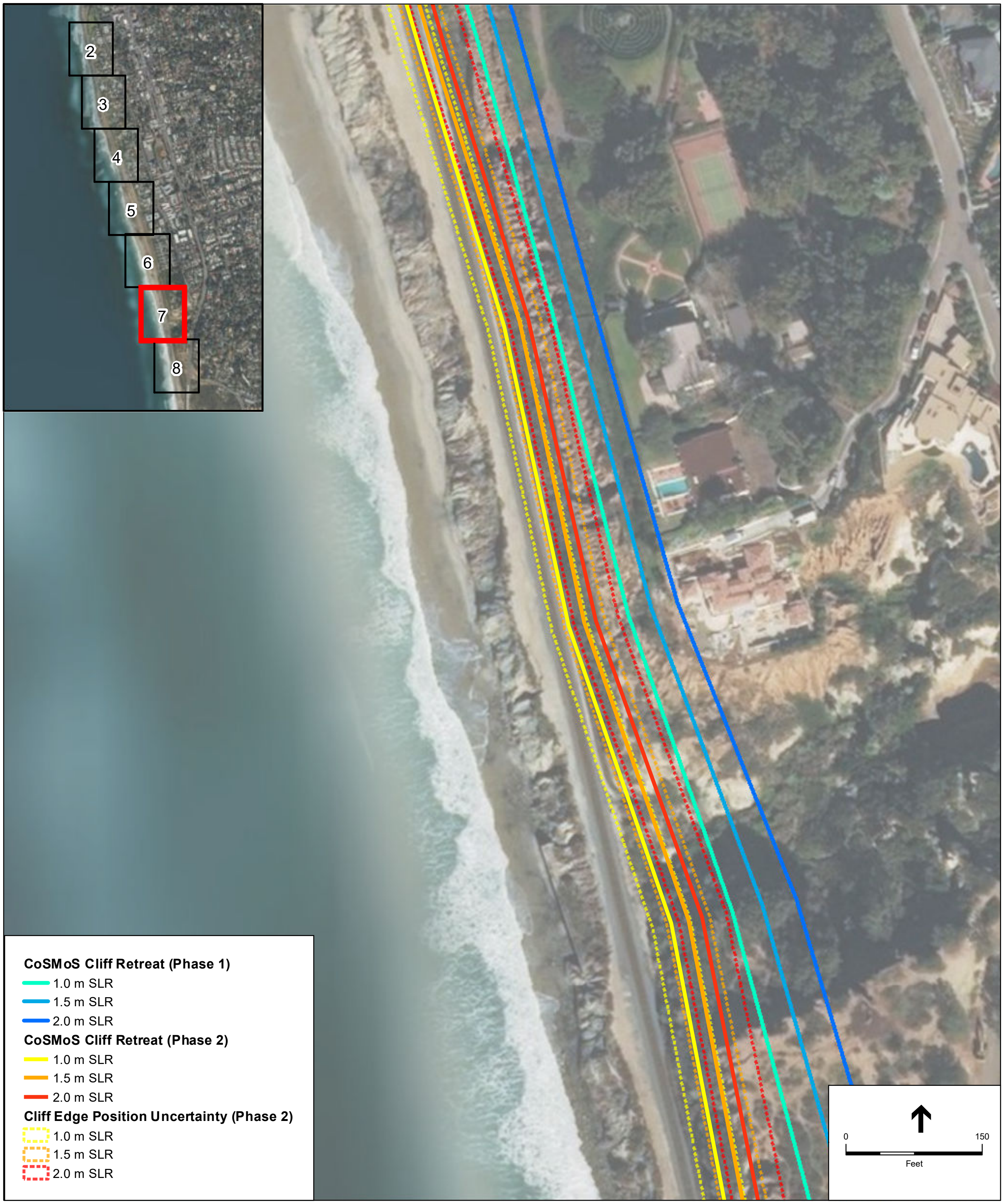
Bluff Retreat Comparison between CoSMoS 3.0 Phase 1 and Phase 2



SOURCE: USGS 2015

Figure 5-6

Bluff Retreat Comparison between CoSMoS 3.0 Phase 1 and Phase 2



SOURCE: USGS 2015

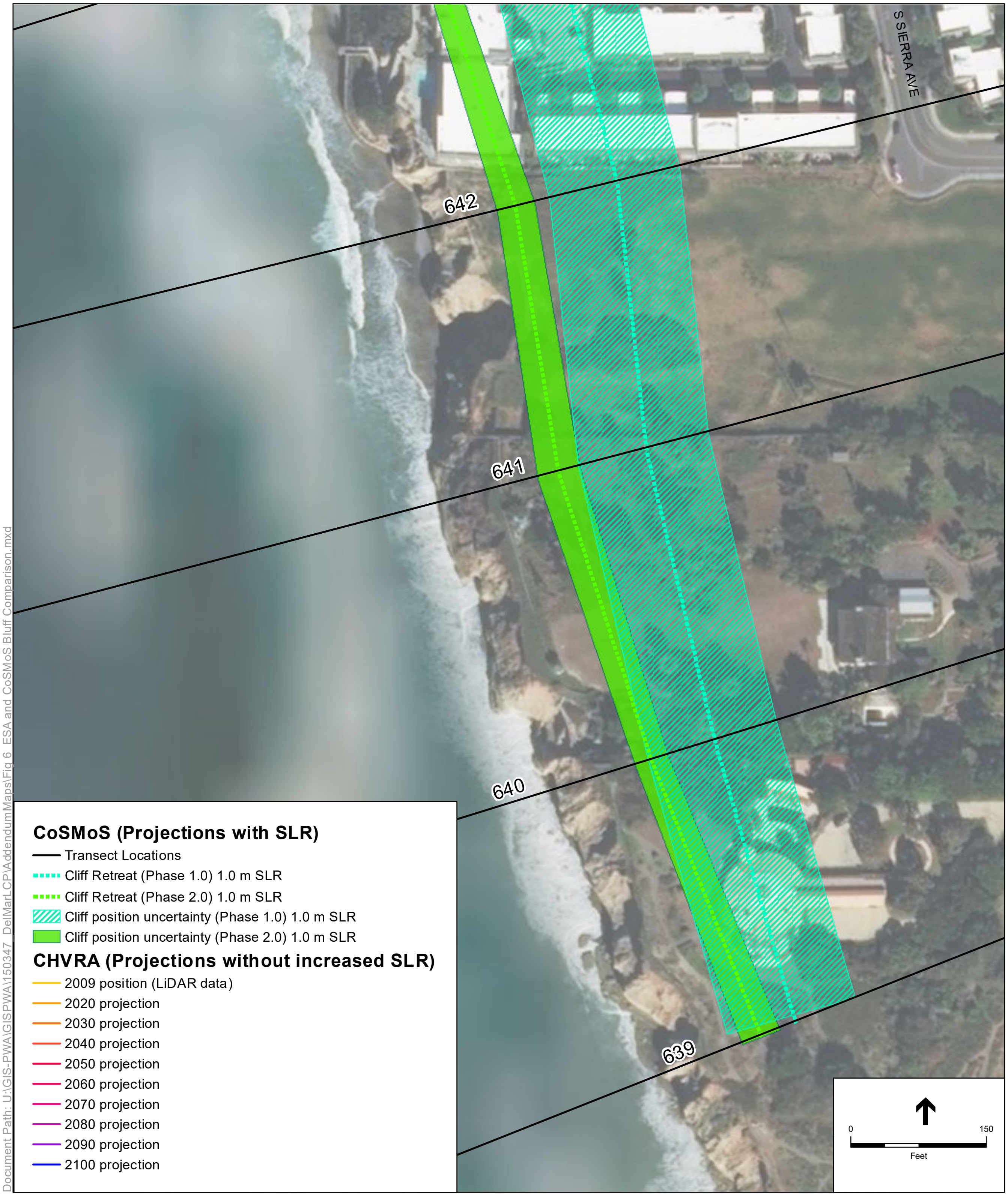
Figure 5-7

Bluff Retreat Comparison between CoSMoS 3.0 Phase 1 and Phase 2

SOURCE: USGS 2015

Figure 5-8

Bluff Retreat Comparison between CoSMoS 3.0 Phase 1 and Phase 2



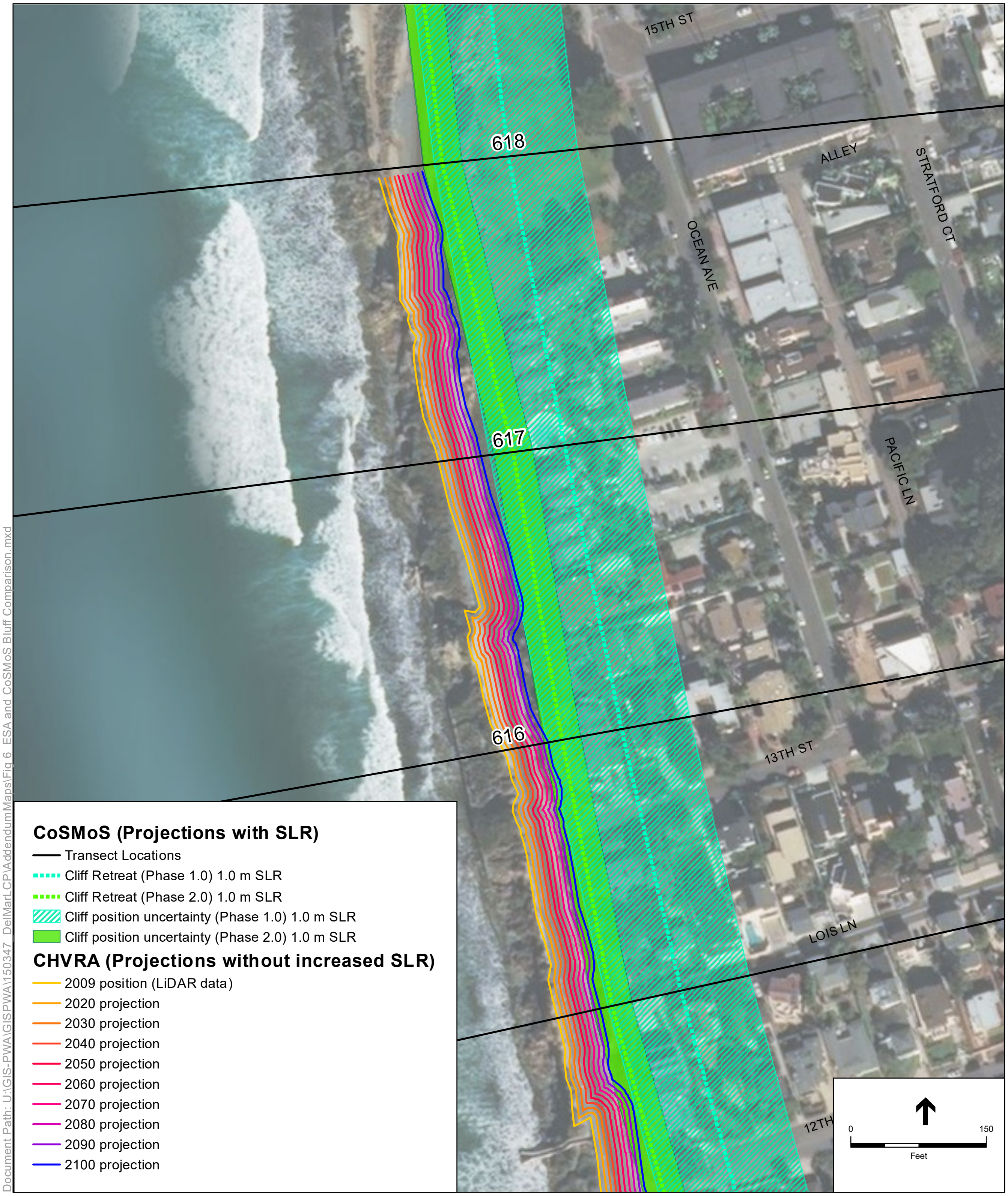
Document Path: U:\GIS-PWA\GISPWA\150347_DelMarLCP\AddendumMaps\Fig 6_ESA and CoSMoS Bluff Comparison.mxd

SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

Figure 6- 1

Comparison of Bluff Retreat Projections without Increased SLR from CHVRA and Projections with SLR from CoSMoS Phase 1 and Phase 2



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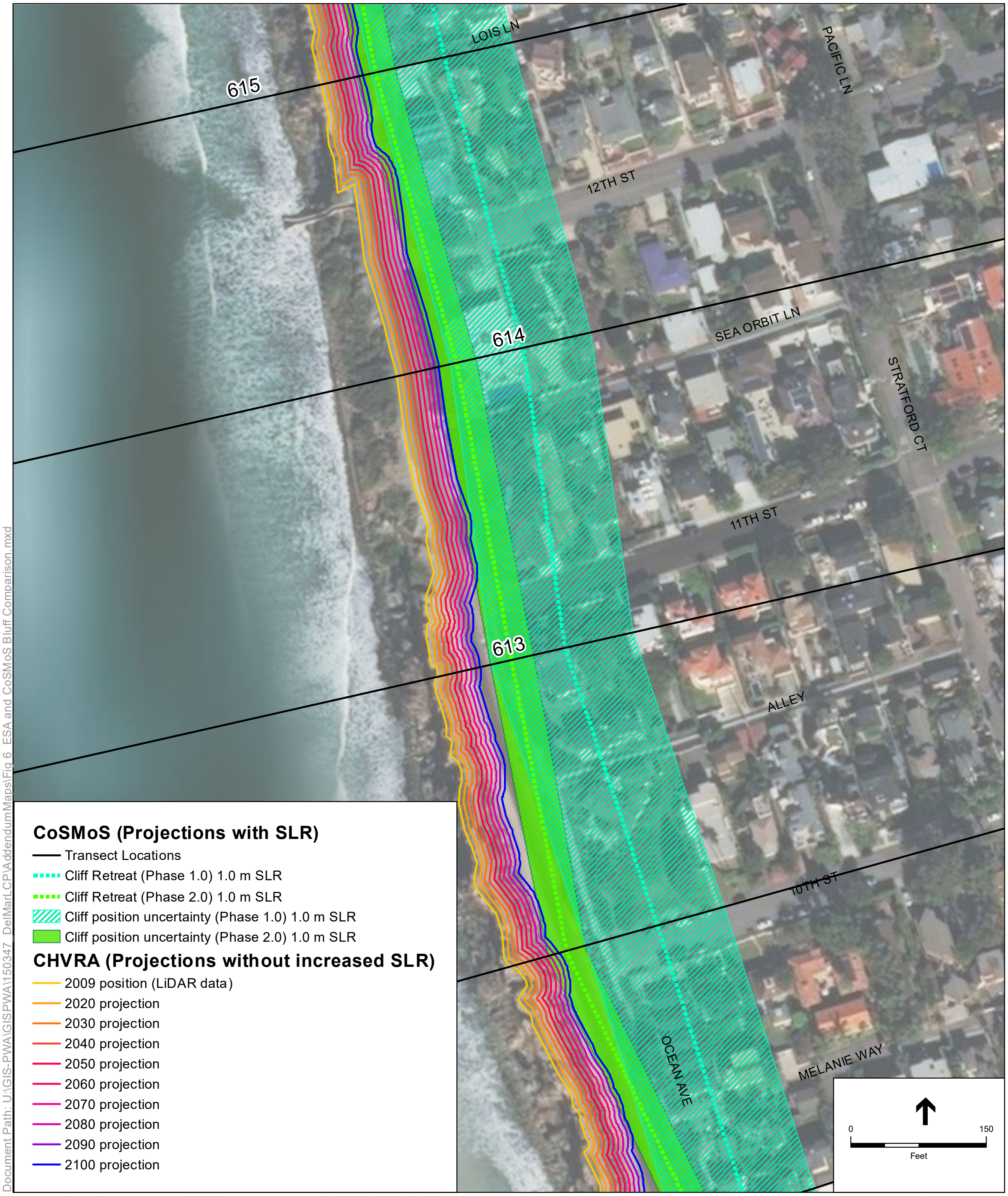
SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

Figure 6- 2

Comparison of Bluff Retreat Projections without Increased SLR from CHVRA and Projections with SLR from CoSMoS Phase 1 and Phase 2



Document Path: U:\GIS-PWA\GISPWA\150347_DelMarLCP\AddendumMaps\Fig 6_ESA and CoSMoS Bluff Comparison.mxd

SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

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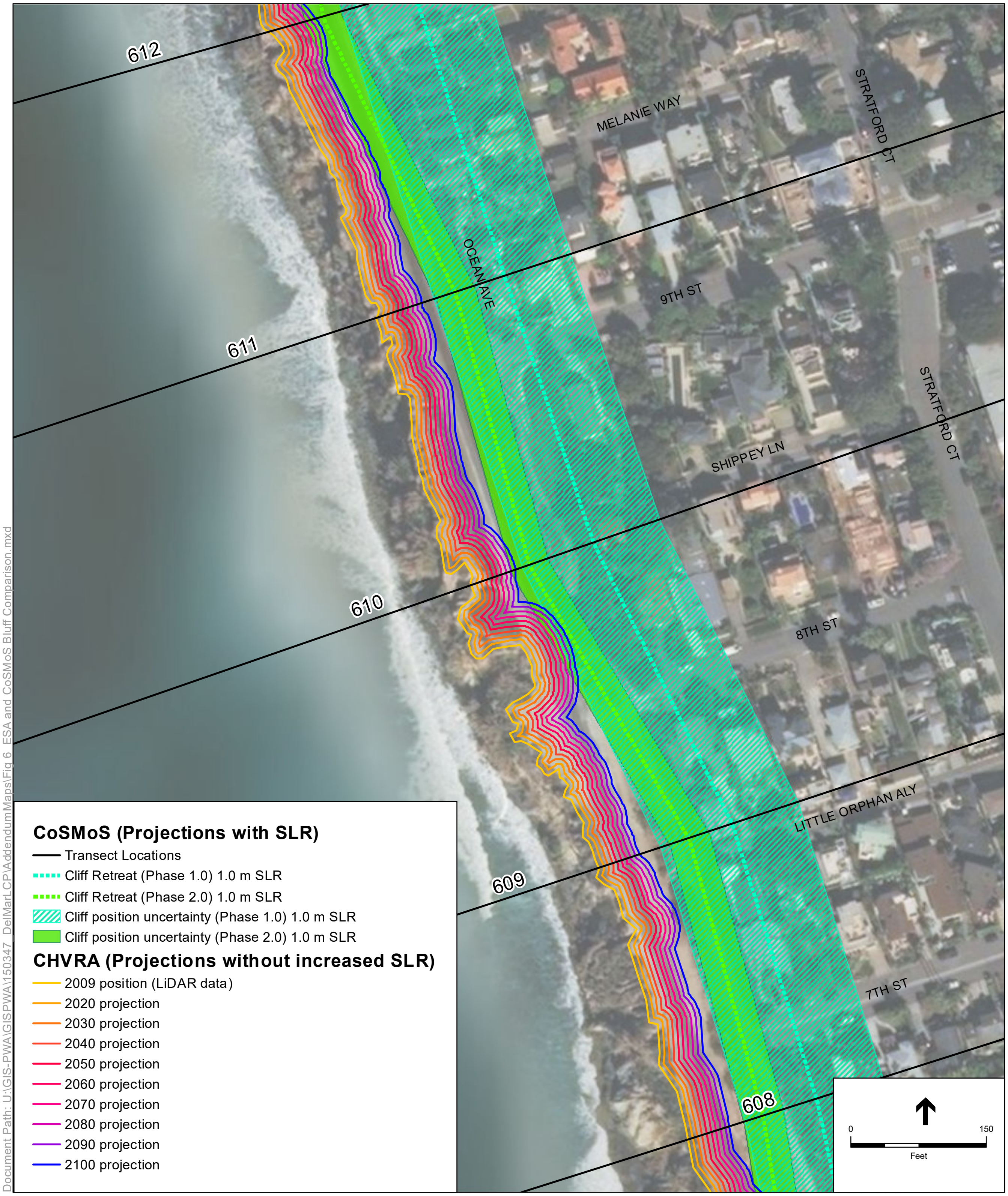
Figure 6- 3

