

Final Draft

COASTAL HAZARDS, VULNERABILITY, AND RISK ASSESSMENT

Del Mar, CA

Prepared for
The City of Del Mar

April 2016 - Updated July 2016



July 13, 2016 bluff collapse at 10th Street

Final Draft

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550 W C Street
Suite 750
San Diego, CA 92103
619.719.4200
www.esassoc.com

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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





Source: Fletcher, 1983

Del Mar Vulnerability Assessment. D150347.00

Figure ES-2
Coastal Damage following 1983 Storm



Source: Fletcher, 1983

Del Mar Vulnerability Assessment. D150347.00

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 2070, 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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

Del Mar Vulnerability Assessment. D150347.00

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**

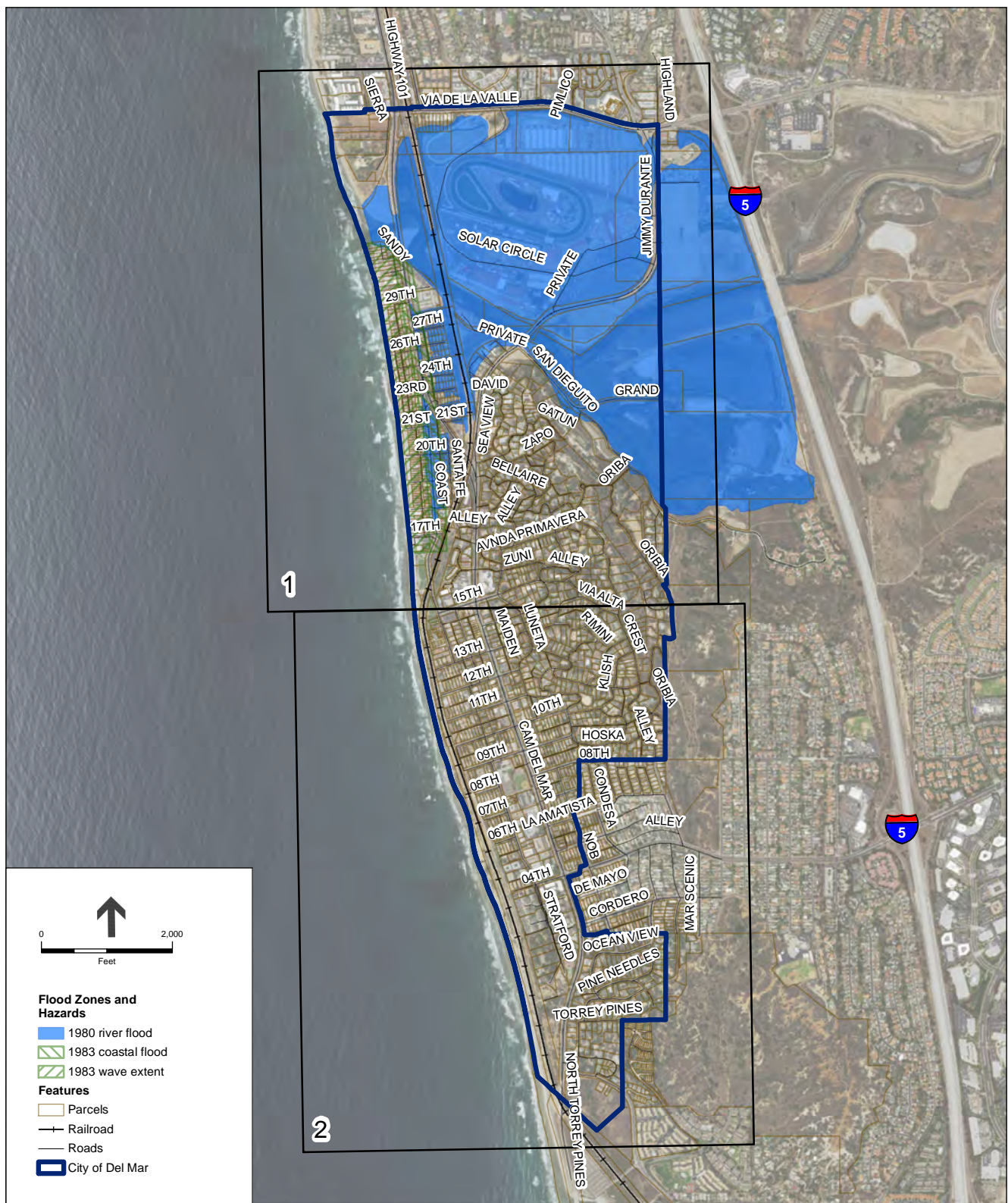
Vulnerability	Coastal Resources and Assets	High Vulnerability Timeframe
Beach erosion and loss	<ul style="list-style-type: none"> Beach access 	2030 to 2070
North Beach District coastal flooding and damage	<ul style="list-style-type: none"> Beach front and adjacent properties including the City's 17th St Beach Safety Center, roads, and amenities 	2050
Del Mar Fairgrounds, Valley District, and North Beach District San Dieguito River flooding and damage	<ul style="list-style-type: none"> Fire Station 	2030
	<ul style="list-style-type: none"> Sewer lift station on San Dieguito Drive 	2050
	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none">• Railroad	2030 or earlier
	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• Vegetated wetland habitat	2070



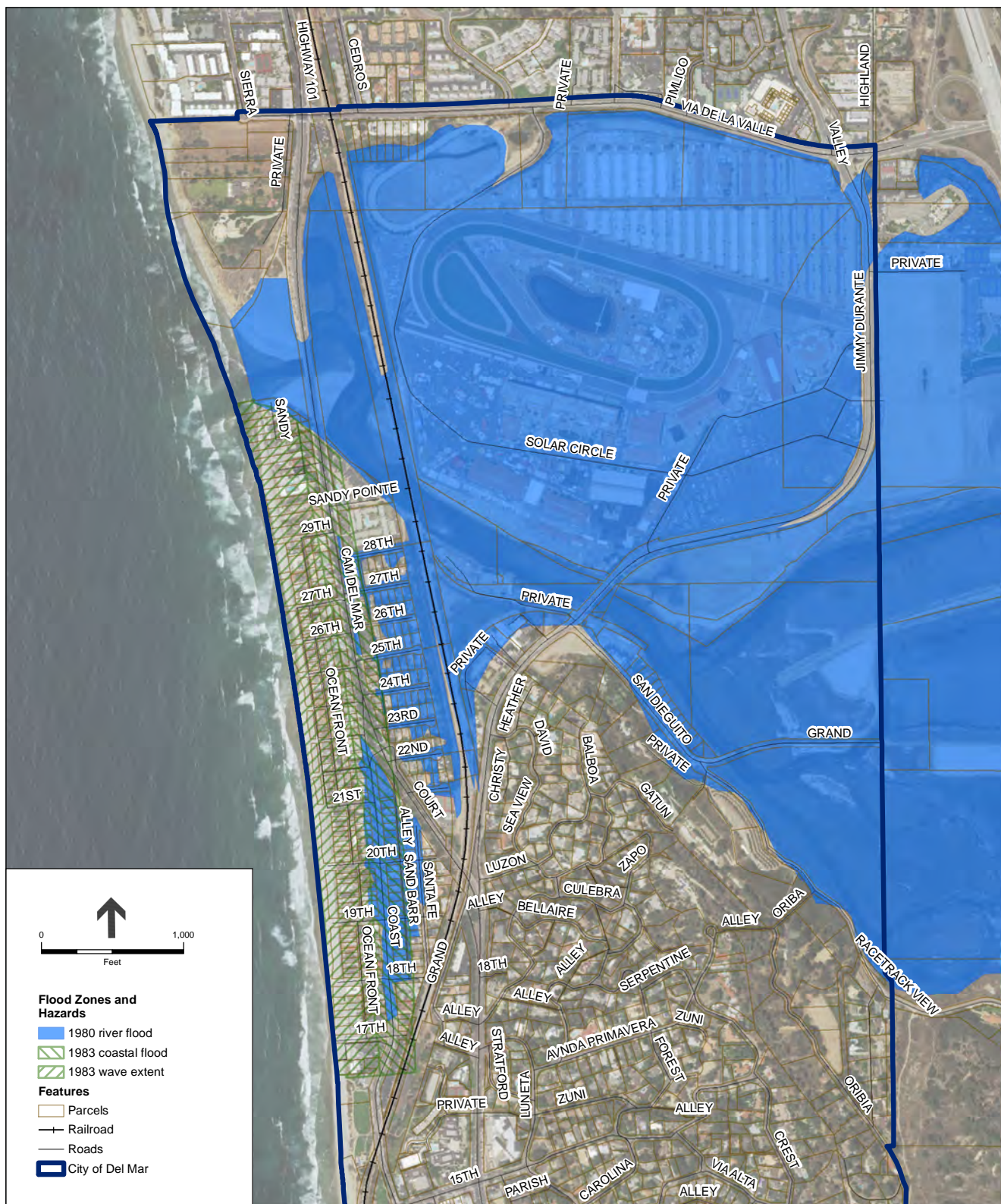
Figure ES-5

Schematic of Coastal Flooding Terms
Photo from March 8th, 2016 – Del Mar



SOURCE: SanGIS 2016, FEMA

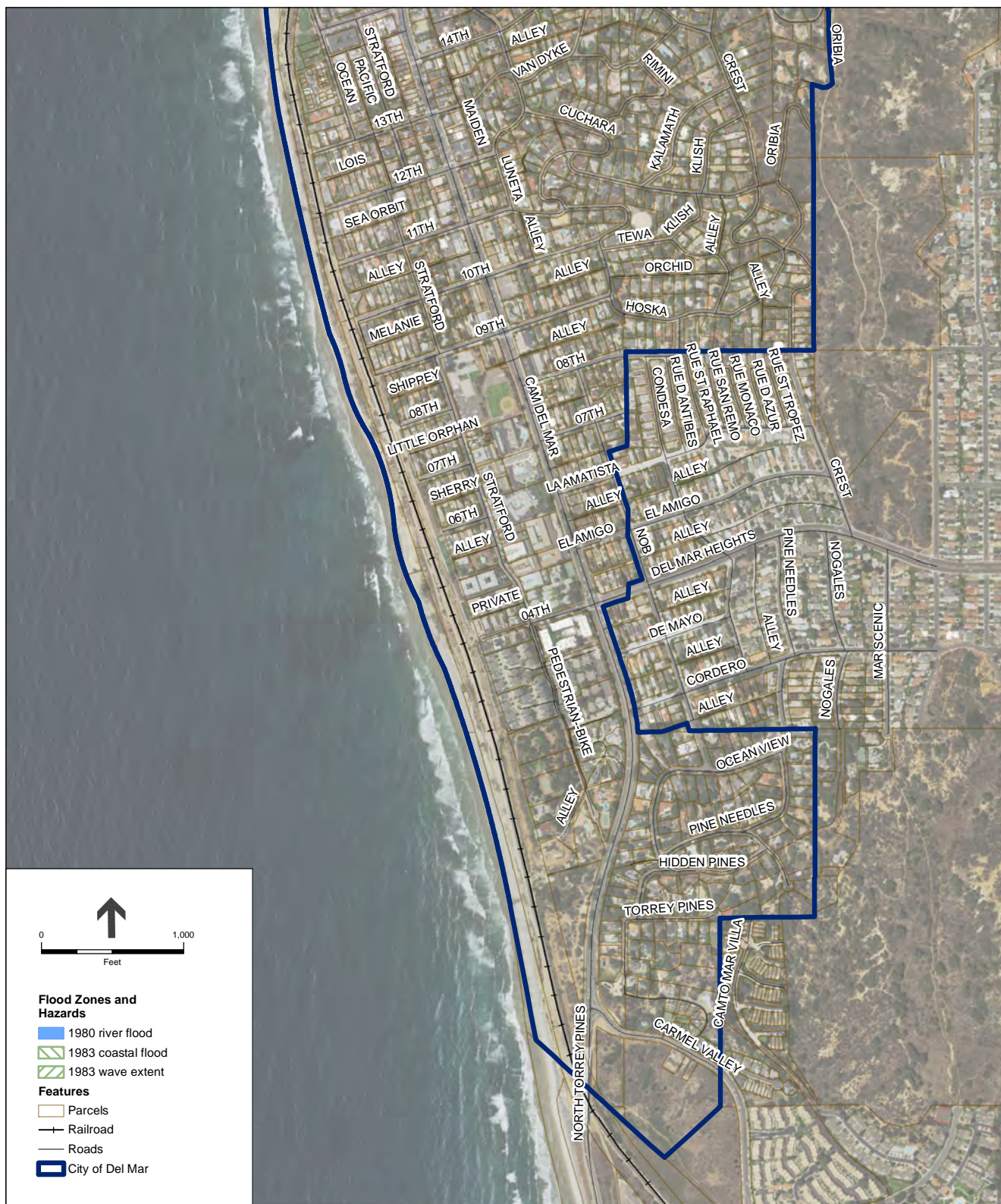
Del Mar Vulnerability Assessment . D150347
Figure ES-6- Map Grid Overview
 1980 and 1983 Events
 Property and Road Vulnerability



SOURCE: SanGIS 2016, FEMA

Del Mar Vulnerability Assessment . D150347

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



SOURCE: SanGIS 2016, FEMA

Del Mar Vulnerability Assessment . D150347

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

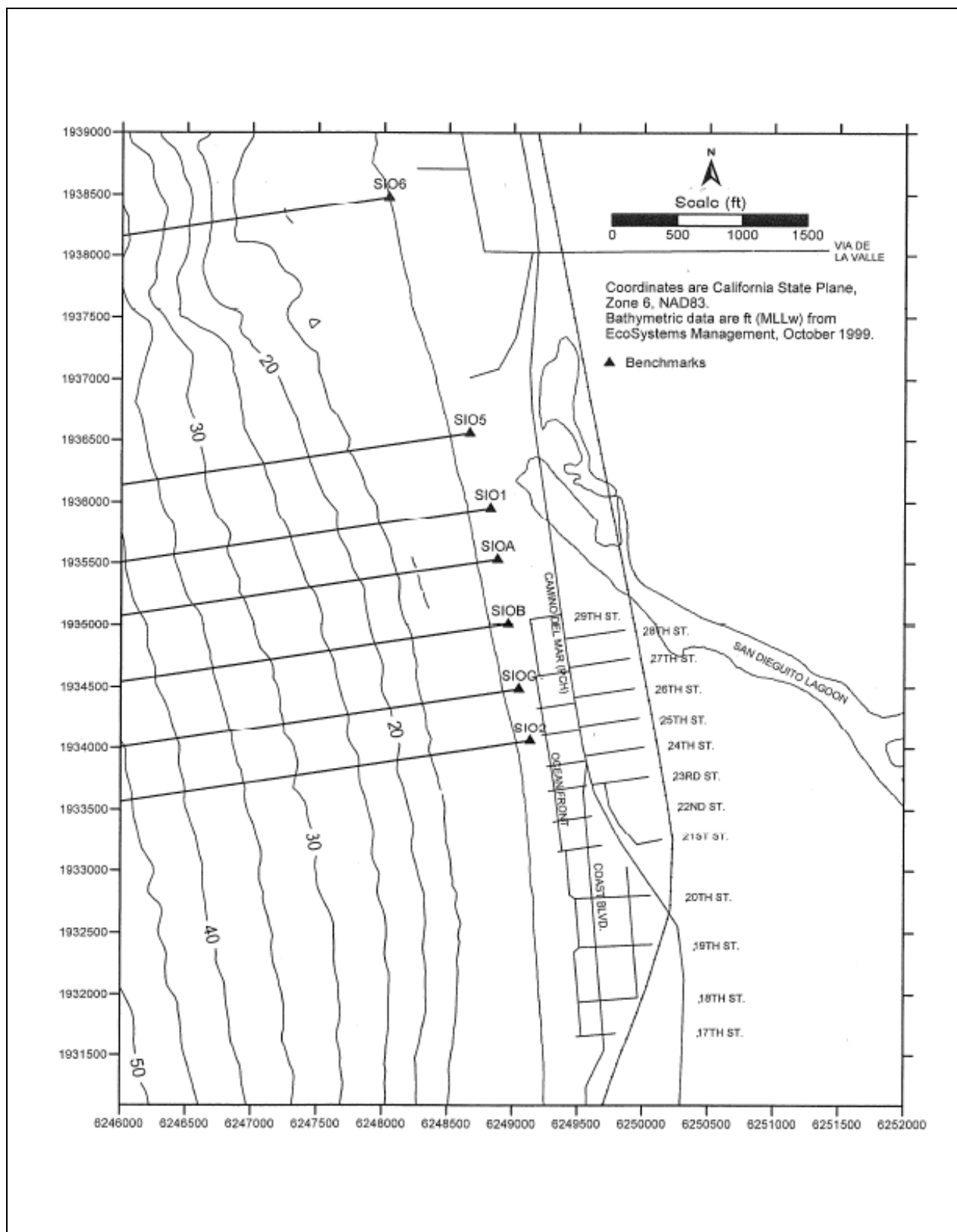
	2030	2050	2070	2100
Mid SLR	5 in	12 in	20 in (1.7 ft)	37 in (3.1 ft)
High SLR	12 in	24 in	38 in (3.2 ft)	66 in (5.5 ft)

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





Source: Coastal Environments

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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

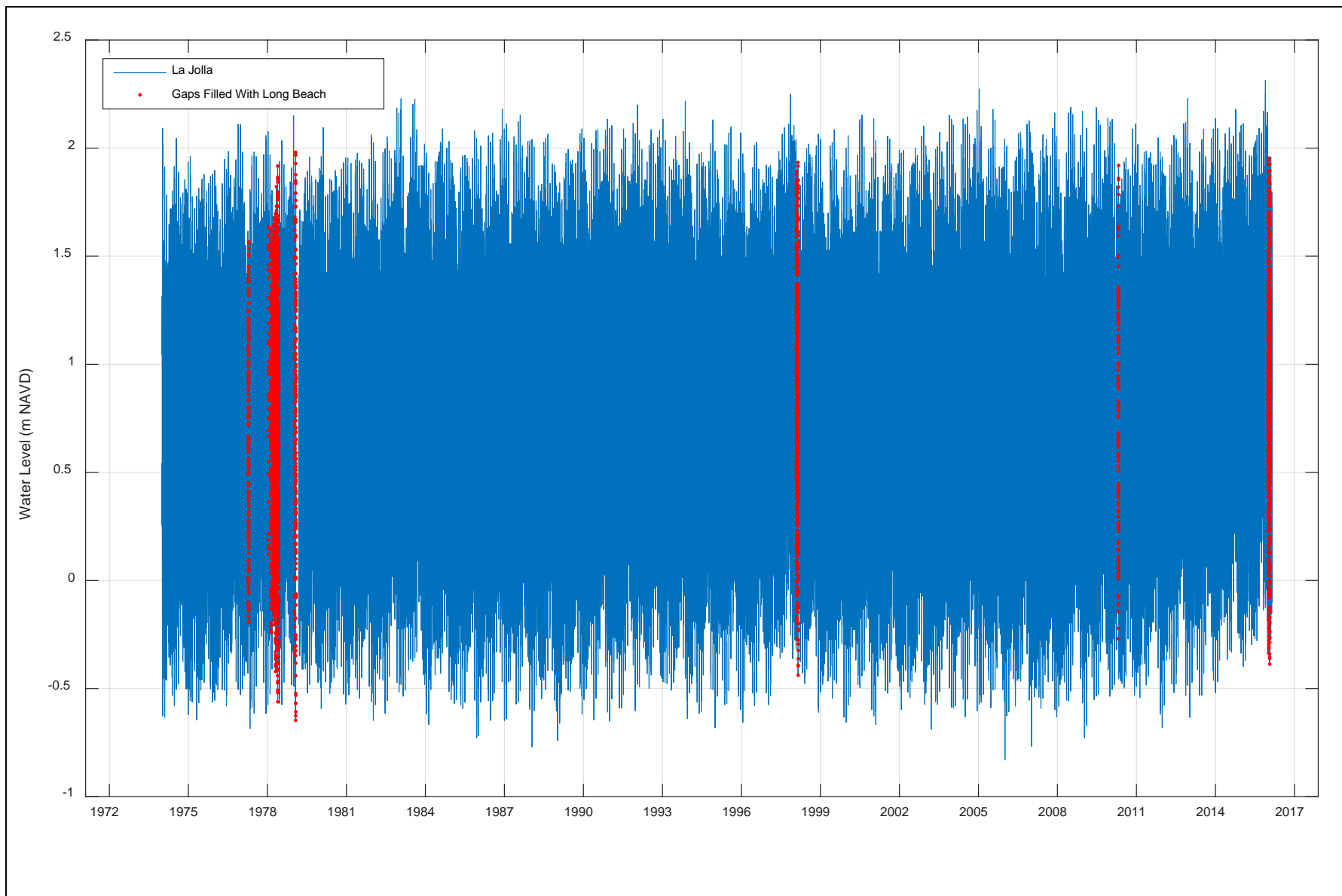
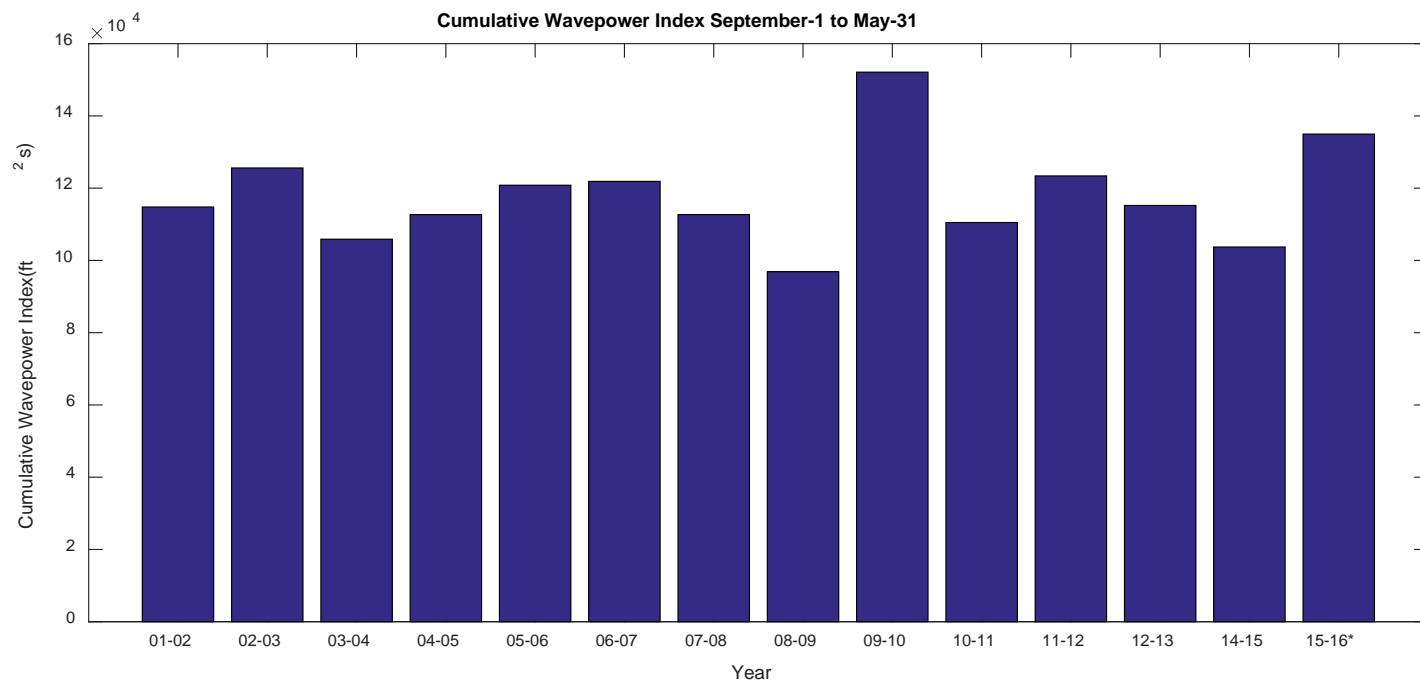


Figure 3
Still Water Level Record from La Jolla Gaps filled with Los Angeles
Outer Harbor Data



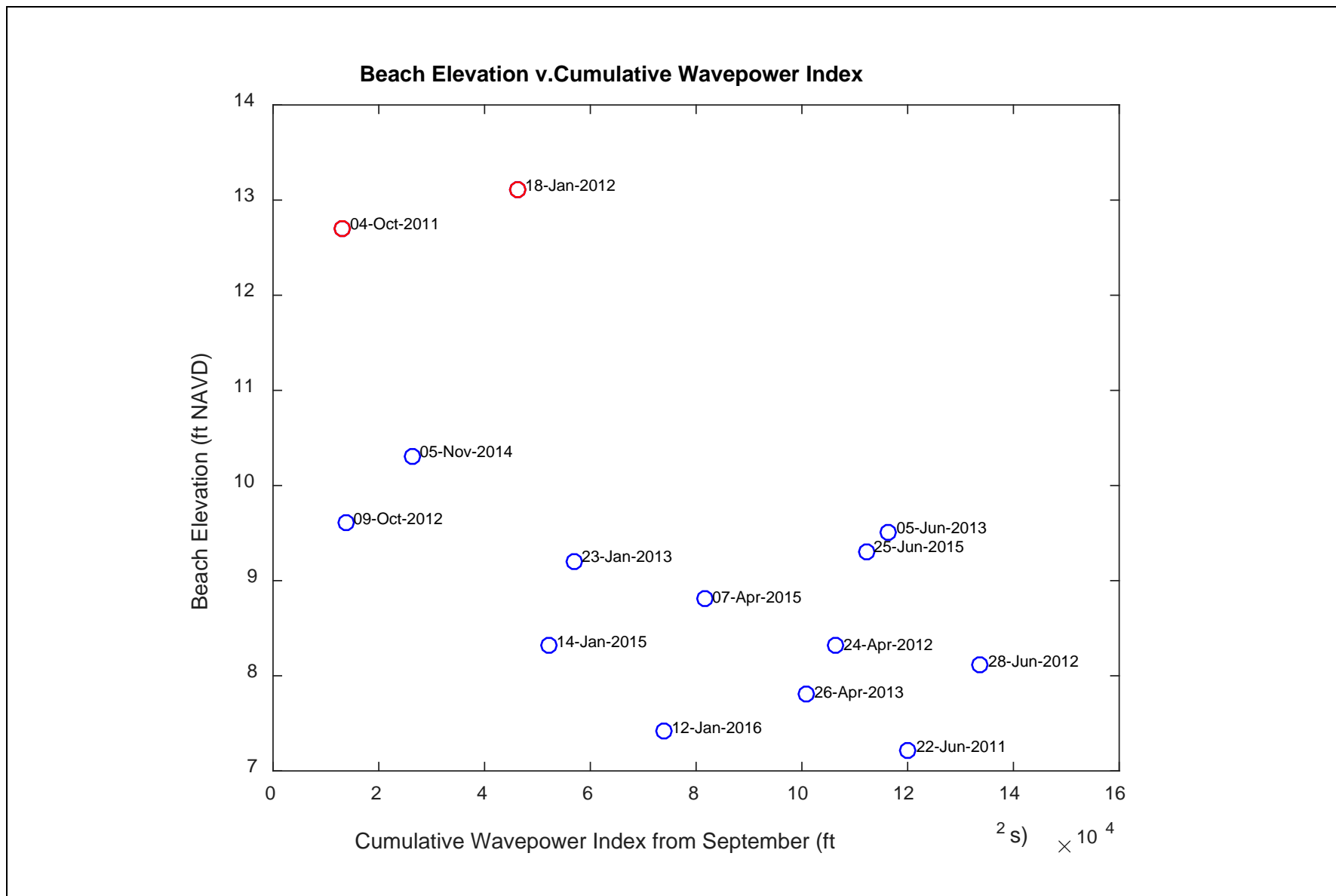


Figure 5
Beach Elevation vs. Cumulative Wavepower Index

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).

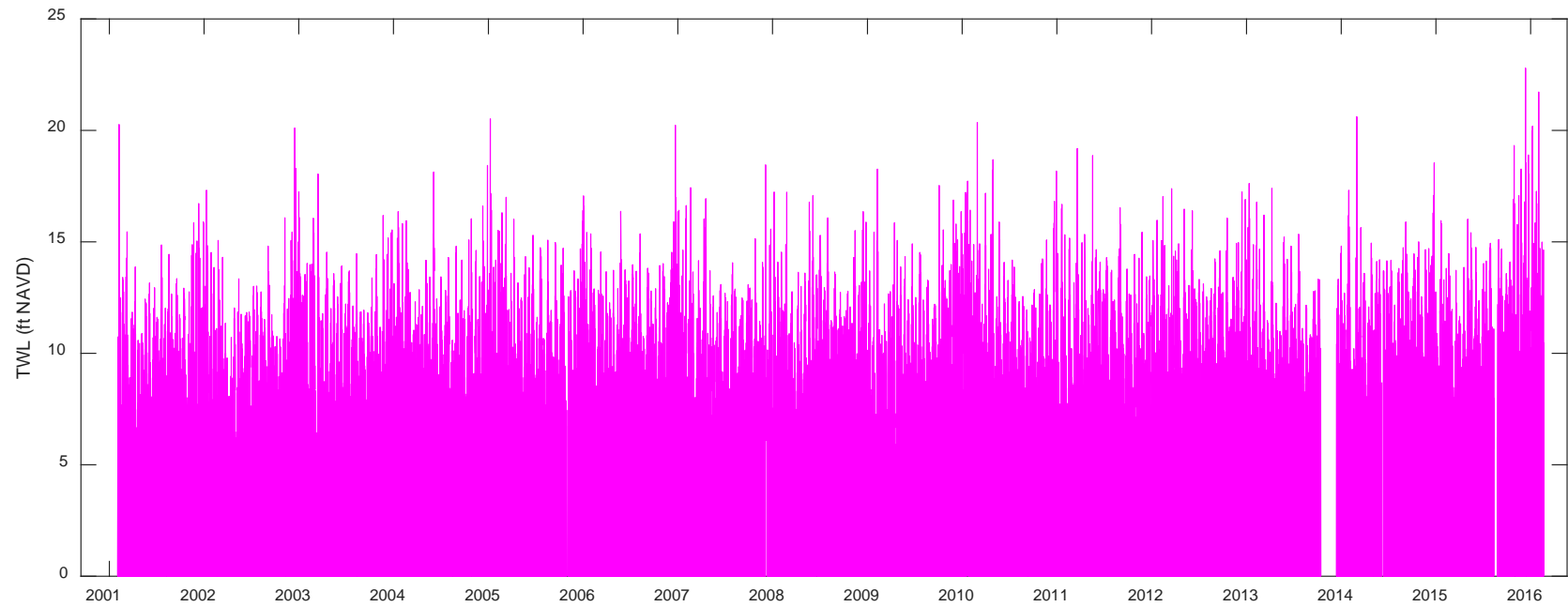
Note that flows in the San Dieguito River are controlled by two water supply storage reservoirs, with the larger downstream Lake Hodges Reservoir capturing discharge from the majority of the watershed; however, the reservoirs are not operated for flood control and have historically filled and overtopped,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



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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 SOIB.

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). The inland extent of these zones

Following the guidelines described in FEMA, 2005, and alternate VE hazard zone was calculated based on a momentum-force index of 200 feet³/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 risk zones associated with the 1983 event in Del Mar are referenced and mapped in Section 5.

A discussion of TWL calculation with SLR and beach erosion is presented in Section 4.

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 timeseries 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

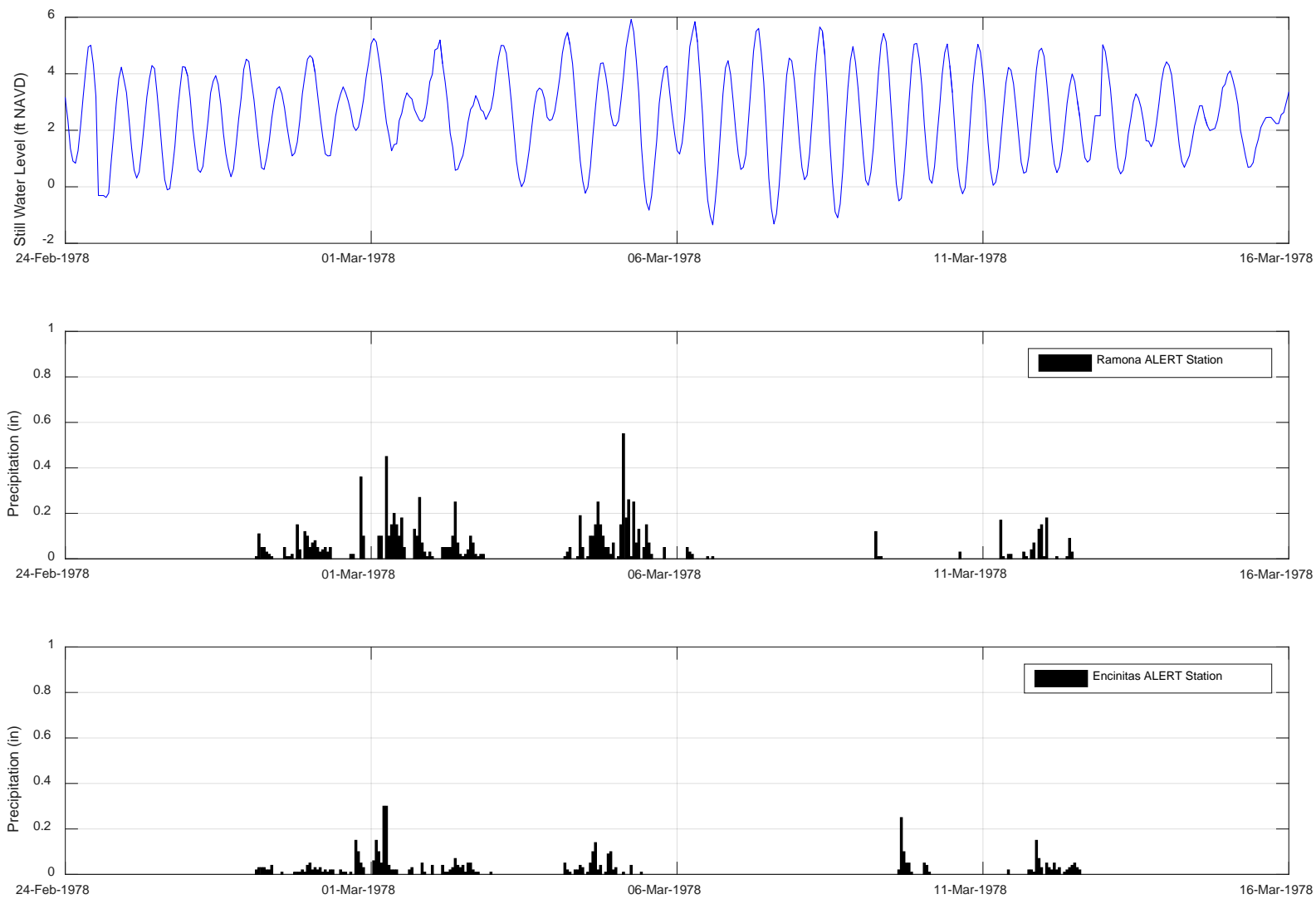
A series of intense storms during the 1982-1983 El Niño season caused serious coastal damage throughout California (Figures 13-14). Economic losses exceeded \$2 billion along the California coastline. \$100 million of this damage occurred in January alone: 3000 homes and 900 businesses were damaged and 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:

Del Mar Vulnerability Assessment. D150347.00

Figure 7
1978 Flooded River Mouth





Source:

Del Mar Vulnerability Assessment. D150347.00

Figure 9

View of San Dieguito River Mouth February 21, 1980



Source: Dustin Fuller

Del Mar Vulnerability Assessment. D150347.00

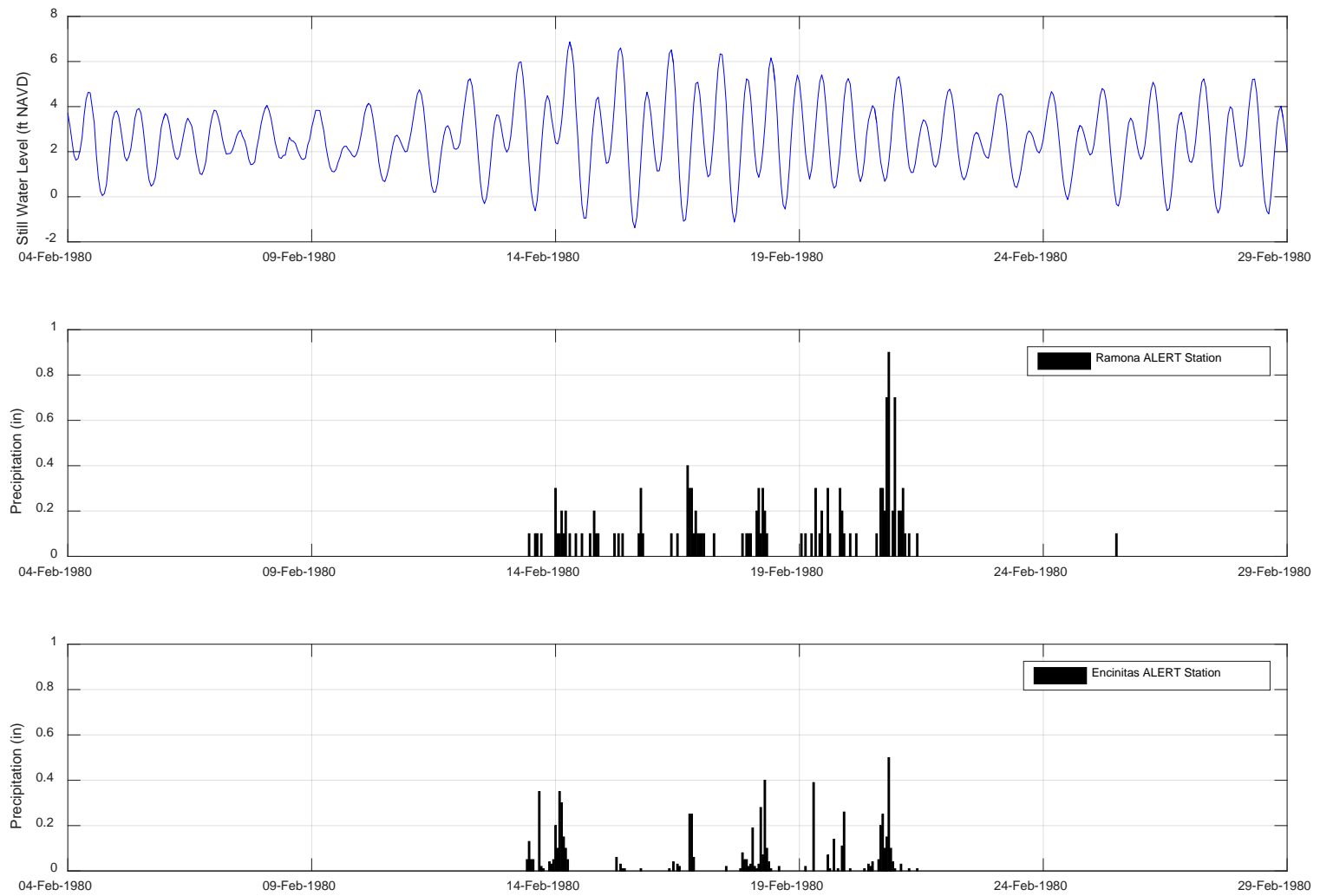
Figure 10
1980 Flooded River Mouth and Racetrack



Source: Bruce Bekkar

Del Mar Vulnerability Assessment. D150347.00

Figure 11
Flooded North Beach Streets, 1980



Del Mar Vulnerability Assessment. D150347.00
Figure 12
SWL and Precipitation – Flood 1980



Source: Fletcher, 1983

Del Mar Vulnerability Assessment. D150347.00

Figure 13
Coastal Damage following 1983 Storm



Source: Fletcher, 1983

Del Mar Vulnerability Assessment. D150347.00

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.

