integral INSIGHT FOR AN EVOLVING WORLD

City of Carmel-by-the-Sea

Overview of the Phase 1 Coastal Engineering and Hazard Assessment for Carmel Beach

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City Council

Presentation Outline

- **Overview of Phase 1, Tasks 1 – 4**
  - Task 1 – Coastal Engineering and Protection Assessment
  - Task 2 – Shoreline and Beach Change Analysis: Seasonal and Long-Term
  - Task 3 - Shoreline and Beach Erosion Exposure Modeling
  - Task 4 - Coastal Hazard and Sea Level Rise Vulnerability Assessment
- **Introduction to Phase 2**

Task 1: Coastal Engineering and Protection Assessment

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Task 1 Findings

- **17** coastal armoring structures were assessed including **6 riprap revetments** and **11 vertical seawalls**.
- **11 coastal access stairways** were also assessed - *however conditions have changed significantly since the assessment*
- Seawalls are identified with an **S**, revetments **R**, and stairs **ST**.
- The map shows the priority of repair rankings from **very low** to **high**
- Of the **6** revetments, **4** are in need of repair; **one** in its **entirety** and the others in some portions
- Blue circles represent stairs that we damaged or undergoing repairs in 2024

High-priority repairs for seawalls

- Seawall just west of the beach volleyball courts between Ocean Ave and Carmel Way.
- Structure is significantly deteriorated and is unstable.
- Revetments R2 and R4 needed restacking to avoid potential toppling onto beach or beach goers

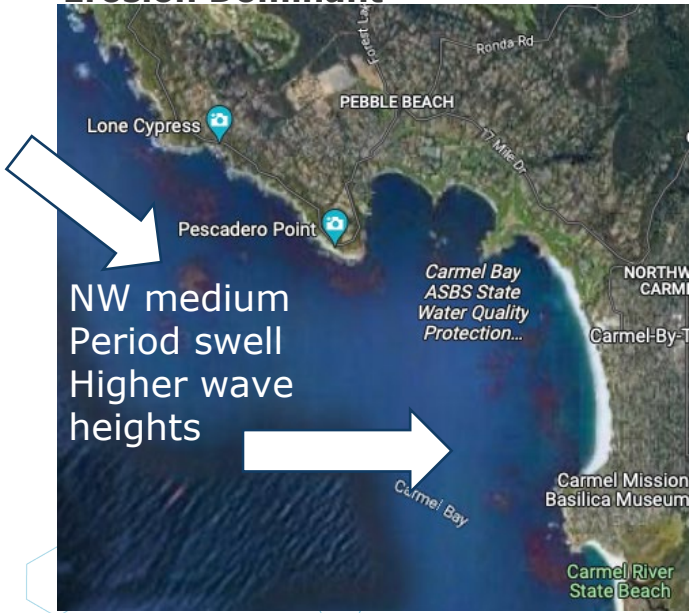
S10 between Carmel Way and Ocean Ave

Task 2: Shoreline and Beach Change Analysis: Seasonal and Long-Term

Winter vs Spring Waves

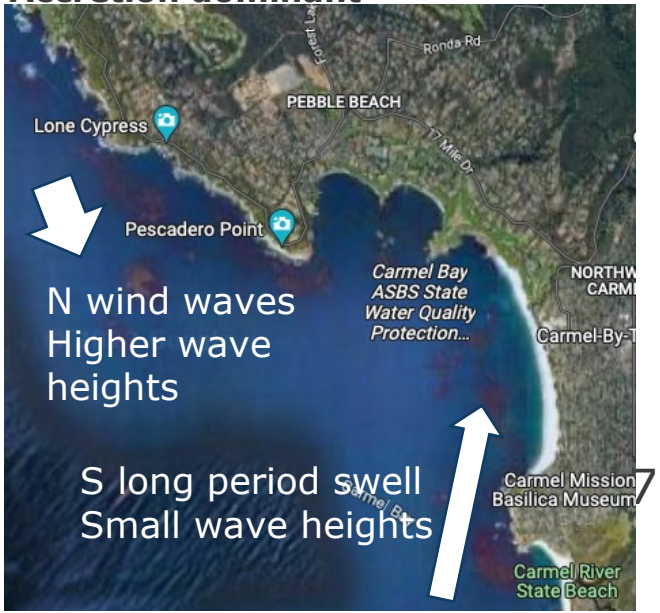
Winter

Erosion Dominant



Spring

Accretion dominant



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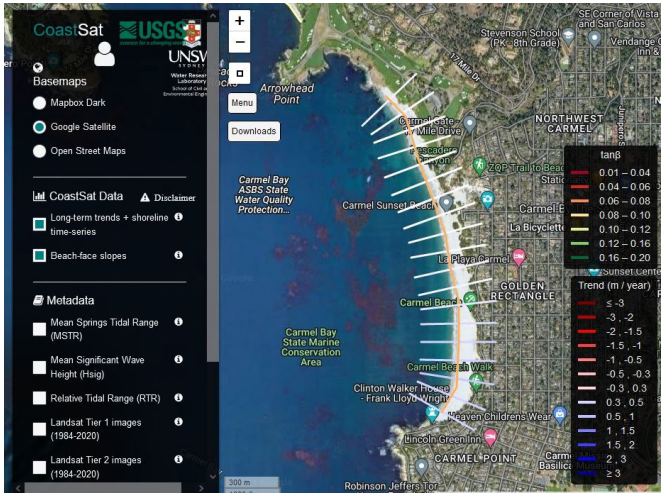
Datasets used for Seasonal and Long-term Change Analysis

- Waves - NDBC Buoys (waves), USGS Waves 1980s to 2100
- Satellite - CoastSat (University of New South Wales and USGS) - ~monthly from 1984 - 2021
- Terrain - Lidar Digital Elevation Models, 8 flights from 1997-2018
- Aerial Photographs from 1941-2022
- Beach Surveys - Willard Bascom, monthly from 1946-47
- Others: Reports, photos, winter of 2022-23 field visits

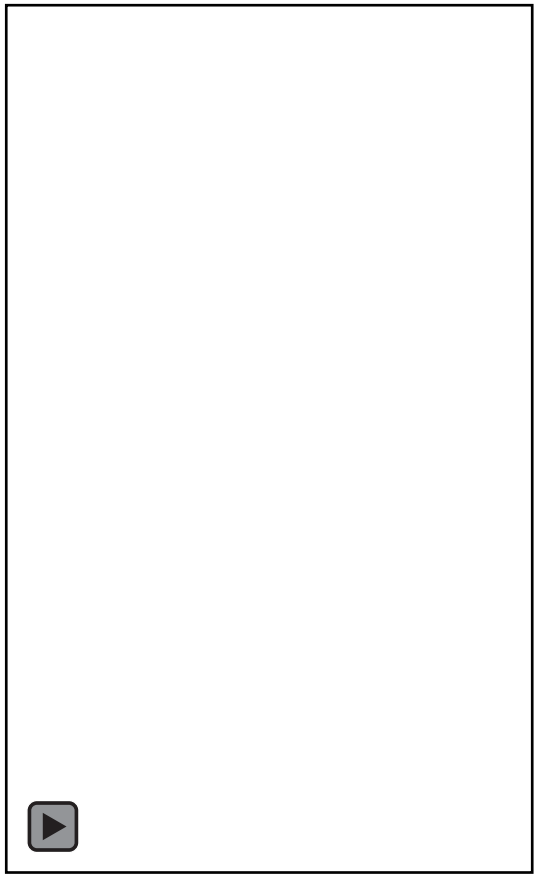


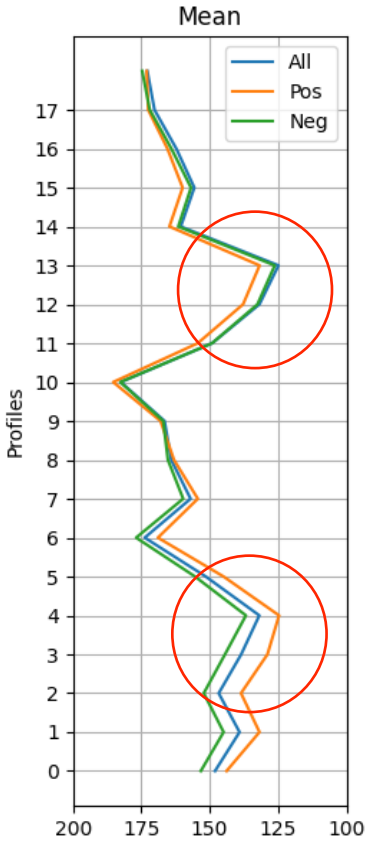
18 CoastSat Transects

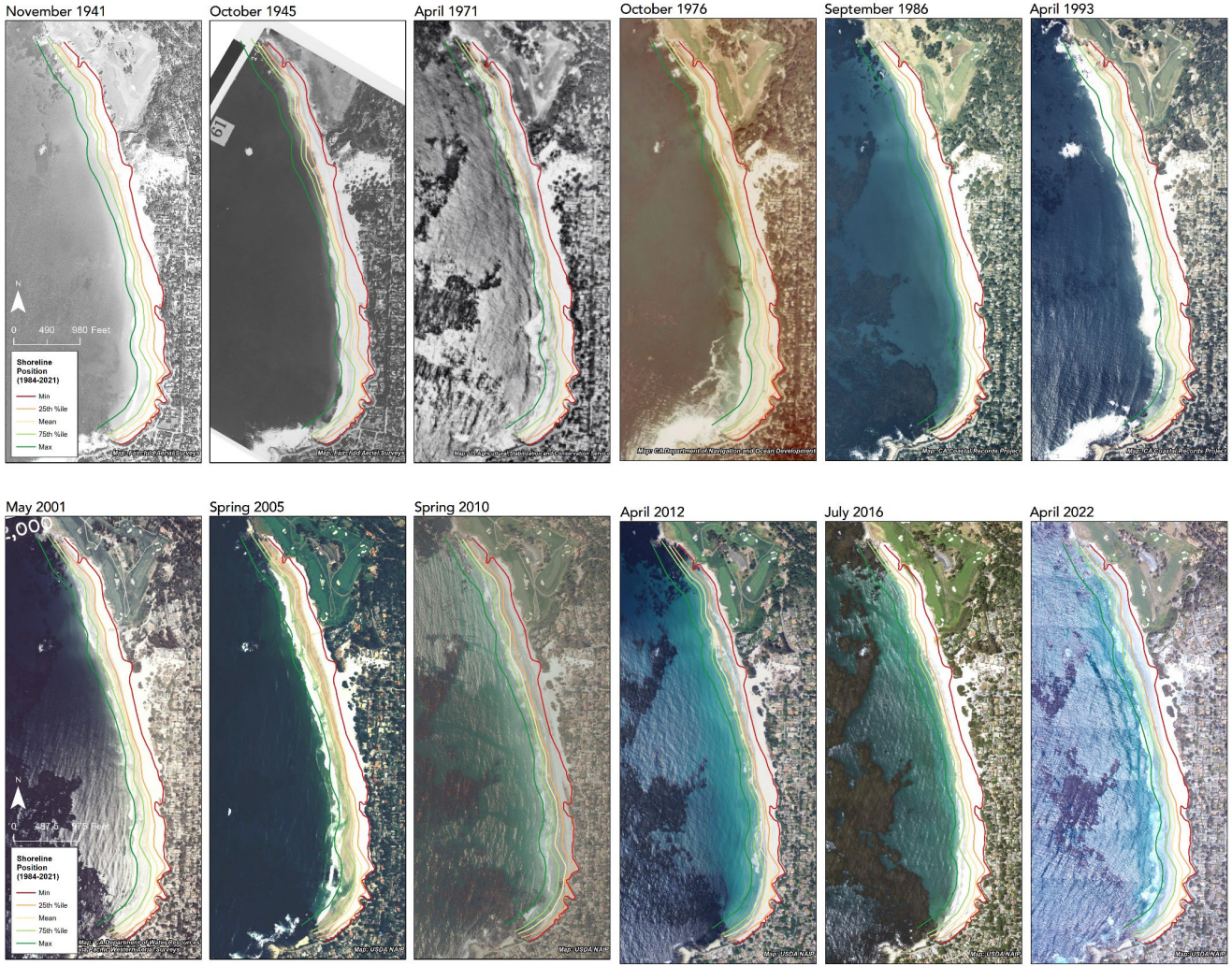
Seasonal/Long-term Change Determined from CoastSat Shoreline Change Analysis

CoastSat Data:

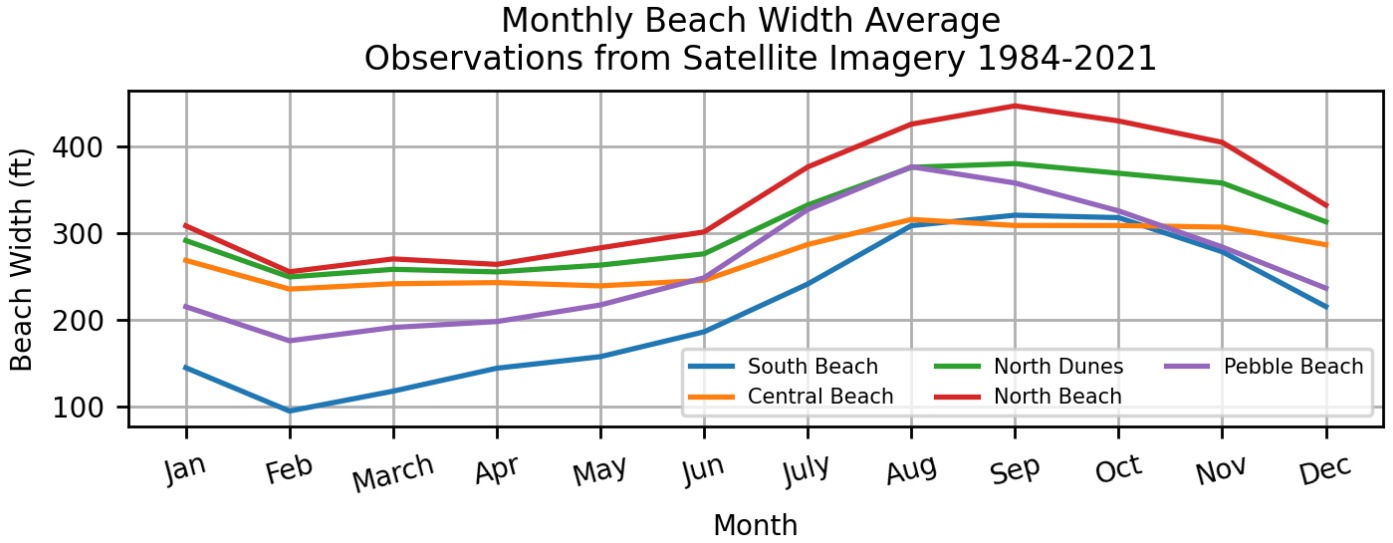
- 1,100 images with shoreline position
- 19 Shoreline Transects
- ~ monthly 1984 to 2021
- Pattern of erosion hotspots – key to consider in adaptation planning







Average Seasonal Beach Width Change

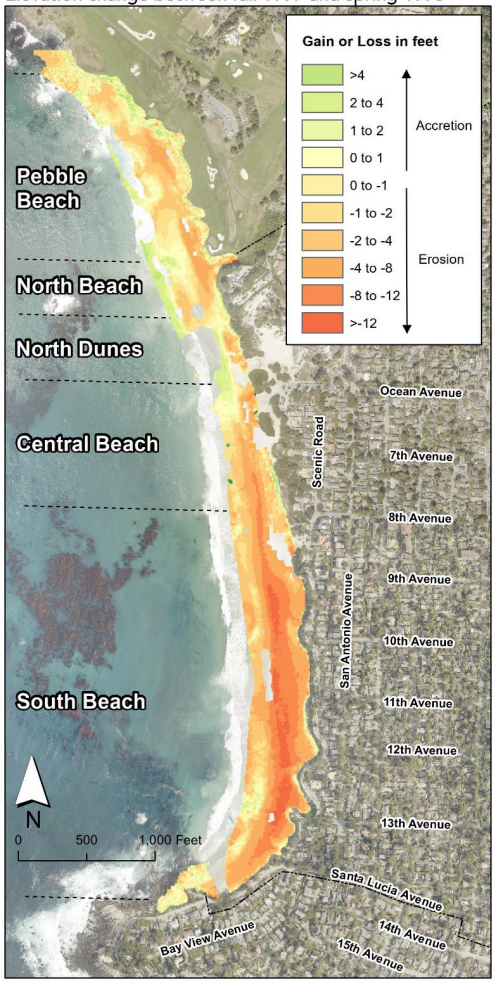


- Beach sections will respond differently throughout the year
- North and south see recovery beginning in late winter, and central areas see recovery beginning more slowly in the spring
- South beach has greatest seasonal beach changes
- Central beach has smallest seasonal beach changes

1997-98 El Niño Response

- Maximum beach scour was ~14 feet (in vertical loss)
- Beach scour was the highest in the South Beach section
- North Dunes area saw the smallest trend with sediment moving into the foreshore
- ~300,000 cubic yards of sand was moved from the beach to offshore bars

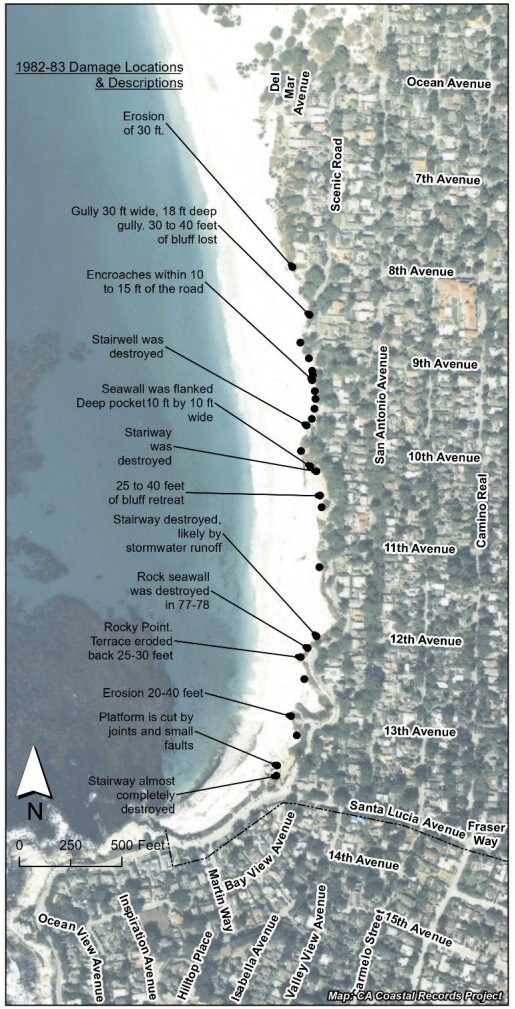
Winter 1997-98 El Niño Shoreline Change
Elevation change between fall 1997 and spring 1998



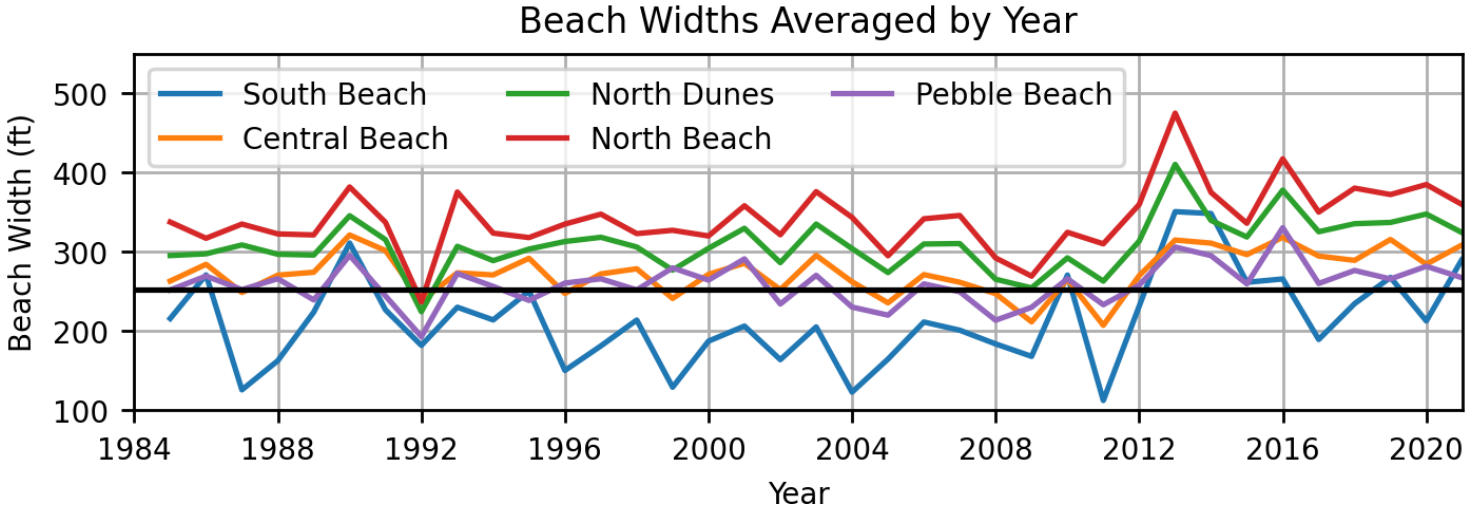
1982 - 83 El Niño Damages Comparison

- Four stairways destroyed or partially destroyed
- Significant outflanking of seawalls
- Significant bluff top erosion, in some places as much as 40 feet
- City Public Works noted that the level of the back beach was 4-10 feet lower in the latter part of July than normal

Winter 1982-83 El Niño Shoreline Damages
With the September 1986 Aerial as Reference



Long-term Beach Width Change



- Most current armoring has been in place since 1984 (with some additions post 1984)
- Shoreline is relatively stable - no long-term trends
- Sediment transport is most likely cross-shore movement (annual cycle)
- The beach widths average about 250 feet without any significant trend in the 30-year dataset
- Particularly erosive years for all beach sections was 1992 (likely related to the 1992 El Niño), 2009 and 2011

Tasks 3 and 4: Shoreline and Beach Erosion Exposure Modeling & Coastal Hazard and Sea Level Rise Vulnerability Assessment

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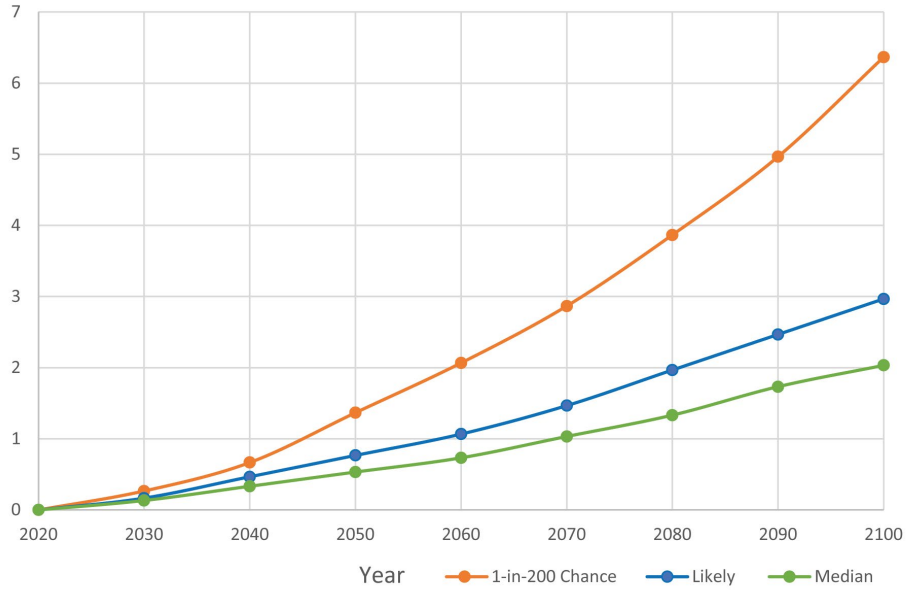
Task 3 and 4 Scope of Work

- Task 3
  - To project beach, cliff, and dune erosion hazards with sea level rise
- Task 4
  - Summarize the risk to public and private infrastructure and assets
  - Determine the likelihood of impact across multiple sea level rise horizons and erosion scenarios.
- Erosion scenarios included:
  - Erosion rate baseline averages: **likely** (0.2 ft/yr), **best** estimate (0.4 ft/yr), **worst case** (0.7 ft/yr) to provide a range of erosion projections
  - **With** and **Without** coastal armoring

Sea Level Rise Scenarios

- Sea level rise projections are based on the State of California Sea Level Rise Guidance from 2018 and the 2024 draft update.
- Sea level rise scenarios considered medium-high risk aversion (.5% likely) to low-risk aversion (66% likely):
  - Current conditions, **2020 baseline** (what is at risk now)
  - Near-term, **1** ft of SLR / **2045 - 2060**
  - Medium-term, **2** ft of SLR / **2060 – 2080**
  - Long-term, **4** ft of SLR / **2080 – 2100+**



Processes Driving Erosion

Coastal Processes:

- Tide level
- Breaking wave run up
- Wave reflection
- Wave overtopping

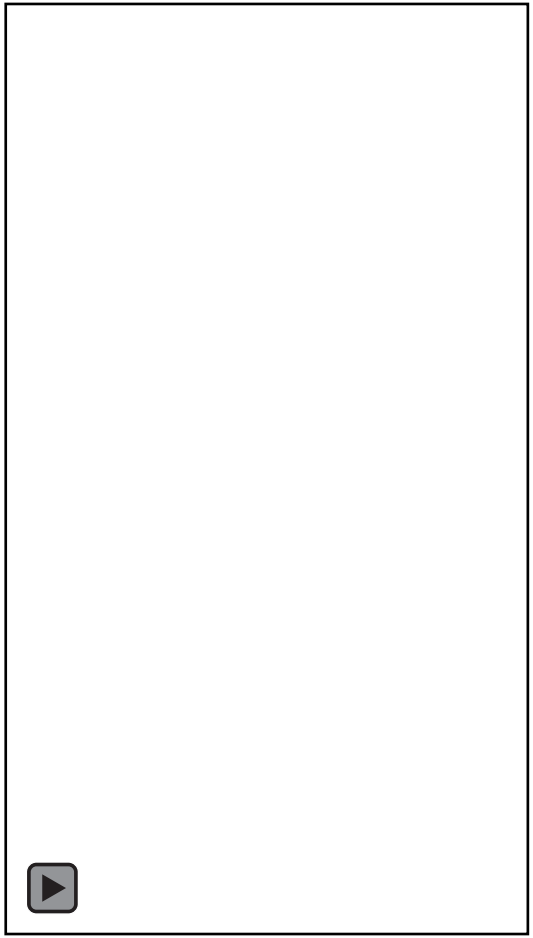
Local Conditions:

- Geomorphology
- Coastal armoring
- Cliff/bluff substrate
- Localized currents generated by waves
- Other factors including stormwater runoff and anthropogenic factors

El Niño years typically have higher water levels and storminess resulting in more erosion

Recent Observations

- Winter storms from 2022/23 and 2023/24 have been powerful and destructive
- Video: Stairs at Martin Way, January 2024
- Four stairwells have been damaged, and the sand ramp at 8th Ave has seen significant erosion



Beach Width Narrowing With Existing Coastal Armoring Methods and Results

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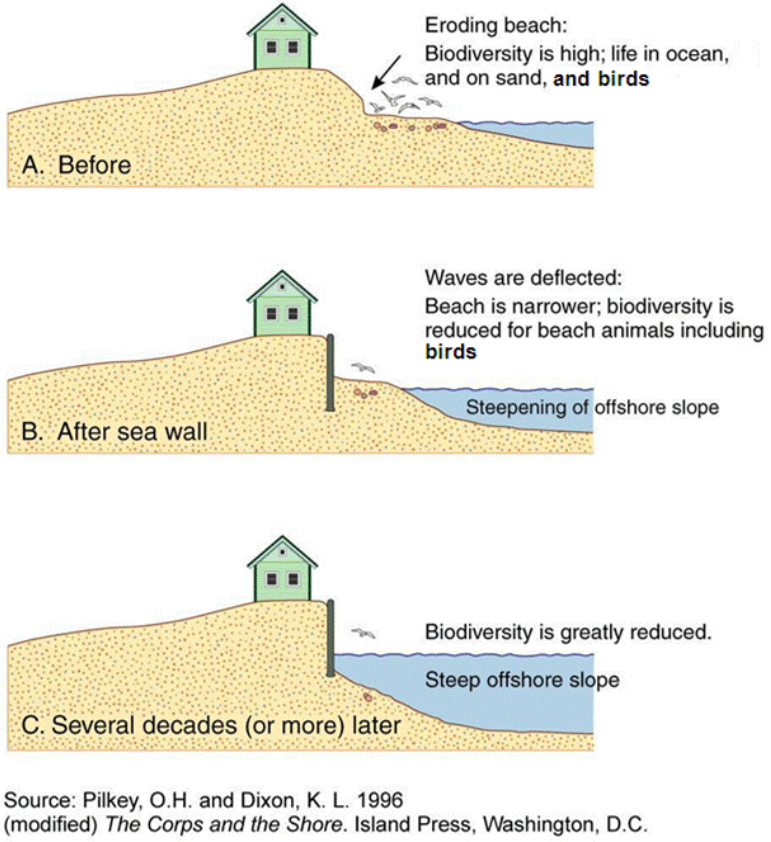
What is Beach Narrowing?

- On armored coastlines, beaches will narrow and can become permanently inundated with sea level rise - this is known as **Coastal Squeeze** or **Passive Erosion**
- Upland development is temporarily saved at the expense of the sandy beach
- Over time, recreational beach areas and habitats will be lost unless action is taken



Source: Pilkey, O.H. and Dixon, K. L. 1996
(modified) *The Corps and the Shore*. Island Press, Washington, D.C.

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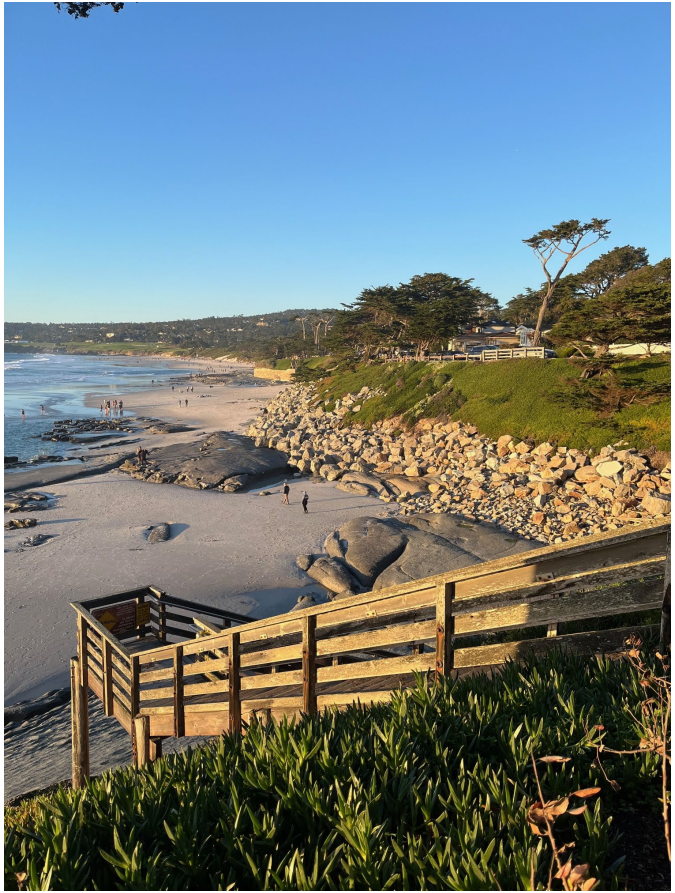
Beach Narrowing Methods

- Project typical summer beach widths for each foot of sea level rise
- Typical summer beach is based the CoastSat data presented in Task 2 (using 75th percentile from 1984-2021)
- Winter beach varies widely and is often scoured completely in the south beach (like now)
- This model can be considered a *"hold the line"* scenario and represents what may occur if **no adaptation** strategies are implemented in the future



Beach Width Narrowing: Short term (2045 - 2060)

- A typical summer beach still exists
- Southern section becomes “squeezed” especially at 12th avenue headland
- Summer beach widths narrow ~**50 - 60** feet for each foot of sea level rise
- Beach widths generally higher in the north than the south
- By **1 ft** of sea level rise, typical summer dry sand beach reduced by **20%**

North

South

Beach Width Narrowing: Medium-term (2060 - 2080)

- The northern beach section remains connected laterally
- Lateral access to areas south of 12th Avenue headland may be restricted
- By **2 ft** of sea level rise, reduced by **39%**, with loss of lateral beach access to areas south of the 12th Avenue headland

North

South

Beach Width Narrowing : Long Term (2080 – 2100)

- Only continuous dry sand beach is between the northern sand ramps to Pescadero Canyon
- Two small pockets between 8th avenue and 11th avenue (~1.5 acres each)
- By **4 ft** of sea level rise, reduced by **78%**, with two small pocket beaches remaining in the south, but dry beach remaining north of the sand ramps

North

South

Beach Width Narrowing beyond 2100

- Very little beach remains by 5 ft of SLR

Sea Level Rise Elevation (ft)	Acres of Dry Sand Beach (summer)	Percentage
0	34.2	100%
1	27.4	80%
2	20.7	61%
3	14.1	41%
4	7.6	22%
5	2.6	8%

North

South

Cliff & Dune Erosion Methods and Results

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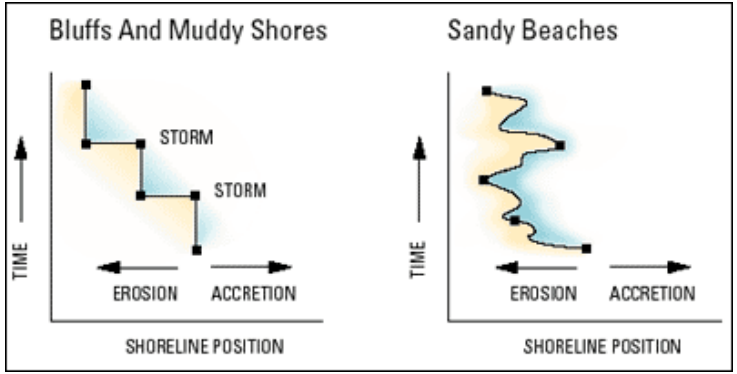
Cliff Erosion vs Sandy Beach Erosion

- Bluffs, cliffs, and dunes experience episodic erosion
- Bluffs and cliffs **do not recover**
- Sandy beaches experience gradual erosion and **can recover**
- Carmel has a multitude of conditions:
  - Del Mar Dunes and North Dunes
  - Unarmored cliffs
  - Seawalls and riprap, primarily at the southern end of the beach



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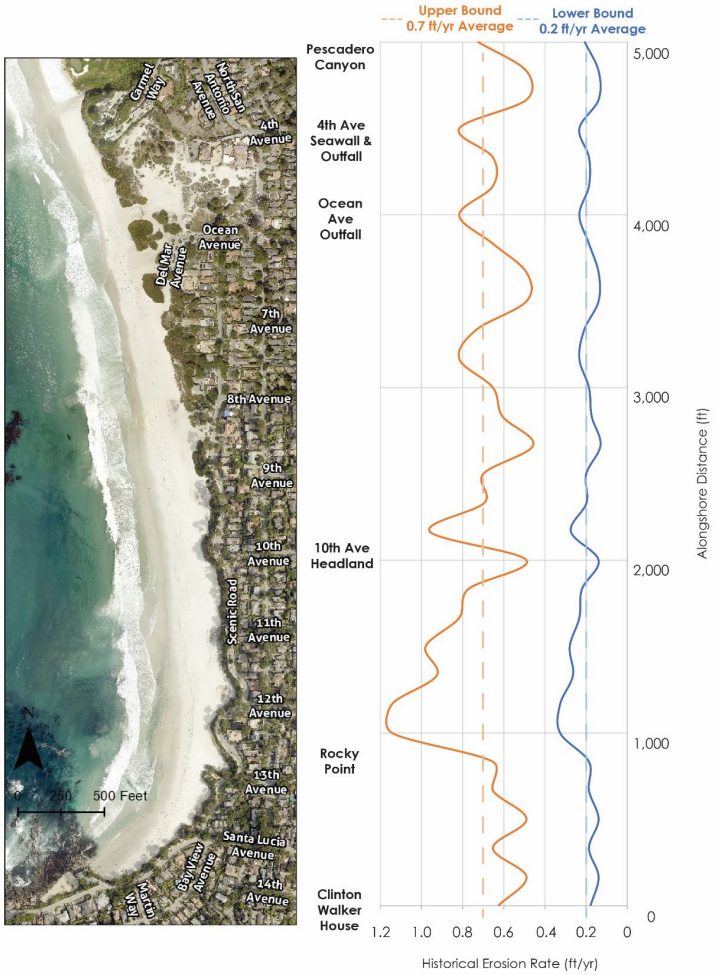
Erosion Rates

- Erosion rates establish baseline erosion projections
- Erosion rates based on previous studies that determined **average** rates across entire City shoreline (Rogers Johnson and Associates, 1983)
- **Location-specific** erosion rates were determined for this study based on local geomorphology and wave conditions



Right: the range erosion rates showing the variability about the mean

Cliff and Dune Overtopping and Erosion
With Coastal Armoring

Erosion and Overtopping Short Term (2045 – 2060)

Overtopping:

- Highest risk between 8th and 10th Avenues

Erosion:

- Most threatened area for erosion is at Central Carmel Beach between 8th and 12th Avenues
- Red circle indicates an unarmored area of shoreline at Scenic Dr. and 12th Avenue

North Central South

Overtopping Potential:

Low
Medium
Medium-High
Very High

Erosion hazard area

Cliff and Dune Erosion Medium Term (2060 – 2080)

Overtopping:

- Overtopping potential highest between 8th and 12th Avenues

Erosion:

- Projected erosion hazards in areas behind seawalls range ~ 20-40ft
- Erosion hazard zones are slightly higher along the dune-backed shoreline

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Cliff and Dune Erosion Long Term (2080 – 2100)

Overtopping:

- South Carmel Beach between Martin Way to 13th Avenue
- North Beach near Pescadero Canyon

Erosion:

- Highest erosion potential around 12th Avenue up to 150 ft (see red circle)

Overtopping Potential:

Low
Medium
Medium-High
Very High

Erosion hazard area

Task 4: Vulnerability Assessment
Assuming no Adaptation in the Future

Current Vulnerabilities

- **Stormwater** conveyance
- All **beach access stairways** and the **beach overlook** at Del Mar
- **Restroom** near Santa Lucia Avenue, located at ~24 ft NAVD 88, which is at the same elevation of the FEMA base flood elevation for this area
- Wave splash (not green water associated with overtopping) may exceed the bluff crest of the armored coastline between 13th Avenue and Martin Way and the private seawall near Pescadero Canyon

Stormwater infrastructure

Restroom near Santa Lucia Ave

Short Term (1 ft SLR, 2045 - 2060)

- **Scenic Road** is exposed in 6 locations from 8th Avenue and 11th Avenue
- **Wastewater mains** are exposed at:
  - Martin Way
  - Between 9th and 10th Avenues
  - Under dunes between 7th and 8th Aves
- The integrity of the **sand dune ramps** may be at risk
- 0.2 acres of **North Dunes Habitat** potentially eroded
- During large storms wave splash could be more frequent between 8th Avenue and 11th Avenue

Sand ramp near the Del Mar Parking Lot

Medium Term (2ft SLR, 2060 - 2080)

- **Scenic Road**: entire length exposed, including underground water and sewer infrastructure
- **Water main** between 8th and 10th avenue
- An additional 0.3 acres of dune habitat
- During large storms, a **wastewater lift station** located at ~24.5 ft may be exposed to wave flooding
- **5 homes** may be vulnerable under the *without armoring* scenario

Wastewater lift station near 8th Avenue

Long Term (2-4ft SLR, 2080 - 2100)

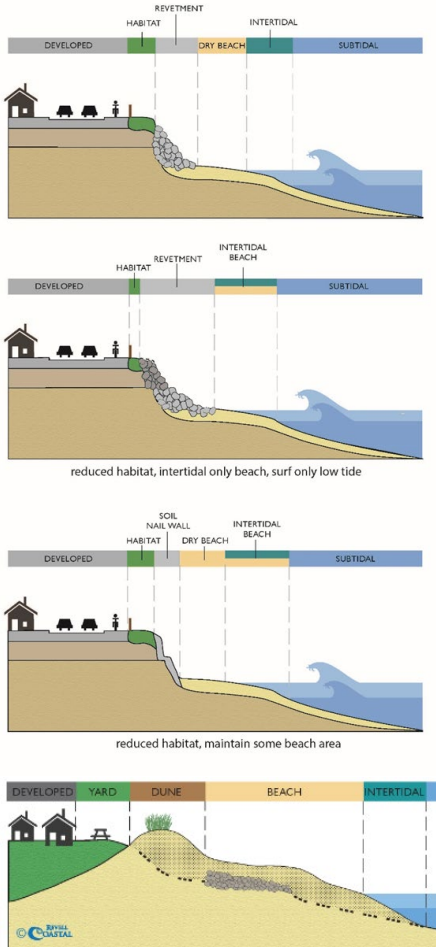
- **44 homes** along Scenic Road and Pescadero Canyon in the *with armoring scenario*
  - Up to **59 homes** in the *without armoring scenario*
- Del Mar Parking Lot
- 0.6 acres of dune habitat is exposed to erosion, for a total of 1.16 acres
- Water main under Scenic Rd. at 13th Ave
- Sewer main at 8th Ave
- Two water storage tanks located near the Del Mar parking lot
- Standing water from wave overtopping during storm events is now more frequent everywhere south of 8th Ave

<u>Assuming high erosion potential:</u>

- Restroom at Del Mar Parking Lots
- Volleyball Courts

What's Coming in Phase 2

- Intro to adaptation – Protect, Accommodate, Retreat
- Community Outreach
- Socio-economic Analysis
- Weighing different adaptation strategies
  - Certainty of success, costs, secondary impacts, co-benefits, expected life of the project
  - