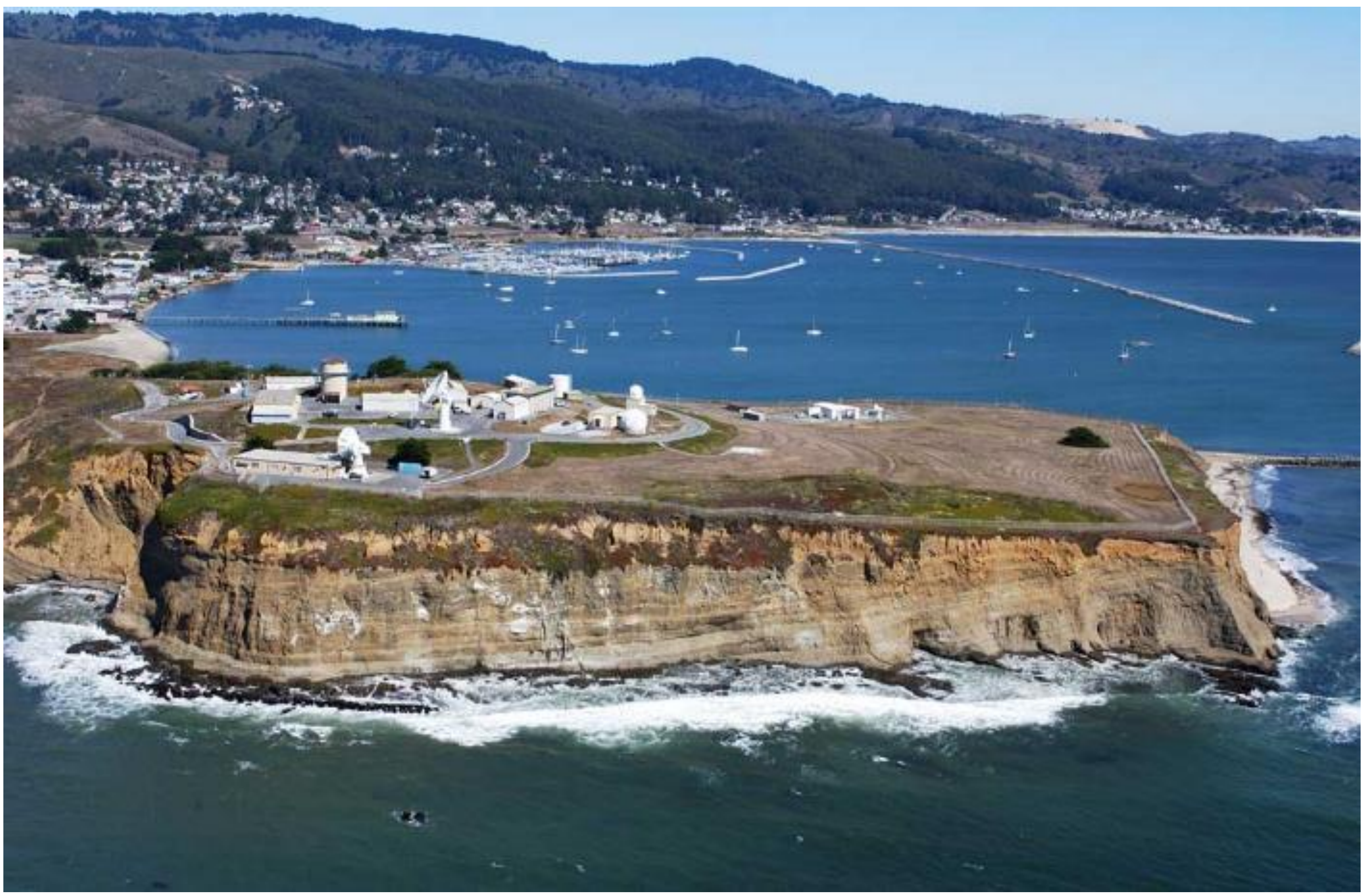
Pillar Point Harbor

Sea-Level Rise Vulnerability Assessment

PREPARED FOR SAN MATEO COUNTY HARBOR DISTRICT

MAY 3, 2018



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Executive Summary

The purpose of this report is to present the findings from our assessment (study) of the vulnerabilities of Pillar Point Harbor (PPH) to the effects of sea level rise (SLR) in accordance with the requirements for Public Trust Lands (Per Assembly Bill AB-691). The figure below shows the study area, which is divided into eight reaches.

Figure 1: Study Area Reach Map

The vulnerability assessment considers impacts to the shore facilities due to SLR: shoreline retreat and coastal flooding at 4 different scenarios (elevations) of SLR. This work followed the recommendations given by the National Research Council (NRC), California Coastal Commission (CCC), and Ocean Science Trust (OST) to quantify relative SLR values (Table 1). The Our Coast Our Future (OCOF) online platform was used to map SLR scenarios in 0.82 feet (25 cm) increments from 0 to 3.28 feet (100 cm) and are presented at the end of this section (Figures 2 to 8).

Table 1: Relative Sea Level Rise for San Francisco (*NRC, 2012)*

Year	Projection (feet)	Range (feet)	Representative OCOF Scenario
2030	0.48 ± 0.17	0.14 - 0.97	0.82 ft (25 cm)
2050	0.92 ± 0.30	0.40 - 2.00	1.64 ft (50 cm)
2100	3.02 ± 0.84	1.39 - 5.46	2.46 ft (75 cm) 3.28 ft (100 cm)

Table 2 lists a summary of results of the SLR mapping and resulting vulnerabilities and recommended mitigation and adaptations.

Table 2: Summary of PPH Vulnerabilities and Recommended Mitigation and Adaptation Measures

Reach No.	Vulnerability	Priority	Recommended Actions
1	Coastal Trail will be flooded more frequently in the future	Low	Monitor erosions near coastal trail
2	Wetland will be flooded more frequently in the future	Low	Monitor vegetation condition within the wetland
3	Beach is actively eroding and the Princeton Community will be vulnerable to future flooding	High	Option 1: Beach nourishment Option 2: Install and improve revetments
4	The permit parking lot will be subject to flooding by the end of century	Low	Monitor breakwater and pier conditions
5	The protected coastal strand onshore of PPH beach will be in the flood zone in the future, while sediment accumulation can cause navigational hazard in the future near the boat launch facility	Low	Monitor sediment accumulation and bathymetry condition
6	The coastal bluff will keep retreating, and Surfer's Beach will disappear in the future.	Medium	Monitor revetment conditions The existing revetment maintained by Caltrans should be extended southward to protect Highway 1 against future shoreline conditions
7	The coastal bluff will keep retreating, but the beach can survive as long as there is room for retreat. Coastal trail will be in the erosion zone in the timeline between 2050 and 2100	Medium	Managed retreat, coastal trail will require adjustment between 2050 and 2100 and must be monitored in the future
8	The beach in front of the revetment will be eroded due to lack of room for shoreline retreat	Medium	Managed retreat, monitor revetment condition\

The following are important results from this table:

- Shoreline retreat will impact most of the reaches at some point in the future (Reaches 1, 2, 3, 6, 7, and 8). However, only two reaches will be affected such that inland areas behind them will be subject to coastal flooding.

- The Princeton Community (Reach 2) will be vulnerable to future inland flooding by 2050; however, the beachfront eroding today. Beach nourishment or constructing a revetment is recommended for this area.

- The shoreline on Reaches 6 and 7 will also retreat, either due to the bluff recession (Reach 7) or lack of room for retreat (Reach 6). The existing revetment maintained by Caltrans should be extended southward to protect Highway 1 in the future.

- By 2050 shoreline retreat will impact public access in reach 6 just south of Surfer's Beach, in reach 6, near the southern end of the Caltrans revetment. Surfer's Beach, located south of the PPH south breakwater on Reach 6, will be eroded by 2050.

- The coastal trail on Reach 7 will be in the erosion zone sometime between 2050 and 2100. Financial costs of SLR including replacement and repairs to harbor facilities are also provided in Table 4

Due to loss of beaches, there will be some recreation losses (Table 3), while public access to the study area beaches will be impacted in the future, especially in areas that are protected with revetment today. EPA (2009) has recommended to consider an amount of $16,946 per acre per year for recreational and ecotourism losses due to loss of beaches. Financial costs of SLR including replacement and repairs to harbor facilities are also provided in Table 4.

Table 3: Aggregate Non-Market Loss Value due to Beach Erosion

Year	Beach Loss (Acres)	Low Estimate - CDBW (2011)	High Estimate - EPA (2009)
2030	1.7	$263,821	$585,450
2050	2.6	$984,201	$2,184,056
2100	4.0	$2,479,073	$5,501,349

*3% Discount Rate

Table 4: Replacement and Repair Costs due to SLR and Shoreline Changes at PPHS

Year	Coastal Trail Adjustment* (Reaches 1,6, and 7)	Western Slope Protection* (Reach 4)	Parking Lot Replacement* (Reach 4)	Total Costs*
2030	-	$150,000 - $200,000	-	$150,000 - $200,000
2050	$214,500	-	-	$214,500
2100	$1,300,000	-	300,000	$1,600,000

*values are in 2017 dollars

AB 691 lists 5 areas to review for impacts due to SLR and shoreline retreat. The results from this study, as described above and the maps following (figures 2-8), indicate that 3 of these 5 will not have significant impacts:

- Coastal habitat
- Commerce
- Navigability

Due to loss of beaches, there will be impacts in the other 2 areas:

- Recreation losses
- Public access

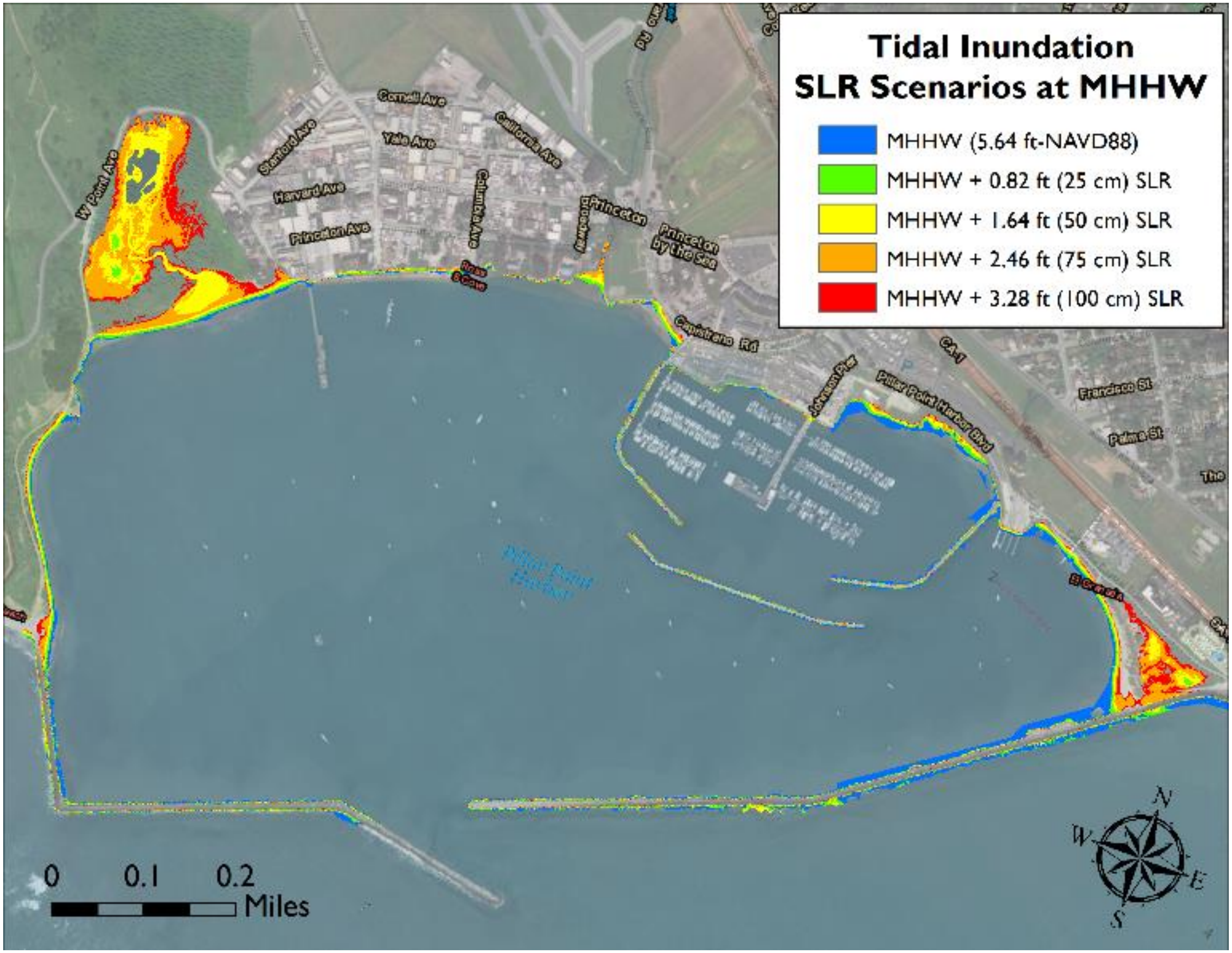

Figure 2: Tidal Inundation Limit under Different SLR Scenarios for Reaches 1-5

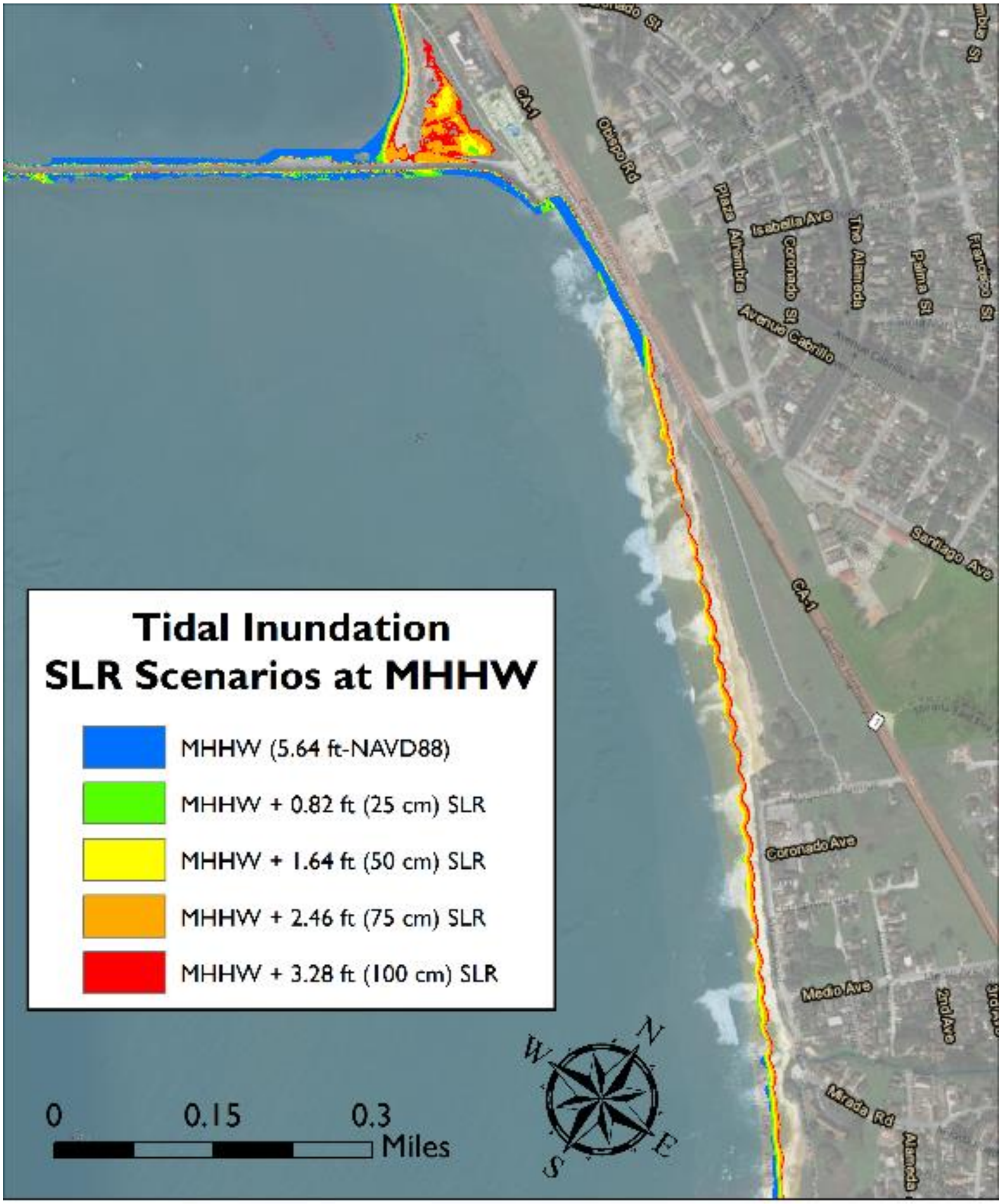

Figure 3: Tidal Inundation Limit under Different SLR Scenarios for Reaches 6-8

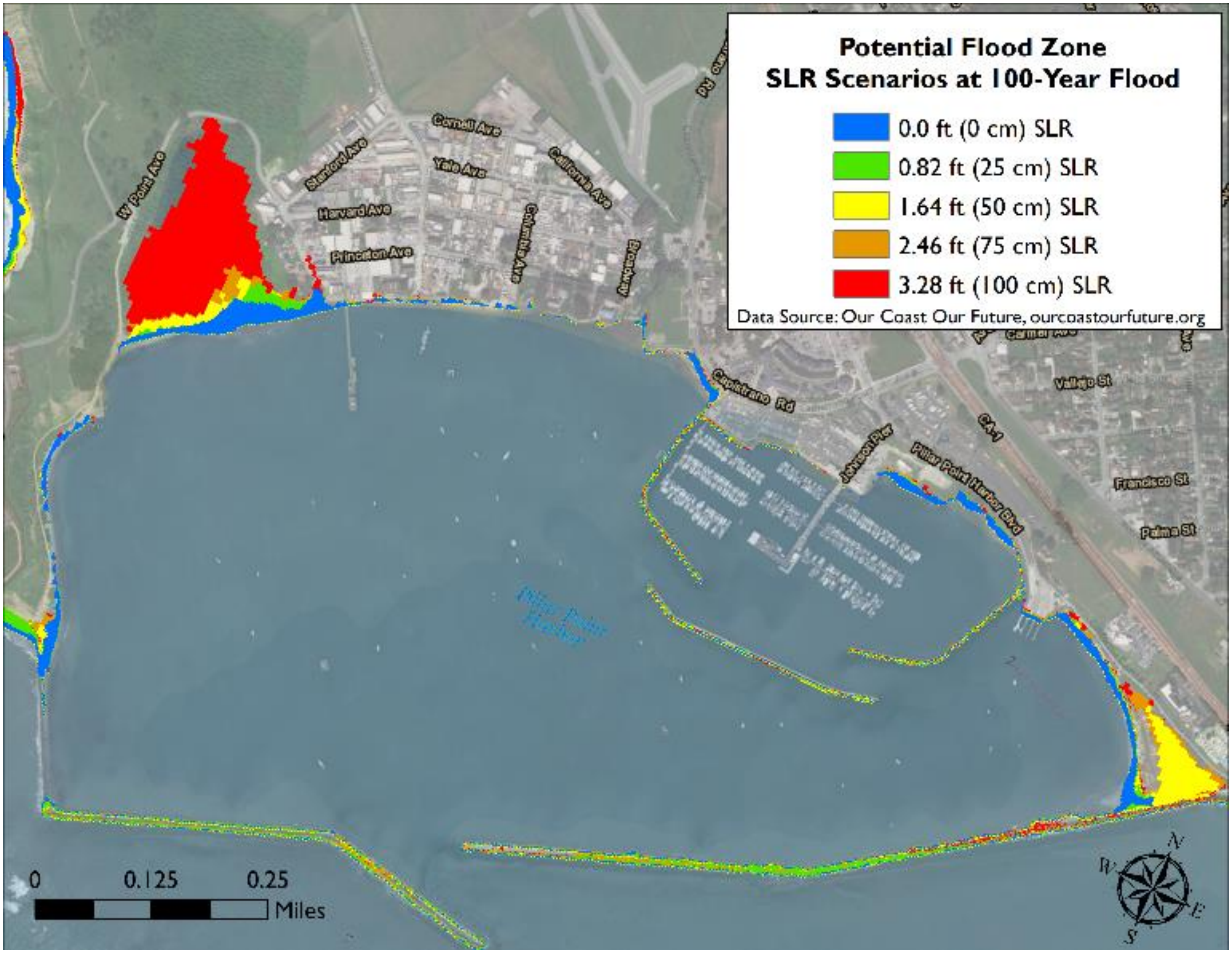

Figure 4: SLR Impacts on Reaches 1-5 (OCOF dataset)