Comparison of Bluff Retreat Projections without Increased SLR from CHVRA and Projections with SLR from CoSMoS Phase 1 and Phase 2



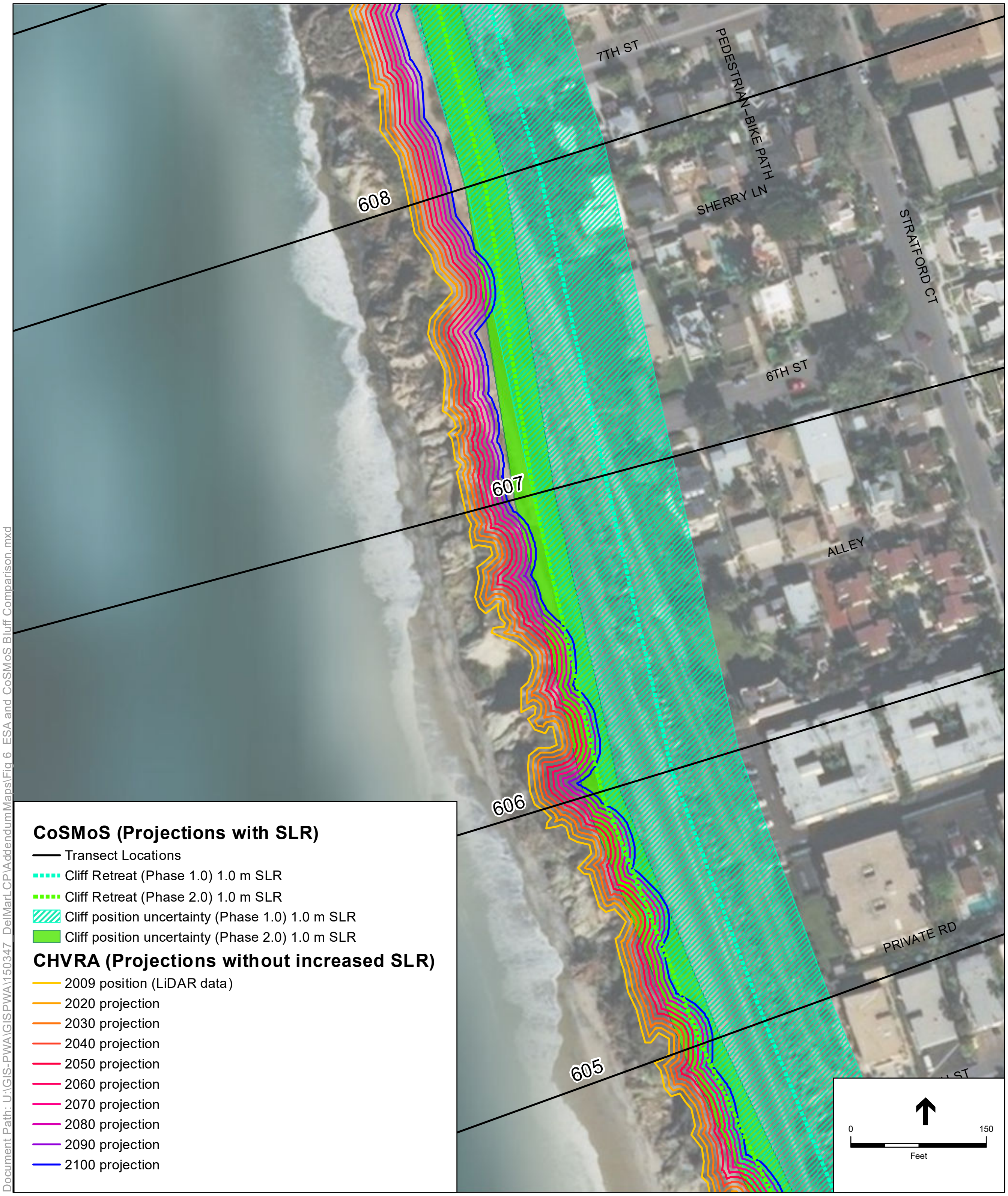
Document Path: U:\GIS-PWA\GISPWA\150347_DelMarLCP\AddendumMaps\Fig 6_ESA and CoSMoS Bluff Comparison.mxd

SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

Figure 6- 4

Comparison of Bluff Retreat Projections without Increased SLR from CHVRA and Projections with SLR from CoSMoS Phase 1 and Phase 2



Document Path: U:\GIS-PWA\GISPWA\150347_DelMarLCP\AddendumMaps\Fig 6_ESA and CoSMoS Bluff Comparison.mxd

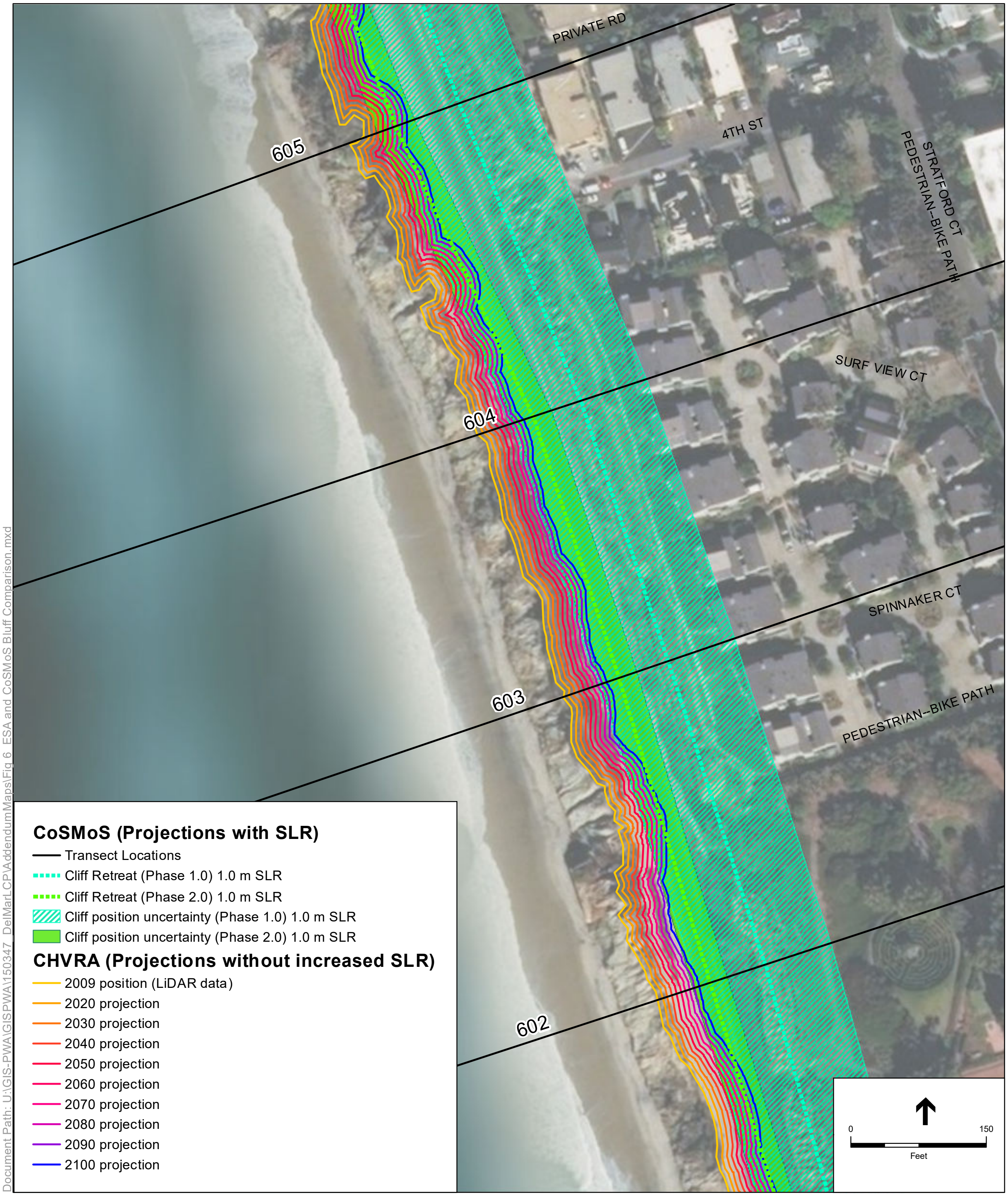
SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

Del Mar Vulnerability Assessment

Figure 6- 5

Comparison of Bluff Retreat Projections without Increased SLR from CHVRA and Projections with SLR from CoSMoS Phase 1 and Phase 2



Document Path: U:\GIS-PWA\GISPWA\150347_DelMarLCP\AddendumMaps\Fig 6_ESA and CoSMoS Bluff Comparison.mxd

