moffatt & nichol

Pacific Grove Shoreline Management Plan

Vulnerability Assessment

PRODUCED FOR EISEN | LETUNIC

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Glossary

CCC	California Coastal Commission
CEM	Coastal Engineering Manual
DEM	Digital Elevation Model
ENSO	El Niño Southern Oscillation
ft	Feet
LCP	Local Coastal Program
LiDAR	Light Detection and Ranging
M&N	Moffatt & Nichol
NAVD88	North American Vertical Datum of 1988
NDBC	National Data Buoy Center
NOAA	National Oceanographic and Atmospheric Administration
NTS	Not To Scale
OPC	Ocean Protection Council
PDO	Pacific Decadal Oscillation
SAFRR	Science Application for Risk Reduction
SLR	Sea Level Rise
TWL	Total Water Level
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

1. Introduction

Eisen | Letunic retained Moffatt & Nichol (M&N) to develop a coastal processes study and vulnerability assessment for the shoreline at Pacific Grove, CA. The study area is shown in Figure 1-1.

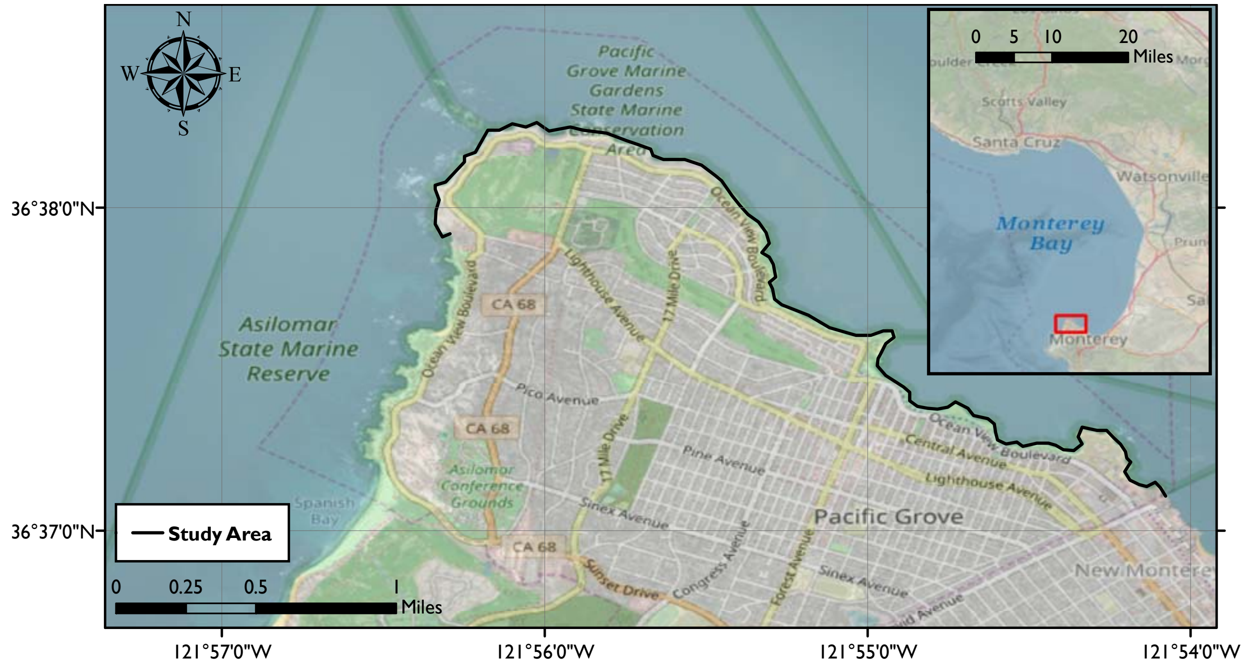


Figure 1-1: Shoreline Study Area

1.1. Project Background

The City of Pacific Grove is located on the Monterey Peninsula and shares borders with the City of Monterey and Pebble Beach.

The Pacific Grove coastline is very diverse, with various sandy beaches, recreational trails, archeological sites, parks, and a golf course. This coastline also encompasses a diversity of natural resources and habitat, supporting endangered and special status species.

Pacific Grove has 4,695 feet of seawalls along the coastline (*City of Pacific Grove, 2017*), which were constructed to protect the former Southern Pacific Railroad, and now protects the recreational trails along the coast. The objective of the current study is to evaluate the coastal processes along the coast and provide a vulnerability assessment that considers impacts of coastal flooding and sea level rise. Additionally, alternatives for shoreline improvement are discussed, including the potential for relocation of portions of the recreational trail and removal of existing coastal armoring.

1.2. Report Purpose and Scope

This study provides a vulnerability assessment for the coastline along Pacific Grove with respect to the coastal processes that have formed and continue to reshape the shoreline. This work includes an assessment of external factors, including tides, waves, storm surges, tsunamis, and sea level rise, as well as geologic factors, to evaluate the vulnerability of the shoreline, and assess impacts on transportation and recreational pathways, and infrastructure.

The results of this work is part of the Shoreline Management Plan developed by Eisen | Letunic for the City of Pacific Grove. In summary, the purpose and scope of this technical study is:

- Understand existing processes that affect shoreline resources
- Quantify the extent of risk to infrastructure and recreational facilities for current as well as future (with sea level rise) conditions;
- Identify conceptual alternatives and a range of potential management or adaptation measures, along with triggers, for implementation of these measures.

2. Coastal Processes

The key elements that affect coastal processes and shoreline vulnerability at Pacific Grove are described in the following sections. These include:

- Offshore water depths, and features of the seabed and shoreline. These affect wave transformation, wave runup, and wave overtopping along the shoreline.
- Water levels, with contribution from tides, storm surge, and sea level rise affect wave heights at the shoreline and thereby wave runup, inundation, and wave overtopping.
- Waves, are present in the form of wind-generated waves associated with the passage of storm systems regionally. Waves also occur in the form of swell, which characterizes long-period waves originating from distant storm systems out over the Pacific. Wave parameters comprised of wave height and wave period, in combination with water depths and water levels, affect wave runup and overtopping along the shoreline. A special case of waves are tsunami waves, which can occur when earthquakes produce a rapid vertical displacement of the seabed in seismically active areas along the Pacific Rim.
- Geologic factors that affect shoreline vulnerability include the durability of cliffs, marine terrace deposits, and sand dunes subject to wave action.
- Land use. Highlights areas and infrastructure affected by wave runup and overtopping when combined with coastal flood mapping.

2.1. Bathymetric and Topographic Data

Bathymetric and topographic data utilized for the study were obtained from different resources, including datasets from USGS, USACE, and NOAA, based on measurements from 1997 to 2016. Figure 2-1 shows the Digital Elevation Model (DEM) used for the study, which is a composite of the following:

- NOAA Monterey Bay Tsunami DEM for deep water regional bathymetry (*Grothe et al., 2012*)
- Nearshore LiDAR from the 2013 TopoBathy Merge Project which provides the most detailed nearshore bathymetry (*NOAA, 2013*)
- USGS 2016 LiDAR data for the landside areas which provides the most detailed above-water topography (*USGS, 2016*)

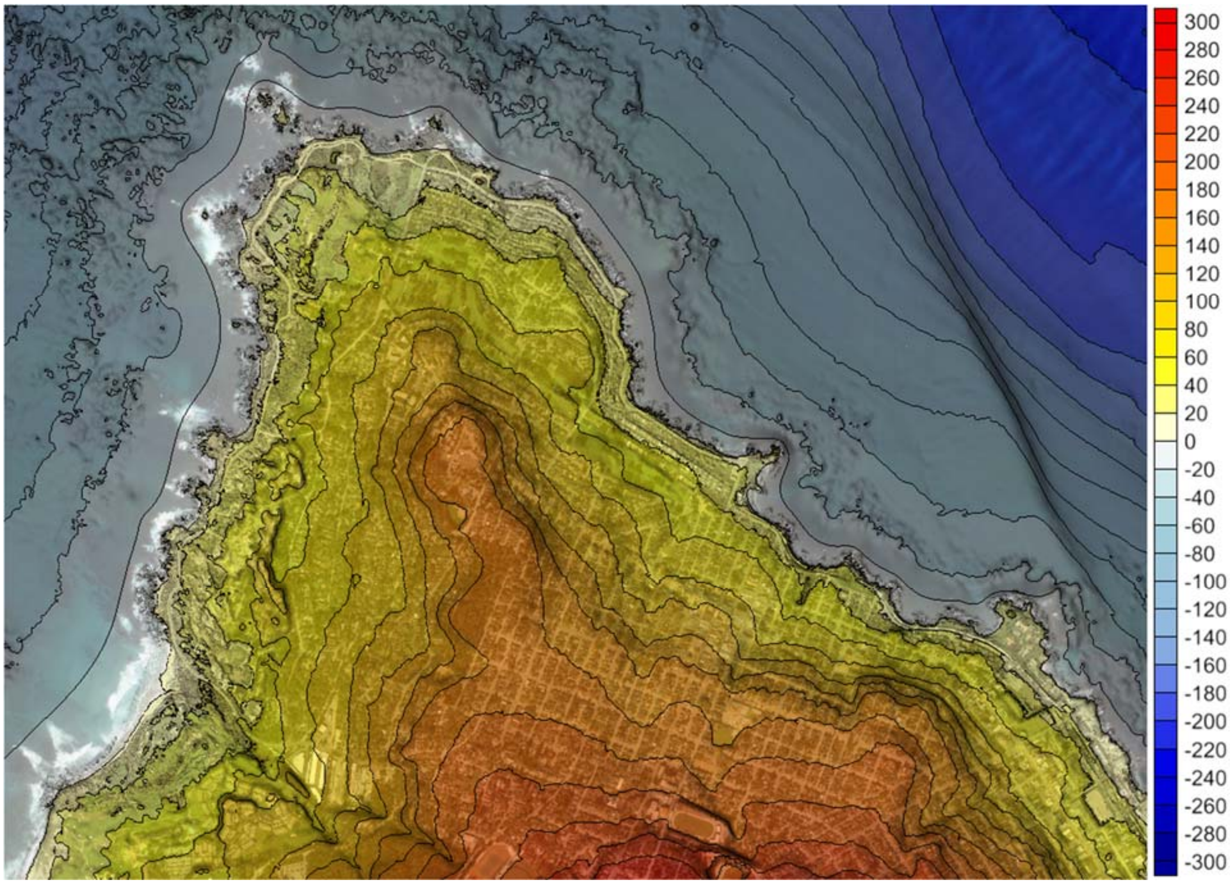


Figure 2-1: Pacific Grove DEM (ft-NAVD88)

Figure 2-2 shows water depths at Pacific Grove from the NOAA navigation chart for Monterey Bay (Chart No. 18685).

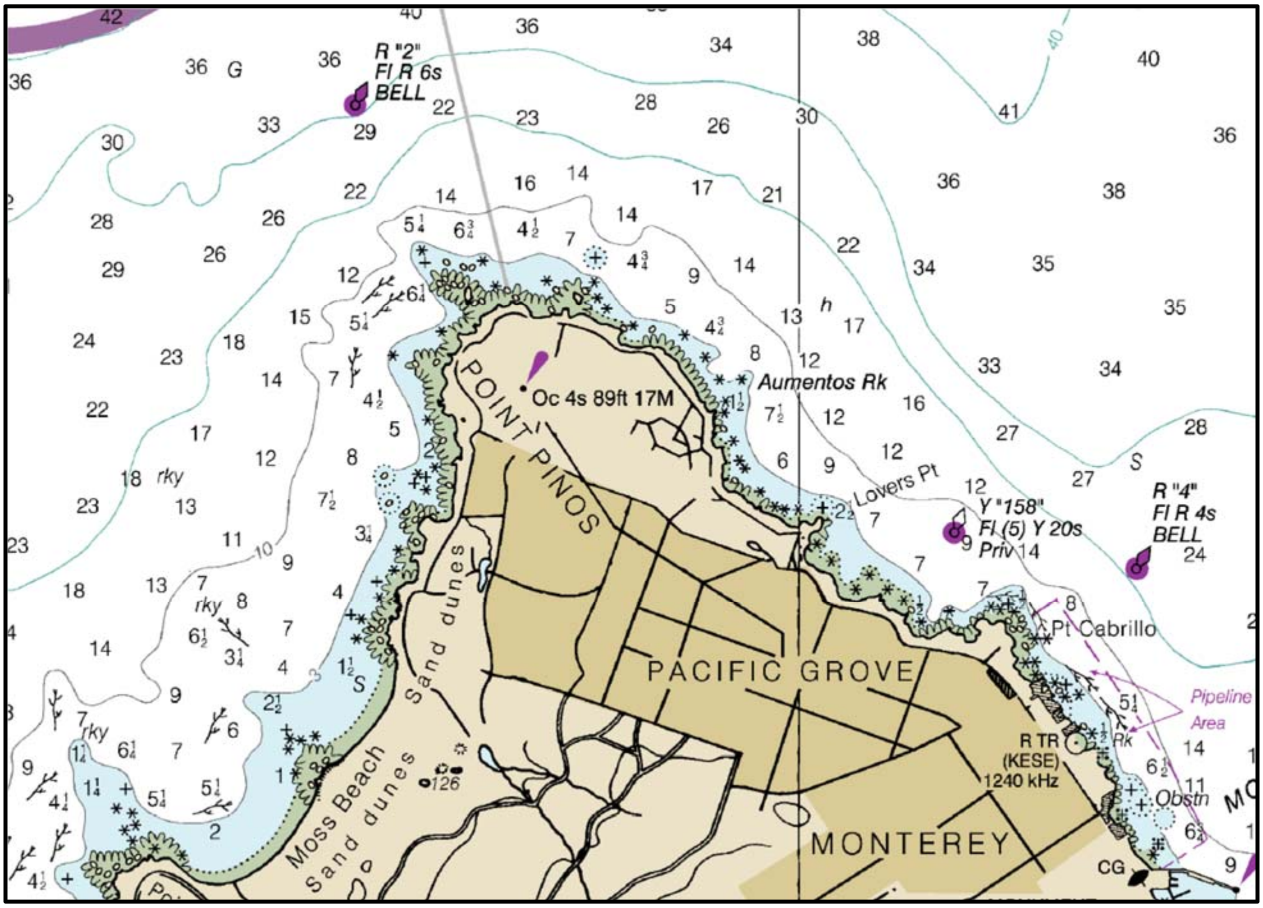


Figure 2-2: NOAA Navigation Chart (Depths in Fathoms relative to MLLW)

2.2. Water Levels

Elevation data used in this study is referenced to NAVD88 unless noted otherwise. Where elevations are referenced to other vertical datums, Table 2-1 provides relations between vertical reference systems, *NOAA (2017)*. The data is based on tides measured at NOAA Station 9413450, which is located at Monterey Harbor. Figure 2-3 shows the location of the tide gauge.

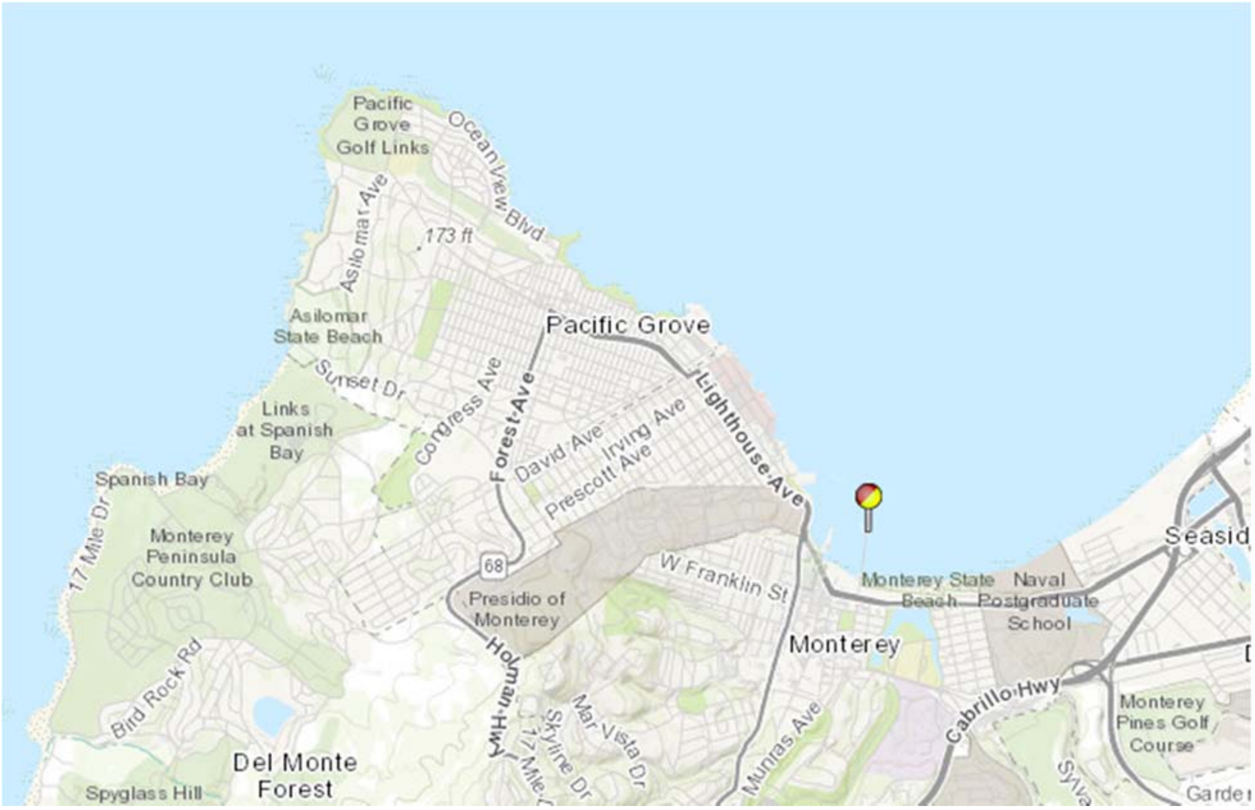


Figure 2-3: Location of NOAA Station 9413450, Monterey, CA

Table 2-1: Vertical datum reference, NOAA Station 9413450, Monterey, CA

Datum	Elevation (feet)		Remarks
	MLLW	NAVD88	
HOWL	+11.26	+11.40	Highest Observed Water Level (01/27/1983)
HAT	+7.04	+7.18	Highest Astronomical Tide
MHHW	+5.34	+5.48	Mean Higher High Water
MHW	+4.64	+4.78	Mean High Water
MTL	+2.87	+3.01	Mean Tide Level
MSL	+2.83	+2.97	Mean Sea Level
DTL	+2.67	+2.81	Diurnal Tide Level
MLW	+1.09	+1.23	Mean Low Water
MLLW	0.00	+0.14	Mean Lower Low Water
NAVD88	-0.14	0.00	North American Vertical Datum of 1988
LAT	-1.91	-1.77	Lowest Astronomical Tide
LOWL	-2.42	-2.28	Lowest Observed Water Level (01/11/2009)

2.2.1. Extreme Water Levels

NOAA (2017) provides estimates of extreme water levels based on recorded water level data. Table 2-2 summarizes data for NOAA Station 9413450. Tide levels have been recorded at Monterey for over 44 years (since 1973).

Table 2-2: Annual exceedance probability levels, NOAA Station 9413450

Annual Exceedance Probability	Elevation (feet NAVD88)	Recurrence Interval
1%	+8.22	100 years
10%	+7.73	10 years
50%	+7.30	2 years
99%	+6.87	1 year
99%	-0.02	1 year
50%	-1.26	2 years
10%	-1.98	10 years
1%	-2.21	100 years

2.2.2. Tsunami

USGS (2013) evaluated tsunami impacts on the Pacific Grove coastline as part of their Science Application for Risk Reduction (SAFRR) program. The SAFRR tsunami scenario is a possible tsunami caused by an earthquake offshore from the Alaska Peninsula which can impact the California Coast. Figure 2-4 shows the SAFRR tsunami inundation area along Pacific Grove. The SAFFR results show that tsunami impacts are limited to the shore, with no inundation of inland areas.

Figure 2-4: Tsunami Inundation Zone (USGS, 2013)

2.2.3. Sea Level Rise

The Ocean Protection Council *(OPC, 2018)* maintains guidance on Sea Level Rise (SLR) for the coasts of California. Table 2-3 provides the OPC probabilistic projections for the height of sea-level rise at Monterey. Two different SLR scenarios are provided; a low emission scenario considering a decrease in green gas emissions, and a high emission scenario. For the years 2030 and 2050 only the high emission scenario is considered.

Table 2-3: Probabilistic SLR Projections for Monterey, CA in Feet (OPC, 2018)

Year	Emission Scenario	Median	Likely Range	1 -in-20 chance	1-in-200 chance
		50% probability SLR meets or exceeds…	66% probability SLR is between…	5% probability SLR meets or exceeds…	0.5% probability SLR meets or exceeds…
2030	High	0.4	0.3 - 0.5	0.6	0.8
2050	High	0.8	0.5 - 1.1	1.3	1.9
2100	Low	1.5	0.9 - 2.3	3.1	5.5
2100	High	2.3	1.5 - 3.3	4.3	6.9

To assess SLR-related vulnerability for Pacific Grove, the projections recommended by OPC for use in low and medium-high risk aversion decisions are used in this work (Table 2-4).

Table 2-4: Low and Medium-High Risk SLR in Feet (OPC, 2018)

Year	Emission Scenario	Low Risk Aversion	Medium - High Risk Aversion
2030	High	0.5	0.8
2050	High	1.1	1.9
2100	Low	2.3	5.5
2100	High	3.3	6.9

2.2.4. Climate Cycles

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).

2.2.4.1. El Niño Southern Oscillation

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

Since 1950, the oceanographic community has used the Oceanic Niño Index (ONI) to characterize ENSO ocean temperatures (Figure 2-5). When warming of the ocean exceeds +0.5˚C El Niño conditions prevail. If the ocean temperature cools below -0.5˚C La Niña conditions are present. Within the range of+/-0.5˚C, conditions are termed ENSO-neutral. 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.

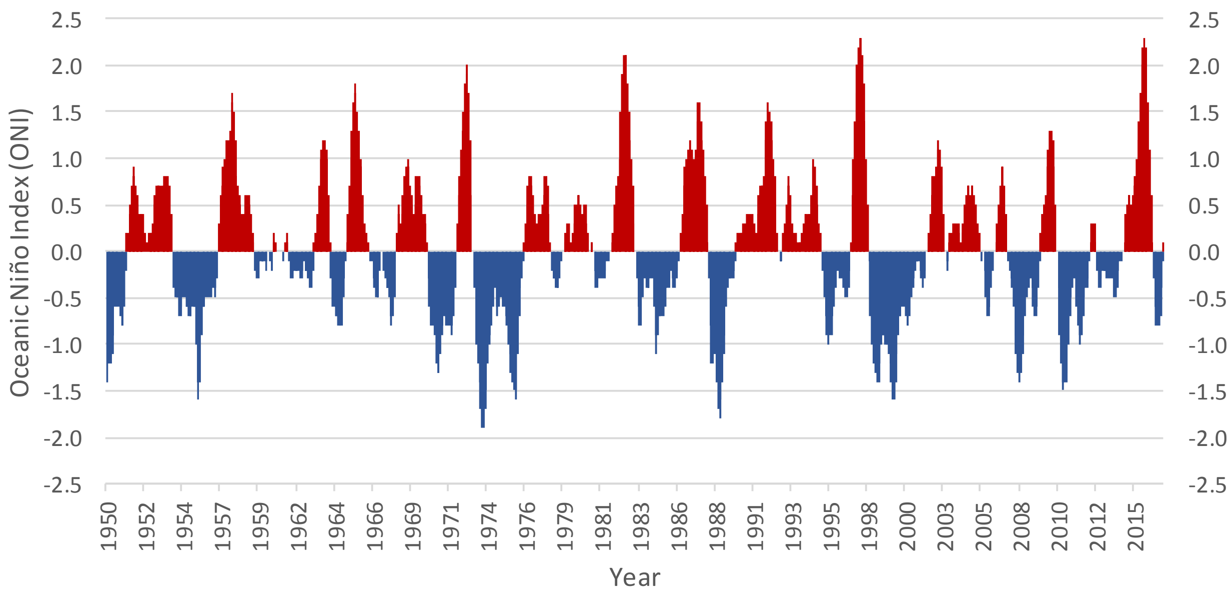


Figure 2-5: ENSO variation (1950-2017)

2.2.4.2. Pacific Decadal Oscillation

Figure 2-6 shows the variation of the Pacific Decadal Oscillation (PDO), which is another climate cycle that produces ocean warming and cooling trends over decades, as opposed to ENSO variations which unfold over months to years.

The data from 1950 to 1976 show a cooling trend (blue), 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 2-5 and Figure 2-6 reveals that variations of the PDO over the short term are influenced by the ENSO directly. Thus, it 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 increased 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.

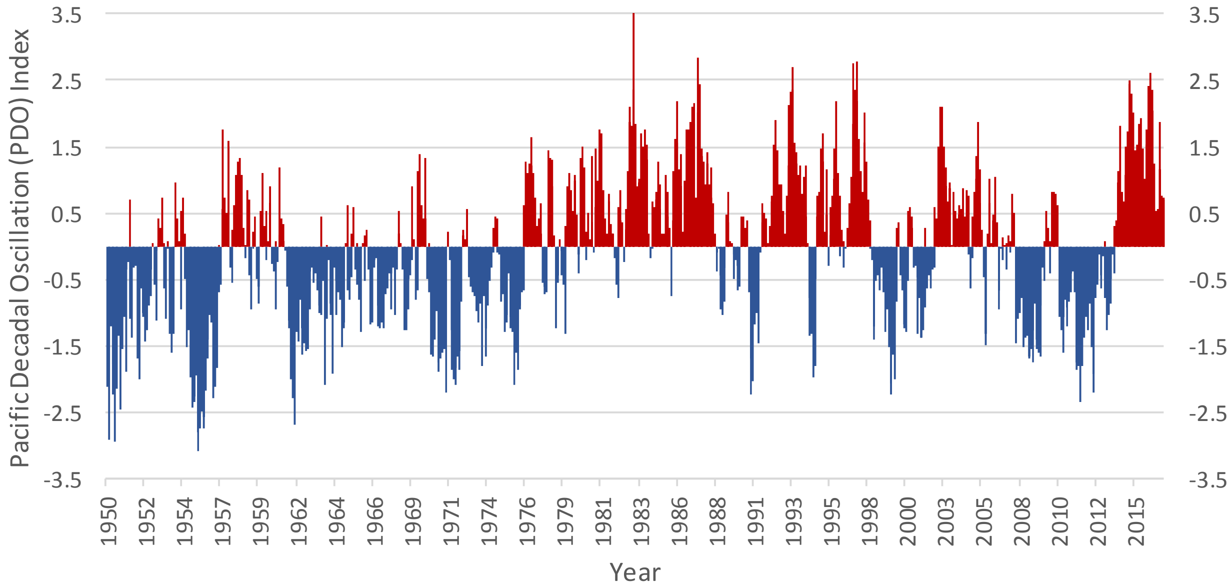


Figure 2-6: PDO variation (1950-2017)

Figure 2-7 shows the variation of tides at NOAA Station 9414290, San Francisco, indicated by the light blue shading, with elevations 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 (ONI-PDO) is superimposed on the figure for comparison (NTS).

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

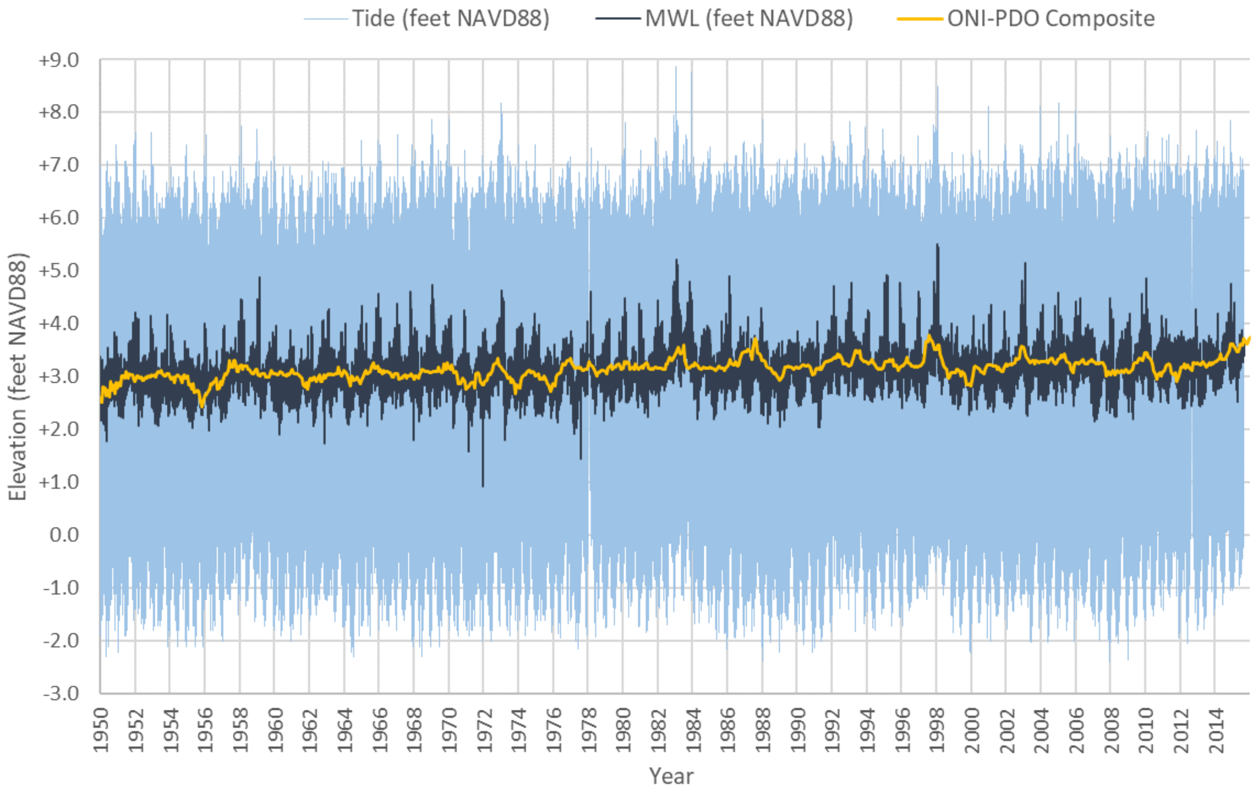


Figure 2-7: Tidal variation, mean water level, and Oceanic Niño – Pacific Decadal Oscillation Index

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

2.3. Wind Climate

The wind climate in the Pacific Grove area can be characterized by measurements collected at the NOAA meteorological station at Monterey (Station 9413450, Figure 2-3). Wind data at this station has been recorded since 2009. From the recorded data and the historical observations at nearby locations, it can be determined that predominant wind directions are from the offshore sector from northwesterly, westerly, southwesterly, southerly, and southeasterly directions. Winds from the overland areas to the north, northeast, and east are less prevalent. The corresponding wind rose is shown in Figure 2-8.

