SLR-VA APPENDIX A

Prepared for California State Parks

September 2024

SEACLIFF STATE BEACH AND NEW BRIGHTON STATE BEACH

Coastal Processes

Document Verification

Client	California Department of Parks and Recreation
Project name	Sea Level Rise Vulnerability Assessment and Adaptation Alternatives
Document title	Seacliff State Beach and New Brighton State Beach
Document subtitle	Appendix A: Coastal Processes
Status	Final
Date	September 25, 2024
Project number	9280-N25
File reference	www.seacliffresilience.org

Revision	Description	Issued by	Date	Checked
2	Final	M. Jorgensen J. Garibay	September 25, 2024	R. Dornhelm

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List of Acronyms

ADA	Americans with Disabilities Act
AP	Adaptation Plan
CONUS	Continental United States
CO-OPS	Center for Operational Oceanographic Products and Services
CoSMoS	{USGS} Coastal Storm Modeling System
CSMP	California Seafloor Mapping Program
CF	cubic feet
CY	Cubic Yards
Fm	{Geologic} Formation
ft	feet
g	gravitational acceleration
GPS	Global Position System
GW	Groundwater
I/O	Input/Output
in	inches
M&N	Moffatt & Nichol
Max.	Maximum
MRLC	Multi-Resolution Land Characteristics Consortium
n/a	not available
NAVD88	North American Vertical Datum of 1988
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
OCOF	Our Coast, Our Future
ONI	Oceanic Niño Index
RV	Recreational Vehicle
s	seconds
SB	State Beach
SD	Standard Deviation
SLR	Sea Level Rise
sq.mi	square miles
SS	Steamship
USGS	United States Geological Survey
VA	Vulnerability Assessment
VLM	Vertical Land Motion
yr	year

Executive Summary

This report provides a site characterization of Seacliff and New Brighton State Beaches (SB), as well as an assessment of coastal processes and geomorphology in Monterey Bay. This information formed the basis for the coastal hazards and sea level rise vulnerability assessment for California Department of Parks and Recreation (Parks) assets and resources.

Subareas at Seacliff SB and New Brighton SB situated at the base of the cliff are located within the elevation range from 0 to 20’ NAVD88 and are exposed to coastal hazards exacerbated by sea level rise (SLR). This includes the Campground, Day Use area, and Rio Del Mar at Seacliff SB, and New Brighton State Beach and Potbelly Beach at New Brighton SB.

Areas located at the clifftop at elevations ranging from 95 to 150’ NAVD88 are exposed to cliff retreat. This primarily concerns areas along the cliff edge at the Upper Lot at Seacliff SB, and at the Campground and Porter-Sesnon at New Brighton SB.

Land use in areas exposed to coastal processes includes low, medium, and high-density development with open space interspersed with evergreen forest, mixed forest, scrub, and grasslands with areas of wooded wetlands and emergent herbaceous wetlands.

The beaches at Seacliff SB and New Brighton SB are important natural resources and recreational attractions to the public. The beaches consist of medium to fine sand with a foreshore slope of about 20H:1V.

The dry beach width at Seacliff SB can range annually from 30 to 190 feet. The beach width varies seasonally with the widest occurring in July and the narrowest in December and January. At New Brighton SB, the summer beach width can be about 150 feet, whereas the beach can disappear temporarily over the winter months.

The beaches are subject to gradual retreat over time, estimated at 0.9 feet of shoreline retreat per year at Seacliff SB and up to 3 feet per year at New Brighton SB.

Wave conditions in Monterey Bay vary seasonally and include North Pacific swell, Southern swell, Northwest wind waves, and local wind waves. Swell waves arrive from distant storm systems over the Pacific whereas wind waves are associated with local forcing and the passage of storm systems. Swell waves often deposit sand on the beach, while storm waves typically contribute to beach erosion. It is estimated that annual winter storms can reduce the beach width by about 26 feet whereas beach loss associated with 25-year storms and higher can be on the order of 100 feet.

Wave action also drives sediment transport along the shoreline, predominantly southward. The transport rate is estimated at about 265,000 cubic yards of sand per year on average.

The average rate of cliff retreat at Seacliff SB and New Brighton SB associated with surface runoff and weathering is about 8 inches per year. The average rate of retreat associated with SLR and associated wave-erosion at the base of the cliff is about 12 feet for every foot of SLR at Seacliff SB, and about 10 feet for every foot of SLR at New Brighton SB.

Cliff retreat, shoreline retreat, and coastal processes dominated by wave forcing are exacerbated by SLR.

1. Site Characterization

1.1. Seacliff and New Brighton SB Park Units

Figure 1-1 shows the location of Seacliff State Beach (SB) and New Brighton SB at the northern end of Monterey Bay. The area is sheltered from northwesterly waves behind the Santa Cruz promontory but exposed to waves from westerly to southerly directions.

Seacliff SB includes a Campground, Day Use area, Upper Lot and Rio Del Mar offering spectacular views of Monterey Bay and two miles of sandy beach. Popular recreational activities include hiking, biking, beach combing, sunbathing, fishing, surfing, swimming, kayaking, whale watching and wildlife viewing. Amenities include a visitor center, BBQ grills and fire pits, campfire center, picnic tables, concession stand, electrical hookups, restroom and shower facilities.

New Brighton SB includes a campground, beach day use area, and the Porter-Sesnon Property fronted by Potbelly Beach, featuring clifftop campground facilities, nature trails, and beach overlooking Monterey Bay and Soquel Cove. Popular recreational include picnicking, walking, hiking, biking, beach combing, photography, painting, fishing, kayaking, snorkeling, surfing, swimming, whale watching, and wildlife viewing. Amenities include a visitor center, BBQ grills and fire pits, a camp store, picnic tables, group camping, RV dump station, electrical hookup, ramada, restroom and shower facilities.

Table 1-1 summarizes acreages for the SB subareas and elevation range. Refer to Figure 1-2 and Figure 1-3 for the subarea locations. The subareas can be divided into facilities located at the base of the cliff, typical elevation range from 0 to 20’ between mean sea level and the base of the cliff. Clifftop facilities are at a typical elevation range from 95 to 150’ NAVD88.

Table 1-1: Seacliff SB and New Brighton SB subareas.

State Beach Areas	Subareas	Acreage (ac)	Elevation Range (feet NAVD88)
Seacliff SB	Campground	11.2	0 – 20’
	Day Use	14.1	0 – 20’
	Upper Lot	9.1	95 – 108’
	Rio Del Mar	28.0	0 – 15’
New Brighton SB	Campground	77.7	20 – 150’
	New Brighton State Beach	2.6	0 – 17’
	Porter-Sesnon	70.9	20 – 150’
	Potbelly Beach	1.9	0 – 20’

The following sections provide information to characterize the sites in terms of their topography, bathymetry, geology, oceanography, coastal geomorphology and land use.

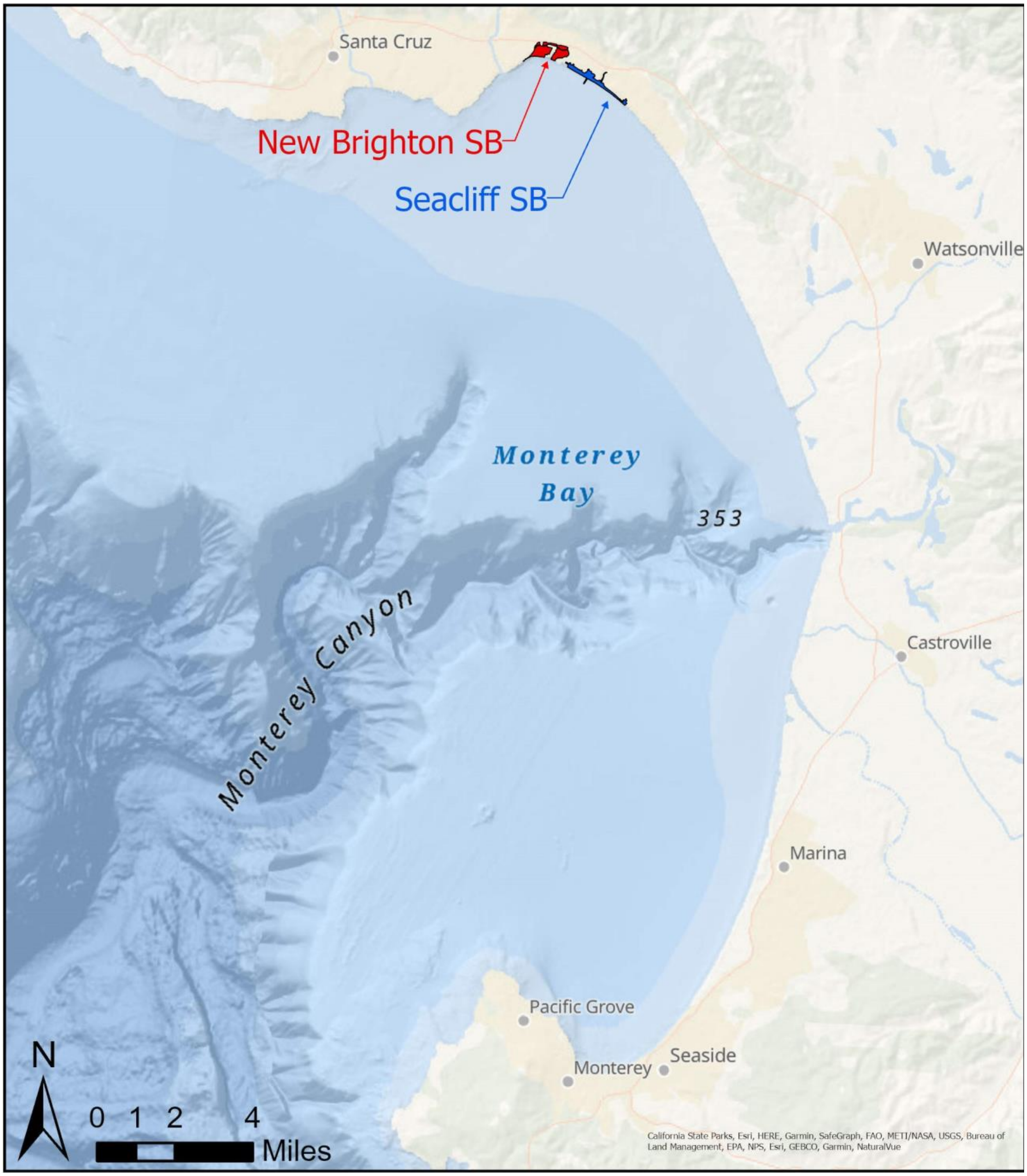

Figure 1-1: Location of Seacliff SB and New Brighton SB.

Figure 1-2: Seacliff SB subareas.

Figure 1-3: New Brighton SB subareas.

1.2. Topography

The majority of Seacliff State Beach and New Brighton State Beach topography is characterized by a sandy beach backed by a tall cliff. The cliff consists of material uplifted by tectonic activity[1], with the base of the cliff consisting of a wave-cut marine terrace in the Purisima Formation overlain by unconsolidated Pleistocene terrace deposits. A 70 to 280 ft wide beach exists at the base of the cliff. The height and width[2] of the beach varies seasonally but is essentially dependent on the level of wave exposure, wave runup and sand supply.

Refer to Figure 1-4 and Figure 1-5 for plates showing elevation contours. Purple lines indicate elevation contours on the seabed, dark blue denotes elevations on the beach up to about El. +20 feet NAVD88. Contour lines in green to yellow are representative of the area at the clifftop. The densely spaced contours in between, ranging from dark blue to green, are representative of the cliff face. Spurs pointing inland from the cliff face at Seacliff SB indicate the locations of ravines, and at New Brighton SB, the locations of Borregas Creek and Old Woman Creek outlets at Potbelly Beach, and Tannery Gulch by the parking lot at the north end of the beach.

Table 1-2 summarizes topographic data for the cliff and beach areas. The slope of the cliff face typically ranges from about 40 to 60° to the horizontal. Slopes of about 30° or flatter may be indicative of the natural angle of repose of loose granular material, typically seen in the talus formations at the base of the cliff, which consist of material from slumps and rockfalls. Similar slopes are seen in some locations along the cliff top where failures in the upper soil profile have occurred.

Table 1-2: Overview of site topography.

Location	Cliff				Beach	
	Elevation (ft NAVD88)	Slope (°) Horizontal at:			Elevation (ft NAVD88)	Width (feet)
		Cliff Top	Cliff Face	Talus		
Seacliff Campground	+140’	49°	60°	38°	+10.5’	125’
Seacliff Day Use	+100’	25°	55°	30°	+13.3’	170‘
Rio Del Mar	+145’	19°	35°	21°	+15.3’	280’
New Brighton State Beach	+122’	30°	48°	30°	+12.4’	70’
Potbelly Beach	+108	17°	40°	16°	+12.4’	195’

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[1] The movement of tectonic plates or uplift of the Earth's crust due to earthquakes.
[2] Beach elevation refers to the dry beach at the base of the cliff or protective structure where present, and width refers to the dry beach, which roughly extends down to the high tide line.

SEACLIFF STATE BEACH
Aptos, CA
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Figure 1-4: Topography at Seacliff SB.

Sanborn Map Company, Santa Cruz County, Maxar, Microsoft

NEW BRIGHTON STATE BEACH
Capitola, CA
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Figure 1-5: Topography at New Brighton SB.

1.3. Bathymetry

As part of the California Seafloor Mapping Program (CSMP), the United States Geological Survey (USGS) has conducted detailed mapping of Monterey Bay, including the geologic setting, seafloor, Monterey submarine canyon, and Soquel Creek Canyon tributary, USGS (2016). The CSMP was initiated by the California Ocean Protection Council in 2007 with the goal of creating a high-resolution map of the seafloor bathymetry, marine benthic habitats, and shallow subsurface geology.

Figure 1-6 from USGS (2016) shows the physiography of the Monterey Bay region from Pigeon Point to the Monterey peninsula. The yellow line shows the limit of California State Waters. The dashed white lines show traces of the San Gregorio Fault Zone and San Andreas Fault Zone. The red box shows outlines the head of Monterey Canyon.

Elkhorn Slough at Moss Landing discharges sediment from inland areas into the Monterey Canyon, which is one of the largest and deepest submarine canyons in the world, reaching depths of up to 5,000 feet. The submarine canyon divides Monterey Bay into southern and northern littoral cell segments.

Littoral sediment transport northward along Monterey, Sand City, and Ford Ord Dunes disperses into the submarine canyon at Moss Landing. Likewise, southward sand transport along Capitola, New Brighton, Seacliff, Rio Del Mar and Pajaro Dunes disperses into the submarine canyon at Moss Landing.

Sediment mobilized by wave action, currents, and outflow from Elkhorn Slough moves westward and deeper into the submarine canyon via downslope, gravity-driven migration.

The submarine canyon also has an effect on waves entering Monterey Bay. As waves propagate over the canyon, a portion of the wave energy may be reflected off the canyon depending on the wave characteristics. The equations below describe the percentages of reflection, R, and transmission, T from AGU (2005).

$$R = \sqrt{\frac{\gamma}{1+\gamma}} \quad , \qquad T = \sqrt{\frac{1}{1+\gamma}}$$

with

$$\gamma = \left(\frac{h^2k^2 - h_c^2k_c^2}{2hkh_ck_c}\right)^2 sin^2(k_cW)$$

Where R and T are the ratios of reflected and transmitted wave energy, h is the water depth outside the canyon, h_c is the water depth inside the canyon, k and k_c represent the cross-canyon wave number outside and inside the canyon, and W is the width of the canyon.

These equations predict that when waves approach the submarine canyon at an oblique angle, nearly all of the wave energy is reflected. The critical angle, θ, for total reflection can be estimated as:

$$|\theta| = arcsin\left(\sqrt{h/h_c}\right)$$

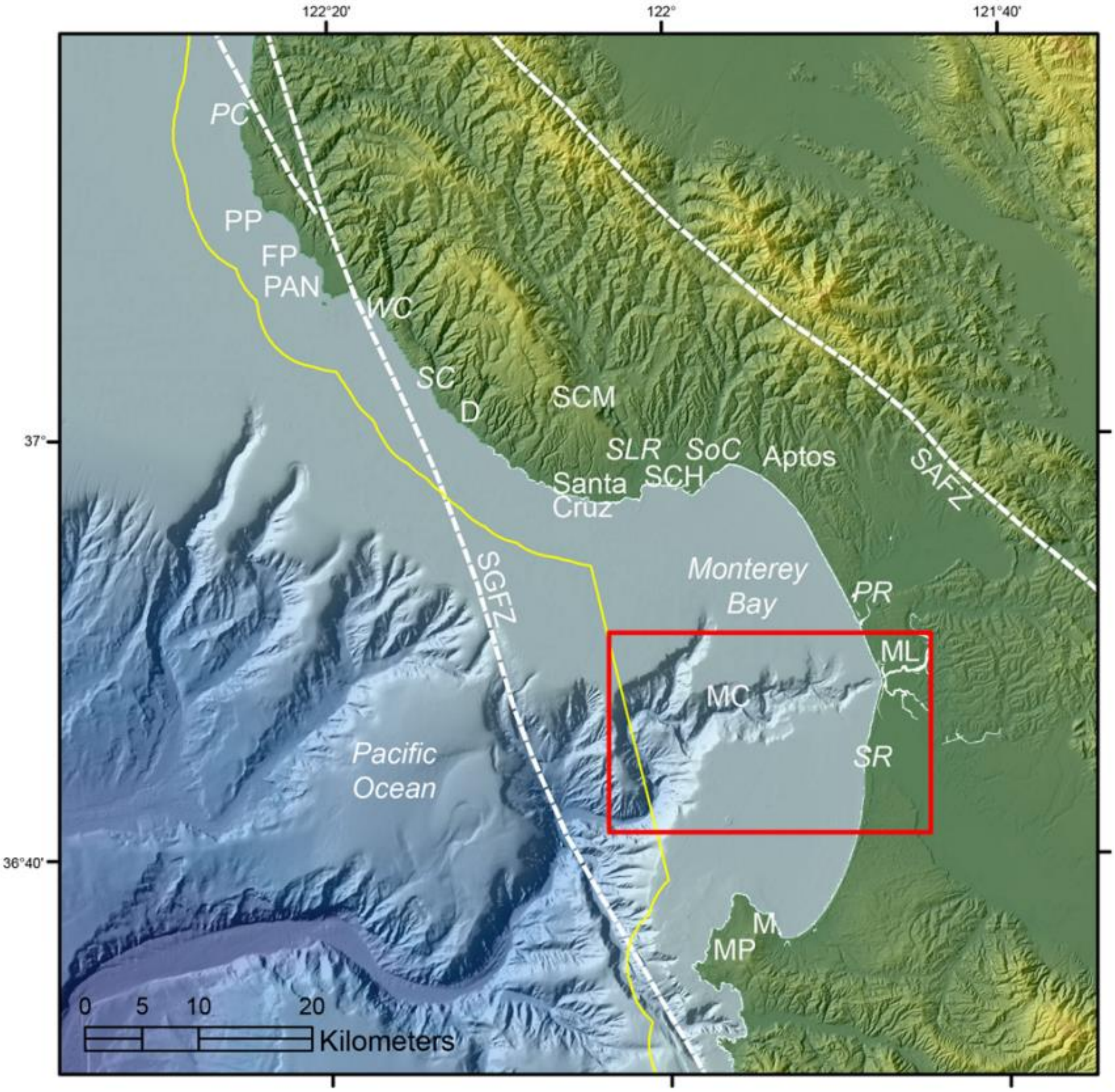
For the Monterey submarine canyon, θ is in the range of 25° to 30°. This means that when waves approach the canyon at angles below this range they will be reflected off the canyon. When waves approach at oblique angles higher than θ there will be components of both reflection and transmission of wave energy across the canyon.

The wave components that are affected can be characterized in terms of water depth and wave period as summarized in Table 1-3. The table summarizes the ratio of water depth to wave length (h/L). Yellow indicates shallow-water waves, which occur when h/L < 0.04. The solid blue color indicates deep water wave conditions when h/L > 0.5. The shading between yellow and blue indicates transitional conditions: 0.04 < h/L < 0.5. In deep water, waves are not affected by the topography of the seafloor and are not subject to wave transformation. As waves enter intermediate water depths, they begin to undergo wave transformation related to changes in water depth. These include depth-refraction, shoaling, depth-limited wave breaking, and reflection and transmission at the submarine canyon.

Table 1-3 shows that over the deeper part of the submarine canyon at water depths from 1,000 to 3,000 feet deep water wave conditions prevail, i.e. the incident waves propagate over the canyon and are not affected by it. In the shallower part of the canyon and near the canyon edge, swell waves transition to intermediate water depths where they become subject to refraction, shoaling, and reflection and transmission. Wind-waves can propagate over the canyon without being affected. As waves propagate into the shallow areas near the shoreline and beach areas, they eventually become subject to shallow-water wave transformation effects including refraction, shoaling and depth-limited wave breaking.

Table 1-3: Influence of water depth on wave characteristics.

Zone	Water Depth (ft)	Wave Period (seconds)									
		Wind-Waves				Swell Waves					
		2	4	6	8	10	12	14	16	18	20
Beach to Intermediate depths	3	0.2	0.1	0.1	0.04	0.03	0.03	0.02	0.02	0.02	0.02
	30	1.5	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.05
	100	4.9	1.2	0.5	0.3	0.2	0.2	0.1	0.1	0.1	0.1
canyon edge	200	9.8	2.4	1.1	0.6	0.4	0.3	0.2	0.2	0.2	0.1
	300	14.6	3.7	1.6	0.9	0.6	0.4	0.3	0.3	0.2	0.2
submarine canyon interior	500	24.4	6.1	2.7	1.5	1.0	0.7	0.5	0.4	0.3	0.3
	1,000	48.8	12.2	5.4	3.1	2.0	1.4	1.0	0.8	0.6	0.5
	2,000	97.6	24.4	10.8	6.1	3.9	2.7	2.0	1.5	1.2	1.0
	3,000	146.5	36.6	16.3	9.2	5.9	4.1	3.0	2.3	1.8	1.5



SGFZ	San Gregorio Fault Zone
SAFZ	San Andreas Fault Zone
D	Davenport
FP	Franklin Point
M	Monterey
MC	Monterey Canyon
ML	Moss Landing
MP	Monterey peninsula
PAN	Point Año Nuevo
PC	Pescadero Creek
PP	Pigeon Point
PR	Pajaro River
SC	Scott Creek
SCH	Santa Cruz Small Craft Harbor
SCM	Santa Cruz Mountains
SLR	San Lorenzo River
SoC	Soquel Creek
SR	Salinas River
WC	Waddell Creek

Figure 1-6: Physiography of Monterey Bay from USGS (2016).

1.4. Land Use & Land Cover

Figure 1-7 provides an overview of the distribution of land cover in the northern part of Monterey Bay, based on Continental United States (CONUS) satellite altimetry data from the National Land Cover Database (NLCD), Multi-Resolution Land Characteristics Consortium, MRLC (2021).