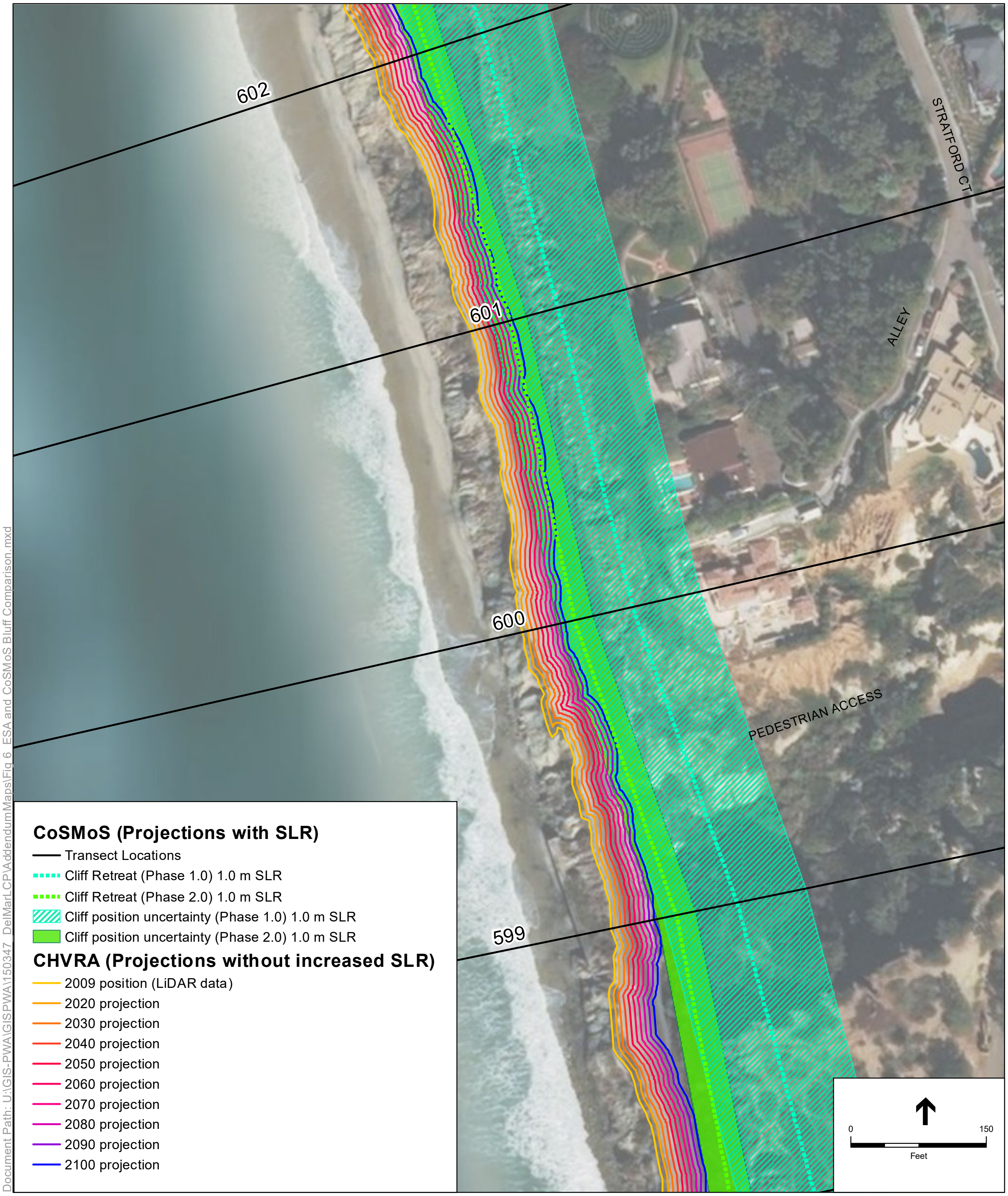
SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

Del Mar Vulnerability Assessment

Figure 6- 6

Comparison of Bluff Retreat Projections without Increased SLR from CHVRA and Projections with SLR from CoSMoS Phase 1 and Phase 2



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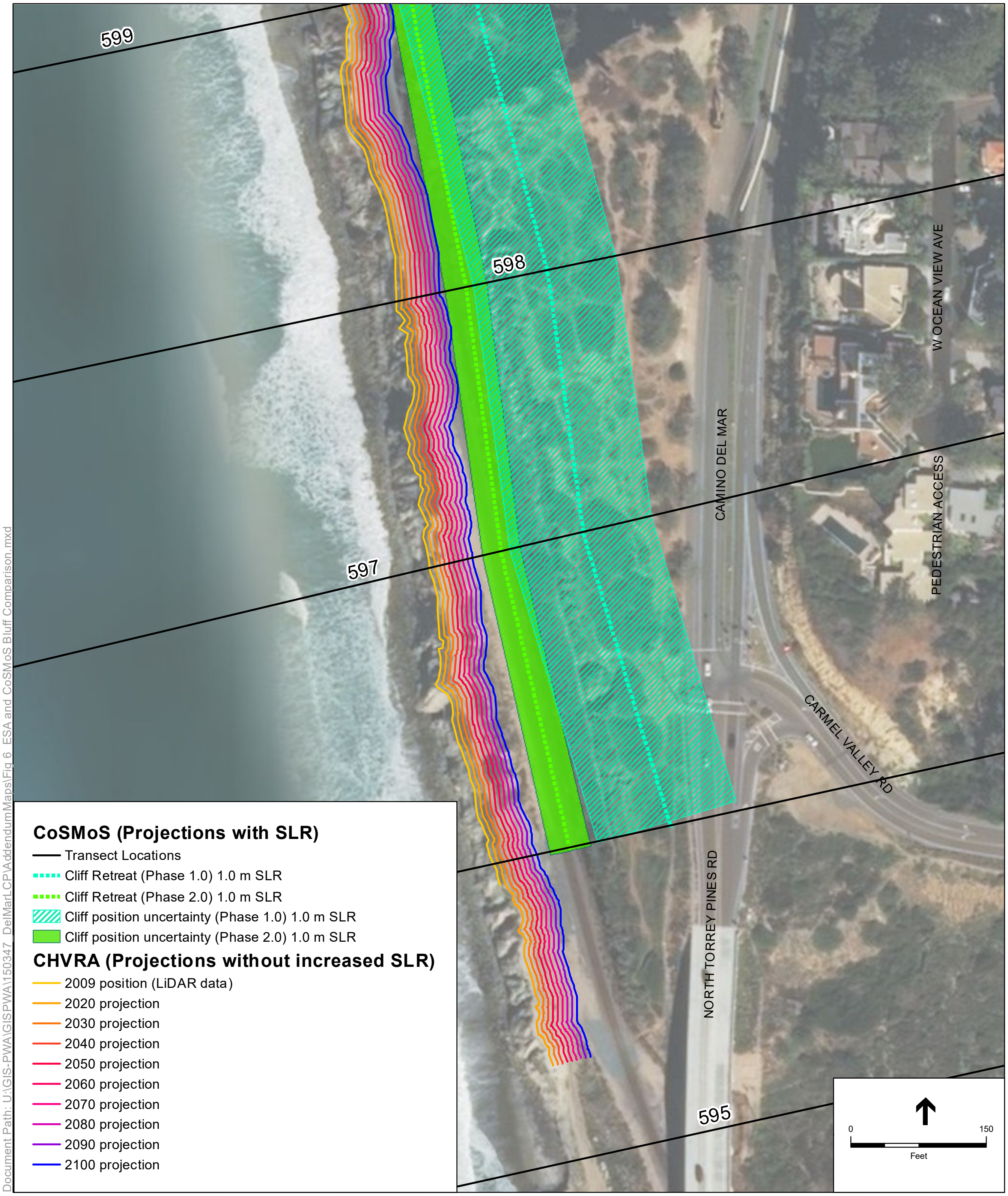
SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

Figure 6- 7

Comparison of Bluff Retreat Projections without Increased SLR from CHVRA and Projections with SLR from CoSMoS Phase 1 and Phase 2



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SOURCE: USGS 2016

Note: Projections are based on the average long term historical cliff top edge retreat rate between 1934 and 2009. Actual future retreat would vary from the average rate and projections. The alongshore variation from the mean historical cliff retreat between 1934 and 2009 is approximately 25 ft (two standard deviations). This provides a measure of how much greater (or less) the retreat could be than the average projected retreat shown.

Figure 6- 8

Comparison of Bluff Retreat Projections without Increased SLR from CHVRA and Projections with SLR from CoSMoS Phase 1 and Phase 2

Document Path: U:\GIS-PWA\GISPWA\150347_DelMarLCP\AddendumMaps\Fig 7 Bluff Overlay Hazard Zones_v2.mxd

Del Mar Vulnerability Assessment

Figure 7- 1

Bluff Erosion Hazard Risk Zones

SOURCE: USGS 2016

Note: ESA does not recommend using the bluff erosion projection in 2100 without increased SLR, which ESA has included for comparison only.

Document Path: U:\GIS-PWA\GISPWA\150347_DelMarLCP\AddendumMaps\Fig 7 Bluff Overlay Hazard Zones_v2.mxd

Del Mar Vulnerability Assessment

Figure 7- 2

Bluff Erosion Hazard Risk Zones

SOURCE: USGS 2016

Note: ESA does not recommend using the bluff erosion projection in 2100 without increased SLR, which ESA has included for comparison only.

Document Path: U:\GIS-PWA\GISPWA\150347_DelMarLCP\AddendumMaps\Fig 7 Bluff Overlay Hazard Zones_v2.mxd

Del Mar Vulnerability Assessment

Figure 7- 3

Bluff Erosion Hazard Risk Zones

SOURCE: USGS 2016

Note: ESA does not recommend using the bluff erosion projection in 2100 without increased SLR, which ESA has included for comparison only.

Document Path: U:\GIS-PWA\GISPWA\150347_DelMarLCP\AddendumMaps\Fig 7 Bluff Overlay Hazard Zones_v2.mxd

SOURCE: USGS 2016

Note: ESA does not recommend using the bluff erosion projection in 2100 without increased SLR, which ESA has included for comparison only.

Del Mar Vulnerability Assessment

Figure 7- 4

Bluff Erosion Hazard Risk Zones

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Del Mar Vulnerability Assessment

Figure 7- 5
Bluff Erosion Hazard Risk Zones

SOURCE: USGS 2016

Note: ESA does not recommend using the bluff erosion projection in 2100 without increased SLR, which ESA has included for comparison only.

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Figure 7- 6

Bluff Erosion Hazard Risk Zones

SOURCE: USGS 2016

Note: ESA does not recommend using the bluff erosion projection in 2100 without increased SLR, which ESA has included for comparison only.

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Figure 7- 7
Bluff Erosion Hazard Risk Zones

SOURCE: USGS 2016

Note: ESA does not recommend using the bluff erosion projection in 2100 without increased SLR, which ESA has included for comparison only.

Document Path: U:\GIS-PWA\GISPWA\150347_DelMarLCP\AddendumMaps\Fig 7 Bluff Overlay Hazard Zones_v2.mxd

Del Mar Vulnerability Assessment

Figure 7- 8

Bluff Erosion Hazard Risk Zones

SOURCE: USGS 2016

Note: ESA does not recommend using the bluff erosion projection in 2100 without increased SLR, which ESA has included for comparison only.

4 COMPARISON OF COASTAL FLOOD HAZARD ASSESSMENT

The following sections summarize the coastal flood hazard assessment methods used in the CHVRA (Section 4.1), CoSMoS (Section 4.2), and FEMA FIS and FIRM (section 4.3). Section 4.4 provides a comparison of the results.