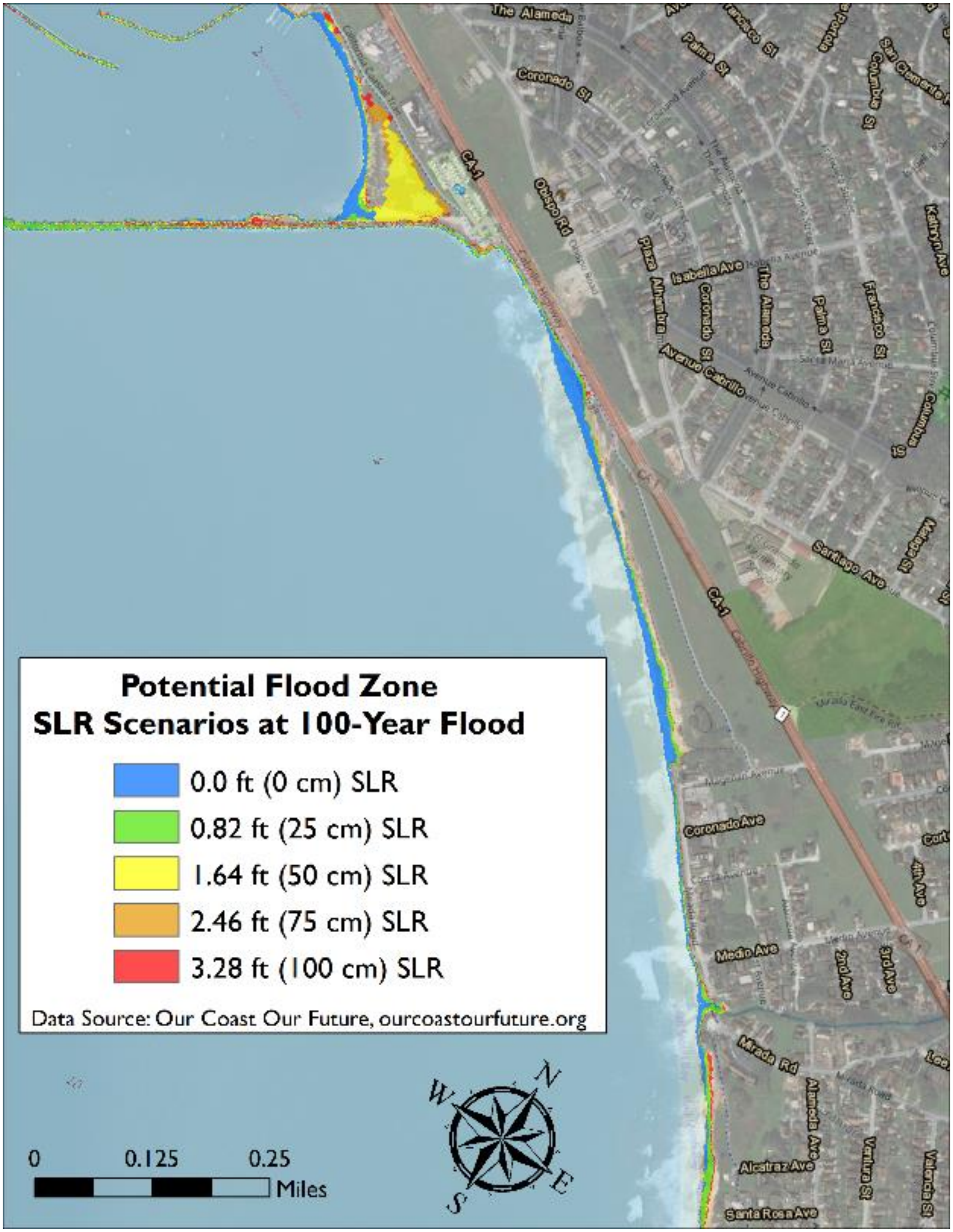

Figure 5: SLR Impacts on Reaches 6-8 (OCOF dataset)

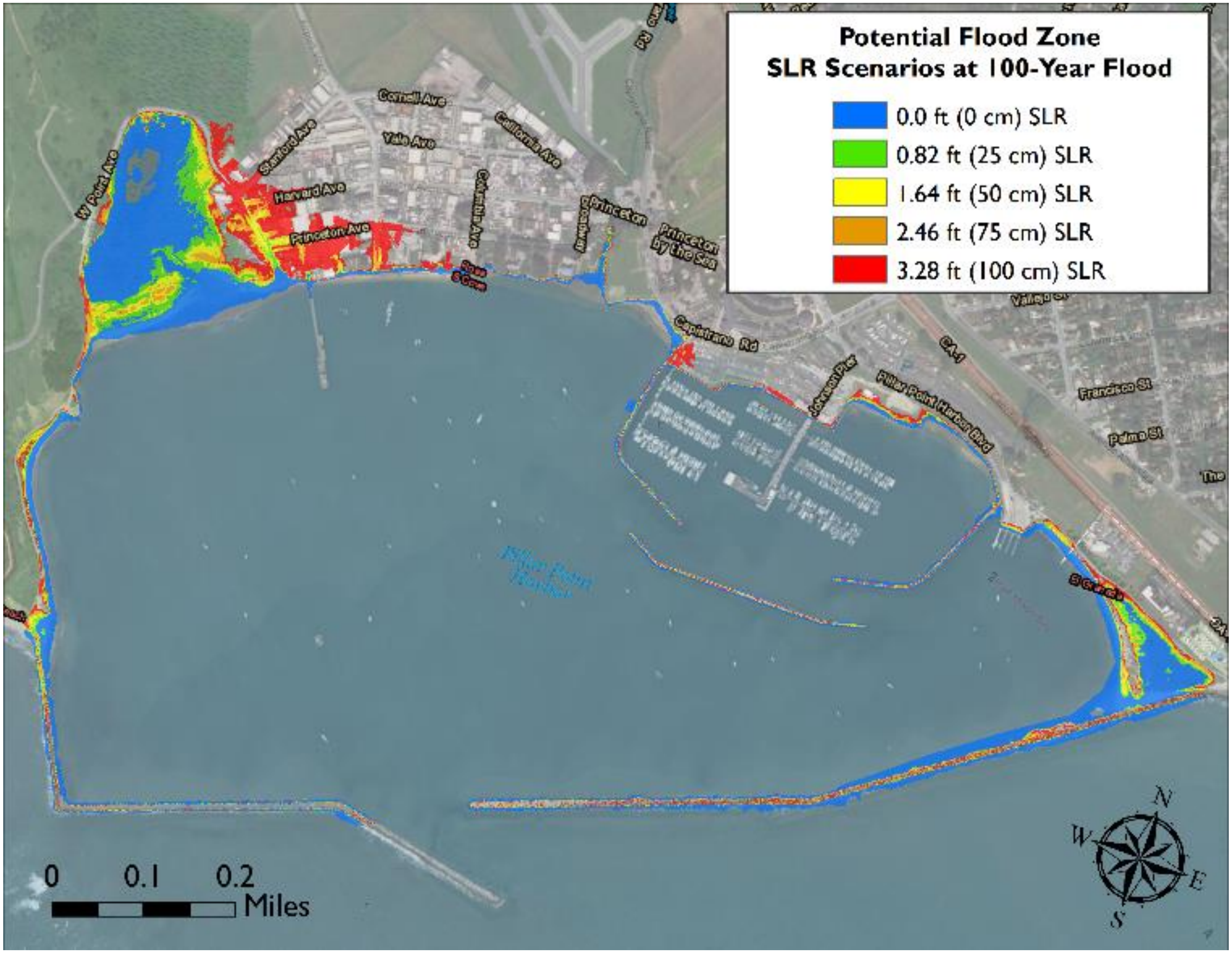

Figure 6: SLR Impacts on Reaches 1-5 (M&N analysis)

Figure 7: Shorelines Condition for Reaches 1-5

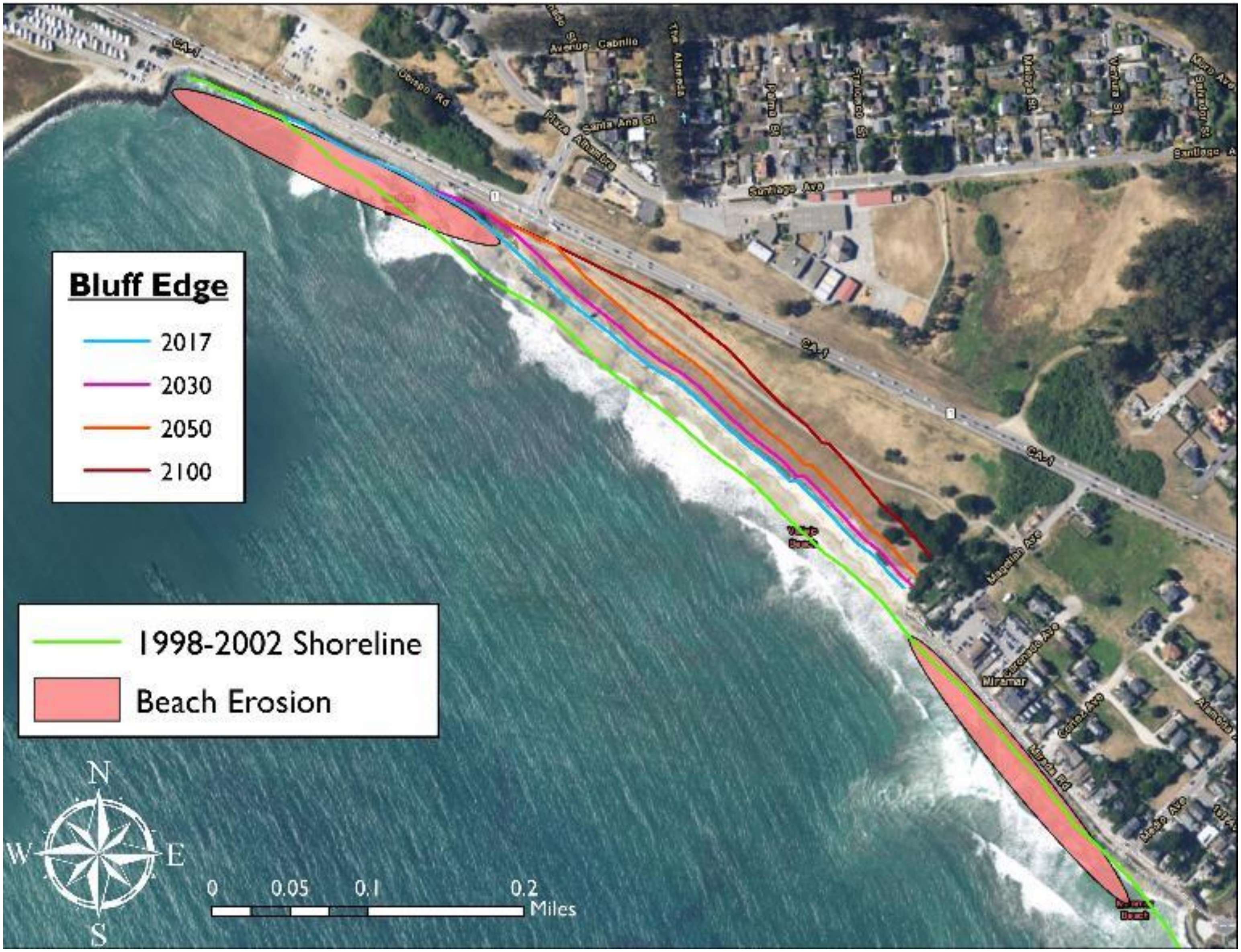

Figure 8: Shoreline Condition for Reaches 6-8

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List of Acronyms

Abbreviation	Meaning
BFE	Base Flood Elevation
CalEMA	California Emergency Management Agency
Caltrans	California Department of Transportation
CCC	California Coastal Commission
CDBW	California Division of Boating and Waterways
CDFW	California Department of Fish and Wildlife
CDWR	California Department of Water Resources
CEM	Coastal Engineering Manual
CSLC	California State Lands Commission
DEM	Digital Elevation Model
DWR	Department of Water Resources
ENSO	El Niño Southern Oscillation
FEMA	Federal Emergency Management Agency
GIA	Glacial Isostatic Adjustment
MSL	Mean Sea Level
MWL	Mean Water Level
M&N	Moffatt & Nichol
NAVD88	North American Vertical Datum of 1988
NDBC	National Data Buoy Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OCOF	Our Coast Our Future
ONI	Oceanic Niño Index
OPC	Ocean Protection Council
OST	Ocean Science Trust
PDO	Pacific Decadal Oscillation
PPH	Pillar Point Harbor
SLR	Sea Level Rise
SLC	State Lands Commission
SMC	San Mateo County
SMCHD	San Mateo County Harbor District
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
VLM	Vertical Land Motion

1. Introduction

1.1. Planning for Sea-Level Rise

Assessing the impacts of Sea-Level Rise (SLR) for legislatively granted Public Trust lands in the State of California is a management priority for local trustees. In 2013, the California legislature passed Assembly Bill 691, Chapter 592, Statutes of 2013 to address assessment criteria for SLR in the state of California. This assembly bill requires all trustees with average annual gross revenue more than $250,000 from their trust lands to prepare and submit an assessment of how they propose to address SLR to the California State Lands Commission (CSLC), by July 1, 2019.

San Mateo County Harbor District (SMCHD) has conducted the current work to provide an SLR assessment for the Pillar Point Harbor (PPH) area. This report provides SLR assessment for Pillar Point Harbor within the area of Half Moon Bay under State SLC grant, indicated on the Grant Plat. Figure 2-1 illustrates the study area defined on the Grant Plat.

1.2. Purpose

The present report builds upon the most recent SLR assessments for the California coasts including SLR projections by the National Research Council *(NRC, 2012)*, California Coastal Commission *(CCC, 2015)*, and Ocean Protection Council *(OPC, 2017)*. The scope of the work is to provide SLR vulnerability assessment for the PPH coastal areas, and include the following tasks:

1. SLR Impact Assessment

   Under this task, the first part of AB 691 Assessment Criteria is covered, including a developed inventory of potentially vulnerable resources and facilities, assessment of storms and extreme events, shoreline retreat, trends in local sea level, and potential impacts to public access, recreation, coastal habitats, and navigability.

2. SLR Flood Hazard Mapping

   Flood hazard maps for different SLR scenarios are developed for the years 2030, 2050, and 2100. M&N used "Our Coast Our Future" (OCOF) and "NOAA Sea Level Rise and Coastal Flooding Impact Viewer" online tools to map SLR-related hazards.

3. SLR Mitigation/Adaptation Measures

   Mitigation strategies for vulnerable areas are identified under this task. Adaptation measures are proposed for the prioritized resources and facilities. The vulnerabilities, estimated time frames for implementation of adaptive measures, and recommended plans to monitor impacts of SLR are also addressed to ensure the efficacy of mitigation and adaptation measures.

4. SLR Impact Cost Analysis

   Based on proposed adaptation and mitigation measures, cost scenarios for the year 2030, 2050, and 2100 are developed for different SLR projections combined with 100-year storm flood scenario. The cost estimate includes replacement and repair costs, non-market values, anticipated costs for adaptation and mitigation measures, and potential benefits of them.

2. Site Description and Environmental Conditions

Pillar Point Harbor (PPH) is located approximately 25 miles south of San Francisco, CA, in the northern part of Half Moon Bay. Before the construction of the harbor, this area was in its natural condition with broad sandy beaches. US Army Corps of Engineers (USACE) constructed the harbor breakwaters between April 1959 and June 1961 (*USACE, 2016*). In 1965, an approximate 1,050 feet extension was added to the west breakwater to decrease the amount of wave energy coming into the harbor.

Figure 2-1 illustrates the study area which extends up to the high-water line onshore. The San Mateo County Harbor District has no granted lands above the high-water line in this area.

Figure 2-2 shows the vicinity of the study area, which includes the northern part of City of Half Moon Bay, as well as three unincorporated communities, Princeton, El Granada, and Miramar.

The study area is divided into eight reaches in this work, demonstrated in Figure 2-3.

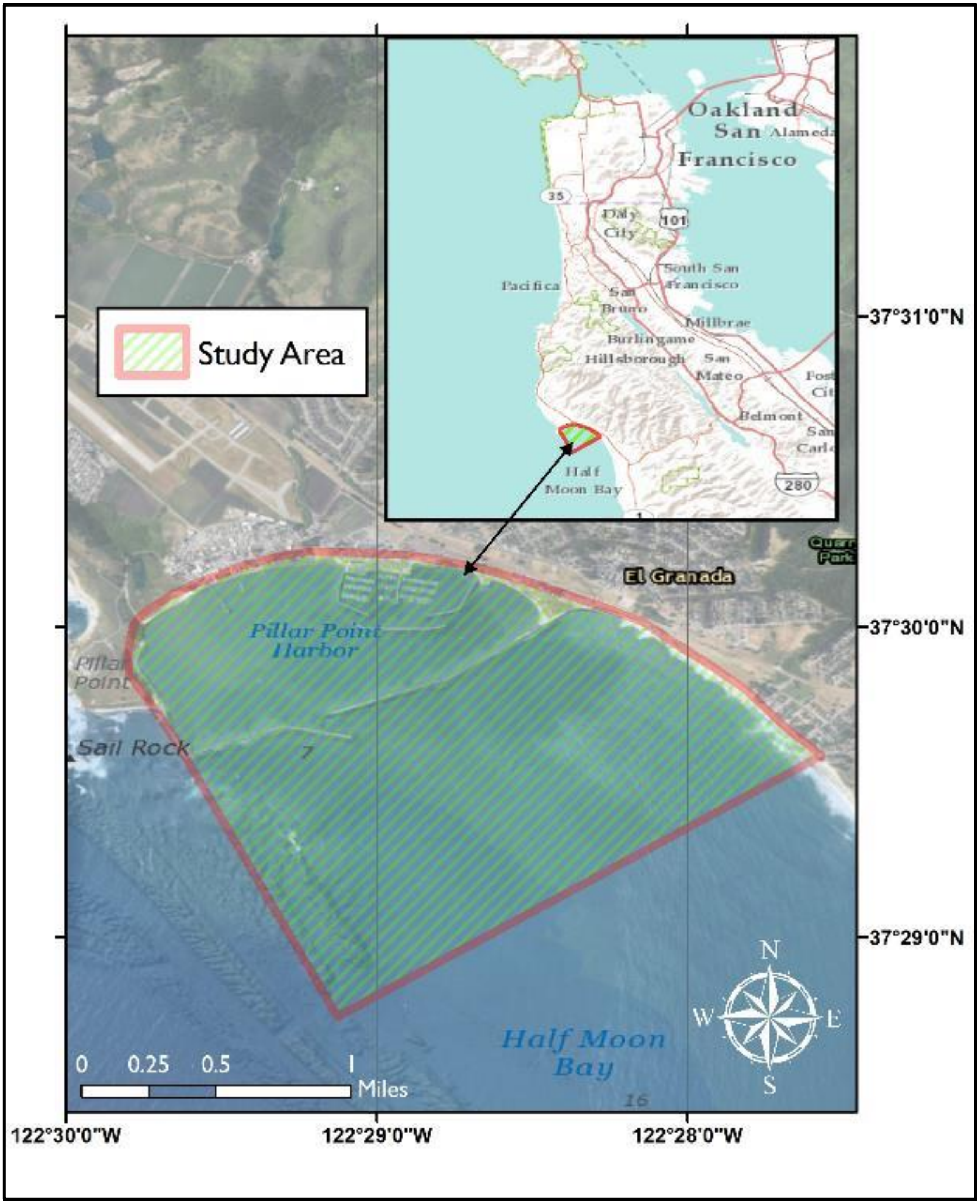

Figure 2-1: Study Area

Figure 2-2: Pillar Point Harbor Vicinity

Figure 2-3: Reach Map

2.1. Land Use

This work utilizes the SMC land use map (*DWR, 2012*) published by the State of California Department of Water Resources in 2012. This dataset was also used to identify manmade and natural resources and facilities within the study area. Figure 2-4 illustrates the land use map for the study area.

The manmade and natural land use terminologies are described in Table 2-1 and Table 2-2.

Table 2-1: Descriptions of Manmade Land Use Categories in Figure 2-4 *(DWR, 2009)*

Category	Description
Field Crops	Cotton, Castor beans, Safflower, Beans (dry), Flax, Hops, Sunflowers, Sugar beets, Hybrid sorghum/sudan, Corn (field & sweet), Millet, Grain sorghum, Sugar cane, Sudan, Miscellaneous field
Truck, Nursery, and Berry Crops	Artichokes, Tomatoes (processing), Asparagus, Flowers, nursery and Christmas tree farms, Beans (green), Cole crops (mixture of 22-25), Mixed (four or more), Carrots, Miscellaneous truck, Celery, Bush berries, Lettuce (all types), Strawberries, Melons, Squash, Peppers (chili, bell, etc.), Cucumbers (all types), Broccoli, Onions, Garlic, Cabbage, Peas, Cauliflower, Potatoes, Brussels sprouts, Sweet Potatoes, Tomatoes (market), Spinach, Greenhouse
Urban	Residential, commercial, and industrial (may be used alone when further breakdown is not required)
Commercial	Offices, Retailers, Hotels, Motels, Recreation vehicle parking, Camp sites, Institutions (hospitals, Prisons, Reformatories, Asylums, Schools, Municipal auditoriums, Theaters, Churches, Buildings and stands associated with race tracks, Football stadiums, Baseball parks, Rodeo arenas, Amusement parks
Urban Landscape	Lawn area - irrigated, Golf course - irrigated, Ornamental landscape (excluding lawns) - irrigated, Cemeteries - irrigated, Cemeteries - not irrigated
Residential	Single family dwellings with lot sizes greater than 1 acre up to 5 acres (ranchettes, etc.), Single family dwellings with a density of 1 unit/acre up to 8+ units/acre, Multiple family (apartments, condos, townhouses, barracks, bungalows, duplexes, etc.), Trailer courts
Paved Area	Parking lots, Paved roads, Oiled surfaces, Flood control channels, Tennis court areas, Auto sales lots, Airport runways

Figure 2-4: Study Area Land Use

Table 2-2: Descriptions of Natural Land Use Categories in Figure 2-4 *(DWR, 2009)*

Category	Description
Barren and Wasteland	Dry stream channels, Salt flats, Mine Tailing, Sand dunes, Barren land
Riparian Vegetation	Marsh lands, Tules, Sedges, Natural high-water table meadow, Trees, Shrubs, Other larger stream side or watercourse vegetation, Seasonal duck marsh, Dry or only partially wet during summer, Permanent duck marsh, Flooded during summer
Native Vegetation	Grass land, Brush and timber, Light brush, Forest, Medium brush, Oak woodland, Heavy brush
Water Surface	River or stream (natural fresh water channels), Water channel (all sizes - ditches and canals - delivering water for irrigation and urban use - ie State Water Project, CVP, water district canals, etc.), Water channel (all sizes - ditches and canals - for removing on-farm drainage water - surface runoff and subsurface drainage - i.e. Colusa drain, drainage ditches in Imperial), Freshwater lake, reservoir, or pond (all sizes, includes ponds for stock, recreation, groundwater recharge, managed wetlands, on-farm storage, etc.), Brackish and saline water (includes areas in estuaries, inland water bodies, the ocean, etc.), Wastewater pond (dairy, sewage, cannery, winery, etc.), Paved water conveyance channels within urban areas (mainly for flood control)

2.2. Public Access

Pillar Point Harbor (PPH) and its surrounding area includes several public beaches and coastal trails. Figure 2-5 shows access routes to the beaches located on Reaches 1, 2 and 3, as well as the coastal trail, bike routes, and pedestrian pathways. To get to this area from Highway 1, one needs to drive through the Half Moon Bay Community of Princeton-By-The-Sea, then turn north onto West Point Ave, and continue to the Pillar Point Marsh parking lot at the end of the road to access Mavericks Beach and Trail. There is a narrow beach in front of the Princeton Community and can be accessed through West Point Ave., Vassar Street, and Columbia Ave. This beach is only accessible during low tide since it is very narrow during hide tide.