The land cover data shows that Seacliff SB includes areas of developed open space, and medium to high density development. The New Brighton SB area classifies as developed open space interspersed with evergreen forest and isolated areas of wooded wetlands and low to medium density development. The Porter-Sesnon area consists of mixed forest, evergreen forest, scrub, and grasslands with isolated areas of emergent herbaceous wetlands.

The distribution of natural resources was assessed based on the Santa Cruz and Santa Clara Fine Scale Vegetation Map, Tukman (2023). The fine-scale vegetation map identifies 121 classes of vegetation communities and agricultural land cover types, including forests, grasslands, riparian vegetation, wetlands, and croplands.

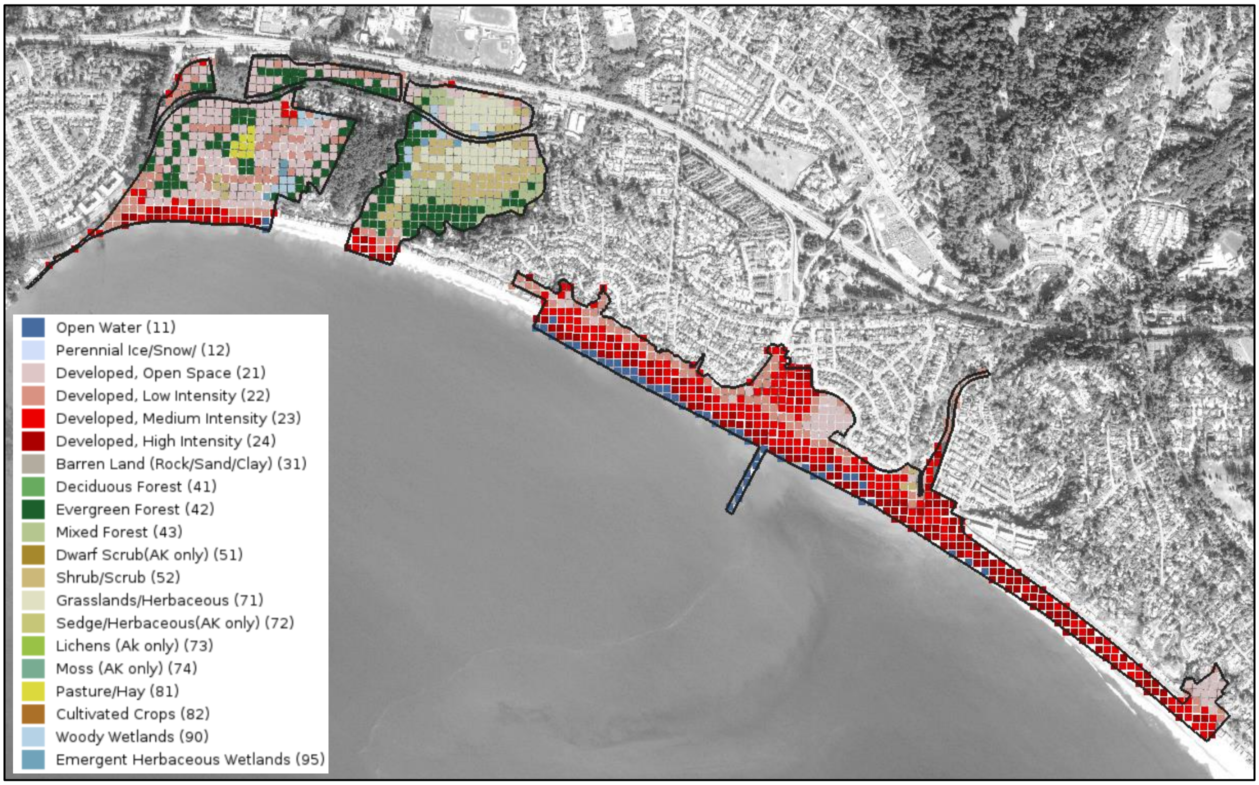


Figure 1-7: NLCD CONUS Land cover, MRLC (2021).

1.5. Groundwater Levels

Groundwater level data was obtained from California Department of Water Resources, DWR (2023). Figure 1-8 identifies well locations along Monterey Bay and inland areas.

Groundwater levels can fluctuate based on water consumption drawn from wells, climatic conditions such as prolonged drought and wet years with above-normal precipitation, and SLR.

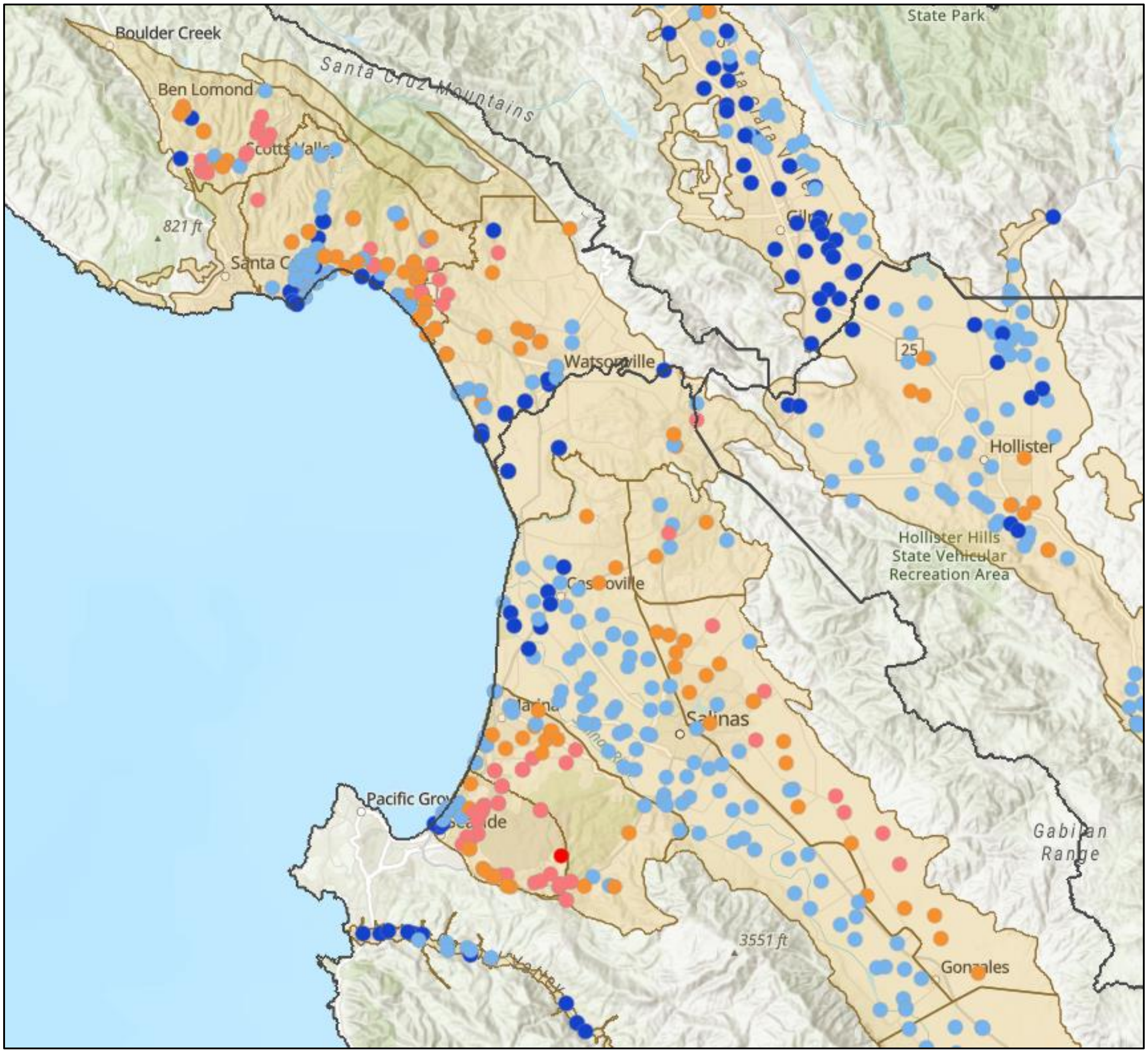


Figure 1-8: Groundwater monitoring wells, DWR (2023).

Based on the DWR (2023) well data, Table 1-4 summarizes groundwater levels at Seacliff SB and New Brighton SB inland areas, at the base of the cliff and on the beach. At the shoreline, the groundwater elevation varies with the tide, and over the beach can be approximated by the Mean High Water (MHW) tide level.

Table 1-4: Groundwater levels at Seacliff SB and New Brighton SB, DWR (2023).

Location	Elevation (feet NAVD88)	Source
Inland	+18.0’	DWR (2023)
Base of cliff	+12.0’	
Beach	+4.8’	MHW, NOAA (2023)

1.6. Coastal Geomorphology

Coastal geomorphology is the study of morphological changes of the coast under the influence of coastal processes. The following sections provide information on the geology at Seacliff SB and New Brighton SB and beach characteristics.

1.6.1. Geology

The geologic formation at Seacliff SB and New Brighton SB consists of the Purisima Formation. The extent of the formation is indicated in Figure 1-9 from Boessenecker (2013). Outcrops of the Purisima Formation can be found as far north as Point Reyes to more extensive exposures in the Santa Cruz Mountains, Powell et al. (2007). The southernmost extent is around San Juan Bautista, CA.

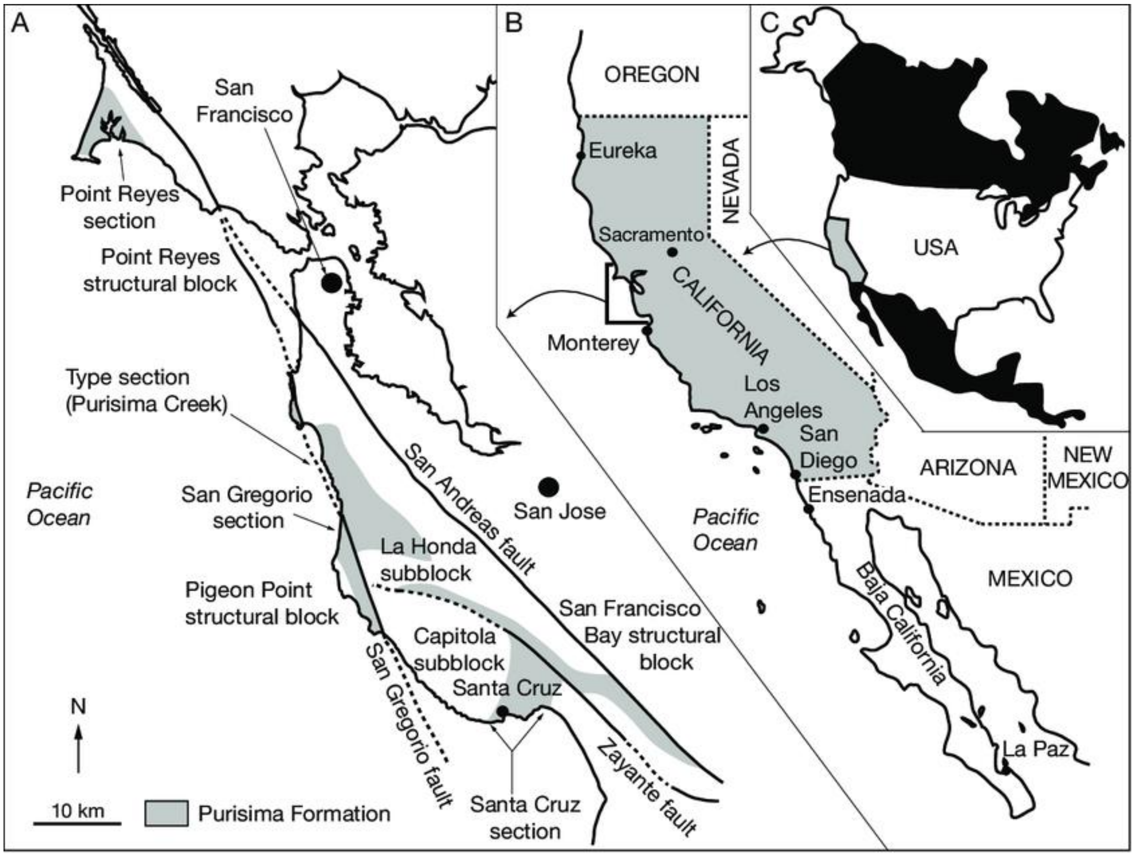


Figure 1-9: Geologic map of the Purisima Formation, Boessenecker (2013).

The Purisima Formation contains fossils dating from the Late Miocene to Late Pliocene, ranging from 3 to 7 million years ago. Fossil species found in the Purisima Formation include species of invertebrate fossils, mollusks, cetaceans and pinnipeds (whales and seals). Lenses of shell hash deposits in the Purisima Formation form resistant ledges that are visible throughout the exposed face of the cliff.

Figure 1-10 shows a detailed geologic map for Northern Monterey Bay from USGS (2002), which identifies the Purisima Formation (Ppu) overlain by marine terrace deposits (Qmt) and terrace deposits (Qt). The seabed is composed of marine sediments (Qms) with large outcrops of Purisima Formation (Ppu).

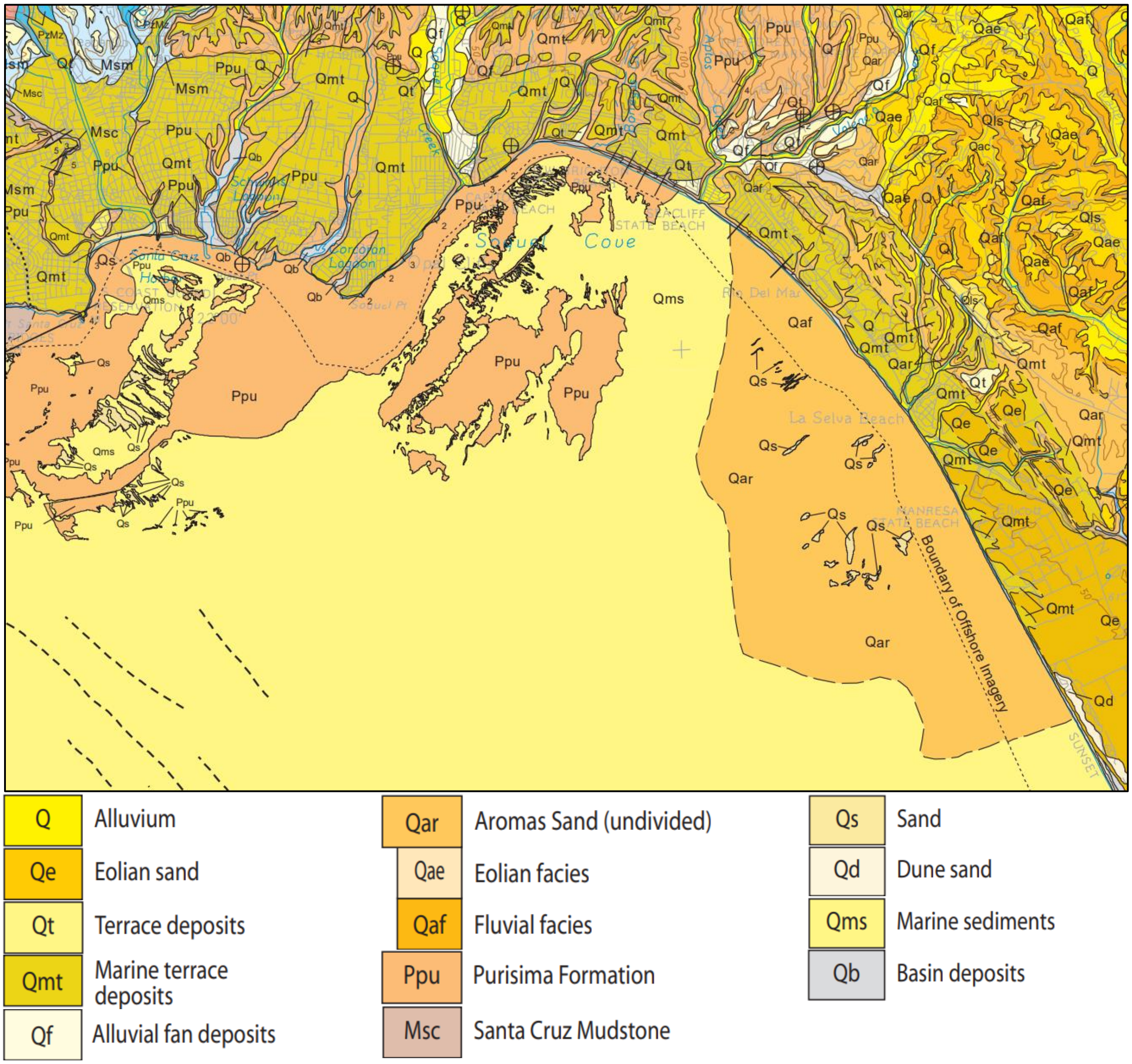


Figure 1-10: Geologic map of Northern Monterey Bay, excerpt from USGS (2002).

1.6.2. Coastal Cliff Formations

The cliff at Seacliff SB consists of 20 to 40 feet of marine terrace beach deposits consisting of poorly consolidated sand and gravel overlying the Purisima Formation, which consists of sandstone, siltstone, conglomerates, and phosphorite. Figure 1-11 shows a block diagram of the composition of the cliff from Hapke (2002).

The upper portion of the cliff face is steep, with a milder slope at the base where debris fans have occurred. The debris fans are covered with vegetation except where debris flow channels or localized failures have occurred. The top edge of the cliff is showing signs of active erosion with linear to cuspate scars where rills, slumps or debris flows have initiated, Hapke (2002).

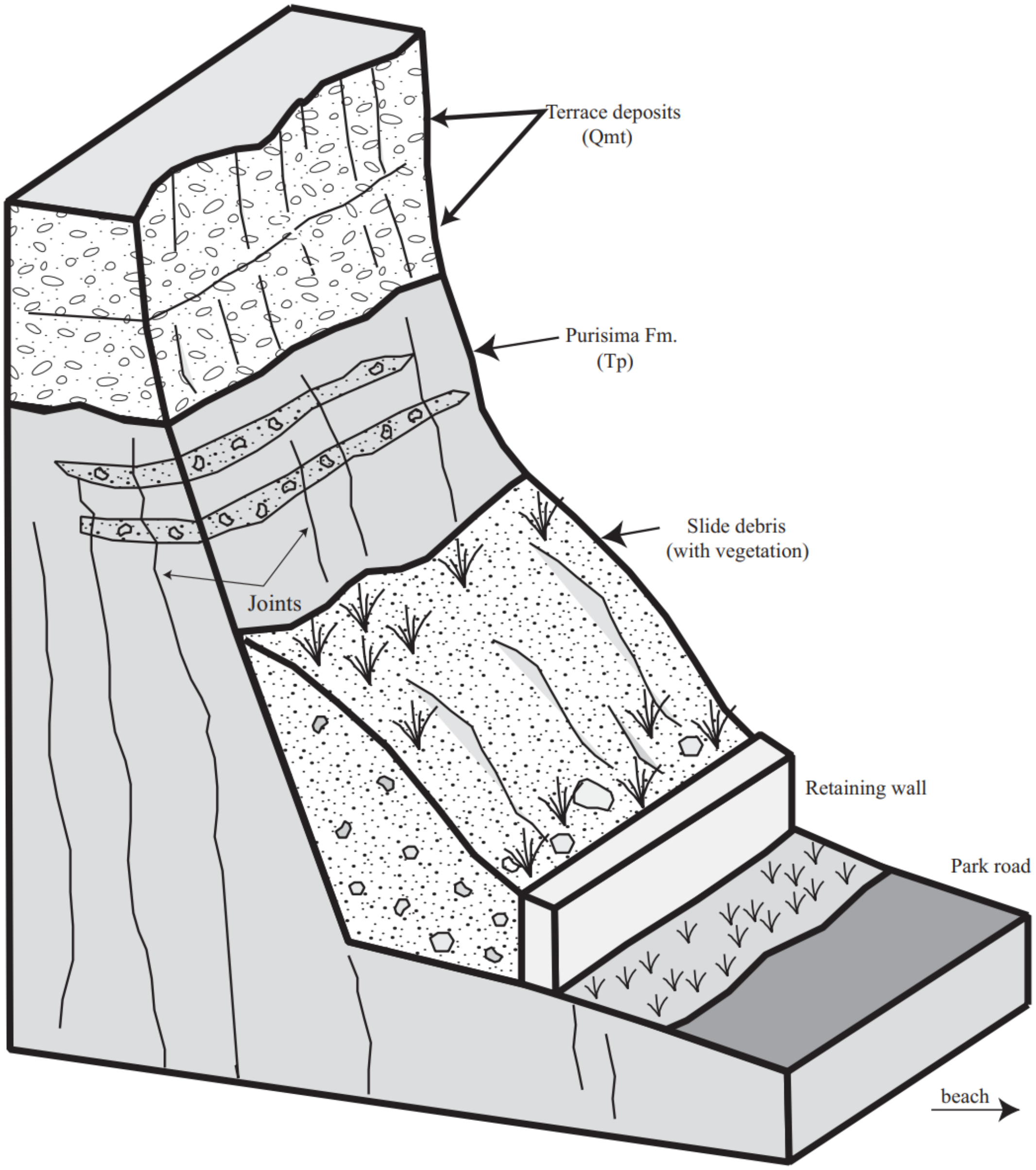


Figure 1-11: Block diagram of typical cliff section at Seacliff State Beach, Hapke (2002).

The portion of the Purisima Formation between Santa Cruz and Rio Del Mar is termed the Santa Cruz Structural Block. This tectonic block is bounded by the San Andreas and Pilarcitos Faults to the northeast and by the San Gregorio Fault to the southwest. The cliff along Seacliff State Beach and New Brighton State Beach is part of the Capitola subblock that was uplifted between 60,000 and 120,000 years ago. The top of the cliff is an indication of the approximate elevation of the paleo (ancient) stand of sea level.

1.6.3. Seismic Activity

The most recent large seismic event that impacted the Seacliff SB and New Brighton SB area was the 1989 Loma Prieta, magnitude 7.1 earthquake, which caused widespread damage in the area from Santa Cruz to San Francisco Bay. Peak horizontal accelerations in the vicinity of the coastal cliffs were estimated to be on the order of 0.47 g to 0.64 g and vertical acceleration 0.40 g to 0.66 g, Hapke (2002).

The earthquake caused abundant coastal cliff landslides in the northern part of Monterey Bay, Griggs & Plant (1990). Several million dollars in damage were attributed to the landslides. The seismic shaking caused loose surficial material to break free and cascade downslope, resulting in a continuous cloud of dust observed along the coastline. There is not much detailed evidence of earlier earthquakes in the historical record, but the indication is that deep-seated or large-scale landsliding or slumping does not appear to have been common, Griggs & Plant (1990).

Cliff failures observed in Northern Monterey Bay were closely tied to the lithologies[3] of the cliff-forming materials. Three types of slides were observed in the region: 1) block falls in well-consolidated sedimentary rocks, 2) translational slides in more friable sandstone, and 3) sand flows in Quaternary dune deposits. The primary failure mode at Seacliff State Beach and New Brighton State Beach was translational failures, which produces many large 100 to 200 ft wide concave upward scarps in the upper 40 to 50 ft of the cliff. Tension cracks extending up to 20 ft inland from the scarps were observed. Talus piles up to 40 ft high were observed along the base of the cliff, Figure 1-12 (left). It should be noted that when the base of the talus piles is subsequently cleared, the remaining piles have a slope the reflects the natural angle of repose of the material. This can mean that there is no factor of safety in terms of the stability of the material and it may be subject to further sliding or slumping. However, over time, vegetation tends to take root in the debris slides and their root systems may to some extent aid in keeping the material together.

In the lower 33 ft of the cliff, fracturing along intersecting blocks undercut the sandstone, dislodging blocks up to 3 ft thick and 10 ft long, Figure 1-12 (right).

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[3] Physical characteristics including material type, color, texture, grain size and composition.

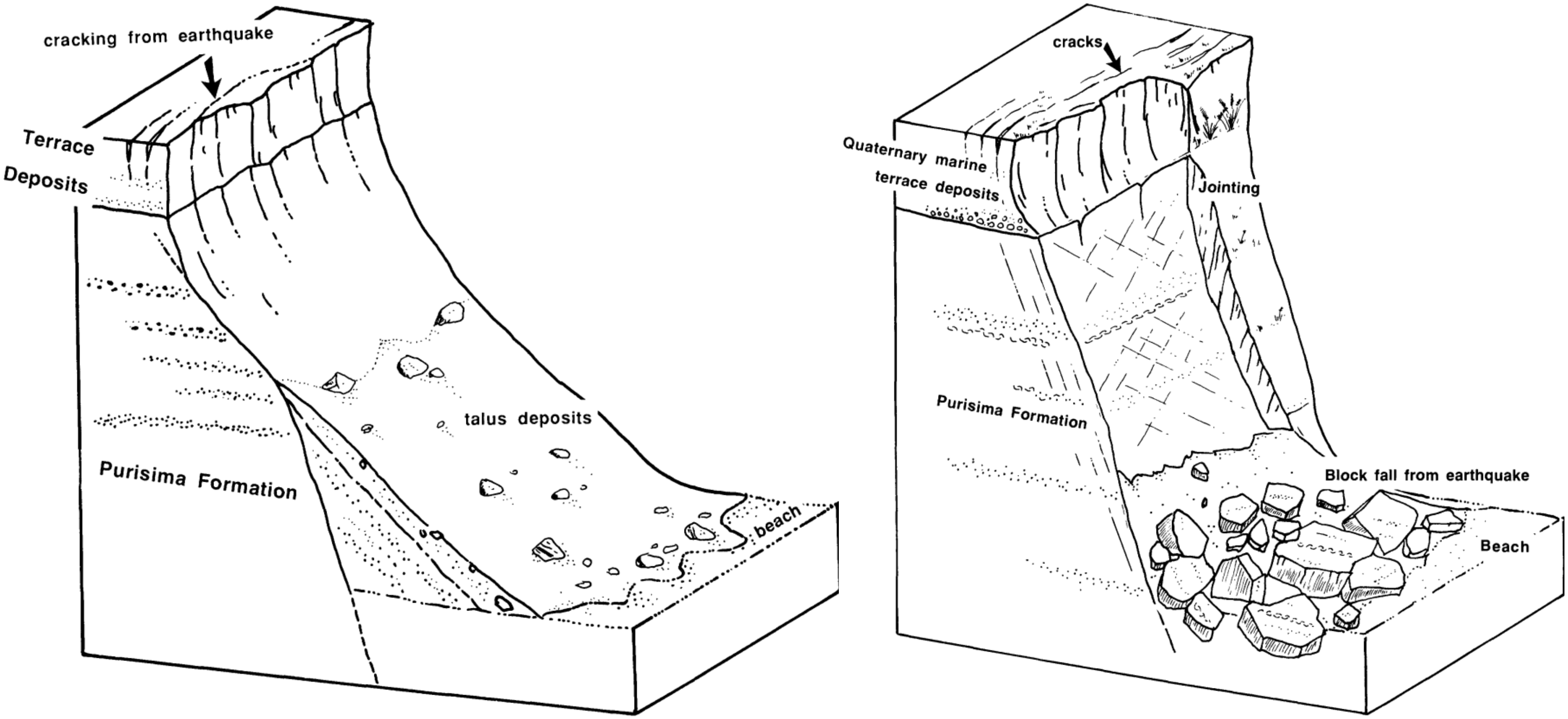


Figure 1-12: Block diagrams of seismically induced debris slides (left) and rockfalls (right), Griggs & Plant (1990).

1.6.4. Beach Width

Beach width was logged based on Google Earth aerial imagery from 1993 to present. The results are summarized in Figure 1-13 and Figure 1-14. Note that the results indicated for January are not well supported as available aerial imagery is limited for that time frame.

The results for Seacliff State Beach (Figure 1-13) indicate that the dry beach width can range annually from around 30 to 190 feet. The dry beach width by month can vary by 40 to 90 feet taken as the difference between the maximum and minimum width. A gradual transition between a summer and winter beach profile is evident, with the widest beach occurring in July and the narrowest in December/January.

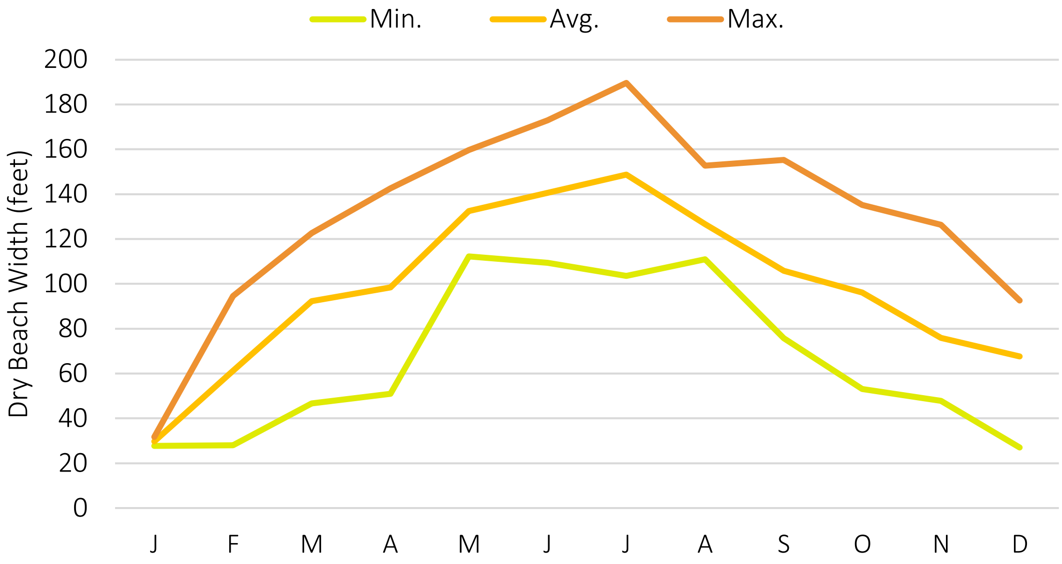


Figure 1-13: Beach width at Seacliff State Beach.

The annual variation of the dry beach width at New Brighton State Beach is shown in Figure 1-14. The dry beach width at this location is generally narrower than at Seacliff State Beach. The width of the beach may fluctuate by 50 to 90 feet month to month and may disappear temporarily at times over the winter months when wave runup reaches the toe of the rock revetment.

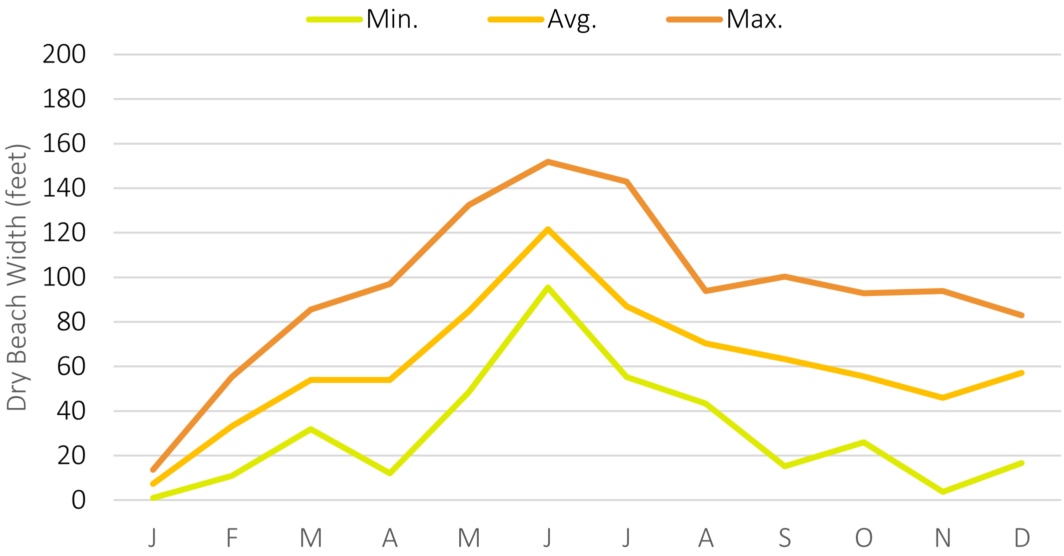


Figure 1-14: Dry beach width at New Brighton State Beach.

Historical Beach Width

Figure 1-15 shows the variation of the dry beach width over time at Seacliff State Beach based on available aerial imagery. The dry beach width is the distance between the mean high water line and the landward seawall, bluff toe, or vegetation line.

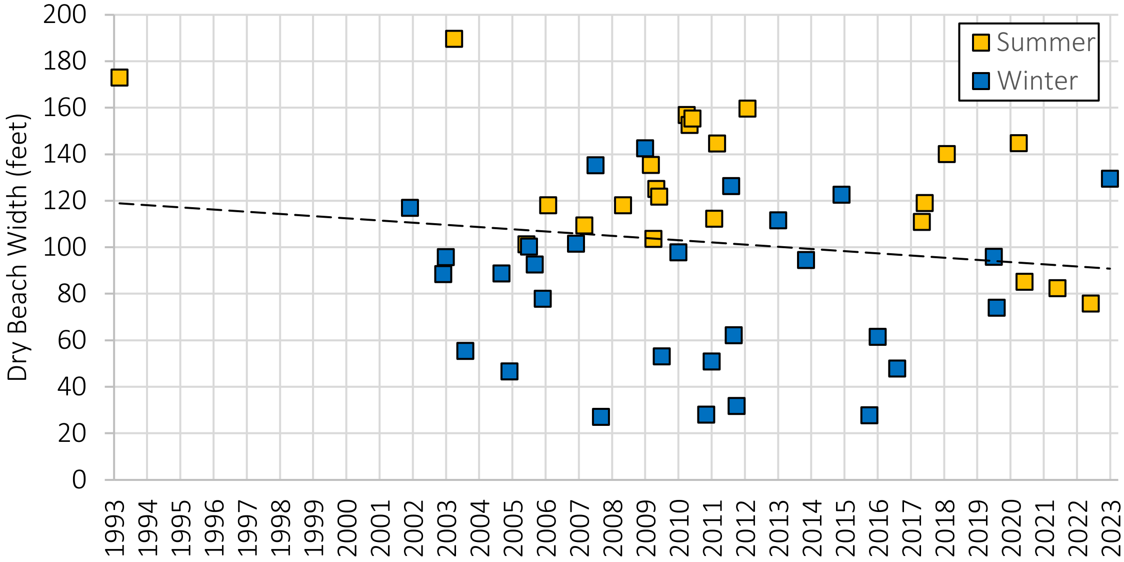


Figure 1-15: Dry beach width at Seacliff State Beach based on historical aerial imagery.

The dashed black trend line in the figure indicates an average rate of shoreline retreat of 0.9 feet per year.

Figure 1-16 shows similar data for New Brighton State Beach. The yellow orange boxes indicate the variation of the dry beach width over time. The data shows that the dry beach width can range from around 140 feet to just a few feet, and at times disappears completely. The dashed black trend line indicates an average rate of shoreline retreat of 3 feet per year.

Figure 1-16: Dry beach width at New Brighton State Beach based on historical aerial imagery.

1.6.5. Beach Slope

Figure 1-17 presents the relationship between beach slope and sediment grain size for California beaches, based on Komar (1998). Data for Monterey is indicated at 1:40 slope and grain size approximately 0.23 mm, categorizing the beach as exposed to moderately protected. This data point is representative of the beaches along the southern part of Monterey Bay, which is partially protected from waves from southerly to southwesterly directions by the Monterey promontory. The central bay is more directly exposed to waves from westerly directions. The New Brighton and Seacliff shoreline areas are partially protected from northwesterly waves. Data representative of this area is indicated by the red diamond symbol in the figure, categorizing the beach area as moderately protected. Refer to Section 1.6.6 for sediment characterization.

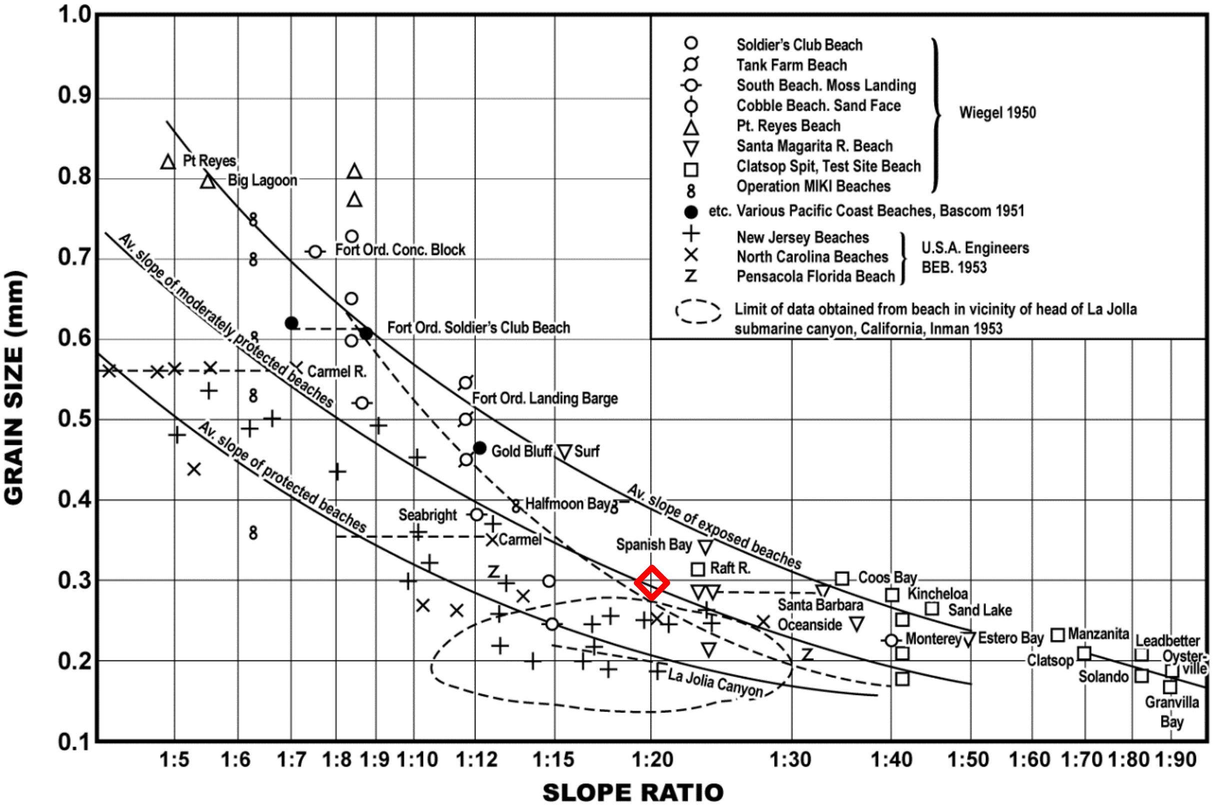
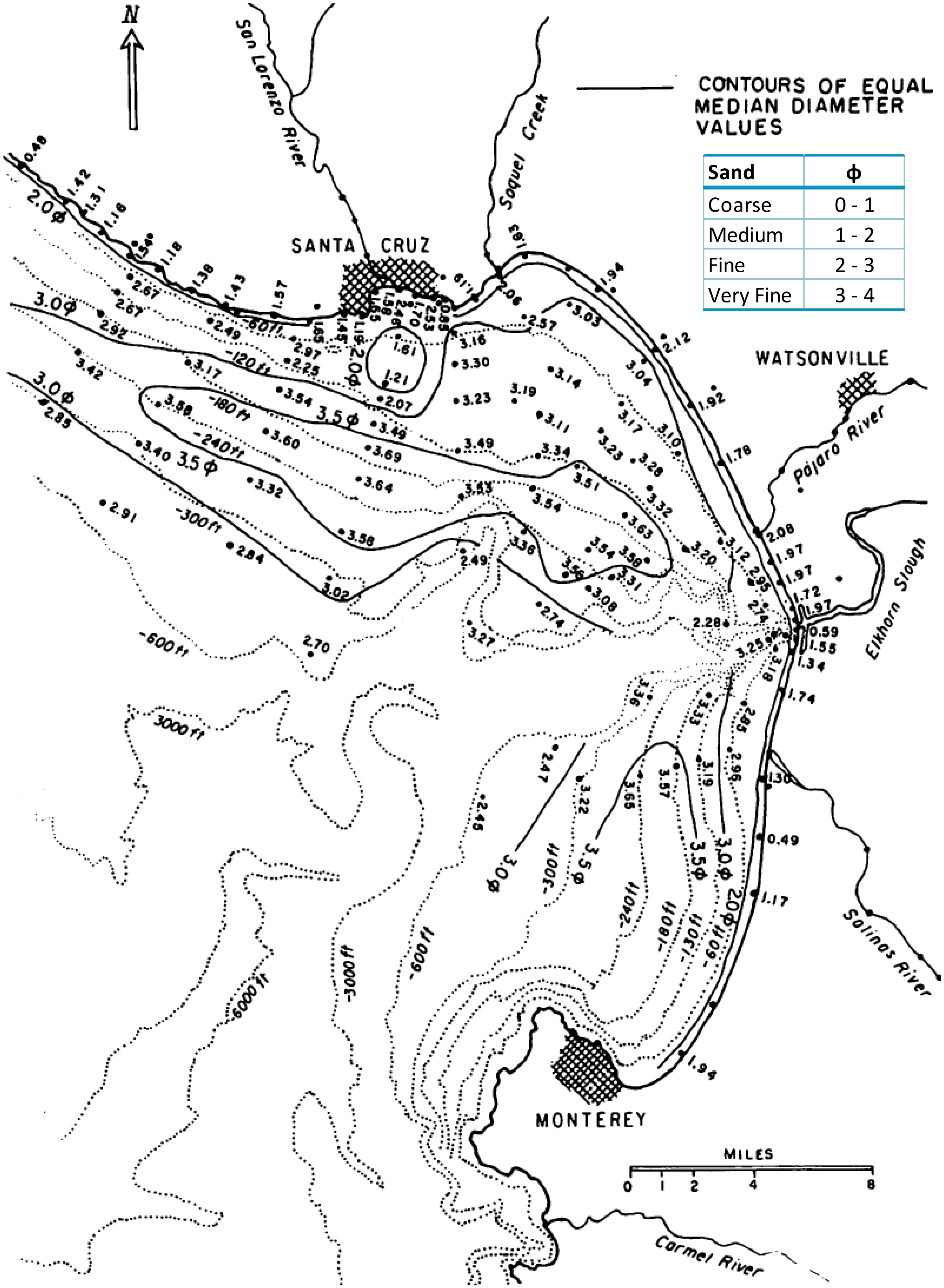


Figure 1-17: Beach slope as a function of grain size, adopted from Komar (1998).

1.6.6. Beach Sediment

Several studies have analyzed and characterized the composition of marine sediments in Monterey Bay. Yancey (1968) evaluated sediment samples in Monterey Bay taken from the shoreline and the seafloor out to the submarine canyon. Figure 1-18 indicates the locations where sediment samples were taken.



Sand	ϕ
Coarse	0 - 1
Medium	1 - 2
Fine	2 - 3
Very Fine	3 - 4

Figure 1-18: Median diameter in Phi () units of the sand (>62 µ) fraction of beach and marine samples.

Sediment diameters reported for New Brighton and Seacliff and adjoining shoreline areas are summarized in Table 1-5. In the table, nearshore refers to shallow water areas along the shoreline, closure depth refers to the seaward limit of the active littoral zone (approximately 48-ft depth). Inshore of this limit, wave action and longshore currents mobilize and actively transport sediment across and along the beach. On the seafloor seaward of this limit, sediment movement is limited.

Table 1-5: North Monterey Bay sediment characterization, Yancey (1968).

Median Diameter (mm) of Sand Fraction of Beach and Marine Samples						
Location	**New Brighton**	**Seacliff**	**Rio Del Mar**	**Manresa**	**Sunset**	**Moss Landing**
Beach	0.32	0.29	0.26	0.23	0.29	0.30
Nearshore	0.24	0.24	0.12	0.12	0.24	0.15
Closure depth	0.17	0.17	0.11	0.11	0.12	0.11
Deeper seafloor	0.11	0.11	0.12	0.11	0.08	0.11
Submarine canyon edge	0.09	0.09	0.09	0.10	0.12	0.21

Based on the Wentworth grain size classification chart provided in Figure 1-19, Wentworth (1922), the data summarized in Figure 1-18 indicates that the sediment on the beach consists of medium sand, fine sand in the nearshore region, transitioning to very find sand over the deeper seafloor out to the submarine canyon edge.