4.1 CHVRA

To determine existing flood extents and depths, ESA calculated Total Water Level (TWL) from 2001 to 2015 and the 1983 and 1998 coastal storm events using measured tide level and wave data (see CHVRA Section 2.6). ESA used a TAW (Technische Adviescommissie voor de Waterkeringen) equation (FEMA 2005) to determine total water levels (the maximum elevation of the water surface) and wave runup (the vertical extent of wave wash) in Del Mar. ESA performed an extreme value analysis of the maximum annual TWL from 2001 to 2015 to estimate the annual chance of occurrence (or return period) of extreme TWLs during coastal storms. To determine future extreme TWLs with SLR, ESA increased measured tide levels by adding the projected amount of SLR, applying beach erosion estimates, re-calculating TWLs for the period from 2001 to 2015, and performing an extreme value analysis on the TWL simulated for this period with SLR. ESA performed this TWL analysis for a mid SLR scenario with 1 ft of SLR in 2050 and 3.1 ft in 2100. ESA then plotted the TWL calculated for the 1983 extreme coastal storm event and a 2015 storm event on the TWL extreme value distributions to estimate the increase in the annual chance of occurrence of these types of coastal storm event with SLR. The results (**Figure 8**) show how coastal flood events are projected to occur more frequently (i.e., have a greater chance of occurring) in the future with SLR as discussed in CHVRA Section 5.1. Note that the future coastal flooding projections account for beach erosion. Sections 2.6.1, 4.3, and 6 in the CHVRA provide more details on the coastal flood hazard mapping and SLR projections.

In addition to the TAW method, ESA performed a more detailed analysis of the inland extent of coastal flood waters for the 1983 storm event using X-beach, a 1-D numerical model. The analysis determined peak wave height, average period, hourly still water level, water elevation, and velocity. ESA used FEMA guidelines to create three existing hazard zones based on wave height (wave heights > 3 ft = VE, wave heights between 3 and 1.5 feet = Coastal VA, and wave heights between 1.5 and 1 feet = VA). ESA also determined an alternative VE hazard zone based on a momentum-force index of 200 ft^3/second. ESA used the 1983 storm event to represent an extreme coastal flooding event. In addition to 1983, ESA also mapped a significant coastal flood event that occurred in 2016. To represent this, ESA mapped the extent of flooding as the zone 10 ft landward of the seawalls.

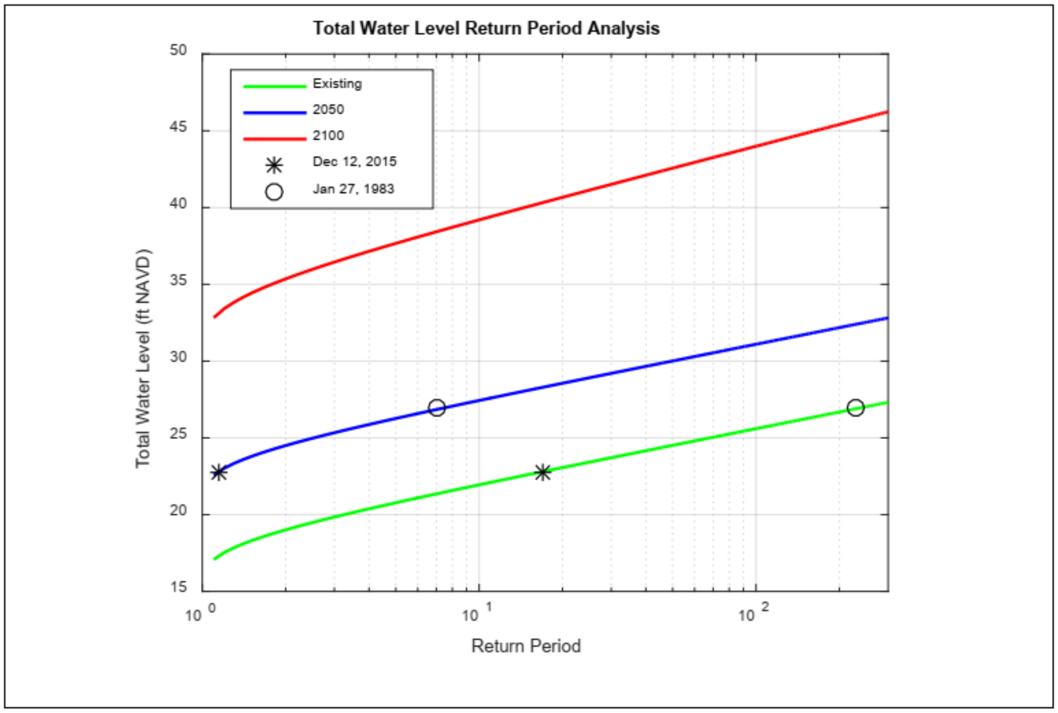
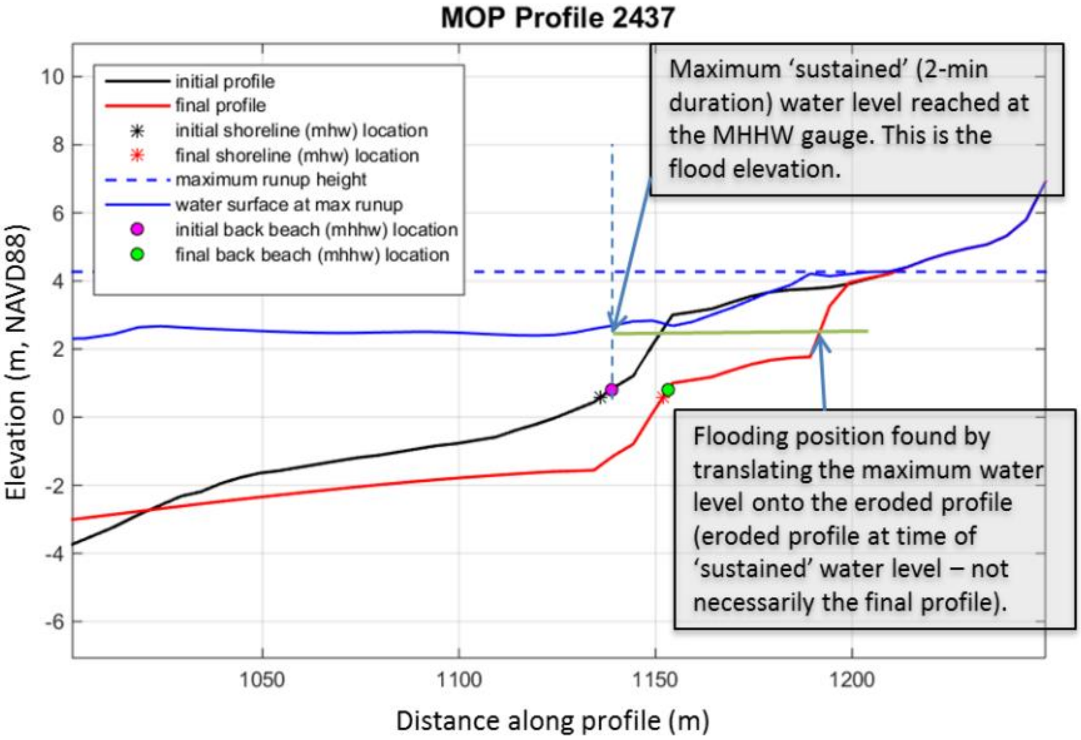


Figure 8. CHVRA Extreme Value Analysis of Total Water Level - Existing and Future Conditions with Sea-Level Rise

4.2 CoSMoS

The CoSMoS coastal flood modeling uses a set of nested models at different scales to determine flooding extents for various storm events under current and future conditions. The model is based on a global climate mode (winds and waves), a Tier 1, large-scale wave growth and propagation model, a Tier II, downscaled, regional wave model, and a Tier III Xbeach cross shore (wave breaking, wave setup, and wave rump) model. CoSMoS determined the flood depth and extent by intersecting the maximum sustained two-minute water level (effectively the still water level plus wave setup) with the eroded shoreline profile for each scenario, as detailed in **Figure 9** below. More detailed information on the CoSMoS flood mapping methodology is available in the CoSMoS 3.0 Phase 2 Southern California Bight Summary document (Erickson et al. 2017) available through the USGS CoSMoS website. CoSMoS results to not provide wave runup or TWL elevations or extents; however, the maximum extent of wave runup on the modeled transects is available as point data. ESA requested this maximum wave runup extent point data from the USGS for Del Mar, which the USGS provided.

CoSMoS modeling and flood mapping include flooding due to the estimated river discharge coincident with the extreme coastal storm. For Del Mar and the San Dieguito River, CoSMoS incudes an estimated 20-year discharge for the San Dieguito River coincident with the 100-year coastal storm event. **Figures 10-12** show the CoSMoS coastal storm flooding inundation extent (still water level and wave setup) and maximum wave runup location points for the 1-year, 20-year, and 100-year storm events.



Maximum 'sustained' (2-min duration) water level reached at the MHHW gauge. This is the flood elevation.

Flooding position found by translating the maximum water level onto the eroded profile (eroded profile at time of 'sustained' water level – not necessarily the final profile).

Figure 9. CoSMoS Flood Extent and Depth Diagram

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SOURCE: FEMA FIRM

Figure 10
CoSMoS 1-year (100% Annual-Chance-of-Occurrence)
Coastal Flooding for Existing Conditions (0 cm SLR), 50 cm (1.6 ft) of SLR,
100 cm (3.3 ft) of SLR, and 175 cm (5.7 ft) of SLR

ESA

SOURCE: FEMA FIRM

Figure 11
CoSMoS 20-year (5% Annual-Chance-of-Occurrence) Coastal Flooding for Existing Conditions (0 cm SLR), 50 cm (1.6 ft) of SLR, 100 cm (3.3 ft) of SLR, and 175 cm (5.7 ft) of SLR

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SOURCE: FEMA FIRM

Figure 12
CoSMoS 100-year (1% Annual-Chance-of-Occurrence)
Coastal Flooding for Existing Conditions (0 cm SLR), 50 cm (1.6 ft) of SLR,
100 cm (3.3 ft) of SLR, and 175 cm (5.7 ft) of SLR

4.3 FEMA

FEMA provided updated coastal flood maps, estimated flood water levels, and flood extents for the 100-year and 500-year flood as part of the FEMA Flood Insurance Study (FIS) and Flood Insurance Rate Maps. FEMA methods consider a range of potential flood mechanisms, including waves and wave runup, storm surge still water elevations, and wave overtopping. FEMA does not consider future projected SLR or coastal erosion. The updated FEMA maps are intended to estimate the current flood hazards for the purposes of the FEMA flood insurance program. The methods used by FEMA for Del Mar are generally described in the FIS (FEMA 2016). A detailed review of the methods and calculations used by FEMA is beyond the scope of this addendum. FEMA methods are similar to the methods used by ESA to estimate extreme TWLs and flood extents. For coastal structures that are not FEMA certified, FEMA methods (as specified in FEMA's 2005 Coastal Flood Analysis and Mapping for the Pacific Coast of the United States (FEMA 2005)) call for analyzing wave runup and flooding for scenario in which the non-certified coastal structure fails due to storm damage. ESA's understanding of the updated FEMA flood maps is that the analysis and mapping do not consider a failed structure scenario. **Figure 13** shows the FEMA flood zones for the 1% (100-year) and 0.2% (500-year) floods.