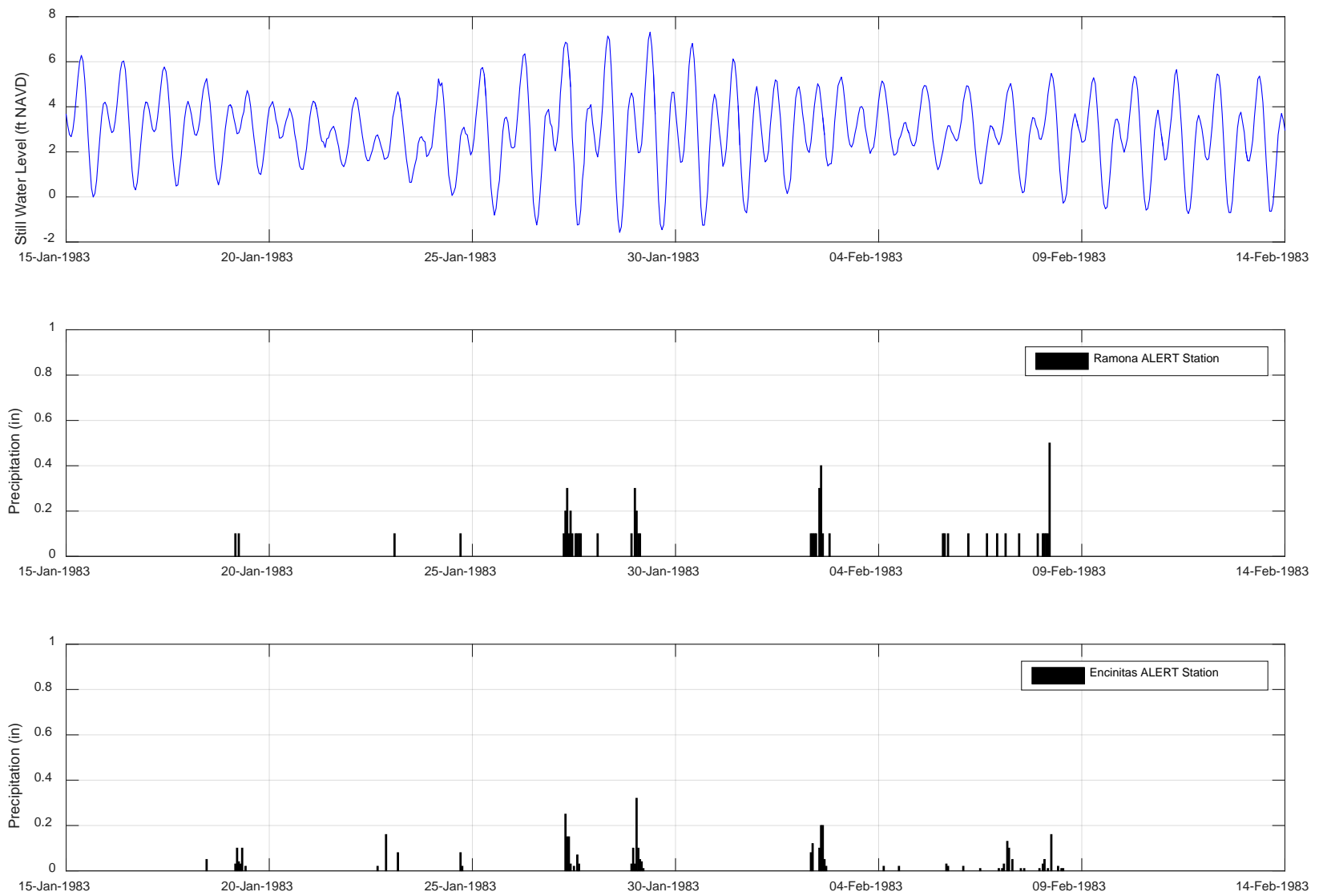
3.4 Coastal Storm of 1998

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 fiberoptic 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).



Del Mar Vulnerability Assessment. D150347.00
Figure 15
SWL and Precipitation – Flood 1983

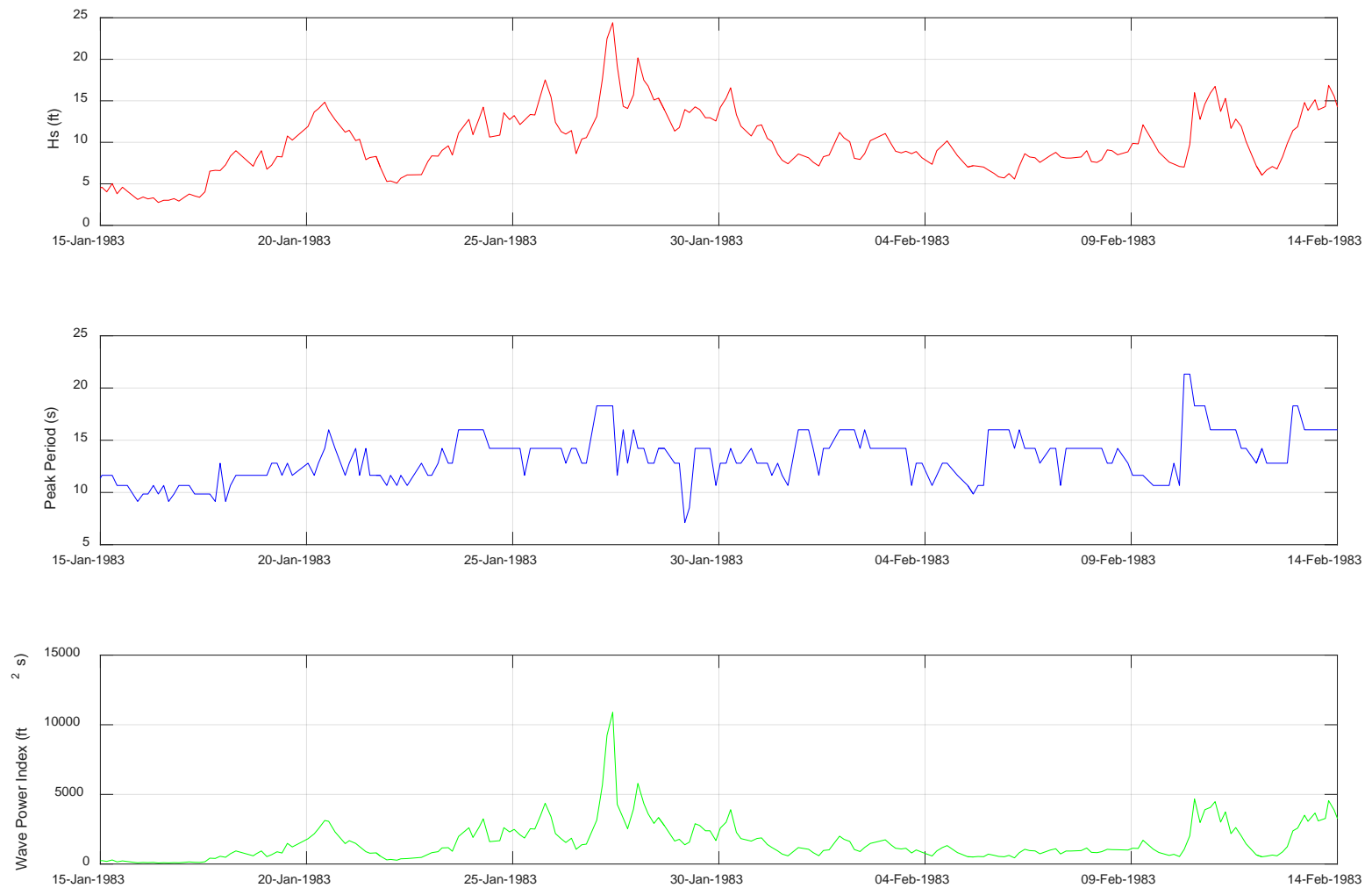
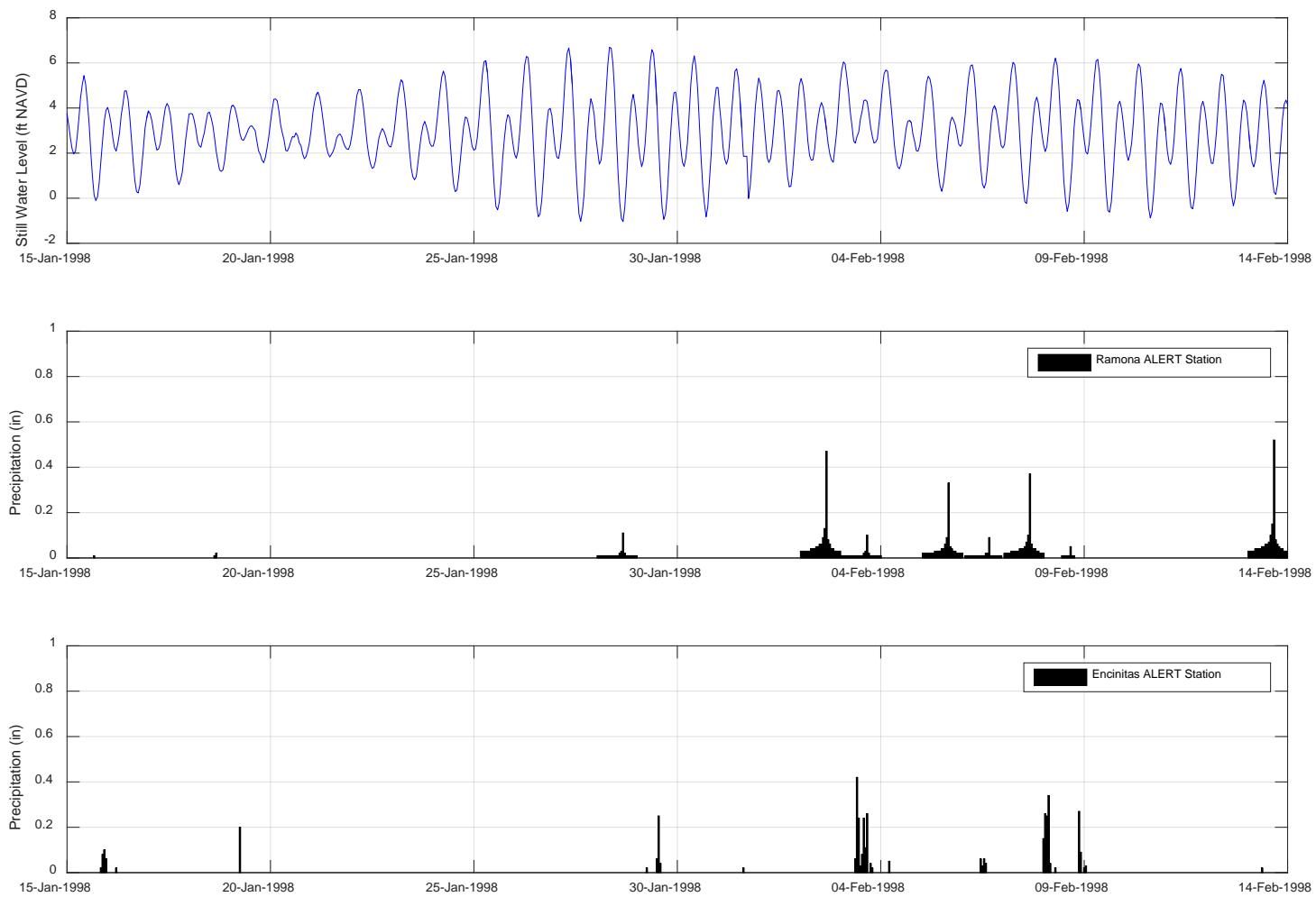
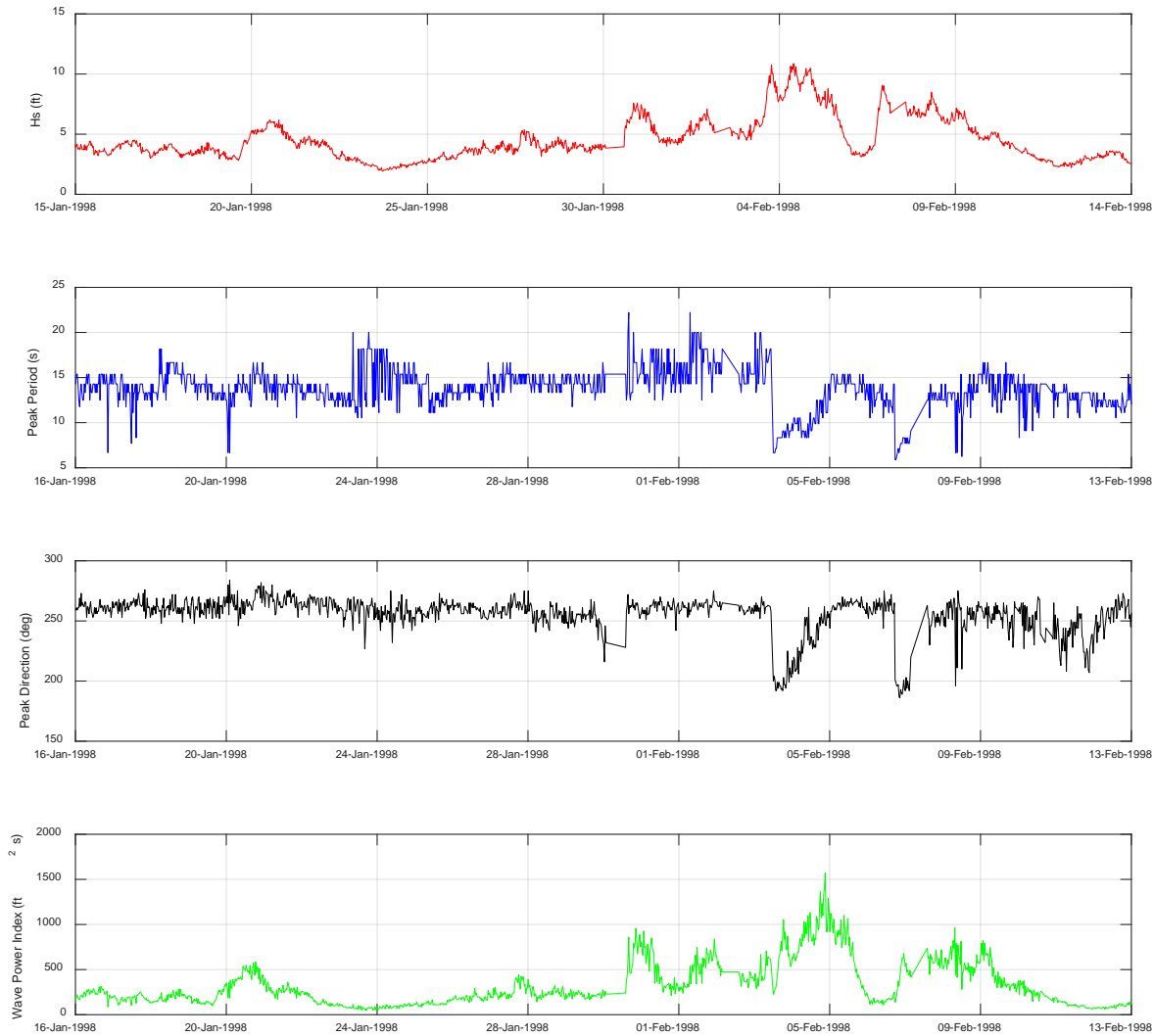


Figure 16
Wave Parameters from Begg Rock Station – Flood 1983







Del Mar Vulnerability Assessment. D150347.00

Figure 19
Large Waves and Runup at La Jolla- December 11, 2015



Source: NBC 7, 2015

Del Mar Vulnerability Assessment. D150347.00
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.

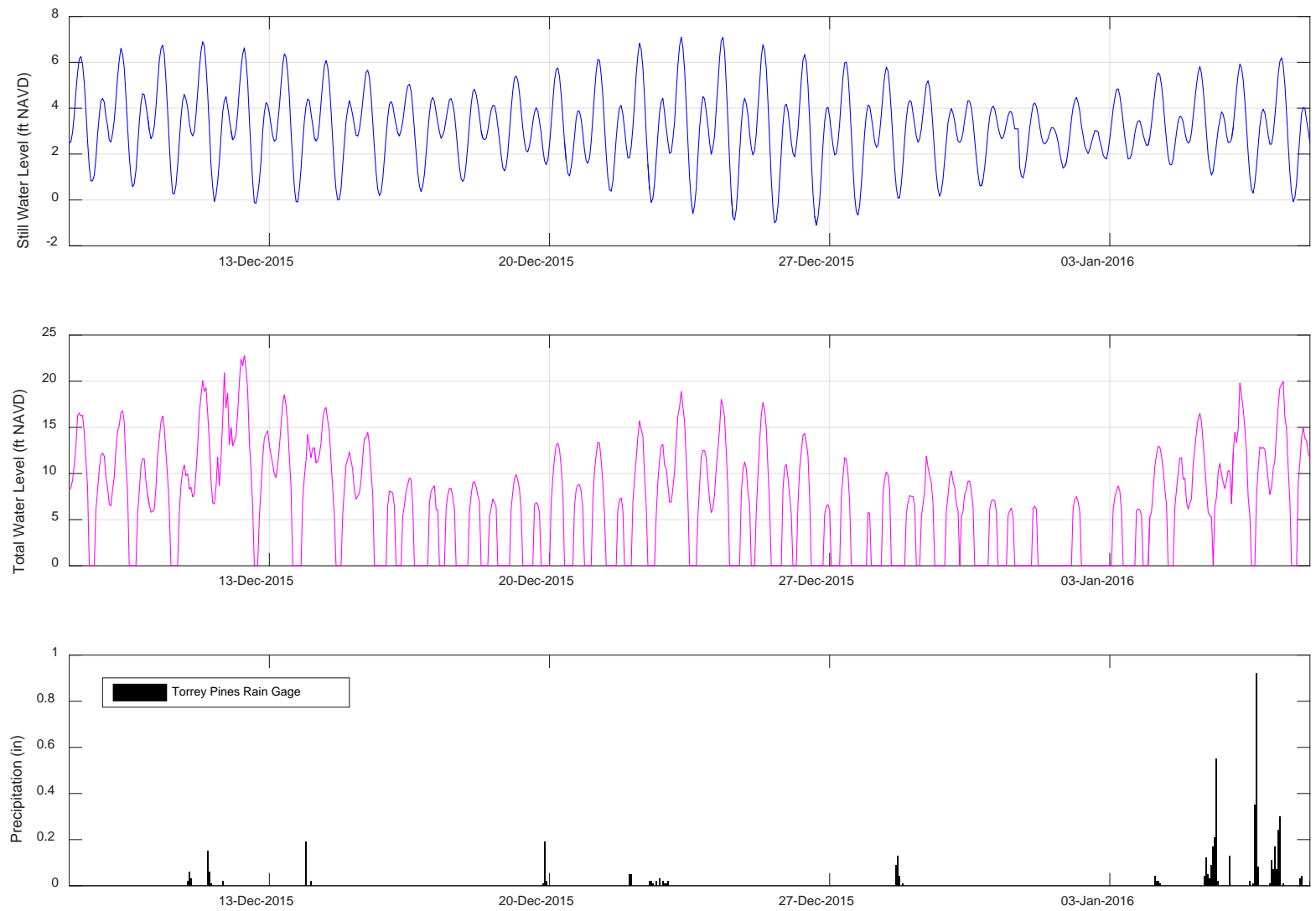
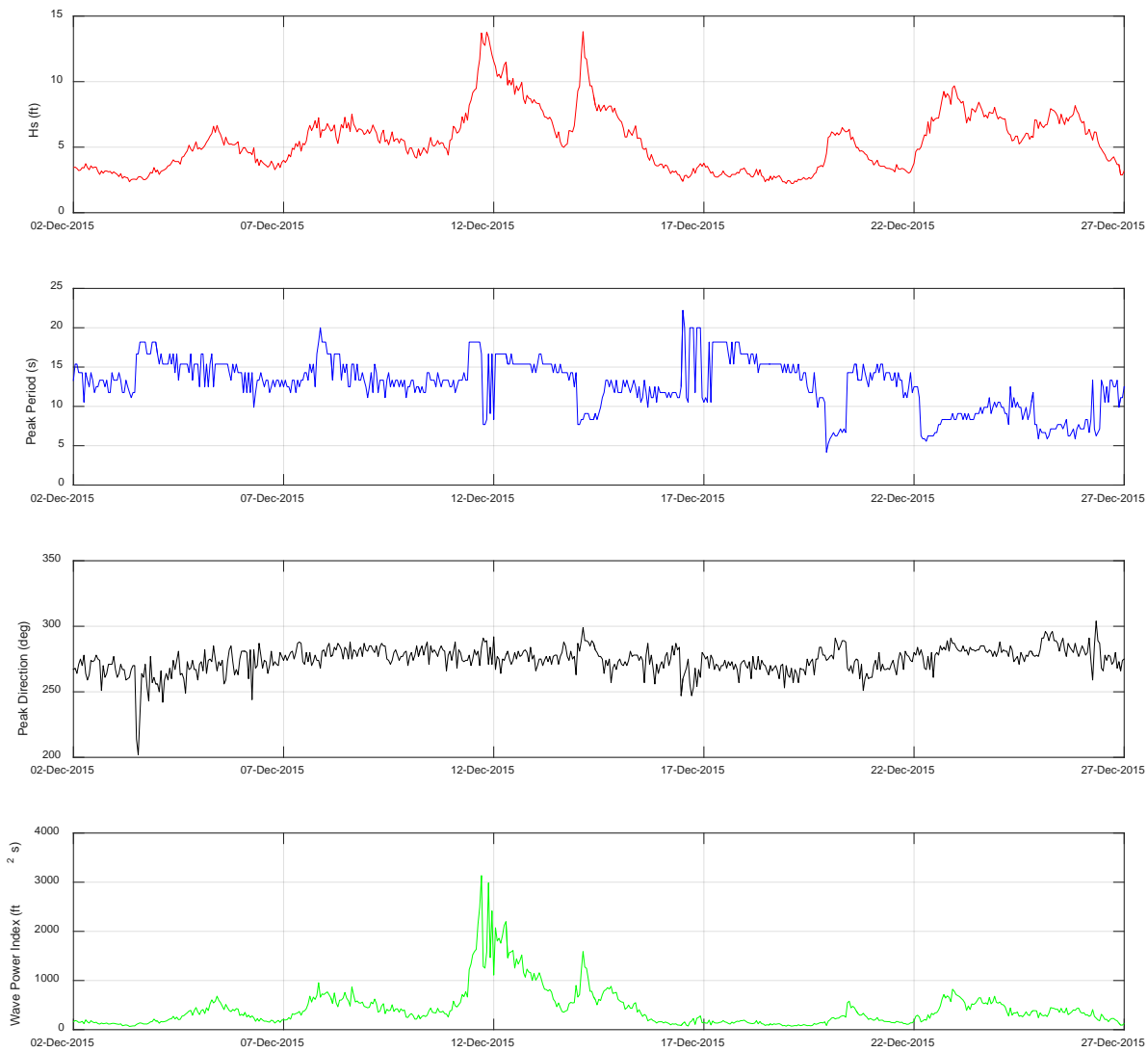


Figure 21
SWL, TWL, and Precipitation – Flood 2015







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, assuming no background erosion (0 feet/year). Though natural background erosion is present along Del Mar, the beach also receives sediment inflows from periodic nourishments and bluff sources. To account for these sediment additions, no background erosion was assumed. 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.

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 SOIB). 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 SOIB using only winter beach profiles and only summer beach profiles. The average winter profile width at SOIB is approximately 70 feet, while the average summer width at SOIB 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.

Note that these calculations do not include the influence of beach nourishment projects, or sediment sources from bluffs. 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. Including historic background erosion rates will further decrease the time to zero beach width in North Beach to 2030. 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, and which means that zero winter beach width will be reached sooner than 2060, and zero summer beach will be reached later than 2060.

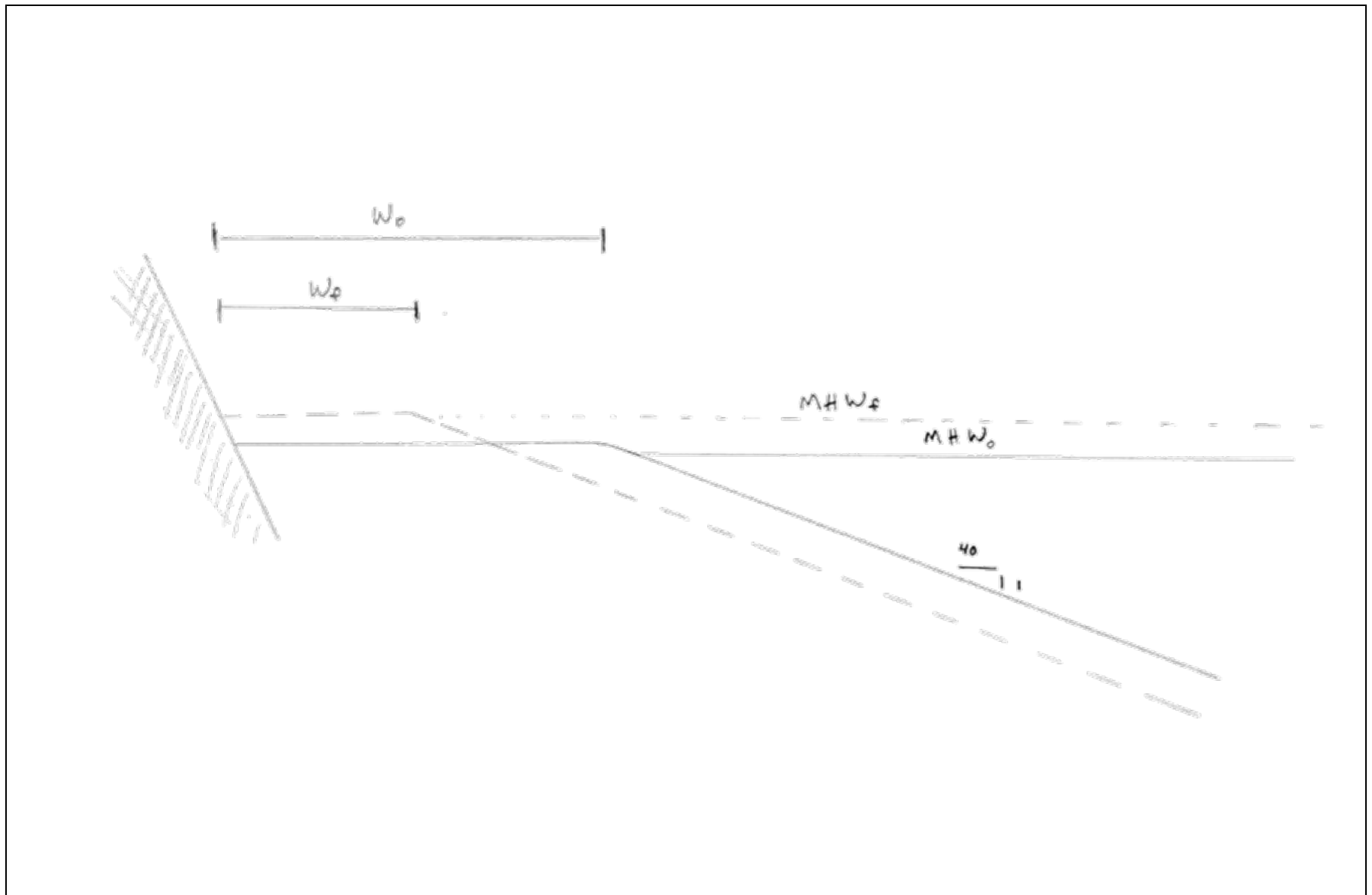
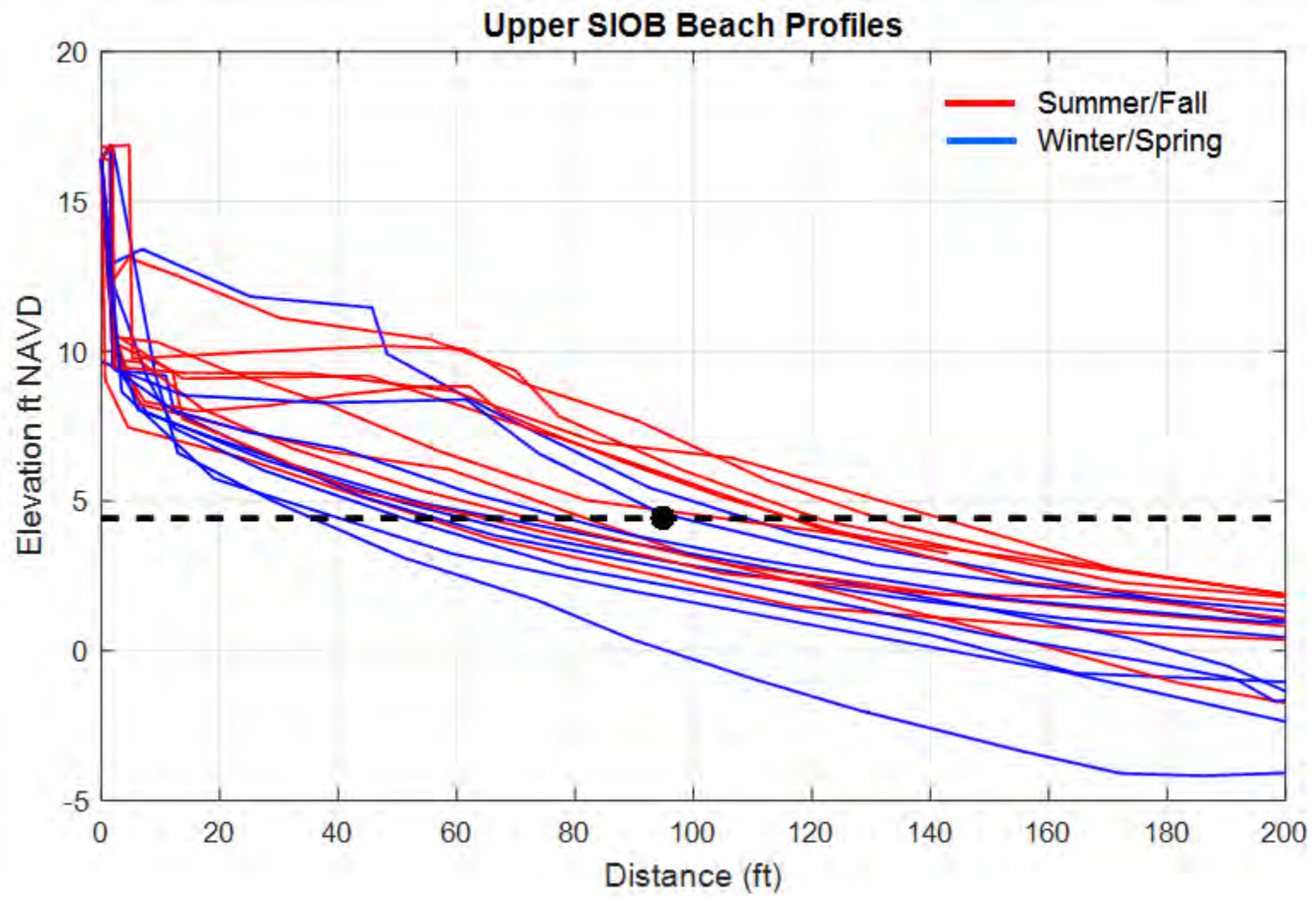


Figure 25
Beach Width Schematic (Not to Scale)



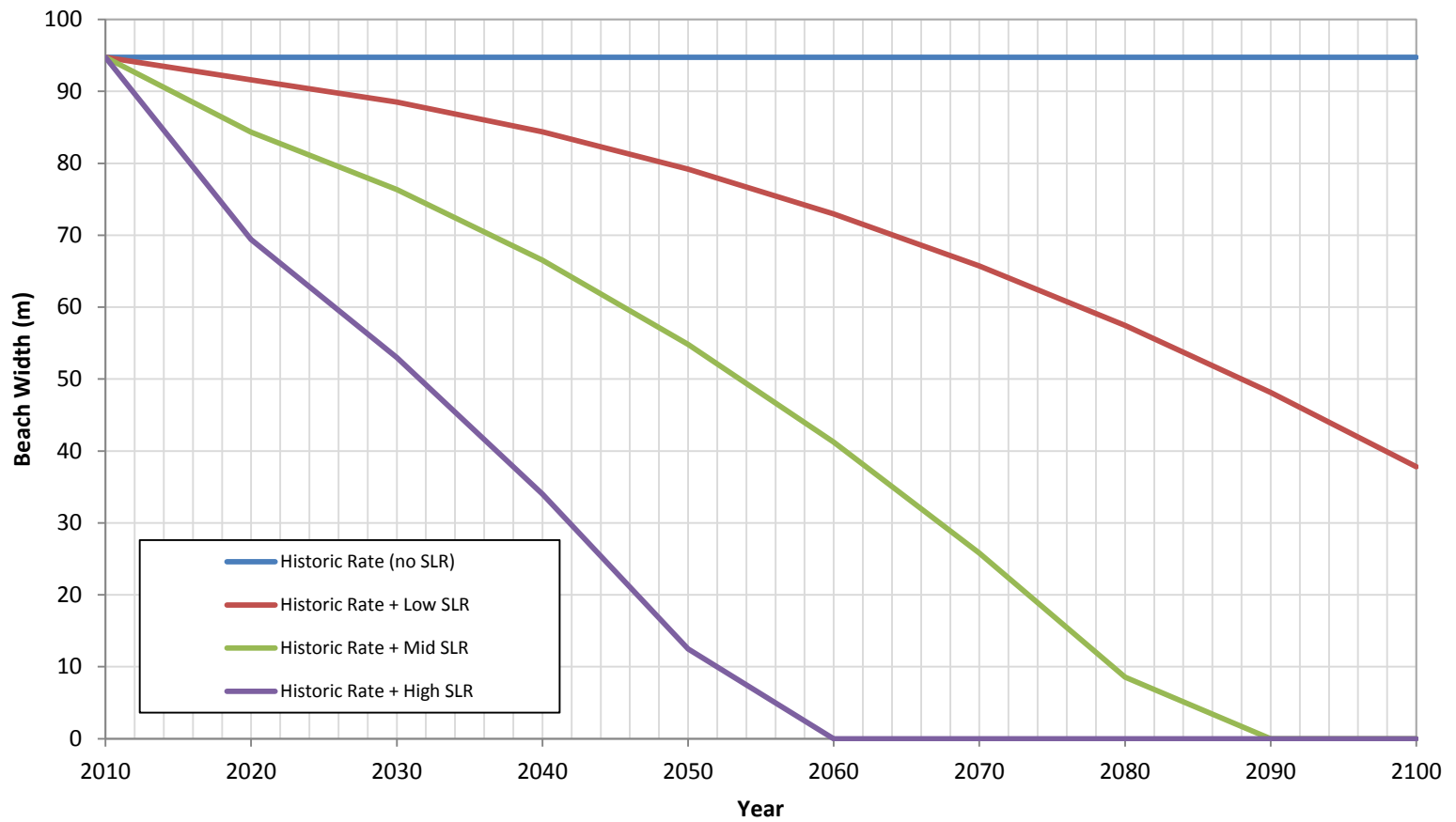


TABLE 4
BEACH WIDTHS OVER TIME WITH SLR

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.

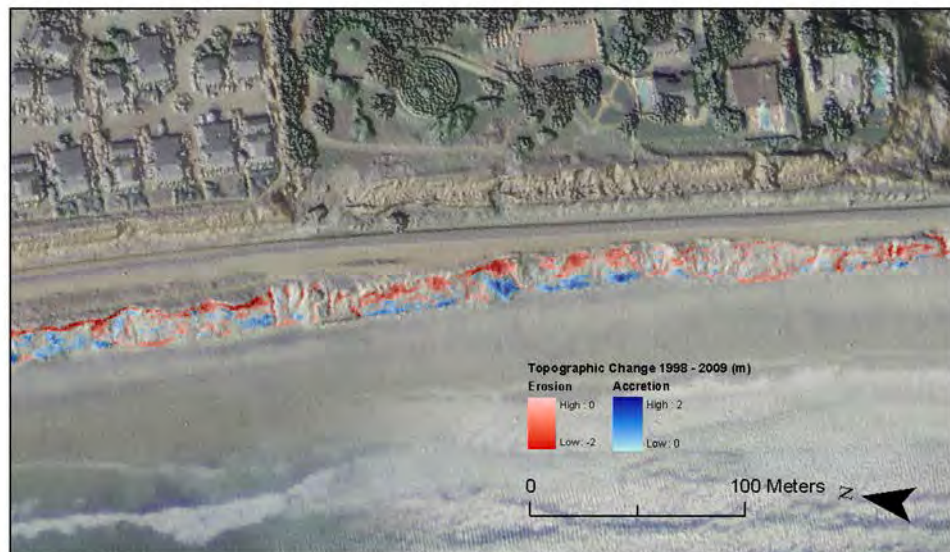
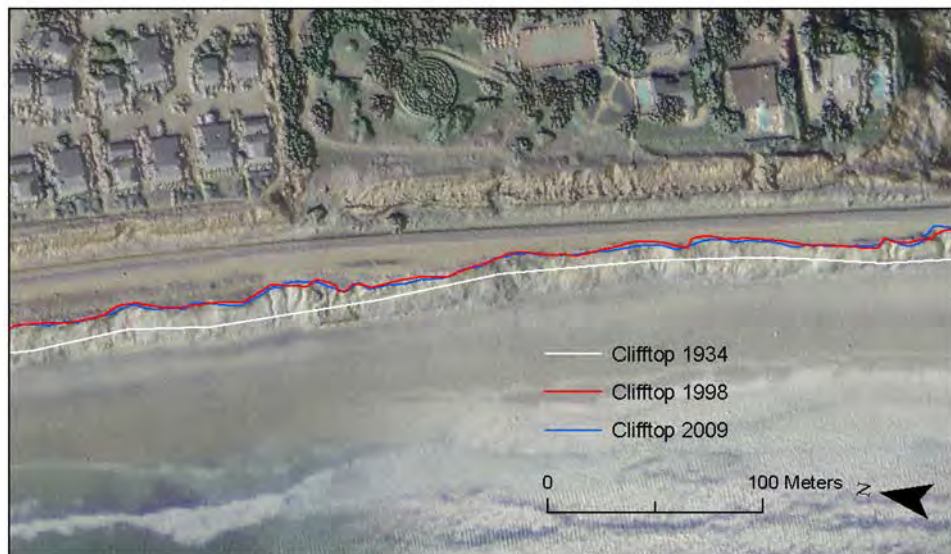


Figure 28

Cliff 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 m². This filtering identifies negative and positive individual topographic change areas with a minimum volume of about 0.6 m³ (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 m³) and large footprint (>2 m²) 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 cliff top 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 cliff top lines that are approximately 7 ft beyond the 2100 cliff top 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.

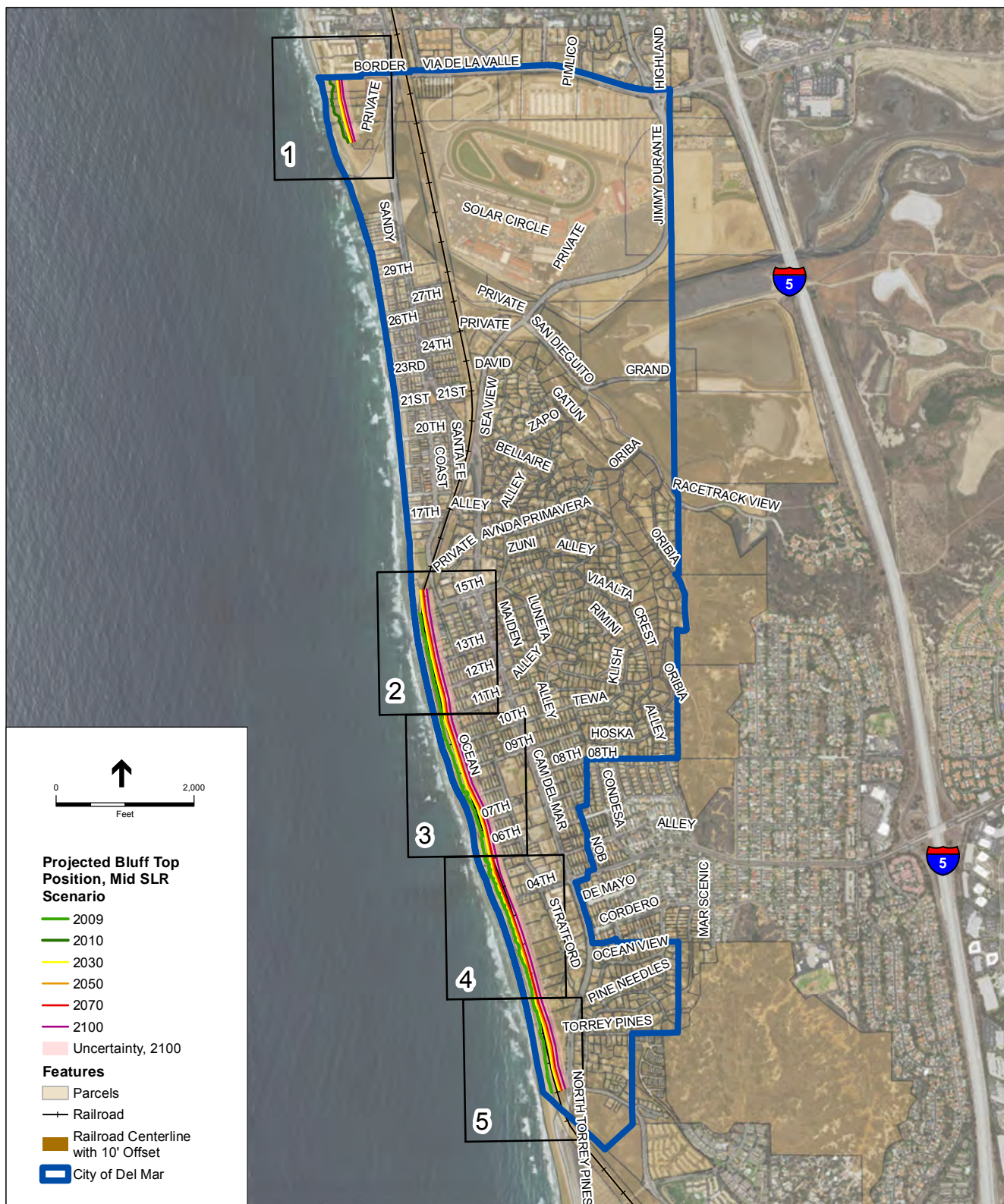
Figures 29 to 30 (and Figures A-1 to A-7) also show the railroad centerline with a 10 ft offset from the centerline to represent the minimum distance from the clifftop that may be acceptable for railroad safety. This 10 ft offset is based on the offset used in Leighton & Associates' (2010) geotechnical 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. 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.