Figure 2-6 shows access routes to the beaches located on Reaches 4 and 5. The Johnson pier, PPH Beach, and a kayak launch are located in this area. The California Coastal Trail passes by the PPH Beach connecting Half Moon Bay to Princeton.

Figure 2-7 shows beach access routes and the coastal trail in the vicinity of Surfer's Beach and Vallejo Beach (Miranda Beach) located on Reaches 6, 7 and 8. At high tide, the waves crash right on the rocks that protect the highway from erosion, making Surfer's Beach inaccessible. However, during the low tide enough sand is exposed for public access. Moreover, Vallejo Beach and Miramar Beach are located on Reaches 7 and 8, in the north of Half Moon Bay community of Miramar. These beaches are accessible from the south through Miramar, and from the north through a staircase located next to the coastal trail.

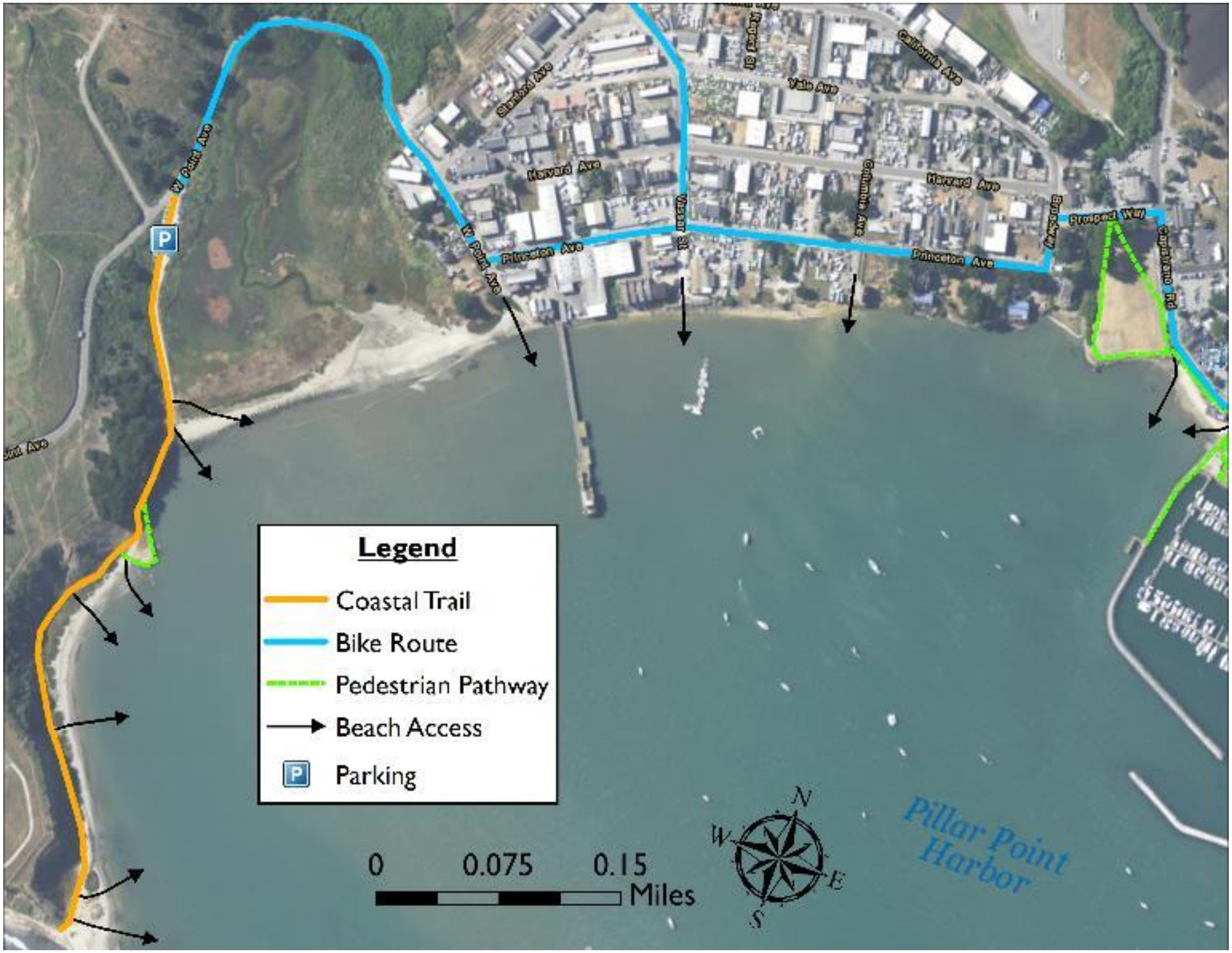

Figure 2-5: Public Access Map for Reaches 1, 2 and 3

Figure 2-6: Public Access Map for Reaches 4 and 5

Figure 2-7: Public Access Map for Reaches 6, 7 and 8

2.3. Habitat

USACE (2015) have provided a review of the biologic environment at Pillar Point Harbor (PPH) and the surrounding area. They reviewed following resources to list existing species in PPH, and discuss potential dredging impacts on the coastal environment.

- United States Fish and Wildlife Service (USFWS) Information, Planning, and Conservation System mapping system (*USFWS, 2015*)
- National Marine Fisheries Service (NMFS) listing of endangered species in the West Coast region (*NOAA, 2015*).
- The California Natural Diversity Database species lists for the Half Moon Bay and Montera Mountain (*CDFW, 2015*)

Based on the *USACE (2015)* work, a brief review of PPH biological habitat is provided here. There are two protected coastal habitats located within the study area (Figure 2-8). Pillar Point Marsh Wetland (Figure 2-2) is a protected area for the salt marsh habitat in PPH. A sandy beach is located at the mouth of the creek that drains from the wetland. Moreover, a coastal strand is located in a fenced off area at the sandy back beach of the PPH Beach (Figure 2-2) near the base of the East Breakwater.

Figure 2-8: Pillar Point Marsh Wetland (Left) and Pillar Point Harbor Beach Coastal Strand

The aquatic and terrestrial habitats in PPH and its surrounding regions support several invertebrates (Table A-1), fish (Table A-2), shorebirds (Table A-3), vegetation (Table A-4), and marine mammals (Table A-5). In many areas, organisms living under the surface of the sand such as clams, crabs, and other invertebrates serve as a significant feeding ground for shorebirds. Several fish species such as striped surfperch, tidepool sculpin, tidepool snailfish, and cabezon inhabit the rocky intertidal regions, where various types of algae grow on the intertidal rocks of the East Breakwater.

Subtidal and intertidal waters afford foraging and summer nursery habitat for fish, while marine birds also feed in this habitat. PPH vicinity supports a variety of shorebirds, diving birds, gulls, terns, wading birds, and waterfowl, as well as several species of migrant birds. Kelp beds have been documented in the subtidal habitat in Half Moon Bay, although *USACE (2015)* mentioned no kelp beds are present in Pillar Point Harbor or close to Surfer's Beach, Vallejo Beach, and Miramar Beach. The most common marine mammals at Pillar Point are the harbor seal and California Sea Lions. Also, species of whales and porpoises have been observed offshore, but it is unlikely for them to be in the nearshore areas.

2.4. Topography and Bathymetry

Topographic and bathymetric data for Pillar Point Harbor (PPH) were obtained from available sources. Figure 2-9 shows the study area topography, obtained from 2-meter resolution LiDAR data (*NOAA, 2016*). The topography data identifies the location of low-lying areas, which are vulnerable to future coastal flooding. As shown in Figure 2-9, several low-lying regions exist within the study boundary (Figure 2-1), including area of the PPH marsh on Reach 2, and the area behind PPH Beach on Reach 5.

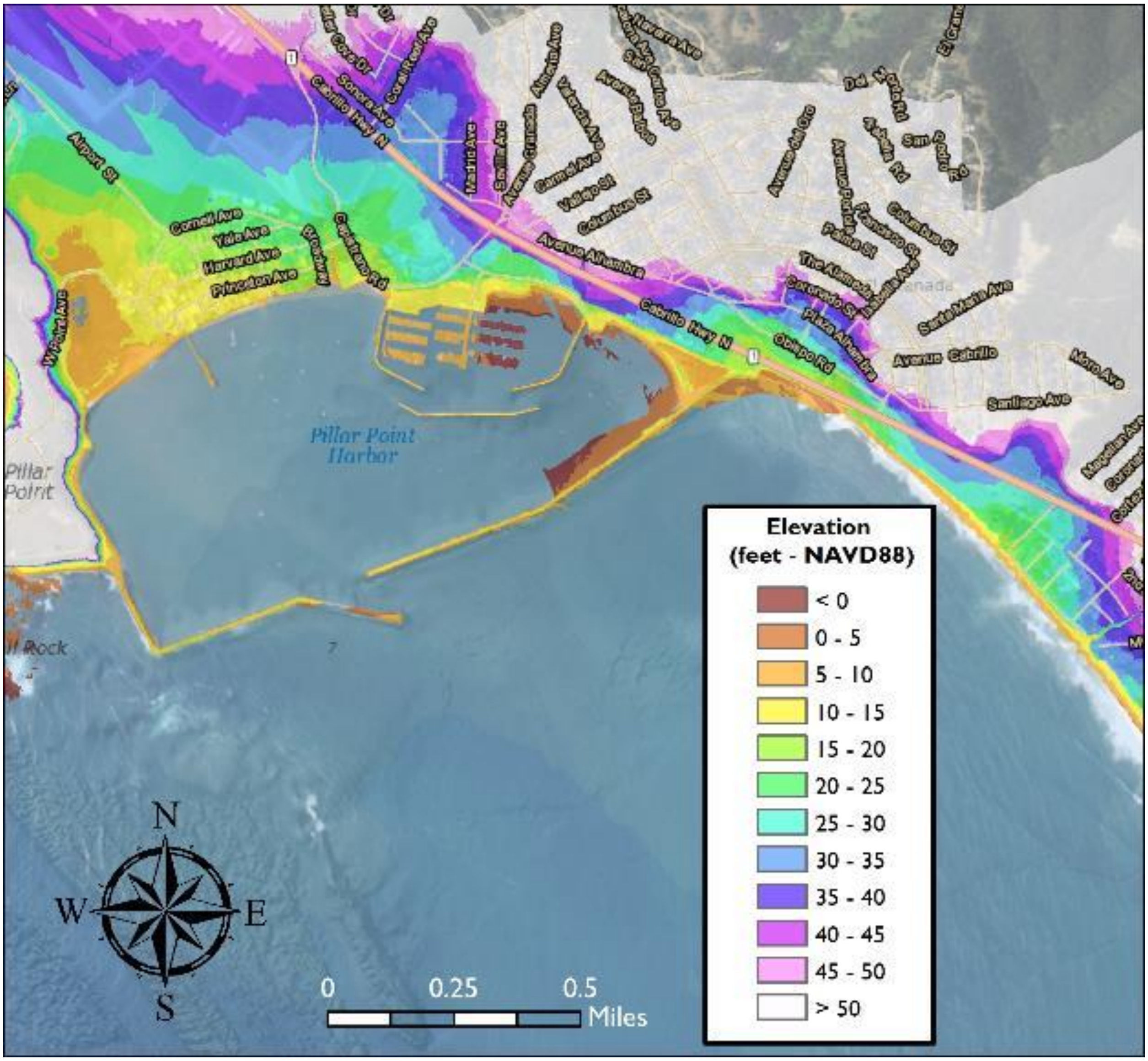

Figure 2-9: LiDAR-Based Bare Earth Elevation

Figure 2-10 shows the study area bathymetry obtained from NOAA's tsunami DEM inventory (*Carignan et al., 2011*). This bathymetric data is in 1/3 Arc-second resolution, approximately 8 meters in longitudinal, and 10 meters in latitudinal directions. The bathymetry data shows that there was no significant sedimentation issue within the harbor at the time the bathymetry data (2001 to 2007) was measured, which is in agreement with *Patsch and Griggs (2007)* who noted that the harbor never needed dredging during its lifetime, nor is there a notable build-up of sand in the proximity of harbor breakwaters.

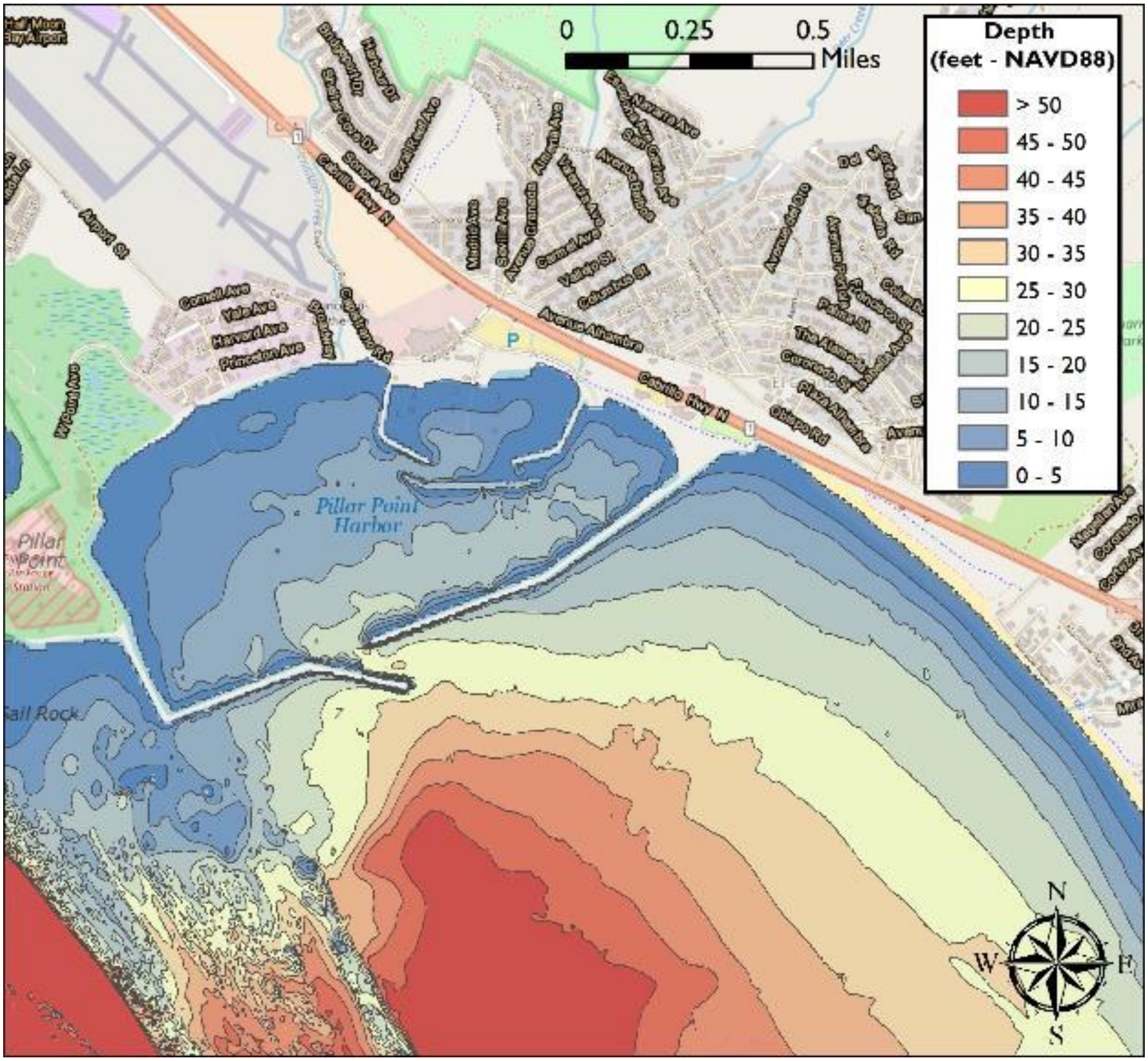

Figure 2-10: Pillar Point Harbor Bathymetry

2.5. Water Levels

2.5.1. Tides

NOAA has been recording water levels at the PPH from 2010 (Table 2-3). The closest NOAA tide gauge to the Pillar Point Harbor (PPH) is the San Francisco gauge (9414290), which has been recording water levels for the past 162 years. Table 2-4 shows tidal datums from the recorded water level data at this gauge. The difference between tidal datums in Table 2-3 and Table 2-4 indicates that the tidal range is slightly less at PPH compared to San Francisco, with a lower MHHW and a similar MLLW datum. *USACE (1996)* estimated the highest observed water level at PPH to be +8.00 ft-NAVD88.

Table 2-3: Tidal Elevations for NOAA Gauge 9414131, Pillar Point Harbor, CA

Datum	Elevation (ft-NAVD88)
Mean Higher-High Water (MHHW)	+5.64
Mean High Water (MHW)	+4.99
Mean Tide Level (MTL)	+3.07
Mean Tide Level (MSL)	+3.03
Mean Low Water (MLW)	+1.15
Mean Lower-Low Water (MLLW)	+0.04

Table 2-4: Tidal Elevations for NOAA Gauge 9414290, San Francisco, CA

Datum	Elevation (ft-NAVD88)
Highest Observed Water Level (HOWL)	+8.72
Mean Higher-High Water (MHHW)	+5.90
Mean High Water (MHW)	+5.29
Mean Tide Level (MTL)	+3.24
Mean Sea Level (MSL)	+3.18
Mean Low Water (MLW)	+1.19
Mean Lower-Low Water (MLLW)	+0.06
Lowest Observed Water Level (LOWL)	-2.82

2.5.2. Extreme Water Levels

NOAA provides estimates of extreme water levels based on recorded water level data. The PPH NOAA Station 9414131 has been recording data for about only 7 years, and cannot be used to properly estimate extreme water levels. Accordingly, the NOAA extreme water level data at San Francisco Station 9414290 is used in this work (Table 2-5). Water levels have been recorded at San Francisco for over 100 years, where the tide gauge has captured events of extreme low and high water levels. This is why the highest observed water level (HOWL) in Table 2-5 surpasses the 100-year water level indicated in Table 2-4, while the lowest observed water level (LOWL) is also lower than the projected 100-year recurrence. The extreme water levels in Table 2-5 are used in this work for flood vulnerability analysis, while as mentioned in the previous section, these numbers are slightly conservative for PPH.

Table 2-5: Annual Exceedance Probability Levels, NOAA Station 9414290

Annual Exceedance Probability	Elevation (feet NAVD88)	Recurrence Interval
1%	+8.66	100 years
10%	+8.17	10 years
50%	+7.67	2 years
99%	+7.02	1 year
99%	-1.09	1 year
50%	-1.68	2 years
10%	-2.07	10 years
1%	-2.33	100 years

2.5.3. Sea-Level Rise

Sea level has been rising globally since about the end of the last ice age about 18,000 years ago. Sea level rise is mainly caused by three processes, land-ice melting, ocean thermal expansion, and loss of ice from polar ice sheets covering Greenland and Antarctica. Although during the 20th-century ocean thermal expansion contributed to about 50% of global SLR, it is expected that ice melt will be the main contributor in the 21st century (*OST, 2017*). Greenland and Antarctic polar ice sheets contain enough ice to raise water levels over 211 feet, which is a lot larger compared to land-ice from glaciers which provide enough water to increase global sea level by just 1.5 feet. Since knowledge about polar ice sheet melting is limited and dependent on future emission levels (which are unknown), global SLR assessments have large uncertainties. Consequently, there are several SLR scenarios available which could cause confusion to quantify SLR. This work follows the recommendations given by the National Research Council (NRC), California Coastal Commission (CCC), and Ocean Science Trust (OST) to quantify reasonable SLR values.