4.4 Comparison

4.4.1 CHVRA and CoSMoS Comparison

Table 2 compares the extreme coastal flood events used for the CHVRA (1983 storm event) and the CoSMoS 100-year event. The water levels, storm surge, wave height and period, and annual chance of occurrence of the extreme events used for the CHRVRA and CoSMoS are similar.

Figures 14 and **15** below show the ESA flood and wave hazards overlaid on the CoSMoS flood outputs. Figure 14 shows the CoSMoS 100-year flood event compared to ESA's extreme coastal flooding storm extent based on the 1983 flood. For current conditions (CoSMoS flood extent for 0 cm SLR shown in blue in Figure 14), CoSMoS shows flooding of the area bounded by Camino Del Mar, 23rd Street, Grand Avenue, and Ocean Front in North Beach. CoSMoS does not map the rest of North Beach as flooded by the 100-year event under current conditions, apparently because the "sustained" water level (i.e., still water level and wave setup) does not inundate this area; however, CoSMoS maximum wave runup point data (blue dots in Figure 14) show that modeled wave runup extends beyond the railroad during the 100-year event. In comparison, ESA's mapping of the coastal flood inundation hazard (hatched white area in Figure 14) is not as far landward as the CoSMoS inundation area in the southern portion of North Beach. ESA applied the coastal flood inundation hazard to the northern portion of North Beach, which extends east of Camino Del Mar to about Sandy Lane. CoSMoS does not show this area as inundated by the 100-year coastal storm event (based on the 2-minute average runup); however, CoSMoS does show that the maximum wave runup reaches farther inland than the CHVRA flood inundation hazard zone. Also, note that much of North Beach is at risk of 100-year San Dieguito River flooding per FEMA mapping, which is not included in CoSMoS, but is included in the CHVRA. The CHVRA maps a coastal wave hazard zone (i.e., zone with wave heights greater than 3 ft shown as white hatched area with a different direction cross-hatching seaward of the inundation hazard zone). CoSMoS does not provide mapping of the wave hazard zone.

Figure 15 shows the CoSMoS 20-year (5% chance) coastal flood inundation and extent with the CHVRA significant coastal flooding hazard, derived from the 2016 storm event and estimated to have a 5% to 10% annual chance of occurrence. Similar to the more extreme coastal flood comparison discussed above, the CHVRA coastal flood zone is slightly landward of the CoSMoS 20-year coastal flood inundation zone; however, CoSMoS shows maximum wave runup beyond the CHVRA significant coastal flood hazard zone.

The CoSMoS results show how the extent of the 100-year coastal flood event will increase with SLR. Since North Beach is already subject to both coastal and river flooding, the CHVRA focuses on assessing how the frequency of flooding will increase with SLR. In summary, CoSMoS and the CHVRA use different approaches and methods; however, the coastal flood hazards shown by CoSMoS and the CHVRA are generally similar in that they both show that there is a risk of extreme coastal flooding in North Beach under current conditions, which is projected to increase with SLR. The CHVRA provides additional information and mapping of the wave hazard zone, which is pertinent for adaptation planning and policy development.

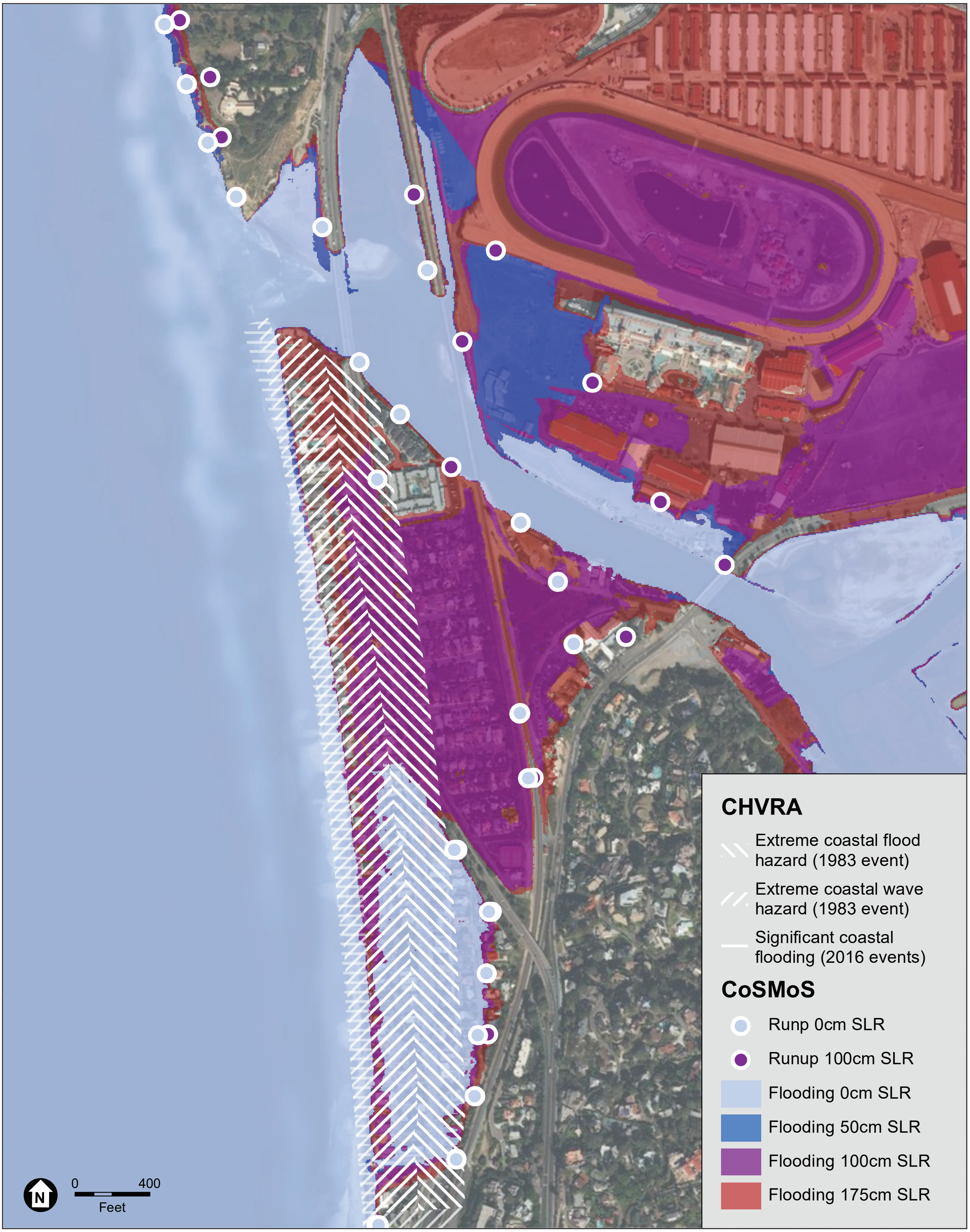
TABLE 2
COASTAL FLOOD EVENT COMPARISON – CHVRA AND COSMOS

	Del Mar CHVRA: 1983 storm	CoSMoS: 2 representative 1% (100-year) storms
SWL (ft NAVD)	6.9	~7.1-7.3
Storm surge (ft)	0.4	0.6 - 0.8
Predicted tide (ft NAVD)	6.6	~ 6.5
Wave height (ft)	24	20 – 22
Tp (s)	18	16 – 18
Annual chance of occurrence	Less than 1%	1%

Source: CHVRA, USGS CoSMoS (2017)