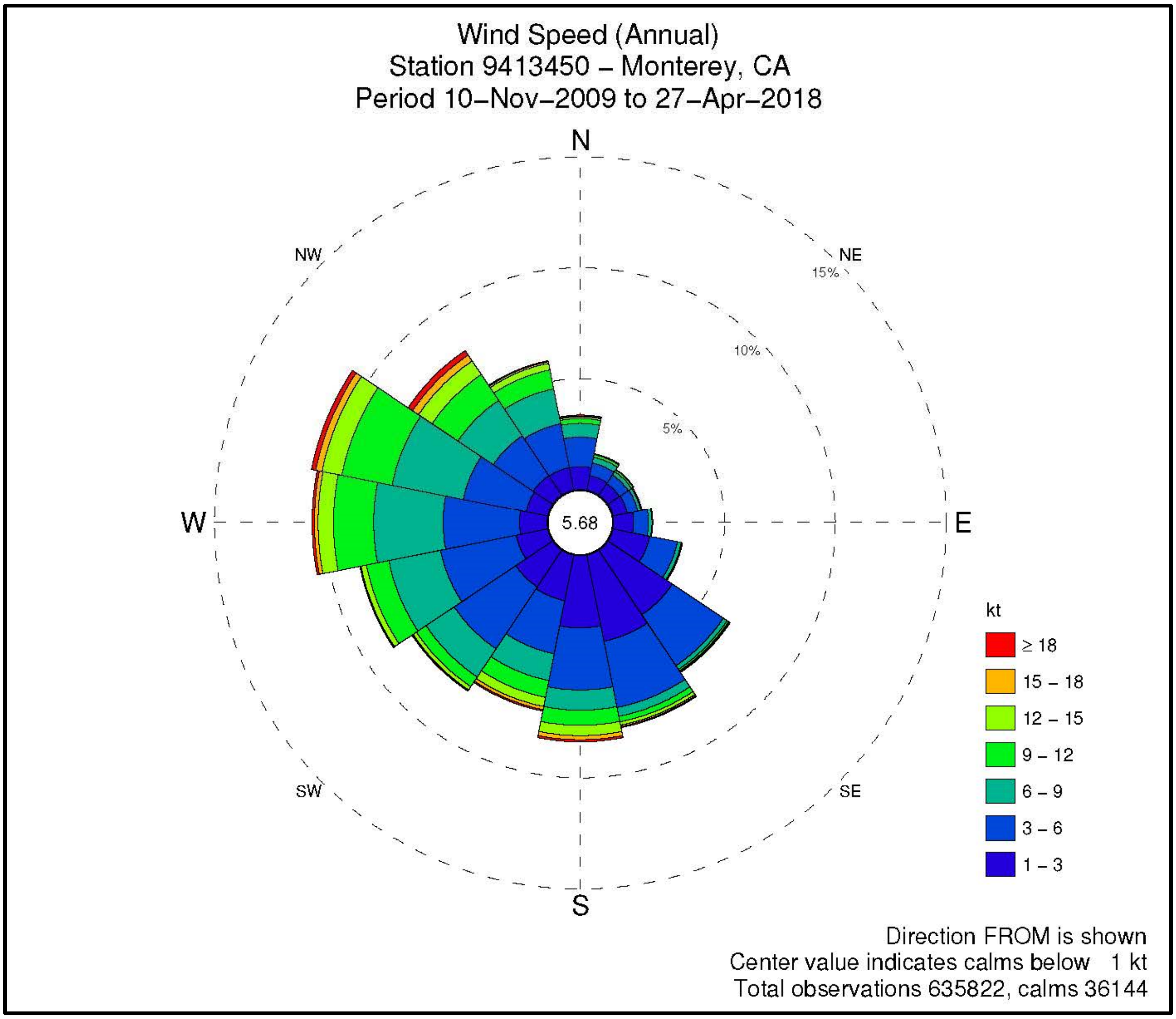


Figure 2-8: NOAA Monterey Station (#9413450) Wind Rose

2.4. Wave Climate

Wave action, in combination with extreme water levels and currents, is the primary cause for sediment transport, coastal flooding and erosion, dune overtopping, and damage to coastal structures. Pacific Grove is located along the Central California coast, where the wave climate consists of swell from the Pacific and local wind waves dependent on seasonal wind patterns. As shown in Figure 2-9, the wave exposure at Monterey can be categorized into four different regimes (*Storlazzi and Wingfield, 2005*), as follows:

1) North Pacific Swell
2) Southern Hemisphere Swell
3) Northwest Wind Waves; and
4) Local Wind Waves

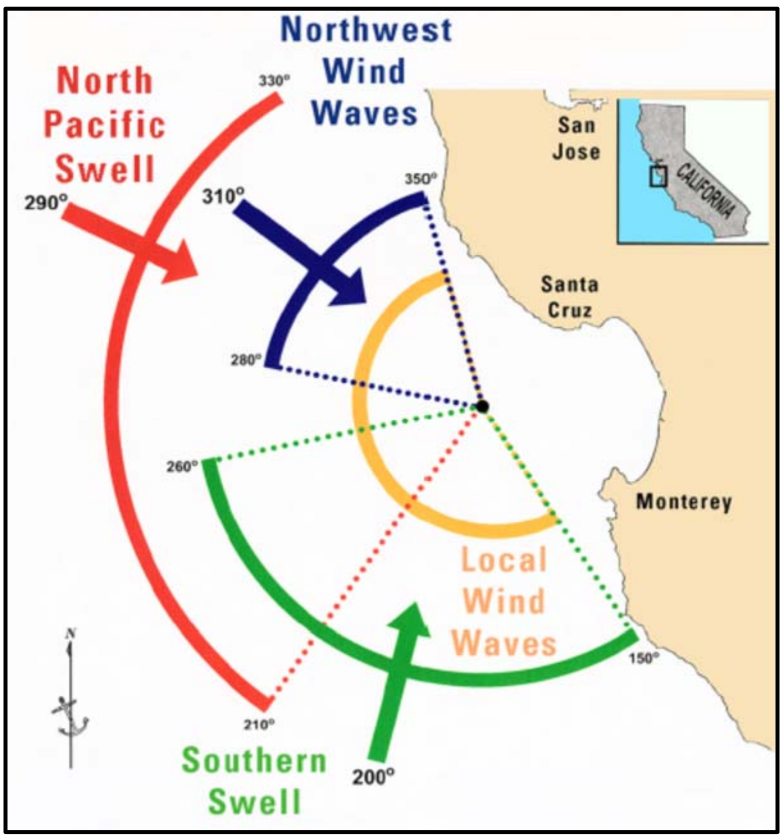


Figure 2-9: General Wave Directions for Central California based on Offshore Buoy Data (*Hapke et al., 2006*)

North Pacific swell is generated by mid-latitude cyclonic storms in combination with cold fronts in the North Pacific. Southern swell is generated by winter storms in the southern hemisphere and is dominant in the summer. Northwest wind waves are the dominant wave condition in the spring and early summer and are generated by daily sea breeze conditions. Nearshore wind conditions generate local wind waves.

The National Data Buoy Center (NDBC) in collaboration with Scrips Institute of Oceanography have installed several wave gauges nearshore and offshore of Pacific Grove to measure the wave climate. The locations of these wave gauges are shown in Figure 2-10. In this work, NDBC wave gauge 46042 located 27 Nautical Miles WNW of Monterey, CA with over 27 years of recorded data is used to quantify offshore wave conditions. For nearshore waves, the NDBC gauge near Cabrillo Point has been studied which has wave data for about 9 years (station #46240).

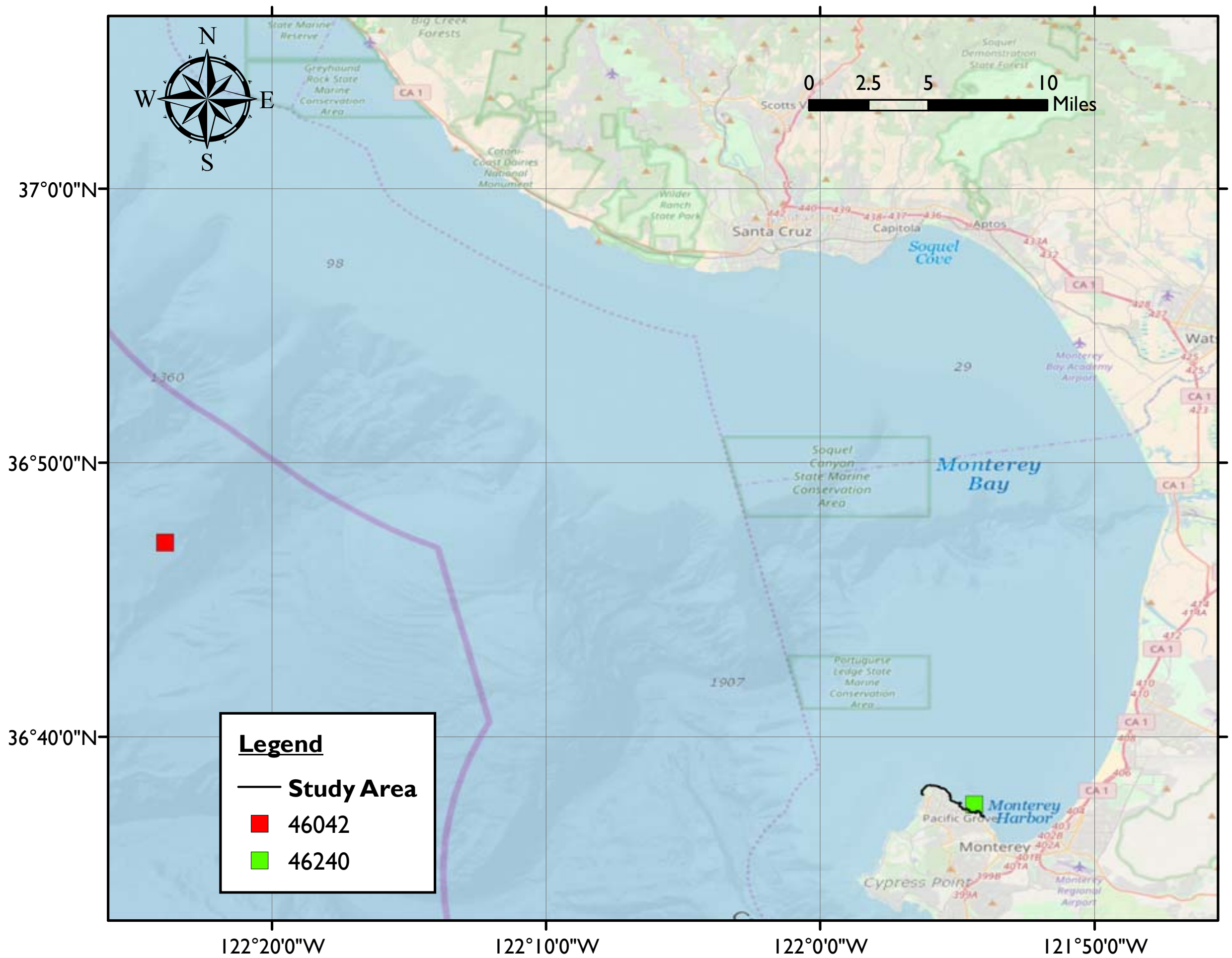
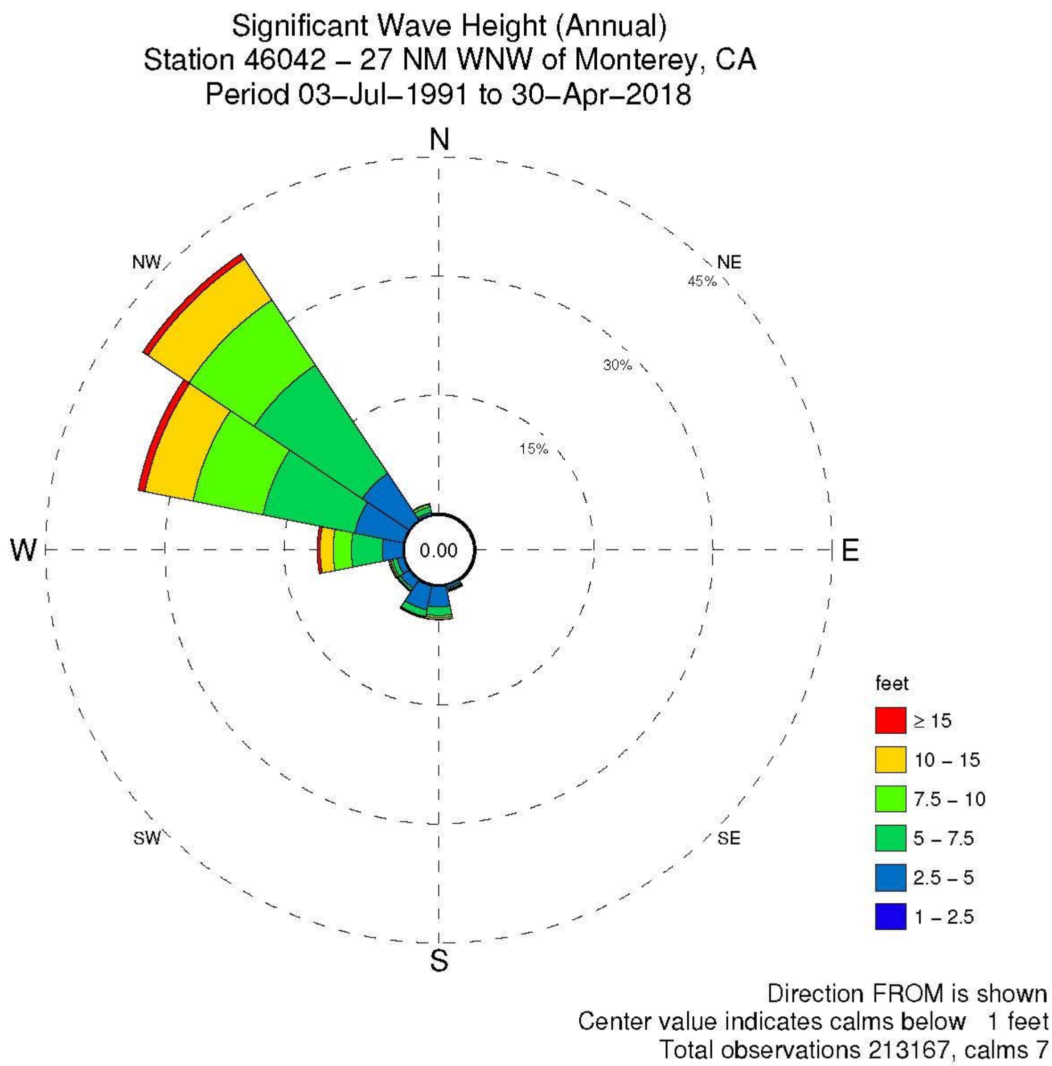


Figure 2-10: Location of NDBC Wave Gauges

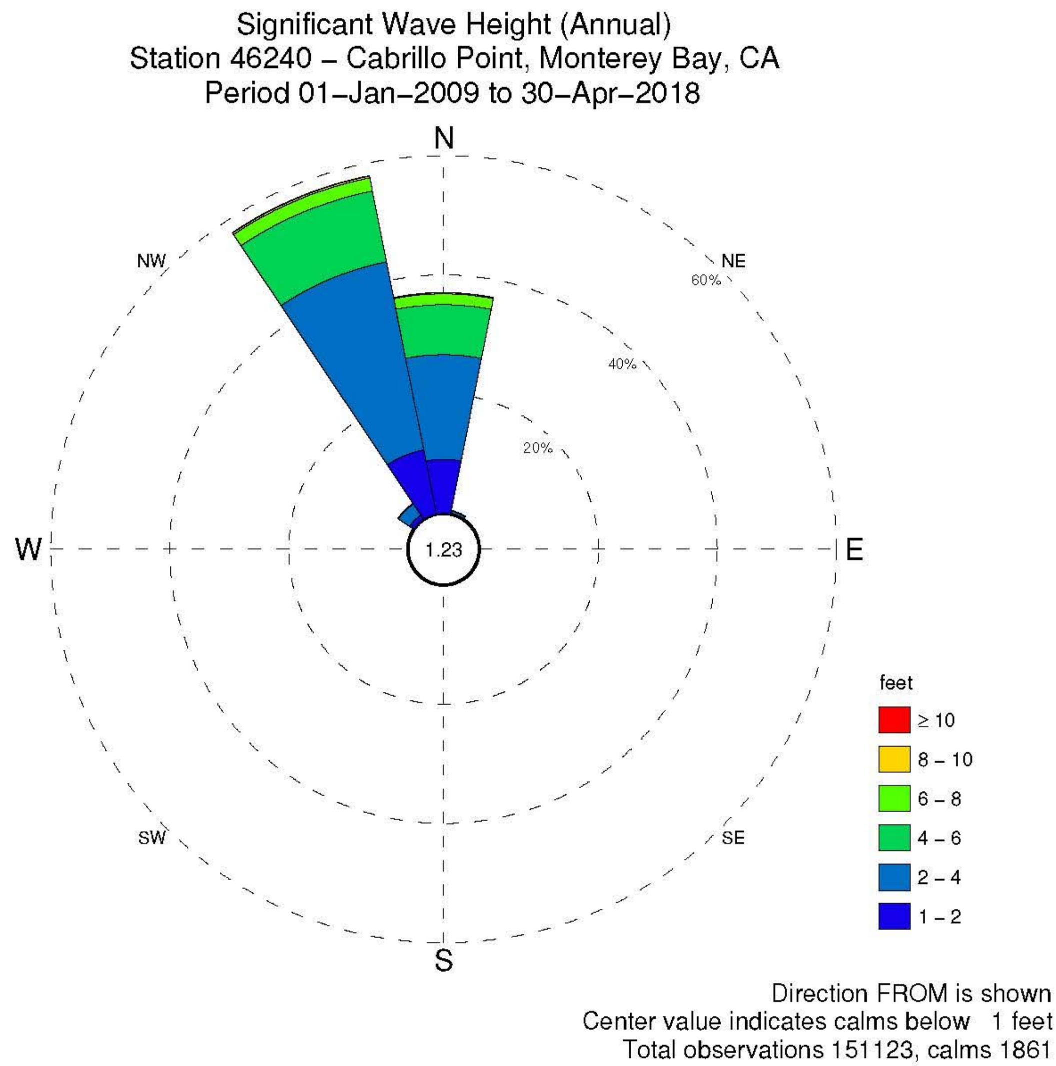
Figure 2-12 and Figure 2-11 show the significant wave height roses for NDBC wave gauges 46042 and 46240.



Percentage of Occurrence

Significant Wave Height, feet	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total								0.84	4.29	4.28	1.85	1.95	10.83	34.11	40.33	1.46	100.00
15+													0.37	0.86	0.74		2.10
10 – 15								0.14	0.23			0.19	1.64	6.18	6.23		14.82
7.5 – 10								0.11	0.27	0.13		0.25	2.28	8.99	9.85	0.33	22.31
5 – 7.5								0.23	1.07	0.89	0.37	0.59	3.91	11.78	16.41	0.71	35.98
2.5 – 5								0.34	2.62	3.06	1.27	0.85	2.60	6.25	7.08	0.33	24.42
1 – 2.5										0.12							0.37

Figure 2-11: Significant Wave Height Rose for NDBC 46042 Wave Gauge



Percentage of Occurrence

Significant Wave Height, feet	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	37.04	0.62													3.24	57.86	98.77
> 10																	0.11
8 – 10	0.17															0.29	0.47
6 – 8	1.81															2.25	4.09
4 – 6	8.38														0.12	12.10	20.69
2 – 4	17.57	0.36													2.26	32.14	52.34
1 – 2	9.06	0.15													0.85	11.00	21.07

Figure 2-12: Significant Wave Height Rose for NDBC 46240 Wave Gauge

Considering the wave statistics from the NDBC wave gauges it can be concluded that North Pacific swell is the dominant wave condition with significant wave heights between 6 and 33 feet and periods ranging from 10 to 25 seconds. These waves mainly occur between October and May. However, from April to October, northwest wind waves are dominant with significant wave heights varying between 3 and 13 feet with a period of 3 to 10 seconds. The southern swell also occurs between April and October, with smaller wave heights compared to Northwest swell and wind waves, with significant wave heights ranging from 1 to 10 feet with a period of 10 to 25 seconds. Local wind-driven waves generally occur between October and April with significant wave heights ranging between 3 and 12 feet and periods of 3 to 10 seconds.

Extreme-value analysis was performed on wave data recorded at NDBC 46240 (9 years) and NDBC 46042 (27 years) to assess 1- to 100-year wave conditions. The results of this analysis are summarized in Table 2-5.

Table 2-5: Extreme Wave Heights

Location	**Cabrillo Point, Monterey Bay**	**27 Nautical Miles WNW of Monterey, CA**
Station Number	46240	46042
Depth (feet)	58.5	5,400
Longitude	121°54'25" W	122°23'54" W
Latitude	36°37'35" N	36°47'5" N
Duration of Measurement	9 years	27 years
Return Period (years)	**Significant Wave Height (feet)**	
1	11.2	23.2
2	11.9	26.1
5	12.8	28.3
10	13.9	30.8
25	14.6	33.1
50	15.4	34.0
100	16.2	35.7

2.5. Geologic Setting

2.5.1. Geologic Factors

The Monterey Peninsula consists of granitic rock overlain by 2- to 12-foot thick marine terrace deposits.

The marine terrace deposits generally consist of uncemented, friable, thinly laminate to thickly bedded silty very fine to coarse grained sand with pebbles and cobbles. The interface between the granodiorite rock and marine terrace deposits typically has a seaward gradient.

The granodiorite bedrock rock is highly durable and erosion resistant, while the upper portion of the granite is highly weathered and more susceptible to erosion. The marine terrace deposits are highly erodible. The supply of sand to the existing beaches comes from erosion of the granodiorite.

Off-shore rock outcrops, promontories, boulders, and sea stacks play an important role in dissipating wave energy. Estimated rates of erosion are provided in Table 2-6.

Table 2-6: Estimated rates of erosion

Geologic Formation	Rate of Erosion
Cliffs	0.8 to 1.8 inches per year
Marine terrace	2.0 to 4.0 inches per year
Dunes	2.6 feet per year

2.5.2. Seismic Hazards

Pacific Grove is located in proximity to a number of quaternary earthquake faults summarized in Figure 2-13. These are characterized as faults that have evidence of movement within the past 1.6 million years (the quaternary geologic period).

Of these faults, the San Andreas fault and the Calaveras fault have the greatest potential to produce large earthquakes. These two faults have been active within the last 150 years. The remainder of the faults shown in the figure have not ruptured for the past 15,000 years.

Techniques for identification and mapping of seismic faults continue to evolve, and many of the earlier named faults are now known to be zones of fault segments, several of these interconnecting with other faults (Figure 2-13).

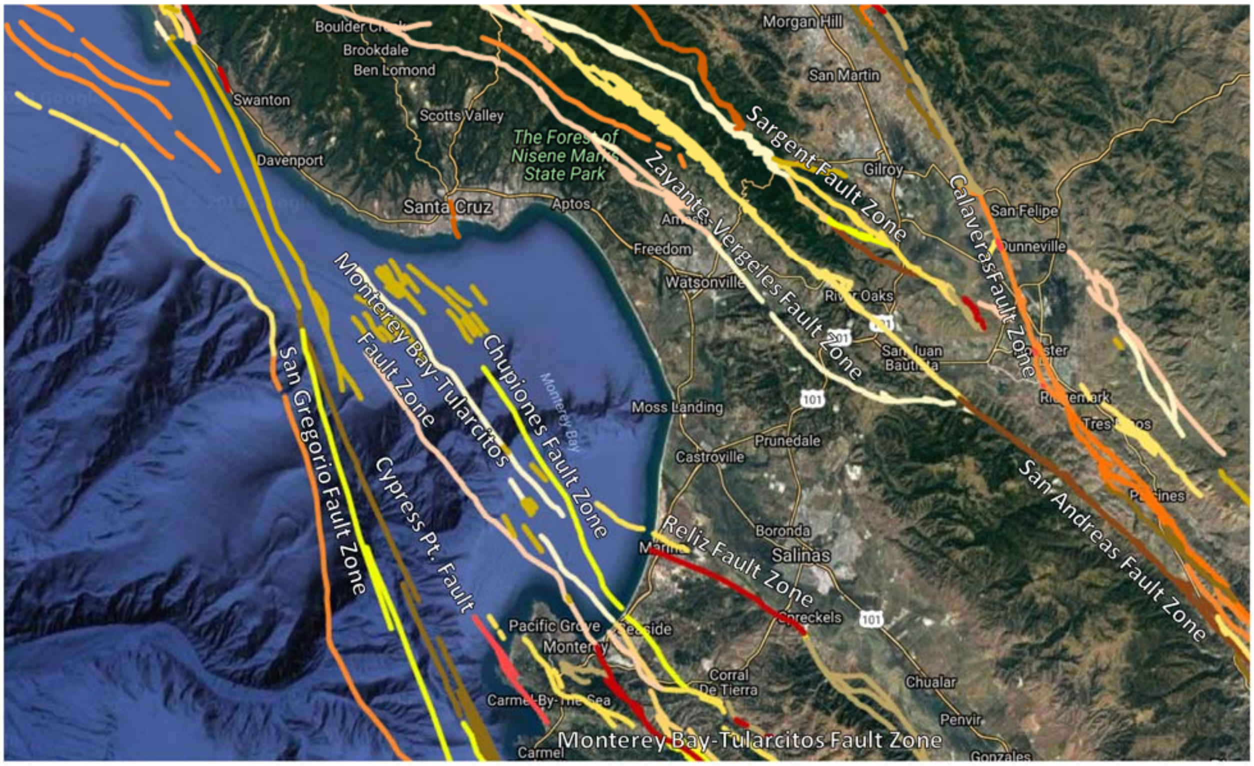


Figure 2-13: Monterey Bay Fault Zones

Earthquakes that have affected Pacific Grove within the past century include:

- The Great 1906 San Francisco Earthquake, a magnitude 7.9 rupture on the San Andreas fault.
- The October 1926 Monterey Bay earthquakes, two earthquakes of magnitude 6.1 and 6.3 which occurred off the coast of Monterey within one hour of each other; and
- The 1989 Loma Prieta Earthquake, a magnitude 6.9 earthquake with an epicenter near Loma Prieta Peak in the Santa Cruz Mountains.

The above quakes caused very little damage in Pacific Grove.

In the event of a severe earthquake, strong ground shaking is considered the most serious hazard to existing structures. Because Pacific Grove is situated in a relatively stable area of granitic bedrock, the city is not prone to seismic hazards in the form of liquefaction, settlement, lateral spreading, landslides, rock falls, or debris flows.

The submarine fault zones indicated in Figure 2-13 are strike-slip faults, which do not undergo significant upward thrust during rupture and are therefore not likely to produce large-scale tsunamis locally. The primary tsunami hazard to Pacific Grove is therefore from distant (transpacific) tsunamis.

2.6. Land Use

EMC (2015) studied and developed land use data as part of the Pacific Grove LCP update. Figure 2-14 shows the land use map for Pacific Grove which delineates the coastal zone and identifies residential, visitor, commercial, and professional land use areas; and open space and recreational trails. Biological resources and other coastal resources, such as public access points to recreational and scenic resources exist along the majority of the Pacific Grove shoreline.

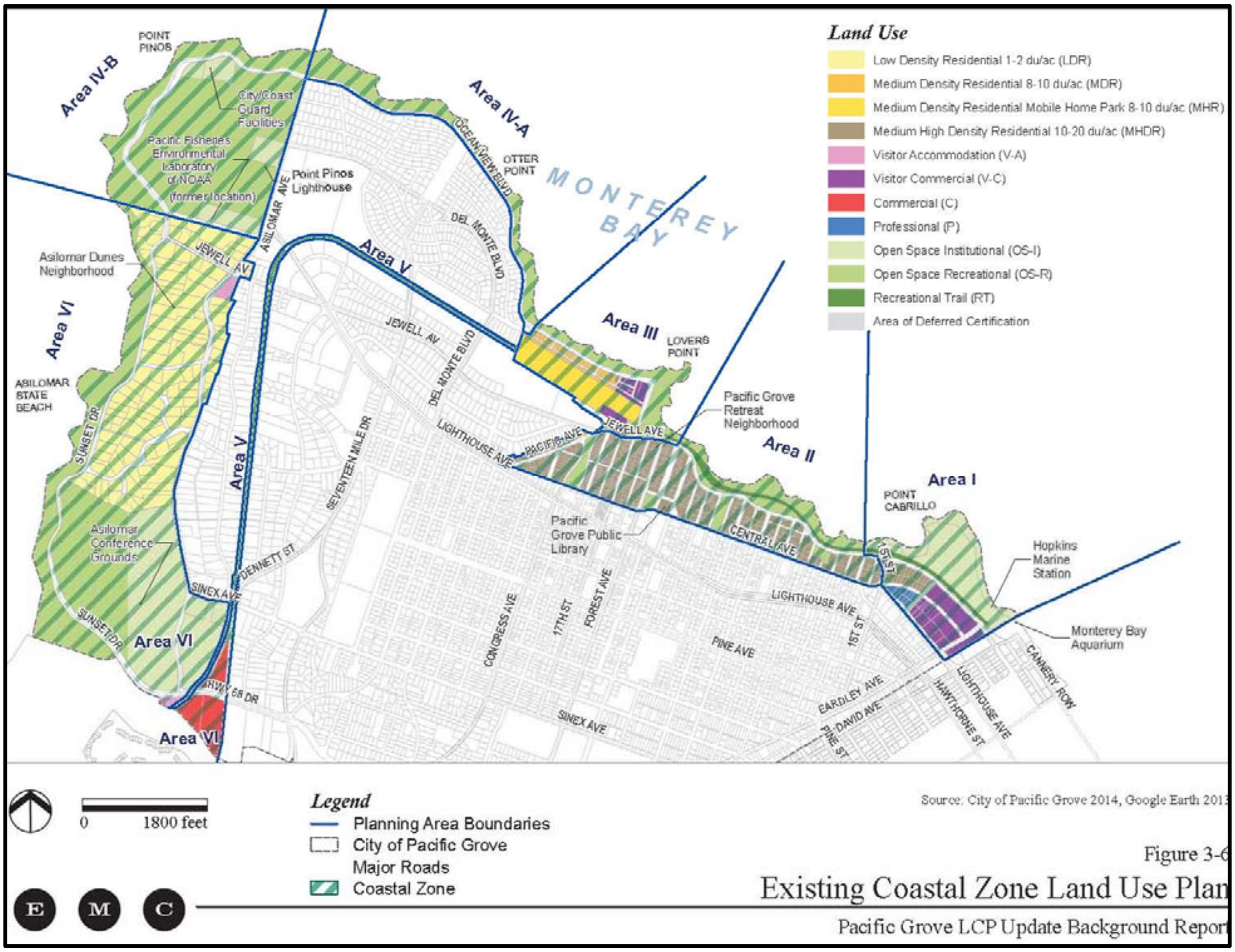


Figure 2-14: Existing Coastal Land Use Plan, *EMC (2015)*

3. Vulnerability Assessment

3.1. Wave Runup and Overtopping

3.1.1. Determination of Extreme Events

To estimate runup and overtopping rates along the Pacific Grove shoreline a 1% annual chance of occurrence event was chosen to account for a 30-year planning horizon. The Total Water Level (TWL), defined as the sum of still water level and the 2% runup *(FEMA, 2005)* was calculated to develop inundation maps for a 30-year planning horizon. The 1% annual chance event combines both wave height and water level. Because these to processes are not independent, the joint return period is around 250 years, combining water level (Table 2-2) and offshore wave conditions (Table 2-5). For example, a 50-year wave condition was combined with a 5-year water level condition and vice versa. Table 3-1 lists the 6 cases considered in order to asses vulnerability to coastal flooding at Pacific Grove.

Table 3-1: Combination of Extreme Wave and Water Level Events

Case Number	Offshore Significant Wave Height (ft.)	Wave Height Return Period (Years)	Water Level (ft. - NAVD88)	Water Level Return Period (Years)
1	35.7	100	7.37	2.5
2	34.0	50	7.54	5
3	33.1	25	7.73	10
4	30.8	10	7.98	25
5	28.3	5	8.05	50
6	26.7	2.5	8.22	100

3.1.2. Wave Analysis

The MIKE-21 Spectral Wave (SW) model was used to investigate offshore wave propagation and wave transformation from deep water to shallow water along the Pacific Grove coastline. The MIKE-21 SW model simulates wave shoaling and refraction due to variations in water depth, wave diffraction, wave reflection at structures, wave breaking in the surf zone, wave dissipation, and non-linear wave-current interaction. The model uses a flexible unstructured grid composed of triangular elements.

The model domain encompasses the Pacific Grove coastline and surrounding shorelines, nearshore, and offshore areas that affect the propagation of swell waves to the shore. The offshore boundary is located at NDBC station 46042 (Figure 2-10) so that swell wave data measured at the buoy can be used for model boundary conditions. Figure 3-1 shows the regional model computational mesh. Figure 3-2 provides a close-up of the more detailed mesh along Pacific Grove.