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).

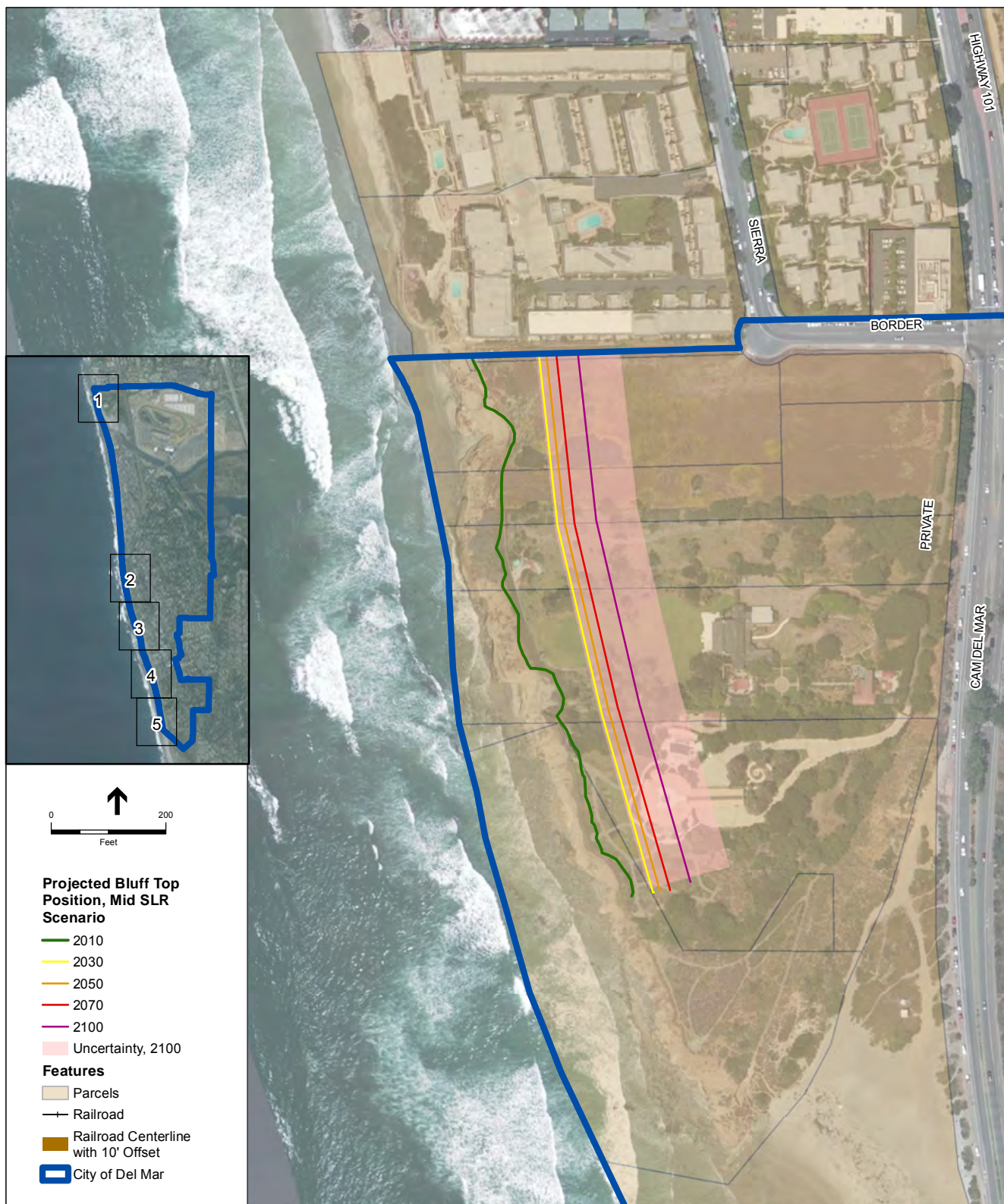


SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

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



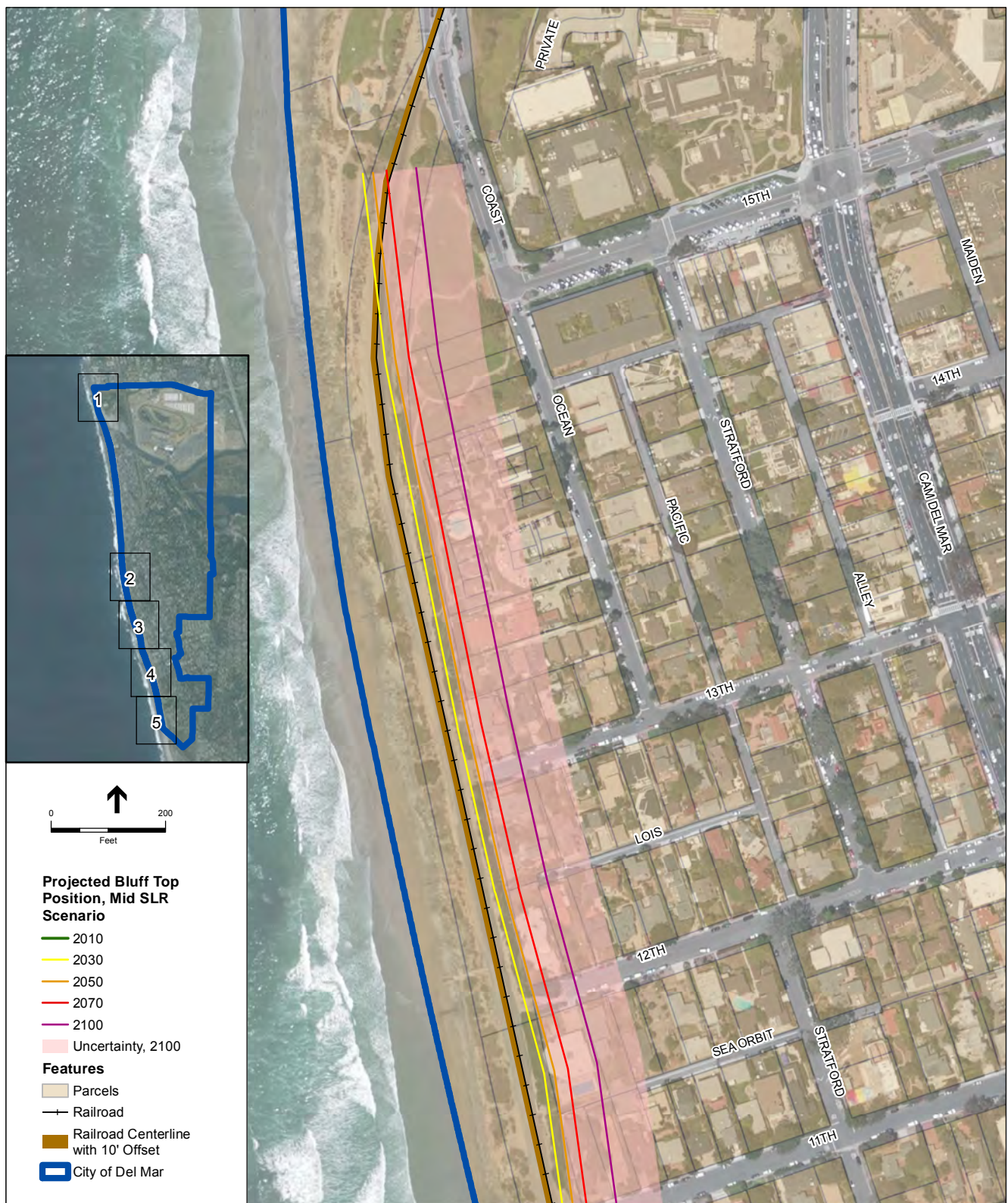
SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

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.

Del Mar Vulnerability Assessment . D150347

Figure 29.2

Mid Sea Level Rise in Del Mar Properties and Roads Vulnerability



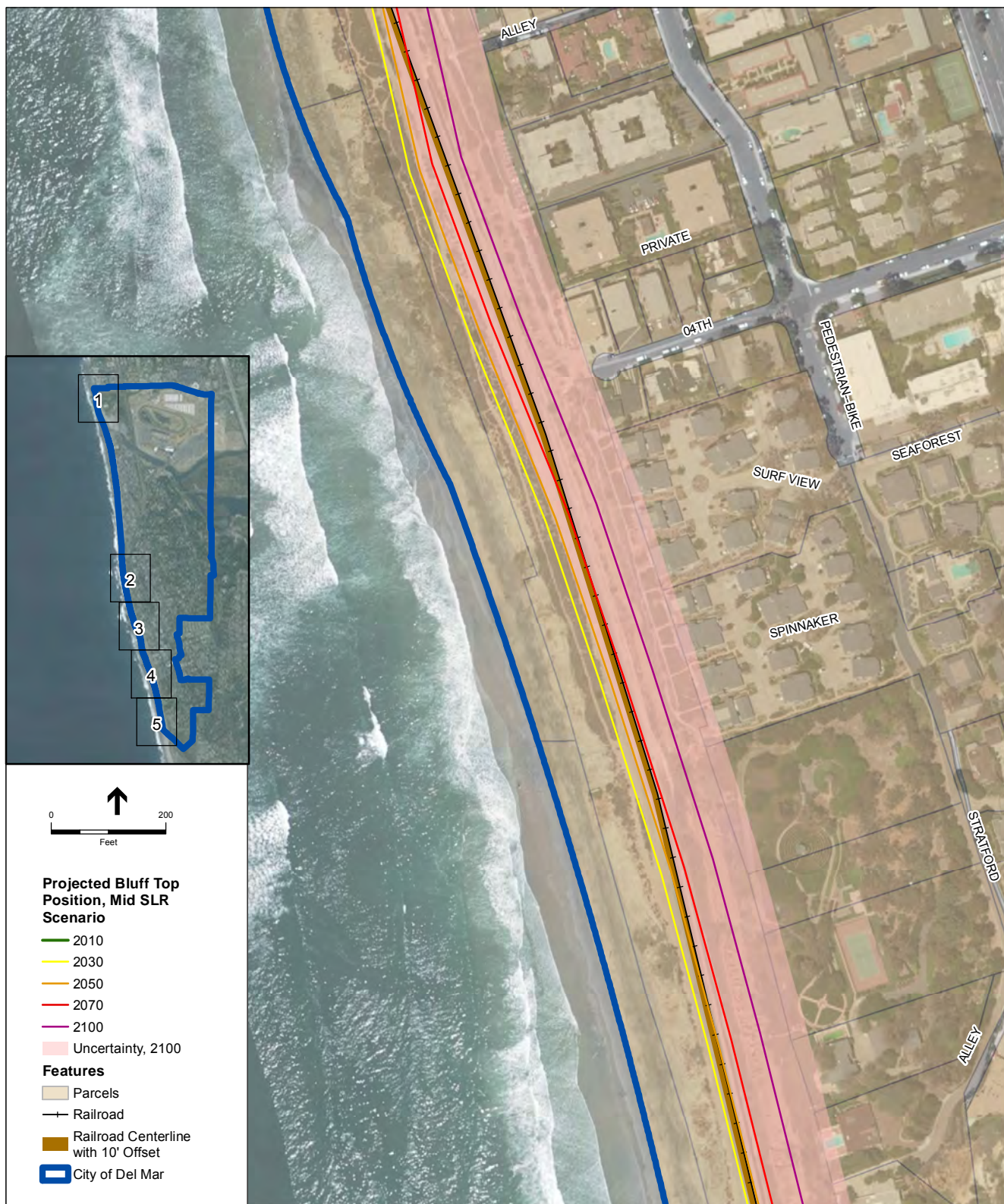
SOURCE: SanGIS 2016, USGS 2015

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



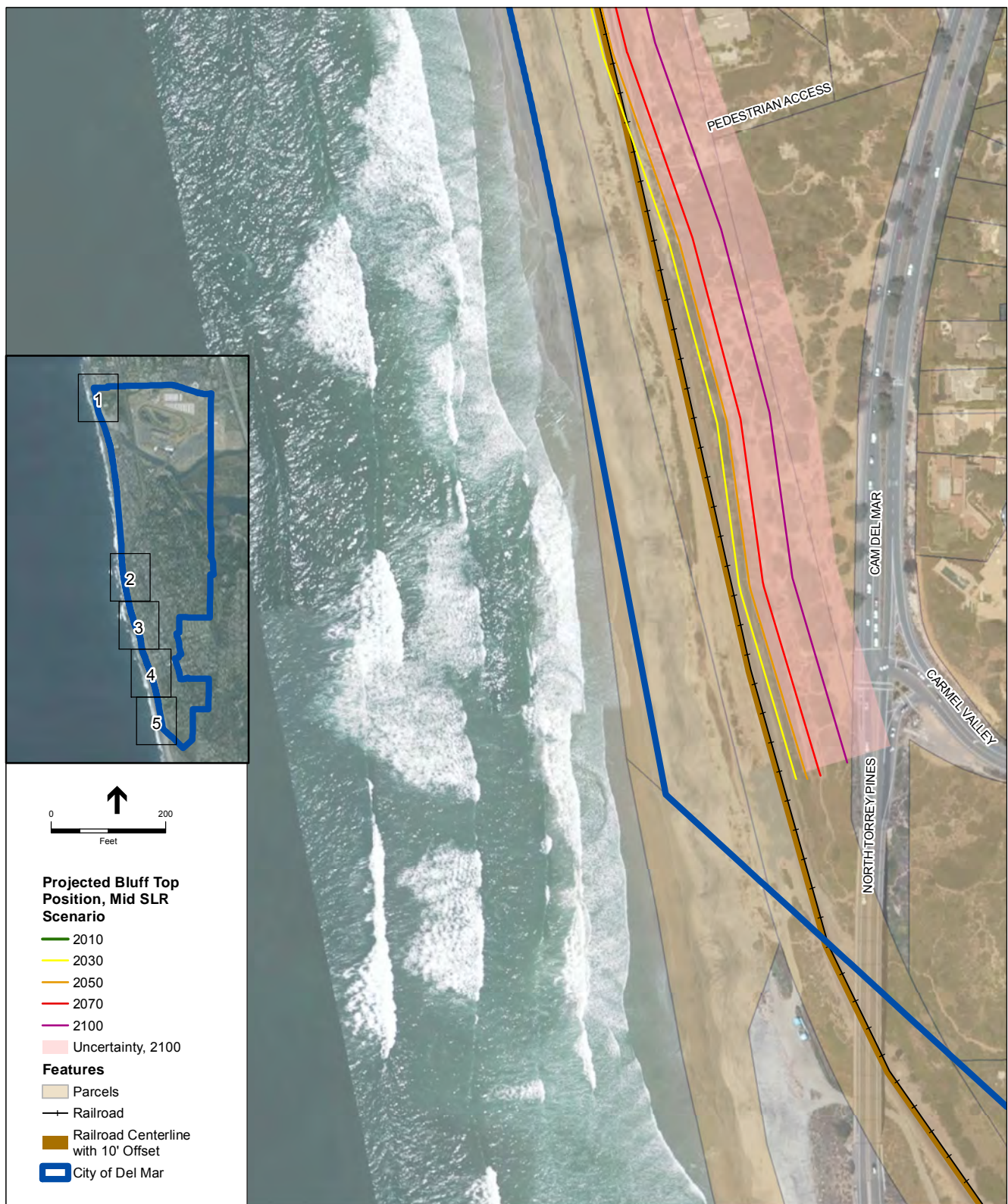
SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

Figure 29.4

Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability



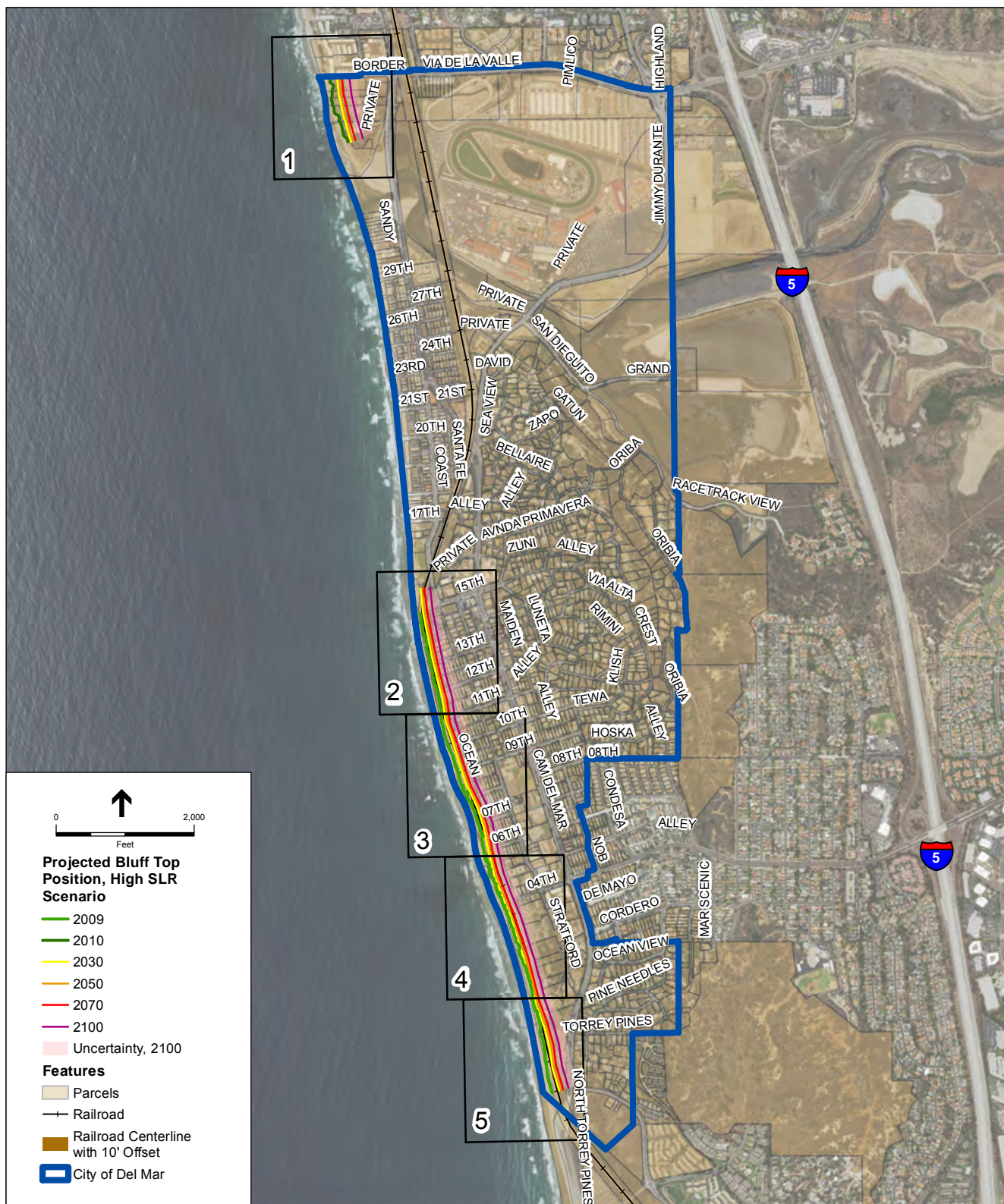
SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

Figure 29.5

Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability

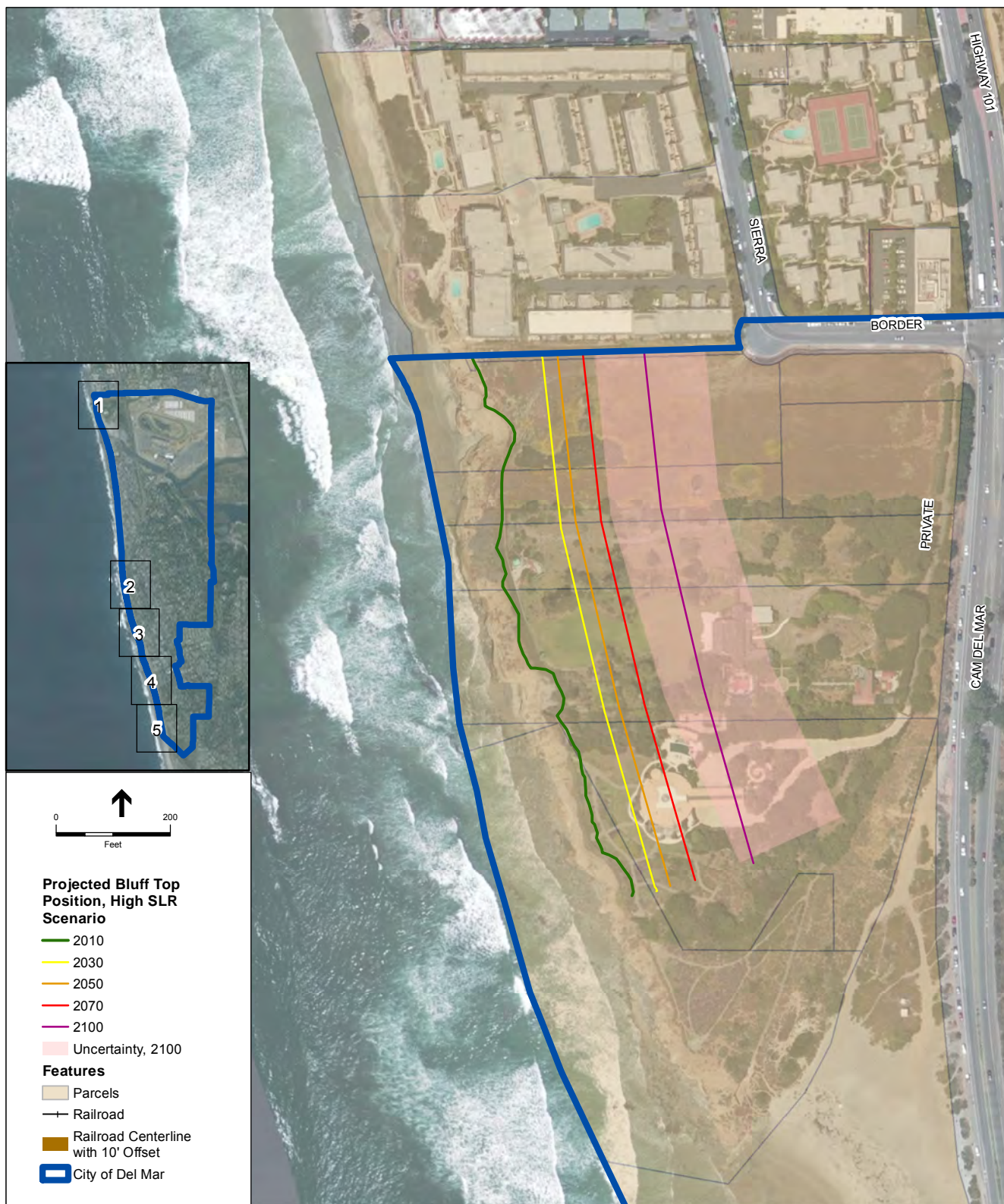


SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

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

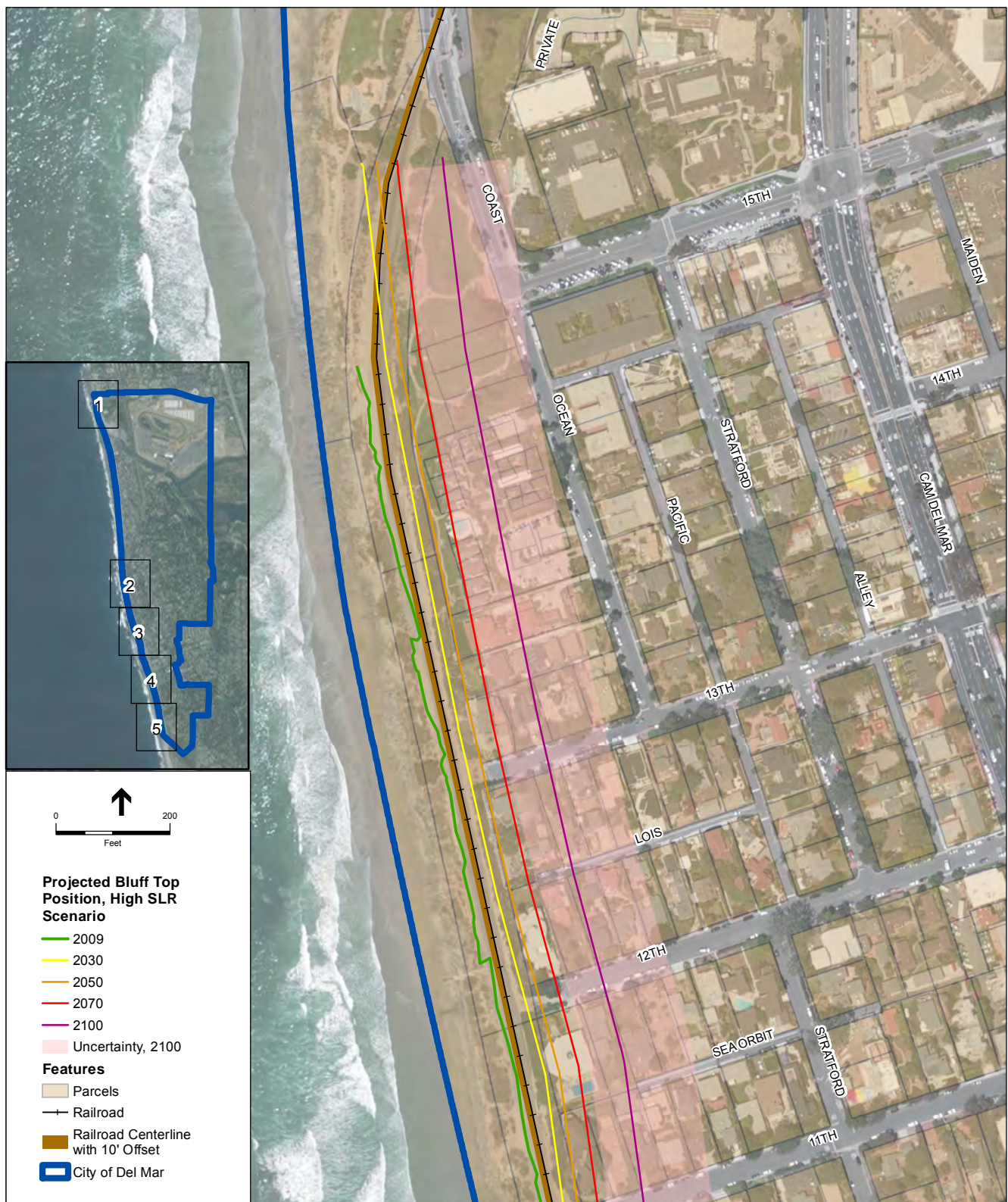


SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

Figure 30.1
High Sea Level Rise in Del Mar
Properties and Roads Vulnerability

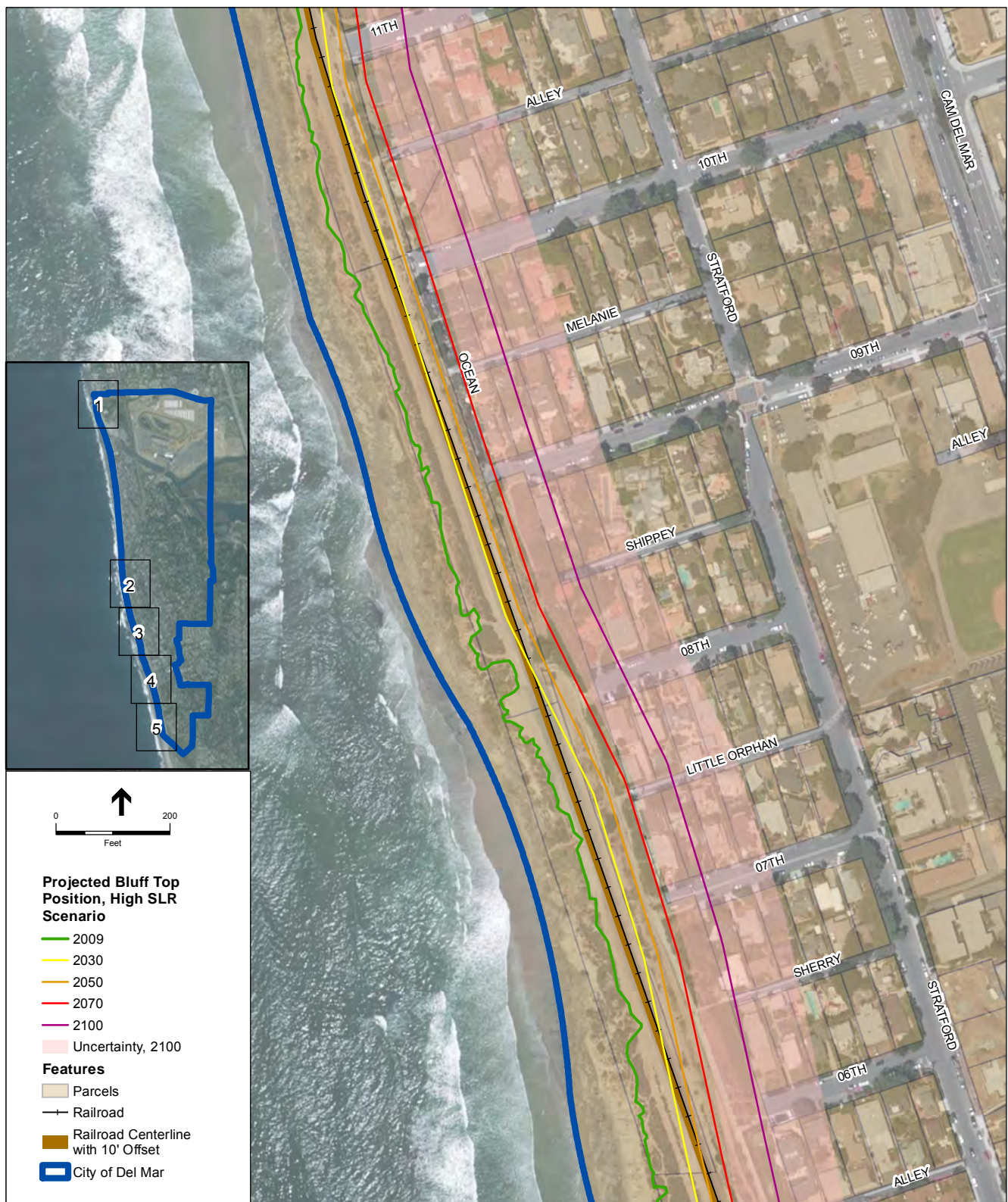


SOURCE: SanGIS 2016, USGS 2015

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

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

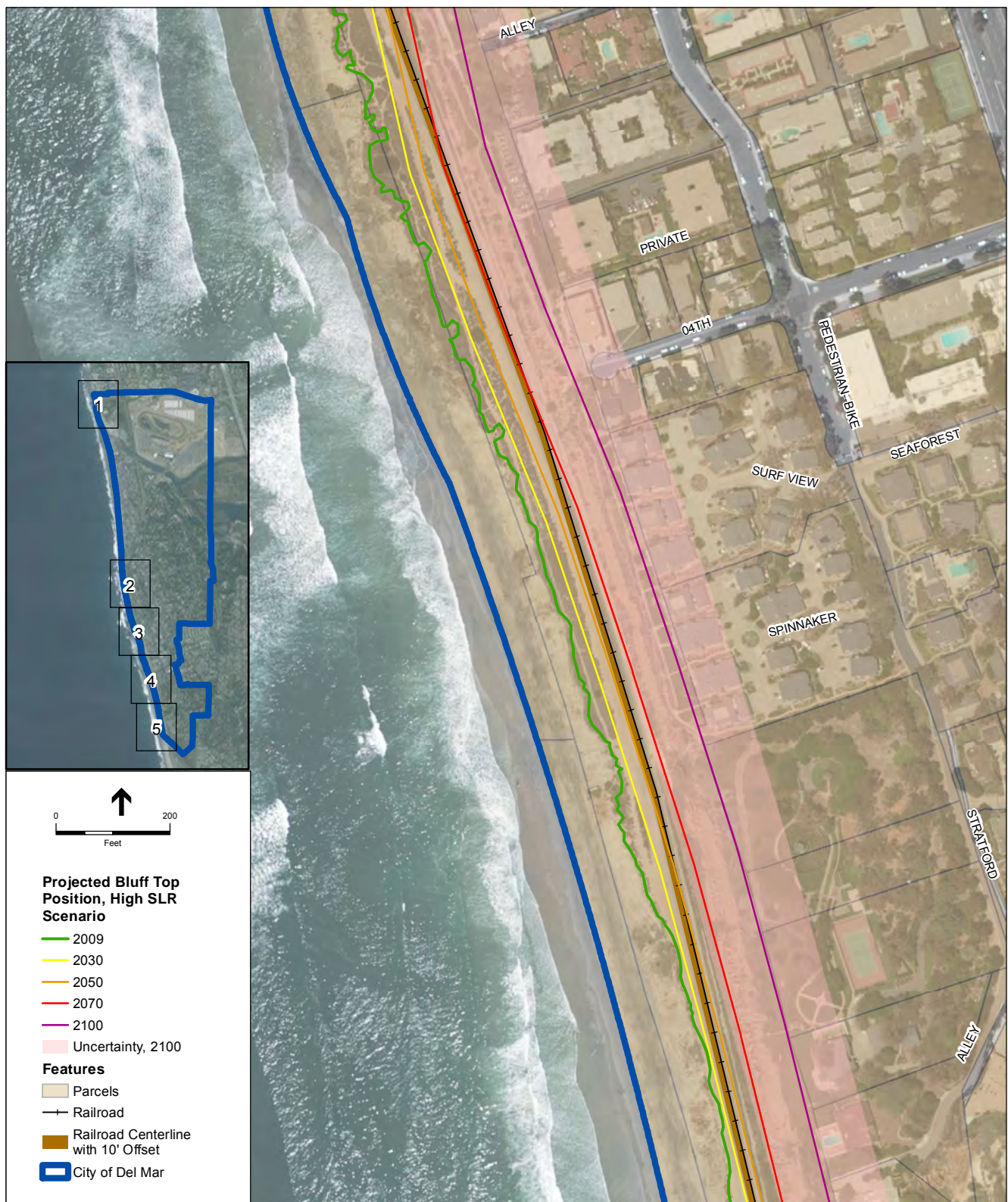


SOURCE: SanGIS 2016, USGS 2015

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 2100 (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

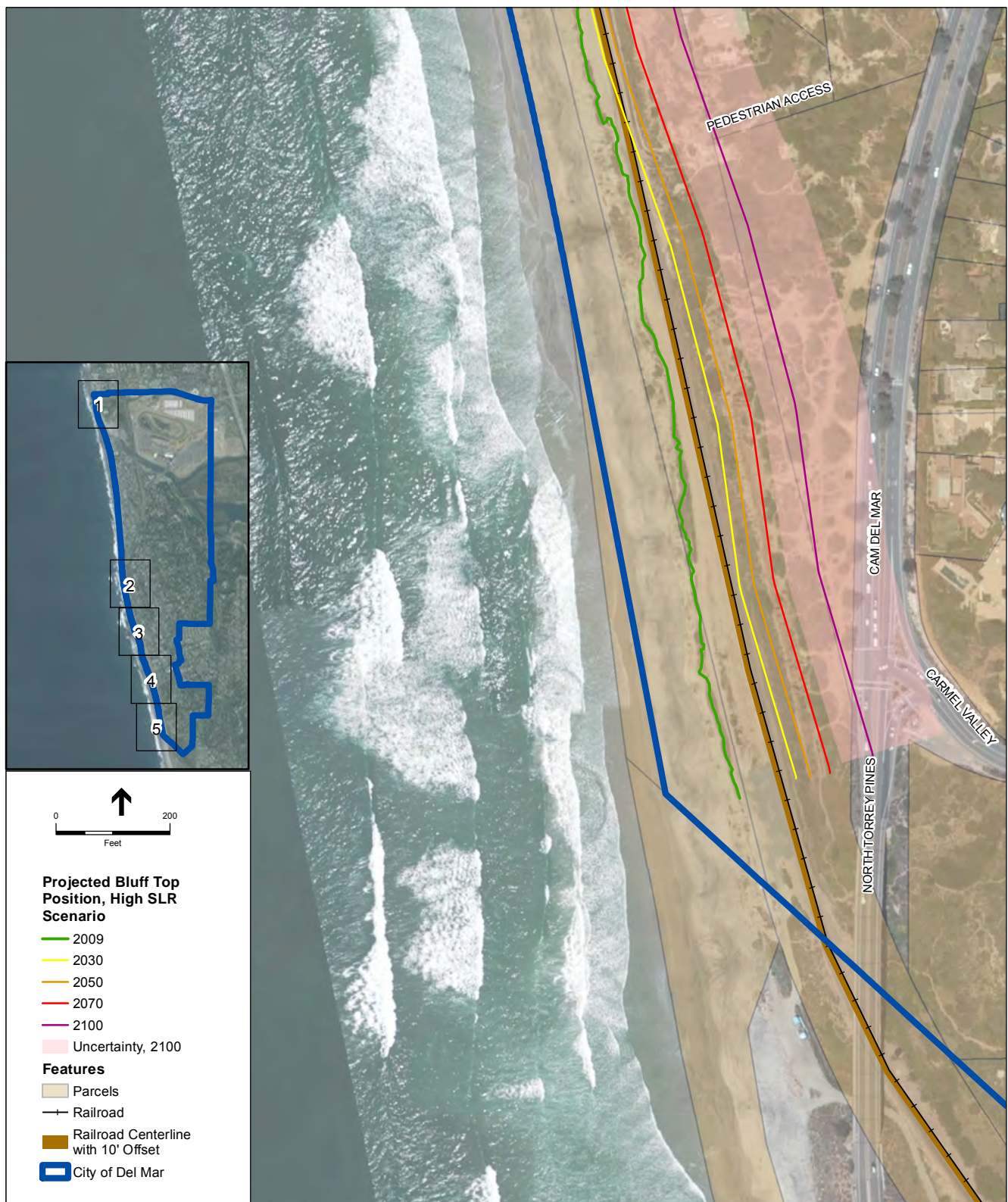


SOURCE: SanGIS 2016, USGS 2015

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 2100 (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 2100 (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

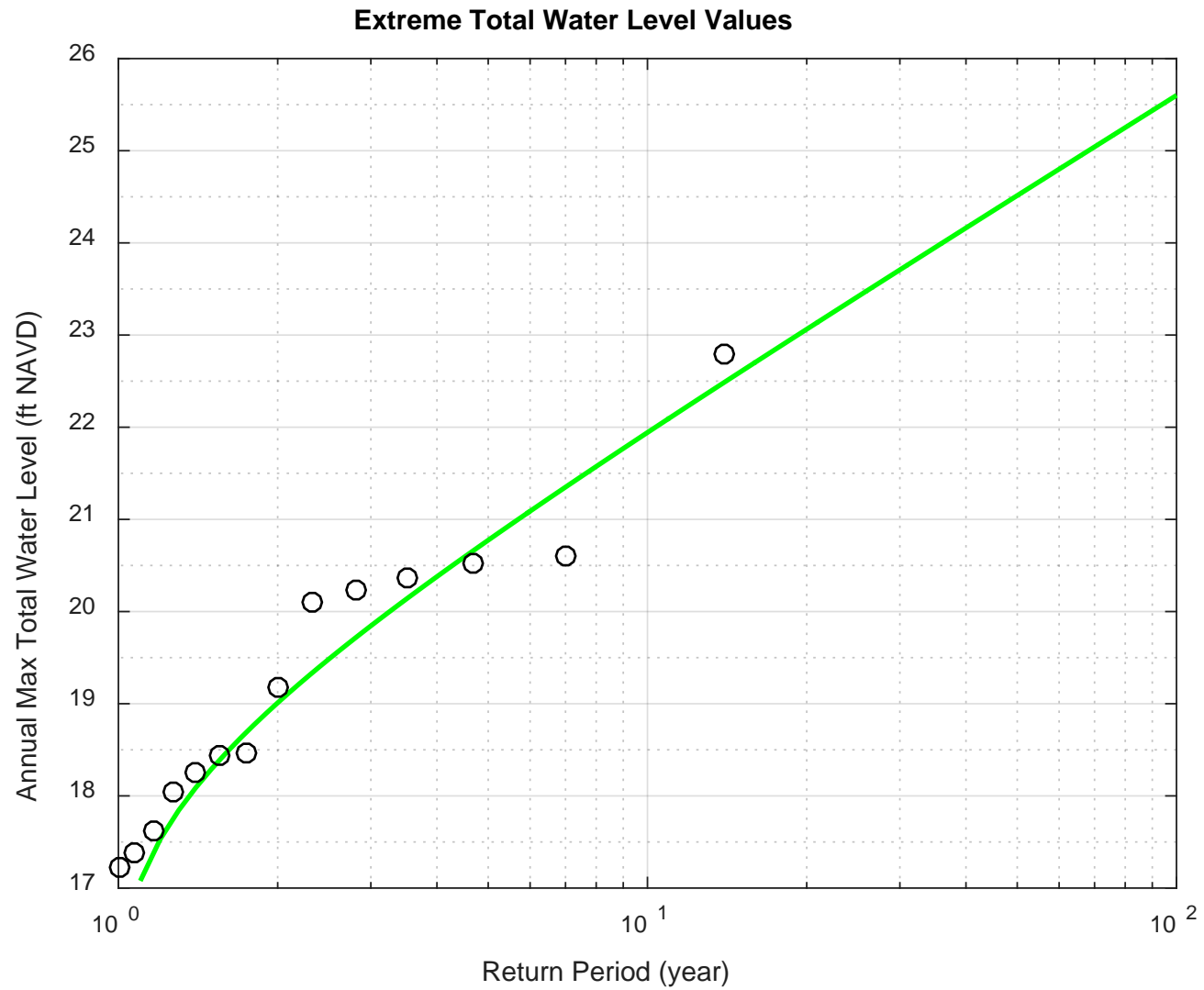


TABLE 6
RETURN PERIODS – EXISTING CONDITIONS

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.

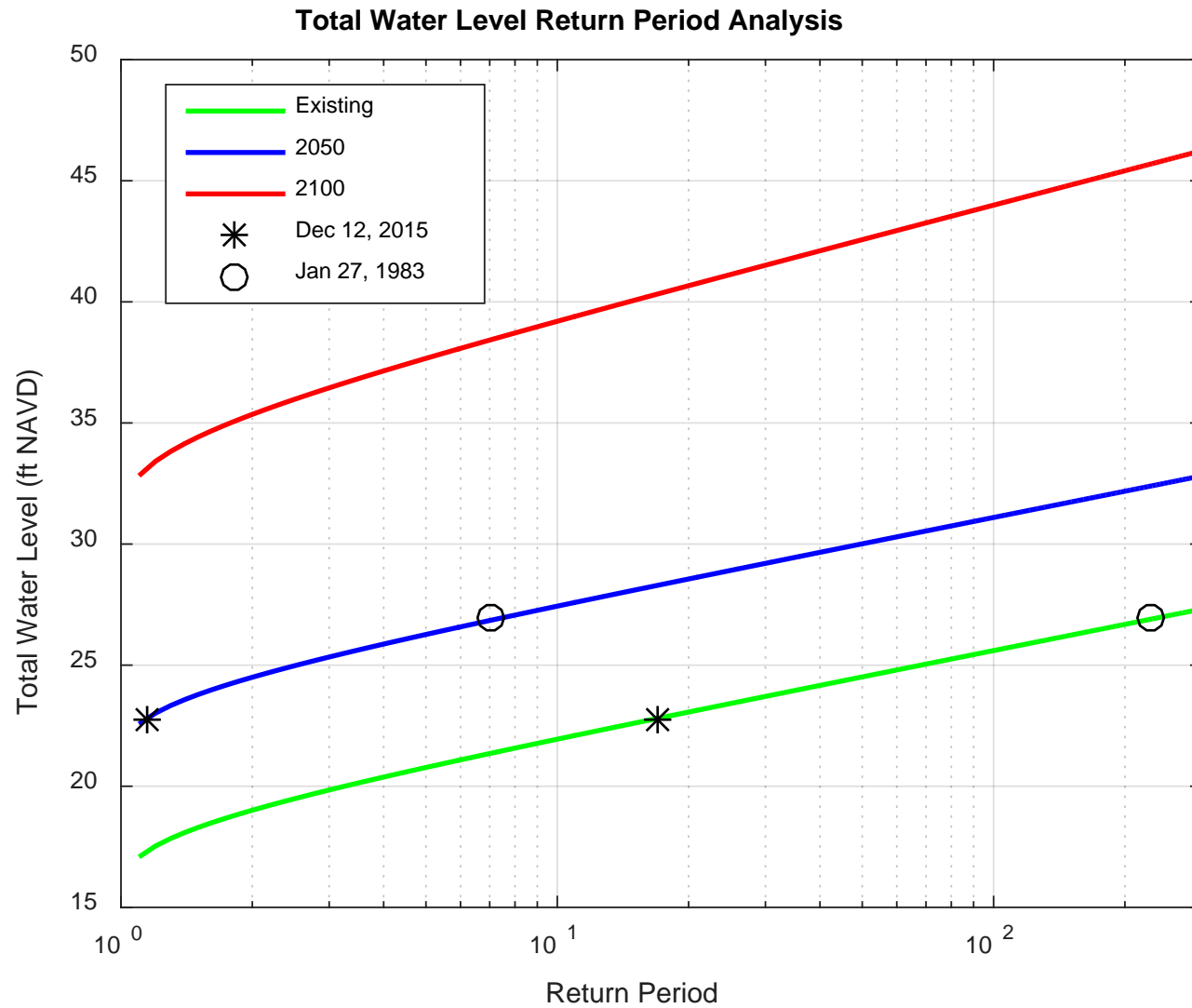
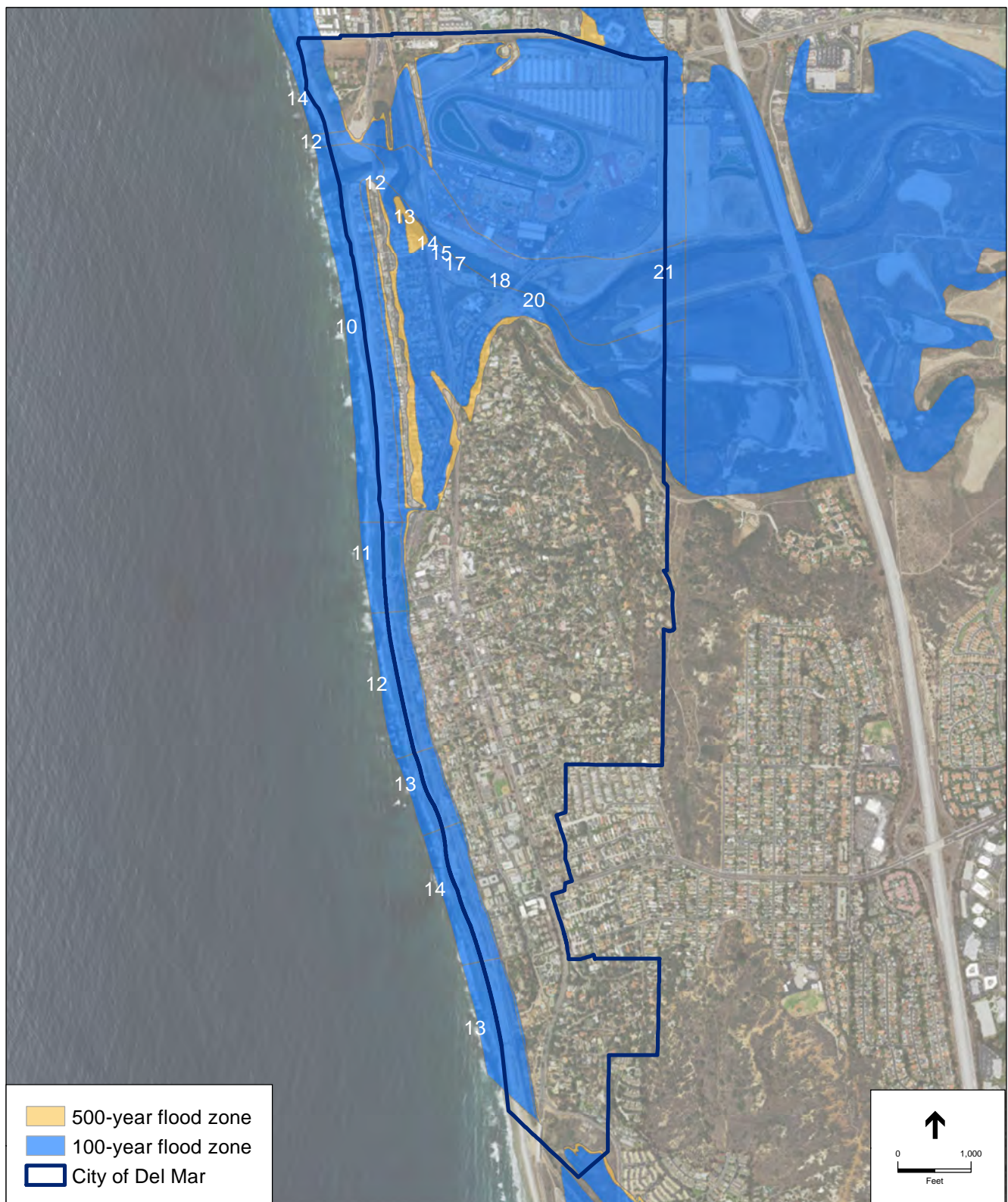


Figure 32
Extreme Value Analysis – Existing and Future Conditions



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 flood 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.

Current Water Surface Elevations for Flood Events

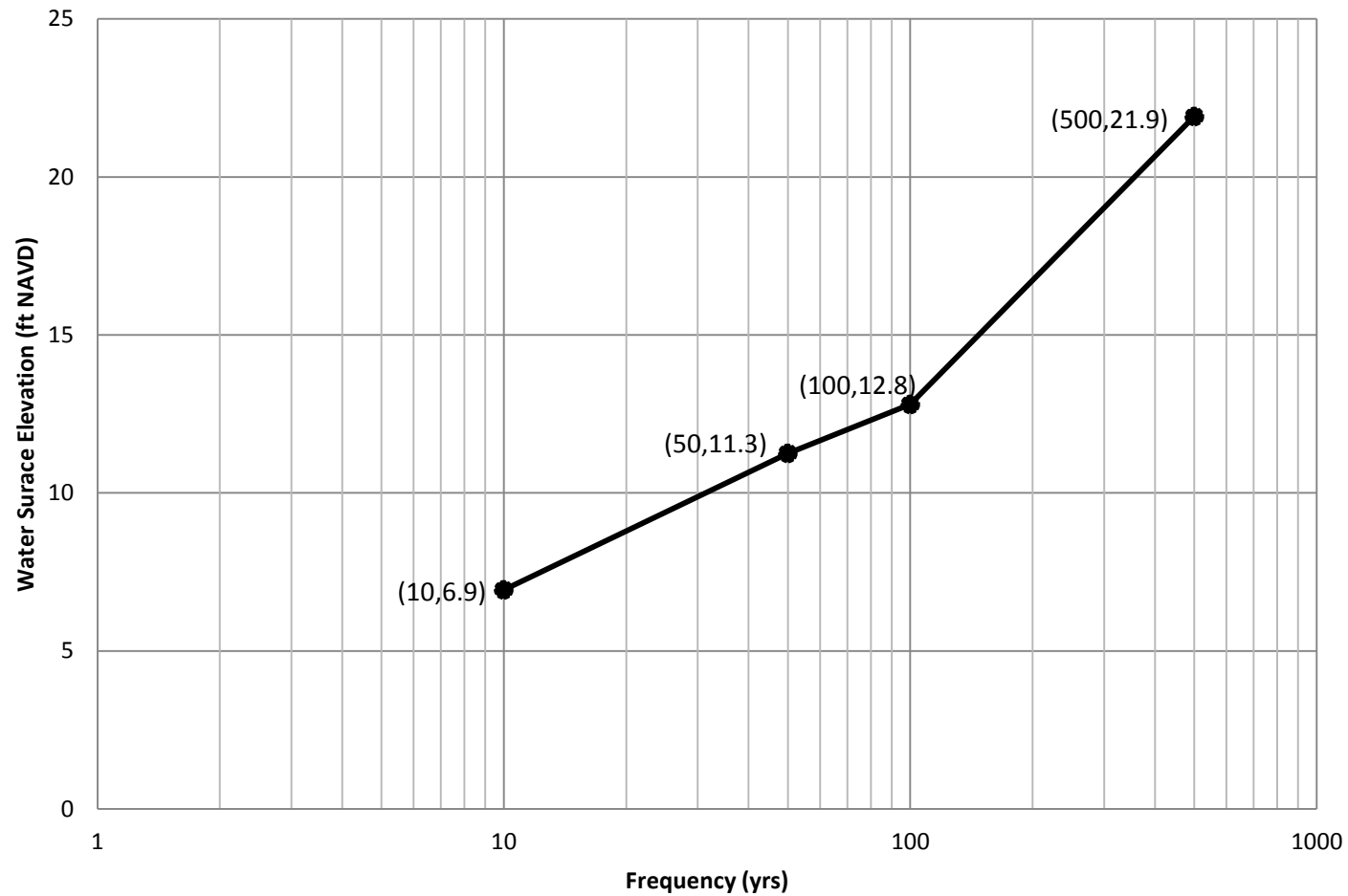


TABLE 7
PRECIPITATION EVENTS, AMOUNTS, AND INTENSITIES ANALYZED

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.

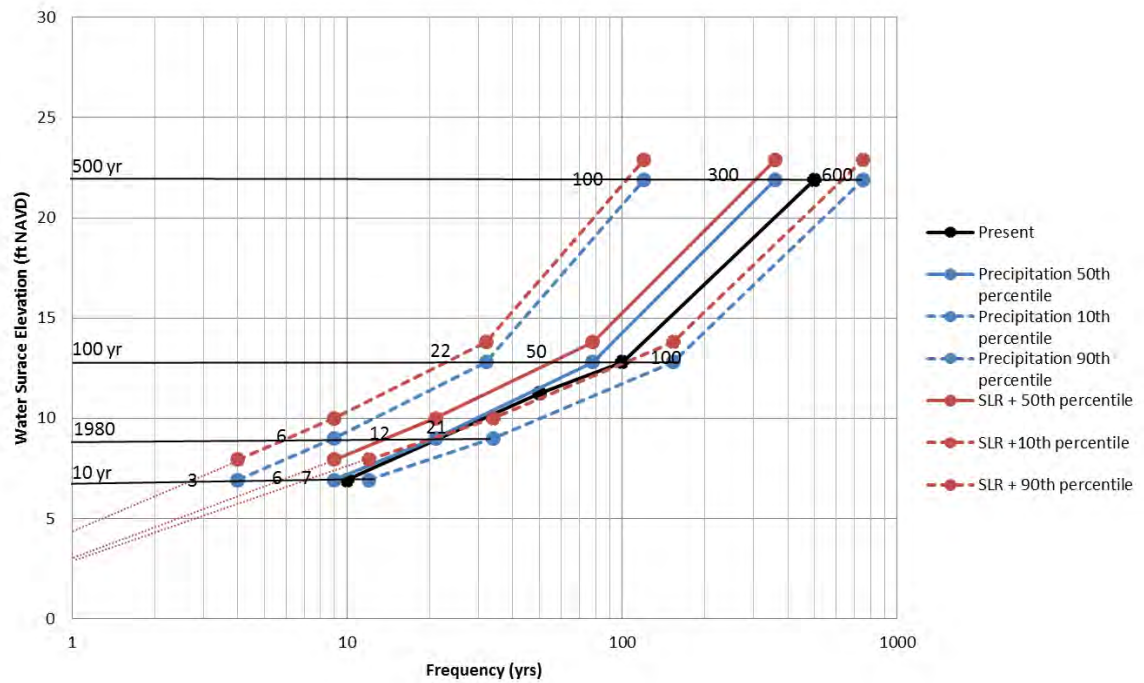
4.4.3 River Flood Level with SLR

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.

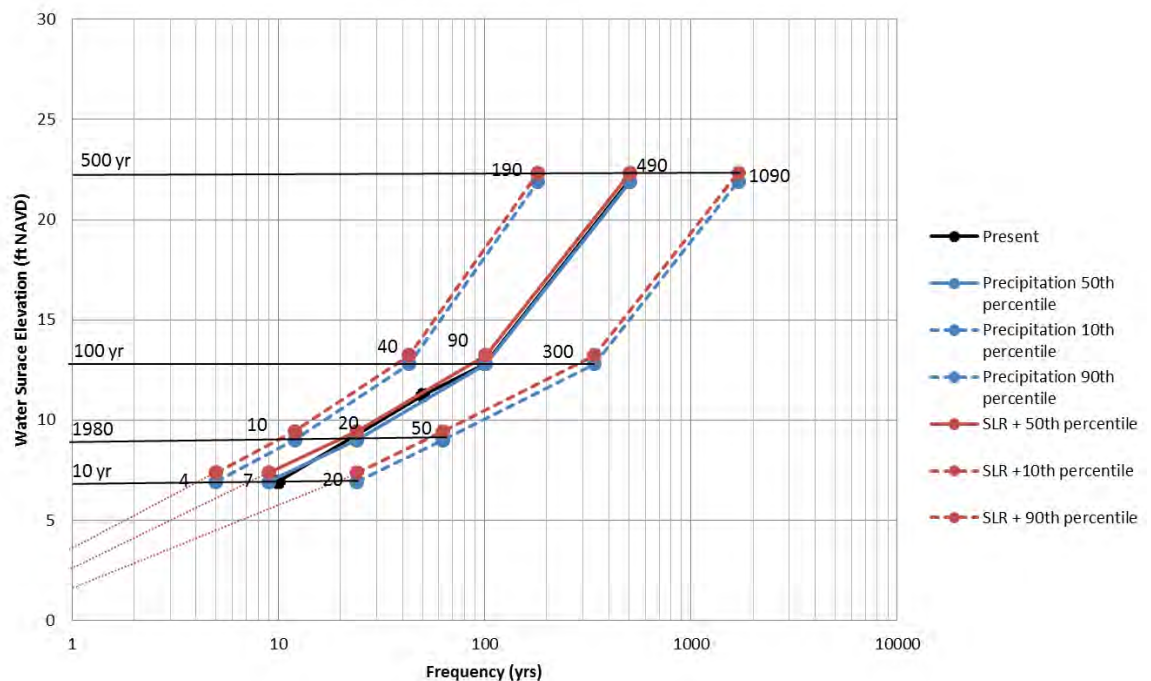
Sea level rise will increase the downstream tide level or tail water elevation during River flood events. During extreme River discharge events such as the FEMA 1% chance (100-year) and 0.2% chance (500-year) events, the River discharge and flood water surface elevations back up behind the Camino del 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.

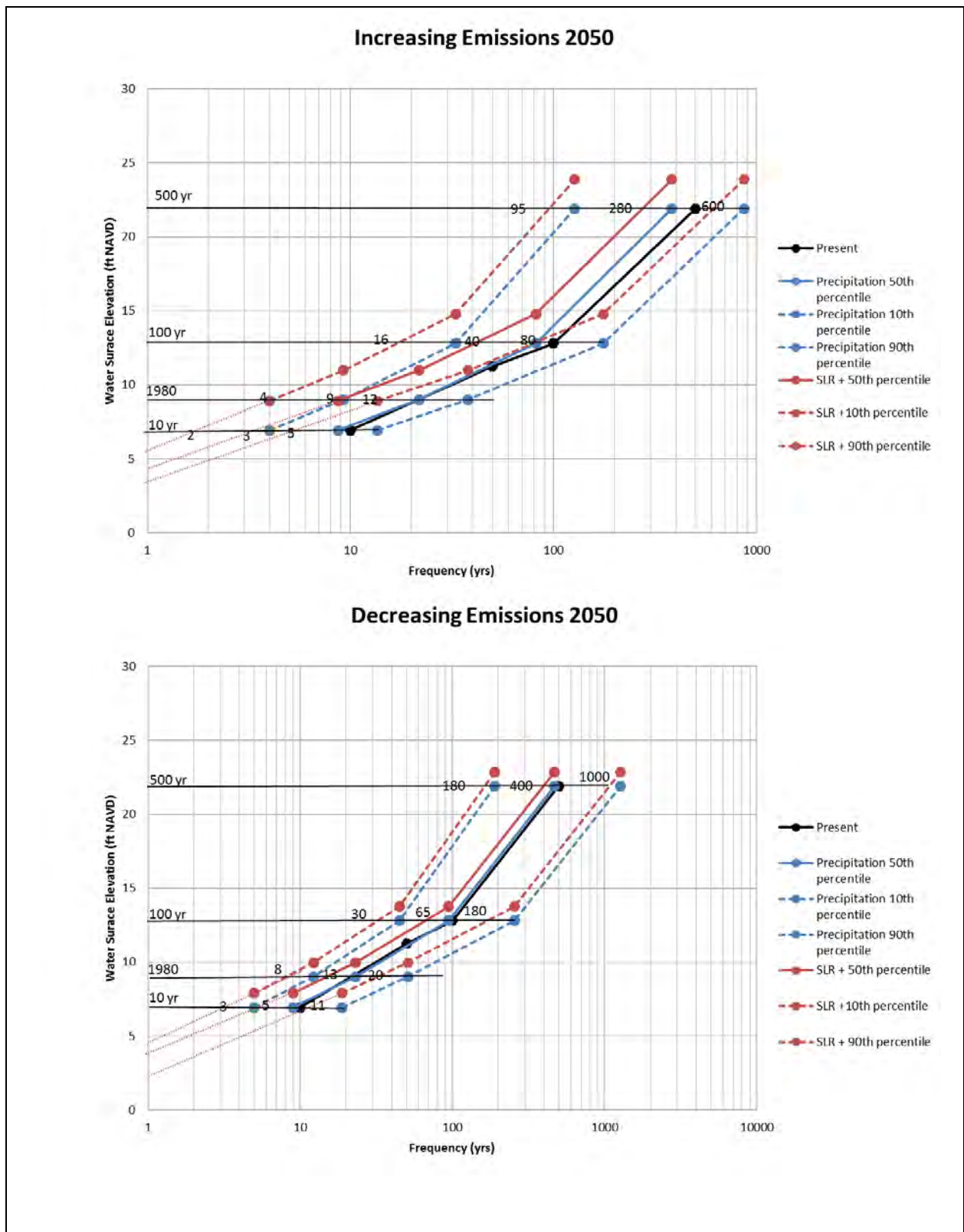
The potential in sediment (sand) deposition in the River channel with sea level rise has a much greater potential to increase River flood levels. The process of long-term channel deposition with sea level rise has not been analyzed or assessed previously (see ESA 12/11/15 Data Gaps Assessment). With 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

Increasing Emissions 2030



Decreasing Emissions 2030





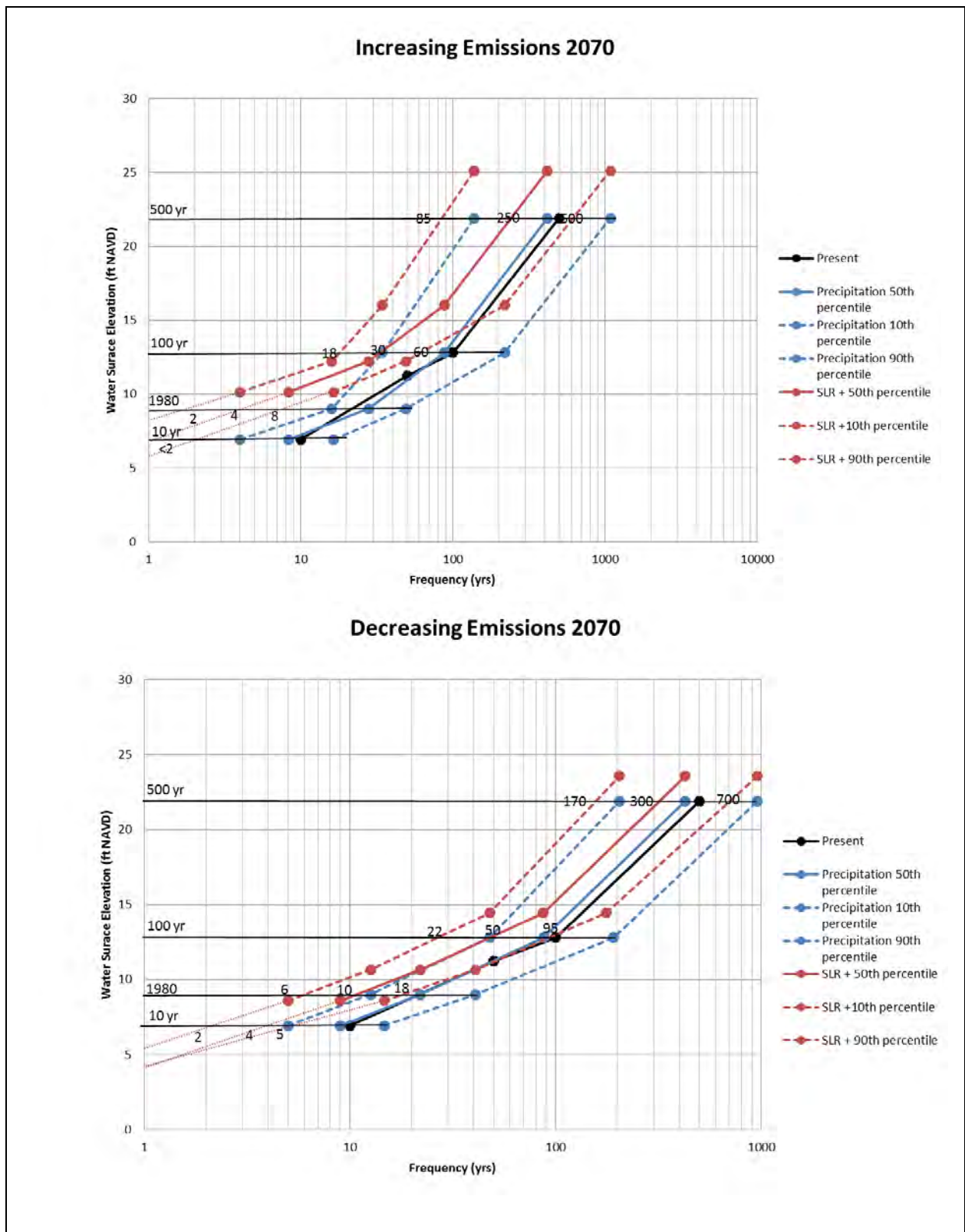


Figure 37
Projected Future River Flood Level Distribution for 2070 for
RCP8.5 (top) and RCP4.5 (bottom) Scenarios

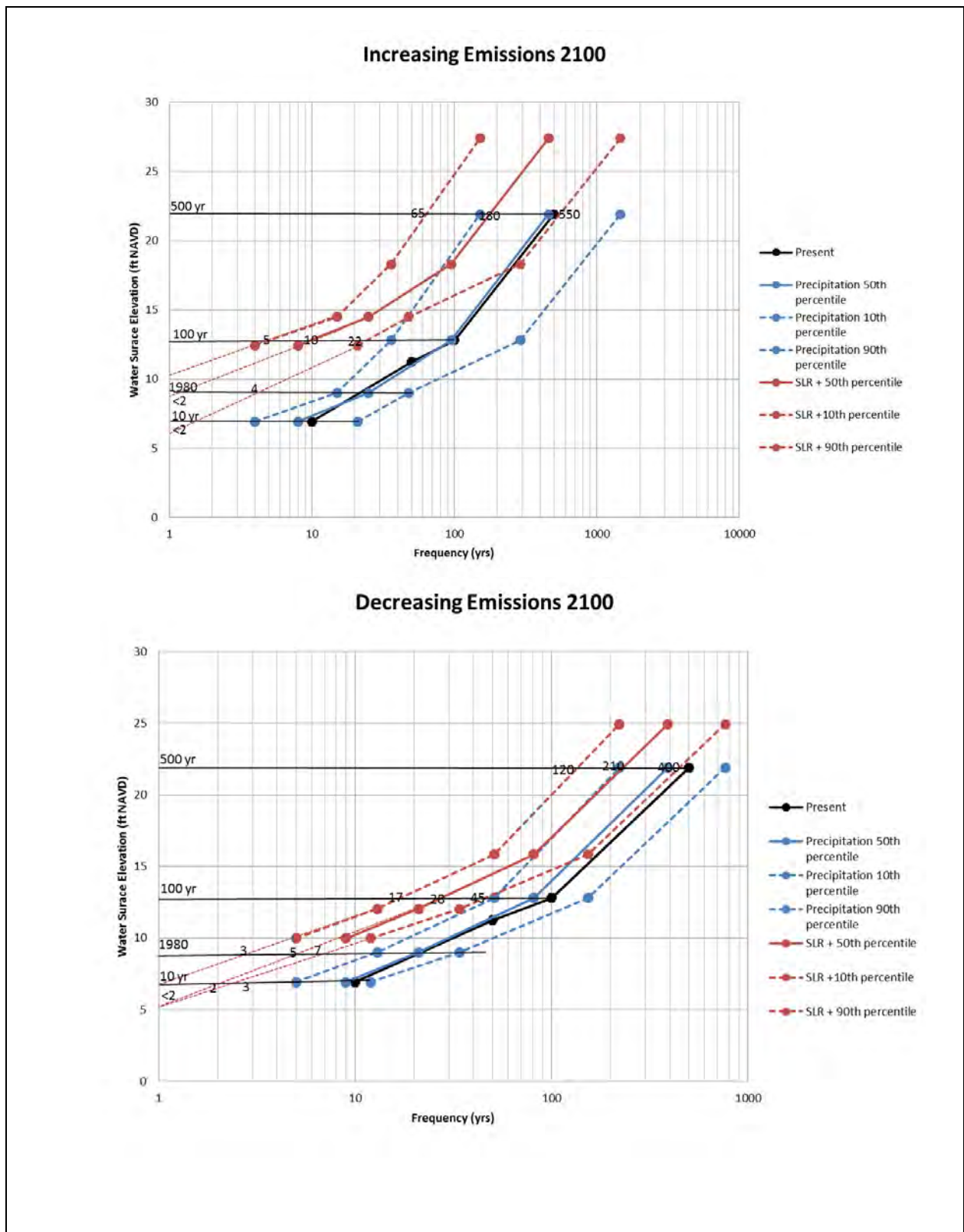


Figure 38
Projected Future River Flood Level Distribution for 2100 for
RCP8.5 (top) and RCP4.5 (bottom) Scenarios

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: Leedschill-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		10 th	50 th	90 th	10 th	50 th	90 th	10 th	50 th	90 th	10 th	50 th	90 th
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		10 th	50 th	90 th	10 th	50 th	90 th	10 th	50 th	90 th	10 th	50 th	90 th
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 2070, 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 criteria 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 (\pm 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 (\pm 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

Del Mar Vulnerability Assessment . D150347

Figure 39

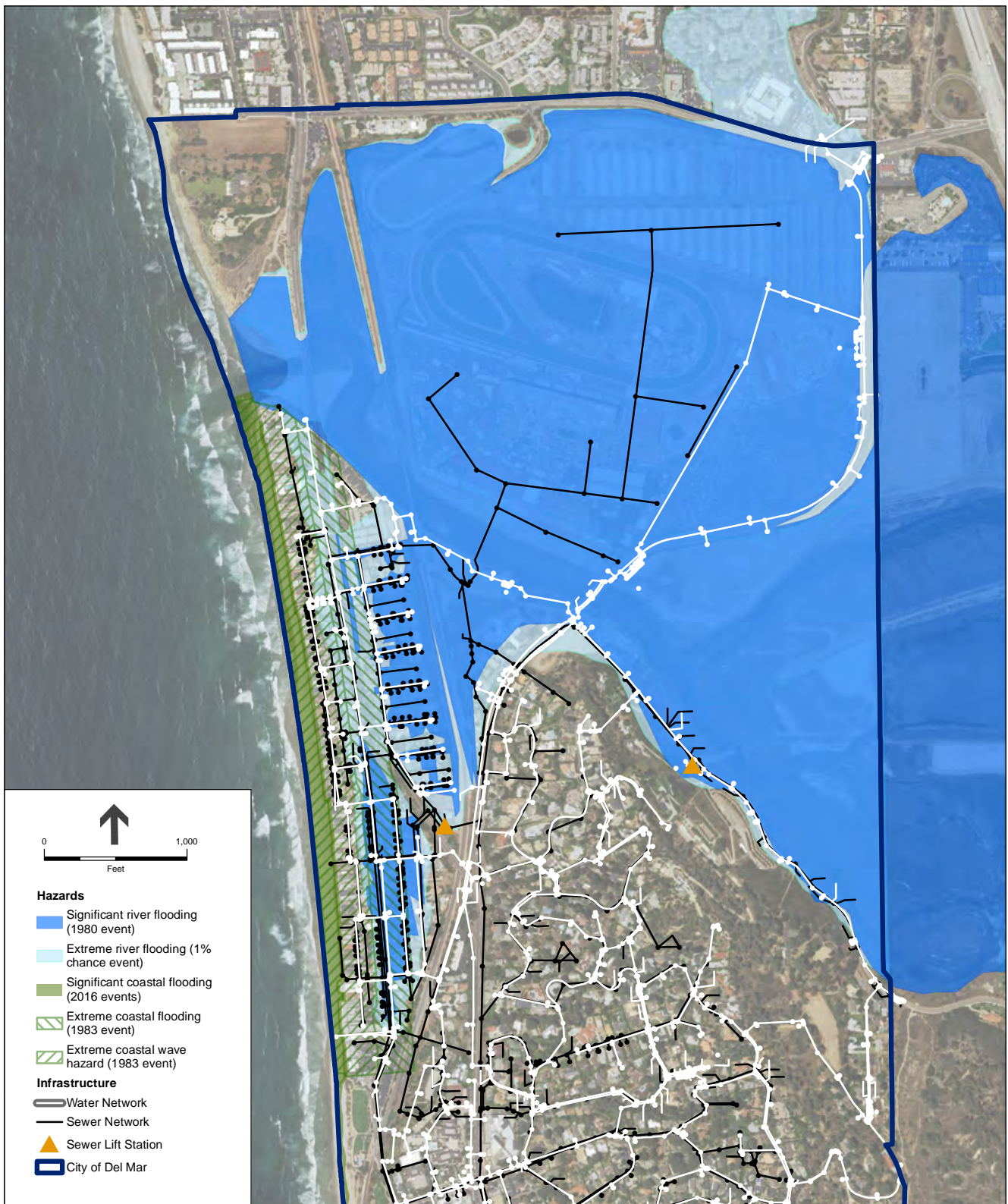
Community Districts in Del Mar



SOURCE: SanGIS 2016, FEMA

Del Mar Vulnerability Assessment . D150347

Figure 40.1
Flood Zones and Hazards
Properties and Roads Vulnerability

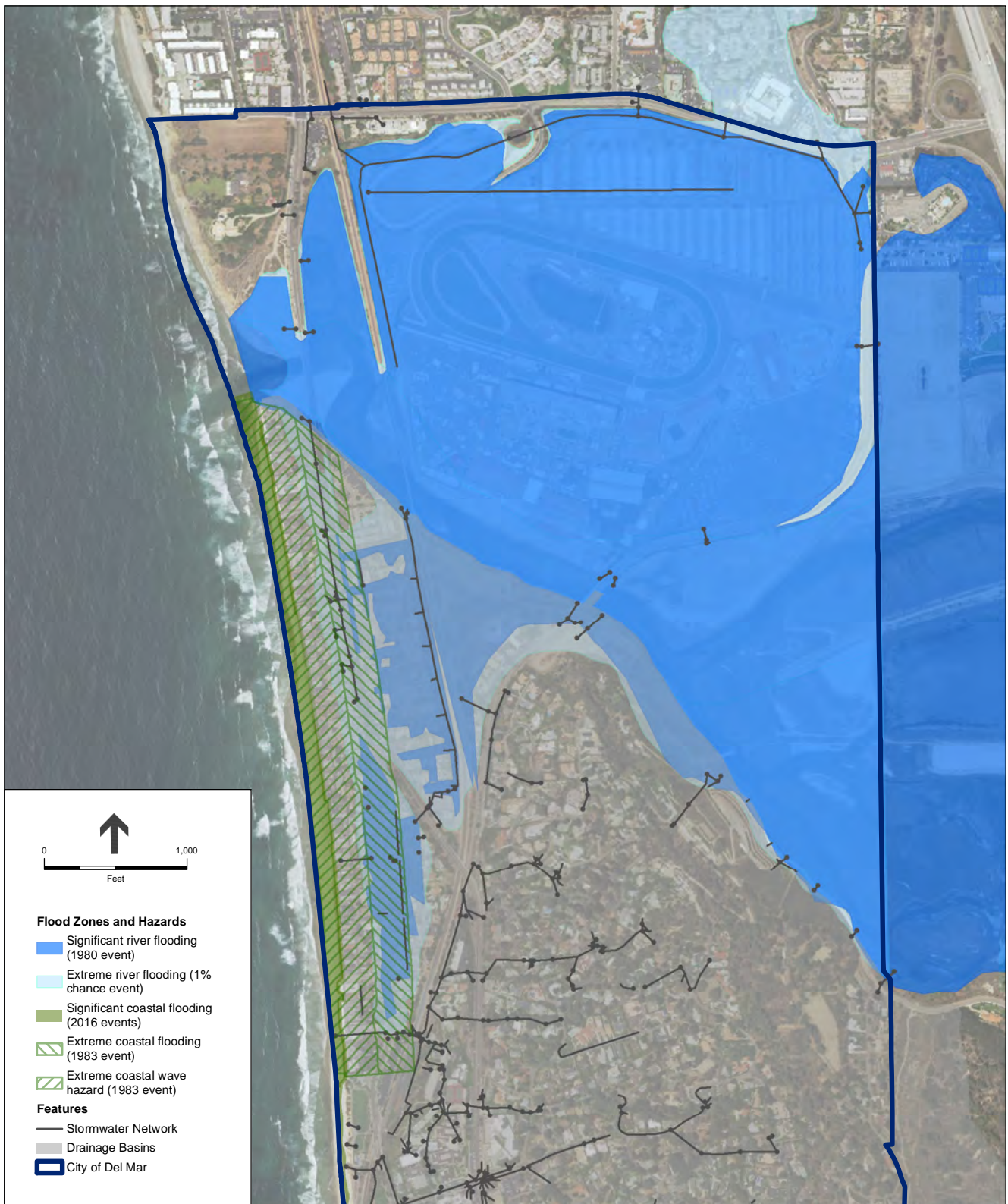


SOURCE: SanGIS 2016, FEMA

Del Mar LCP Update . D150347

Figure 40.2

Flood Zones and Hazards
Water and Sewer Infrastructure Vulnerability



SOURCE: SanGIS 2016, FEMA

Del Mar Vulnerability Assessment . D150347

Figure 40.3

Flood Zones and Hazards
Stormwater Infrastructure Vulnerability

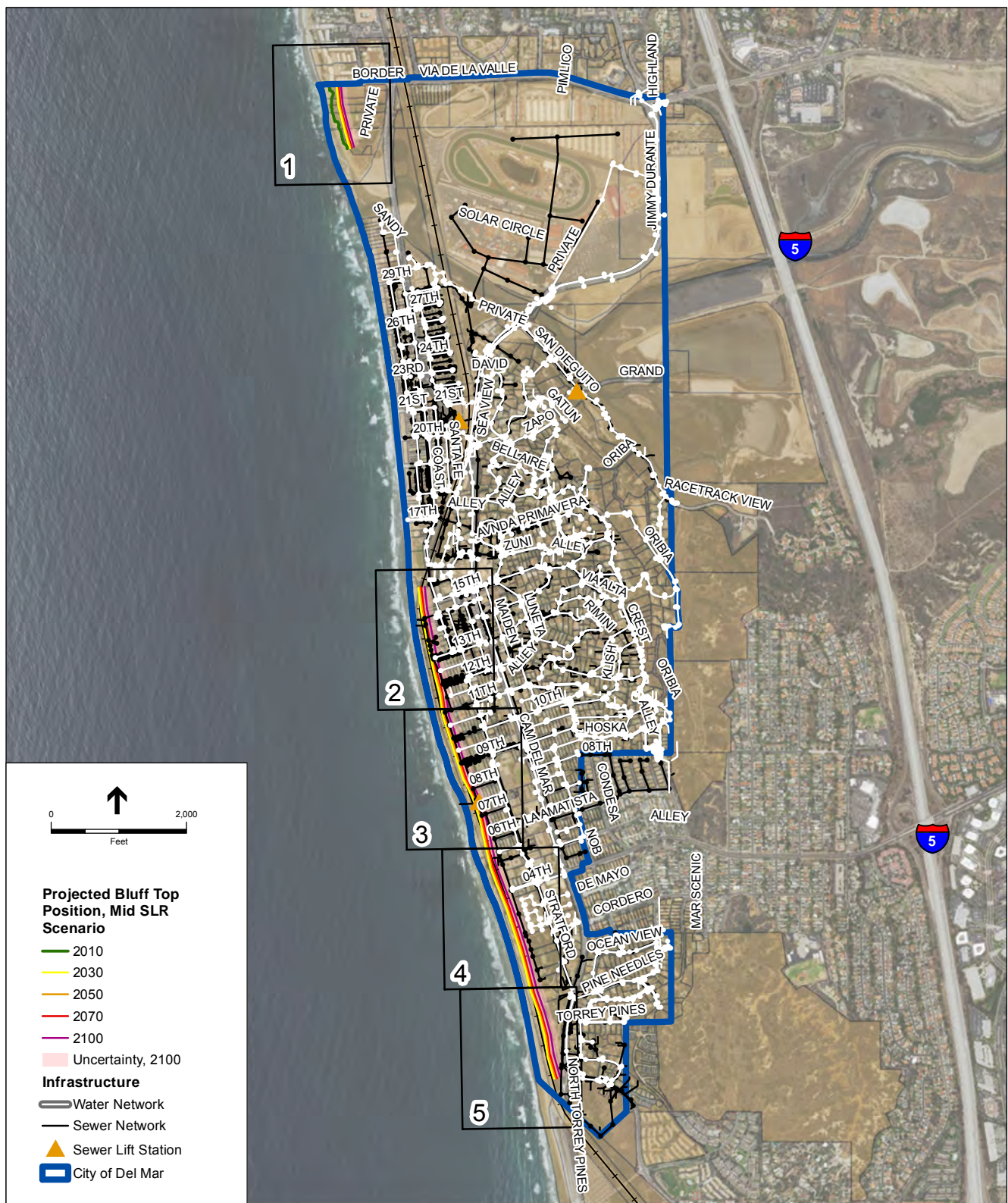


SOURCE: SanGIS 2016, USGS 2015

Del Mar Vulnerability Assessment . D150347

Figure 40.4

Flood Zones and Hazards
Public Access and City Services Vulnerability

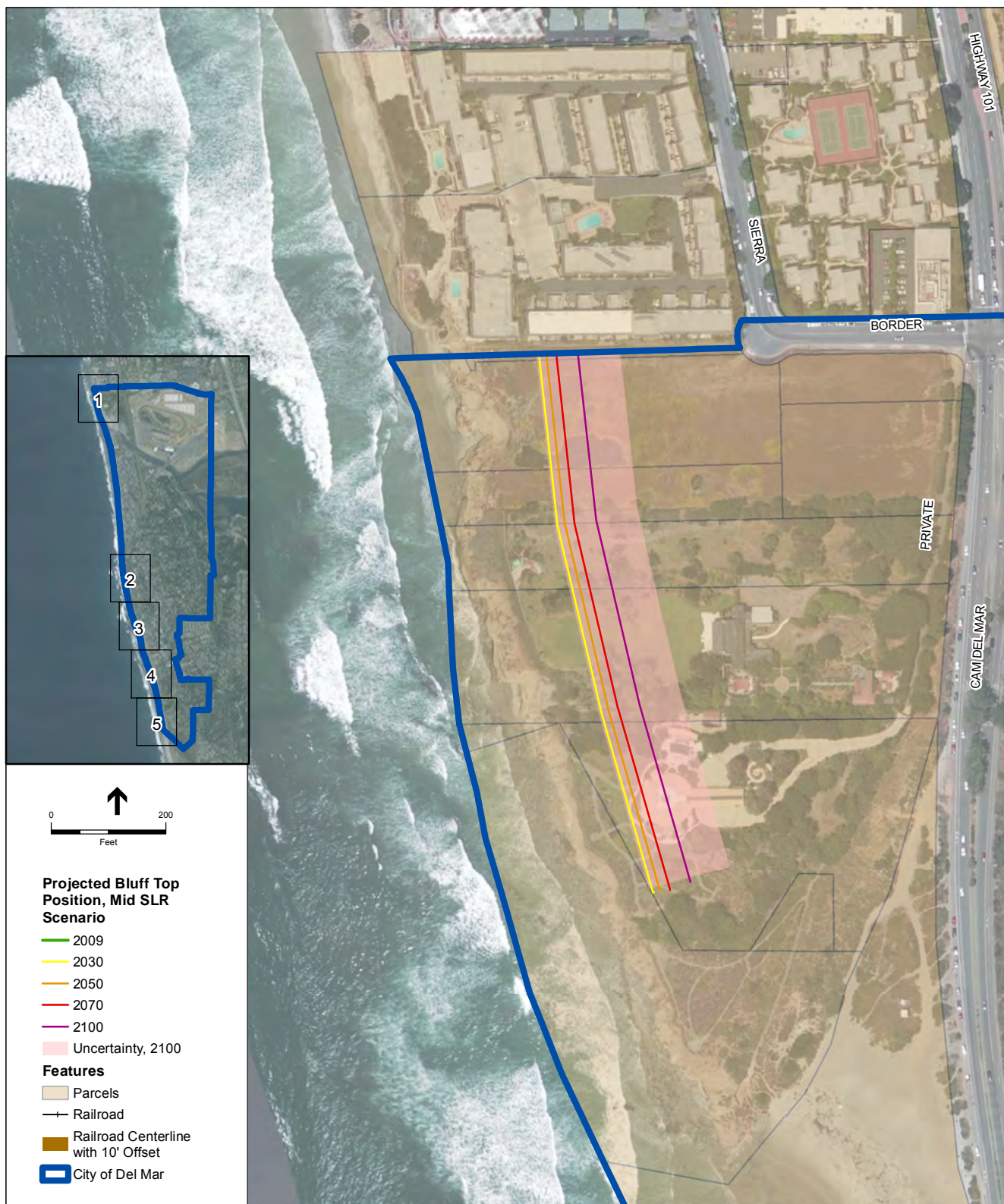


SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

Figure 41- Map Grid Overview
Mid Sea Level Rise in Del Mar
Water and Sewer Infrastructure Vulnerability



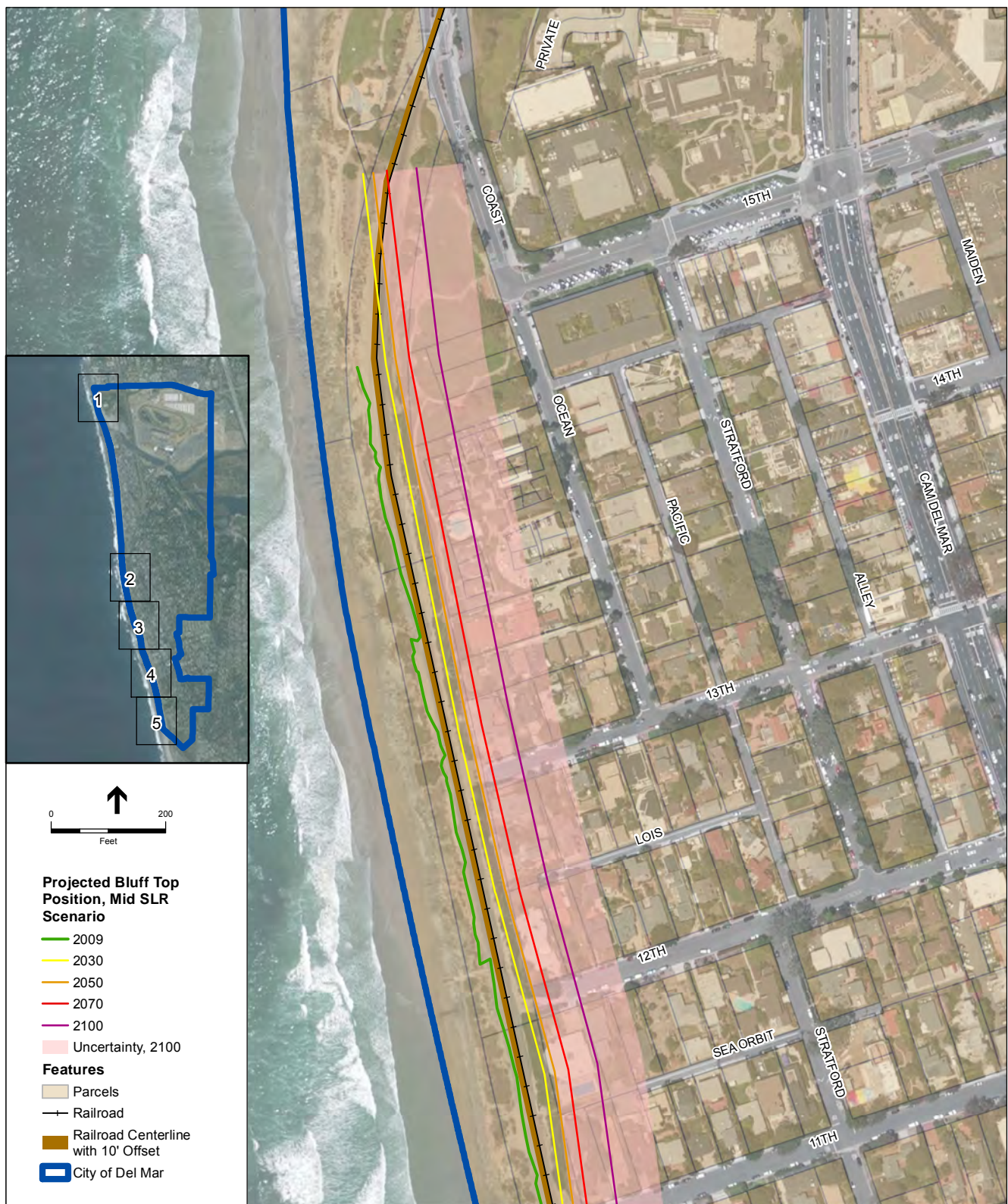
SOURCE: SanGIS 2016, USGS 2015

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

Figure 41.1

Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability



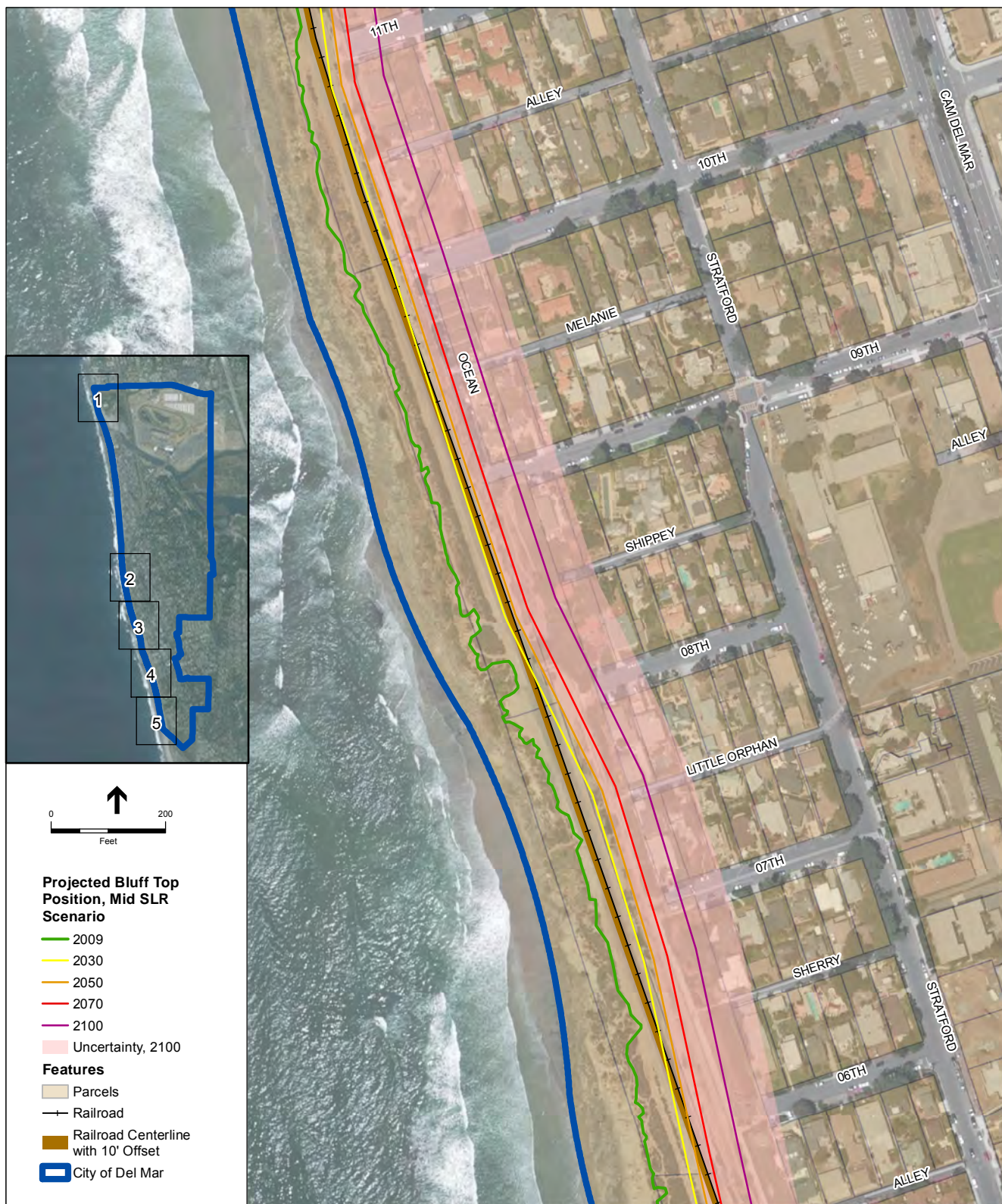
SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

Figure 41.2

Mid Sea Level Rise in Del Mar Properties and Roads Vulnerability



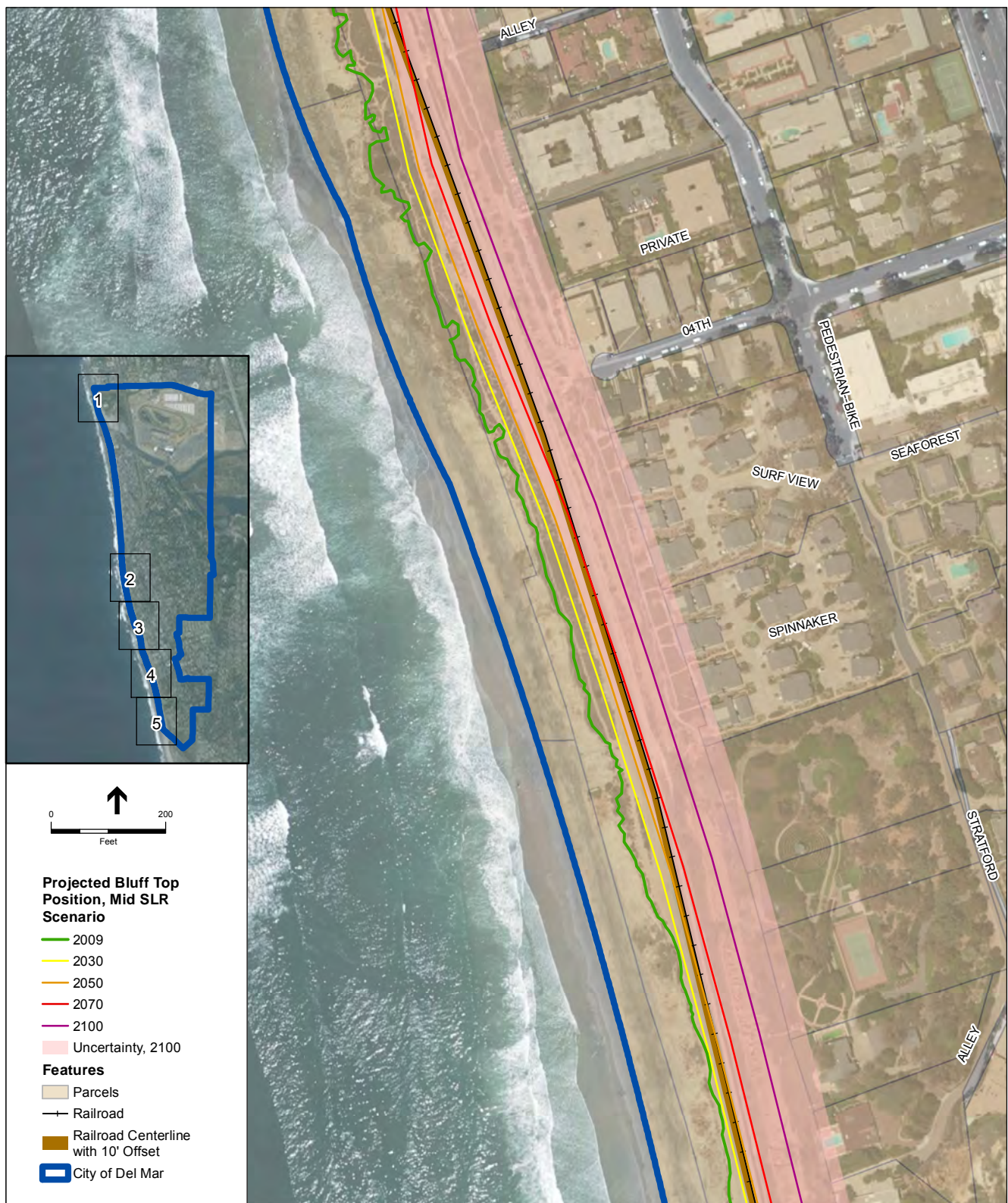
SOURCE: SanGIS 2016, USGS 2015

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

Figure 41.3

Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability



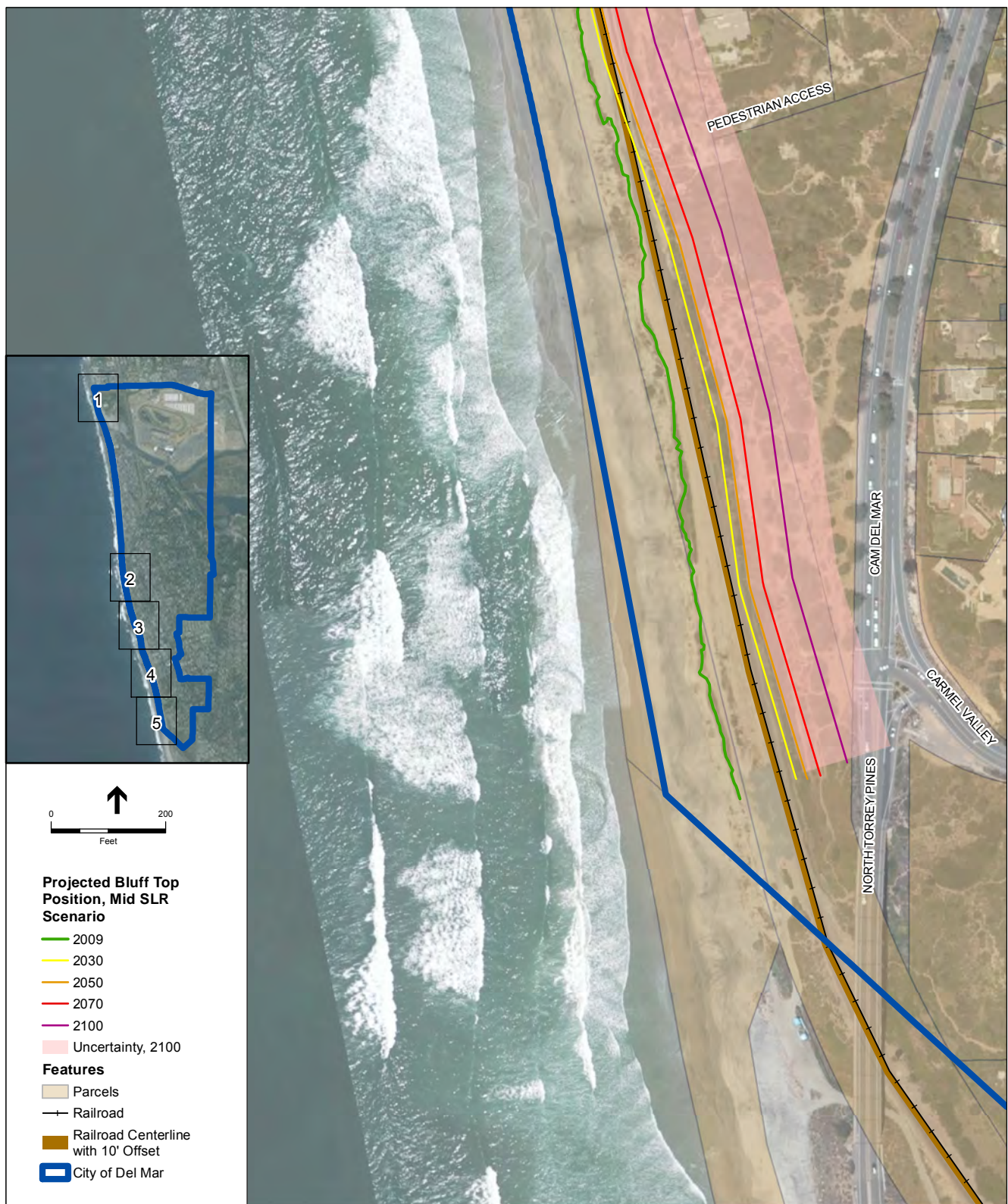
SOURCE: SanGIS 2016, USGS 2015

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

Figure 41.4

Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability



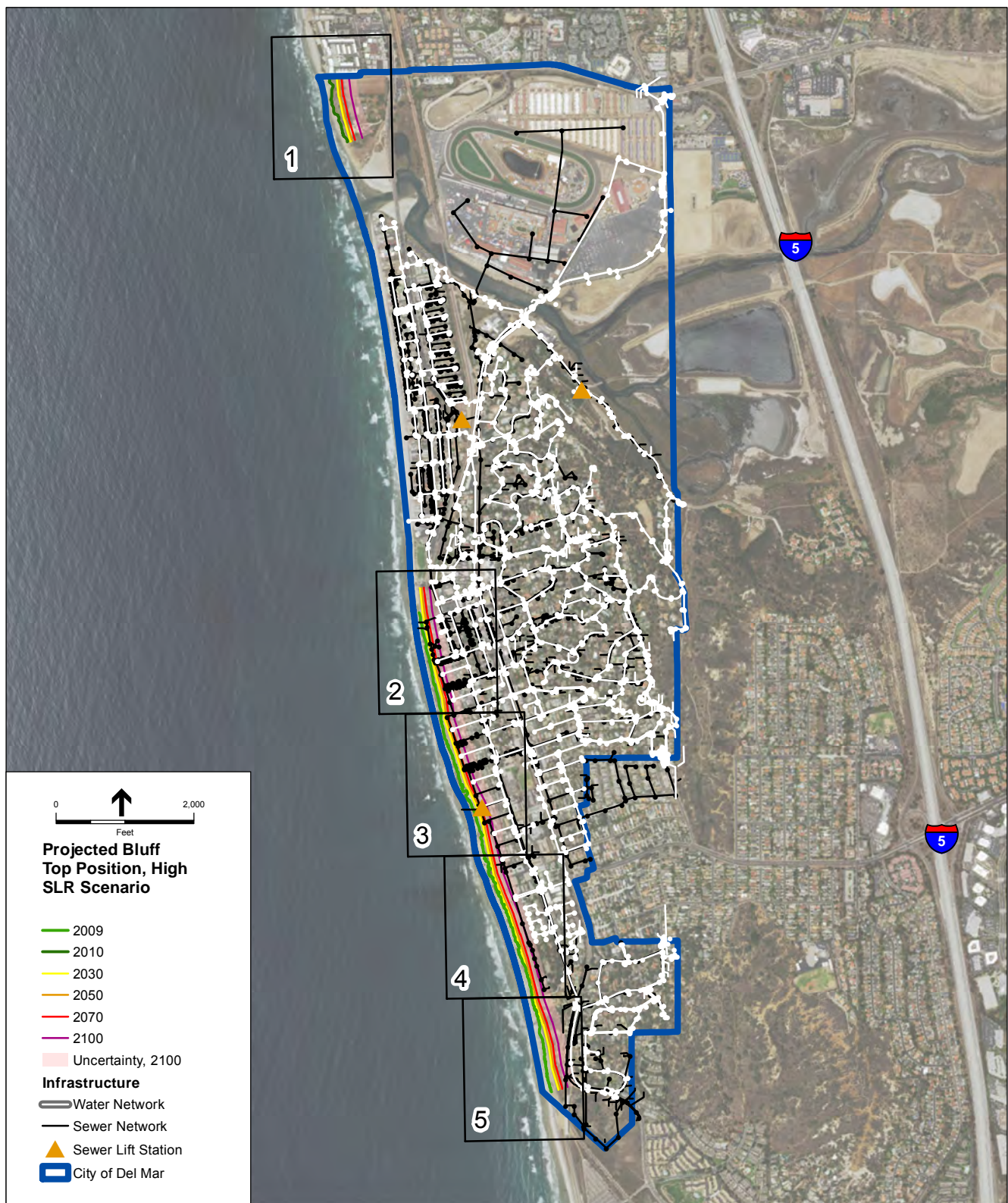
SOURCE: SanGIS 2016, USGS 2015

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

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Figure 41.5

Mid Sea Level Rise in Del Mar
Properties and Roads Vulnerability

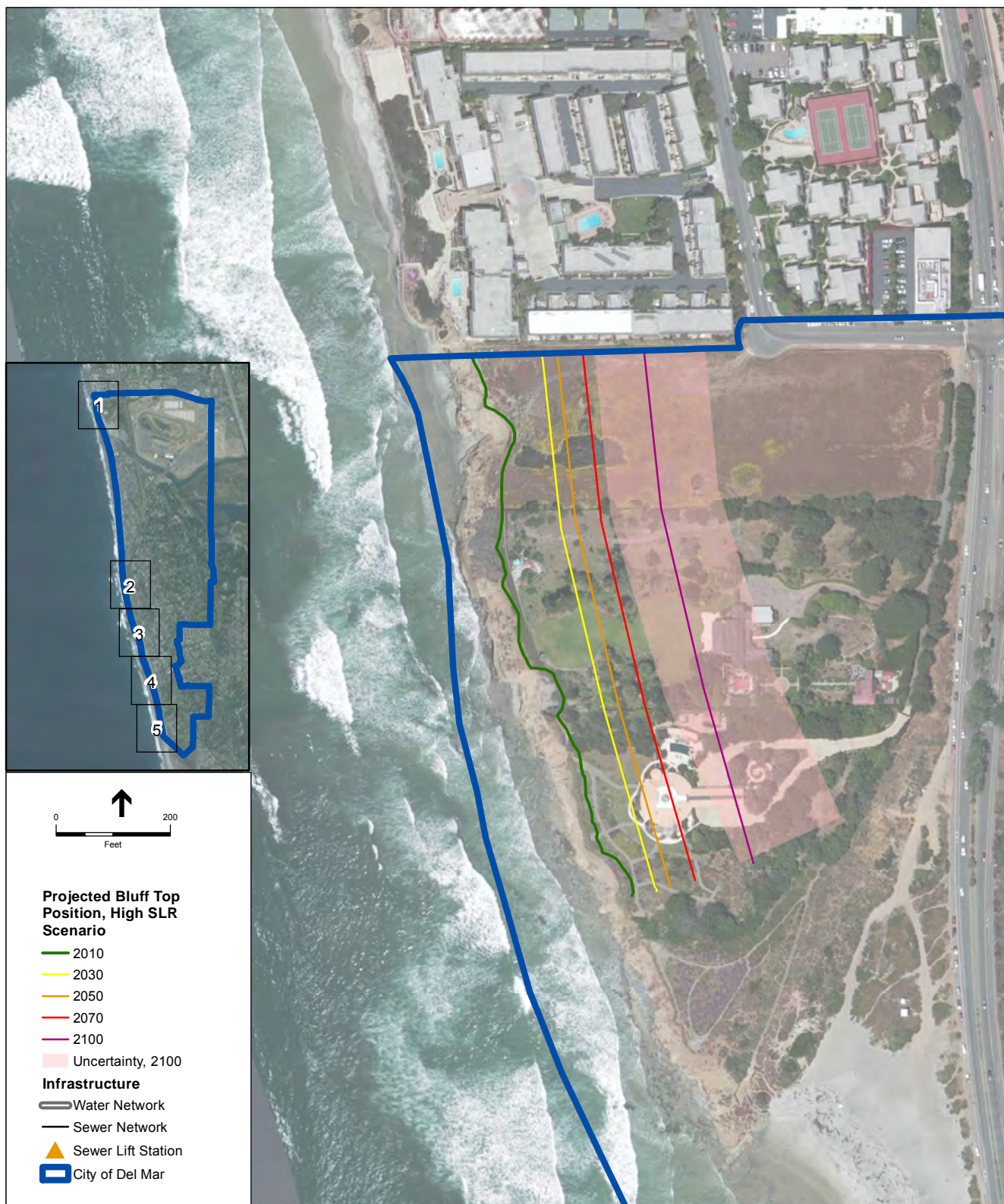


SOURCE: SanGIS 2016, USGS 2015

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.

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Figure 42- Map Grid Overview
High Sea Level Rise in Del Mar
Water and Sewer Infrastructure Vulnerability



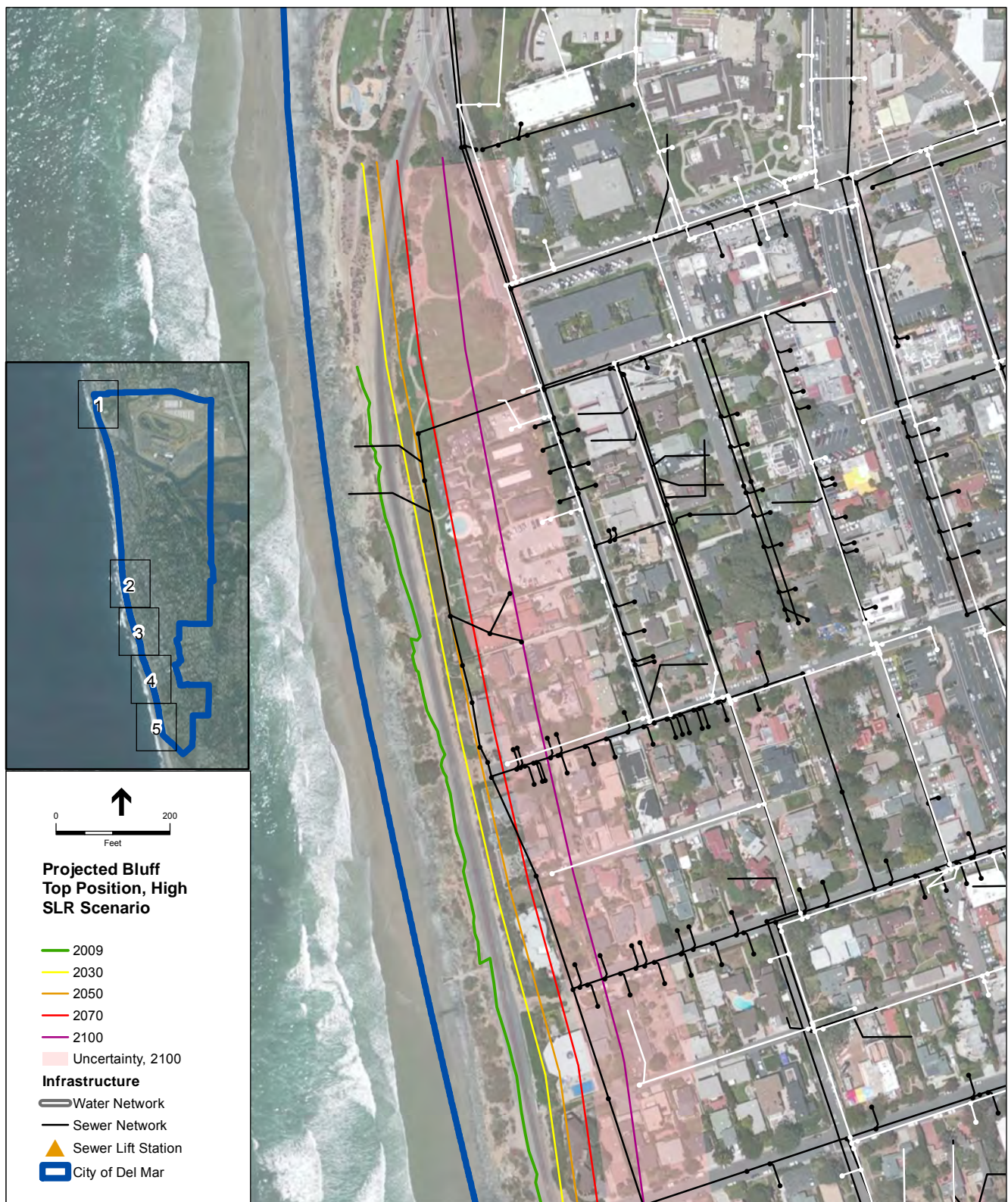
SOURCE: SanGIS 2016, USGS 2015

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.

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Figure 42.1

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



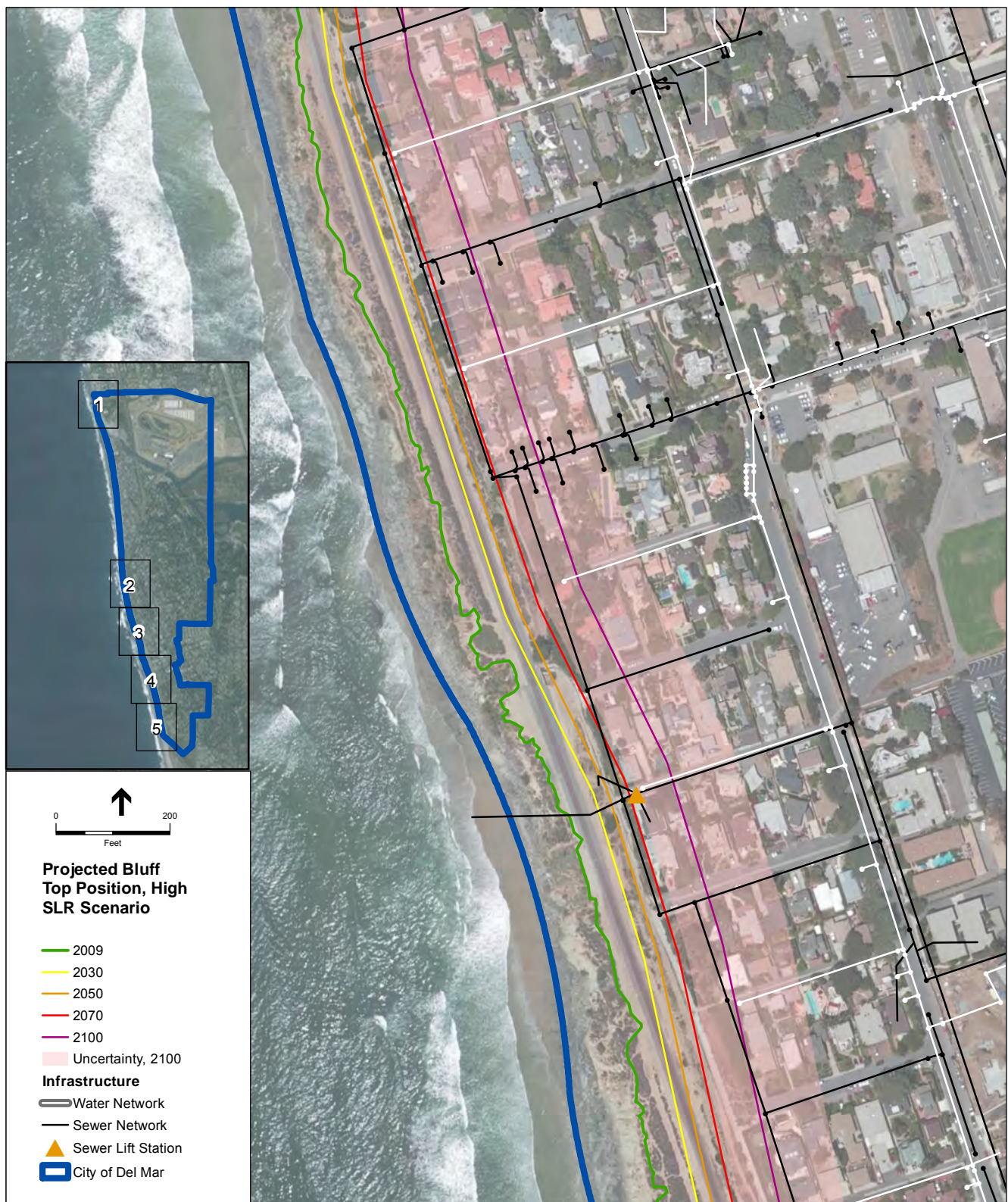
SOURCE: SanGIS 2016, USGS 2015

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

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Figure 42.2

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



SOURCE: SanGIS 2016, USGS 2015

Del Mar Vulnerability Assessment . D150347

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

Figure 42.3
High Sea Level Rise in Del Mar
Water and Sewer Infrastructure Vulnerability



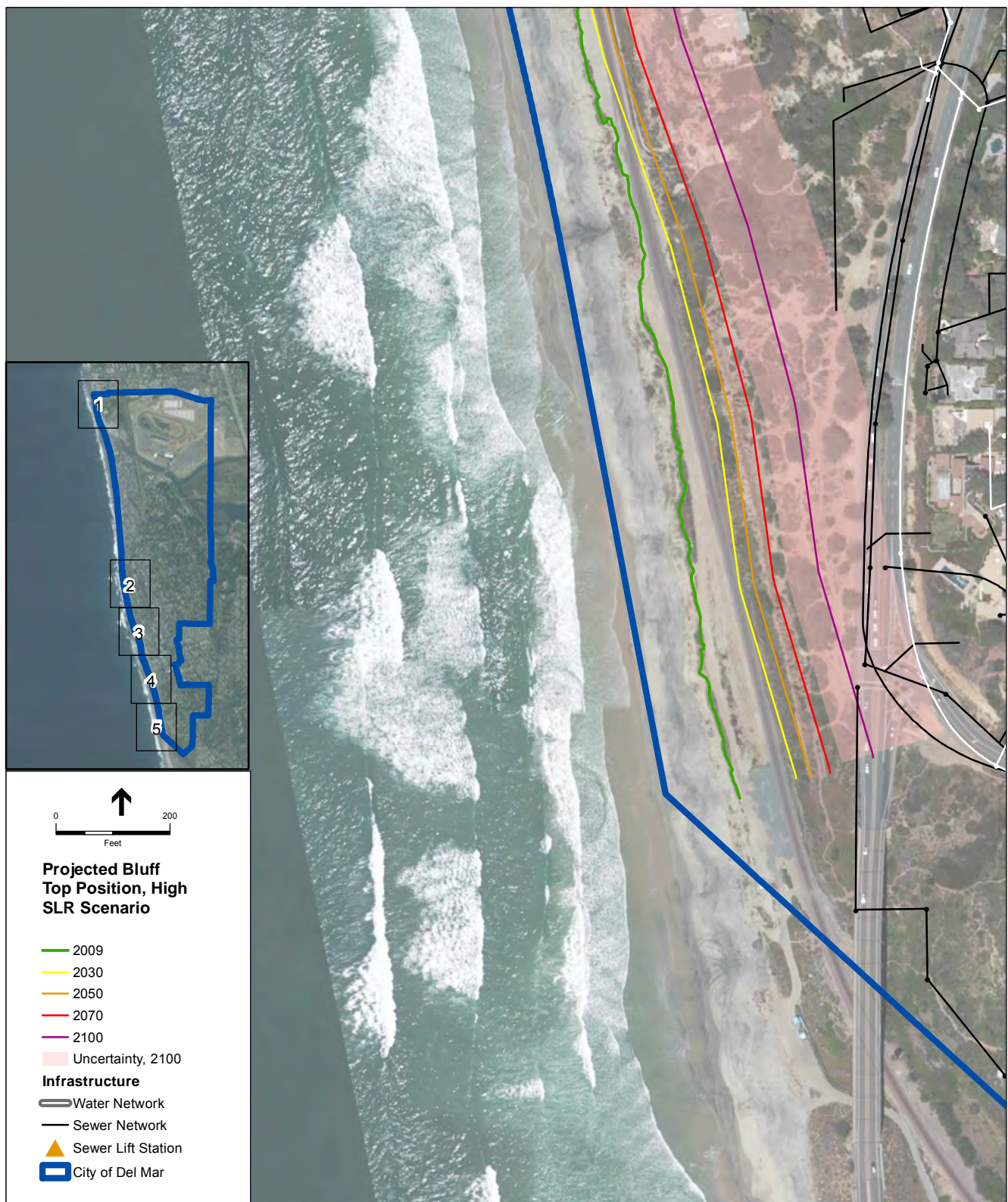
SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

Figure 42.4

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

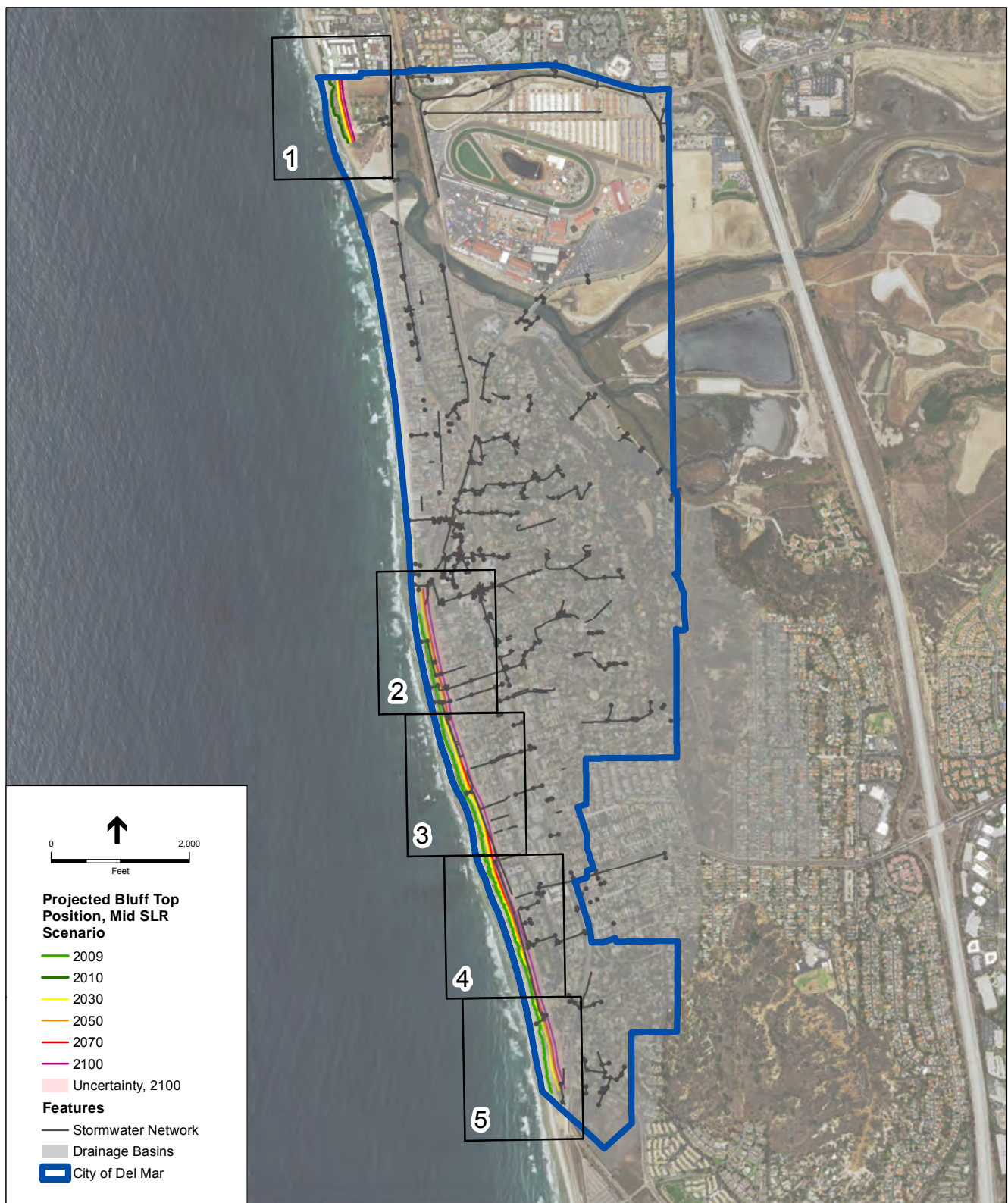


SOURCE: SanGIS 2016, USGS 2015

Del Mar Vulnerability Assessment . D150347

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 2100 (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.

Del Mar Vulnerability Assessment . D150347

Figure 43- Map Grid Overview

Mid Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability



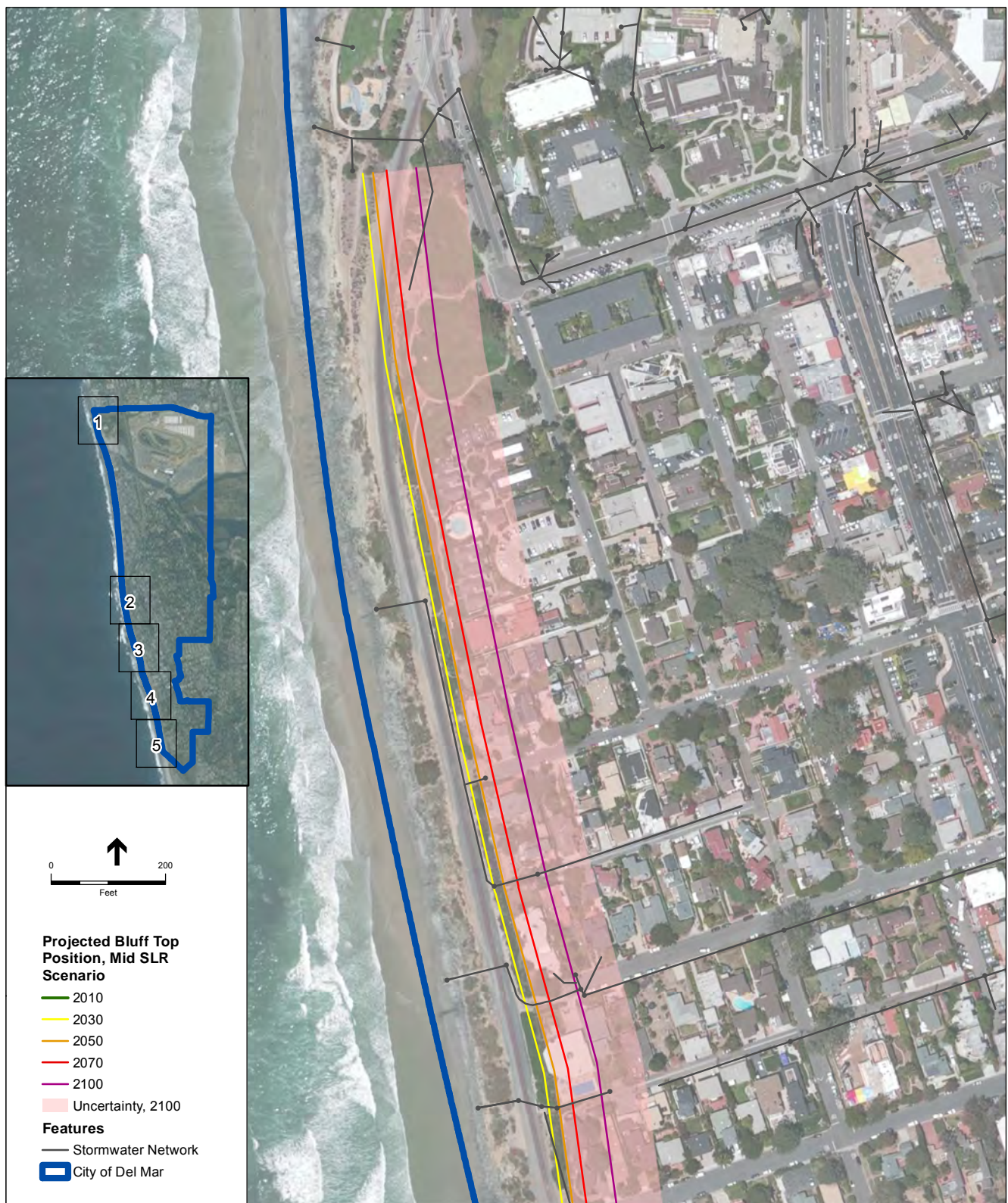
SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

Figure 43.1

Mid Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability



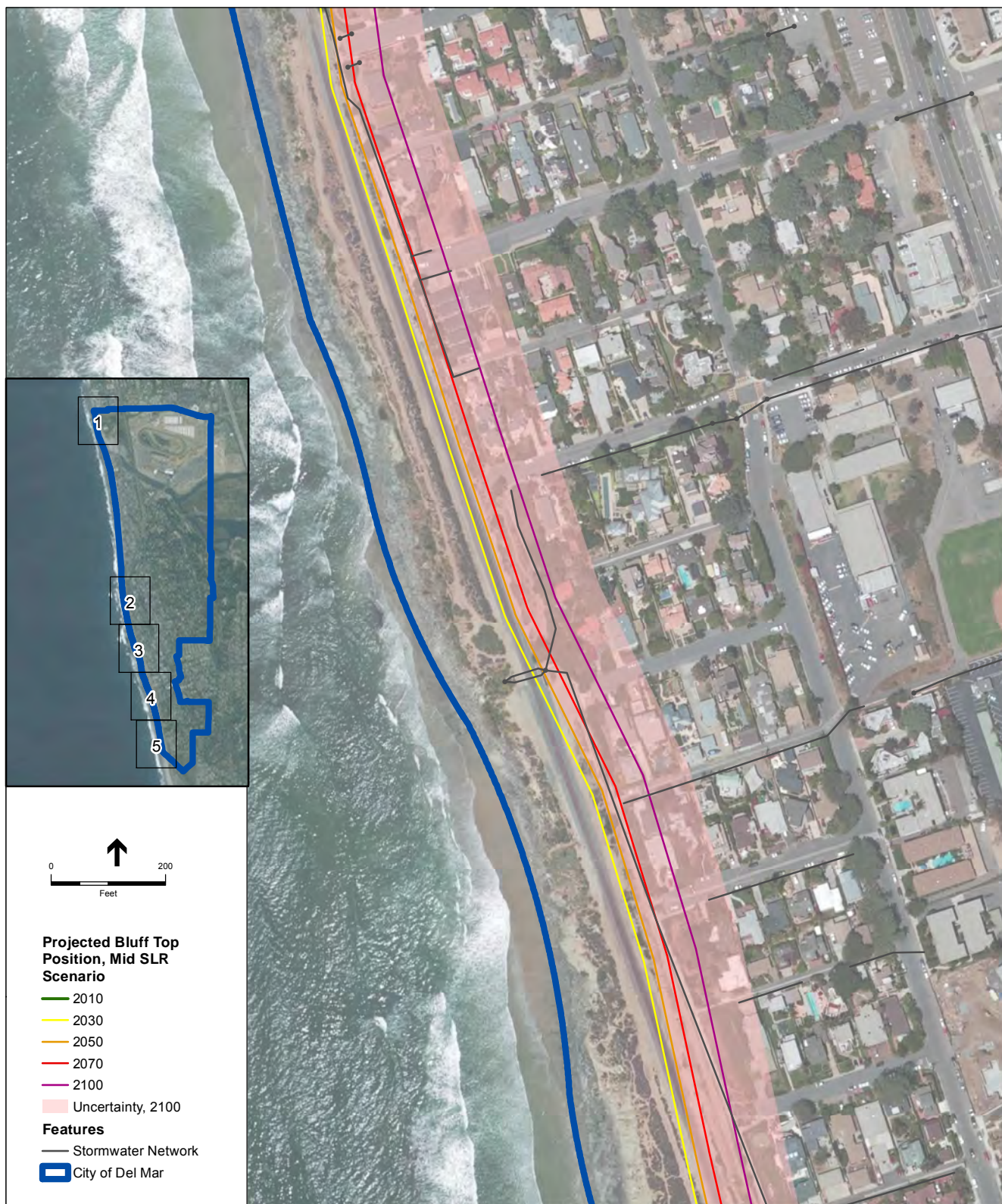
SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

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.

Del Mar Vulnerability Assessment . D150347

Figure 43.3

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.

Del Mar Vulnerability Assessment . D150347

Figure 43.4

Mid Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability



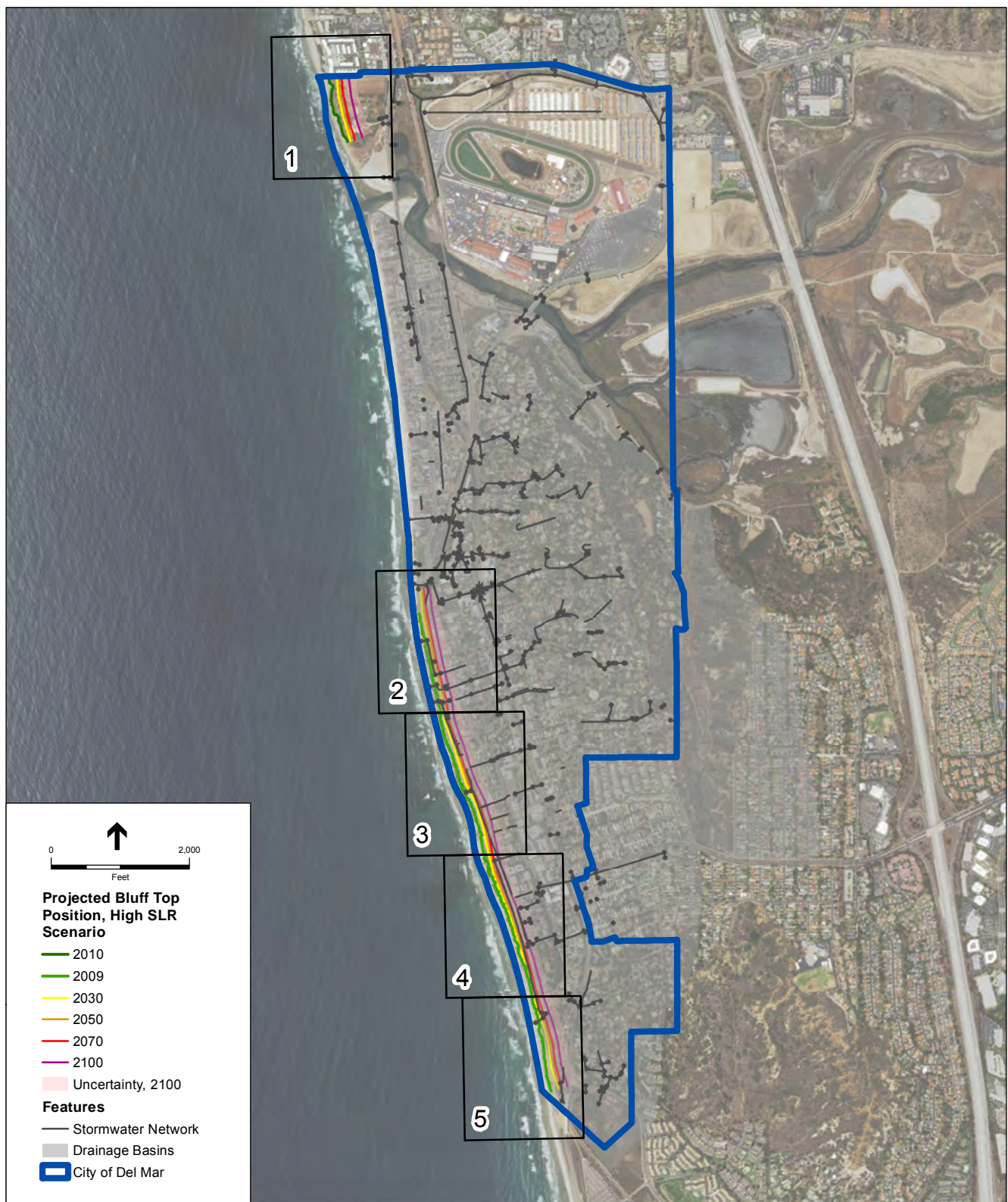
SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

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.

Del Mar Vulnerability Assessment . D150347

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

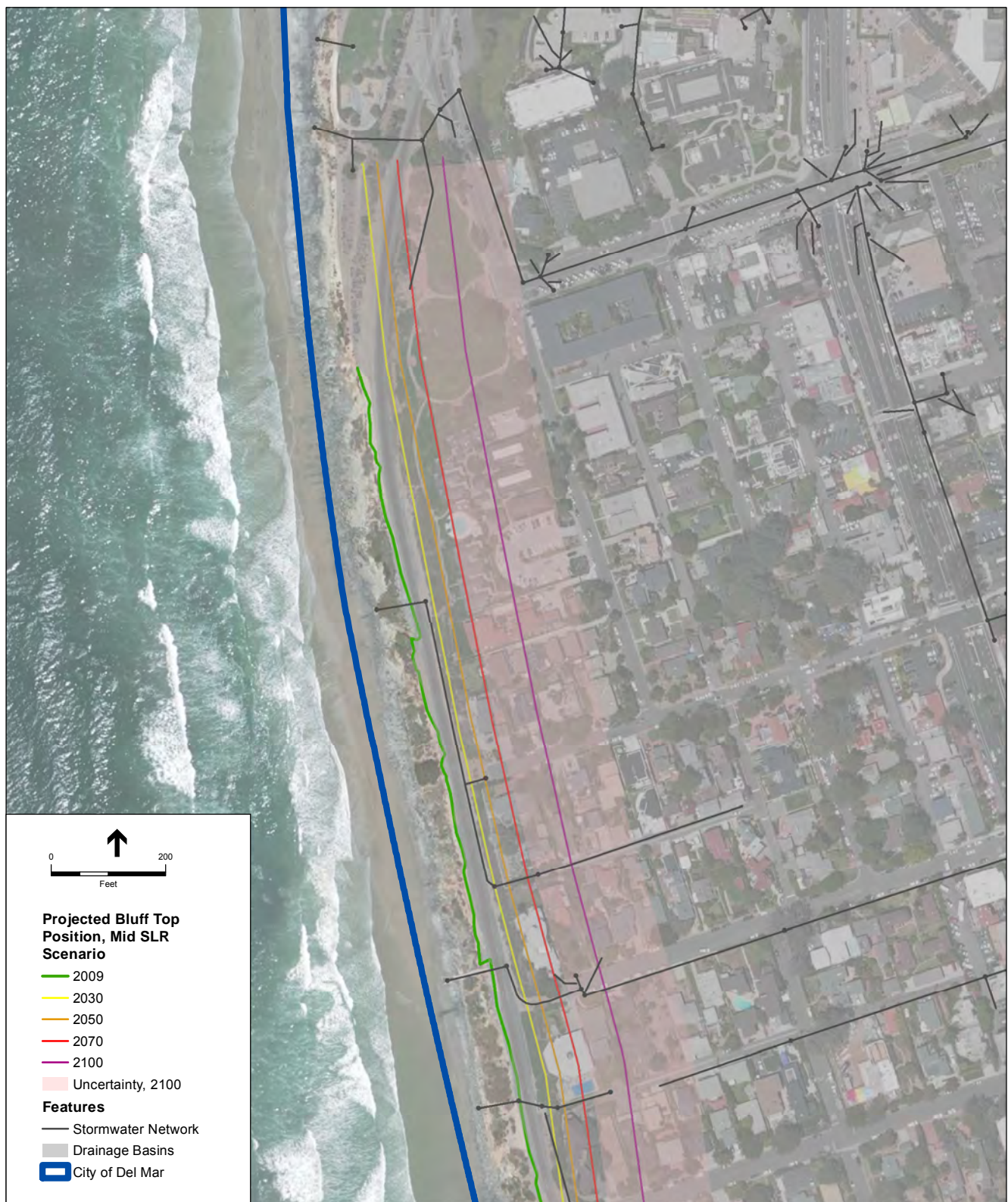


SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

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

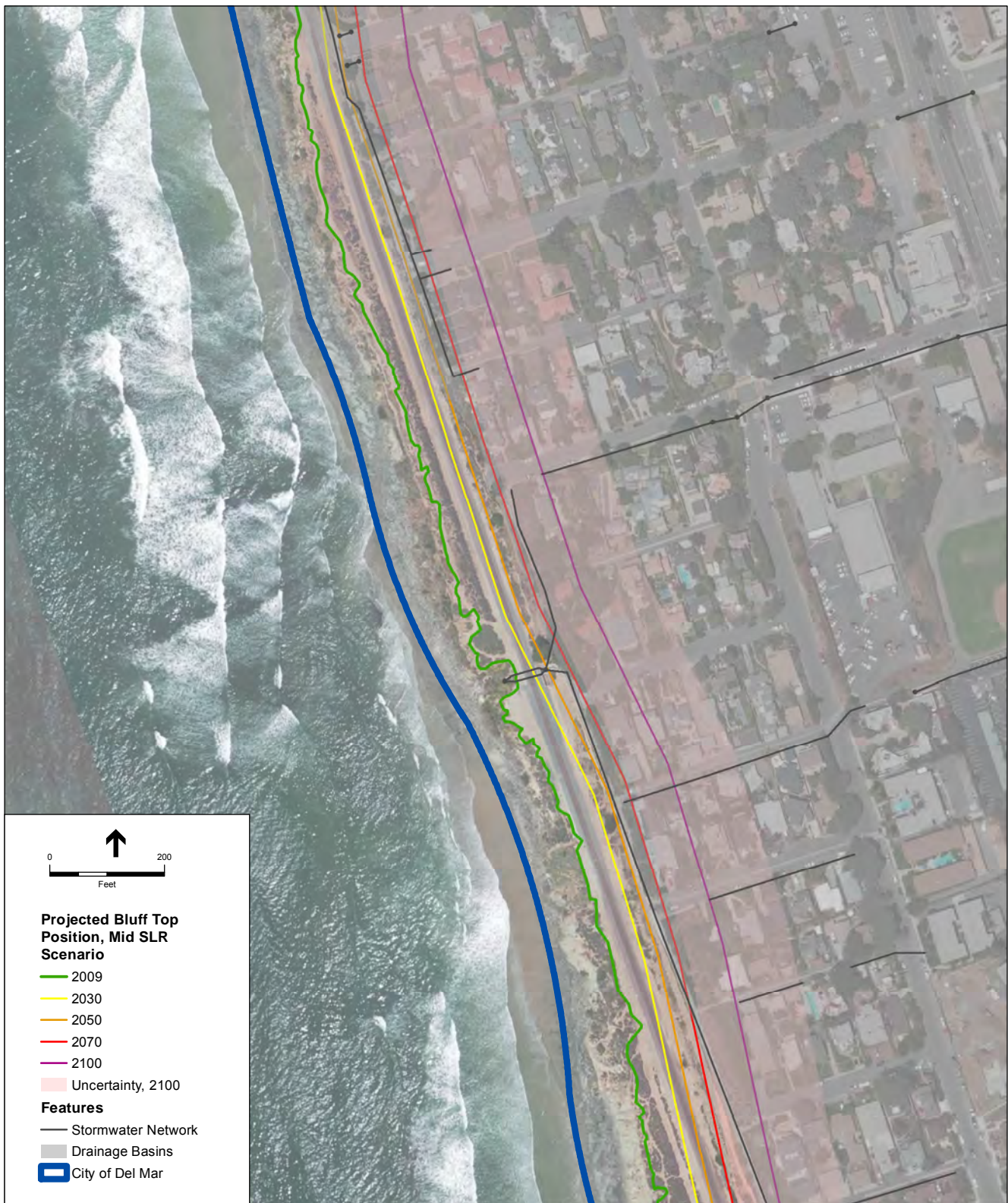


SOURCE: SanGIS 2016, USGS 2015

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

Figure 44.2
High Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability

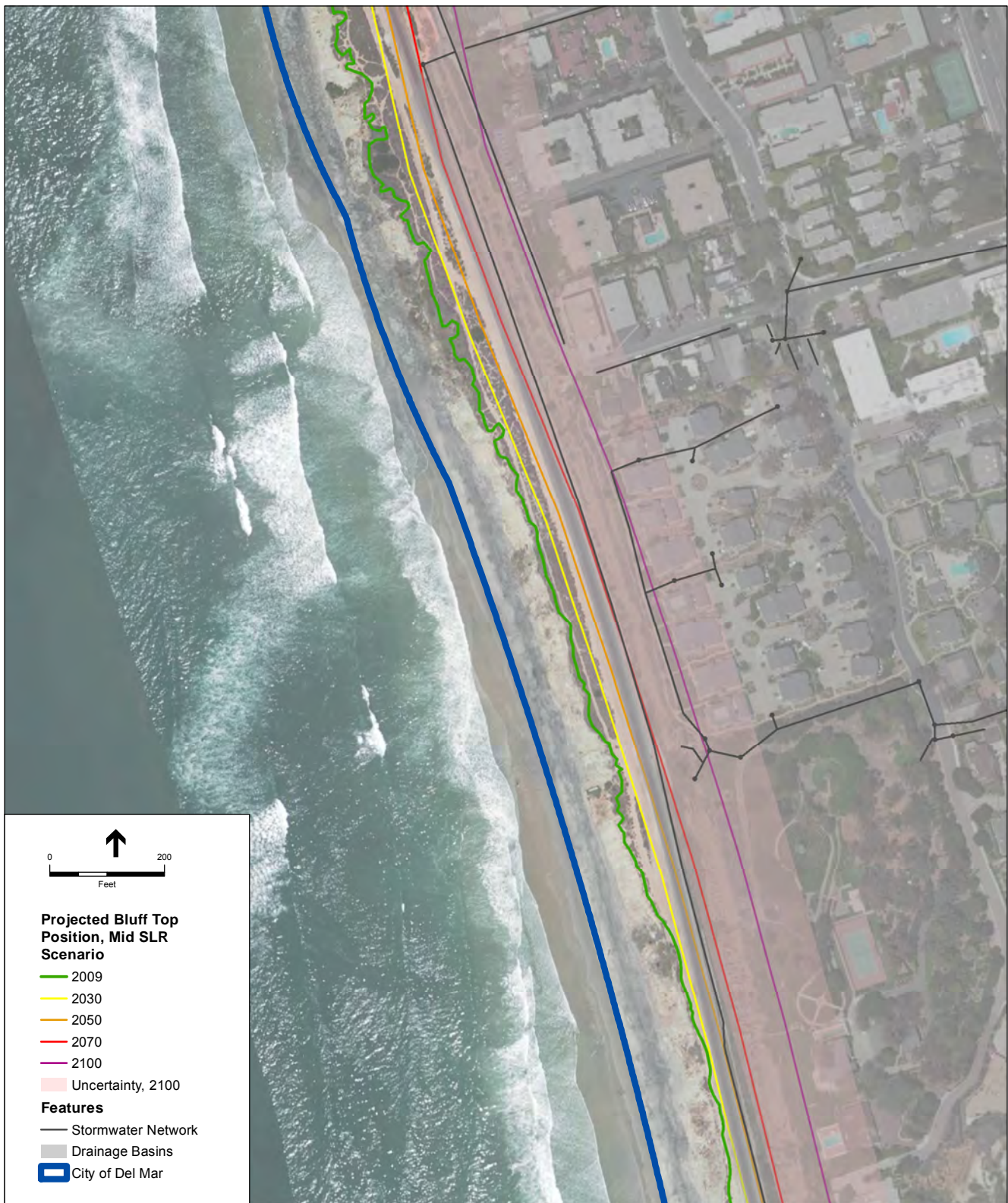


SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

Figure 44.3
High Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability

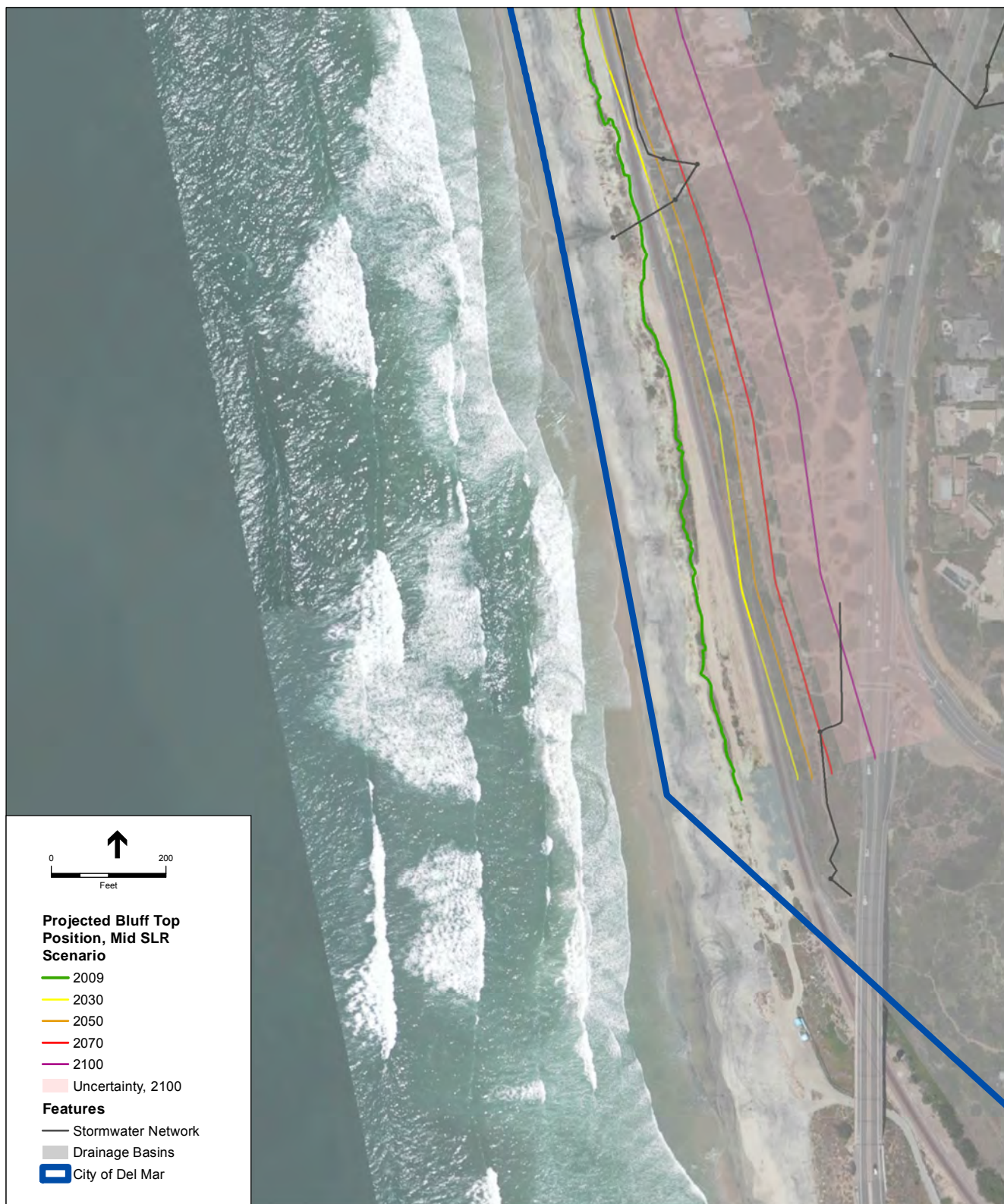


SOURCE: SanGIS 2016, USGS 2015

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

Figure 44.4
High Sea Level Rise in Del Mar
Stormwater Infrastructure Vulnerability

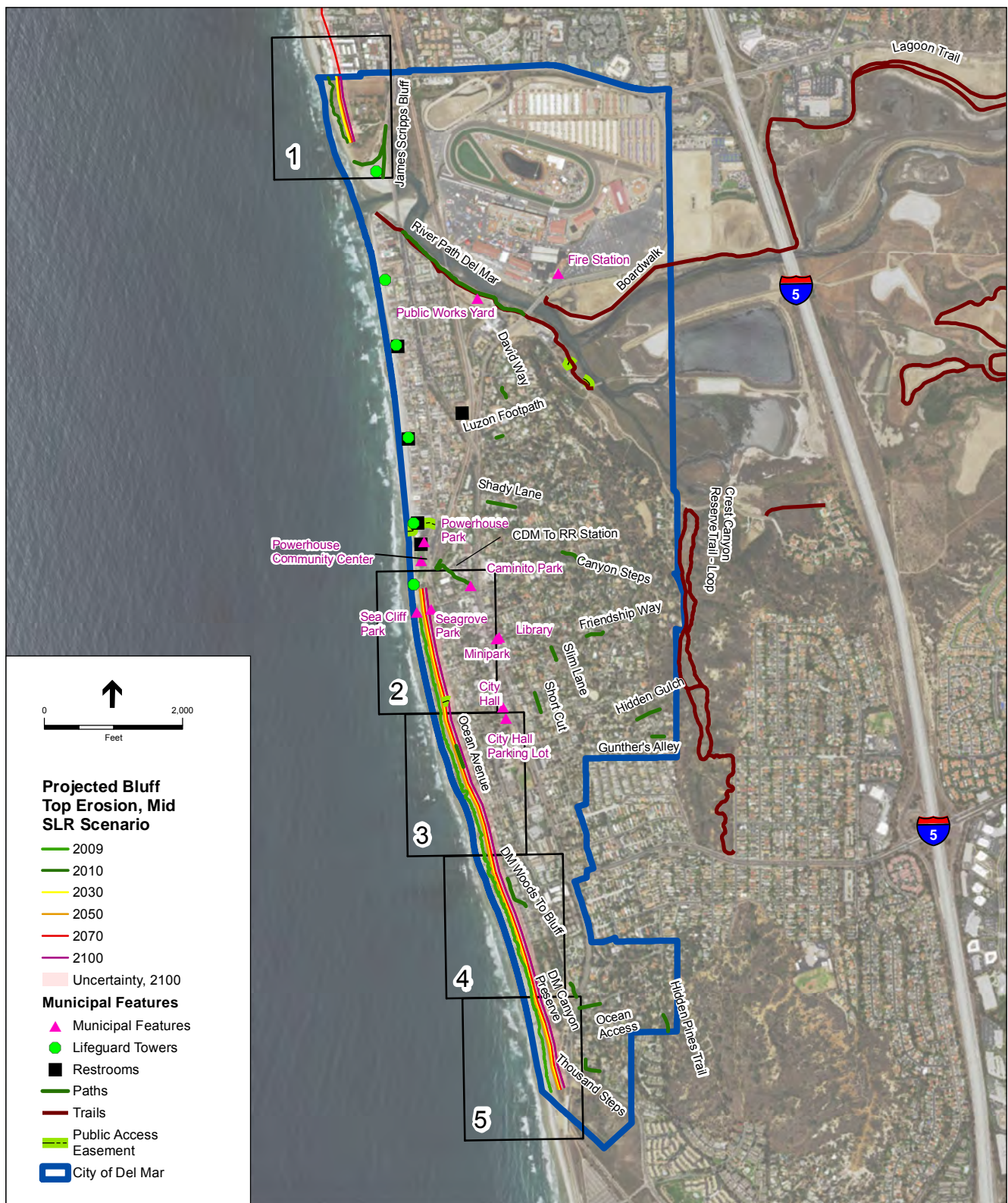


SOURCE: SanGIS 2016, USGS 2015

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

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.

Del Mar Vulnerability Assessment . D150347

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.

Del Mar Vulnerability Assessment . D150347

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

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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.

Del Mar Vulnerability Assessment . D150347

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.

Del Mar Vulnerability Assessment . D150347

Figure 45.4

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

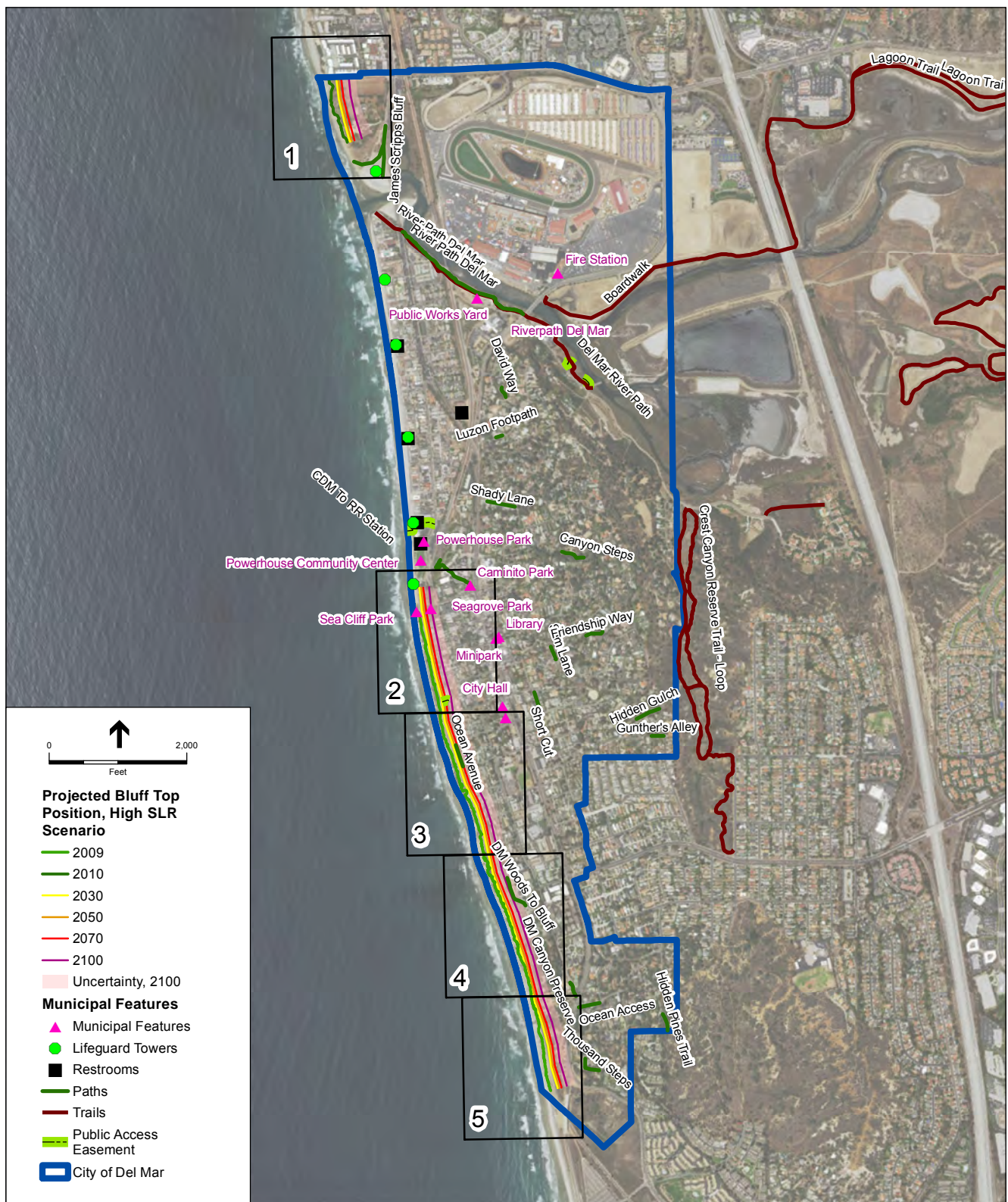


SOURCE: SanGIS 2016, USGS 2015

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

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

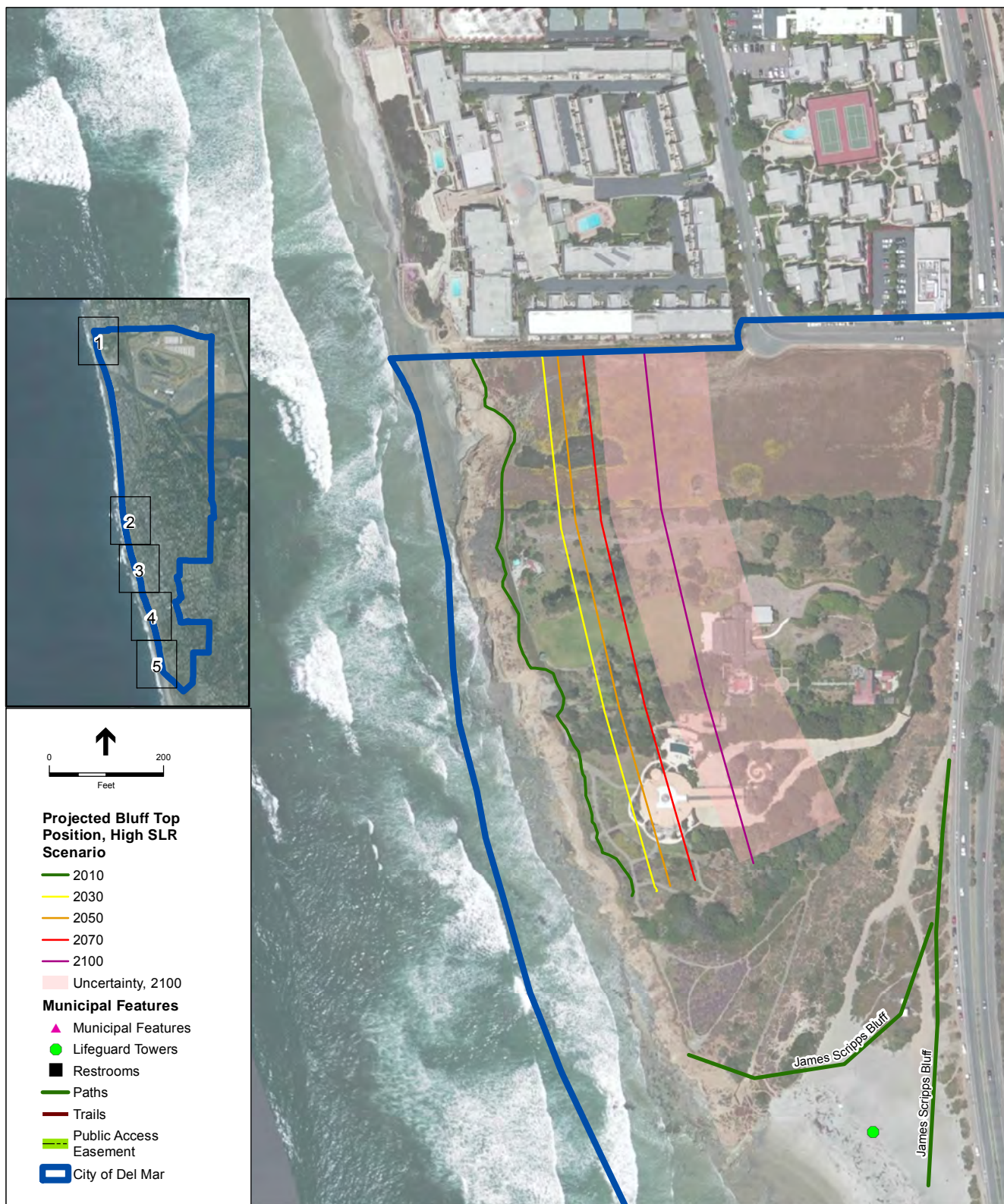


SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

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.

Del Mar Vulnerability Assessment . D150347

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.

Del Mar Vulnerability Assessment . D150347

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

Del Mar Vulnerability Assessment . D150347

Figure 46.3

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



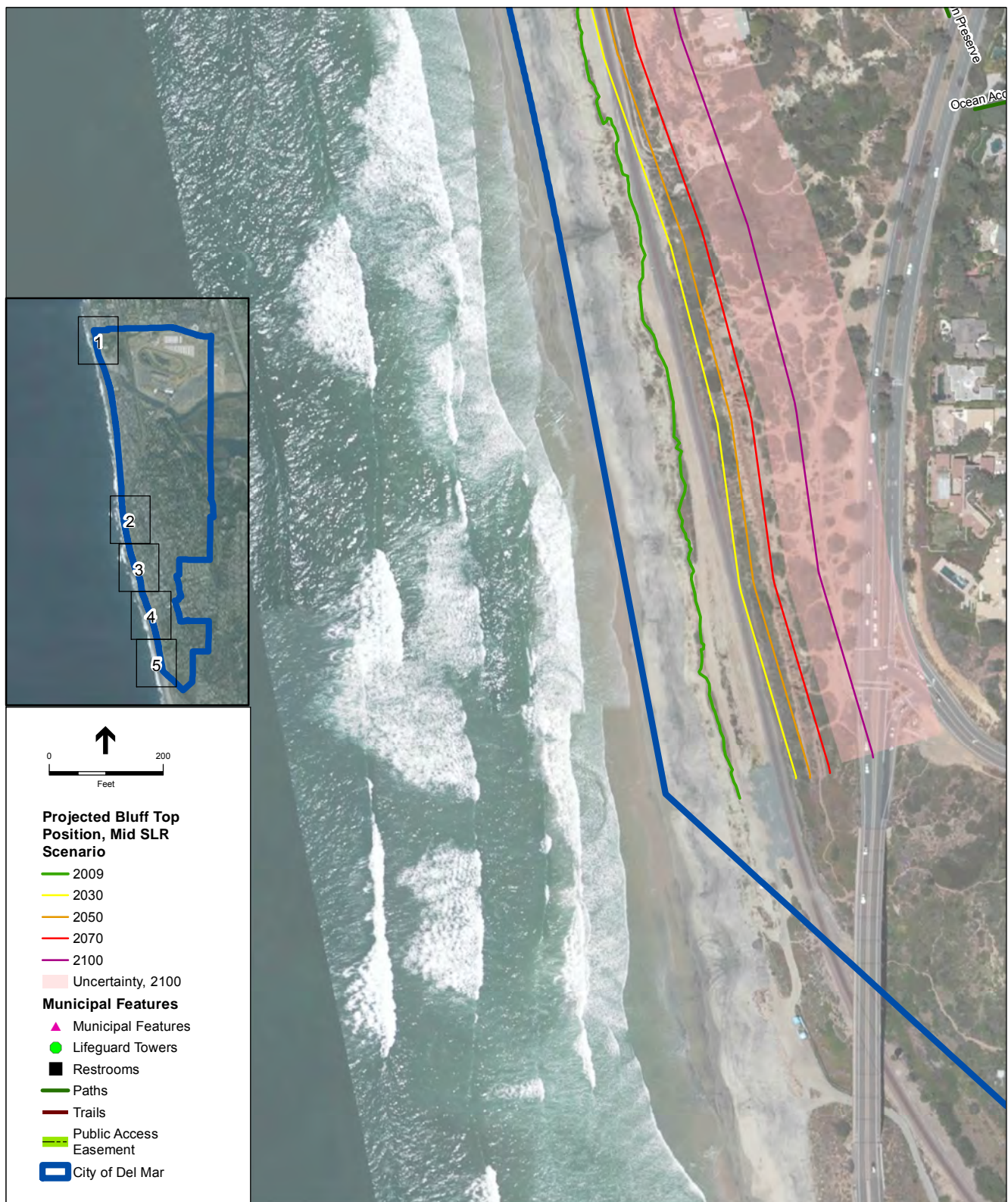
SOURCE: SanGIS 2016, USGS 2015

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.

Del Mar Vulnerability Assessment . D150347

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 2100 (north) and 2009 (south) are based on LiDAR elevation data.

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 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.

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 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 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 17 th to 29 th Streets		Moderate 10%	High 50%	High 100%		
	Extreme (e.g., 1983 storm)	• West of Sand Barr Ln.	• Ocean Front • Camino Del Mar/Coast Blvd.	• 17 th 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, 28 th St, and RR • General vicinity of Coast Blvd. and Santa Fe between 17 th St. and 23 rd St.	• San Dieguito Drive • Jimmy Durante Bridge • East ends of 17 th to 29 th 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	<ul style="list-style-type: none"> Beach access 	2030 to 2070
North Beach District coastal flooding and damage	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Fire Station 	2030
	<ul style="list-style-type: none"> Sewer lift station on San Dieguito Drive 	2050
	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Railroad 	2030 or earlier
	<ul style="list-style-type: none"> Bluff top property in South Beach, South Bluffs, and North Bluffs 	2050
	<ul style="list-style-type: none"> Sewer infrastructure in South Beach and South Bluffs 	
San Dieguito River Lagoon wetland habitat conversion and loss	<ul style="list-style-type: none"> 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 2070, 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 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).

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 a 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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9 LIST OF PREPARERS

This report was prepared by the following individuals:

Nick Garrity, PE – ESA

Bob Battalio, PE – ESA

Hannah Snow, EIT – ESA

Ellen Buckley, EIT – ESA

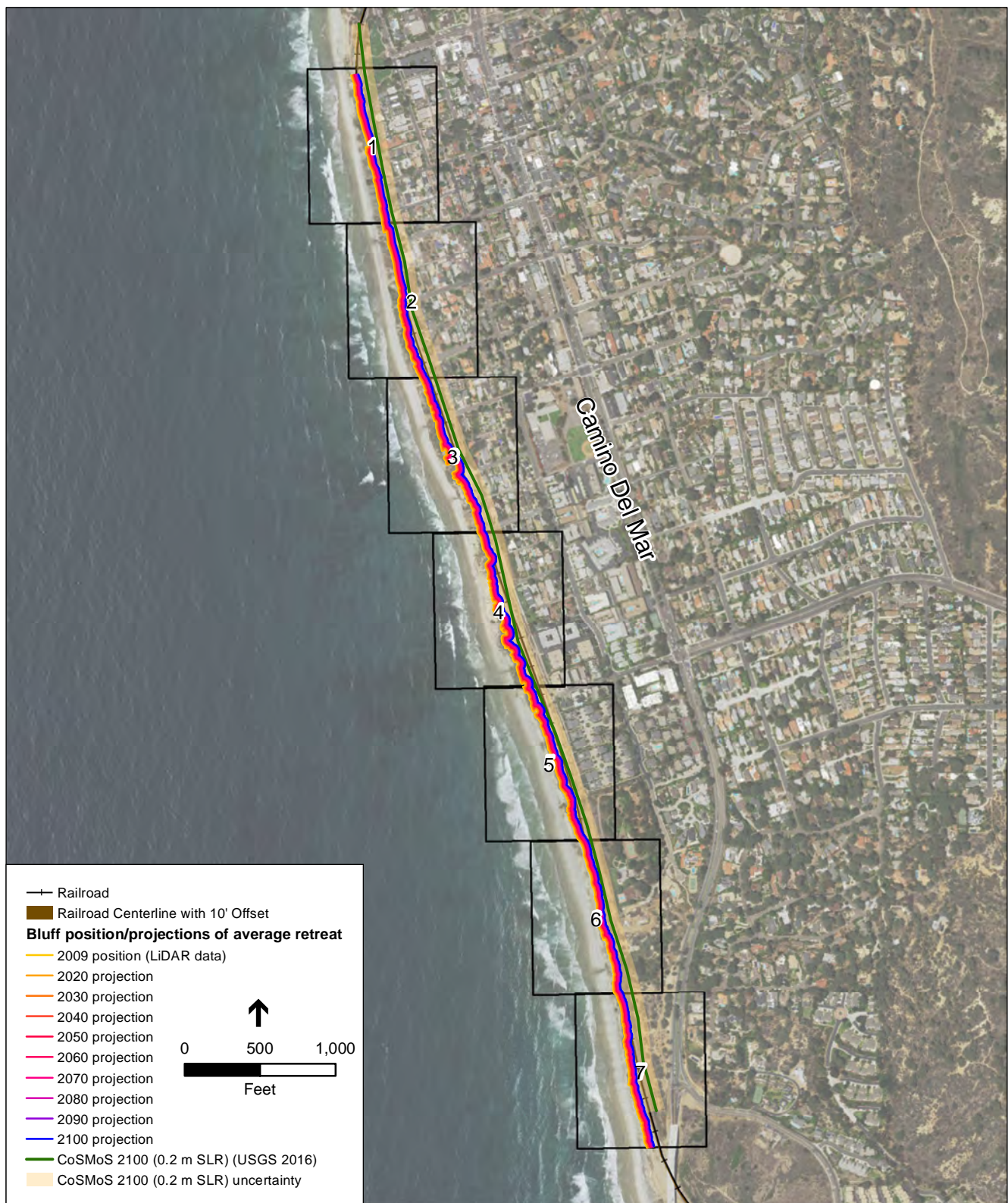
Hunter Connell – ESA

Dr. Adam Young, PhD – Scripps Institute of Oceanography

Robert Dickinson – Argos Analytics, LLC

APPENDIX A

Bluff Erosion Maps

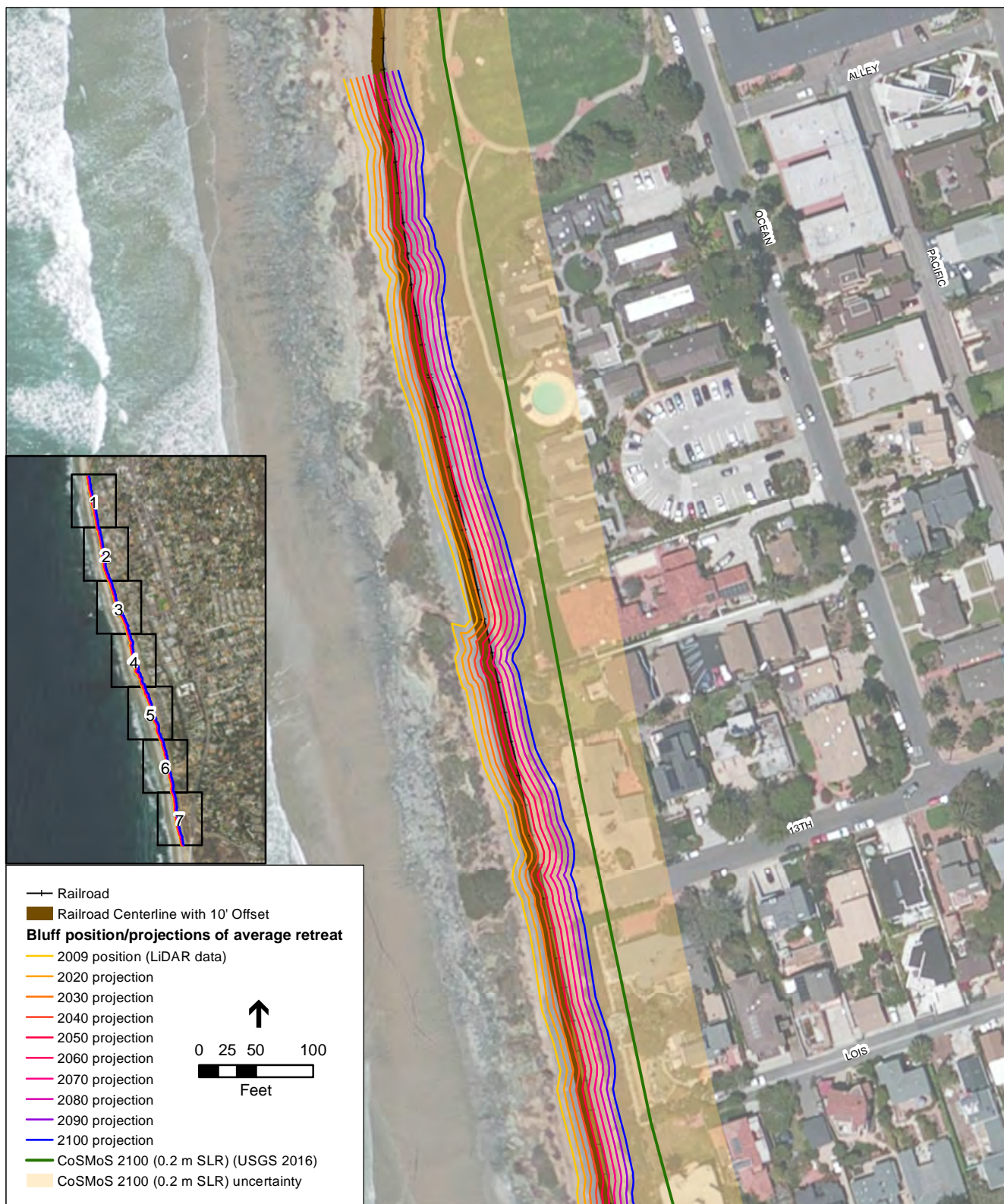


SOURCE: USGS 2016

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)



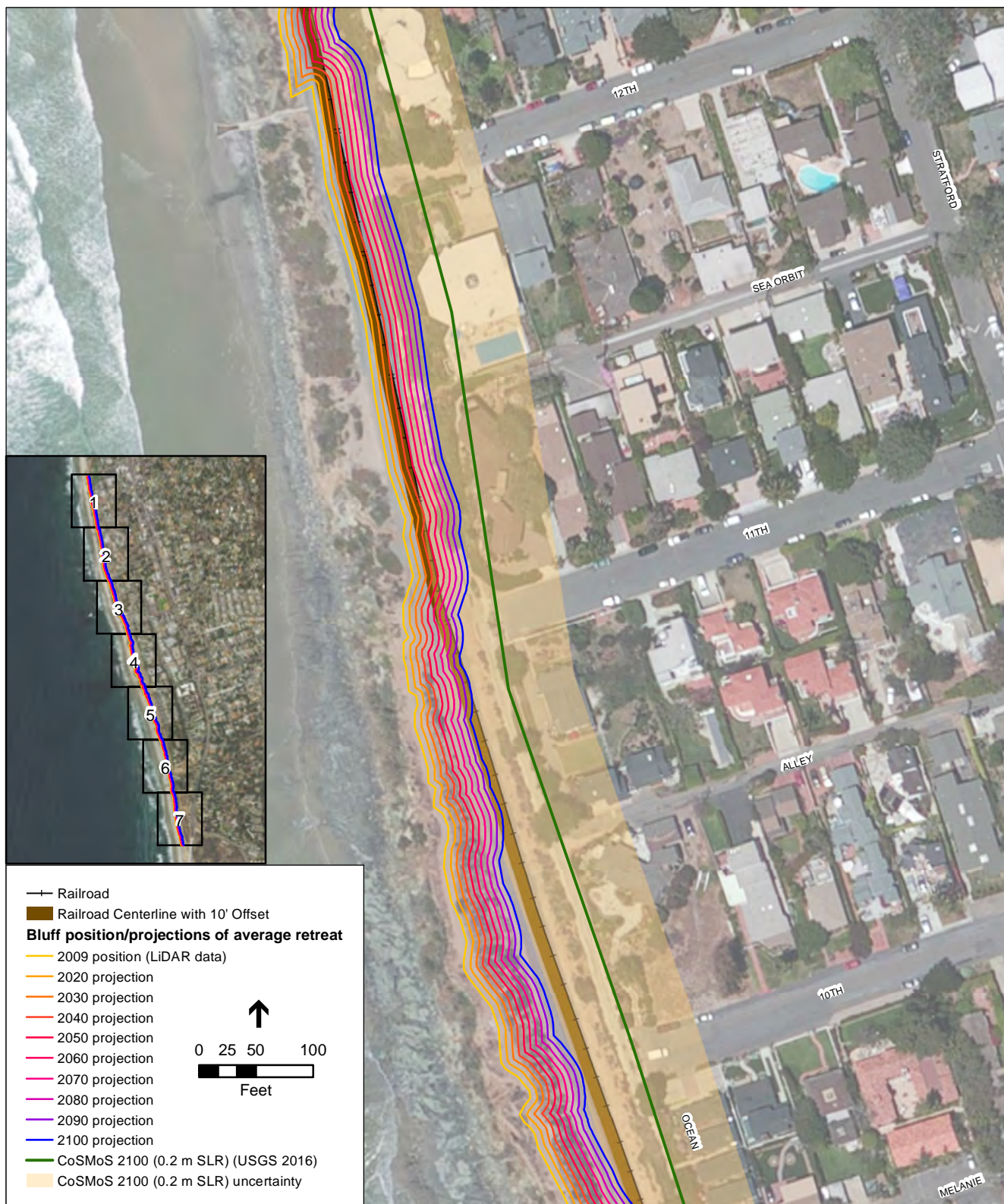
SOURCE: USGS 2016

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)



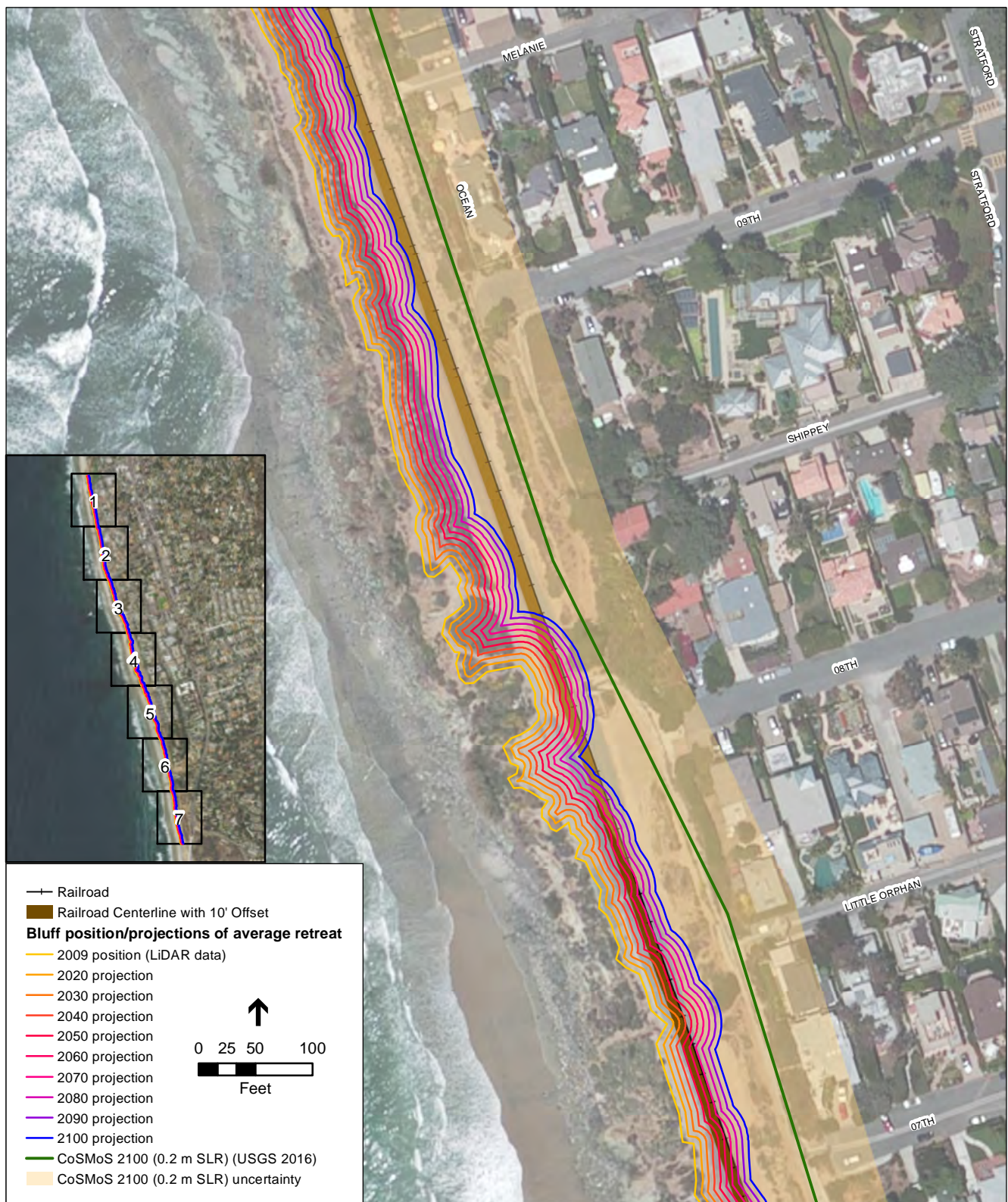
SOURCE: USGS 2016

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 A2

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



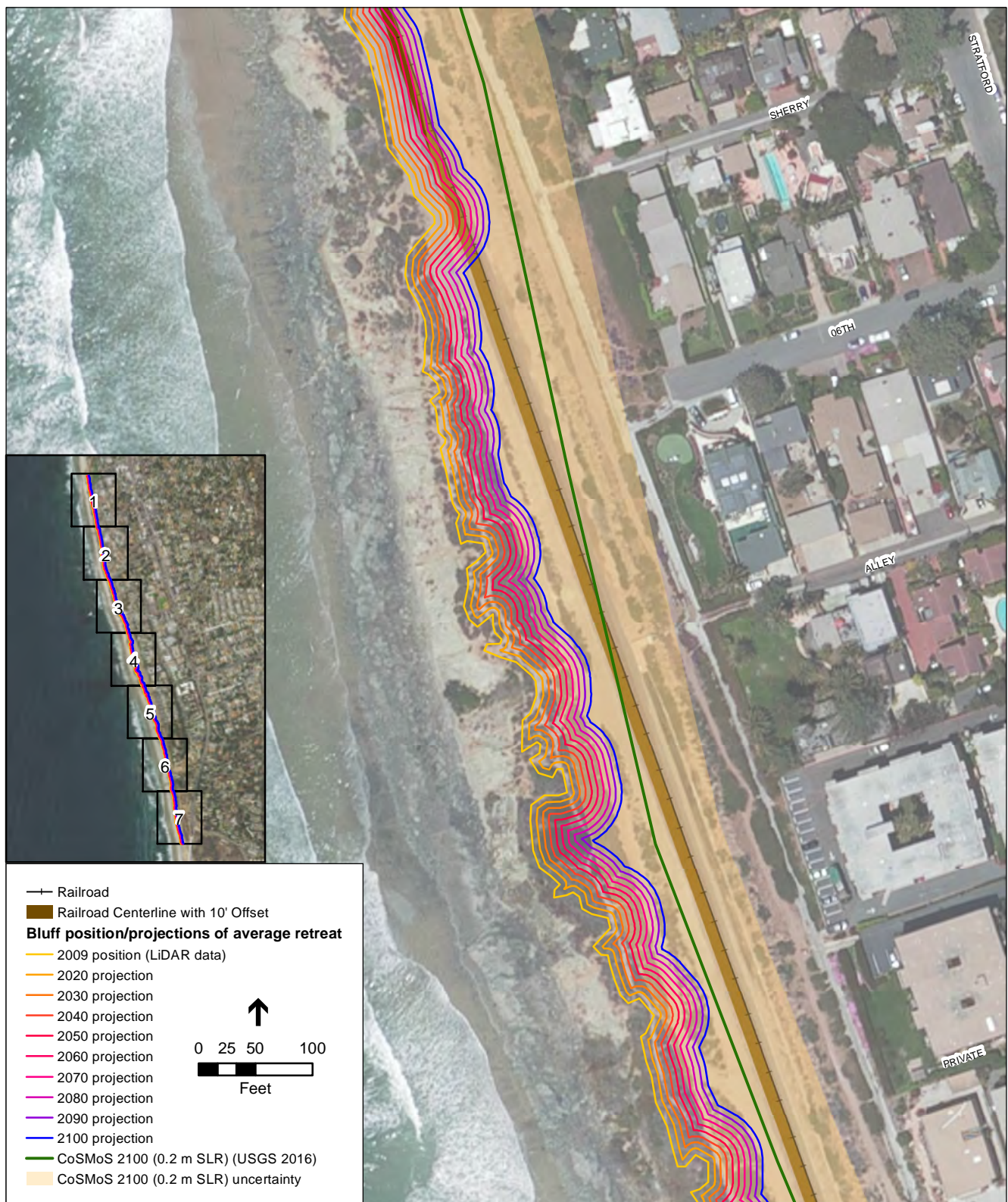
SOURCE: USGS 2016

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.

Del Mar LCP Update . D150347

Figure A3

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



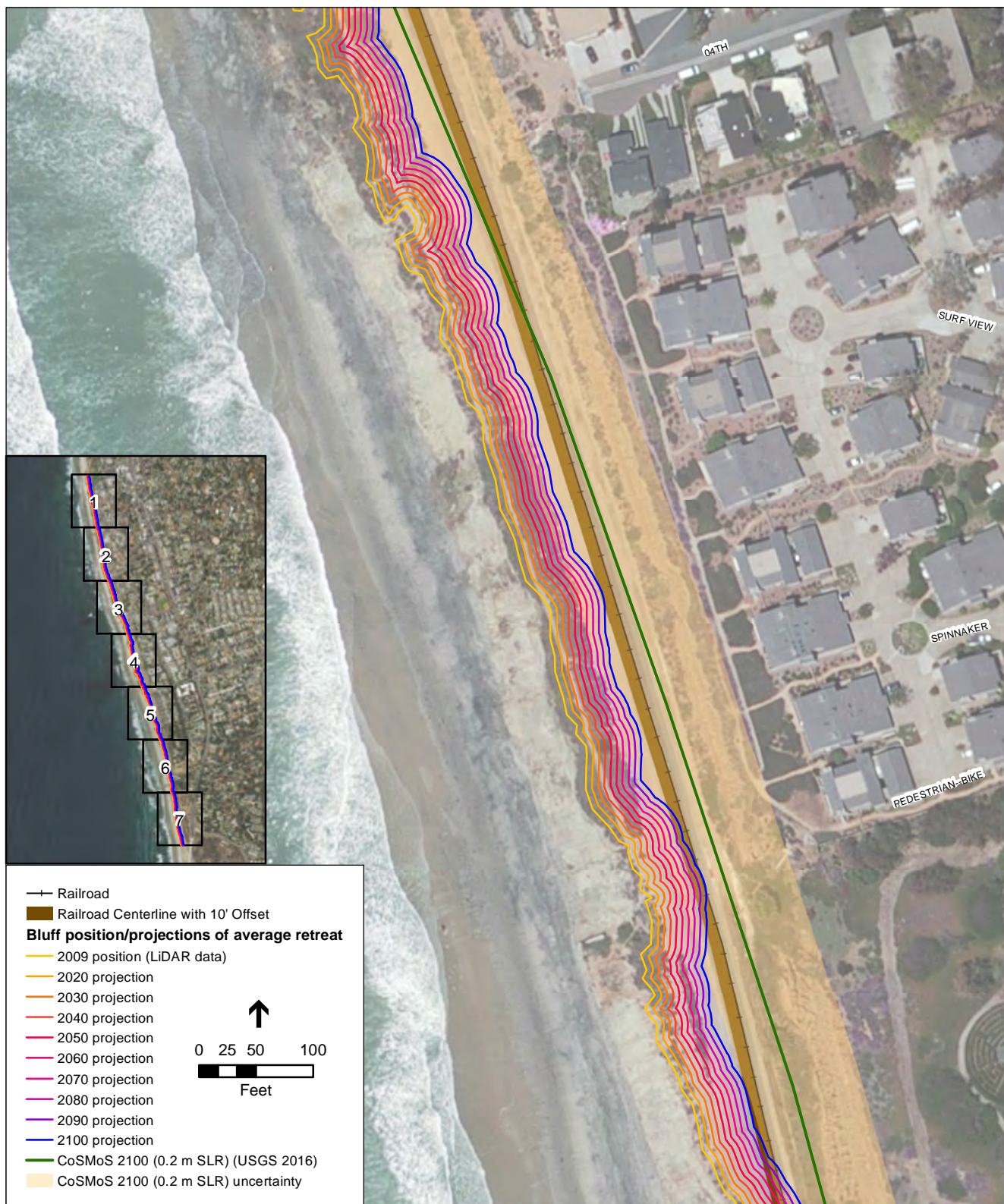
SOURCE: USGS 2016

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.

Del Mar LCP Update . D150347

Figure A4

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



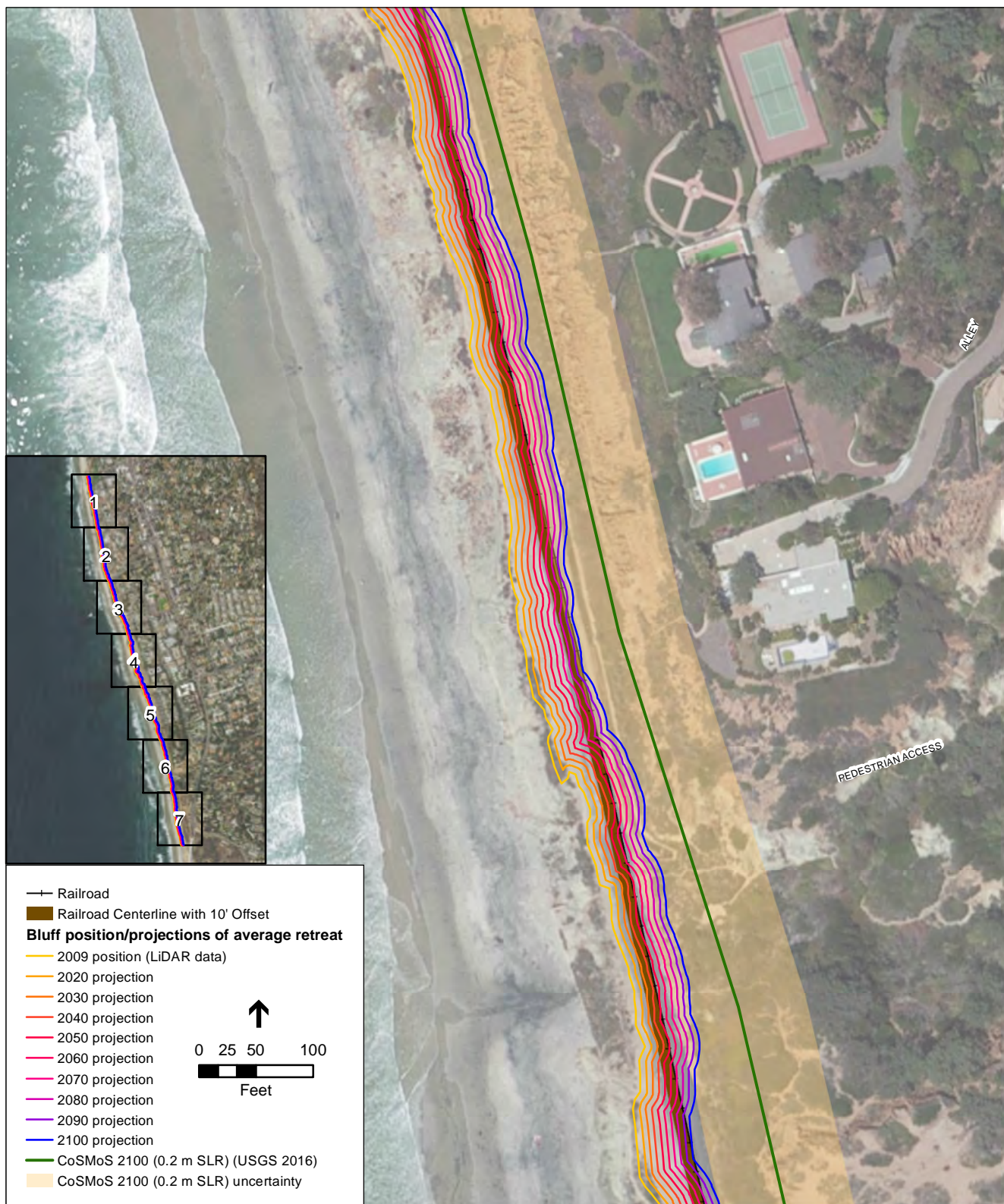
SOURCE: USGS 2016

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)



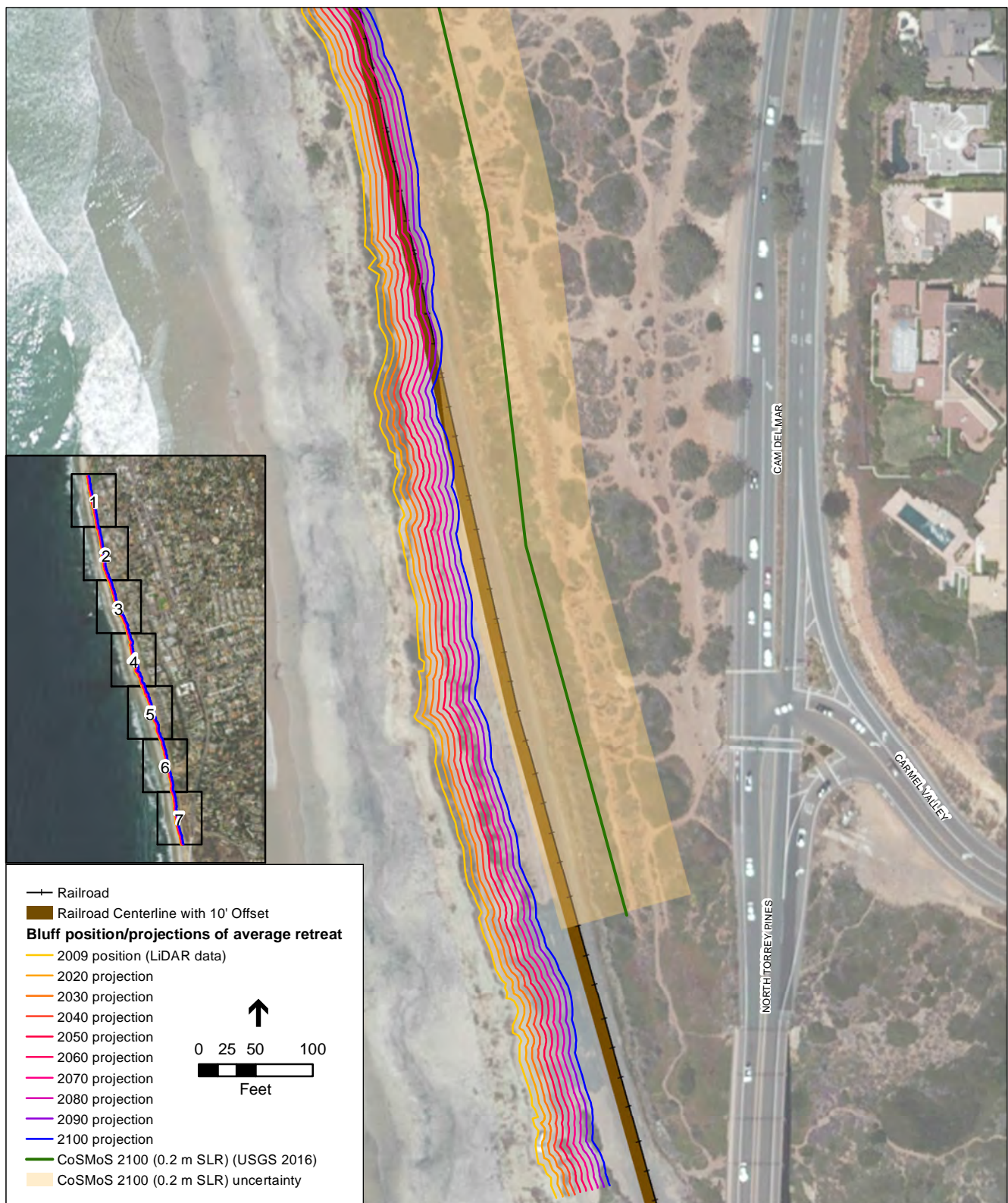
SOURCE: USGS 2016

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.

Del Mar LCP Update . D150347

Figure A6

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.

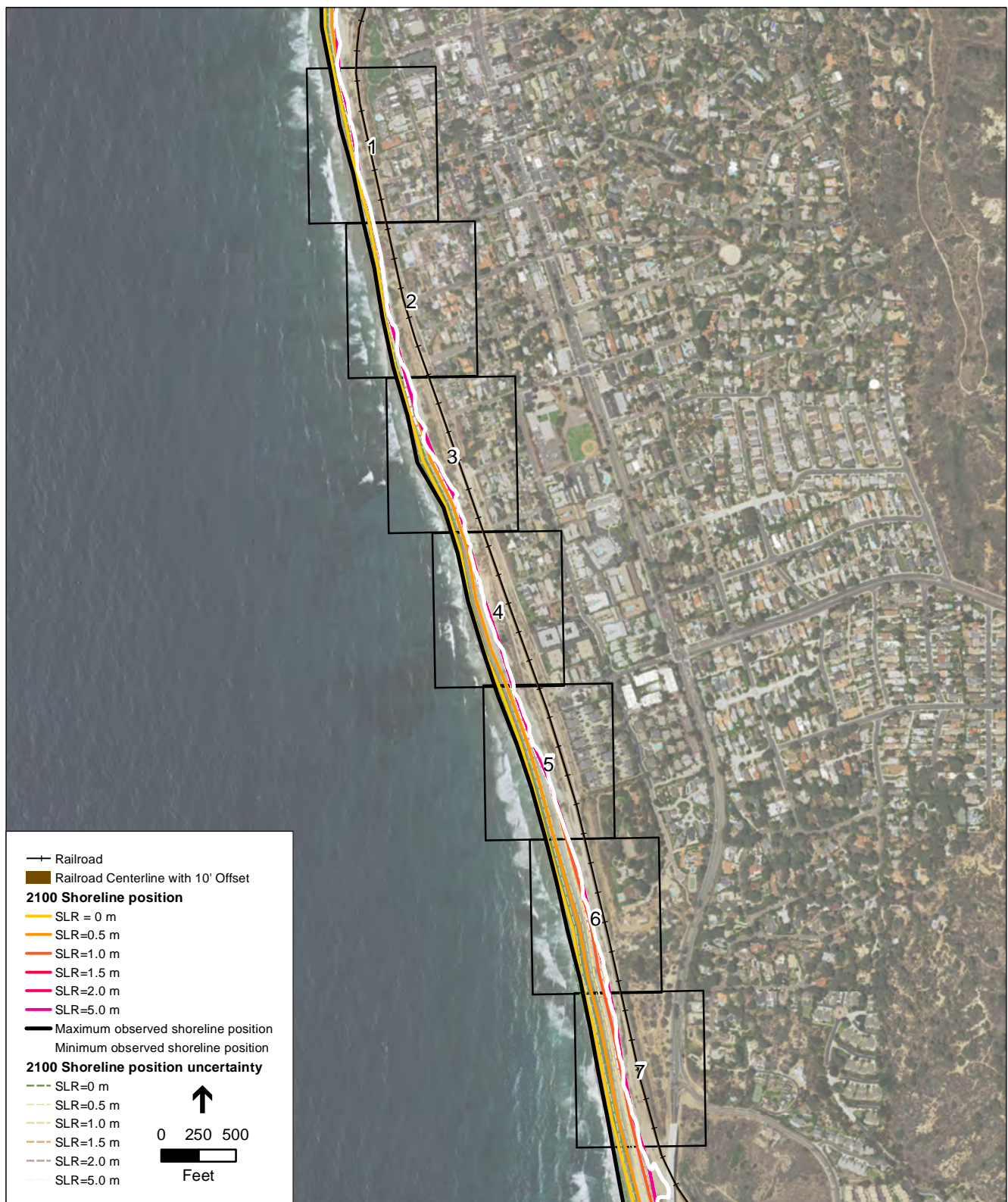
Del Mar LCP Update . D150347

Figure A7

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

APPENDIX B

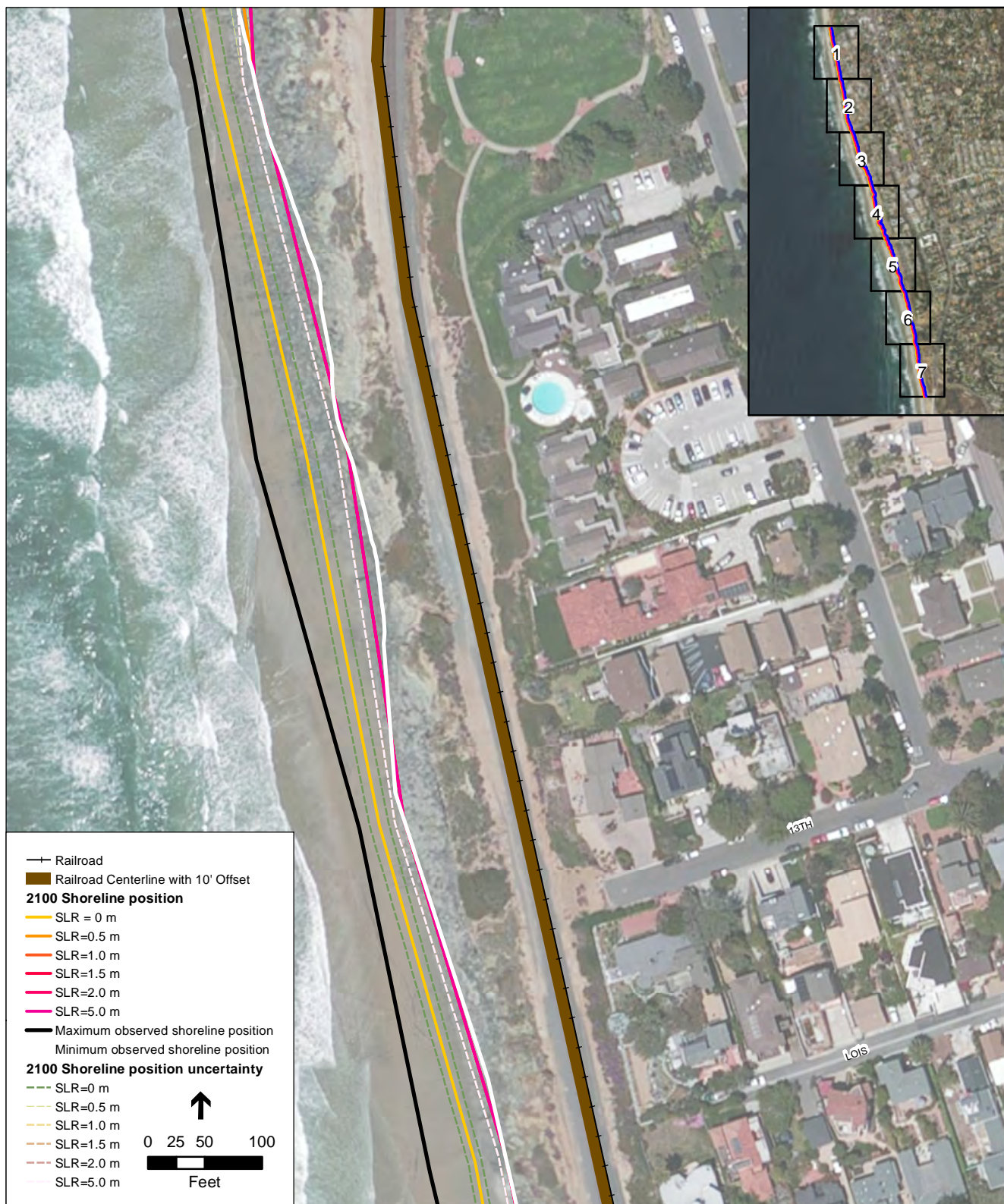
CoSMoS Beach Erosion Maps



SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure B- Map Grid Overview
 CoSMoS Beach Erosion- Shoreline Change by 2100



SOURCE: USGS 2016

Del Mar LCP Update . D150347

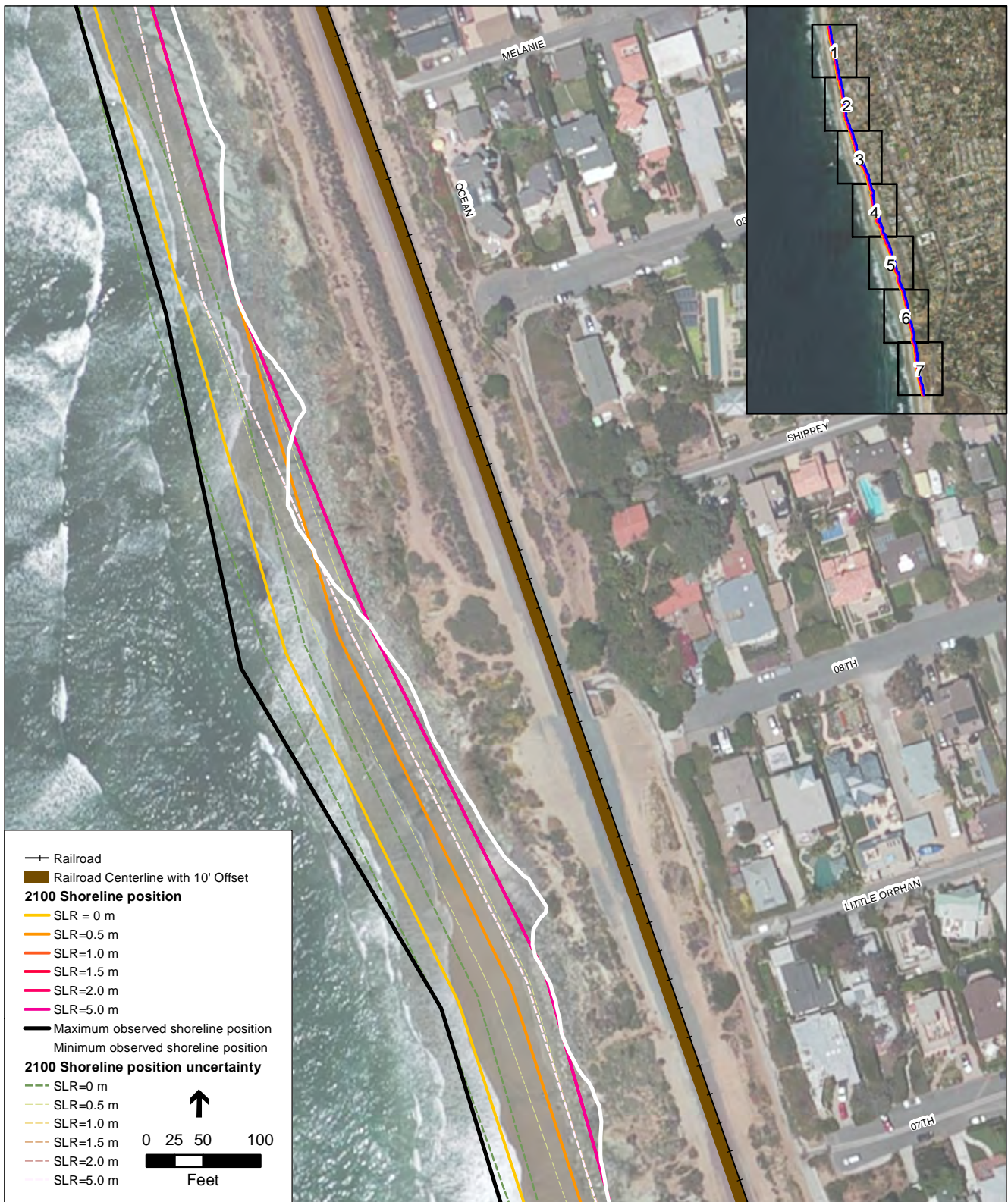
Figure B1
CoSMoS Beach Erosion- Shoreline Change by 2100



SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure B2
CoSMoS Beach Erosion- Shoreline Change by 2100

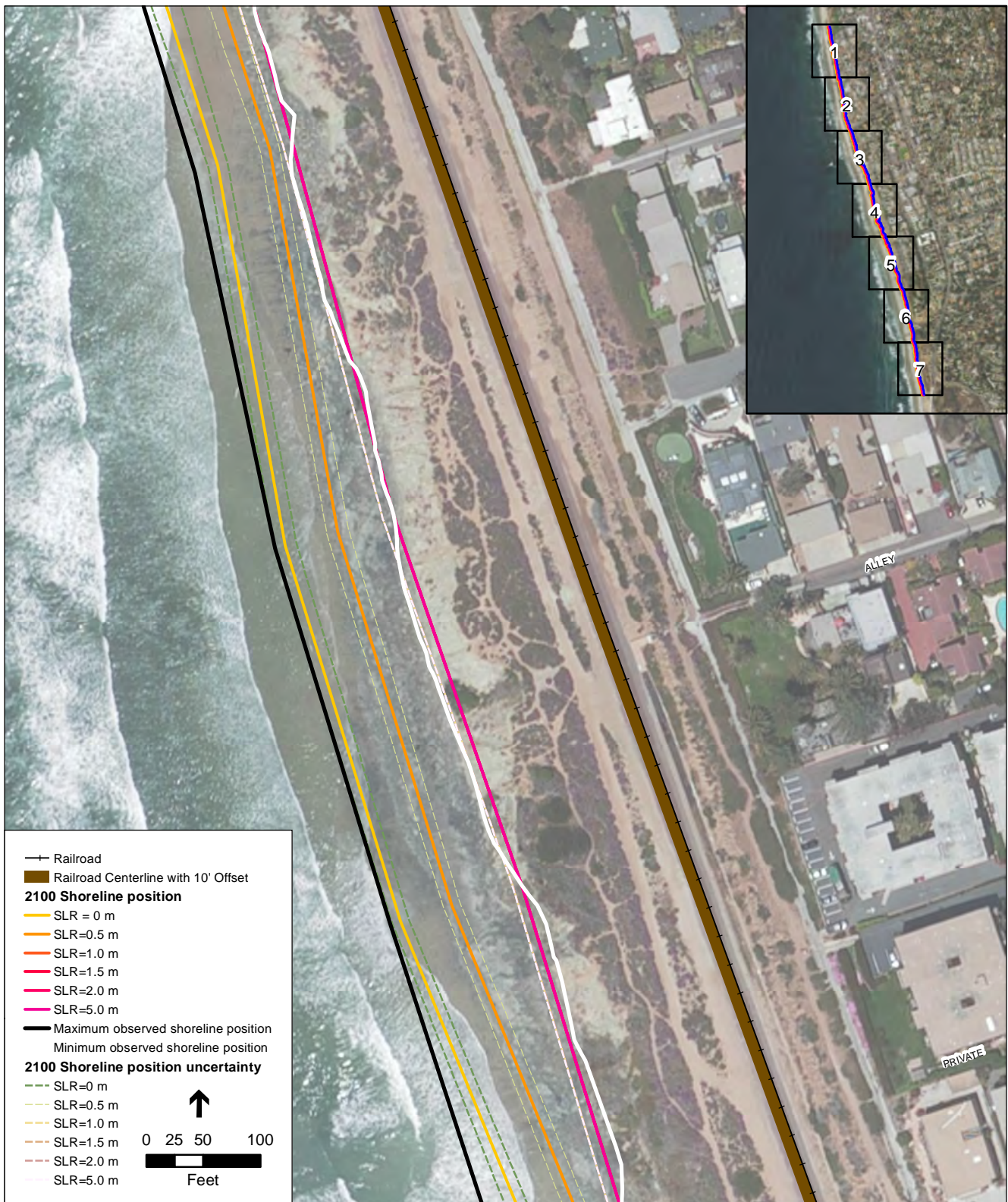


SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure B3

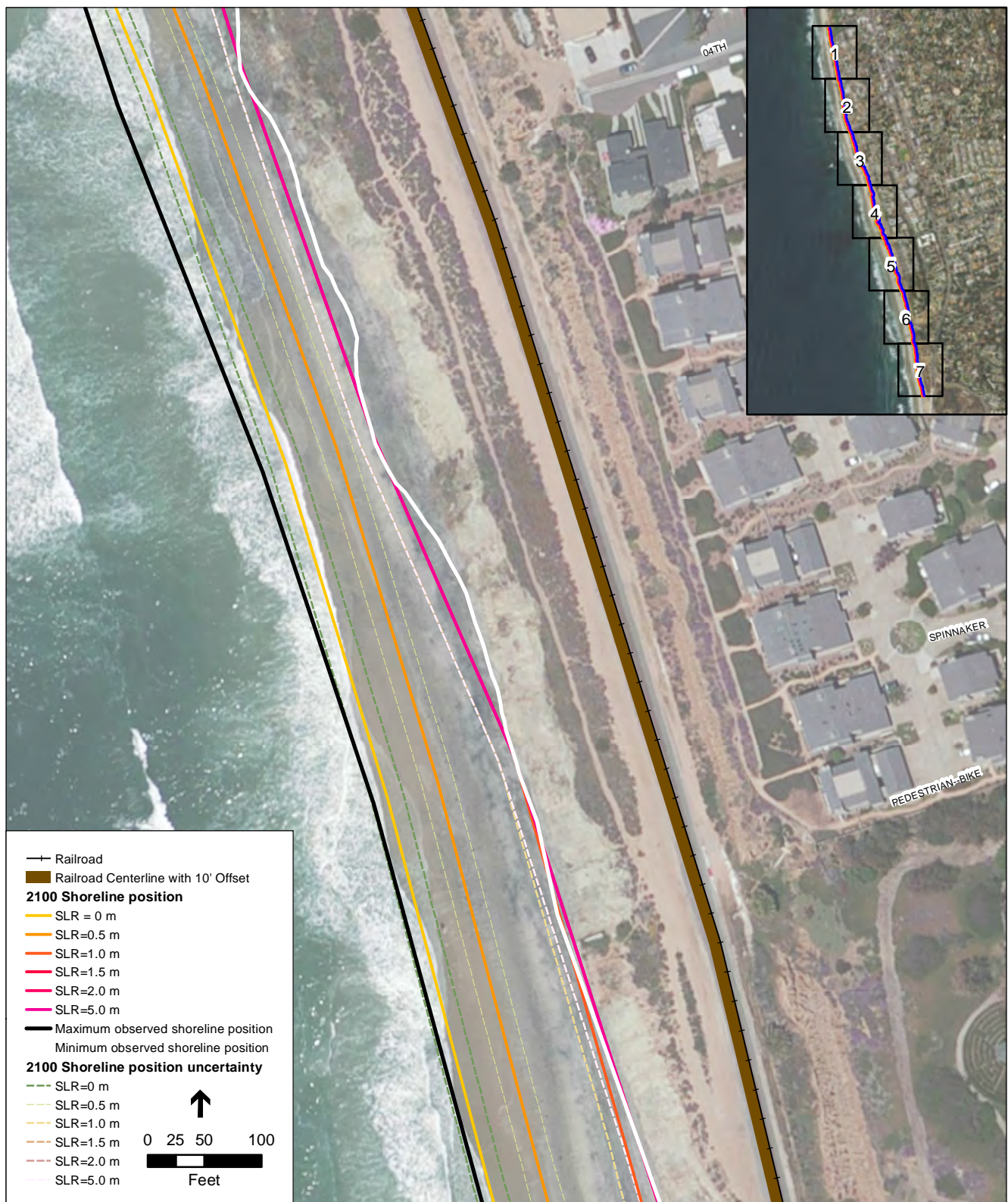
CoSMoS Beach Erosion- Shoreline Change by 2100



SOURCE: USGS 2016

Del Mar LCP Update . D150347

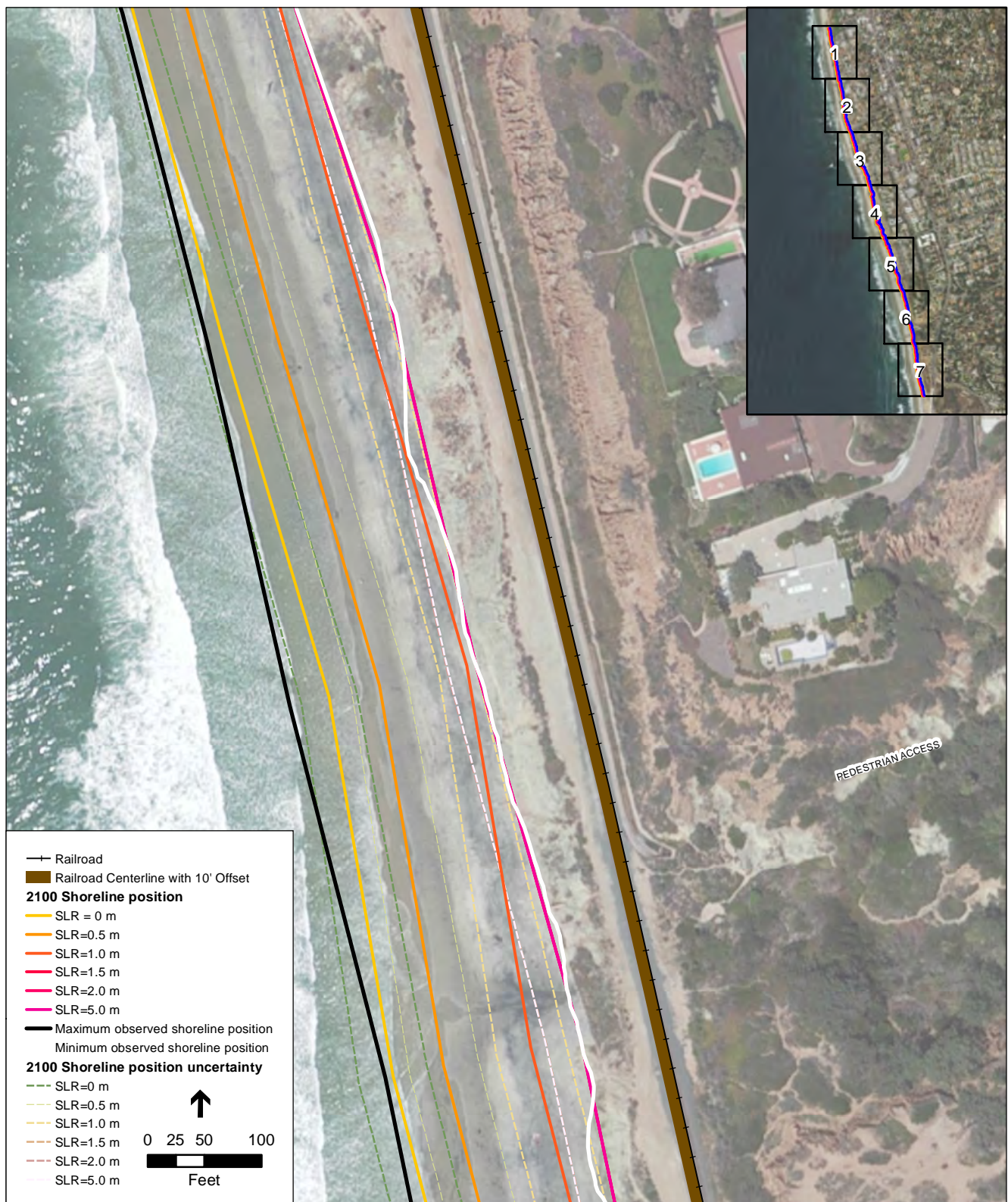
Figure B4
CoSMoS Beach Erosion- Shoreline Change by 2100



SOURCE: USGS 2016

Del Mar LCP Update . D150347

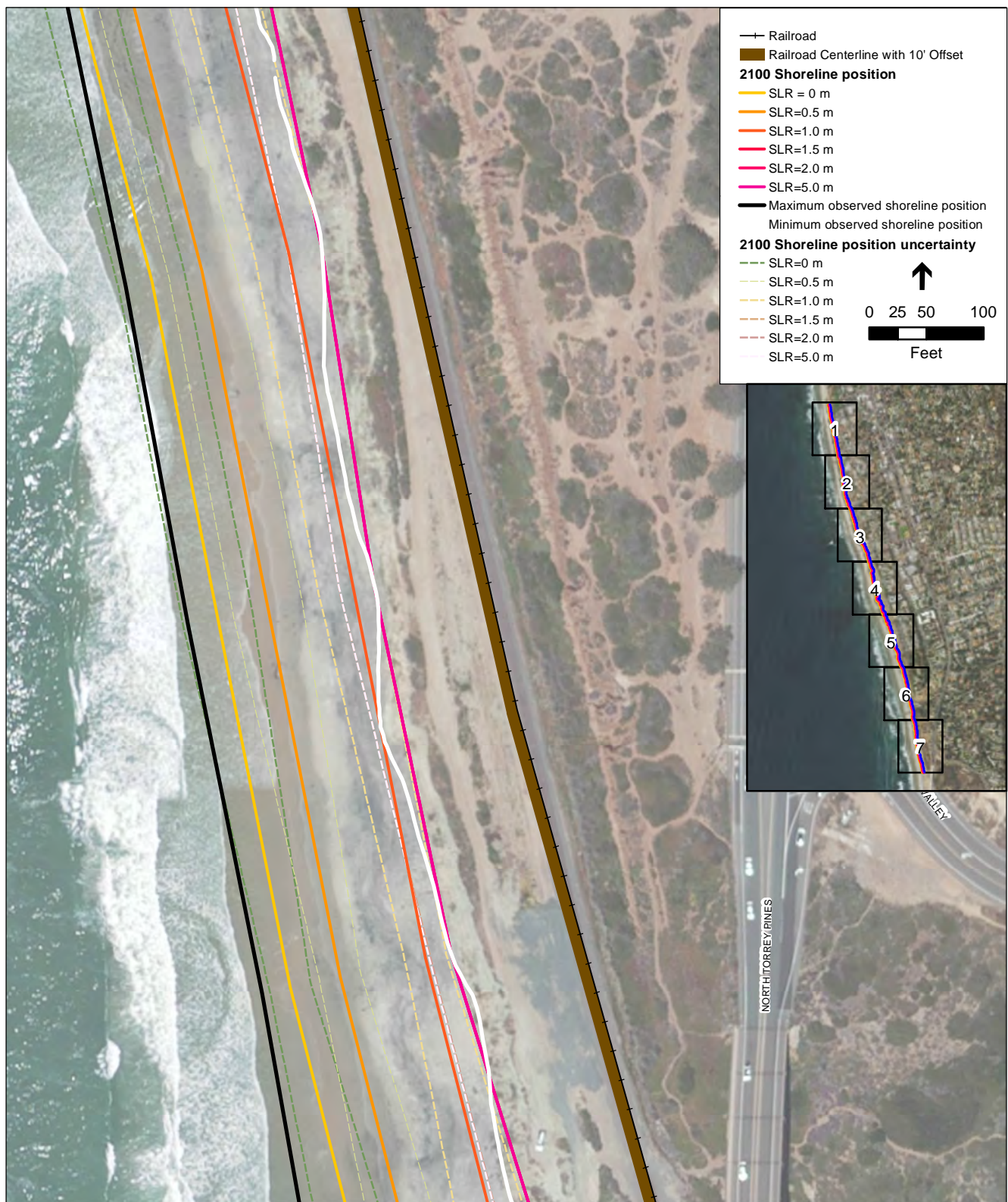
Figure B5
CoSMoS Beach Erosion- Shoreline Change by 2100



SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure B6
CoSMoS Beach Erosion- Shoreline Change by 2100



SOURCE: USGS 2016

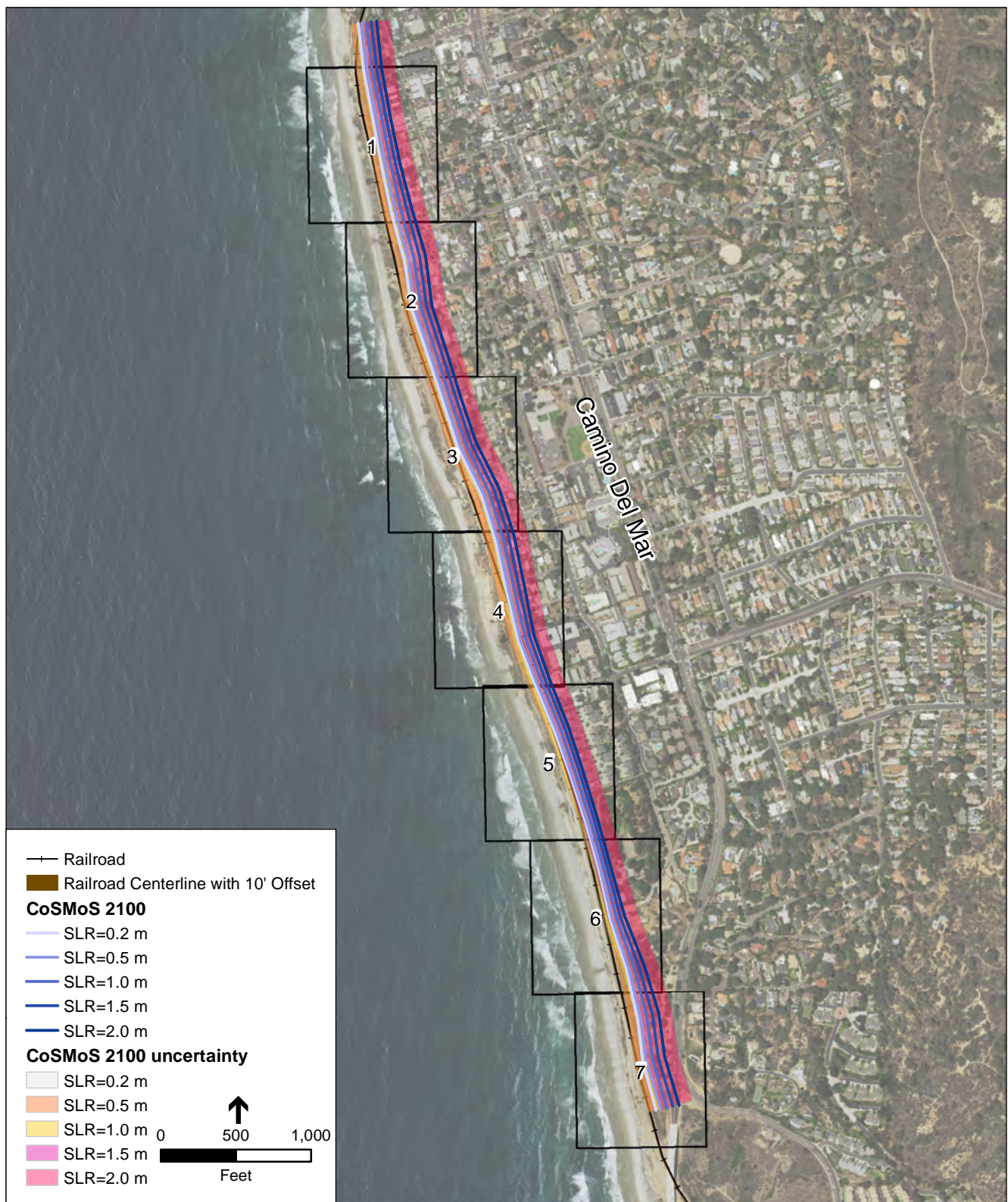
Del Mar LCP Update . D150347

Figure B7

CoSMoS Beach Erosion- Shoreline Change by 2100

APPENDIX C

CoSMoS Bluff Erosion Maps



SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure C- Map Grid Overview
CoSMoS Bluff Erosion- Cliff Retreat by 2100



SOURCE: USGS 2016

Del Mar LCP Update . D150347

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

Del Mar LCP Update . D150347

Figure C4
CoSMoS Bluff Erosion- Cliff Retreat by 2100



SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure C5
CoSMoS Bluff Erosion- Cliff Retreat by 2100



SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure C6

CoSMoS Bluff Erosion- Cliff Retreat by 2100



SOURCE: USGS 2016

Del Mar LCP Update . D150347

Figure C7

CoSMoS Bluff Erosion- Cliff Retreat by 2100

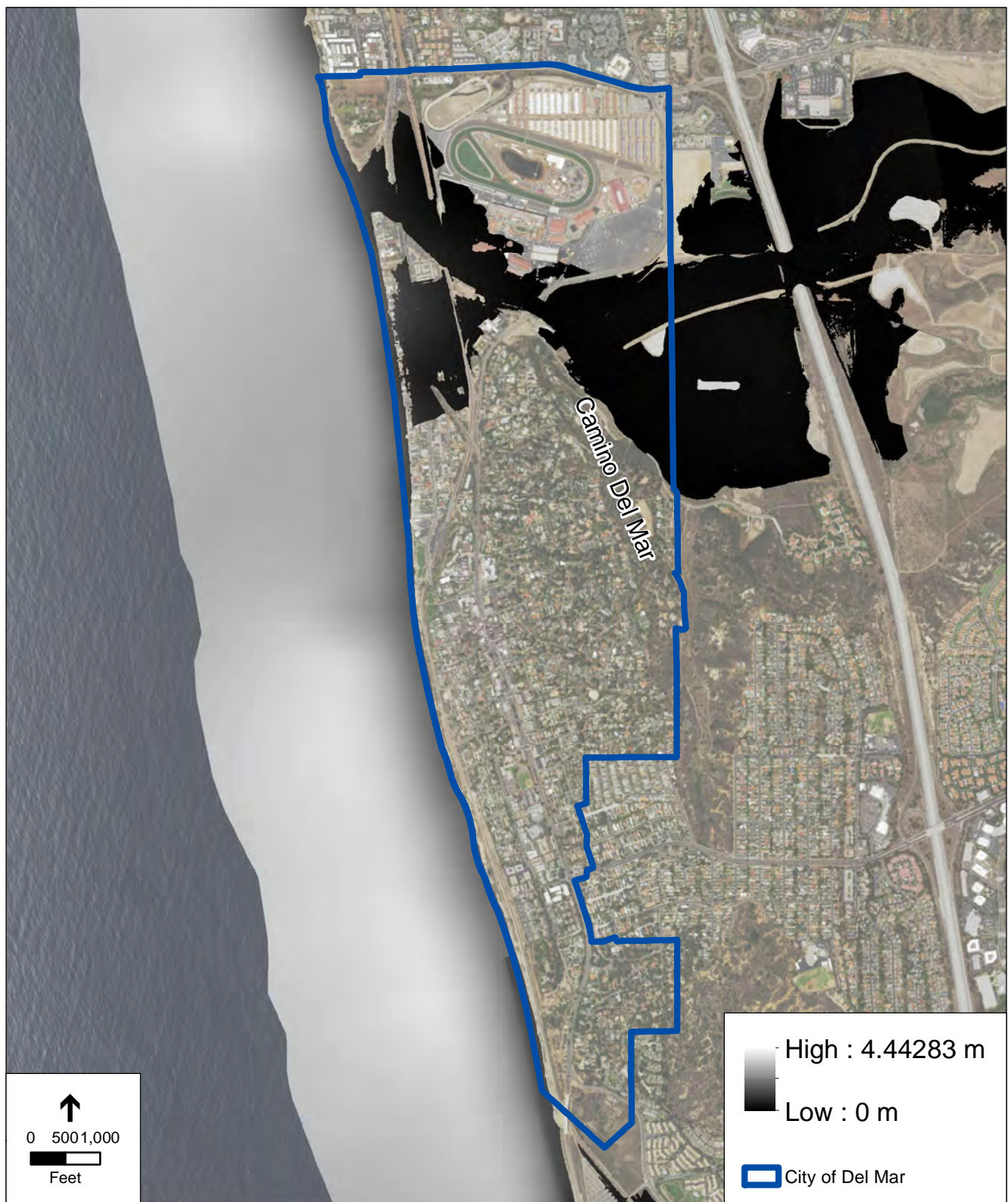
APPENDIX D

Precipitation Event Frequency Analysis



SOURCE: USGS 2016

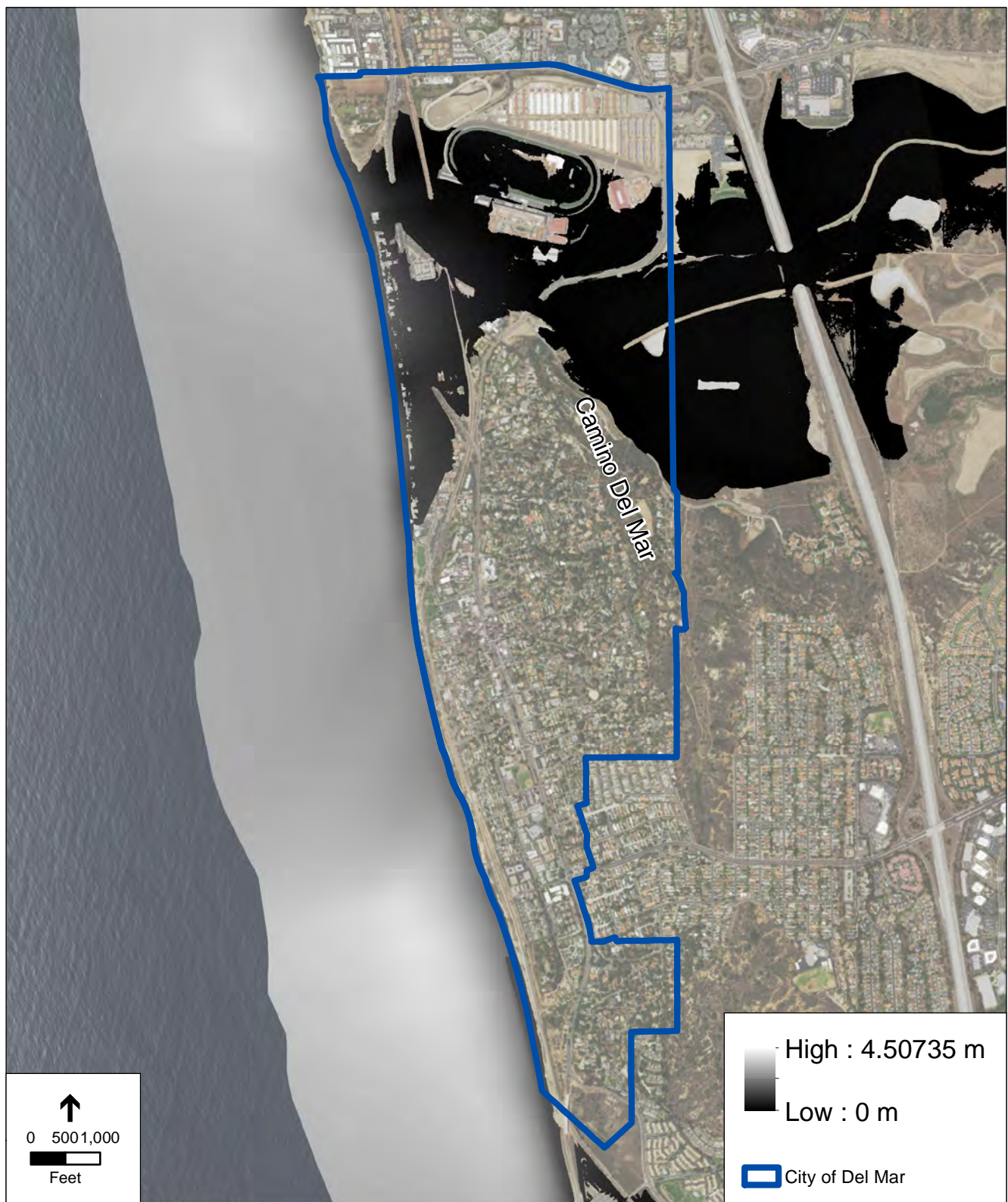
Del Mar LCP Update . D150347
Figure D1
Wave Hazards, 0 cm SLR



SOURCE: USGS 2016

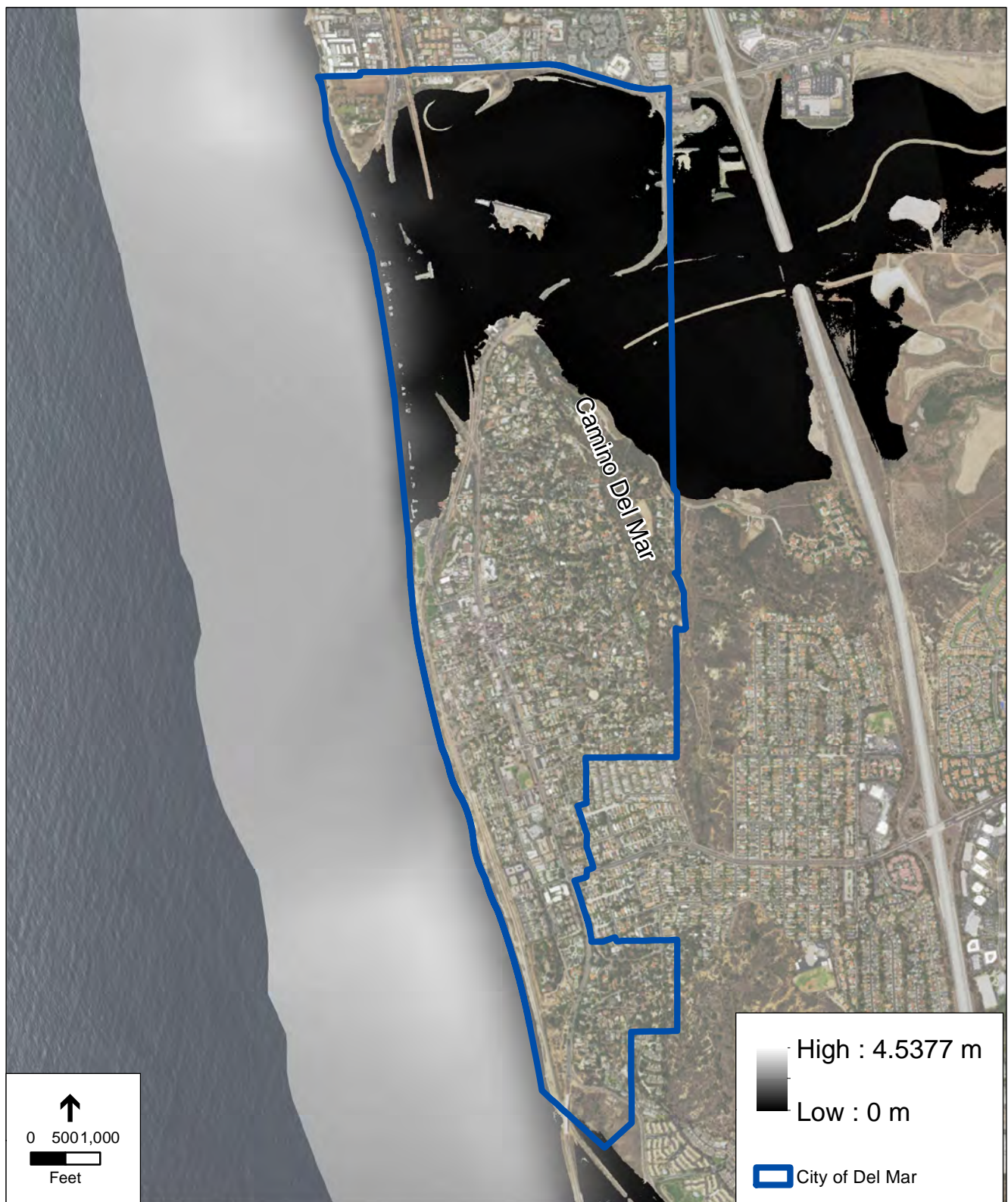
Del Mar LCP Update . D150347

Figure D2
Wave Hazards, 50 cm SLR



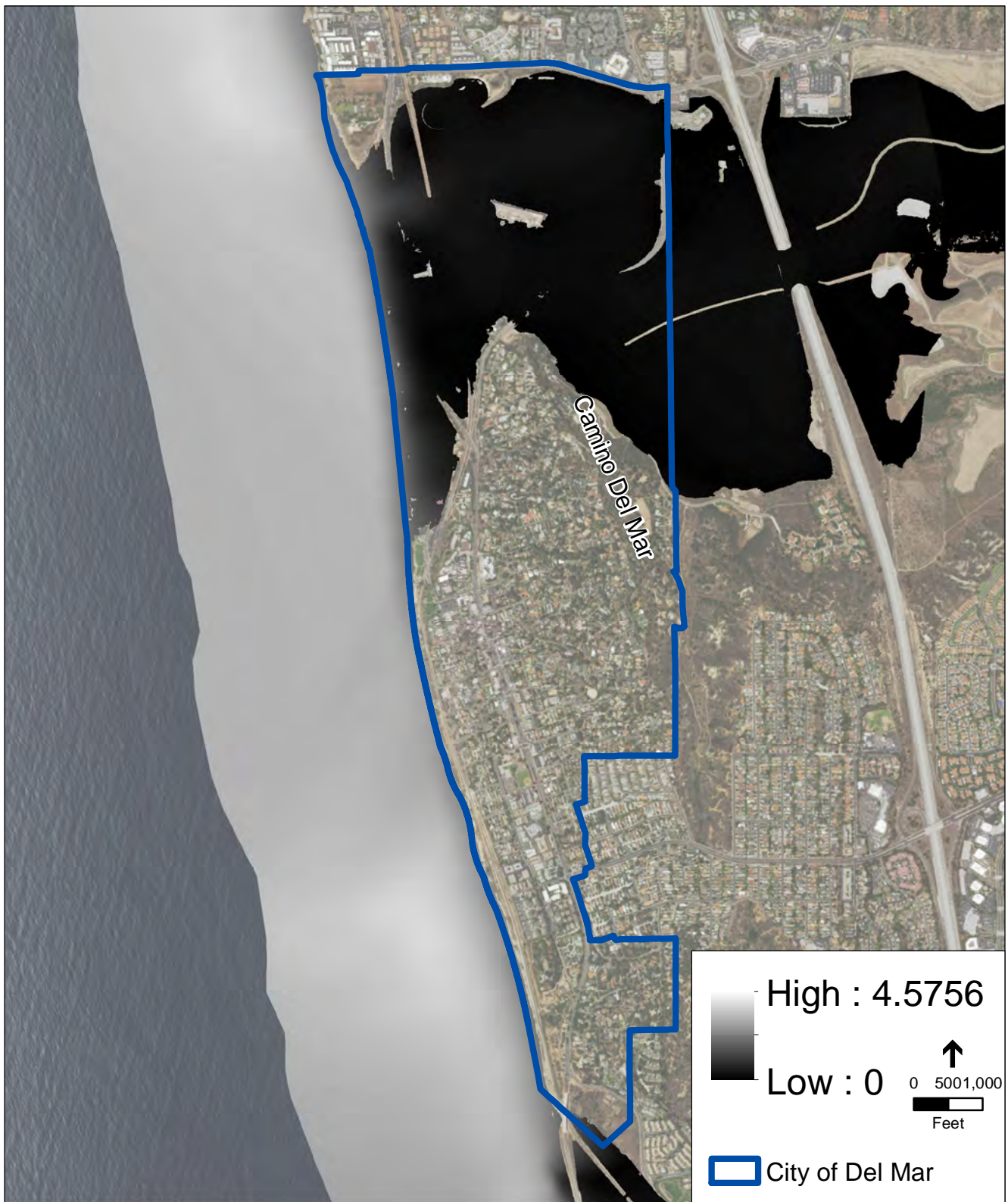
SOURCE: USGS 2016

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

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

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

Low SLR

Mid SLR[illegible]

High SLR

Habitat in ~2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Upland	Upland	Upland	Upland	Upland	Upland	Upland	Upland	Upland	Upland
Transiti on	Transiti on	Transiti on	Transiti on	Transiti on	Transiti on	Transiti on	Transiti on	Transiti on	Transiti on
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