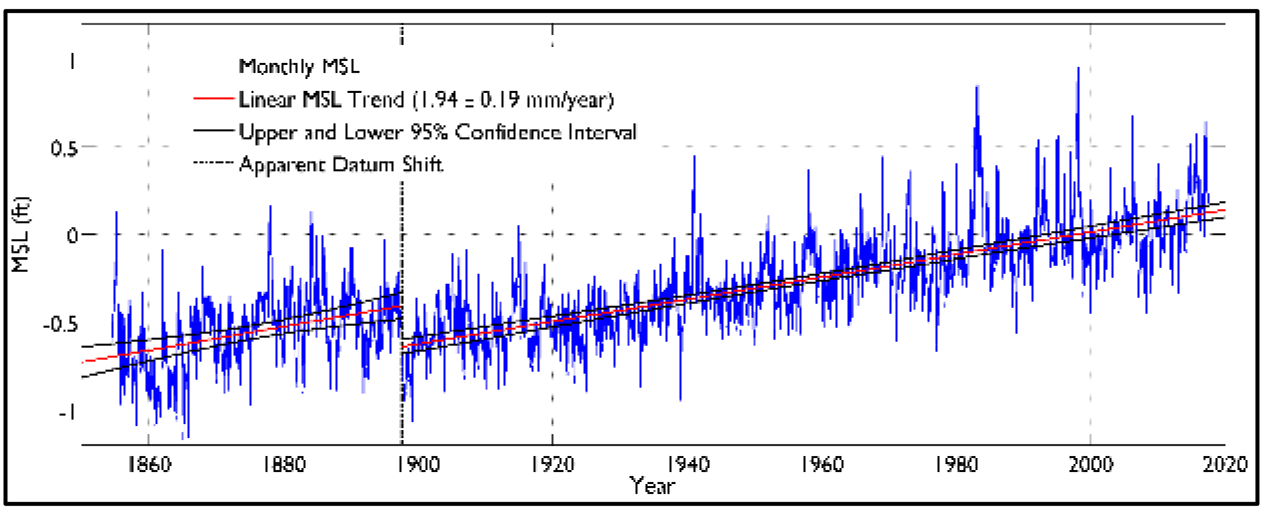

Figure 2-11: Mean Sea Level (MSL) Relative to Year 2000 MSL, Recorded at San Francisco Tide Gauge

NOAA provides monthly Mean Sea Level (MSL) data to track sea level rise rates for the US coasts. Figure 2-11 illustrates the monthly averaged MSL, recorded at San Francisco tide gauge. The MSL shown in this figure is relative to the averaged MSL of the years between 1991 to 2010 (Also referred to as year 2000 MSL). Based on this data, the sea level rise rate is about 1.94 mm/year (7.64 inches/century) at San Francisco.

2.5.3.1. SLR Scenarios

The present California Coastal Commission (*CCC, 2015*) SLR guidance builds upon guidance from the National Research Council study (*NRC, 2012*). The NRC guidance for locations south of Cape Mendocino is summarized in Table 2-6. Values have been converted from centimeters to feet.

Table 2-6: Sea Level Rise Projections and Ranges for San Francisco, *NRC (2012)*

By Year	Projection (feet) (most likely)	Range (feet)
2030	0.26	0.20 - 0.32
2050	0.58	0.42 - 0.74
2100	1.89	1.22 - 2.50

OST (2017) also provides a comprehensive summary of various SLR projections. They consider the most recently updated scenarios for three global emissions scenarios known as Representative Concentration Pathways, or RCPs. RCP8.5 projects a future with the highest greenhouse gas emissions, high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and greenhouse gas emissions. RCP4.5 assumes that global emissions can be curbed and stabilized by 2100. RCP2.6 goes a step further and assumes that net negative carbon dioxide emissions can be achieved before the end of the century. *OST (2017)* also considers the *NOAA (2017)* H++ scenario as an upper-end estimate of sea level rise based on high rates of Antarctic ice loss developing in the last half of this century.

2.5.3.2. Relative Sea-Level Rise

Vertical Land Motion (VLM) plays an important role in terms of sea level rise, as uplift of the coastal landmass will reduce the impact of sea level rise. Likewise, subsidence will cause a more rapid increase in the relative sea level. Accordingly, relative sea level rise, which is the combination of SLR and local VLM, determines the risk that coastal communities face in the future due to global changes in the sea level. The work conducted in *NRC (2012)* found that much of the coast south of Cape Mendocino is sinking at an average rate of about 1 mm per year. The major components of vertical land motion are due to tectonic movement and Glacial Isostatic Adjustment (GIA). Table 2-7 provides the rate of VLM for San Francisco Provided by *NRC (2012)*.

Table 2-7: Rate of VLM for San Francisco *(NRC, 2012)*

Year	Projection (feet)	Range (feet)
2030	0.15	0.02 - 0.28
2050	0.25	0.03 - 0.46
2100	0.50	0.07 - 0.92

Because the San Andreas Fault around the Bay Area is several 100 miles inland, tectonic components are negligible around San Francisco. Therefore, the primary vertical land motion is due to GIA.

Because GIA estimates are taken as an ensemble across several different models, ±1 standard deviation is added to the central estimate. It must be noted that the values provided in Table 2-7 are based on current tectonic movements, and could possibly change after a significant earthquake in the future *(OST, 2017).*

By adding the values of SLR provided in Table 2-6 to the values of VLM provided in Table 2-7, the relative SLR values are obtained *(NRC, 2012)*. Consequently, Table 2-8 provides projections and ranges of relative sea level rise provided by *NRC (2012)*.

Table 2-8: Relative Sea-Level Rise for San Francisco *(NRC, 2012)*

Year	Projection (feet)	Range (feet)
2030	0.48 ± 0.17	0.14 - 0.97
2050	0.92 ± 0.30	0.40 - 2.00
2100	3.02 ± 0.84	1.39 - 5.46

The *NRC (2012)* SLR projections provide a range (e.g., 0.14 to 0.97 feet SLR by 2030) due to the uncertainties about the future emission levels and the ice melting rate. The most probable numbers represent the main projected value for 2030 (0.48 feet), 2050 (0.92 feet), and 2100 (3.02 feet), with a tolerance range associated with them (e.g., ± 0.17 feet for 2030). The values listed in the above table are used as the main SLR guidance in this study.

2.5.4. Climate Cycles

Several climate cycles impact water levels on the US West Coast. The two primary climate cycles that govern climate patterns on the Pacific Coast are the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). Extreme ENSO events can increase the sea level between 0.3 to 0.7 feet, while PDO could also result in 0.7 feet increase in water level (*NRC, 2012*).

2.5.4.1. El Niño Southern Oscillation

The El Niño Southern Oscillation reflects irregular variations of the sea surface temperature in the Eastern Pacific. The warming phase is termed El Niño while the cooling period is named La Niña.

Since 1950, the Oceanic Niño Index (ONI) has been utilized to characterize ENSO ocean temperatures (Figure 2-12). El Niño conditions prevail when warming of the ocean exceeds +0.5˚C. If the ocean temperature cools below -0.5˚C La Niña conditions are present, while conditions are termed ENSO-neutral within the range of ±0.5˚C. The ENSO cycle affects temperatures and rainfall worldwide.

El Niño and La Niña cycles typically last 9 to 12 months. They often commence in June or August and reach their peak during December through April, and subsequently decay over May through July of the following year. Their periodicity is irregular, occurring every 3 to 5 years on average.

2.5.4.2. Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) is another climate cycle that produces ocean warming and cooling trends over decades, as opposed to ENSO variations which unfold over months to years (Figure 2-13).

A cooling trend (blue) can be observed from 1950 to 1976, followed by a warming phase from 1976 to 2005. A brief cooling phase occurred from 2005 to 2014, after which another warming phase has commenced. A comparison of Figure 2-13 and Figure 2-12 reveals that variations of the PDO over the short term are directly influenced by the ENSO. It therefore seems that when these two oscillations are out of phase, they may to some extent moderate ocean cooling and warming, and when they are in phase, combine to produce heightened warming or cooling.

Warming of the ocean causes it to expand, increasing the water level above normal. The effects that may combine to intensify shoreline erosion include El Niño conditions, typically reaching a peak in the winter months where storms are prevalent, which in combination with a warming phase of the PDO can lead to above-normal shoreline erosion.

Figure 2-14 shows the variation of tides at NOAA Station 9414290, San Francisco, indicated by the light blue shading. Elevations are referenced to NAVD88. The dark blue line indicates the variation of the Mean Water Level (MWL) obtained through tidal filtering, i.e. removal of the tidal variation, leaving the mean. A composite of the Oceanic Niño Index and Pacific Decadal Oscillation Index is superimposed on the figure for comparison (NTS).

It can be seen that several instances of increases of the MWL coincide with peaks in the ONI-PDO variation. A similar trend is observed for cooling of the ocean, i.e., lower MWL coinciding the lower ONI-PDO, although the cooling cycles are not as obvious as the warming cycles.

The maximum increase of the MWL recorded at San Francisco has been 2.6 feet, while the largest decrease of the MWL has been -2.0 feet. Periods of elevated or decreased ocean levels can be on the order of months, while the peak highs and lows occur on the scale of days to weeks.

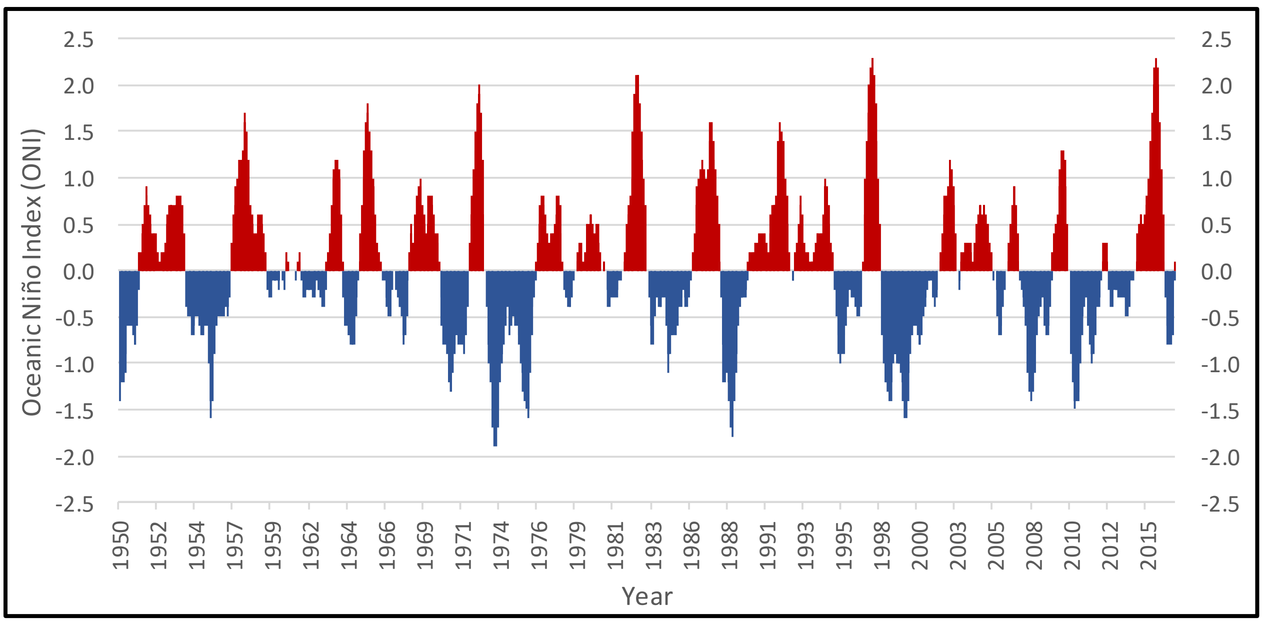

Figure 2-12: ENSO variation (1950-2017)

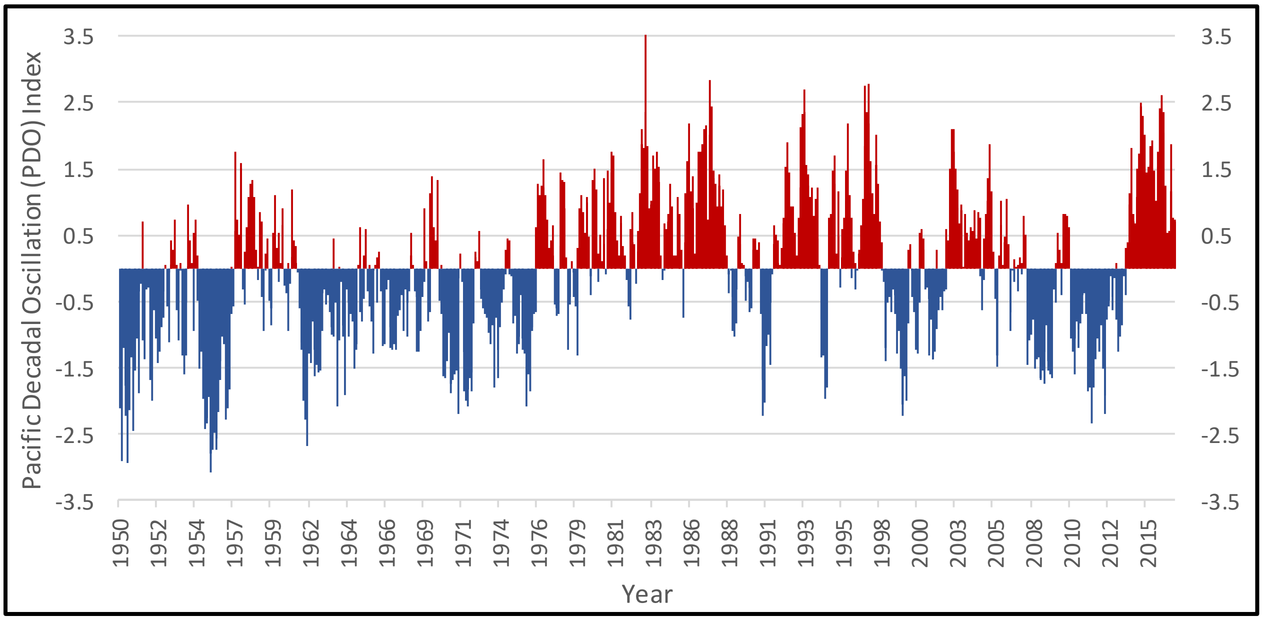

Figure 2-13: PDO variation (1950-2017)

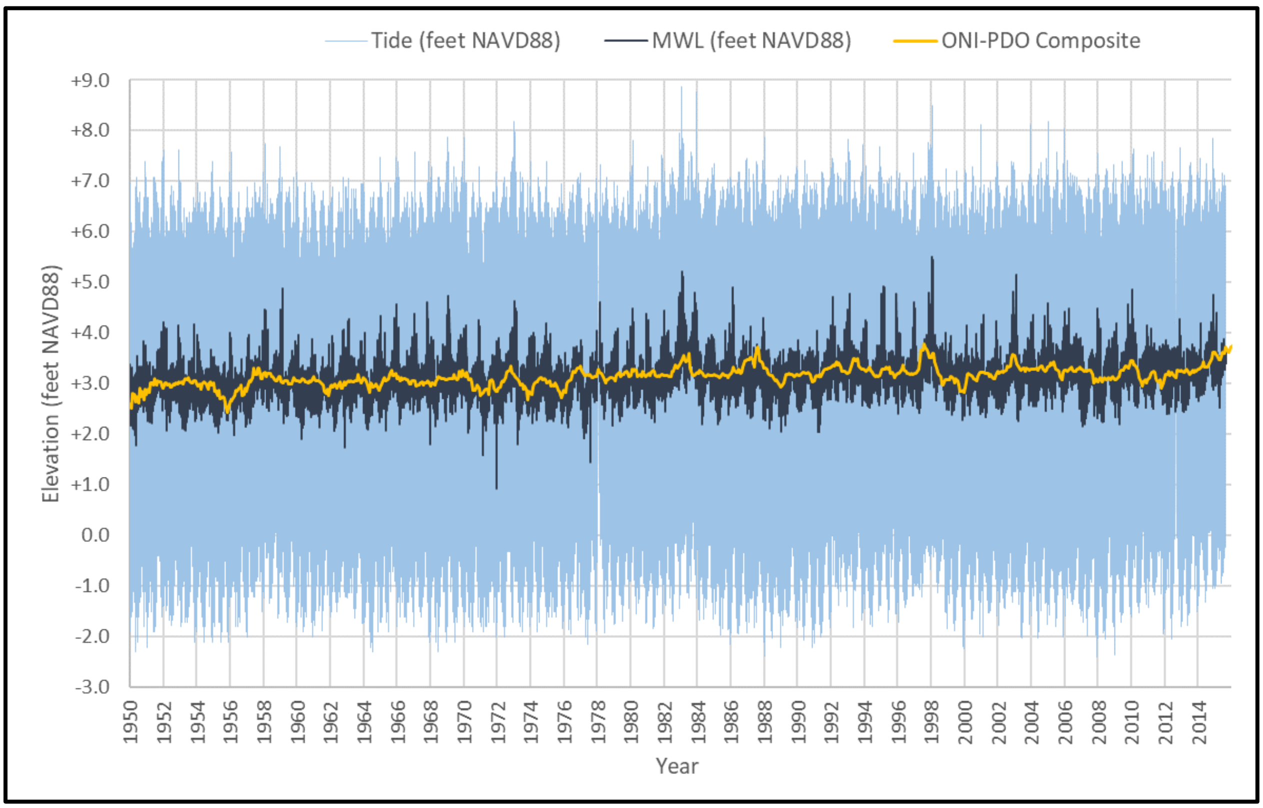

Figure 2-14: Tidal variation, mean water level, and Oceanic Niño – Pacific Decadal Oscillation Index

2.6. Wind and Wave Climate

The wind climate in the Pillar Point Harbor (PPH) area can be characterized by measurements collected at the Half Moon Bay buoy (NDBC 46012). The wind data at this station has been recorded since 1980, with over 30 years of available data. The recorded data determines that the predominant wind direction is from the northwest, where 65% to 75% of winds from spring through fall comes from this direction *(Lin et al., 2015)*. During the winter season, the wind is from the northwest about 40% of the times, with contributions from other directions including northeast (21%), and Southeast (24%) *(Lin et al., 2015)*.

Coast & Harbor Engineering (2012) have studied storm wave design criteria for the PPH, as part of the Mavericks trail (Figure 2-2) shoreline protection project. They estimated 100-year wave height and period inside the PPH utilizing a wave transformation analysis from offshore, as well as local wind-induced wave growth within the harbor. Table 2-9 provides *Coast & Harbor Engineering (2012)* estimated wave parameters. They concluded that a sea level rise of 4 feet did not cause any notable impact on the 100-year storm waves at this site. These values are in agreement with *M&N (2001)* estimation of wave climate within PPH as part of a study to evaluate shoreline conditions at Princeton. In addition, a fetch limited approach based on the Coastal Engineering Manual (CEM) guidance was used in this study to check numbers provided in Table 2-9.

Table 2-9: 100-year Storm Waves Parameters Within PPH *(Coast & Harbor Engineering, 2012)*

Wave Type	Significant Wave Height (feet)	Peak Wave Period (Seconds)
Locally Generated Short Waves	2.0	3.00
Swell Waves	1.5	17.00

2.7. Impacts of Extreme Events

This section provides a brief review of possible coastal flooding impacts during storms and tsunamis in Pillar Point Harbor (PPH) and its adjoining shorelines.

2.7.1. Coastal Flooding

Figure 2-15 and Figure 2-16 show the FEMA 100-year flood zones for the project area. The areas indicated by orange color illustrate the 500-year flood zones. Based on the FEMA flood maps, beach access will be limited during the 100-year storm condition for almost all of the reaches within the study area.

2.7.2. Tsunami

Tsunamis are long waves caused by either seismic activities (mainly subduction) or landslides on the Ocean floor. Although the Pacific Rim is one of the most seismically active regions in the world, tsunamis rarely occur in a way to impact California coasts significantly. For example, existing records show that the 2011 Tohoku-Oki tsunami did not cause significant damage or flooding in the vicinity of the study area.

Figure 2-17 shows the tsunami inundation zone in the study area (*CalEMA, 2009*). Although a significant portion of the study area falls into the inundation zone shown in Figure 2-17, it must be noted that this map was obtained from the envelope of tsunami inundation zones for 15 local and distant tsunami sources. Some of the tsunami sources considered for this work have return periods larger than 1,000 years. There is no data available for the changes in tsunami inundation zone due to SLR. However, it is expected that the tsunami would impact areas further inland during higher sea levels.