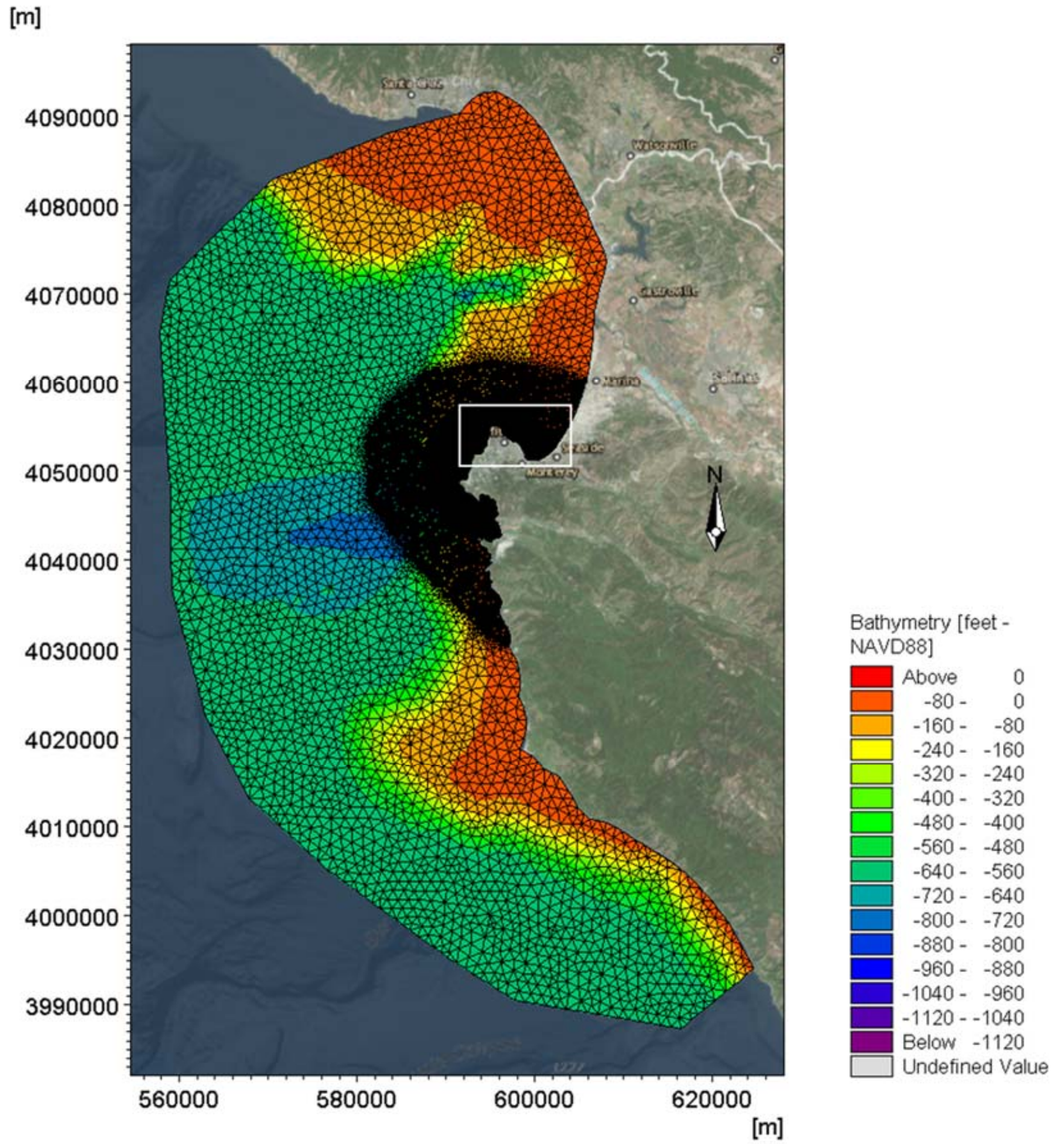


Figure 3-1: MIKE21 SW Computational Domain.
(X and Y Axis Values Indicate Northing and Easting)

The flexible-mesh capabilities of the Mike21-SW model allow the high-resolution representation of wave transformation and diffraction processes in the shallow areas along Pacific Grove. Figure 3-2 provides a close-up view of the model grid indicated by the white box in Figure 3-1.

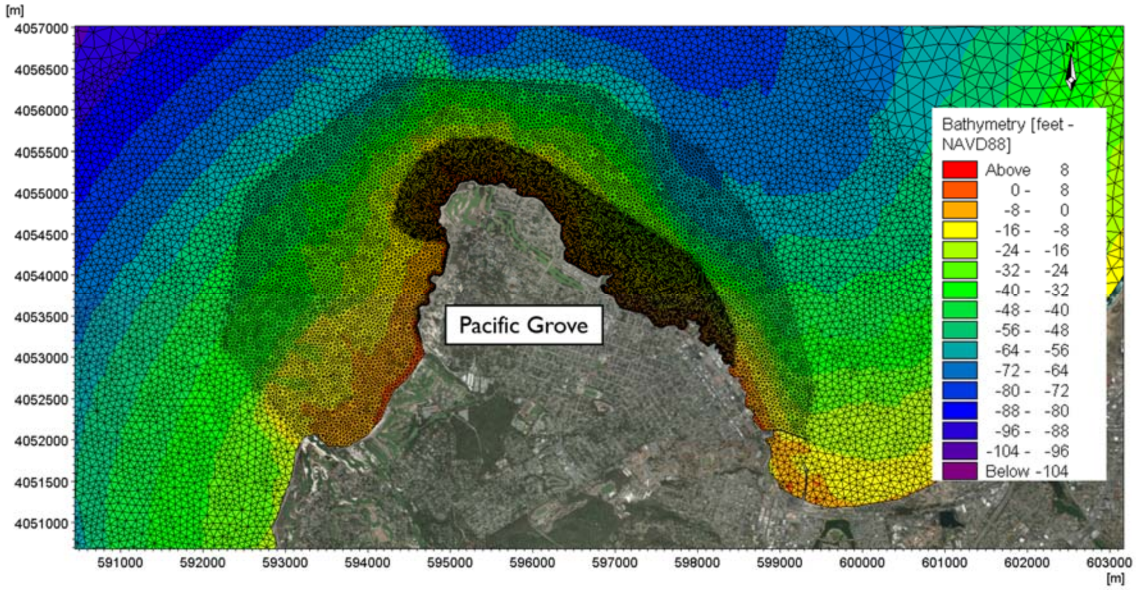


Figure 3-2: MIKE21 SW Model Gridding along the Pacific Grove Shoreline.
(X and Y Axis Values Indicate Northing and Easting)

The wave model was run for the 6 cases mentioned in Table 3-1 representing offshore swell boundary conditions with varying directions. For each wave case, seven directions were modeled ranging from 250° N to 310° N (Figure 2-9) at 10° increments in order to identify the worst wave direction for each wave scenario mentioned in Table 3-1. Peak wave periods for each wave case were determined from a curve-fitting analysis on the available data from NDBC 46042 buoy. Figure 3-3 shows example model output depicting the significant wave height variation for swell waves from 280° N.

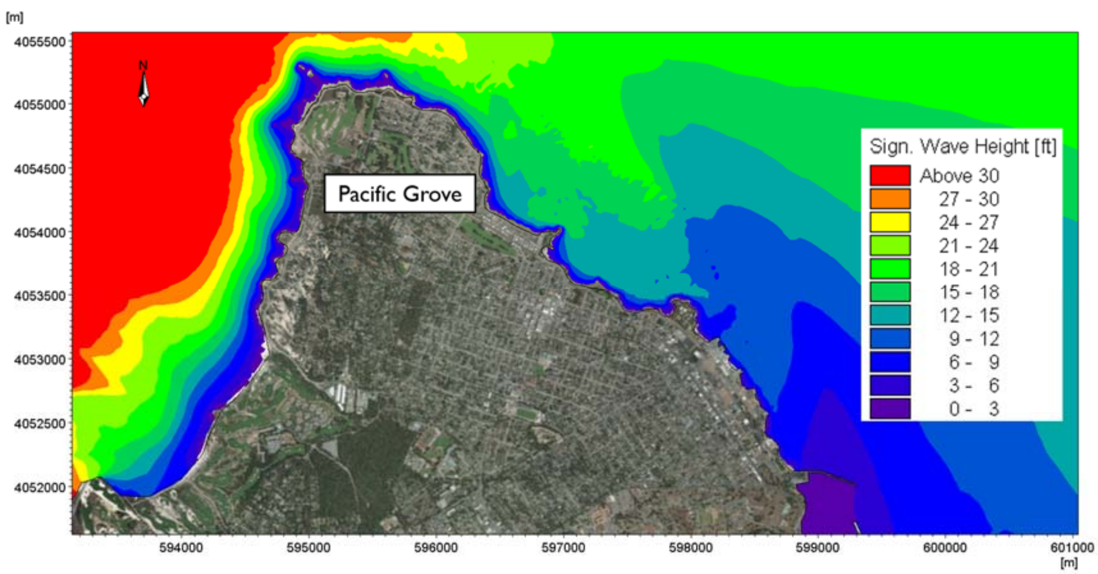


Figure 3-3: Significant Wave Height for Swell Waves from 280°N.

The results for each case were recorded along the Pacific Grove shoreline to consider the reduction and amplification of the significant wave height for case. The parameters of interest for runup calculation included the significant wave height (H_s) and peak wave period (T_p).

3.1.3. Wave Runup

The coastal flood inundation limit is a function of the local wave runup ($R_{2\%}$). The 2% wave runup is the elevation reached by the largest 2% of incident waves. The 2% runup is calculated following the *FEMA (2005)* recommendations combined with extreme water levels to estimate the inland extent of coastal flooding.

Wave heights along the Pacific Grove coastline were developed based on the MIKE-21 SW model results, discussed in the previous section. The wave attributes and bathymetry were recorded every 10 feet along the Pacific Grove shoreline. These values were used to calculate Iribarren number (surf-similarity parameter), to be inserted in the modified Van der Meer equation (FEMA, 2005, D.4.5-19) to calculate wave runup every 10 feet along the Pacific Grove shoreline.

The method utilizes four reduction factors to incorporate the influence of roughness (γ_r), a berm (γ_b), angled wave attack (γ_β), and structure permeability (γ_p). However, beside surface roughness reduction factor (γ_r), all other reduction factors were conservatively assumed to be 1.0. The resulting inundation line is determined from the maximum Total Water Level (TWL) and its extent onshore, using the maximum runup value of the six cases listed in Table 3-1. Figure 3-4 depicts the resulting 1% coastal flood inundation limit.

Figure 3-4: Inundation Line for 1% Coastal Flood Event at Pacific Grove, CA

3.1.4. Wave Overtopping

Wave overtopping rates were calculated following the recommendations of *FEMA (2005)*. The wave runup values along the Pacific Grove shoreline were calculated using the wave and water level scenarios discussed before, as well as the freeboard values for cross-sections every 10 feet along the shoreline. Freeboard (R_c) is defined as the onshore elevation above the mean sea level. In order to use the Coastal Engineering Manual *(USACE, 2002)* guidelines to estimate vulnerabilities along the Pacific Grove shoreline (Figure 3-5), the overtopping results are reported in Litres per Second per meter unit (Figure 3-6).

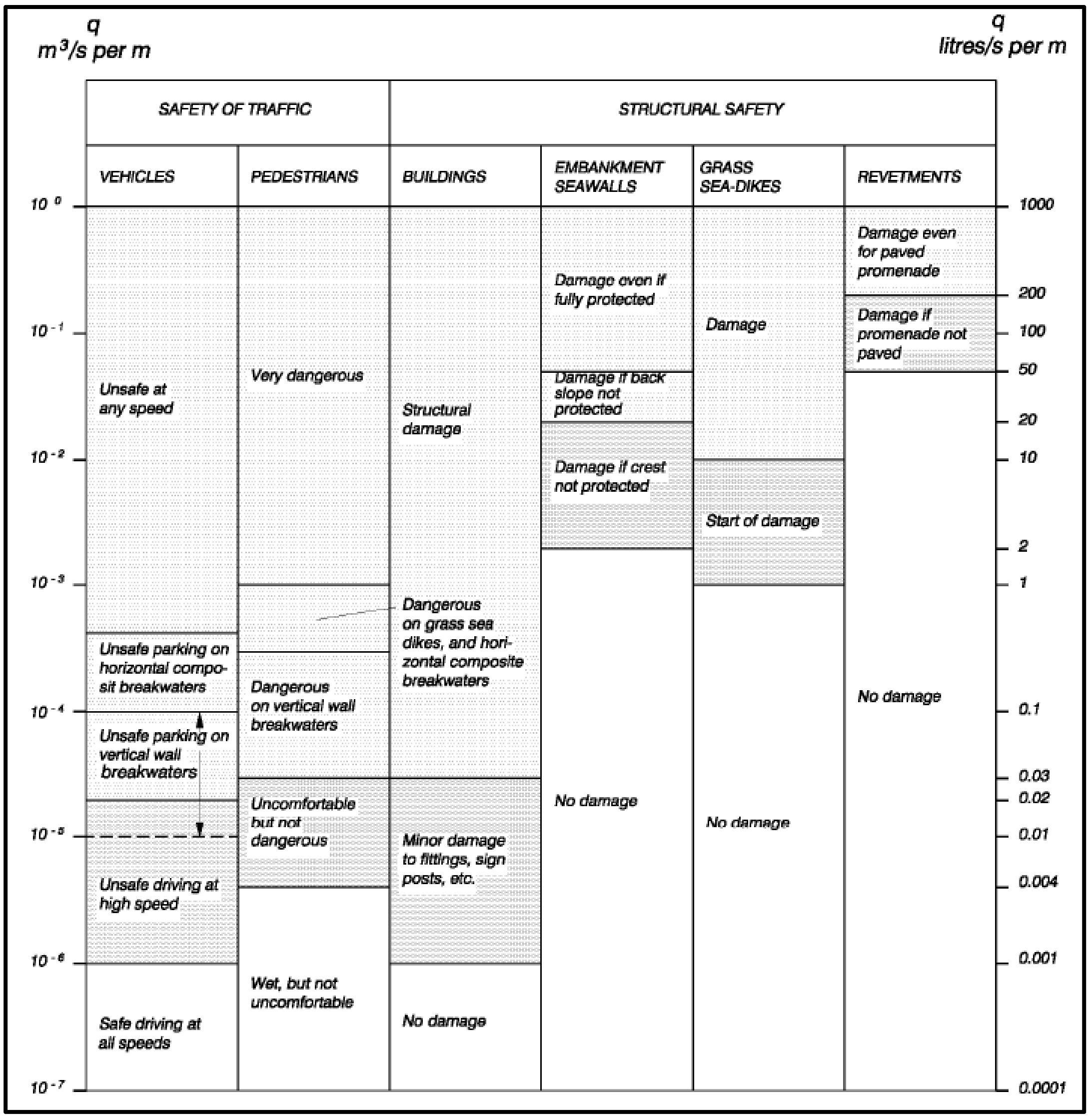


Figure 3-5: Critical Values of Average Overtopping Discharges,
Figure taken from CEM (USACE, 2002, Table VI-5-6)

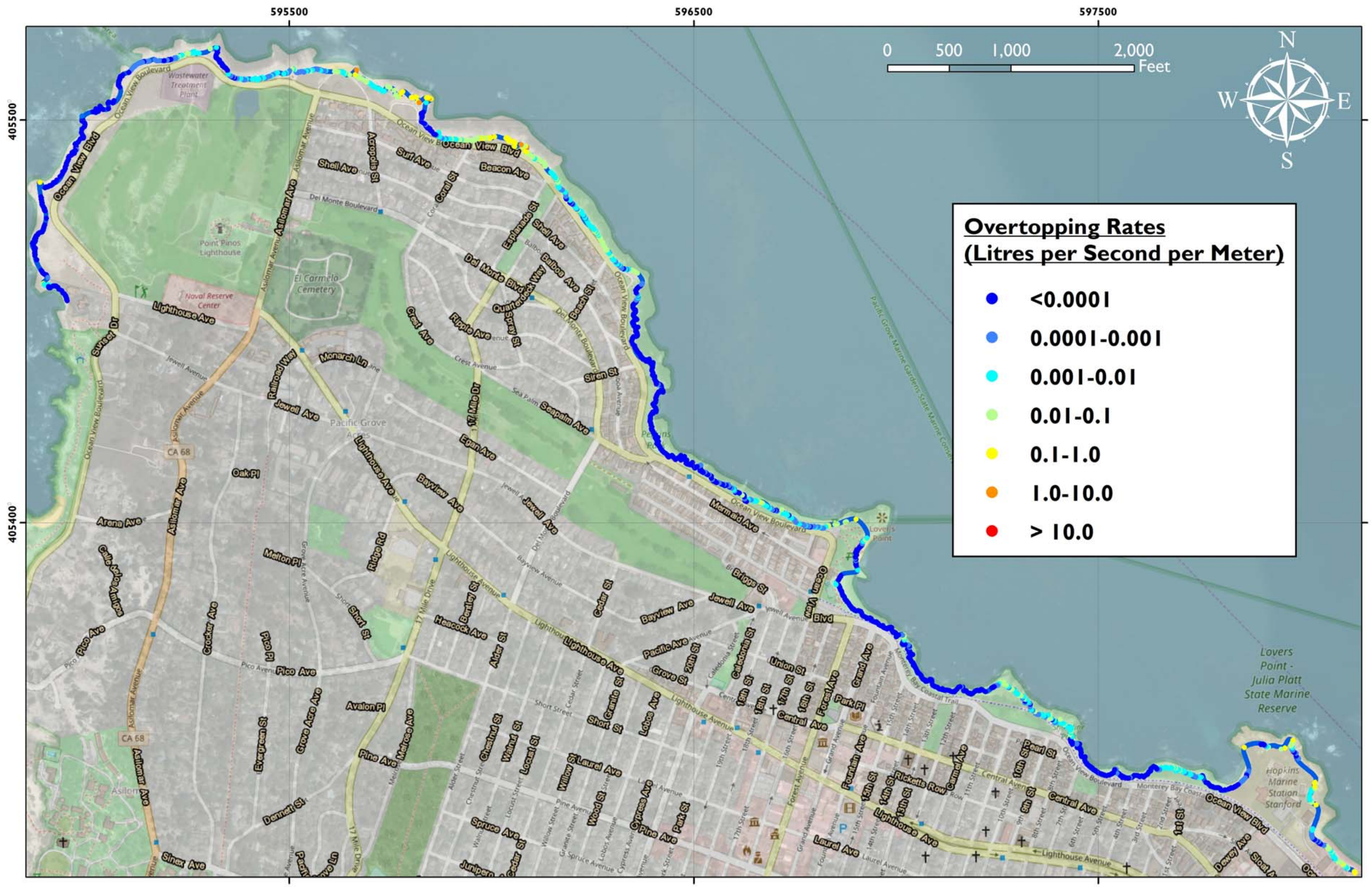


Figure 3-6: Overtopping Rates along Pacific the Grove Shoreline

3.2. Sea Level Rise

In order to consider Sea Level Rise (SLR) impacts on the Pacific Grove shoreline, the medium-high risk aversion SLR scenarios (Table 2-3) were considered. SLR projection values were added to TWL elevations to generate 1% annual flood inundation maps projected for years 2030, 2050, and 2100. Figure 3-7 presents the inundation due to SLR on the project area for the existing conditions for the four SLR scenarios described above.

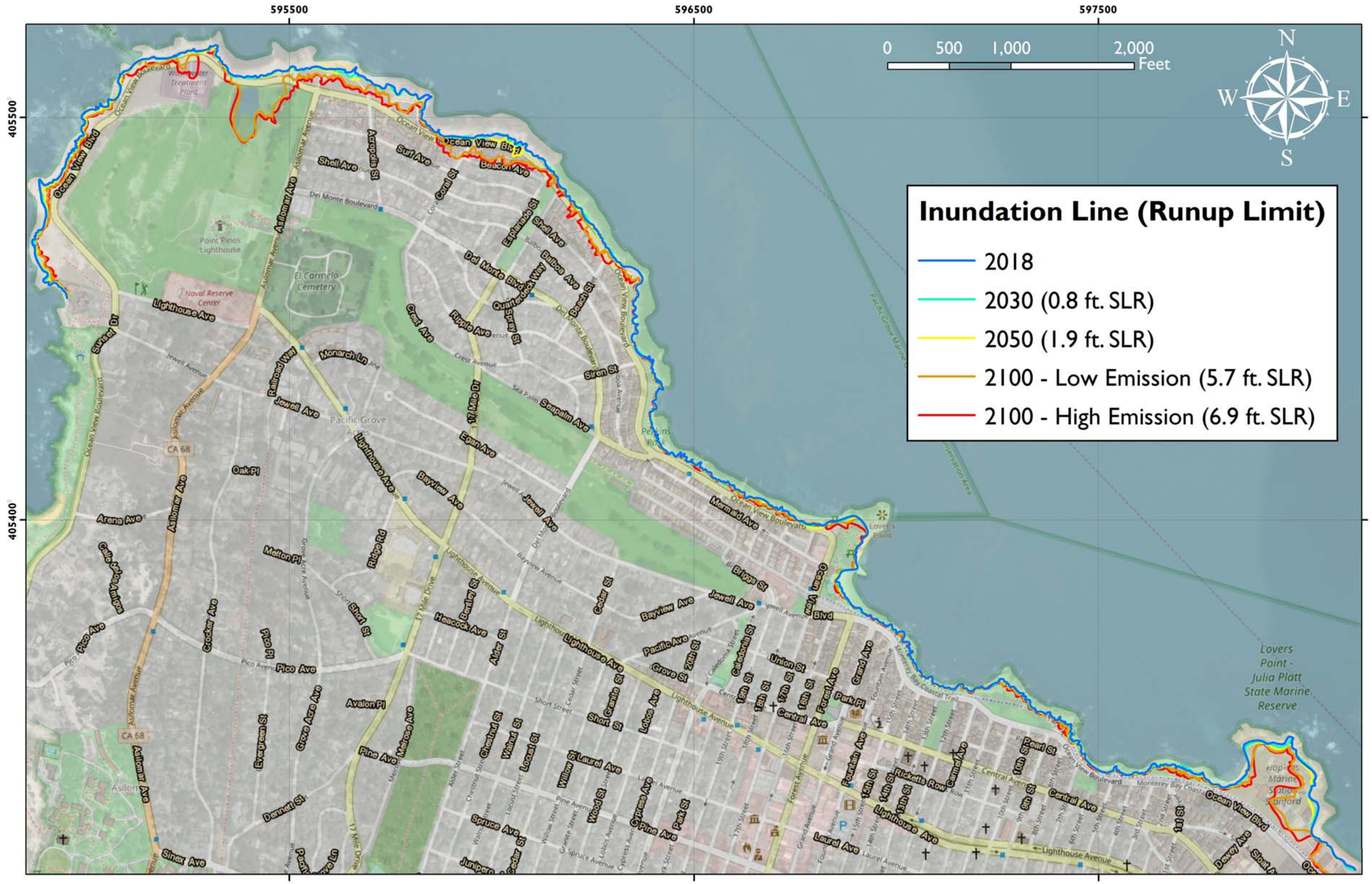


Figure 3-7: 2030, 2050, and 2100 1% Coastal Flood Inundation Limits for Pacific Grove, CA

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