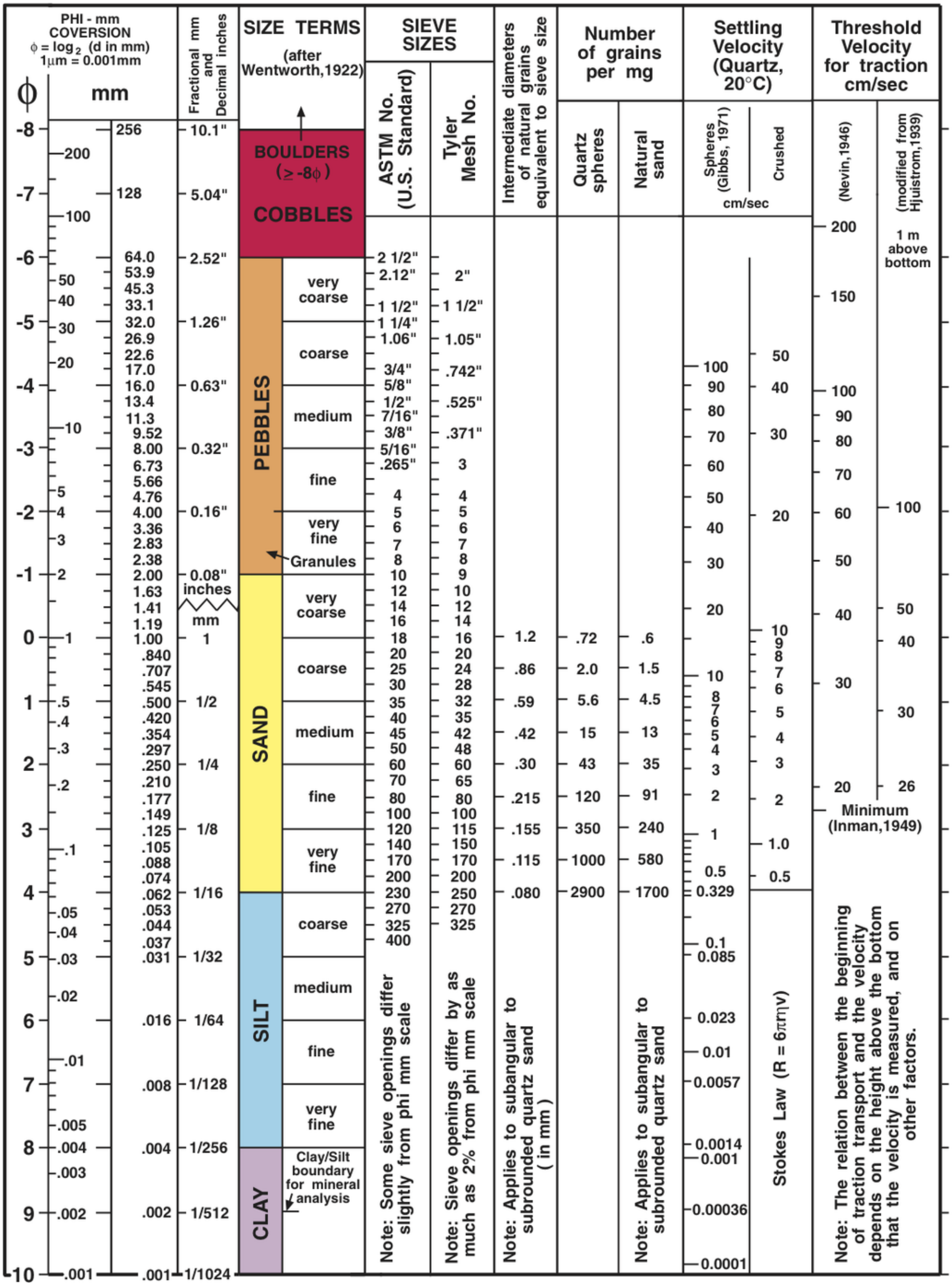


Figure 1-19: Grain size classification chart, Wentworth (1922).

1.7. Oceanography

Oceanography involves the study of the physical conditions and physical processes of the ocean, including tides, water level extremes, El Niño, and waves as described in the following.

1.7.1. Tides & Water Level Extremes

The tidal variation on the California Coast can be categorized as a mixed semi-diurnal tide, which has two unequal highs and lows each tidal day as depicted in Figure 1-20.

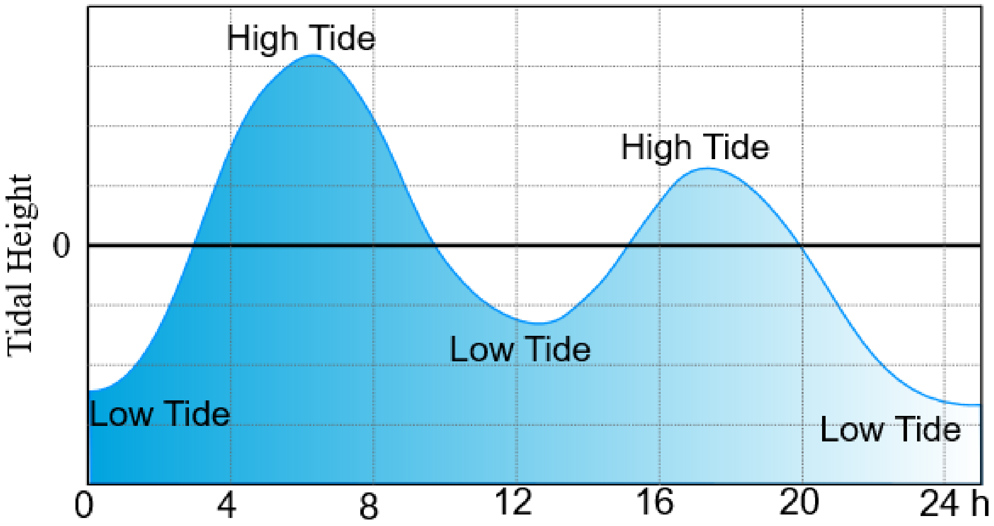


Figure 1-20: Typical daily tidal progression for mixed semi-diurnal tides.

Table 1-6 summarizes tidal datums at Monterey, NOAA station 9413450.

The highest tide level projected over the 19-year cycle referred to as a tidal epoch is labeled the Highest Astronomical Tide (HAT). The Lowest Astronomical Tide over an epoch is defined as LAT. The central portion of the table from HAT to LAT is representative of astronomical tidal variations governed by the movement of the moon and the earth in relation to the sun.

Table 1-6: Tidal datums at Monterey, NOAA (2023).

Datum	ft NAVD88	Comments
HAT	+7.21	Highest Astronomical Tide
KT	+7.04	King tide
MHHW	+5.48	Mean Higher High Water
MHW	+4.78	Mean High Water
MSL	+2.97	Mean Sea Level
MLW	+1.23	Mean Low Water
MLLW	+0.14	Mean Lower Low Water
NAVD88	0.00	North American Vertical Datum of 1988
LAT	-1.80	Lowest Astronomical Tide

The tides vary around the Mean Sea Level (MSL). The average height of all high tides is termed Mean High Water (MHW), while the average of all low tides is defined as Mean Low Water (MLW). The average height of the daily higher tides is termed Mean Higher High Water (MHHW) and similarly for the average of daily lower tides defined as Mean Lower Low Water (MLLW). The highest and lowest tides annually typically occur in January/December and July/August and are commonly termed King Tides.

Water Level Extremes

Meteorological conditions can increase (or depress) the sea level in addition to the astronomical forcing. Extreme high water levels occur due to a combination of storm surge due to wind shear and low barometric pressure, high astronomical tides, and El Niño effects.

There are two ways that storm systems can increase the water level. One is due to the low barometric pressure of the storm system, which can raise the local water level. The second effect is wind shear, which can push water up against the downwind shoreline.

Table 1-7 summarizes water level extremes at Monterey, NOAA station 9413450.

Table 1-7: Water level extremes at Monterey, NOAA (2023).

Datum	ft NAVD88	Comments
100-YRP	+8.22	100-year high water level
50-YRP	+8.08	50-year high water level
25-YRP	+7.94	25-year high water level
10-YRP	+7.73	10-year high water level
5-YRP	+7.54	5-year high water level
Refer to Table 1-6 for Range of Astronomical Tides		
5-YRP	-1.86	5-year low water level
10-YRP	-1.98	10-year low water level
25-YRP	-2.09	25-year low water level
50-YRP	-2.15	50-year low water level
100-YRP	-2.21	100-year low water level

1.7.2. El Niño Southern Oscillation

El Niño effects (and La Niña) refer to cycles of warming and cooling of the Pacific Ocean, typically lasting 9 to 12 months. These cycles often commence in June or August and reach their peak during December through April, and subsequently decay over May through July. Their periodicity is irregular, occurring every 3 to 5 years on average. The warming associated with El Niño produces a rise of the ocean level, which can be on the order of 6 to 18 inches. The period 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.

Notable flood events in the historical record, such as the winters of 1982-83 and 1997-98 were caused by a combination of elevated ocean levels during strong El Niño episodes, high tides, and the passage of low-pressure storm systems. Figure 1-21 provides an overview of the periodicity of El Niño and La Niña cycles from GGWS (2023).

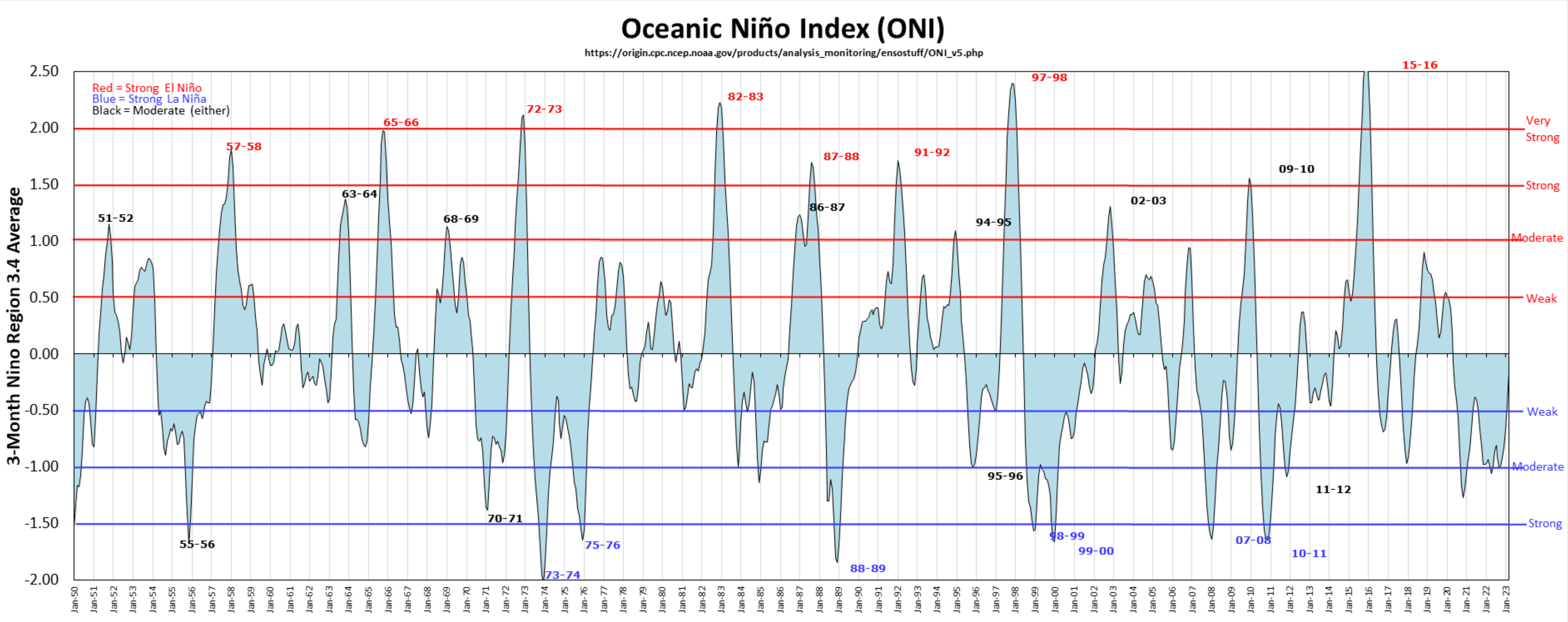


Figure 1-21: Overview of El Niño and La Niña events from 1950-2023, GGWS (2023).

During El Niño winters, storm tracks move further south in the Pacific and storms are generally stronger. Storm systems and waves approach the coast 5-10 degrees further south during El Niño episodes, and waves are often driven by winds from the westerly directions. This means that there is a more direct incidence of waves into Monterey Bay, and the New Brighton and Seacliff area more exposed to wave action. Waves may be up to 30% larger than normal when strong El Niño conditions are present. Rainfall can also be greater than normal, particularly in Southern California.

1.7.3. Historic SLR

Figure 1-22 shows the relative sea level trend at Monterey based on NOAA tide gauge measurements. The blue curve indicates the monthly mean sea levels without the regular seasonal fluctuations from coastal ocean temperatures, salinity, wind, atmospheric pressure, and ocean currents. The red line indicates the relative sea level trend, while the black lines indicate the 95% confidence interval of the estimated trend.

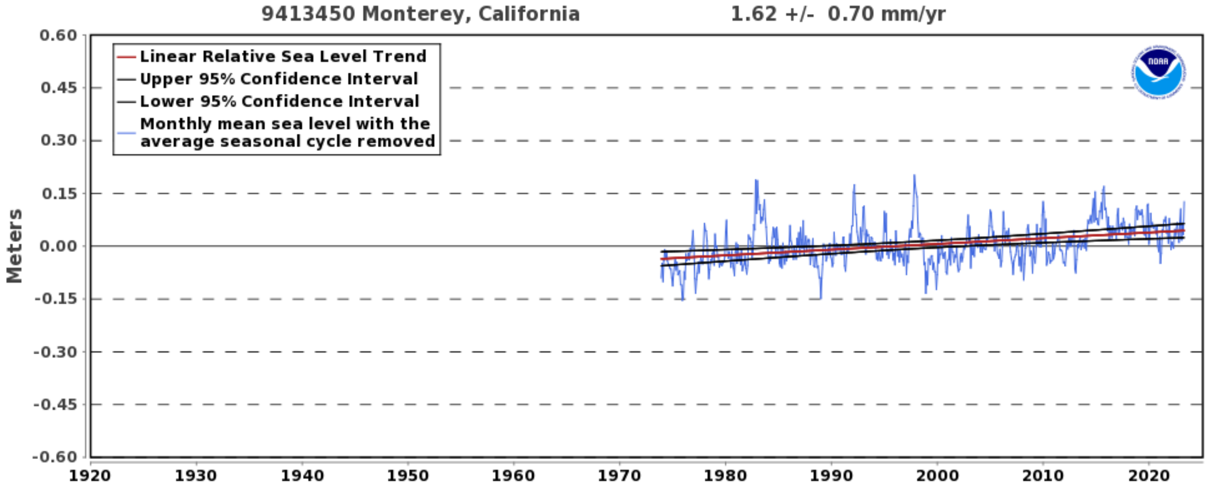


Figure 1-22: SLR trend for Monterey, CA, NOAA (2023).

The plotted values are relative to the most recent Mean Sea Level datum established by NOAA CO-OPS. Note that the data portrayed is reported in metric units. The results indicate that Monterey has been subject to about 1.77 inches of SLR since 1996 (zero in NOAA data).

1.7.4. Offshore Wave Climate

Monterey Bay is exposed to wind-waves generated by local storm systems as well as swell waves originating from distant storms over the Pacific. Figure 1-23 from USGS (2006) summarizes the general angles of wave incidence at Monterey Bay.

There are four different wave systems that affect the bay: 1) North Pacific swell waves originating from distant storms over the North Pacific, 2) Southern swell originating from distant storms in the South Pacific, 3) Northwest wind waves generated by regional wind systems, and 4) Local wind waves which can occur from any direction with open water. North Pacific swell waves are generated by extratropical storm systems, mid-latitude low-pressure systems, and cold fronts over the North Pacific, USGS (2006).

Southern swell is generated by storms in the Southern Hemisphere and occurs in the summertime. Swell waves are characterized by long wave periods, typically from 8 to 18 seconds.

Northwest wind waves are generated by regional weather systems as they approach the coast and are more pronounced in the winter and spring, USGS (2006). Wind waves are generated by local wind conditions and produce waves with shorter periods, typically from 3 to 8 seconds. Local storms can occur from October through April.

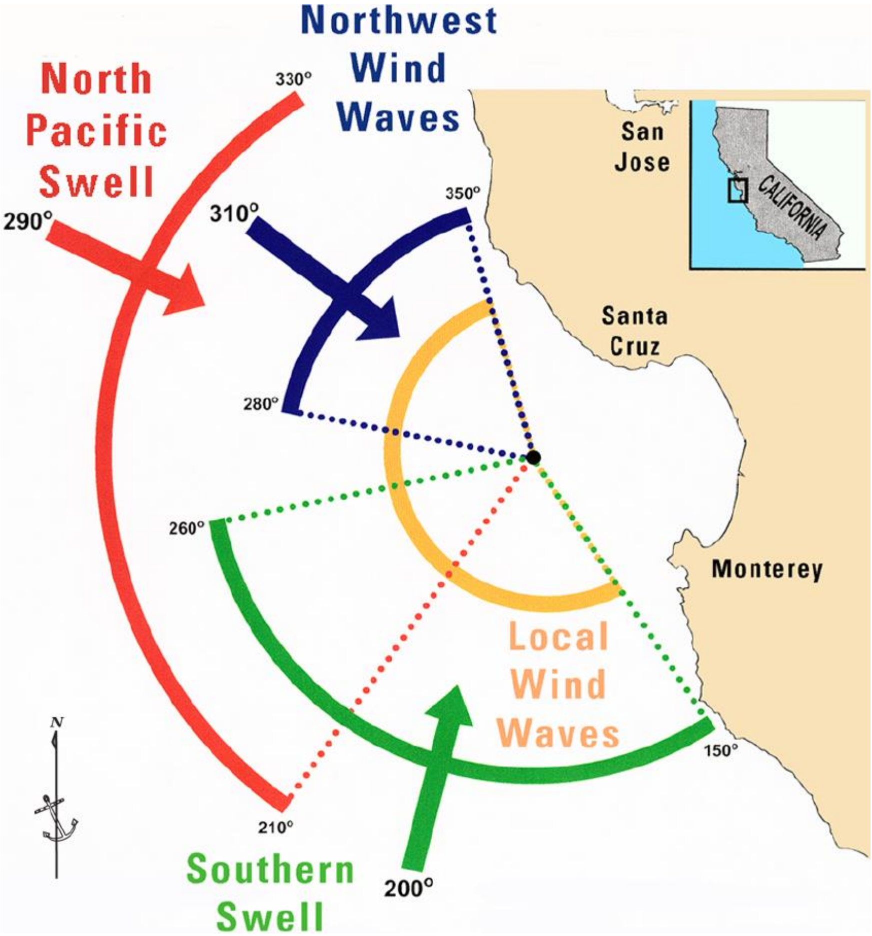


Figure 1-23: Angles of wave incidence at Monterey Bay, adopted from USGS (2006).

Table 1-8 summarizes the percentage of occurrence of waves by significant wave height[4] and direction (from). Waves arrive from west-northwesterly to northwesterly directions for the majority of the time and these waves can reach heights of up to 20 feet and larger. Waves arrive from these directions about 74% of the time, and from westerly directions about 10% of the time. Southern swell is limited in terms of percentage of occurrence, arriving from directions SSE to SSW about 8.9% of the time.

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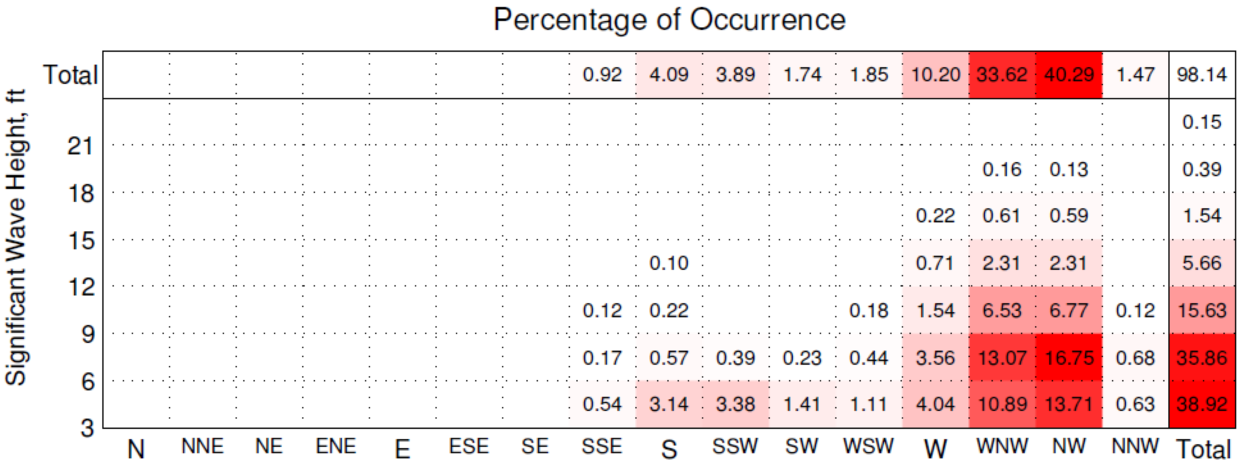
[4] The significant wave height is defined as the average height of the one-third largest waves and is comparable to what a visual observer would estimate as being the mean wave height.

Table 1-8: Percentage of occurrence of significant wave heights by direction at Monterey Bay.



Percentage of Occurrence

Significant Wave Height, ft	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total								0.92	4.09	3.89	1.74	1.85	10.20	33.62	40.29	1.47	98.14
21–																	0.15
18–21														0.16	0.13		0.39
15–18													0.22	0.61	0.59		1.54
12–15									0.10				0.71	2.31	2.31		5.66
9–12								0.12	0.22			0.18	1.54	6.53	6.77	0.12	15.63
6–9								0.17	0.57	0.39	0.23	0.44	3.56	13.07	16.75	0.68	35.86
3–6								0.54	3.14	3.38	1.41	1.11	4.04	10.89	13.71	0.63	38.92

Wave Conditions

Wave conditions were assessed based on the USGS Coastal Storm Modeling System (CoSMoS), OCOF (2023).

The CoSMoS model makes detailed predictions of storm-induced coastal flooding, erosion, and cliff failures over large geographic scales. CoSMoS was developed for hindcast studies, operational applications and future climate scenarios to provide emergency responders and coastal planners with critical storm-hazards information that can be used to increase public safety, mitigate physical damages, and more effectively manage and allocate resources within complex coastal settings.

The system employs a dynamic modeling approach that has been developed by the United States Geological Survey in order to allow more detailed predictions of coastal flooding due to both future SLR and storms integrated with long-term coastal evolution, including beach changes and cliff retreat over large geographic areas. CoSMoS models all the relevant physics of coastal storms, including tides, waves, and storm surge, which are then scaled down to local flood projections for use in community-level coastal planning and decision-making. Rather than relying on historic storm records, CoSMoS uses wind and pressure from global climate models to project coastal storms under changing climatic conditions during the 21st century.

Projections of multiple storm scenarios (daily conditions, annual storm, 20-year- and 100-year-return intervals) are provided under a suite of SLR scenarios ranging from 0 to 6.6 feet, along with an extreme 16-foot SLR scenario. This allows users to manage and meet their own planning horizons and specify degrees of risk tolerance.

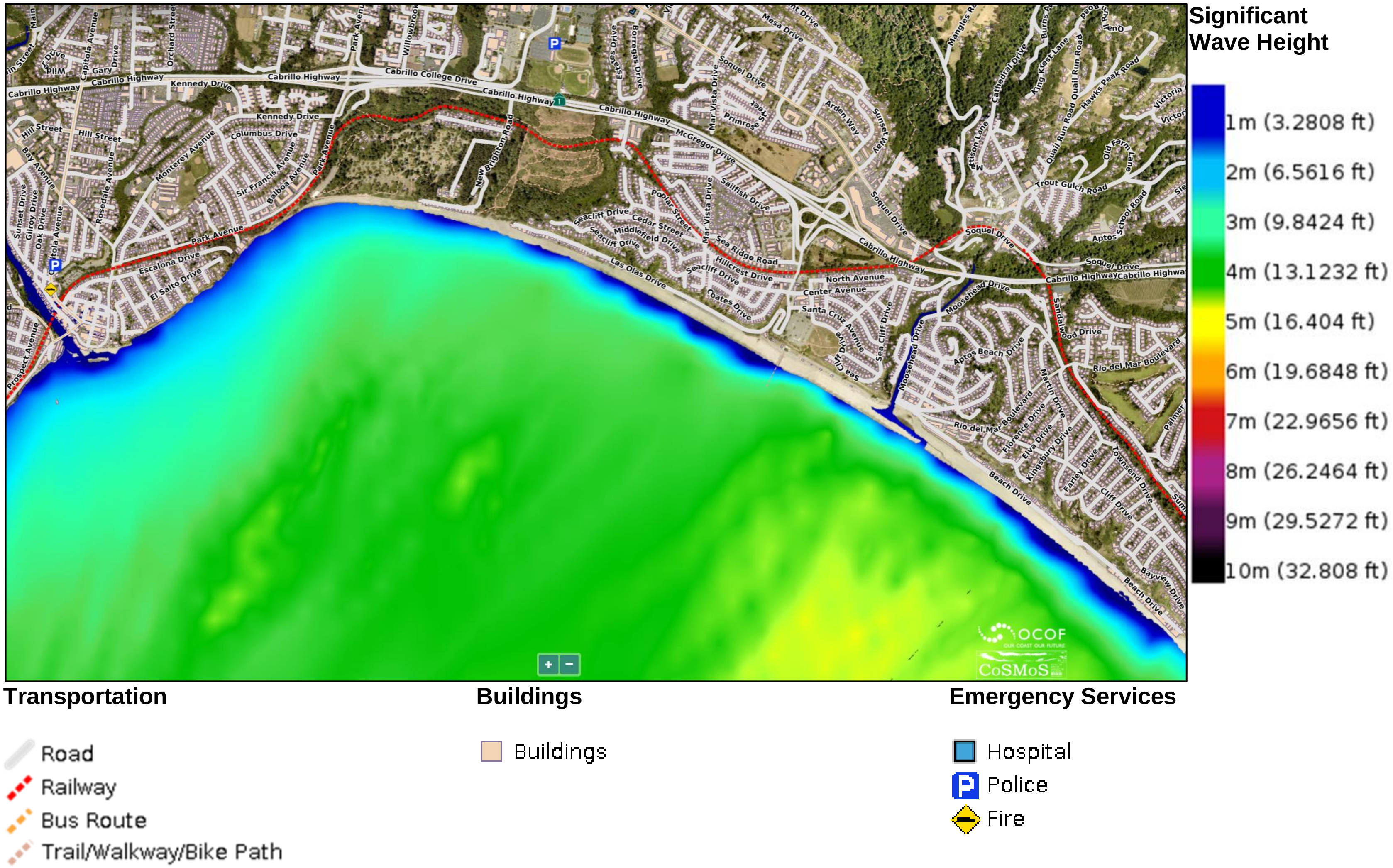


Figure 1-24: Annual average wave height variation at Seacliff State and New Brighton State Beach, OCOF (2023).

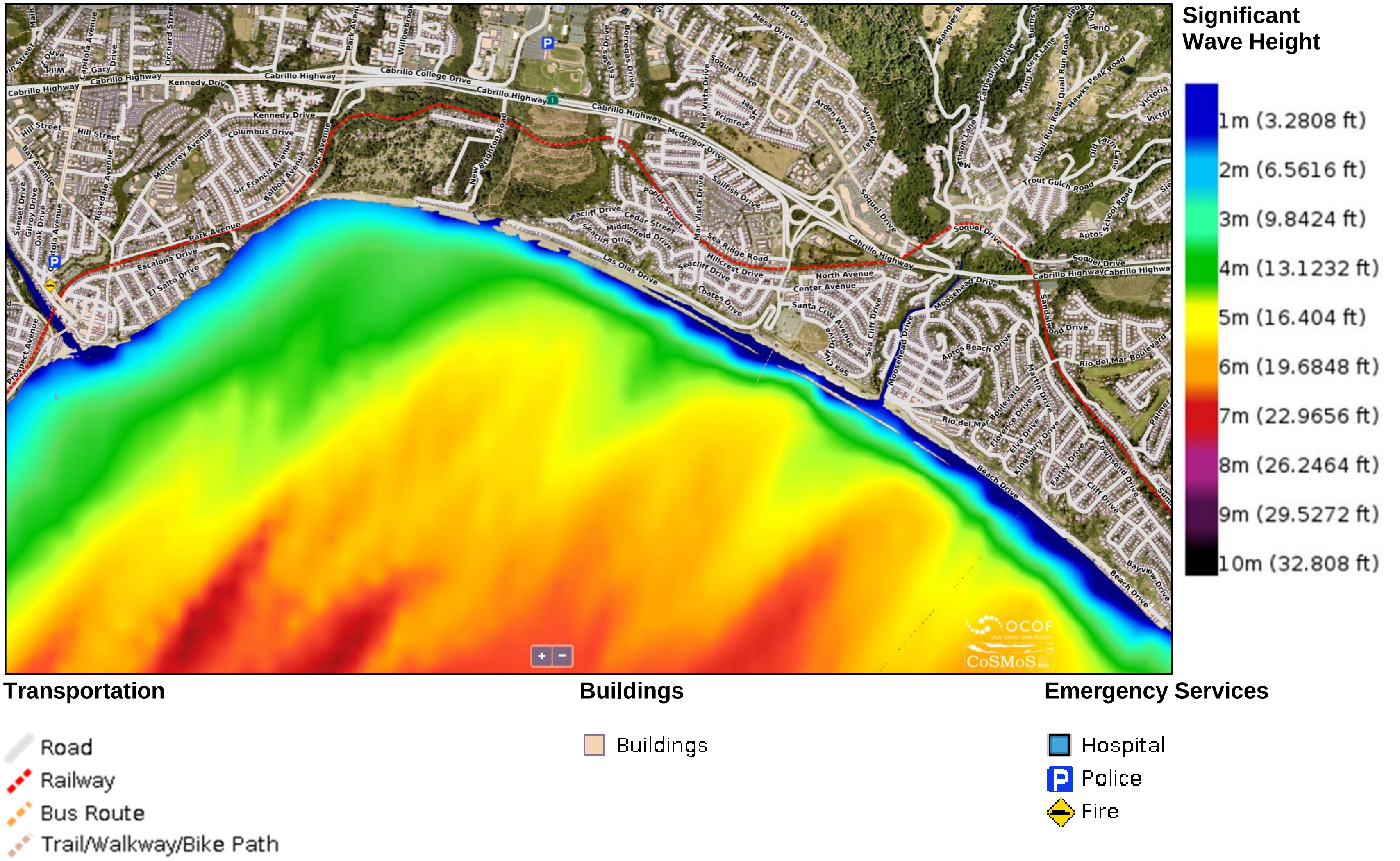


Figure 1-25: 100-year wave height variation at Seacliff State Beach and New Brighton State Beach, OCOF (2023).

1.7.5. Nearshore Wave Transformation

Wave transformation analysis was conducted for representative wave conditions to illustrate transformation of waves as they propagate into Monterey Bay to the shores of Seacliff SB and New Brighton SB. The wave height at the shoreline is important as it determined the level of wave runup and coastal flooding. The wave angle of incidence in the surf zone determined whether the sand transport is southward or northward. Table 1-9 summarizes the incident wave conditions analyzed, which cover the angles of incidence depicted in Figure 1-23.

Table 1-9: Representative offshore wave conditions at Monterey Bay.

Wave Direction (from)	Significant Wave Height Offshore (feet)	Peak Wave Period (s)
NNW	21.8	14.9
NW	24.3	15.8
WNW	34.3	18.7
W	36.6	19.4
WSW	29.1	17.3
SW	5.0	7.2
SSW	11.5	10.8
S	10.5	10.4

The plots presented in Figure 1-26 to Figure 1-33 show how waves transform as they propagate into Monterey Bay.

In the plots, the color scale is representative of the significant wave height variation, where red denotes the largest waves, transitioning over orange and yellow to green, indicative of waves of intermediate size. Color bands from green to blue indicate progressively smaller wave height, with purple indicating the smallest waves.

The black arrows in the plots indicate the direction of wave propagation. Wave transformation effects such as refraction, diffraction, reflection, shoaling, and wave breaking may alter the direction and magnitude of waves, in the plots seen as gradual changes of the direction arrows and variation of the color bands. The variation of the seabed plays a significant role in wave transformation at intermediate to shallow water depths. Select contours of the Monterey Canyon are indicated as outlines in black to identify its location in the bay. Straight black lines extending from shore at select locations indicate the direction of the shore-normal, a line perpendicular to the shoreline orientation. If incident waves (black arrows) approximately line up with a shore-normal, longshore sand transport will be limited. If the wave direction has an angle to the shore-normal, sand transport will be in the direction of the arrow along the shore, in many cases predominantly southward.

The following can be concluded based on the wave transformation analysis. Wave direction indicated in bold and percentage of annual occurrence in Monterey Bay in parentheses.

1. **NNW Waves (1.5%).** Seacliff State Beach and New Brighton State Beach are generally sheltered from these waves. These wave conditions may drive longshore sediment transport into the bay along the coastline of Santa Cruz, Opal Cliffs, and Capitola. From New Brighton State Beach, the longshore transport is southward, ultimately conveying littoral transport into the submarine canyon.

2. **NW Waves (40.3%).** Seacliff State Beach and New Brighton State Beach are partially sheltered from these waves, which may drive longshore transport of sediment into the bay similar to NNW waves. These wave conditions may cause focusing of waves in the area of La Selva Beach, presumably due to reflection of waves off the edge of the submarine canyon,

3. **WNW Waves (33.6%).** These wave condition produce a significant exposure at Seacliff State Beach and New Brighton State Beach, and may contribute to transport of significant amounts of material along Santa Cruz, Opal Cliffs and Capitola, but also producing strong southward sand transport down the coast.

4. **W Waves (10.2%).** Westerly waves can reach sizable magnitude and results in exposure to severe wave conditions in the majority of the bay. Seacliff State Beach and New Brighton State Beach will see a significant exposure under these conditions and there is a pronounced focusing of wave energy at Rio Del Mar. Severe wave conditions from this direction play a role in eroding the cliffs along Opal Cliffs to Capitola. The waves will arrive near-perpendicular to the shoreline and longshore sediment transport limited for milder wave conditions, but may be significant for larger waves, dominated by cross-shore transport. Long-period swell waves often deposit sand on the beach, whereas winter storm waves will tend to erode the beach.

5. **WSW Waves (1.9%).** Waves from this direction are a relatively rare occurrence but will produce an increased wave exposure at Rio Del Mar and significant exposure at Seacliff State Beach and New Brighton State Beach. Modes of sediment transport will be similar to those for waves arriving from westerly directions.

6. **SW to S Waves (9.8%).** Waves from these directions characterize southerly swell. Seacliff State Beach and New Brighton State Beach will experience a direct exposure to these waves, but these are some of the only conditions that will produce longshore sand transport northward in the bay. These wave conditions will consequently bring sand to the beach areas at Capitola New Brighton and Seacliff. The sand transport at Santa Cruz and Opal Cliff remains eastward, into the bay.

The following general findings can be made in relation to sediment transport based on the above wave conditions.

Waves incident at Monterey Bay erode the cliffs along the Santa Cruz promontory and Opal Cliffs and are responsible for the high rates of cliff retreat in this area. The net longshore transport direction is in all cases eastward into the Bay. This means that New Brighton State Beach and Seacliff State Beach receive a more or less continuous supply of sand. However, depending on the direction and magnitude of the waves, the sand transport along Seacliff and New Brighton may be larger or more moderate. If the southward transport is smaller than the supply from the north, the sand will tend to pile up and the beaches widen. If the southward transport is larger than the rate of supply from the north, the beaches narrow. In most wave conditions the sand transport along New Brighton State Beach and Seacliff State Beach is southward. But when southerly swell wave conditions are present, the longshore transport may reverse in a northerly direction and transport sand to Seacliff and New Brighton State Beach from the south. The sand transport along Opal Cliffs will remain eastward and the northern corner of the bay will therefore experience a significant accumulation of sand.

Certain wave conditions, such as long period swell will tend to deposit sand on the beach, whereas short period storm wave conditions tend to remove sand. Under these conditions, sand eroded from the shoreline will be deposited in deeper water and the appearance at the shoreline will be a narrower beach. The sand deposited offshore (or a portion thereof) may be lost to deep water or may return to the beach if swell conditions ensue.

The overriding result is that the beach width at New Brighton State Beach and Seacliff State Beach can be highly variable and fluctuate rapidly.

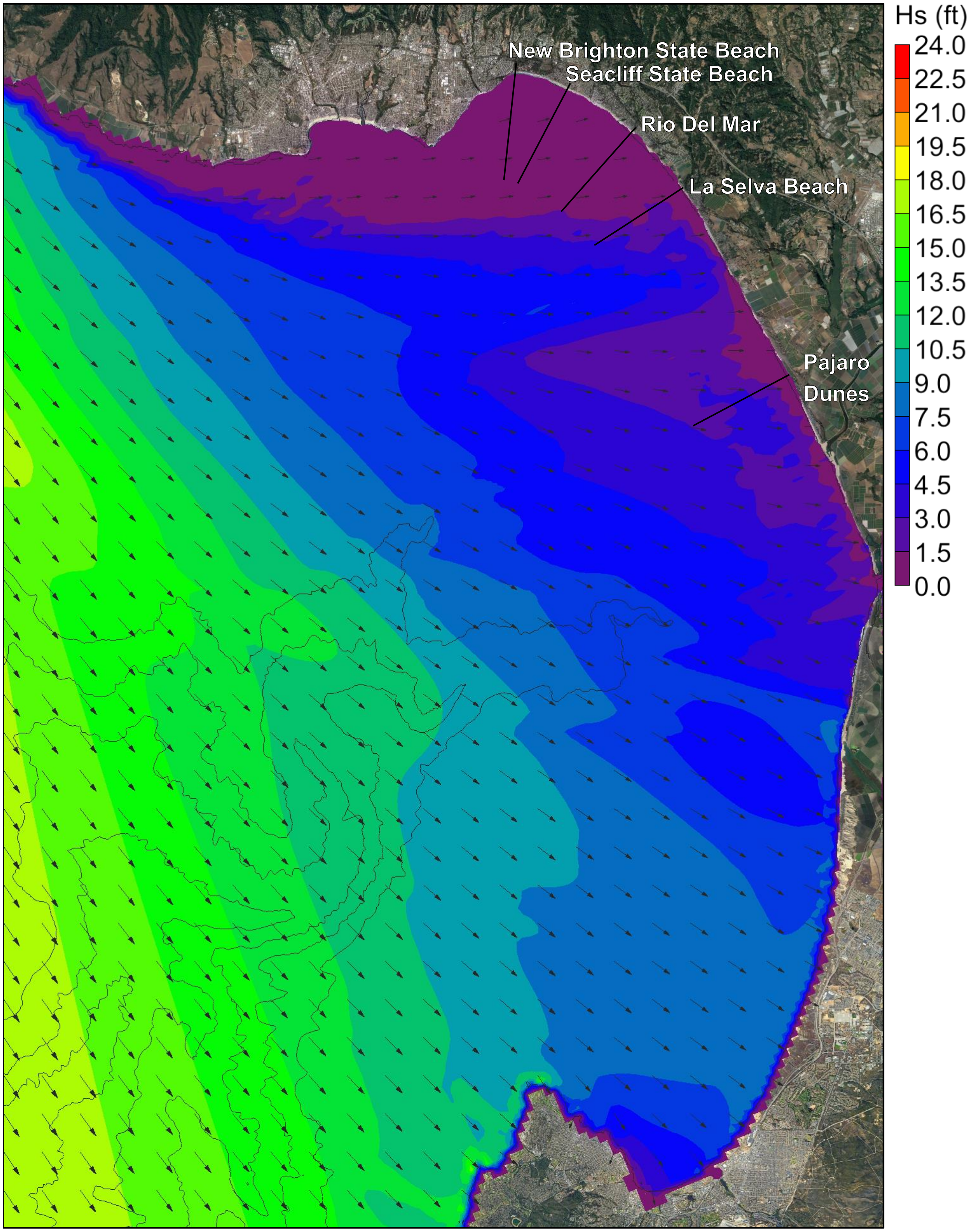


Figure 1-26: Significant wave height variation for NNW waves.

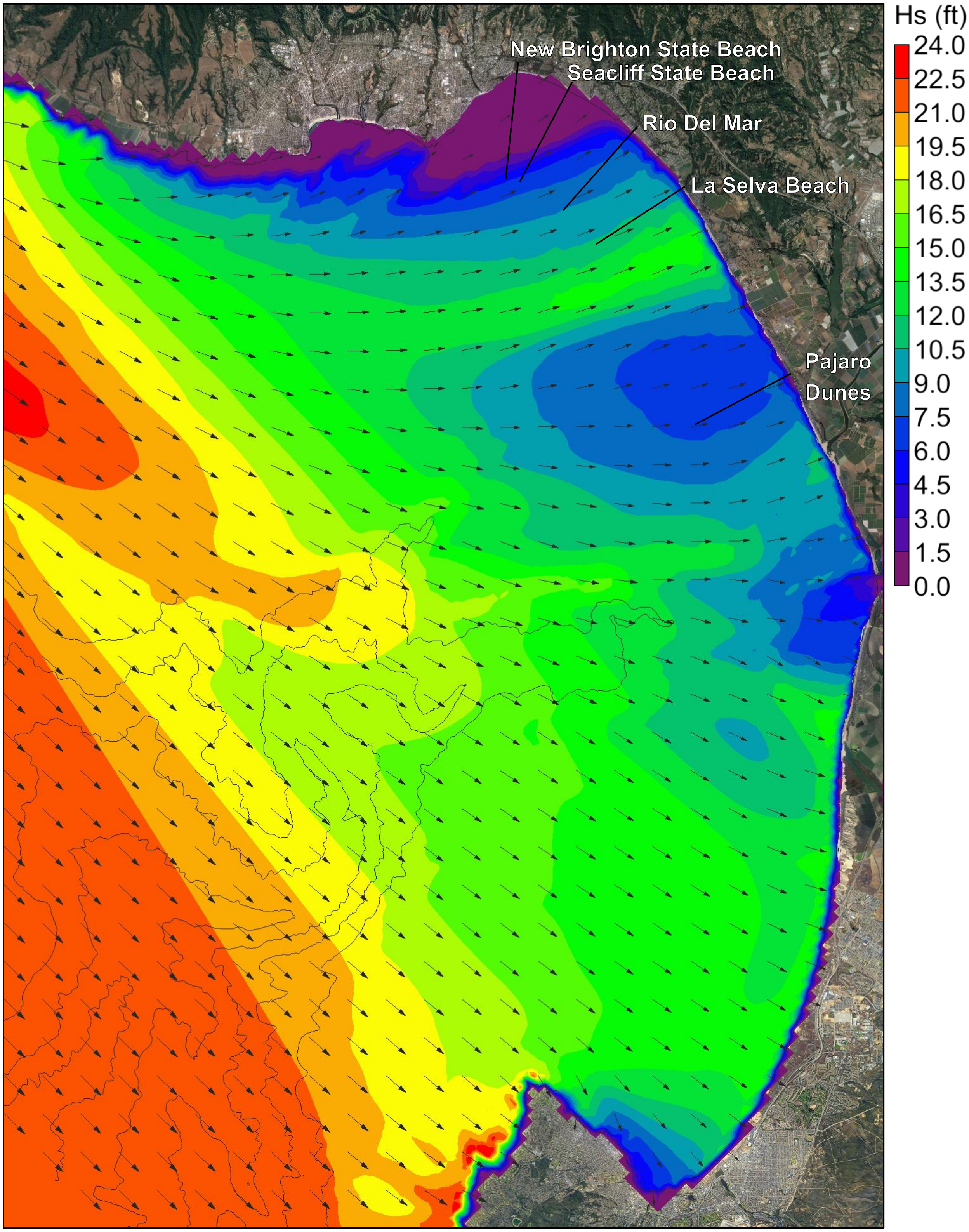


Figure 1-27: Significant wave height variation for NW waves.

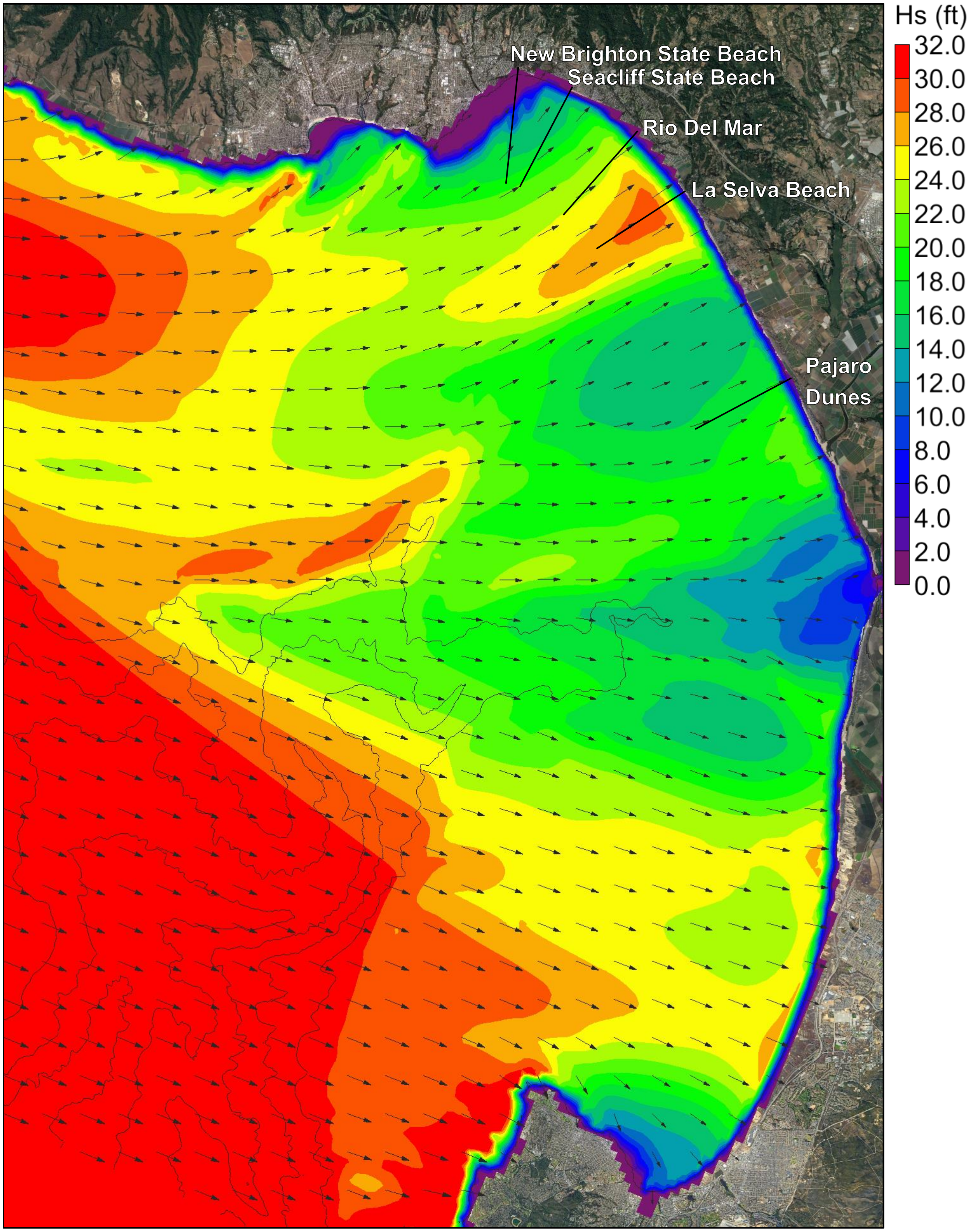


Figure 1-28: Significant wave height variation for WNW waves.

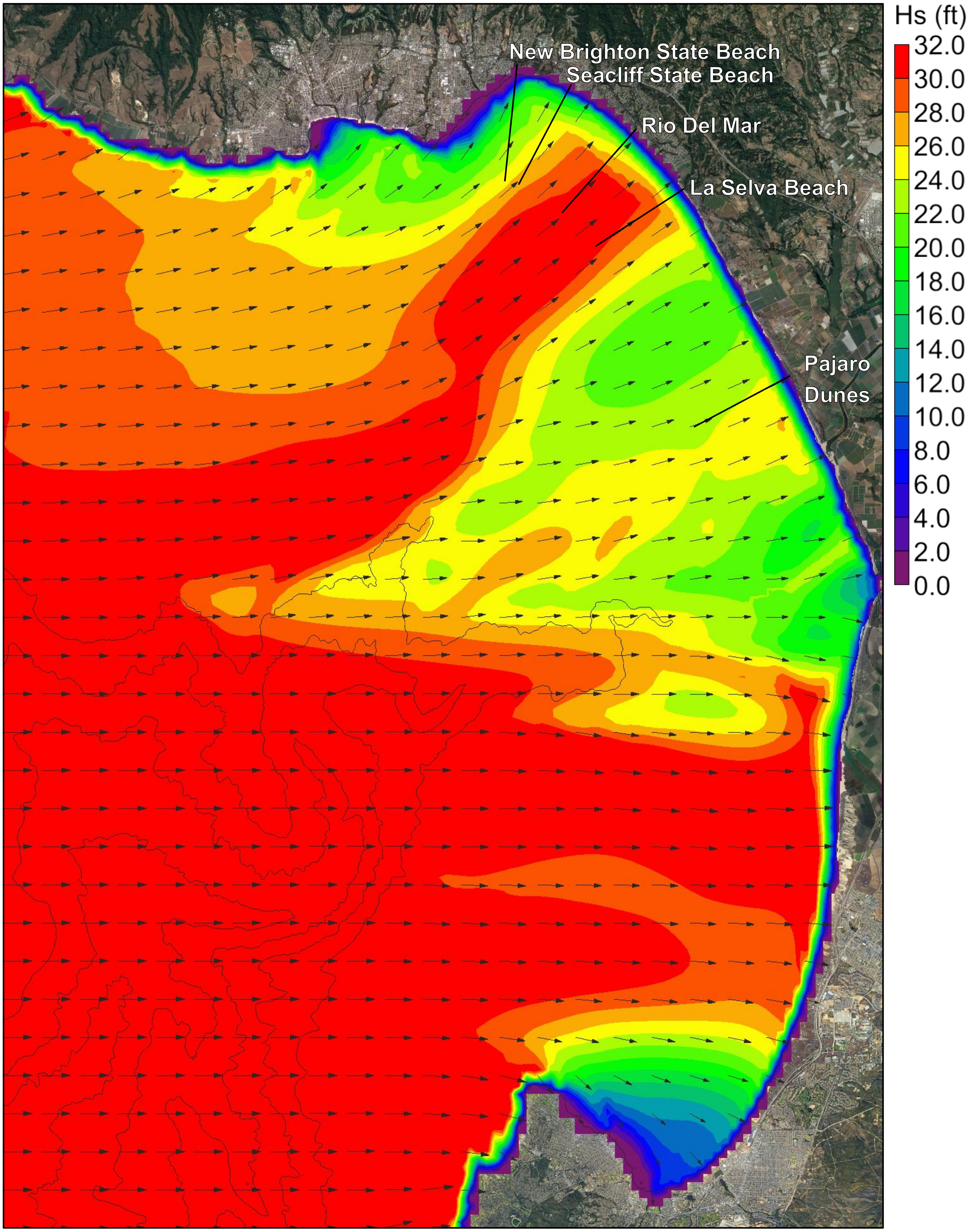


Figure 1-29: Significant wave height variation for W waves.

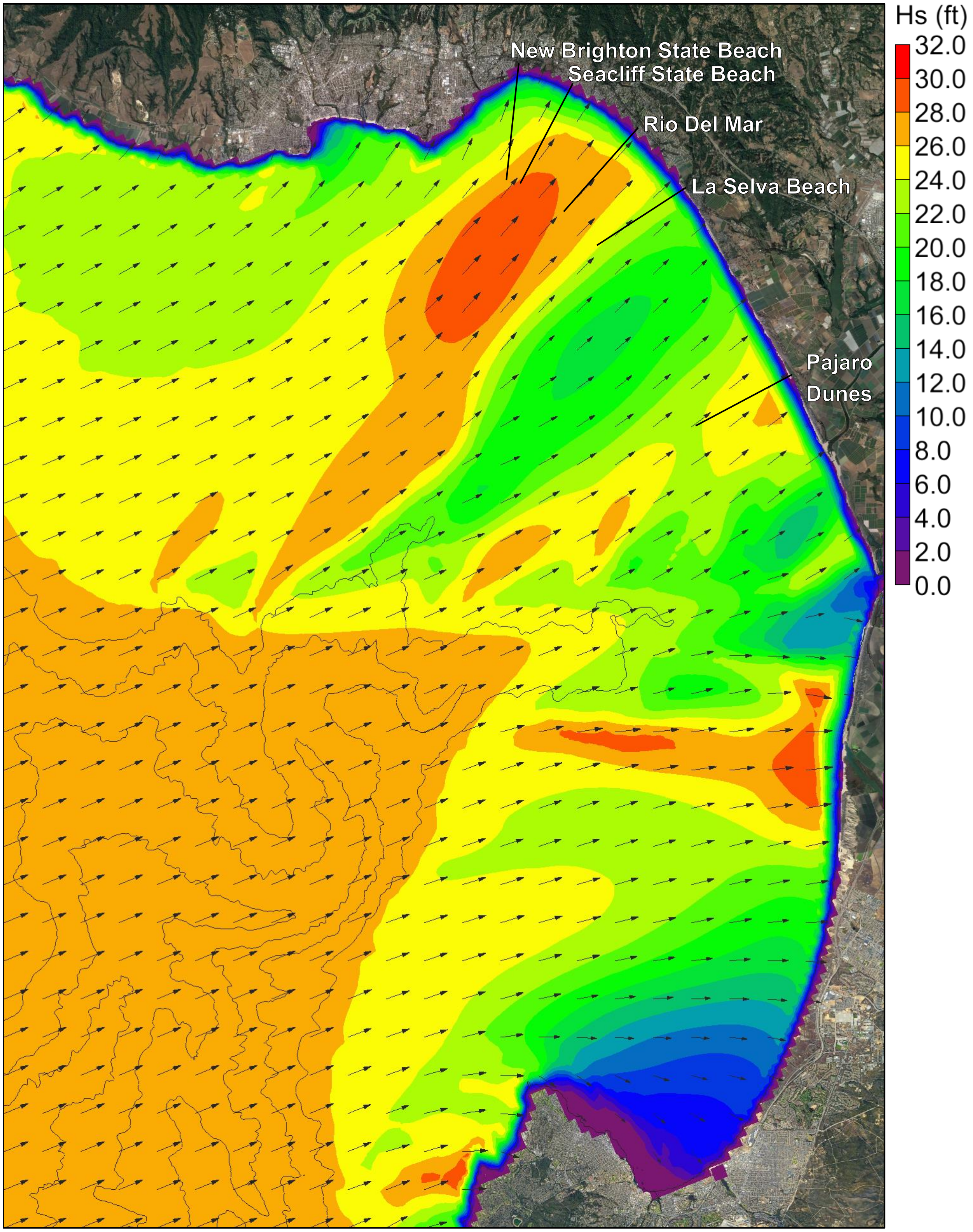


Figure 1-30: Significant wave height variation for WSW waves.

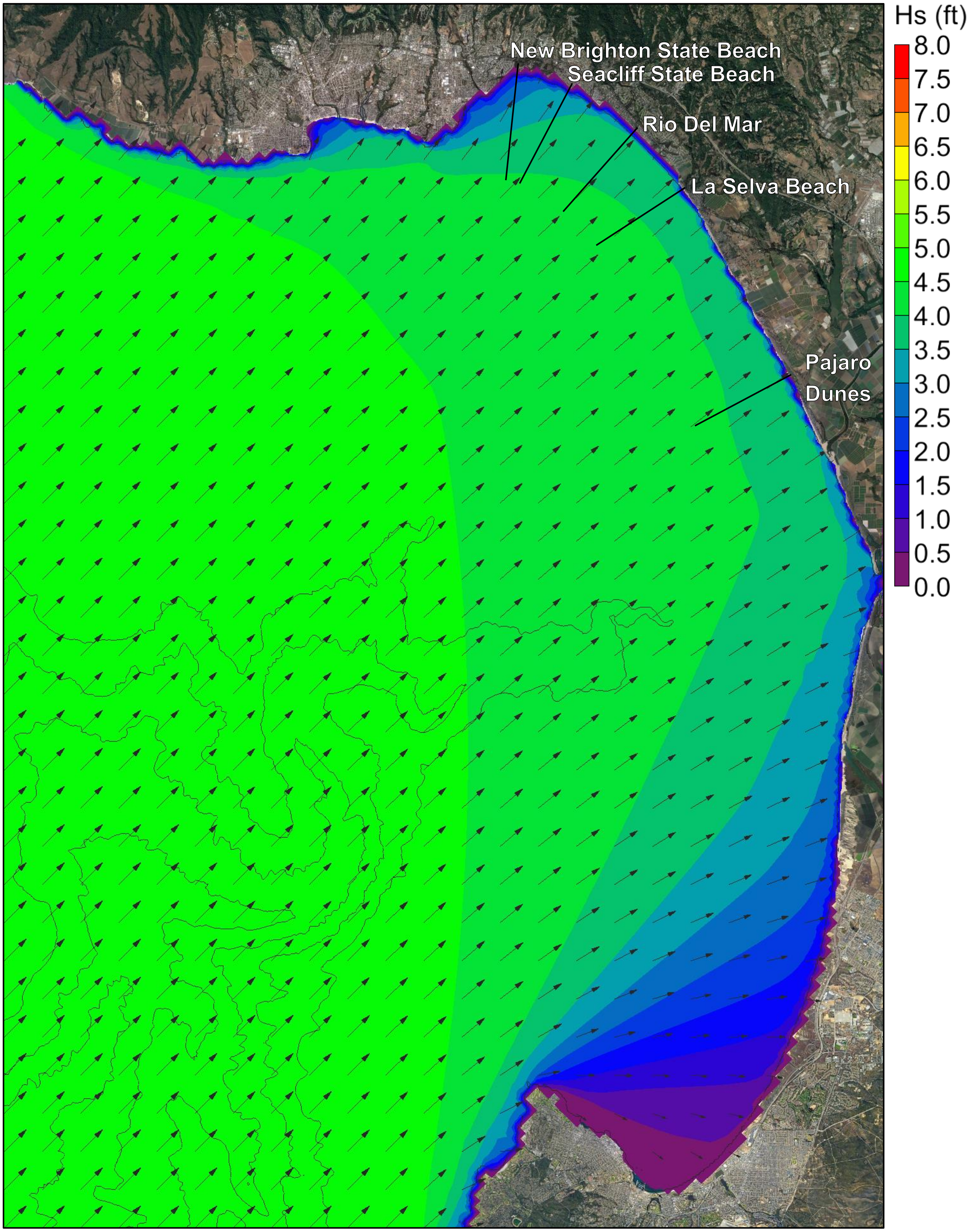


Figure 1-31: Significant wave height variation for SW waves.

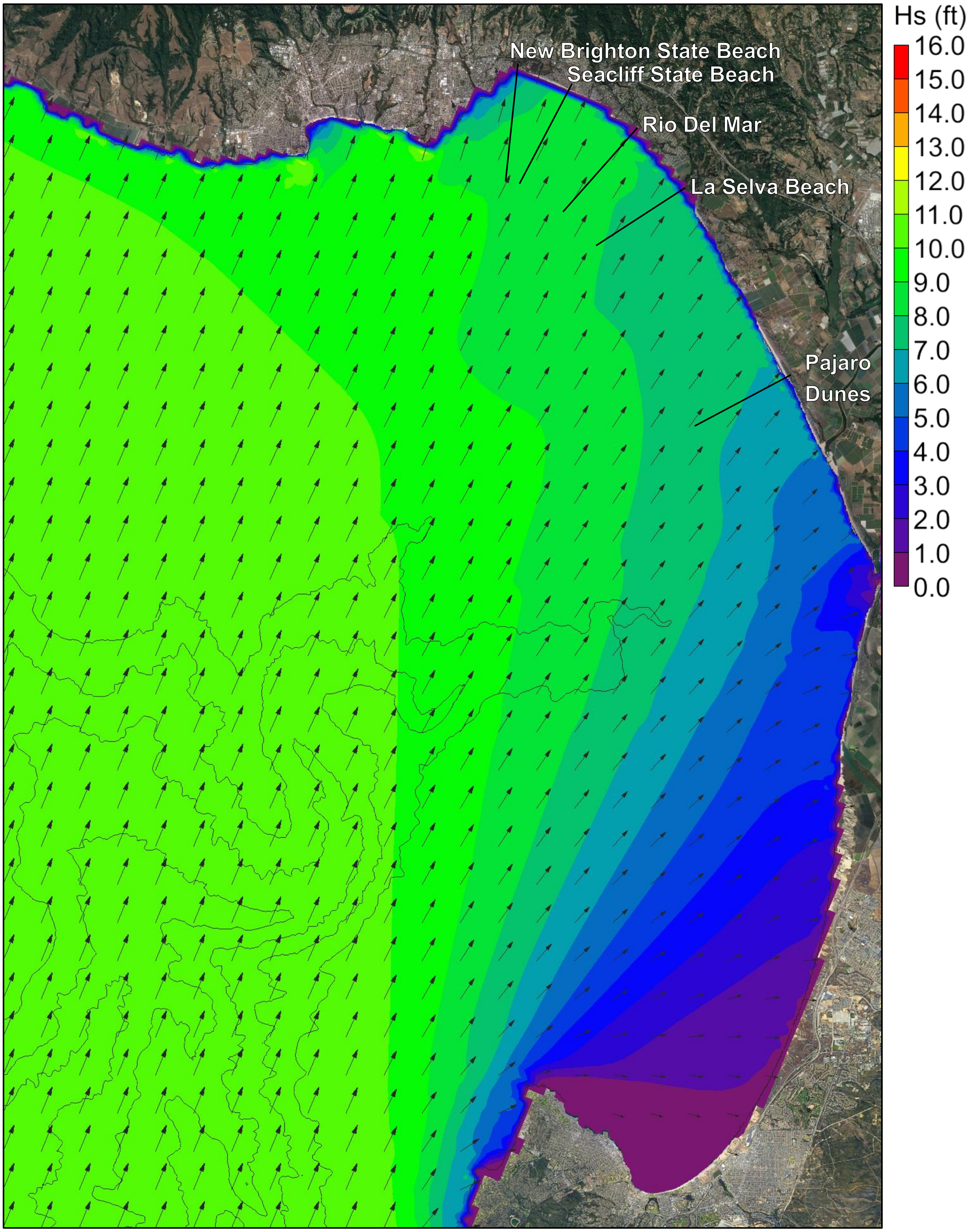


Figure 1-32: Significant wave height variation for SSW waves.

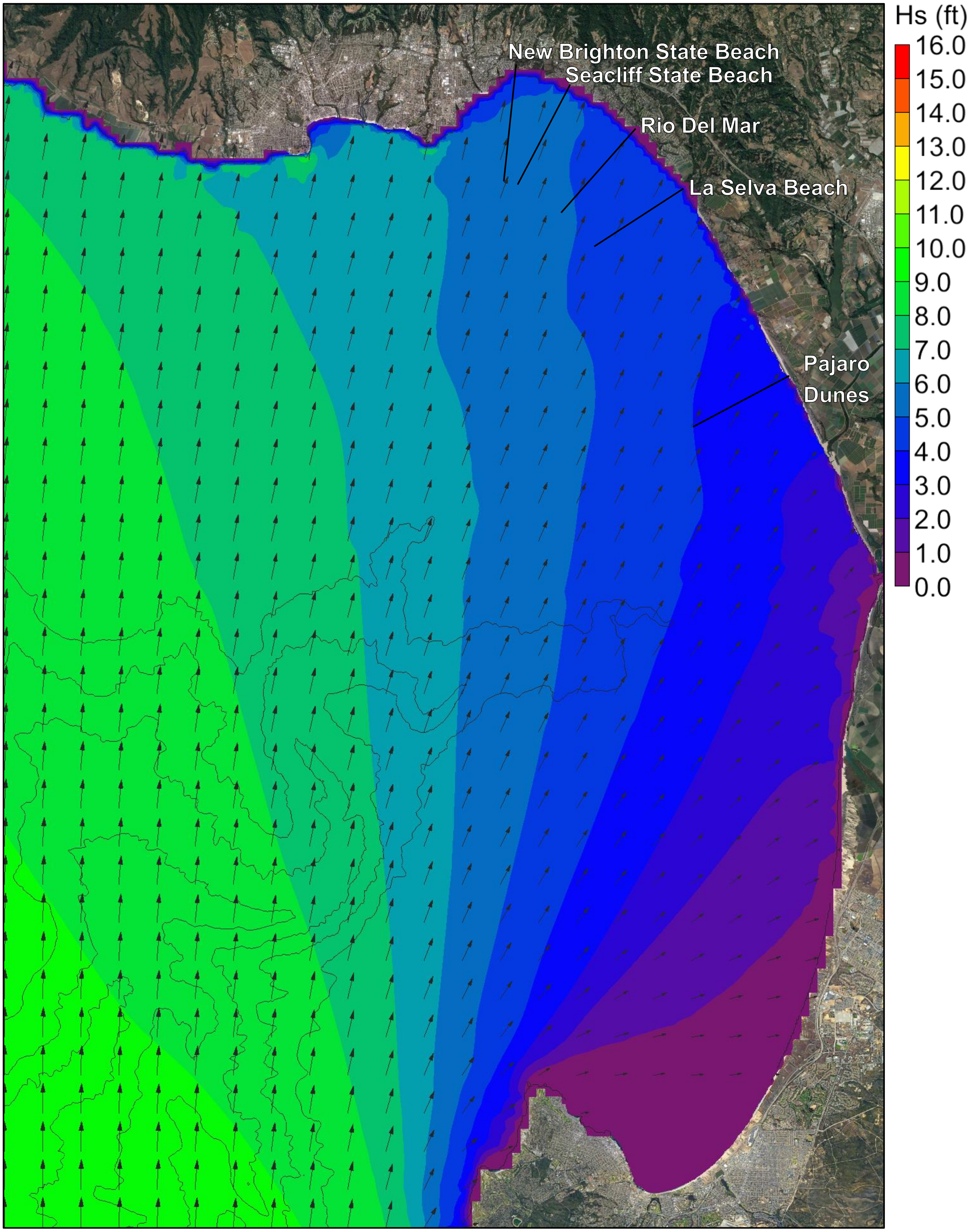


Figure 1-33: Significant wave height variation for S waves.

1.8. Shoreline Protective Structures

Table 2-1-10 provides a categorization of shoreline structures protective at Seacliff State Beach and New Brighton State Beach. Intervening areas of non-Parks privately owned parcels are included in the rightmost column.

The majority of the shoreline areas within these park units are protected with shoreline protective structures, including rock armoring, timber bulkhead, or concrete seawall sections. Potbelly Beach and a portion of New Brighton State Beach are backed by cliff.

Table 2-1-10: Seacliff State Beach and New Brighton State Beach Distribution of Shoreline Structures.

Shoreline Structure Extent (feet)	New Brighton SB		Seacliff SB		
	New Brighton Beach	Potbelly Beach	Campground	Day Use Area	Rio Del Mar
Rock Armoring	1,693	-	-	-	979
Timber Bulkhead	-	-	2,563	2,465	471
Concrete Seawall	-	-	-	-	2,953
No Structure	1,256	563	-	-	-
Total Length (feet)	**2,949**	**563**	**2,563**	**2,465**	**4,403**
Hardened Shoreline	57%	0%	100%	100%	100%

2. Beach Processes

Beaches are shaped by forcing that affects the movement of sediment such as tides, waves, currents, and wind. There are several types of processes that describe changes to the beach such as erosion, deposition, transportation, and weathering.

Weathering is the process of sediment grains being ground down due to waves, current, and wind forcing. Transportation of material can occur onto the beach (deposition), off the beach (erosion), and along the shoreline.

Beach processes at Seacliff SB and New Brighton SB are described in the following.

2.1.1. Seasonal Variation

Beaches undergo regular cycles where waves pull sand off the beach into deeper water and the width of the beach narrows as a result. Waves subsequently bring sand back to the beach and restore its width. In many places this pattern manifests as a seasonal cycle, where larger and steeper waves in the winter months pull sand away from beach areas. The corresponding narrowing of the beach characterizes the winter beach profile. Swell waves occurring over the summer months mobilize sand from deeper water and deposit it on the beach via wave runup. If there is a sufficient supply of sand in the system, this can result in widening of the beach, which characterizes the summer beach profile.

In Monterey Bay, this seasonal cycle also occurs but is affected by a number of factors that also impact beach width as follows.

New Brighton and Seacliff are somewhat sheltered from waves associated with storms from northwesterly directions by the Santa Cruz promontory and more directly exposed to westerly waves and waves from southwesterly directions. The direction of littoral transport at New Brighton and Seacliff is generally southward. This is because waves from north-northwesterly to southwesterly directions move sand south along the shoreline. These wave conditions occur for about 90% of the time. The southward transport will have the effect of removing sand from the northerly beaches in Monterey Bay, which will result in narrowing of the beaches similar to conditions caused by winter storms. Waves from southerly directions occur for about 10% of the time and move sand northward in Monterey Bay, widening the beach at Seacliff SB and New Brighton SB.

Wave conditions that exacerbate supply and longshore transport of sand along the Santa Cruz coast can send sizable pulses of sand to the beaches at Seacliff and New Brighton. This sand resupply can result in a significant widening of the beach.

Wave runup is another factor that affects beach width. Seacliff and New Brighton can be subject to significant wave runup both due to wind-generated waves and due to swell waves originating in distant storms. The wave runup affects the foreshore and can have an impact on public access along the beach. This wetted portion of the beach is typically very pleasant to walk on, but if the wave runup is too energetic may displace users to higher portions of the beach. The foreshore frequently exhibits beach cusps, which also play a role in the perception of the accessible beach width.

2.1.2. Closure Depth

The closure depth defines the approximate seaward limit of seabed profile fluctuation over multi-year time scales.

The area of the seabed and beach inshore of the closure depth defines the zone of active littoral sand transport. In deeper water, seaward of the closure depth, sediment movement is limited.

The closure depth, h_c, in Monterey Bay was estimated using the following equation by Hallermeier:

$$h_c = 2\overline{H} + 11\sigma_H$$

Where $\overline{H}$ is the annual mean significant wave height and σ_H is the standard deviation of significant wave height.

The results indicate a closure depth of approximately h_c= 48 feet.

2.2. Response to Storms & El Niño Conditions

Figure 2-1 shows estimated eroded beach profiles resulting from storms with recurrence intervals ranging from 1 to 100 years on average. Note that the beach profile will tend to rebalance and recover following storm events, trending to the initial profile (black line), although subject to changes in the equilibrium beach profile dependent on long term wave conditions.

The process depicted in the figure is that a portion of the beach will be removed during storms and deposited offshore. One of the reasons for this is that the equilibrium beach profile subject to the storm waves is a flatter beach profile. I can be noted that the depth of erosion at the back beach can be on the order of about 10 feet and it is also worth nothing that 25-year to 100-year storms may produce comparable damage.

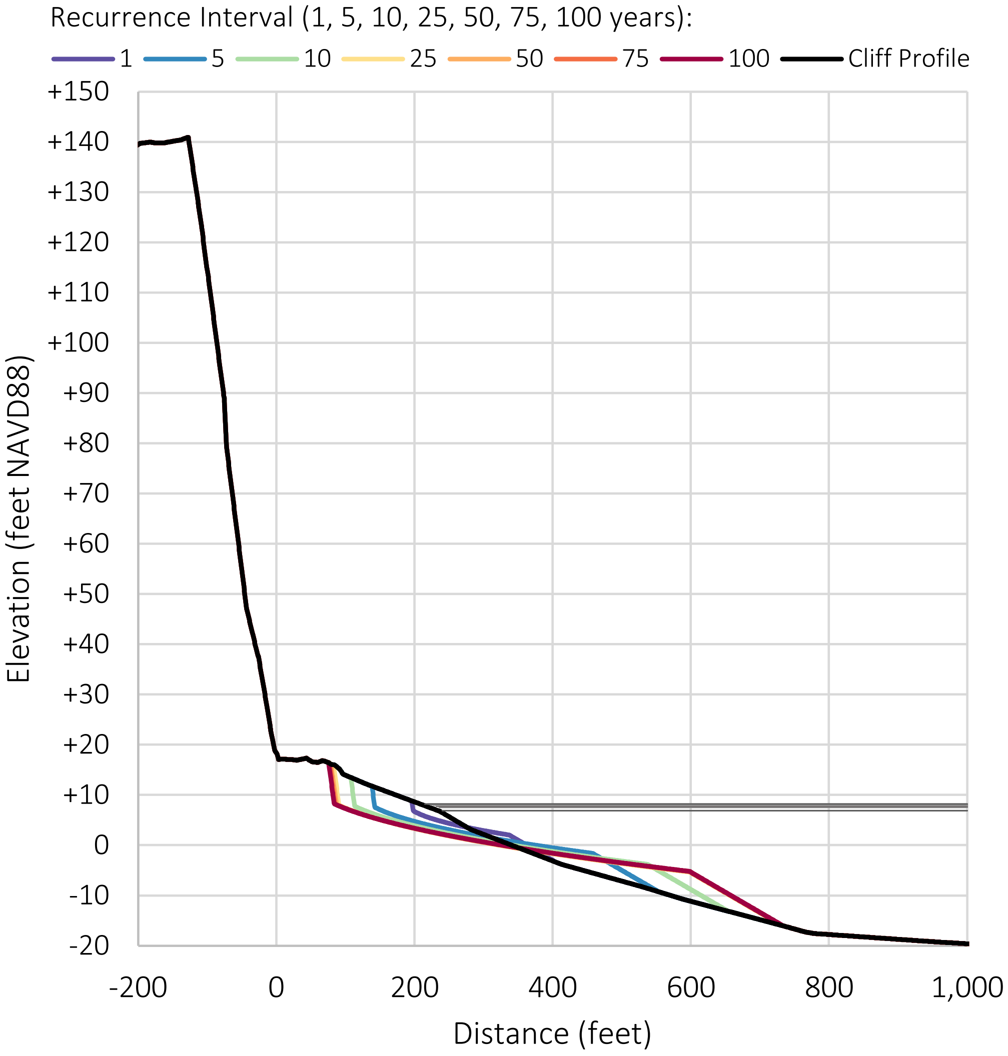


Figure 2-1: Estimated eroded beach profiles due to storms.

The estimated loss of beach width due to storms is summarized in Table 2-1. It should be noted that these estimates are theoretical, and the realized beach loss will depend on the actual site conditions. A key finding from the Table 2-1 data is that storms with higher recurrence intervals trend to similar estimates of beach loss. This is because beach loss is closely tied to the water level during the storm event. And because water level extremes don’t change much for the 25 to 100-year conditions, the estimated beach loss also doesn’t change very much. The conclusion is that the beach loss experienced during a 100-year storm event could be similar to e.g. a 25-year storm event. Conversely, that 25-year storm events, which are more frequent, may produce levels of damage comparable to a “storm of the century”.

Table 2-1: Theoretical beach loss due to storms.

Storm Recurrence Interval (years)	Estimated Beach Loss	
	Width (feet)	Volume (cf/ft) 1)
1	26’	120
5	56’	487
10	78’	813
25	96’	1,124
50	100’	1,147
75	103’	1,162
100	105’	1,172

1) cubic feet per linear foot along beach.

The strong relationship between beach loss and water level is exemplified when El Niño conditions are present. In years with strong El Niño conditions, above-normal impacts are reported for coastal areas. This is to some extent tied to the increase in the mean sea level related to the thermal expansion of the Pacific associated with El Niño conditions. This transient water level increase can be seen as a form of temporary SLR.

Based on the Table 2-1 estimates, SLR would be expected to produce significant loss of beach width in coastal areas. Refer to Section 4.4 for a perspective on beach loss due to storms with SLR.

El Niño Conditions

During episodes of El Niño conditions, beach areas may have reduced width. Two primary drivers for this are:

1. Thermal expansion of the Pacific during El Niño episodes causes the ocean level to rise, which means that a larger than normal area of the beach may be submerged.
2. El Niño storms often cause above-normal beach recession due to the intensity of the storms and elevated water levels.

The larger storms that can occur in El Niño years can pull sand into deeper water outside of the normal seasonal beach profile variation. The sand is then lost and won’t return to the shoreline. The recovery of the shoreline then becomes dependent on the amount of sand supplied within the alongshore littoral cell. Following El Niño episodes, the recovery of beach areas returns to the normal seasonal cycles of beach profile variation. The time for impacted beaches to recover can be on the order of 6 to 18 months. However, following El Niño episodes with larger than normal storms and sand lost to deep water, the recovery of beach areas can be on the order of years.

The extent to which beach areas are impacted by erosion will depend on the strength of the El Niño episode, the rise of the ocean level, the number and severity of winter storms, and whether these coincide with high tide conditions. The condition of the beach in the years preceding the El Niño year is of importance as it can relate to the abundance of sand in the littoral system or lack thereof. Mild winter conditions can mean that the beach profile is wider and has greater resilience to El Niño related impacts. The resilience of beaches to erosion is improved by a wide beach profile, elevated beach berm, and dune growth, which all contribute to storage of sand. Having the buffer of sand can prevent waves from impacting shoreline facilities and infrastructure and from eroding the cliff. Conversely, harsh winter wave conditions preceding or following an El Niño episode can damage the coast due to scarcity of sand.

Rivers and streams seasonally provide quantities of sand, gravel and fine sediment to the shoreline environment. But preceding drought years can lead to the coast being sand starved as the climate cycle enters an El Niño episode. Conversely, wet winters can result in an abundance of sand supplied to the coast.

Climate scientists have as yet not fully established how climate change will impact El Niño and La Niña cycles, but a preliminary indication is that El Niño episodes could increase in terms of severity and frequency.

2.3. Sediment Budget

Wave and current driven littoral transport is responsible for the majority of sand transport along the coast. Earlier studies estimated the longshore transport rate at Santa Cruz to around 300,000 to 500,000 cubic yards per year. After construction of the Santa Cruz Port jetty, the longshore transport is estimated to have reduced to about 195,000 cubic yards per year based on the amount of dredging that is bypassed at the Port entrance.

Rivers and streams provide a significant amount of input of sand to the littoral system. Table 2-2 identifies contributing watersheds by size, which is an indication of the sediment yield.

Table 2-2: Regional watersheds.

Watershed	Drainage Area (sq.mi)
San Lorenzo River	138
Arana/Rodeo Gulch	3.5
Soquel Creek	42
Borregas Creek	0.04
Aptos Creek	25
Pajaro River	1,300
Elkhorn Slough	70

Table 2-3 identifies several sources of sediment input to the Santa Cruz littoral cell, which commences at Pillar Point, Half Moon Bay and terminates at the Monterey Canyon at Moss Landing. The predominant direction of sediment transport is southward along the coast.

Table 2-3: Sources of sediment in the vicinity of New Brighton and Seacliff.

Sediment Source	Transport Rate (CY/year)
Littoral transport (pre jetty) [a)]	300,000 to 500,000
Littoral transport (post jetty) [b)]	195,000
San Lorenzo River	89,000
Arana/Rodeo Gulch	42
Soquel Creek	33,000
Borregas Creek	80
Aptos Creek	45,300
Pajaro River	60,500
Elkhorn Slough [c)]	n/a

a) USACE estimate prior to construction of the Santa Cruz jetty.

b) Griggs et al. estimate based on dredging at Santa Cruz.

c) Not considered, as the majority of the sediment output is lost to the Monterey Submarine Canyon.

Patsch & Griggs (2007) developed a sand budget for the Santa Cruz Littoral Cell, which is summarized in Table 2-4.

Table 2-4: Sand budget for North Monterey Bay, Patsch & Griggs (2007).

I/O	Transport Rate (CY/yr)	Sediment Source
I	+194,500	Dredging at Santa Cruz Port
I	+10,000	Cliff erosion
I	+60,500	Rivers and streams
O	-undetermined	Loss of deep water offshore
O	-265,000	Loss to Monterey Canyon

3. Cliff Retreat

Cliff retreat can occur as a result of wave-driven cliff-base erosion, erosion associated with surface runoff, weathering, and seismic activity, leading to downslope movement of rock and soil.

Moore & Griggs (2001) studied long-term cliff retreat in the northern part of Monterey Bay. Their findings are summarized in Table 3-1. They estimated a mean cliff erosion rate of 7.9 inches per year.

Table 3-1: Monterey Bay cliff retreat rates, Moore & Griggs (2001).

Location	Extent (feet)	Cliff Erosion Rate (in/yr)		
		Mean	Mean + 1 SD [a)]	Max.
Opal Cliffs	2,330	6.7	11.0	18.1
Depot Hill	1,640	6.3	8.7	11.8
Seacliff & New Brighton [b)]	-	7.9	11.0	15.2
Manresa	1,673	12.6	18.1	25.2
South of Manresa	2,034	3.9	6.7	9.8

a) 1 SD = one standard deviation.

b) Not included in Moore & Griggs (2001) study. Estimated value interpolated between Depot Hill and Manresa.

Hapke et al. (2002) conducted measurements and interpretation of coastal cliff erosion data at Seacliff to study the response of the cliff to climatic and seismic events.

The majority of the cliff along Seacliff State Beach and New Brighton State Beach is fronted by shore protection structures, bulkheads or seawalls that will intercept wave runup coming from the beach. Interspersed between Parks facilities, private residences are located at the base of the cliff and the frontage of these are typically protected with rock revetments or seawalls. In addition to this ad hoc line of defense, the fronting beach plays a role in attenuating wave runup.

Consequently, wave runup only reaches the base of the cliffs during storms that occur on the order of once every several decades, Hapke (2002). The sea cliff failures and resulting cliff retreat that currently occurs along this stretch of coast is primarily a result of terrestrial processes including overland flow, groundwater flow, and seismic shaking.

Figure 3-1 illustrates the potential failure surface involved in cliff retreat. Surface water runoff and perched groundwater flow atop the Purisima Formation during precipitation events may contribute to failures in the terrace deposits at the top of the cliff. Refer to Section 1.5 for information on groundwater levels. The dashed yellow lines indicate joints in the formation where potential failure surfaces would be likely to develop.

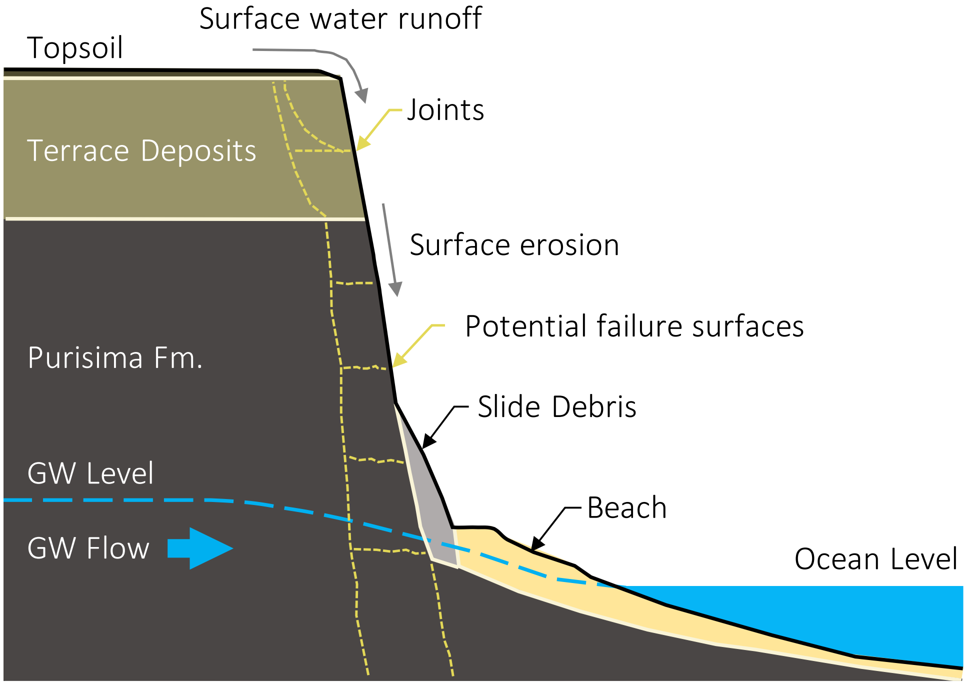


Figure 3-1: Schematic cliff profile and potential failure surfaces.

Figure 3-2 shows the mechanism of cliff retreat in the upper terrace deposits, which is the most frequent failure mode present-day. These failures are localized slips and slumps in the terrace deposits, often intersected by weak, approximately horizontal bedding planed in the terrace deposits. Slumps and slide debris will settle in a talus formation at the base of the cliff.

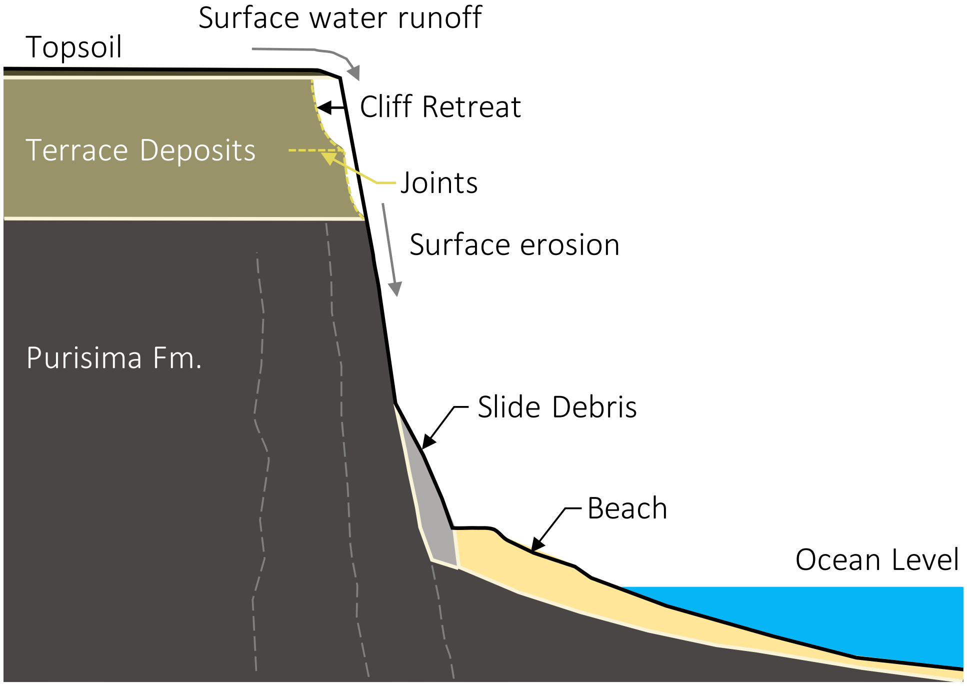


Figure 3-2: Cliff failures in upper terrace deposits.

Seismic events may initiate similar failure modes in the terrace deposits and induce rockfalls along portions of the cliff face. Refer to figure and discussion of seismic hazards in Section 1.6.3.

Figure 3-3 summarizes cliff retreat data from Hapke (2004) gathered over a 3,280 ft (1,000 m) section of the seacliff at Seacliff State Beach. The light gray bars indicate the long-term cliff retreat in meters. The dark gray bars indicate the short-term retreat on a decadal scale. Cliff retreat attributed to El Niño conditions are indicated in black.

The data shows that in areas where cliff retreat occurs over both time periods the short-term retreat makes up nearly half the long-term retreat amounts, suggesting that large-scale events such as earthquakes and El Niño episodes are responsible for much of the long-term retreat.

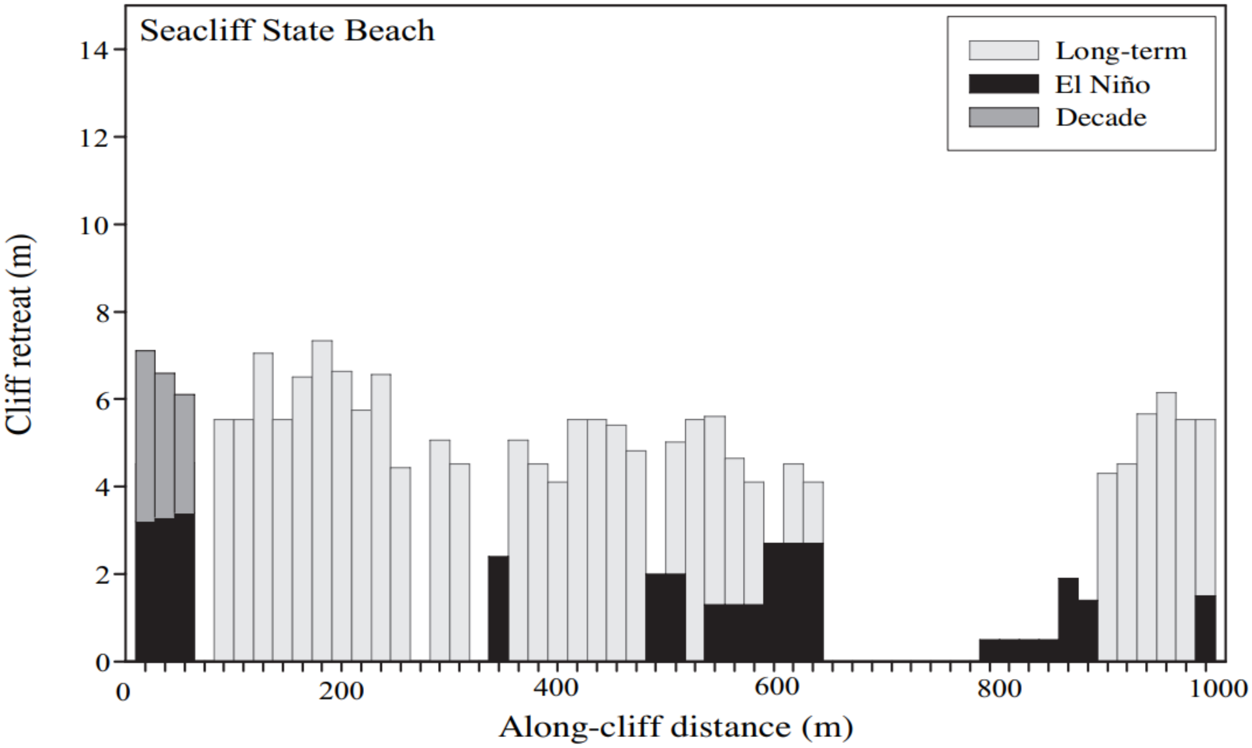


Figure 3-3: Long-term vs short-term cliff at Seacliff State Beach, Hapke (2004).

The following conclusions were made based on the findings of Hapke (2004):

- The long-term cliff retreat at Seacliff State Beach is fairly uniform with no apparent hotspots.
- The estimated long-term average rate of retreat is approximately 7.9 inches per year (20 cm/year).
- Seacliff State Beach experienced a significant amount of cliff retreat during the 1997-98 El Niño, attributed to the weakness of the cliff material in this location where numerous debris flows were initiated during high rainfall events.

- The one stretch of cliffs that did not fail during any of the time periods studied is a section where there is no development on the top of the cliffs, which suggests that runoff from developed parcels and/or lawn irrigation may be playing a role in the retreat of the cliffs.

- The long-term record of cliff retreat is not a reliable indicator of where the cliff is prone to failure in the short-term, i.e. cliff failures can be characterized as irregular and episodic.

4. SLR Projections

The project-adopted SLR projections are summarized below and in Table 4-1:

- 1 foot by ~2050. Intermediate-high SLR scenario for near-term actions.
- 2 feet by ~2070. Intermediate-high SLR scenario for mid-term planning.
- 4 feet by ~2100. Intermediate-high SLR scenario for long-term planning.
- 6 feet by ~2100. High SLR scenario to evaluate higher-end of possibilities for highly risk-averse facilities (e.g., wastewater treatment) for long-term planning.

Table 4-1: SLR projections.

Scenario	**Projected SLR in feet by:**			
	PD	**2050**	**2070**	**2100**
Intermediate-high SLR scenario	0.1’	1.0’	2.0’	4.0’
High SLR scenario	-	-	-	6.0’

PD – Present-day

4.1. Vertical Land Motion

There are several natural processes that can contribute to vertical land motion (VLM), which include tectonic movement, glacial isostatic rebound, soil compaction, erosion and deposition. Positive VLM is termed uplift, and subsidence denotes negative VLM. Hammond et al. (2016) studied VLM in California and Nevada and per their findings, the rate of VLM in the area of Seacliff State Beach and New Brighton State Beach is near zero. VLM does therefore not contribute significantly to relative SLR at Seacliff State Beach and New Brighton State Beach.

4.2. Relative SLR

Relative SLR refers to how the height of the ocean rises relative to land at the project location.

Section 4.1 established that vertical land motion does not contribute significantly to relative SLR at Seacliff State Beach and New Brighton State Beach. The following assessment evaluates the impact of erosion and deposition on relative SLR.

The area of the active zone of sediment transport in North Monterey Bay is estimated to approximately 15.6 square miles. In relation to the approx. 265,000 CY of sediment input annually, the average rate of potential sand accumulation over this area comes out to 0.2 inches per year.

The indication is therefore that once the rate of SLR exceeds 0.2 inches per year, the longshore sediment transport balance would start to become impacted by SLR.

In relation to the current SLR trend estimated by NOAA and the project-adopted SLR Projection, this threshold could be exceeded in the near future. Refer to Table 4-2.

Per the project-adopted SLR projection, the 0.2 in/year threshold would already be exceeded. For perspective, the current NOAA SLR trend estimates a somewhat lower rate of SLR but it should be noted that this analysis determines the trend based on past historical data and has not established if the rate of SLR has started to increase (accelerate).

Table 4-2: Projected SLR and Rate of SLR.

Year	Projected SLR (feet)	Rate of SLR (in/yr)	NOAA SLR Trend (in/yr)
PD	0.1	0.27	0.064
2030	0.3	0.33	To Be Determined
2040	0.6	0.41	
2050	1.0	0.50	
2060	1.5	0.59	
2070	2.0	0.67	
2080	2.6	0.76	
2090	3.3	0.85	
2100	4.0	0.94	

PD – Present-Day

4.3. Loss of Beach Width with SLR

Figure 4-1 illustrates the change in dry beach width anticipated with projected SLR.

The scale along the bottom of the figure indicates years from 2002 to present-day, continuing to the end of the century. The blue data points reflect the dry beach data from Figure 1-15. The solid yellow line indicates the location of the Mean High Water (MHW) line taken as representative of the dry beach width.

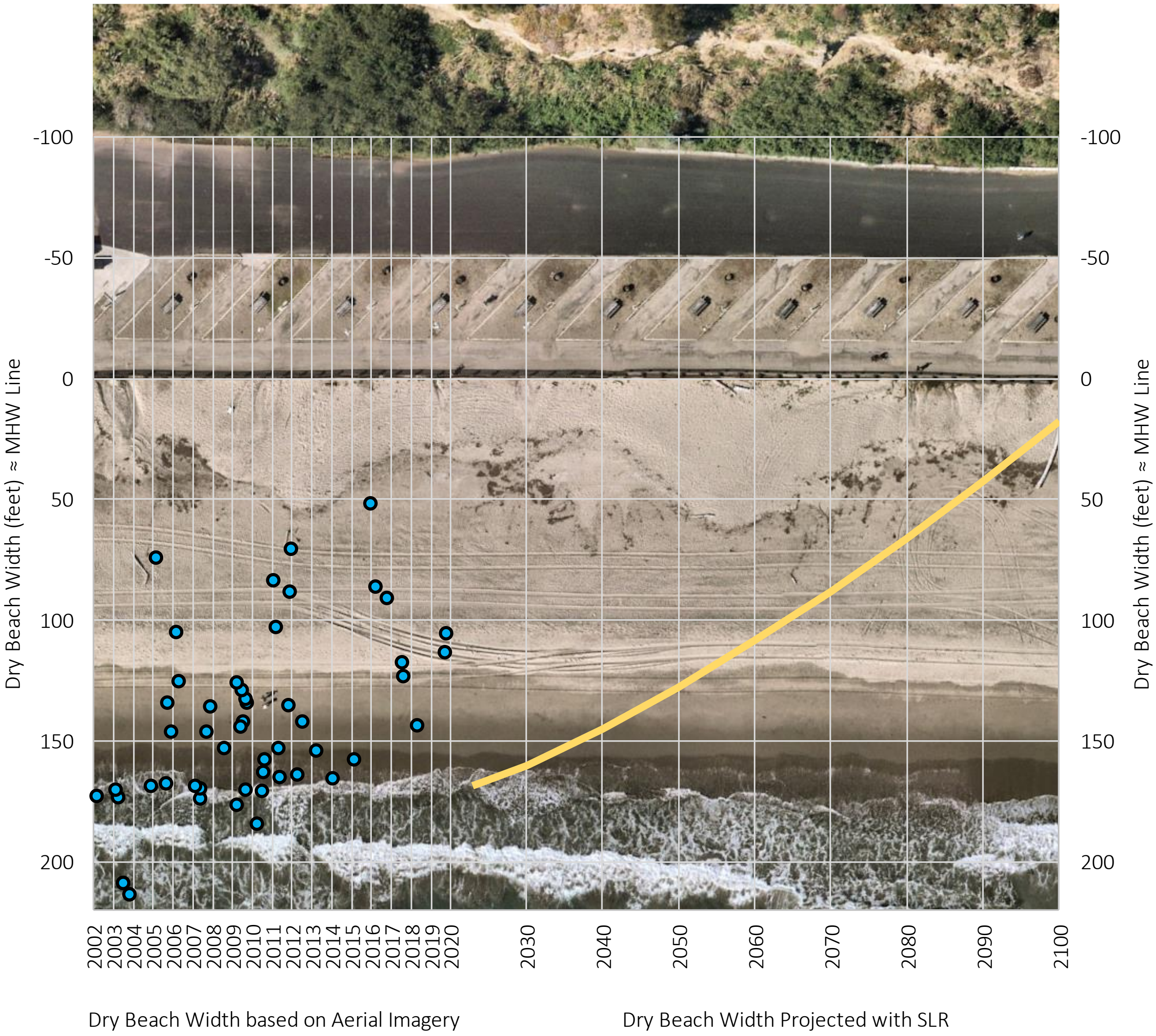


Figure 4-1: Projected change in dry beach width with SLR.

4.4. Beach Loss due to Storms and SLR

Figure 4-2 shows the loss of beach width that can be expected due to storms and SLR. The horizontal axis indicates storm recurrence intervals ranging from 1 to 100 years. The vertical axis indicates the loss of beach width. The colored curves indicate the loss of beach width associated with SLR. The legend at the top of the figure indicates the amount of SLR projected by years from present-day to the end of the century.

Beach loss due to storms is temporary, provided that the sand supply to the area is sufficient for recovery of the beach. Loss of beach width associated with SLR may be permanent if sand supply is insufficient for the active seabed profile to accrete at the same rate as SLR.

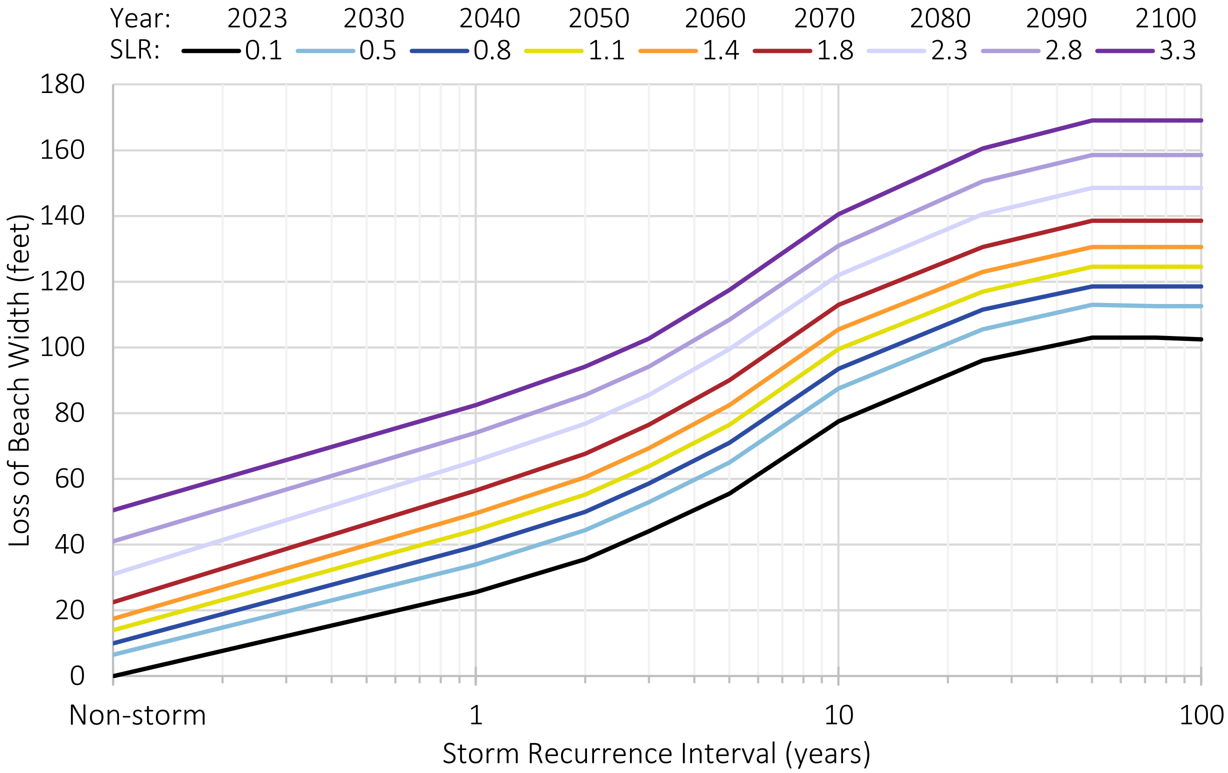


Figure 4-2: Projected loss of beach width due to storms and SLR.

4.5. Cliff Retreat with SLR

There are several processes that can affect cliff retreat, which can be categorized as follows:

- Coastal processes occurring at the base of the cliff include wave action and water level variations, both of which would be affected by SLR. Of these processes, wave conditions can change hourly and are also subject to a seasonal variation. Tides are subject to a daily, monthly, and annual variation.
- Surface runoff at the top of the cliff has a seasonal variation, which is not driven by SLR but may be affected by changes in hydrological cycles associated with climate change.
- Seismic activity, which is infrequent with long periods between events. Large seismic events in the recent historical record have triggered localized failures regionally and instances of block falls. Refer to Section 1.6.3 for a description of cliff retreat associated with the 1989 Loma Prieta earthquake.

The protective structures that currently exist at the base of the cliff protect the base of the cliff from being eroded[5]. Consequently, the present-day cliff retreat manifests as localized failures due to surface runoff, primarily occurring in the terrace deposits at the top of the cliff. Refer to Chapter 3 for field investigation findings by Hapke (2002).

Slumps, block falls, and slide debris accumulates at the base of the cliff in the form of talus deposits. Some of these deposits have side slopes corresponding approximately to the angle of repose of the debris material. This means that there may be little or no factor of safety ensuring the stability of these materials, and they may be subject to further sliding or slumping, e.g. in a seismic event.

Figure 4-3 provides an overview of cliff retreat mechanisms when impacted by surface runoff, SLR, tidal action and wave runup.

Once the talus deposits become exposed to wetting and drying and wave runup, wave action will mobilize and remove the slide debris. It should be expected that a sorting process will take place, where fines and smaller diameter material will be removed first, and larger diameter material may withstand wave action over a longer extent. If the slide debris contains large blocks, these may to some extent aid in armoring the seabed provided they are large enough to remain unaffected by wave action.

However, it should be expected that the talus deposits will be short-lived. Once wetting and drying, and wave action can impact the base of the cliff, a significant increase in the rate of cliff retreat should be anticipated. Blocks and cliff fragments will tend to fail and dislodge along the joints in the cliff formation (dashed yellow lines). Once block sections become dislodged along the base of the cliff, the overhanging blocks above are likely to dislodge and come down as block falls. Slumps and slip failures will impact the terrace deposits at the top of the cliff.

The change in cliff failure modes and ensuing retreat with SLR is likely that larger sections of the cliff face will fail as opposed to the irregular localized failures along the bluff top present day.

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[5] Refer to Section 1.8 for a categorization of shoreline protective structures.

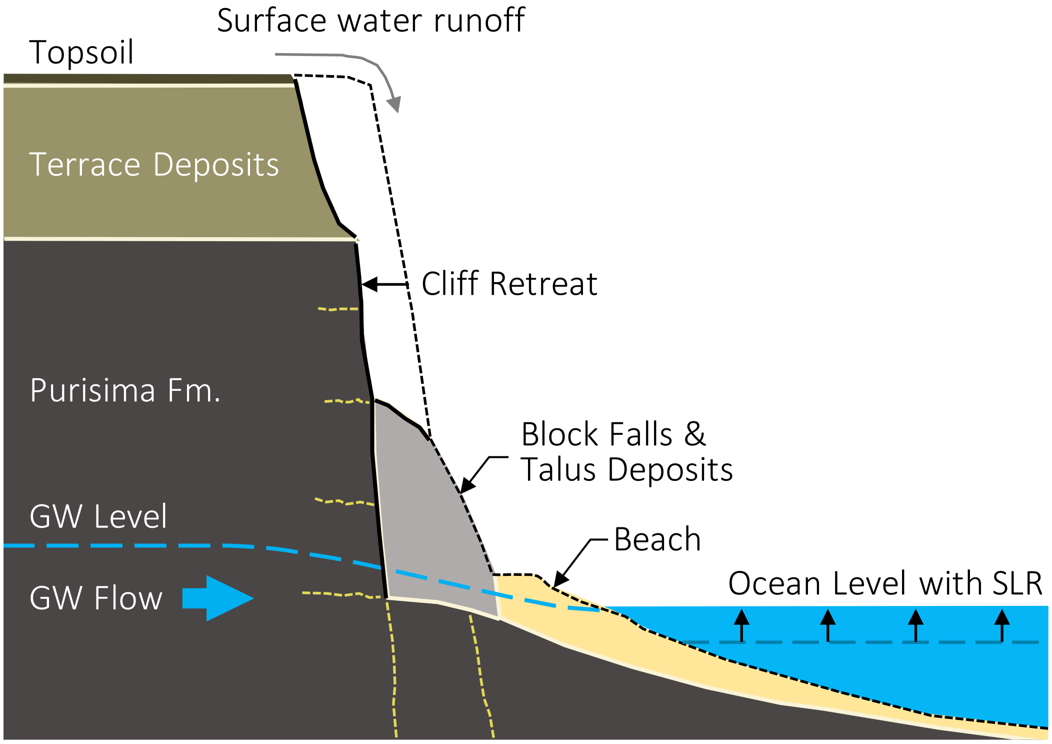

Figure 4-3: Schematic cliff profile depicting mechanism of cliff retreat.

Figure 4-4 summarizes cliff retreat estimates from OCOF (2023), which project a slightly higher rate of cliff retreat at Seacliff SB (blue curve) compared to New Brighton SB (yellow curve).

The average rate of retreat estimated for Seacliff SB is about 12 feet of cliff retreat for every foot of SLR, or about 1 foot for every inch of SLR.

The average rate of retreat for New Brighton SB is about 10 feet of cliff retreat for every foot of SLR, or about 0.8 feet of retreat for every inch of SLR.

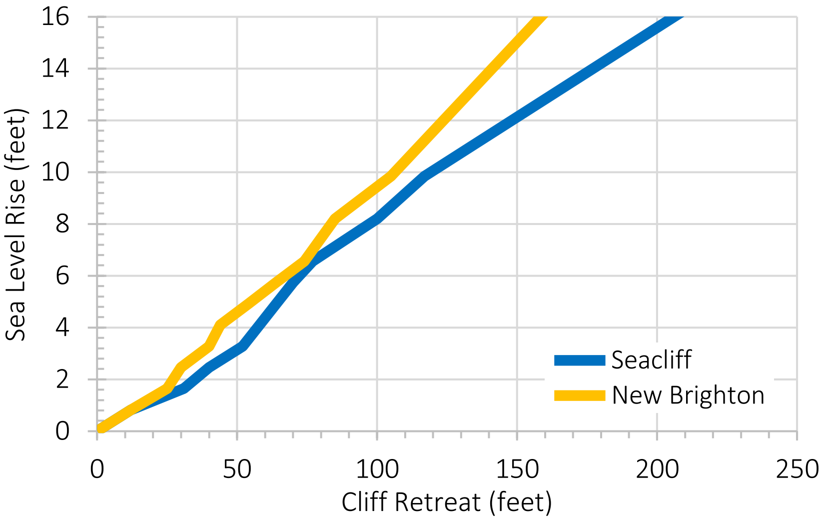

Figure 4-4: Cliff retreat with SLR, OCOF (2023).

5. References

AGU (2005). *Reflection and tunneling of ocean waves observed at a submarine canyon.* Authored by: Jim Thomson, WHOI-MIT Joint Program in Oceanography, Woods Hole, Massachusetts, USA and T. H. C. Herbers, Naval Postgraduate School, Monterey, California, USA. Geophysical Research Letters, Vol. 32, L10602, doi:10.1029/2005GL022834, 2005. American Geophysical Union. 0094-8276/05/2005GL022834.

Boessenecker (2013). *A new marine vertebrate assemblage from the Late Neogene Purisima Formation in Central California, part II: Pinnipeds and Cetaceans.* Robert W. Boessenecker. Geodiversitas 35(4):815-940. December 2013.

DWR (2023). *Groundwater Levels.* California's Groundwater Live. California Department of Water Resources. https://sgma.water.ca.gov/CalGWLive/#groundwater

GGWS (2023). *El Niño and La Niña Years and Intensities Based on Oceanic Niño Index (ONI).* Golden Gate Weather Services. https://ggweather.com/enso/oni.htm

Griggs & Plant (1990). *Coastal-Bluff Failures in Northern Monterey Bay Induced by the Earthquake.* The Loma Prieta, California, Earthquake of October 17,1989: Strong Ground Motion and Ground Failure - Landslides. U.S. Geological Survey Professional Paper 1551-C.

Hammond et al. (2016). *GPS Imaging of vertical land motion in California and Nevada: Implications for Sierra Nevada uplift.* By William C. Hammond, Geoffrey Blewitt, and Corné Kreemer. Journal of Geophysical Research: Solid Earth. 2016.

Hapke (2004). *The Measurement and Interpretation of Coastal Cliff and Bluff Retreat.* Published in USGS Professional Paper 1693. *Formation, Evolution, and Stability of Coastal Cliffs – Status and Trends.* Contributors: Edil, Tuncer B., Griggs, Gary B., Guy, Donald E., Hampton, Monty A., Hapke, Cheryl J., Kelley, Joseph T., Komar, Paul D., Mickelson, David M., Patsch, Kiki B., and Shipman, Hugh M. U.S. Department of the Interior. U.S. Geological Survey.

Hapke et al. (2002). *Map Showing Seacliff Response to Climatic and Seismic Events, Seacliff State Beach, Santa Cruz County, California.* Miscellaneous Field Studies Map MF-2399. By Cheryl J. Hapke, Bruce M. Richmond, and Mimi M. D'Iorio. U.S. Geological Survey. https://pubs.usgs.gov/mf/2002/2399/

Komar (1998). *Beach Processes and Sedimentation.* Prentice-Hall, Inc. 544 pages. By: Komar, P.D., 1998.

MRLC (2021). *NLCD Land Cover 2021 CONUS Land Cover.* Multi-Resolution Land Characteristics Consortium. U.S. Geological Survey, Earth Resources Observation and Science Center. MRLC Project, 47914 252nd Street, Sioux Falls, SD 57198-0001. https://www.mrlc.gov/viewer/

Moore & Griggs (2001). *Long-term cliff retreat and erosion hotspots along the central shores of the Monterey Bay National Marine Sanctuary.* By: Laura J. Moore, Gary B. Griggs. Earth Science Department and Institute of Marine Sciences, University of California Santa Cruz, Santa Cruz, CA 95064, USA. Marine Geology, International Journal of Marine Geology, Geochemistry and Geophysics. Received 19 November 1999; accepted 16 July 2001.

NOAA (2023). *Relative Sea Level Trend.* Tides and Currents. NOAA Station 9413450 Monterey, California. Center for Operational Oceanographic Products and Services (CO-OPS), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), 1305 East-West Highway, Silver Spring, MD 20910-3281. https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9413450

OCOF (2023). *Hazard Map.* Our Coast, Our Future. Coastal Storm Modeling System. USGS and Point Blue Conservation Science. https://ourcoastourfuture.org/

Patsch & Griggs (2007). *Development of Sand Budgets for California's Major Littoral Cells. Eureka, Santa Cruz, Southern Monterey Bay, Santa Barbara, Santa Monica (including Zuma), San Pedro, Laguna, Oceanside, Mission Bay, and Silver Strand Littoral Cells.* Prepared by: Kiki Patsch and Gary Griggs. Institute of Marine Sciences, University of California, Santa Cruz. California Department of Boating and Waterways. California Coastal Sediment Management Workgroup. January 2007.

Powell et al. (2007). *Age, Stratigraphy, and Correlations of the Late Neogene Purisima Formation, Central California Coast Ranges.* By Charles L. Powell II, John A. Barron, Andrei M. Sarna-Wojcicki, Joseph C. Clark, Frank A. Perry, Earl E. Brabb, and Robert J. Fleck. USGS Professional Paper 1740.

Tukman (2023). *Santa Cruz and Santa Clara Fine Scale Vegetation Map.* Final Report. Prepared for Santa Cruz Mountains Stewardship Network. Prepared by Tukman Geospatial & Aerial Information Systems for the Santa Cruz Mountains Stewardship Network, June 19, 2023. https://vegmap.press/cruz_clara_finescale_final_report

USGS (2016). *California State Waters Map Series – Monterey Canyon and Vicinity, California.* Open-File Report 2016–1072. Prepared by: By Peter Dartnell, Katherine L. Maier, Mercedes D. Erdey, Bryan E. Dieter, Nadine E. Golden, Samuel Y. Johnson, Stephen R. Hartwell, Guy R. Cochrane, Andrew C. Ritchie, David P. Finlayson, Rikk G. Kvitek, Ray W. Sliter, H. Gary Greene, Clifton W. Davenport, Charles A. Endris, and Lisa M. Krigsman. USGS, 2016. https://www.usgs.gov/centers/pcmsc/science/california-seafloor-mapping-program

USGS (2006). *National Assessment of Shoreline Change Part 3: Historical Shoreline Change and Associated Coastal Land Loss Along Sandy Shorelines of the California Coast.* Cheryl J. Hapke, David Reid, Bruce M. Richmond, Peter Ruggiero and Jeff List. Open-File Report 2006-1219. U.S. Department of the Interior. U.S. Geological Survey.

USGS (2002). *Geologic Map of the Monterey 30'x60' Quadrangle and Adjacent Areas, California.* Compiled by: David L. Wagner, H. Gary Greene, George J. Saucedo and Cynthia L. Pridmore. 2002. Digitized by: Sarah E. Watkins, Jason D. Little and Joseph J. Bizzarro. USGS, California Geological Survey, California Conservation.

Wentworth (1922). *A Scale of Grade and Class Terms for Clastic Sediments.* By: Chester K. Wentworth, Journal of Geology, 1922. Grain size chart reproduced from United States Geological Survey Open-File Report 2006-1195. https://en.wikipedia.org/wiki/Grain_size

Yancey (1968). *Recent Sediments of Monterey Bay California.* Prepared by T.E. Yancey. Hydraulic Engineering Laboratory College of Engineering, University of California Berkeley, July 1968.