Figure 2-15: FEMA 100-year Flood Map for Reaches 1-5

Figure 2-16: FEMA 100-year Flood Map for Reaches 6-8

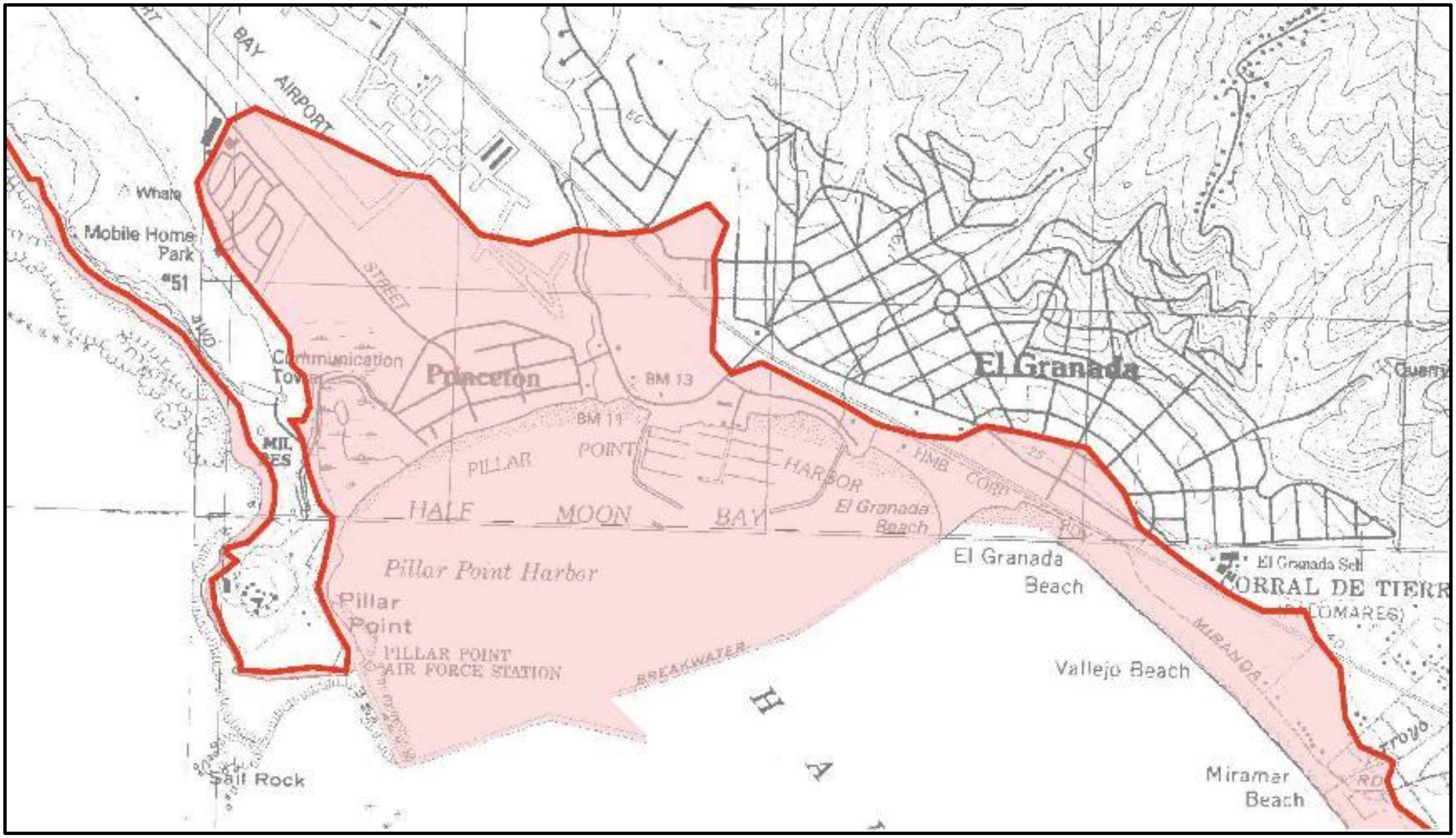

Figure 2-17: Tsunami Inundation Map for North Half Moon Bay

(From CalEMA tsunami inundation map for San Mateo County)

2.8. Shoreline Conditions

2.8.1. Background

Before human occupation, Pillar Point Harbor (PPH) had wide sandy beaches with minimal erosion. The construction of the outer breakwaters stabilized the shorelines within the harbor. However, the construction of PPH increased cliff retreat and beach erosion south of the East Breakwater. Several remedial actions have been implemented since to control cliff erosion, including the rubble-mound revetment build by Caltrans to protect Highway 1 (Cabrillo highway). The shoreline condition provided in this work refers to *USACE (2009, 2016)* who reviewed the shoreline condition in the study area as part of their shoreline improvement project for Northern Half Moon Bay. Table 2-10 provides a timeline of the construction and its impacts on shoreline condition in the study area.

Table 2-10: Timeline of Construction at PPH and Shoreline Condition *(USACE, 2009)*

Date	Construction Timeline	Shoreline Condition
Before 1959	Natural condition	Minimal erosion with broad sandy beach
1959 - 1965	Two outer breakwaters built	Increase in erosion with a loss of approximately 75,000 cubic yards per year south of the East Breakwater
Before 1971	500 feet revetment built starting at the root of East Breakwater	Stopped local cliff retreat
1982	Two inner breakwaters built	No impact on erosion south of the East Breakwater
1965 - Present	Various remedial actions including rubble-mound revetments	Erosion rates south of the East Breakwater increased from 3 inches per year to as much as 80 inches per year where sea cliff is exposed

2.8.2. Morphologic Patterns and Sediment Transport

The construction of the outer breakwaters has changed nearshore wave refraction patterns. Although shorelines inside the harbor experience a milder wave climate after the harbor construction, the wave energy focused more on the south of the East Breakwater. Consequently, waves approaching from the northwest have a greater impact on Surfer's Beach. The area south of Pillar Point is a log spiral beach where it is protected from prevailing northwest waves. A log spiral beach is a type of beach protected by a headland, in an area called the shadow zone. *Lajoie and Mathieson (1985)* reported that the increased erosion along Surfer's Beach is due to the shift in the center of the log-spiral to the south after harbor construction, as well as lack of sand supply from the north. They concluded that post-construction wave field tend to force a return to an equilibrium log spiral configuration, causing the most significant morphologic changes occur where the spiral is the tightest, south of the East Breakwater. Figure 2-18 shows the impact of harbor construction on wave refraction and the log spiral beach shape, as well as dominant longshore sediment transport patterns.

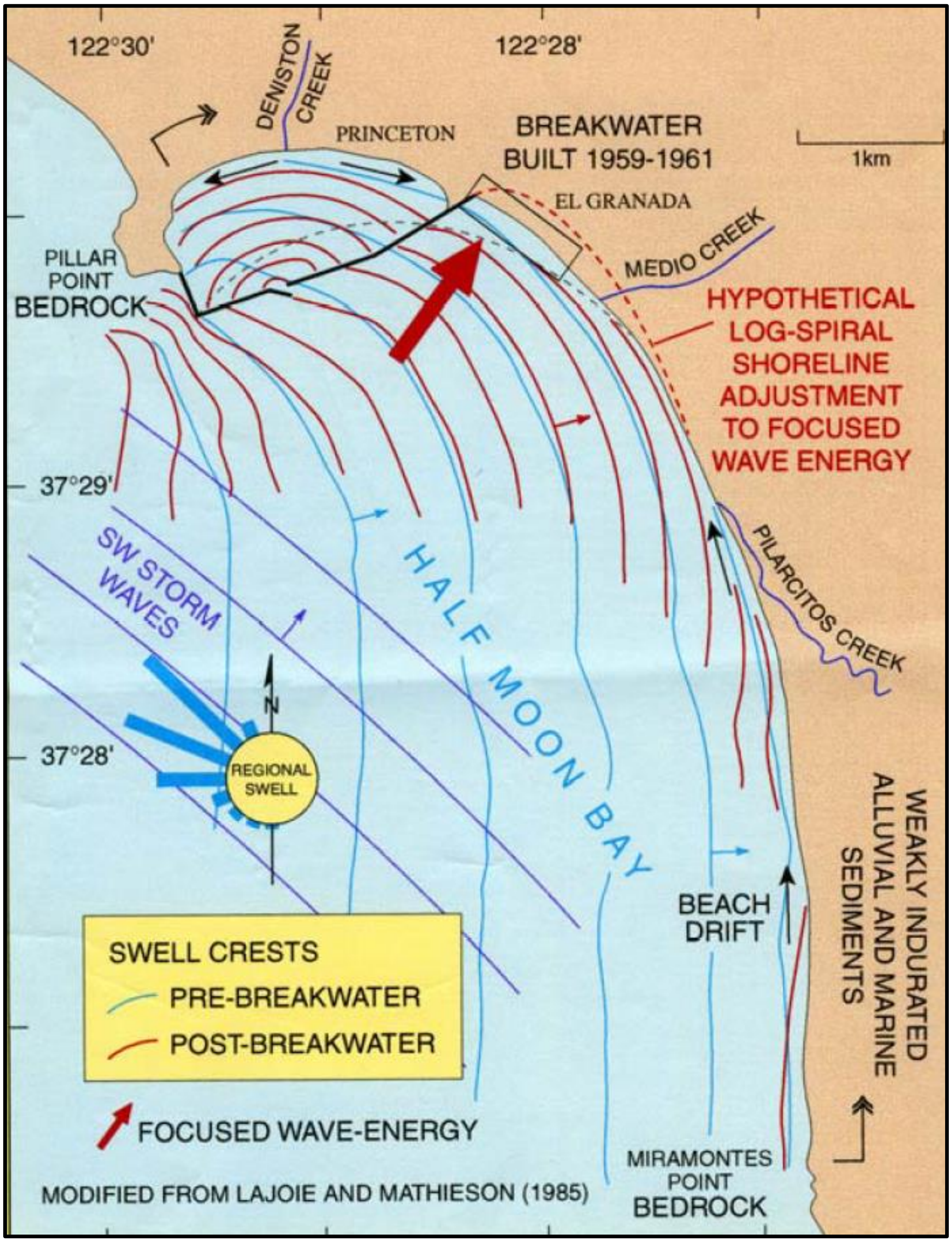

Figure 2-18: Hypothetical Log-spiral Shoreline Adjustment to Refocusing of the Incident Wave Energy Following Construction of the PPH Breakwaters
(*Lajoie and Mathieson*, USGS poster)

The longshore sediment transport (littoral drift) in Half Moon Bay could be both northward and southward depending on the wave climate with the net drift being from northwest to southeast due to the predominant northerly to westerly wave climate (*USACE, 2009*). The longshore sediment transport is combined with cross-shore transport patterns during winter where short-period waves move sediment offshore, as well as summer when longer period waves move sediment back onshore. *USACE (2009)* reported that the Half Moon Bay shoreline has been eroding since the 19th century due to natural processes, while the rate of retreat was low due to the presence of a permanent broad sandy beach and an equilibrium shoreline shape relative to the incident waves.

Inside the harbor, sediment has accumulated north of the East Breakwater (Reach 5), creating PPH Beach which contains more than 73,000 cubic yards of sand above water (*USACE, 2015*). The sand probably came from erosion of the Princeton shoreline and fluvial sediment from Denniston Creek and Deer Creek (*USACE, 2009*). It is also possible that some of the sand at the PPH Beach originates from the south, passing through the breakwater during extreme storms (*USACE, 2016*). Once the sand reaches inside the harbor through the East Breakwater, it does not move back into the littoral system to the south of the breakwater due to lack of sufficient wave inside the harbor.

It can be concluded that the outer breakwater construction has increased the erosion rate south of PPH in the area between the East Breakwater and Arroyo de en Medio. Except for the Princeton shoreline and some few spots which are discussed in the next section, the shorelines inside the harbor are either stable or accreting.

2.8.3. Current Shoreline Retreat Condition

In this section, a review of current shoreline conditions at Pillar Point Harbor (PPH) and its surrounding area is provided. In the following discussion, the reach definition demonstrated in Figure 2-3 is employed to explain shoreline conditions within the study area. Also, the California Coastal Record's pictures of the study area, which were taken in June 2013, are included in Appendix B for further clarification.

Reach 1 is located between the west breakwater and the tidal wetland within the Pillar Point Harbor (Figure B-1 and Figure B-2). This area mainly consists of sandy beaches backed by a tall bluff between 40 to 80 feet high. In the northern part of Reach 1, low bluffs exist near Reach 2 (Figure B-2), which are actively eroding (Figure 2-19; *GHD, 2016*). The San Mateo County Harbor District conducted an emergency repair to part of the shoreline in January 2016 to the drainage and outfall structure, shown in Figure B-2. *GHD (2016)* reported that the bluff recession was 0.6 feet per year on average during 1986 to 2016. This area is currently protected by revetment.

Reach 2 consists of a wide sandy beach backed by a low-lying marsh (Figure B-2 and Figure B-3). There is a coastal dune between 8 to 10 feet high separating the marsh from the beach while protecting it against wave action.

Reach 3 is the shoreline of Princeton Community (Figure B-3 and Figure B-4), where the beach in front of it consists of fine dark sand backed by bluffs 1 to 2 feet high. The shoreline in Reach 3 is protected by several revetments, mainly to protect buildings and parking lots against erosion. The Denniston Creek inlet is located on this reach, which brings fluvial sediment input into the harbor. The beach in Reach 3 has reportedly been subject to erosion issues in recent years (*M&N, 2001*).

Reach 4 is the shoreline of the inner harbor (Figure B-5 and Figure B-6). This area has a small trace of a berm near its entry, with wide beaches with very fine dark sand, backed by cliffs about 15 feet high. Deer Creek inlet is located on this reach.

Reach 5 is located between the inner breakwaters and the Pillar Point Harbor east breakwater, in the southernmost part of the Pillar Point Harbor (Figure B-7). Sediment has been building up in this area, after the construction of the breakwater in 1961, creating PPH Beach (Figure B-7), backed by a 10-15 feet high bluff. The harbor boat launch is located in this reach in the vicinity of the inner harbor.

Reach 6 is located south of the Pillar Point Harbor (Figure B-8 and Figure B-9). After the construction of the breakwater finished in 1961, the erosion rate has reportedly increased from 3 inches per year up to 80 inches per year (Figure 2-20; *Patsch and Griggs, 2007*). Accordingly, the Army Corps of Engineers has constructed a rubble-mound revetment to protect Highway 1. However, the unprotected shorelines in the south of Reach 6 are actively receding. The bluff is about 10 feet high in Reach 6.

Reach 7 consists of a wide beach with moderately fine sand, backed by a bluff about 10 feet high (Figure B-9 and Figure B-10). The bluff has been retreating over the past decades, which has caused damage to the old coastal trail (Figure 2-20).

Reach 8 is the coastline of Miramar Community (Figure B-11 and Figure B-12). The shoreline in this reach consists of a wide beach, backed by a bluff approximately 10 feet high. In order to protect the Miramar Community, and the Mirada Road (Figure B-11), San Mateo County has constructed a rock revetment along the shoreline of Reach 8.

Finally, Figure 2-21 and Figure 2-22, which are taken from *William et al. (2001)*, provide a schematic preview of shoreline conditions and processes at Pillar Point Harbor and Miramar Shorelines. As discussed above, several areas are protected with revetments, while the shoreline retreat and bluff recession are common in unprotected regions within the study area.

Recession rates and shoreline changes are discussed in the upcoming sections of this report, as part of the discussion on vulnerability to future sea levels, shoreline condition, and related coastal hazards.

Figure 2-19: Shoreline Changes near the Mavericks Coastal Trail
Picture Taken from *GHD (2016)*

Figure 2-20: Bluff Recession on Reaches 6 and 7 from 2003 to 2017

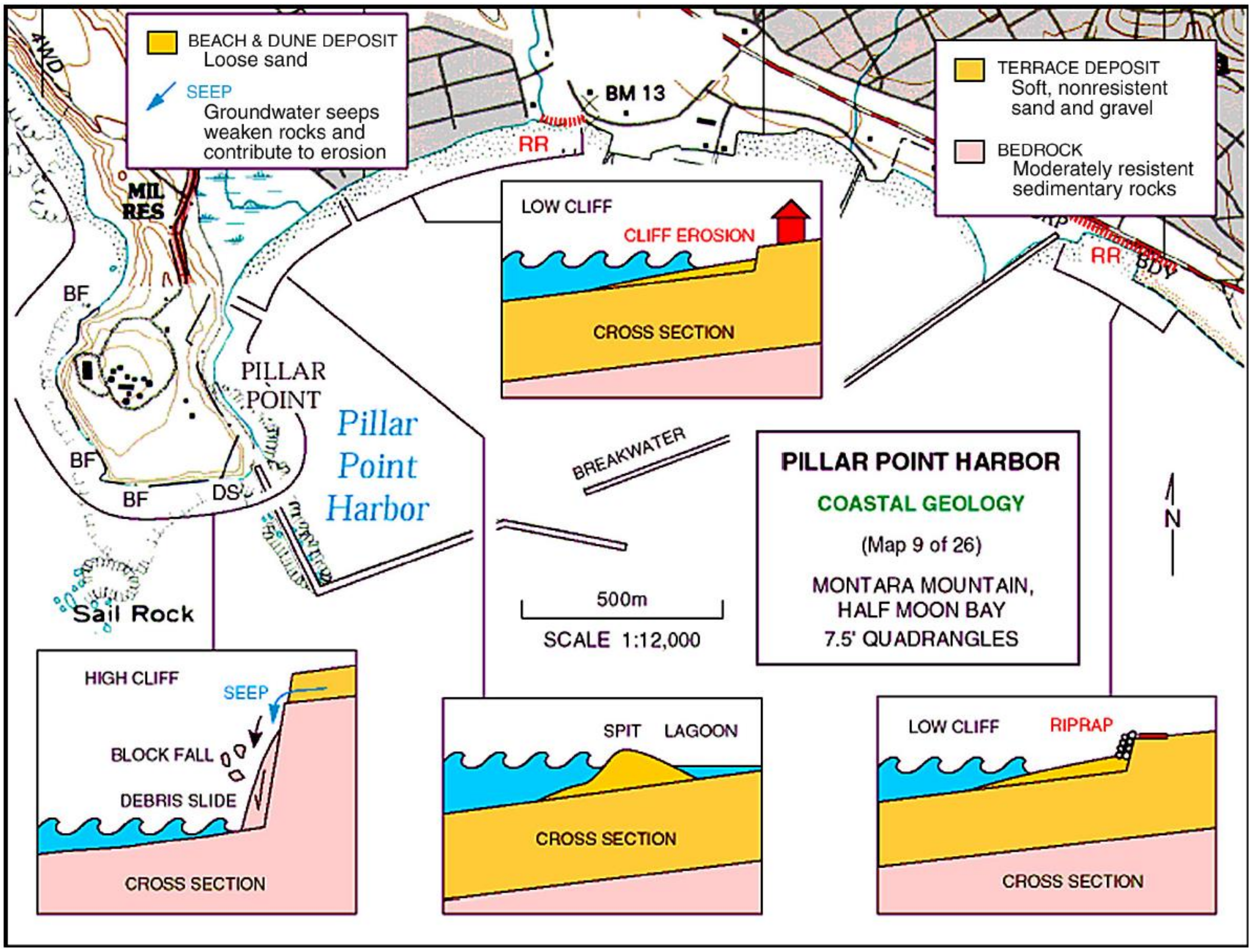

Figure 2-21: Pillar Point Harbor Shoreline Condition Schematic Map
(Figure from *Williams (2001)*, Figure 5.30)

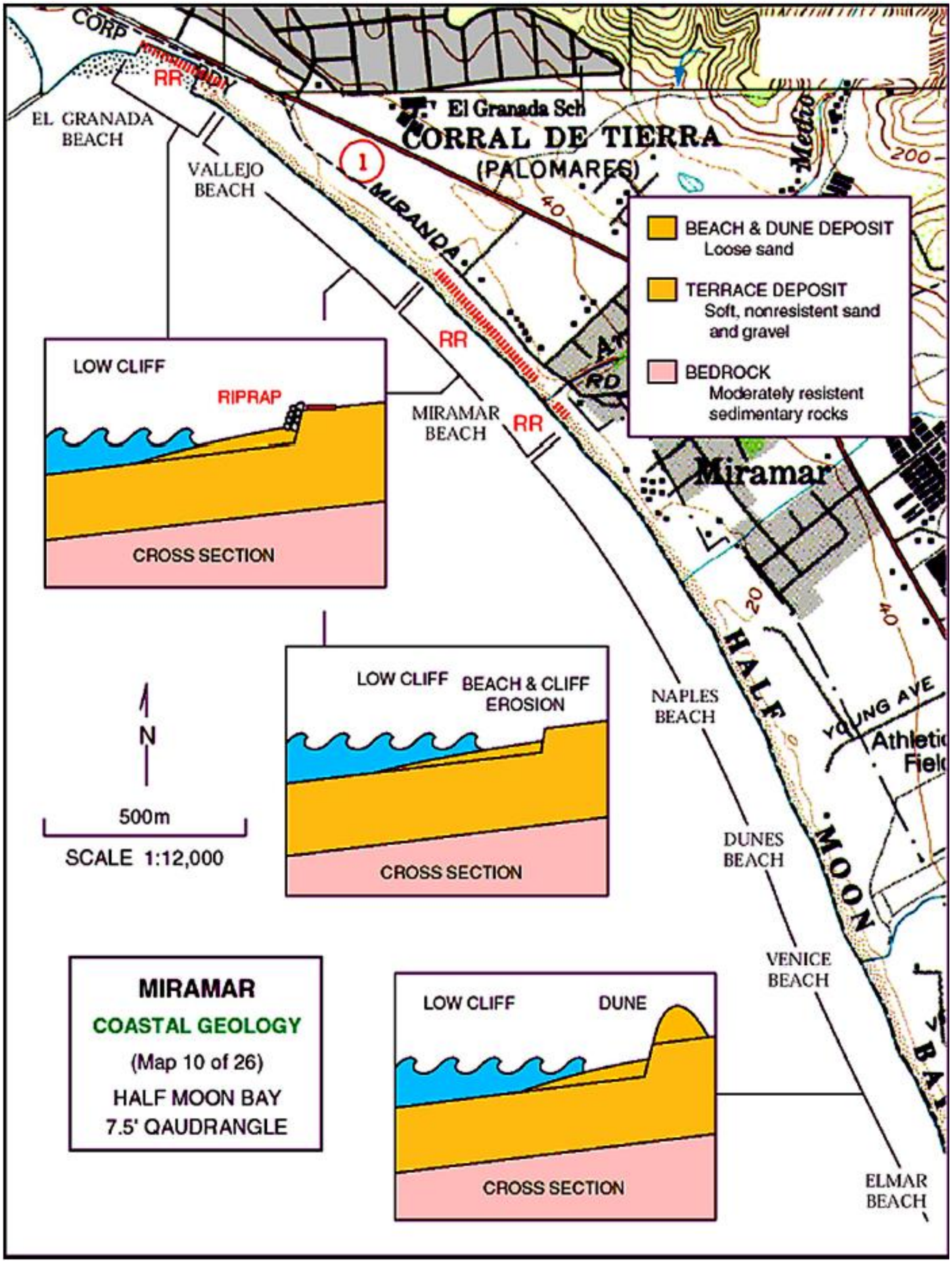

Figure 2-22: Miramar Shoreline Condition Schematic Map
(Figure from *Williams (2001)*, Figure 5.31)

3. Future SLR and Shorelines Changes Impact on Pillar Point Harbor

3.1. Future Sea-Level Rise Impacts

Pillar Point Harbor's vulnerability to Sea-Level Rise is investigated using two available online mapping tools and a flood mapping analysis. The Our Coast Our Future (OCOF) and NOAA Sea-Level Rise Viewer are the online mapping tools utilized here to evaluate PPH vulnerability to coastal flooding exacerbated by SLR. The advantage of the OCOF platform compared to the NOAA SLR viewer is the inclusion of storm scenarios. The OCOF platform makes it possible to investigate different SLR scenarios ranging from 0.82 to 6.56 feet (25 to 200 cm) with 0.82 feet (25 cm) SLR steps, in combination with storm conditions (Annual, 20-yr, 100-yr). Accordingly, OCOF platform chosen as the basis of study for this work.

The SLR values were chosen considering the discussion provided in Section 2 regarding local relative SLR (Table 2-8). The 0.82 feet (25 cm) SLR represents the upper range SLR scenario for 2030 and lower mid-range for 2050. 1.64 feet (50 cm) SLR corresponds to upper mid-range SLR for 2050 and the lower range of SLR projected by 2100. The 2.46 and 3.28 feet (75 and 100 cm) SLR scenarios represent the lower and upper mid-range SLR scenarios for 2100. It is important to note that the SLR at the end of the century could be higher than 100 cm (3.28 feet); however, due to a high level of uncertainty, the upper mid-range SLR was considered as the highest SLR studied.

Figure 3-1 and Figure 3-2 show the tidal inundation limit under SLR scenarios discussed above for all the reaches within the study area. The MHHW datum (5.64 ft-NAVD88, Table 2-3) was chosen as reference mapped over the most recent topographic data (Figure 2-9). Based on the data shown in Figure 3-1 and Figure 3-2 two reaches will be impacted by SLR even without considering 100-year storm condition. The tidal marsh located in Reach 2 will be more frequently inundated during high tide as well as the area behind the PPH Beach dune in Reach 5.

Figure 3-3 and Figure 3-4 illustrate the 100-year flood hazard zone within the study area for the SLR scenarios (0.82 -3.28 feet) discussed above based on the data provided by OCOF. Similar to the tidal inundation pattern (Figure 3-1 and Figure 3-2), these maps show that the tidal marsh located in Reach 2 and the back beach of PPH Beach (Reach 5) will be regions the most impacted by coastal flooding in the future.

Although Figure 3-3 shows that the area of eastern Princeton near the West Point Ave. (Reach 3) will face coastal flooding problems in the future, it is clear that the OCOF data does not have sufficient resolution in this area to draw a definitive conclusion. Considering that the Princeton Community is already facing coastal flooding issues (*M&N, 2001*), a coastal flood analysis was performed for the part of the study area inside the harbor to provide a better understanding of the challenges they face during future sea levels. For this analysis, 100-year water levels under different SLR scenarios was considered using the data from the San Francisco tide gauge (Table 2-5), which is slightly conservative as discussed in Section 2.5.2. Then, 100-year wave conditions (Table 2-9) were utilized to consider wave runup and generate the inundation map. Figure 3-5 shows the results of this analysis, demonstrating the flood zone under the 100-year storm and different SLR scenarios.

The main difference between M&N's analysis and the OCOF data (Figure 3-3) is the inundation area for Princeton (Reach 3) as expected. Figure 3-5 shows that the area east of Columbia Ave. will face coastal flooding in the future, and the condition is worse for the part of Princeton near the marsh, especially the area around West Point Ave. Also, another difference between M&N and OCOF data is the flooding of the parking lot located behind the inner harbor (Reach 4), which will face flooding issues with 3.28 feet (100 cm) SLR based on M&N analysis. It must be noted that the OCOF data has sufficient resolution for Reach 6-8 located outside the harbor, and therefore no further analysis was performed by M&N for that region.

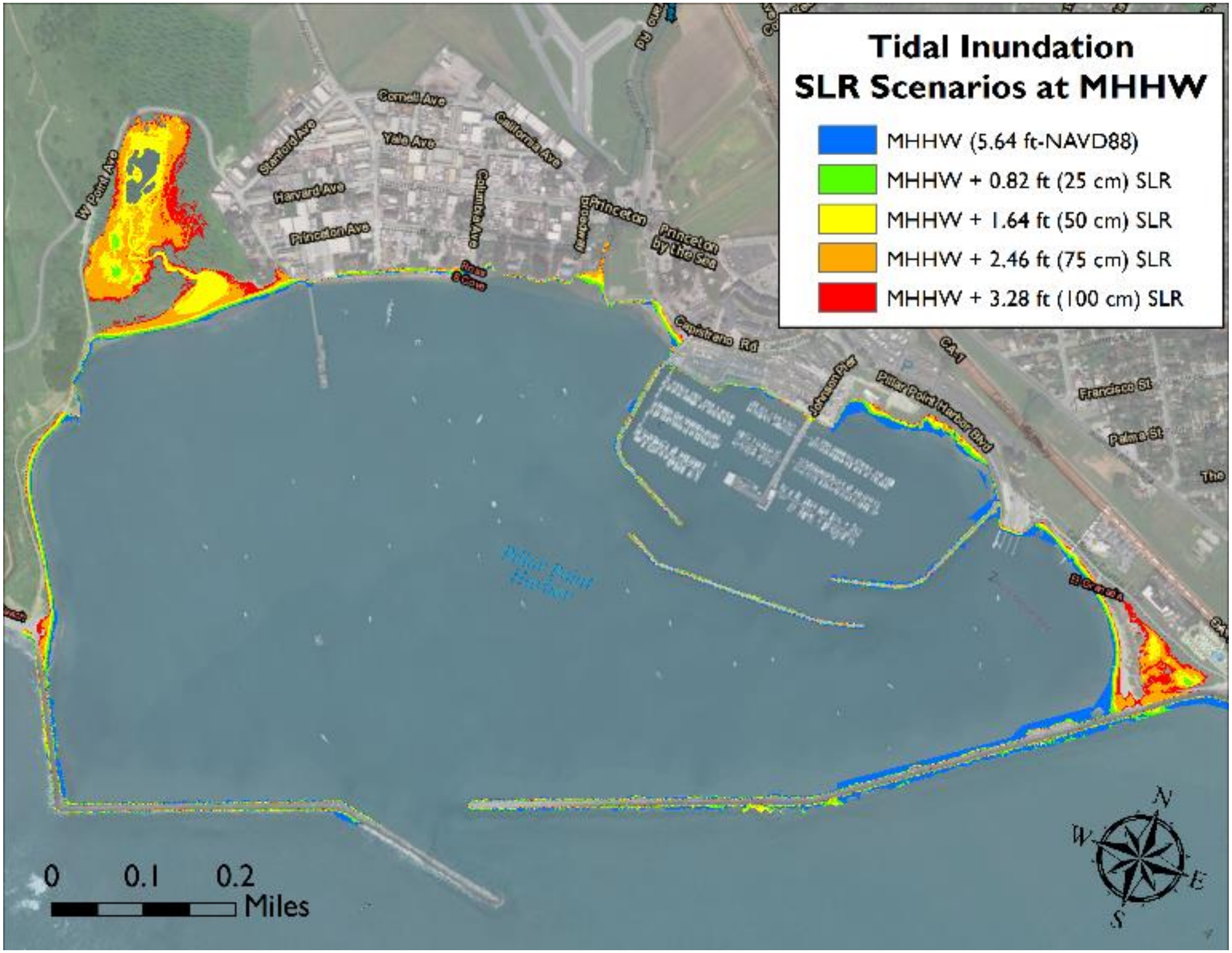

Figure 3-1: Tidal Inundation Limit under Different SLR Scenarios for Reaches 1-5

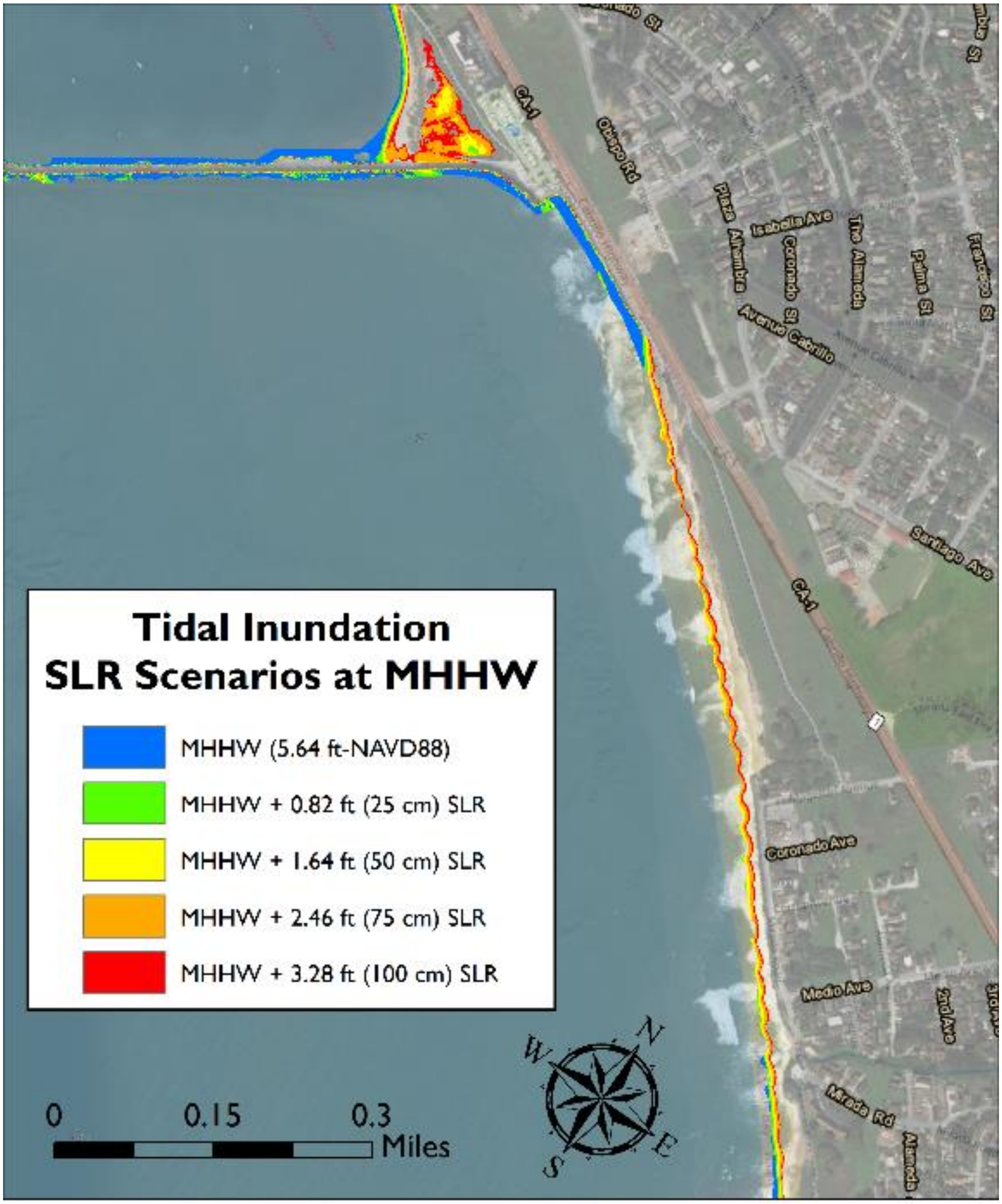

Figure 3-2: Tidal Inundation Limit under Different SLR Scenarios for Reaches 6-8

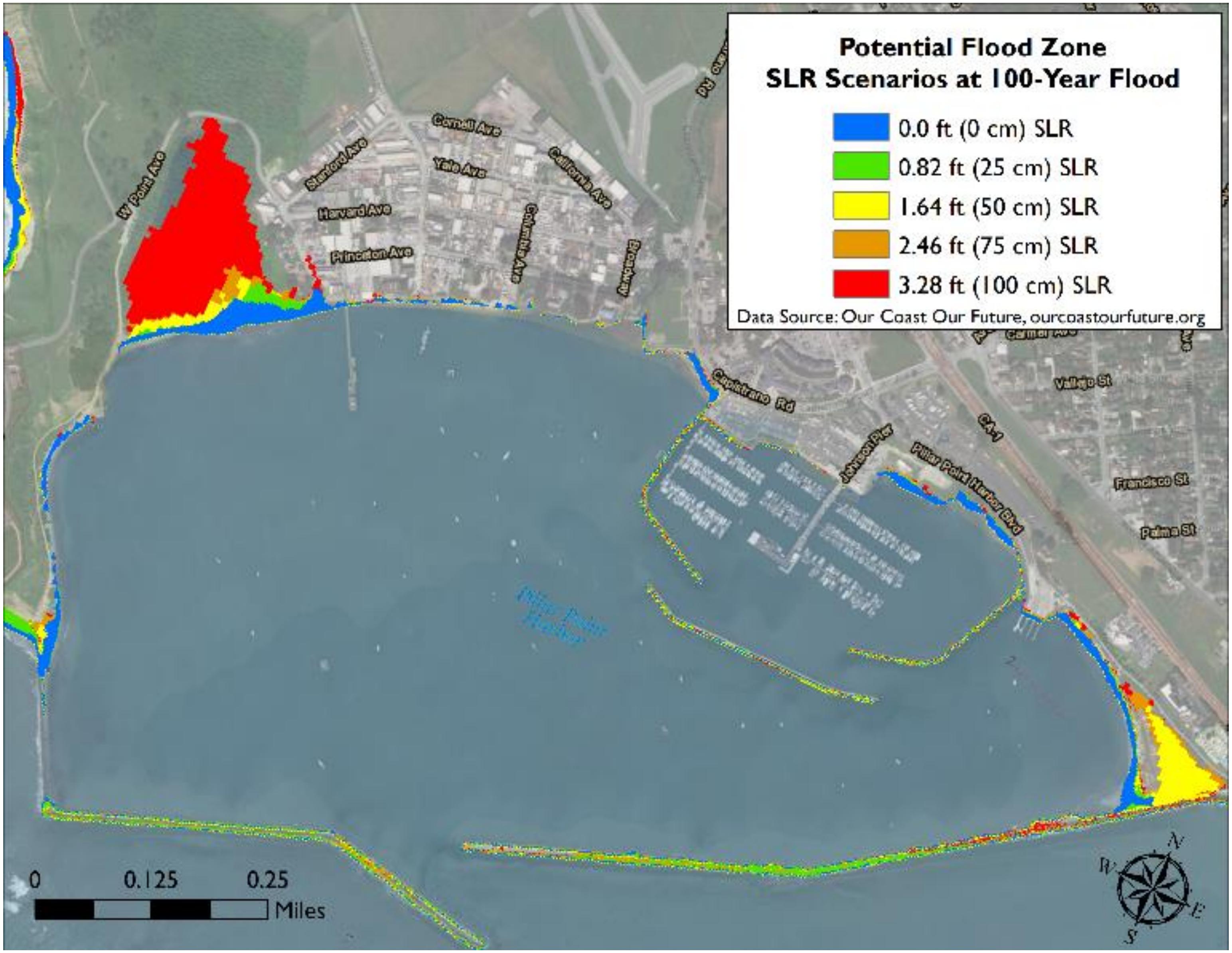

Figure 3-3: SLR Impacts on Reaches 1-5 (OCOF dataset)

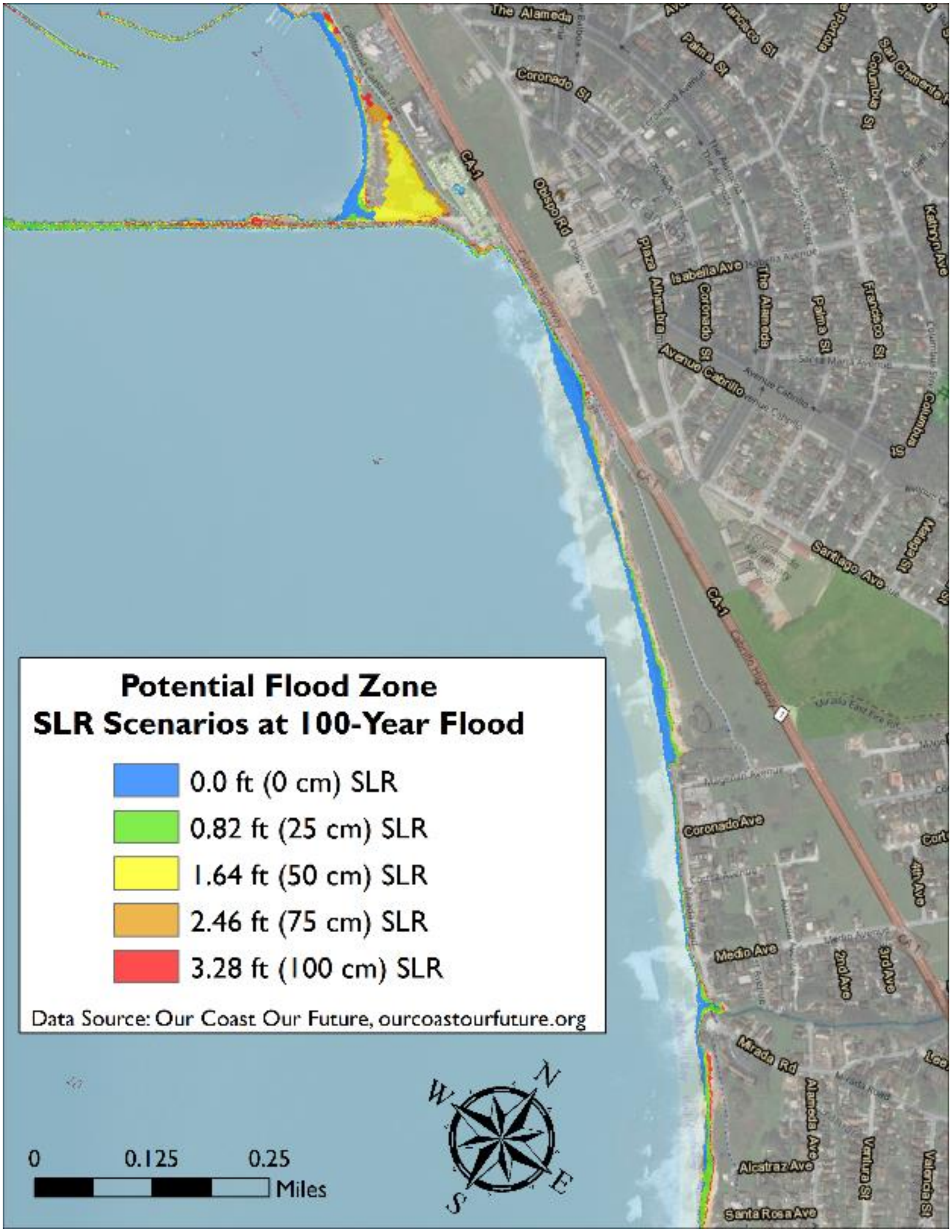

Figure 3-4: SLR Impacts on Reaches 6-8 (OCOF dataset)

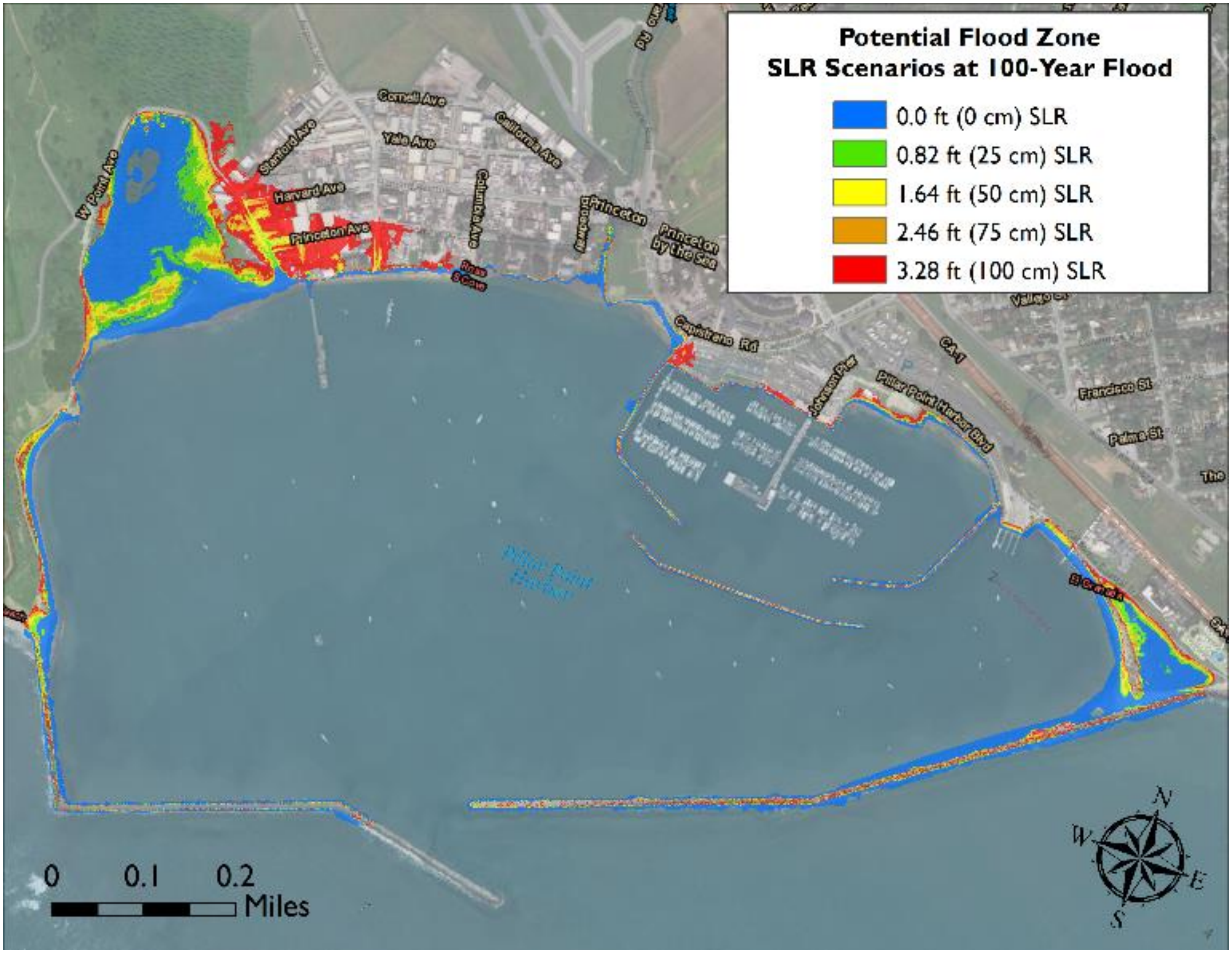

Figure 3-5: SLR Impacts on Reaches 1-5 (M&N analysis)

3.2. Future Shoreline Conditions

In this section, a discussion on future shoreline conditions for Pillar Point Harbor (PPH) and other regions within the study area is provided, following the discussion on morphologic processes in Section 2.8.

Figure 3-6 shows the shoreline changes for Reaches 1 to 5 which are located inside the harbor. The green line shown in this picture depicts the shoreline location between 1945 and 1976 measured by USGS. The comparison between the current shoreline and the USGS data shows that the shorelines inside the harbor are generally stable except for a few locations. The Princeton Beach is being actively eroded and will disappear in the future without a beach nourishment plan. Also, the area to the west of PPH Marsh beach will face erosion, where the berm would probably disappear in that particular spot (Figure 2-19), due to the presence of revetment and lack of sediment input. Moreover, the PPH Beach will keep accumulating sand as expected due to processes discussed in Section 2.8.

Figure 3-7 illustrates shoreline retreat for Reach 6 to 8 which are located outside the harbor. In areas where revetment is present, the berm and the beach in front will be eroded due to higher sea levels in the future. In contrast, the beach and the berm will probably survive future conditions in areas not protected by revetment, and the shoreline will migrate shoreward due to cliff erosion. The bluff erosion is expected to be about 3 feet/year south of the Caltrans Revetment decreasing southward to rate of 1.5 feet per year north of Miramar. It must be noted that the future bluff edge shown in Figure 3-7 is based on the assumption that Caltrans will continue to protect Highway 1, either through extension of the rubble-mound revetment or other protection measures. Surfer's Beach and the beach along Miramar which are currently only accessible during low-tide will be eroded, since there is no room for them to retreat due to revetments behind them.

Figure 3-6: Shorelines Condition for Reaches 1-5

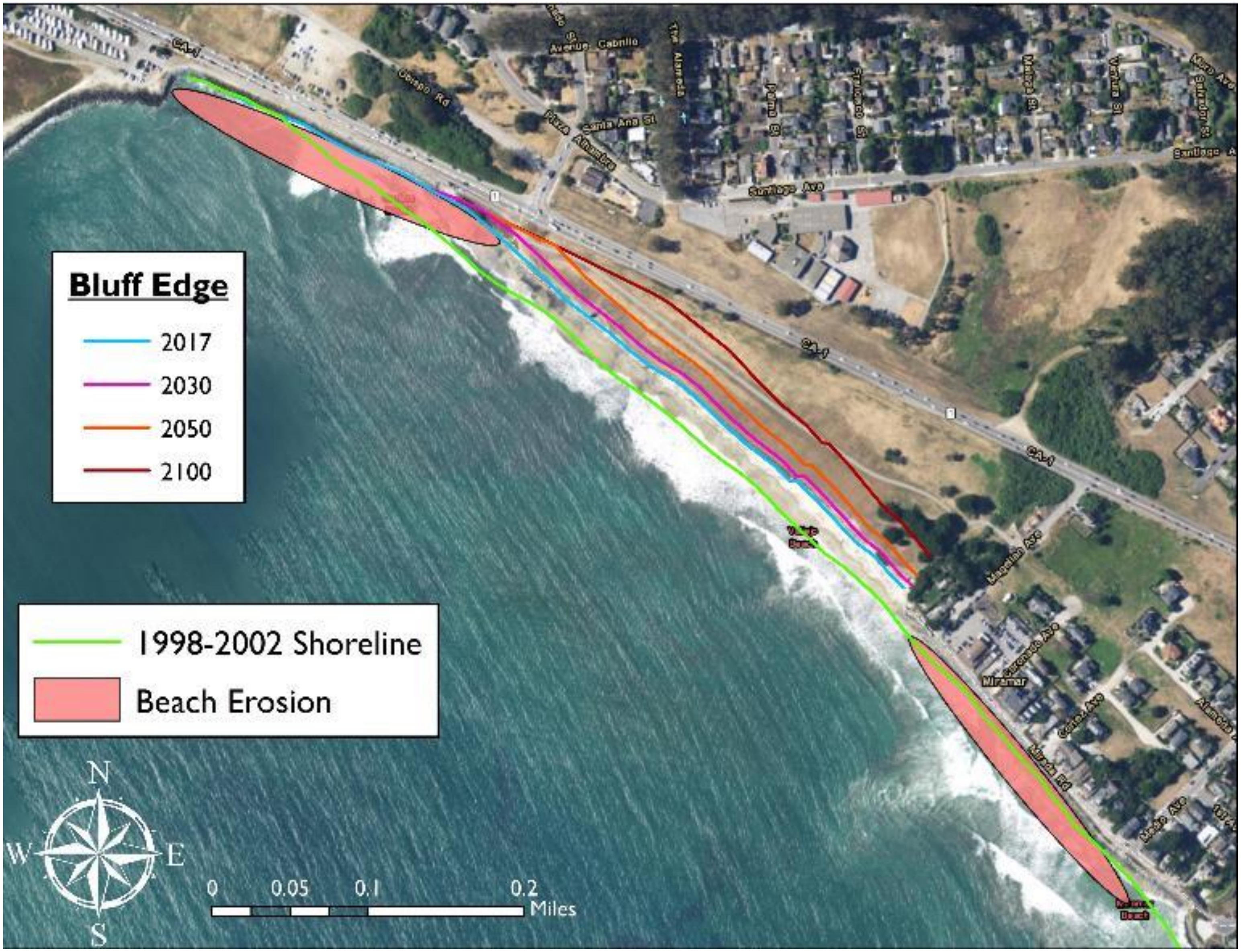

Figure 3-7: Shoreline Condition for Reaches 6-8

3.3. PPH Vulnerabilities to Future Sea Levels

Future Sea-Level Rise will affect public access, commerce, recreation, coastal habitats and navigability at Pillar Point Harbor (PPH) and its surrounding shorelines. Considering the discussion in the previous section about future coastal flooding, and shoreline retreat in the study area, this section provides insights on the probable PPH vulnerabilities to future sea levels and shoreline conditions. Table 3-1 and Table 3-2 summarize future 100-year flood and shoreline retreat potential impacts within the study area. The information listed in these tables are used as the basis for the discussion provided in this section.

Table 3-1: 100-year Strom Impacts Under Different SLR Scenarios

Year	2030	2050	2100	
SLR	0.82 ft (25 cm)	1.64 ft (50 cm)	2.46 ft (75 cm)	3.28 ft (100 cm)
Reach 1	Beach access will be limited	Beach access will be limited	Coastal trail will be partially flooded	Coastal trail will be partially flooded
Reach 2	Beach access will be limited	Costal dune will be partially overtopped	Costal dune will be overtopped	The area next to W. Point Ave. will be flooded
Reach 3	Beach access will be limited	W. Point Avenue will be flooded up to Princeton Ave.	W. Point Avenue will be flooded up to Harvard Ave. Princeton Ave. will be flooded for one block east of W. Point Ave. Vassar Ave. will be partially flooded	W. Point Avenue will be flooded up to Stanford Ave. Princeton Ave., Harvard Ave. and Stanford will be flooded for one block east of W. Point Ave. Vassar Ave will be flooded
Reach 4	Beach access will be limited	Beach access will be limited	Beach access will be limited	The Inner Harbor parking will be partially flooded
Reach 5	The area behind the PPH beach sand dune will be flooded	The area behind the PPH beach sand dune will be flooded	The area behind the PPH beach dune will be flooded	The area behind the PPH beach dune will be flooded
Reach 6	Beach access will be limited	Beach access will be limited	Coastal Trail will be partially flooded	Coastal Trail will be Flooded The Vallejo Beach will not be accessible though the current staircase
Reach 7	Beach access will be limited	Beach access will be limited	Beach access will be limited	Beach access will be limited
Reach 8	Beach access will be limited	Beach access will be limited	Beach access will be limited	Beach access will be limited

Table 3-2: Shoreline Retreat Conditions

Location	Current Condition	Future Condition without any Mitigation and Adaptation
Reach 1	Sandy beaches backed by a tall bluff	Stable shoreline except for the area near the tidal marsh where some erosion may occur
Reach 2	Wide sandy beach backed by a low-lying tidal marsh and a low-elevated sand dune	Generally stable shoreline except for the area bordering Reach 1 which will have minor erosion issues
Reach 3	Very narrow beach backed by bluffs 1-2 feet high protected by intermittent revetment	The beach and berm in front of the Princeton will be eroded exposing the revetments to harsher wave climate and higher possibility of being overtopped
Reach 4	Inner Harbor Shoreline	Minimal change is expected due to negligible wave action
Reach 5	Boat Launch and PPH Beach which is backed by a sand dune and low lying coastal strand	Sediment will keep accumulating near Pillar Point Harbor beach
Reach 6	Narrow beach backed by bluffs about 10 feet high protected by revetment	Surfer's Beach and berm would be eroded. The erosive pattern will move southward overtime
Reach 7	Wide beach backed by an unprotected bluff about 10 feet high	The bluff and the beaches will retreat with an approximate rate of 3 feet per year in the north of the reach, decreasing to 1.5 feet per year in the southern portion of the reach
Reach 8	Narrow beach backed by a protected bluff approximately 10 feet high	The beach and the berm will be eroded due to lack of room for retreat in the presence of current revetment

3.3.1. Public Access

Several public access routes in the study area could be affected due to future sea levels and shoreline conditions if no mitigation and adaptation measures are taken into consideration. Part of the Mavericks coastal trail in Reach 1 (Figure 2-5 and Figure 3-5) will be flooded during storms with SLR larger than 1.64 feet (50 cm). The beach access in Reach 3 will be limited due to beach erosion and possibility flooding. The access route from W. Point Ave., Vassar St., and Columbia Ave. to the beach through the Princeton Community will be limited due to beach erosion and future flooding (Figure 2-5 and Figure 3-5). Outside of the harbor, south of the East Breakwater, Surfer's Beach will be eroded and the beach access from the current stairway will be limited (Figure 2-7), while a small portion of the coastal trail falls inside the potential flood zone with 3.28 feet (100 cm) SLR (Figure 3-4). Also, if bluff recession continues at current rates in Reaches 6 and 7 (Figure 3-7), a portion of the current coastal trail will be in the erosion zone sometime between 2050 and 2100.

3.3.2. Recreation

A variety of recreational activities occur within PPH and its surrounding region. The study area is used by surfers, fishermen, birdwatchers and other passive recreational users. Future sea levels and shoreline condition will impact recreation through the public access issues mentioned before. Also, without any adaptation and mitigation measures (e.g., beach nourishment), the narrow beach in front of Princeton (Reach 3) and Miramar (Reach 8) will be eroded, similar to Surfer's Beach south of the East Breakwater (Reach 6). This will happen mainly due to shoreline retreat and higher flood potential considering future sea levels, as well as lack of room for retreat due to the existence of revetments.

3.3.3. Coastal Habitat

There are two coastal habitats within the project area that will be affected by future sea levels; the PPH marsh located in Reach 2, and the protected coastal strand shoreward of the PPH beach sand dune in Reach 5.

There are few examples of marsh loss in the historical records which were directly related to sea-level rise *(Kirwan and Megonigal, 2013)*. The reality is that most of the coastal wetlands build vertically at rates similar or higher than the recorded trend of SLR. The rate of vertical accretion of the marsh compared to the local relative SLR is the critical factor controlling wetland sustainability. The vegetated marshes seem to be stable during recent years, even with accelerated trends in SLR. In fact, the US marshes have been entirely stable between 2004 to 2009 *(Kirwan and Megonigal, 2013).*

As shown in Figure 3-1, Figure 3-3 and Figure 3-5, the PPH marsh will be more frequently flooded in the future. This marsh can be categorized as a high-marsh. A high-marsh is located above the MHHW datum and is mainly flooded during high spring tides and storms, while a low-marsh is flooded daily on high tides. Many areas within the current PPH marsh will likely be categorized a low-marsh in the future, especially after 2050. This will accelerate the vertical accretion of the marsh itself. *Kirwan et al. (2016)* reported that the low-marshes build up at an average rate of 0.27 inches per year (6.9 mm/year), which is almost twice the rate for high-marshes, and twice the current global SLR rate of 0.146 inches per year (3.7 mm/year). Therefore, it can be concluded that the marsh habitat, located in Reach 2, will likely survive future sea levels through vertical accretion.

The coastal strand behind the PPH Beach sand dune is located on a low-lying region that will experience more frequent flooding in the future if it does not vertically build up as fast as the SLR rate (Figure 3-1, Figure 3-3 and Figure 3-5). Considering that scenario, the current coastal strand will likely become a high-marsh by the end of 2050, and will go through the same process discussed above due to the availability of the sediment within that area of PPH (Reach 5). However, because this particular region has been accumulating sand after the construction of the outer breakwaters, it is also possible that this area keeps up with the SLR trend, and does not become a wetland in the future.

3.3.4. Commerce

Pillar Point Harbor (PPH) is a service facility for visitors as well as being a home port for commercial fishing, sports fishing, and pleasure boating. Visitors find many opportunities for outdoor activities including whale watching, recreational boating, fishing, and kayaking, as part of the services available at PPH. These services include 369 berthing slips, an active search and rescue operation, a commercial fish-buying center, ice-making facilities, a fuel dock, a guest dock, and a fishing pier as well as an RV lot, a six-lane launch ramp, pump-out facilities, restrooms, and hot showers for beachgoers. Table 3-3 provides the revenues at PPH provided by SMCHD as part of their 2017/18 budget analysis, showing approximately $6.5 million revenue for PPH. This number excludes the fish sales which is estimated to be about $7.3 million per year.

Table 3-3: PPH Revenue from SMCHD 2017/18 Budget Analysis

Revenue Category	Amount	Type
Berth / Slip fees	1,837,000	Enterprise
Leases and CAPs	450,000	Enterprise
Live Aboard	232,118	Enterprise
Dist RV Lot & Launch Fees	232,118	Enterprise
Events	30,000	Enterprise
DBW Vessel Grants	55,000	Enterprise
Misc. Enterprise Fees	67,000	Enterprise
Tax Revenue	3,590,172	Public
Total Revenue	**6,493,408**	Combined

Facilities in vulnerable areas to future sea levels may be subject to more frequent coastal flooding in the future, while the loss of beach and shoreline access can impact the number of beachgoers which might affect commerce at PPH.

3.3.5. Navigability

Future sea levels and shoreline conditions will not impact the navigability within most of PPH and other parts of the study area. *USACE (2015)* mentioned that there was no maintenance dredging required inside the PPH during its lifetime. However, in Reach 5, at the area between the inner breakwater the East Breakwater, sufficient sand has accumulated over the years that it has raised concern from the Harbor District about restricted small-boat access to the inner harbor through the east entrance *(USACE, 2009).* This area should be monitored in the future since sedimentation could threaten the functionality of the small boat launch facility if sand keeps accumulating north of the East Breakwater.

4. Financial Costs of SLR

4.1. Replacement and Repair Costs

In this section, the *Port of Long Beach (2016)* approach was adopted to provide a cost analysis based on a qualitative tiered categorization approach (low, medium, high). As part of their climate adaptation and coastal resiliency plan, *Port of Long Beach (2016)* used this method to classify port vulnerabilities under three SLR scenarios in combination with 100-year storm event and shoreline retreat. Here, a similar approach is used to assess repair or replacement cost estimates of resources and facilities of Pillar Point Harbor (PPH). Table 4-1 lists the cost impact categorization adopted from *Port of Long Beach (2016).*

Table 4-1: Cost and Impact Categorization (*Port of Long Beach, 2016*)

Impact Level	Cost to Repair / Adaptation Costs (asset damage)	Value of Lost Use / Adaptation Benefit (cargo damage and operation disruptions)
Low	No repairs, but storm surge flood waters need to recede before asset can be used / administrative, procedural, and/or permitting action	No loss of critical port asset and/or loss of high-value cargo staging area. Port operations temporarily disrupted
Medium	Repair infrastructure / installation of temporary protective measures	Temporary loss of critical port asset(s) and/or loss of high-value cargo staging area
High	Requires new capital construction projects.	Loss of critical port asset(s) and/or loss of high-value cargo staging area and/or port-wide infrastructure limitations

The majority of critical building structures, including harbor master's office and service buildings, are located at a high elevation and will not be impacted by the levels of SLR and storm surge considered in this work. The existing breakwater protects the inner and outer harbor area. However, due to future sea levels, larger waves will affect the breakwaters and increase wave transmission into the protected harbor regions. Also, the breakwaters will more frequently be exposed to wave overtopping and consequently a higher chance of structural damage. Thus, the breakwaters need to be regularly monitored to be prepared for future conditions. Currently, a portion of the Western Breakwater, which is maintained by USACE, has been subject to wave-induced damage.

The elevation of Johnson Pier and the shoreside facilities at Pillar Point are above the tide level of the sea level rise projections considered in this work. This elevation along with the protection from wave runup provided by the breakwaters makes the facility at low risk for flooding in the future as sea level rises (*M&N, 2014*). However, the current western slope within the inner harbor is sloughing down into the harbor, resulting in the riprap falling and the underlying soil being exposed. The bare slope will be subject to greater erosion and cutting back of the soil. The riprap protection should be repaired or a seawall installed similar to the portion at the Harbormaster Building and East Basin.

Table 4-2 provides a list of vulnerable facilities and their qualitative repair costs sue to SLR and shoreline retreat. The analysis is based on the asset inventory and the vulnerability profiles discussed in previous sections of this report. It must be noted that no direct financial impacts or cost estimates were calculated with this analysis due to the complex nature of the harbor functions, and damage considerations.

Table 4-2: PPH facilities impact and repair cost categorization due to SLR and Shoreline Retreat

Facility	Reach	SLR			
		0.82 ft (25 cm)	1.64 ft (50 cm)	2.46 ft (75 cm)	3.28 ft (100 cm)
Coastal Trail	1	No Impact	No Impact	Will be partially flooded during storms Impact: Low Cost to Repair: Mid	Will be partially flooded during storms Impact: Low Cost to Repair: Mid
Inner Harbor	4	The western slope will be subject to erosion and cutting back of the soil Impact: Low Cost to Repair: Mid	The western slope will be subject to erosion and cutting back of the soil Impact: Mid Cost to Repair: Mid	The western slope will be subject to erosion and cutting back of the soil Impact: High Cost to Repair: Mid	Partial inundation of tanks during storms Impact: Low Cost to Repair: Low
Permit Parking Lot	4	No Impact	No Impact	No Impact	The Inner Harbor parking will be partially flooded during storms Impact: Low Cost to Repair: Low
Coastal Trail	6,7	No Impact	No Impact	Trail will be partially flooded during storms Impact: Low Cost to Repair: Low	Trail will be partially flooded during storms and end up inside the erosion zone Impact: High Cost to Repair: Mid

The California Division of Boating and Waterways (*CDBW, 2011*) have reviewed several approaches to assess economic costs of SLR to California beach communities. They estimated that structural adjustments to roads and trails were at $6,500,000 per mile of hard surface trail, and the parking lot replacement cost was at $30 per square foot considering 2011 dollars. Also, *CDBW (2011)* concluded that in 2011 seawall construction cost about $7,200 to $10,000 per foot in Northern California with annual maintenance costs of 2.5 to 3.0 percent of the total cost of construction. Accordingly, rough estimates of PPH facilities repair and replacement costs are provided in Table 4-3 based on above values and the impacts listed in Table 4-2. Estimates were converted to 2017 dollars, using available online tools which use the US inflation rates to perform dollar value conversion.

Table 4-3: Replacement and Repair Costs due to SLR and Shoreline Changes at PPH

Year	Coastal Trail Adjustment* (Reaches 1,6, and 7)	Western Slope Protection* (Reach 4)	Parking Lot Replacement* (Reach 4)	Total Costs*
2030	-	$150,000 - $200,000	-	$150,000 - $200,000
2050	$214,500	-	-	$214,500
2100	$1,300,000	-	300,000	$1,600,000

*values are in 2017 dollars

4.2. Non-market Loss Value

In this section, potential non-market losses due to SLR are estimated for recreational and ecosystem services, as well as public trust resources that could be impacted by future sea levels and shoreline conditions. Economists classify recreation and ecosystem services as non-market. The non-market value, cannot be determined from a market price, which is for services and goods that can be bought and sold.

To determine the non-market values, economists suggest using the concept of willingness to pay, which is defined as the value of an individually consumed non-market good as the amount that an individual consumer would be willing to pay to consume the good or use the service (*Raheem et al., 2009*). These values are identified through empirical research (e.g., *Costanza et al., 2006; Raheem et al., 2009, 2012*). The resources recommended by Assembly Bill 691 Assessment Criteria was utilized to estimate the non-market value of the recreational and ecosystem services within PPH and other regions within the study area, including resources from Center for the Blue Economy Library and Duke Marine Ecosystem Services Partnership, as well as the California Department of Boating and Waterways (*CDWB, 2011*).

The analysis of future sea levels and shoreline retreat provided in the previous chapter showed that some regions with non-market values within the study area will be impacted in the future. These areas are listed as follows,

1. The beach in front of the Princeton Community in Reach 3
2. Surfer's Beach south of the East Breakwater in Reach 6 and 7

It must be noted that, Vallejo Beach in Reach 7, as well as PPH Beach in Reach 5 and Mavericks Beach in Reaches 1 and 2 will most likely survive the future conditions, either due to the availability of a sand source or the existence of room for beach retreat. On the other hand, the beach along Princeton Community, and Surfer's Beach will be lost since there is no room for retreat in existence of revetments.

Beaches provide services with different non-market economic values. These services include recreational value, storm-buffering capacity, and provision of biological and ecological diversity (*CDBW, 2011*). In California, beaches below the high water line are in public trust, and there is no market value for them. One of the recommended methods to determine the non-market values of a beach is to divide its value into use and non-use values. The use values include but not limited to direct use benefits such as recreation (boating, birding, fishing, etc.), and indirect use benefits including flood control, shoreline protection, and groundwater discharge. The non-use values include biodiversity, cultural, and heritage existence benefits.

Although in practice it is challenging to measure or determine non-market values, there are several theoretical methods to determine non-market beach value. As part of Environmental Protection Agency (EPA) work to determine the economic value of coastal ecosystems in California, *Raheem et al. (2009)* reviewed the results of a collaborative effort by a team of economists, conservation biologists, and staff members of the California Ocean Protection Council to provide spatially explicit and policy-relevant values for ecosystem services generated in coastal regions in California (Table

4-4). They did not address specific ecosystem services explicitly and valued non-market beach values in a spatially explicit manner.

Table 4-4: Non-market Ecosystem Service Values *(EPA, 2011)*

Service Category	Per Acre Per Year*
Disturbance Control	$31,131
Recreation and Ecotourism	$16,946
Cultural Heritage and Benefits	$27

*values are in 2006 dollars

The values presented in Table 4-4 are not site-specific, while the non-market value of beaches is theoretically dependent on the attendance per year. The National Ocean Economics Program (oceaneconomics.org) has provided environmental and recreation beach (non-market) values from different resources, listed in Table 4-5.

Table 4-5: Non-Market Beach Value based on Consumer Surplus per Activity Day

Source	Consumer Surplus / Activity Day
Dornbusch et al. (1986)	$12.00
Dornbusch et al. (1987)	$14.85 - $15.81
Leeworth and Wiely (1993)	$12.19 - $77.61
King (2001)	$25.78 - $33.72
Lew and Larson (2005)	$11.00

To use the values in Table 4-5, a reliable estimate of beach attendance per year is required, which depends on a lot of factors and is not deterministic. Also, as shown in the table above, these valuations range from $11 to $77 per consumer surplus per day, which complicates the non-market beach valuation if these numbers are used.

In 2011, the California Division of Boating and Waterway (CDBW) conducted research to evaluate economic costs of SLR to California beach communities. They reviewed several available methods to investigate potential financial losses at several beaches in California, including Ocean Beach, San Francisco, and Venice Beach, Los Angeles. Accordingly, *CDBW (2011)* recommended considering a non-market ecological value of $1,620 per acre per year ($4,000 per hectare per year) for beaches, including biodiversity and environmental values, as well as storm damage control benefits. However, this does not consider the recreational value which they estimated to be between 10 to 40 times the non-market ecological value of $1,620 per acre per year depending on the beach location and surrounding environment. *CDBW (2011)* mentioned that their estimates were conservative and significantly lower than values provided in Table 4-4 by *EPA (2009)*.

In this work, the *EPA (2009)* assessments (Table 4-4) were used to provide a high estimate, and the *CDBW (2011)* method was used to provide a low estimate of non-market loss for the study area. Estimates from both methods were converted to 2017 dollars. Table 4-6 shows the annual non-market loss values for Princeton Beach, and beaches south of the East Breakwater including Surfer's Beach and Miramar Beach for years 2030, 2050 and 2100. The beach loss estimates are provided based on the analysis provided in the previous sections (Figure 3-6 and Figure 3-7).

Table 4-6: Non-Market Annual Loss Value due to Beach Erosion

	South of the East Breakwater (Reach 6)	**Non-Market Annual Loss Value**		**Princeton Community (Reach 2)**	**Non-Market Annual Loss Value**	
Year	Beach Loss (Acres)	Low Estimate* - CDBW (2011)	High Estimate* - EPA (2009)	Beach Loss (Acres)	Low Estimate* - CDBW (2011)	High Estimate* - EPA (2009)
2030	1.2	$29,914	$66,384	0.5	17,806	27,660
2050	2.1	$52,350	$116,171	0.5	17,806	27,660
2100	3.5	$87,250	$193,619	0.5	17,806	27,660

*values are in 2017 dollars

Table 4-7 provides the cumulative beach and non-market loss due to erosion in the entire study area for years 2030, 2050, and 2100. As recommended by CDBW (2011), a three percent discount rate was used to calculate these estimations. Based on this analysis, the non-market loss of beach would be roughly between $0.2 to $0.6 million by 2030, $0.95 to $2.2 million by 2050, and $2.5 to $5.5 million by 2100.

Table 4-7: Cumulative Non-Market Loss Value due to Beach Erosion

Year	**Beach Loss (Acres)**	**Low Estimate - CDBW (2011)**	**High Estimate - EPA (2009)**
2030	1.7	$263,821	$585,450
2050	2.6	$984,201	$2,184,056
2100	4.0	$2,479,073	$5,501,349

*3% Discount Rate

5. SLR Mitigation and Adaptation Measures

5.1. Adaptation and Mitigation Strategies

Several adaptation and mitigation approaches can be taken to control and reduce the potential threats that future sea levels and shoreline conditions pose to coastal communities. In general, these approaches can be divided into three categories listed below (*CDBW, 2011*),

- Soft Solutions (e.g., beach nourishment)
- Hard Solutions (e.g., revetment)
- Passive Solutions (e.g., managed retreat)

Adaptation and mitigation measures taken to manage shoreline retreat and prevent future inland flooding must be as sustainable as they are cost-effective and environmentally friendly. It is challenging to achieve all these goals with one solution, and policymakers and public planners need to consider all advantages and disadvantages of each solution before making a decision. Accordingly, this section initially provides a brief description of these adaptation and mitigation strategies, their differences, as well as their advantages and disadvantages. Then, the recommended SLR adaptation and mitigation for Pillar Point Harbor and its surrounding area, as well as the anticipated cost of such measures is discussed.

5.1.1. Soft Solutions

Beach nourishment is the main soft solution to shoreline retreat and flood potential. Beach nourishment can save the recreational value of sandy coasts, and create an environment suitable for coastal habitat. Another advantage of beach nourishment is that it increases the real-estate value of coastal properties (*CDBW, 2011*). Beach nourishment, however, is known to be a semi-sustainable solution to beach erosion since it is vulnerable to wave action. Therefore, beach nourishment could be a viable solution if sufficient sources of sand are available, such as the sand dredged from nearby harbors and marinas.

5.1.2. Hard Solutions

In California, seawalls, revetments, and jetties are the primary hard solutions to manage shorelines. Seawalls are vertical structures that protect inland areas against wave action. Revetments are sloped structures consisting of rock to dampen the wave energy and prevent shoreline retreat. In contrast to beach nourishment, hard solutions are considered to be long-term or even permanent to stabilize the shoreline and prevent inland flooding. However, several negative consequences are associated with revetments and seawalls. Since the hard structures fix the shoreline location, there will not be any room for retreat during future higher water levels, which results in loss of the beach in front of them (Figure 5-1). The erosion problem at Surfer's Beach (Reach 6) is an example of this negative effect of revetments. Also, hard structures are not known to be environmentally friendly, with several reports that coastal armoring reduced the diversity and abundance of coastal habitats (*CDBW, 2011*).

Figure 5-1: Loss of Beach Access Due to Revetments

5.1.3. Passive Solutions

Passive solutions, also known as managed retreat, have lately become a hot topic in SLR adaptation and mitigation strategies due to sustainability and cost-effectiveness. The vulnerable structures and facilities are removed from nearshore regions as part of a managed retreat solution. Managed retreat can decrease the potential for storm flooding with minimal maintenance costs. Also, the monitoring of nearshore vulnerabilities is another dimension of the passive solution, especially for areas which do not require immediate adaptation and mitigation due to SLR and shoreline retreat. However, the disadvantage managed retreat is that coastal property owners are generally against it due to loss of land and property. Currently, in the US, managed retreat is a viable solution for the areas owned by public resources, where property owners do not influence politicians and policymakers.

5.2. Proposed Adaptation and Mitigation

This section provides proposed mitigation and adaptation strategies to address the vulnerabilities of the eight reaches within the study area to future sea levels and shoreline conditions, and their anticipated costs.

Reach 1 will be subject to more frequent flooding in the future. The coastal trail along Reach 1 will be located inside the future flood zone, and considering the ongoing erosion problems (*GHD, 2016*), it is recommended to monitor shoreline conditions regularly to assure the trail sustainability in the future.

The marsh and the beach in Reach 2 also will be subject to more frequent flooding in the future. However, the marsh is expected to survive future conditions through vertical rise. As mentioned before, as long as the vegetation within the marsh area is maintained, the wetland is poised to adapt to future conditions. It is recommended to monitor vegetation status within this reach. Further actions may be required in the future as soon as signs of vegetation stress are observed.

Reach 3 is subject to shoreline erosion currently, and a significant portion of the Princeton Community will fall into flood zone by the end of the century. There are two options available to deal with this situation. The first option is beach nourishment which will improve the flood protection and provide better public access to nearby beaches. Beach nourishment can also be considered as an improvement of the environmental conditions. However, the nourished beach will be subject to erosion and will require maintenance and re-nourishment. The second option is to install revetment. This could be done through repair and improvement of the current revetments along the shoreline of Princeton. Although revetment would be a long-term or even a permanent solution, it will result in loss of the beach and public access.

The cost of beach nourishment is between $40 and $70 per cubic yard, depending on several factors such as the choice between dredging sand from nearby areas or buying higher quality sand. Following the mentioned range, Table 5-1 provides a rough estimate of Princeton beach nourishment costs and required sand volume under different SLR scenarios. The numbers shown in this table confirm that beach nourishment can be a viable option, since the cost is less than the recreational and ecosystem beach value that it saves, discussed in the section 4.2. The other option would be to install a seawall or revetment which costs between $100,000 to $300,000 and is considered to be long-term, however it will not restore the recreational and ecosystem value due to beach loss.

Table 5-1: Princeton Beach Nourishment Costs Under Different SLR Scenarios

SLR	0	0.82 ft (25 cm)	1.64 ft (50 cm)	2.46 ft (75 cm)	3.28 ft (100 cm)
Sand Volume (CY)	2,650	3,312	3,975	4,637	5,300
Low estimate	$105,000	$135,000	$160,000	$185,000	$220,000
High estimate	$185,500	$240,000	$280,000	$325,000	$370,000

Similar to other reaches, Reach 4 will experience more frequent flooding in the future, where the permit parking lot will be inside the future flood zone by the end of the century. However, this reach is not currently in danger of any immediate impacts from SLR and shoreline retreat, considering the Johnson

Pier is sufficiently elevated to deal with future sea levels. It is recommended to monitor the inner breakwater and pier conditions regularly to ensure the harbor's functionality in the future.

Reach 5 is the only region in the study area which is accumulating sediment and is not expected to be impacted by shoreline erosion. The coastal strand behind the PPH Beach will fall inside a flood zone by mid-century. However, this area is expected to either vertically rise or become a high marsh in the future, which can provide a environment for coastal habitat to thrive. It is recommended to monitor sand accumulation in Reach 5 to avoid a navigational hazard due to sedimentation in the future and keep the boat launch facility functional.

Reach 6 is expected to experience significant beach erosion. Currently, Surfer's Beach is not accessible during high tide due to erosion and is expected to be entirely eroded by the mid-century. Also, the coastal trail on reach 6 will be in a flood zone by the end of the century. It is recommended to monitor the revetment and coastal trail, and manage retreat of shoreline along Surfer's Beach south of the East Breakwater. There is no room for retreat along this reach, and beach nourishment will not be sustainable due to the highly active wave climate in this reach.

Reach 7 will experience significant bluff retreat in the future. However, since there is room for retreat, the beach in front of the bluff will survive and rebuild itself. The coastal trail though will fall inside the erosion zone by the end of the century and will require adjustment. For this reach, it is recommended to execute managed retreat, while monitoring the retreat pattern regularly to ensure the functionality of the coastal trail and beach access.

Reach 8 conditions are similar to those of Reach 6 where due to the existence of revetment, the beach will be eroded in the future. Since there is no room for retreat and wave action is high along this reach, there is no viable solution to save the beach. It is recommended to monitor revetment conditions regularly to avoid inland flooding in the future.

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Appendix A. List of Species Observed within and near Pillar Point Harbor

Table A-1: Subtidal and Intertidal Invertebrates Observed within PPH Habitat

Common Name	Scientific Name	Picture
Polychaete Worms	*Mediomastus californiensis*	
	Polydora kempi	
Anemones	*Actiniaria*	
Shrimp	*Neomysis rayii*	
	Bathyleberis sp.	
	Euphilomedes carcharodonta	
Crab	*Hemigrapsus nudus*	
Bivalves	*Macoma secta*	
	Transennella tantilla	
Seastars	*Amphiodia sp.*	
Gammarid Amphipods	*Aoroides columbiae*	
	Corophium acherusicum	

Table A-2: Fish Species Observed within PPH Habitat

Common Name	Scientific Name	Picture
English sole	*Parophrys vetulus*	
Shiner Surfperch	*Cymatogaster aggregate*	
Pacific herring	*Clupea harengus*	
Rockfish	*Sebastes sp.*	
Starry Flounder	*Platichthys stellatus*	
Topsmelt	*Atherinops affinis*	
Northern Anchovy	*Engraulis mordax*	
Pacific Sardine	*Sardinops sagax*	
Mackerel	*Trachurus*	
Striped bass	*Morone saxatilis*	
California Grunion	*Genus leuresthes*	

Table A-3: Bird Species Observed within PPH Habitat

Common Name	Scientific Name	Picture
Brown Pelicans	*Pelecanus occidentalis*	
Pelagic, Brandt's, and Double-crested Cormorants	*Phalacrocorax pelagicus/ penicillatus/auritus*	
Black Oystercatchers	*Haematopus bachmani*	
Western, California, and Mew Gulls	*Larus occidentalis/ californicus/canus*	
Murres	*Uria aalge*	
Sooty Shearwater	*Puffinus griseus*	
Cassin's Auklets	*Ptychoramphus aleuticus*	
Snowy Plover	*Charadrius nivosus*	
Spotted and Pectoral Sandpiper	*Actitis/Calidris macularius*	
Goldeneye	*Bucephala clangula*	
Surf Scoters	*Melanitta perspicillata*	

Table A-4: Vegetation Species Observed within PPH Habitat

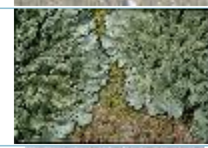
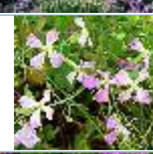
Common Name	Scientific Name	Picture
Sea Lettuce	*Ulva sp*	
Lichens	*Lichenized fungus*	
Plantains	*Plantago maritime*	
Bristly ox Tongue	*Picris echioides L*	
Beach Bur	*Ambrosia chamissonis*	
Gumweed	*Grindelia willd*	
Sealavender	*Limonium P. mill*	
Wild Radish	*Raphanus sativa*	
Iceplant	*Carpobrotus chilensis*	
Sea Rocket	*Cakile maritime*	

Table A-5: Mammal Species Observed within PPH Habitat

Common Name	Scientific Name	Picture
Harbor Seal	*Phoca vitulina*	
California Sea Lions	*Zalophus*	
Long-tailed Weasel	*Mustela frenata*	
Broad-handed Mole	*Scapanus latimanus*	
Gray Whale (Spotted Offshore)	*Eschrichtius robustus*	
Humpback whale (Spotted Offshore)	*Megaptera novaeangliae*	
Blue Whale (Spotted Offshore)	*Balaenoptera musculus*	
Harbor Porpoise	*Phocoena phocoena*	

Appendix B. California Coastal Records 2013 Pictures of the Study Area

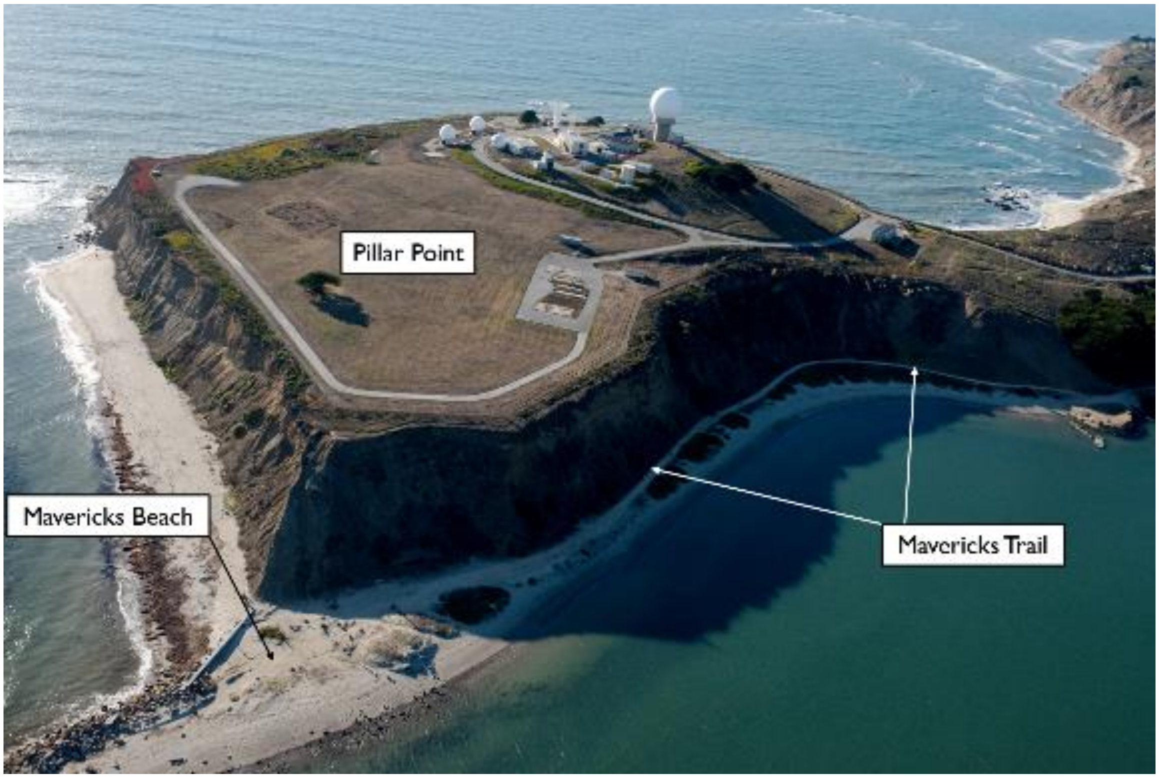


Figure B-1: Reach 1 Shoreline

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Figure B-2: Reaches 1 and 2 Shorelines

Figure B-3: Reaches 2 and 3 Shorelines

Figure B-4: Reach 3 Shoreline

Figure B-5: Reach 4 Shoreline

Figure B-6: Reaches 4 and 5 Shorelines

Figure B-7: Reach 5 Shoreline

Figure B-8: Reach 6 Shoreline

Figure B-9: Reaches 6 and 7 Shorelines

Figure B-10: Reach 7 Shoreline

Figure B-11: Reach 8 Shoreline

Figure B-12: Reach 8 Shoreline

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