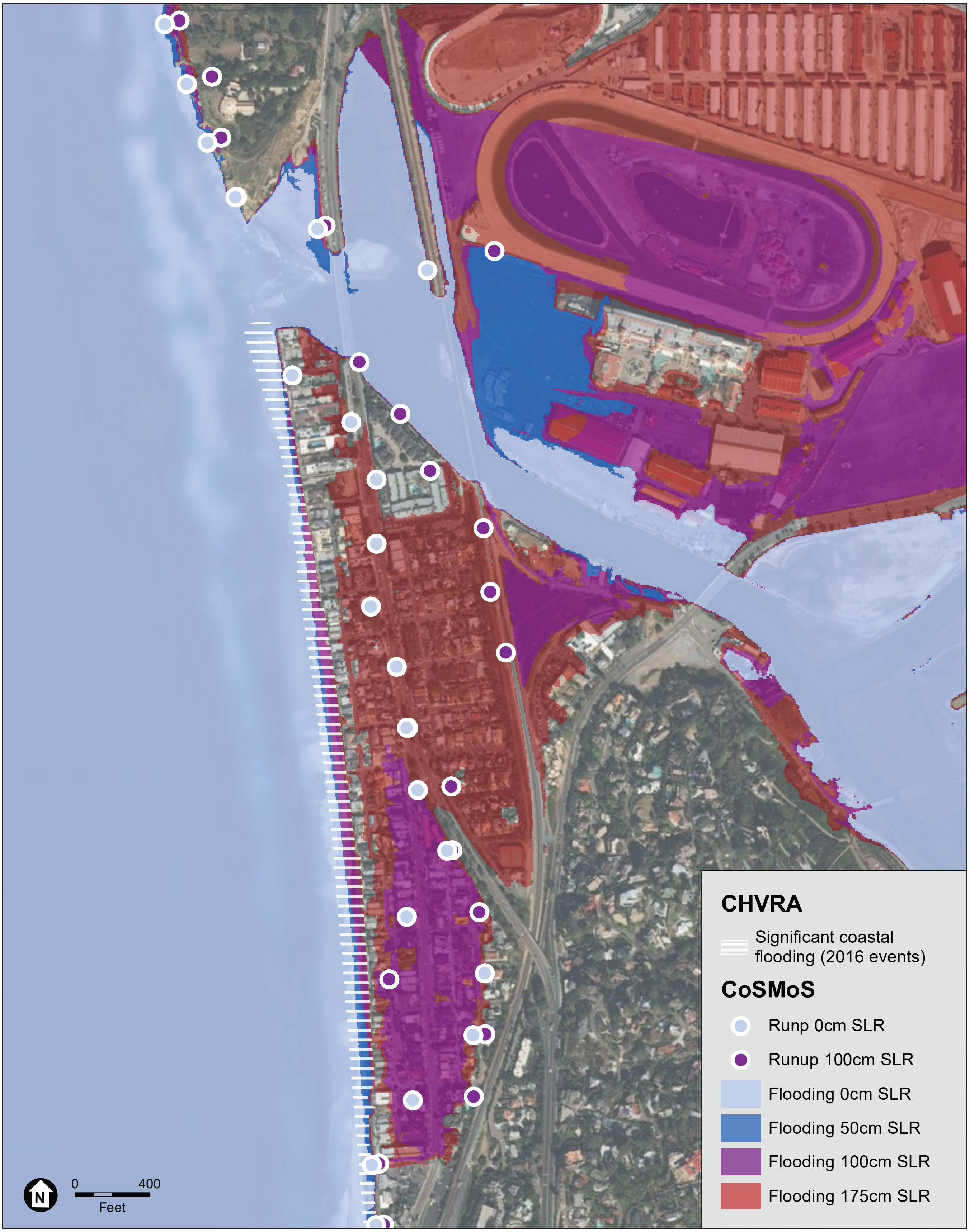
SOURCE: FEMA FIRM

Figure 13
FEMA Coastal Flooding Map



SOURCE: CHVRA 2016, USGS 2017

Figure 14
Comparison of Extreme Coastal Flood Hazard Map for CHVRA (1983 Storm Event) and CoSMoS (100-Year Storm Event)



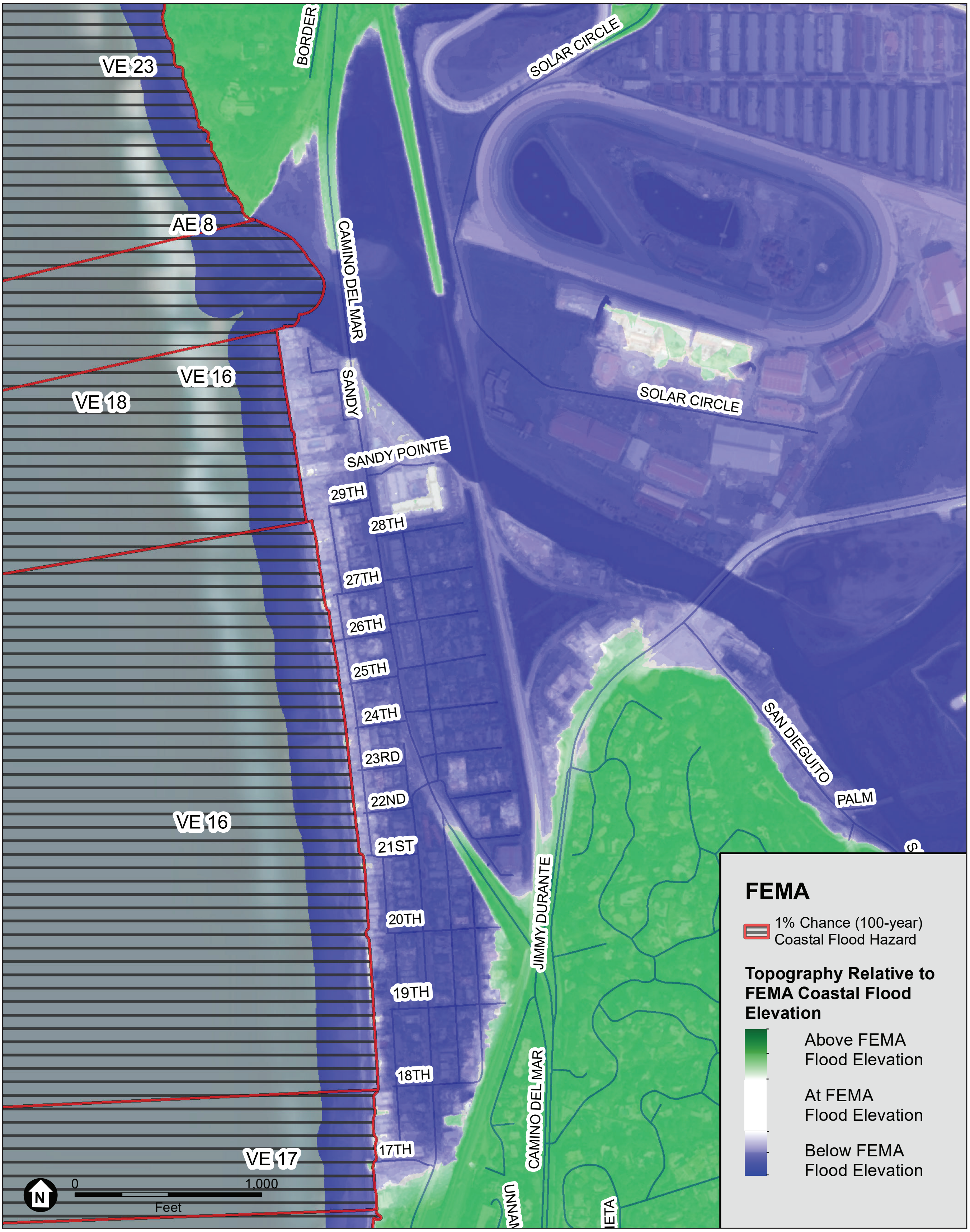
SOURCE: CHVRA 2016, USGS 2017

Figure 15
ESA CHVRA and CoSMoS 5% Chance (20-Year) Coastal Flooding

4.4.2 CHVRA and FEMA Comparison

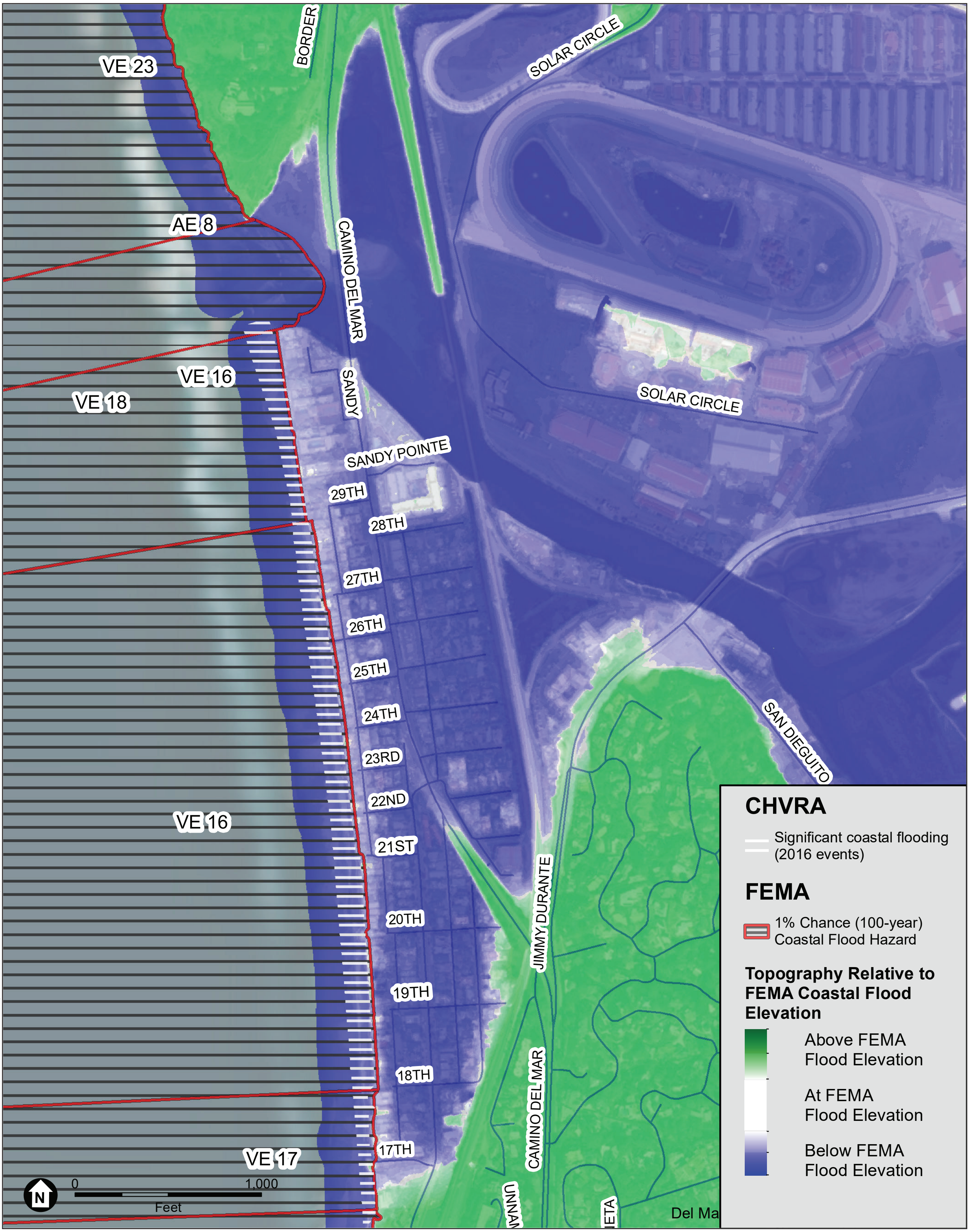
Figures 16-18 compare the CHVRA hazard mapping and FEMA flood hazard mapping. Figure 16 overlays the FEMA coastal flood zone on the existing topography. Areas below the FEMA coastal flood elevations are shown in blue, areas above the flood elevation are shown in green, and areas that are at or near the flood elevations are shown in white. As seen in Figure 16, the FEMA 1% chance (100-year) coastal flood hazard zone (black hatching), stops within a short distance landward of the existing sea walls in North Beach at a narrow strip of high ground that is at or near the flood elevations. The areas landward of the flood zone and this strip of high ground is below the coastal flood elevation.

Figures 17 compares the 100-year coastal flood zone identified by FEMA with the significant (2016) storm flood extents used in the CHVRA (shown with white hatching). Both the FEMA 1% chance coastal flood zone and the significant coastal flood zone from the CHVRA, which is estimated to have a 5% to 10% annual-chance-of-occurrence, are limited in extent by the existing sea walls and, therefore, coincide. Figure 18 shows the FEMA 100-year coastal flood zone with the CHVRA extreme coastal flood zone (white hatching), as well as the CoSMoS 100-year maximum wave runup point data for current conditions (pink dots). The CHRVA’s extreme coastal flood zone was defined by the 1983 storm event, which is estimated to have a 0.5% annual-chance-of-occurrence (i.e., 200-year event), is mapped beyond the existing sea walls and the FEMA coastal flood zone. CoSMoS results also show wave runup well beyond the existing sea walls for CoSMoS’ 100-year event. In summary, the FEMA coastal flood hazard zone represents a coastal flood condition that is limited to and does not extend landward of the existing sea walls, whereas the CHVRA uses a coastal flood hazard zone that represents conditions that occurred during the 1983 coastal storm event, in which coastal structures failed and flooding extended beyond the structures.



SOURCE: CHVRA 2016, USGS 2017, FEMA 2017

Figure 16
FEMA 1% Chance Coastal Flood Hazard Zone and
Topography Relative to FEMA Coastal Flood Elevation



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SOURCE: CHVRA 2016, USGS 2017, FEMA 2017

Figure 17
Comparison of FEMA 1% Chance Coastal Flood Hazard Zone and
Del Mar CHVRA Significant Coastal Flood Hazard Zone
(Defined by a 5% to 10% Chance Storm Event That Occurred in 2016)

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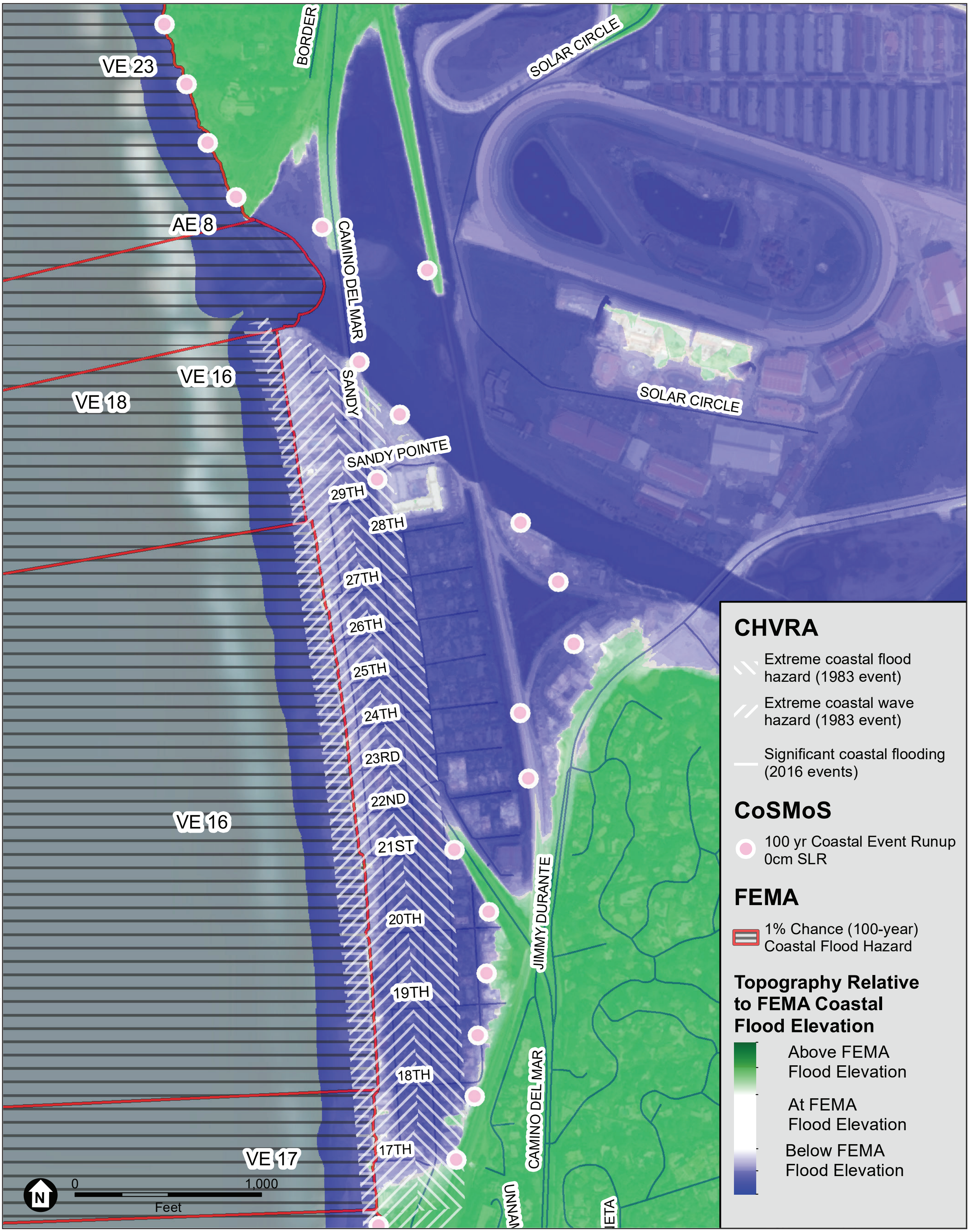

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SOURCE: CHVRA 2016, USGS 2017, FEMA 2017

Figure 18
Comparison of FEMA 1% Chance Coastal Flood Hazard Zone, Del Mar CHVRA Extreme Coastal Flood Hazard Zone, and CoSMoS Current Conditions Maximum Wave Runup for 100-year Coastal Storm Event

5 CONCLUSIONS

ESA analyzed and assessed coastal hazards, vulnerabilities, and risks for the CHVRA including beach and bluff erosion and coastal and San Dieguito River flooding for the purpose of informing adaptation planning and coastal policy for the City of Del Mar. The updated final CoSMoS results for beach erosion and coastal flooding, which were released after completion of the CHVRA, are generally consistent with the CHVRA's results. The updated FEMA flood maps, also released after completion of the CHRVA, do not consider SLR and show a coastal flood risk that is limited to the existing sea walls for the purposes of the FEMA flood insurance program. In contrast, both the CHVRA and CoSMoS show coastal wave hazards landward of the existing sea walls for current and future conditions with SLR. The comparisons performed for this addendum and general agreement between the results of the CHVRA and CoSMoS support that the CHVRA coastal flood zones are appropriate for the purposes of adaptation planning and coastal policy development.

ESA recommends that the CHVRA results and hazard mapping be used for the purposes of City adaptation planning and policy. The CHVRA includes information and mapping of coastal wave hazard zones based on flooding and storm damage that occurred in Del Mar during the 1983 storm event, whereas CoSMoS does not provide wave hazard zone mapping and FEMA maps do not reflect this risk or address future SLR. The CHVRA coastal flooding and wave hazard mapping are therefore the best available and most appropriate mapping for the purposes of adaptation planning and policy. Note that while the CHVRA, CoSMoS, and FEMA use different methods to assess coastal flooding, all consider the existing seawalls and revetments and all show that beachfront properties are currently vulnerable to coastal flooding.

For beach erosion hazards, the CHVRA is generally consistent with CoSMoS. Note that CoSMoS beach erosion or shoreline projections should not be used independently of the CHVRA results because CoSMoS results for certain intermediate years (e.g., 2033, 2066, and 2075) under-predict the potential erosion as discussed in Section 2.3 above. Results from CoSMoS or other analyses of beach erosion or flooding should not be applied in place of CHVRA results without a comparison to CHVRA results and an independent third-party review by a qualified coastal engineer and/or geologist, such as ESA.

As discussed in Section 3.3 ESA does not recommend updating the CHVRA's projection of future bluff erosion with SLR (which is based on CoSMoS Phase 1 results) with the CoSMoS Phase 2 results because ESA's comparison of the different models indicates that the CoSMoS Phase 2 results may under-predict future erosion with SLR. ESA recommends that ESA and Dr. Adam Young perform an independent, site-specific analysis with modeling of projected future bluff erosion with SLR for the Del Mar bluffs. Note that modeling independent from CoSMoS was not included in the City's work program for the CHVRA because the work program was based on using CoSMoS. ESA does not recommend using CoSMoS Phase 2 results to update bluff erosion overlay zones for the Local Coastal Program (LCP) Amendment or other planning purposes at this time. An independent bluff erosion analysis as recommended above would provide additional information for the basis of refining the LCP and planning. If an independent analysis is not performed, an alternative approach to refining the bluff erosion hazard overlay zone would be to sub-divide the bluff erosion hazard overlay zone into subareas with different levels of risk. If the City chooses to take this approach, ESA recommends using the CHVRA (i.e., CoSMoS 3.0 Phase 1) and the outer/landward uncertainty of the CoSMoS 3.0 Phase 2 model projections for the high sea-level rise scenario in 2100 (items 1 and 2 above). ESA does not recommend using the bluff erosion projection without increased SLR in 2100, which ESA has included for comparison only.

Note that the bluff erosion projections from the CHVRA and CoSMoS do not consider existing bluff armoring or stabilization measures because the existing armoring and stabilization may not limit or prevent bluff erosion over the long-term. Also note that the bluff erosion hazard and vulnerability assessments from the CHVRA and CoSMoS assume that the bluffs would erode past the railroad; this approach provides the baseline “no action” scenario for the purposes of adaptation planning and policy development.

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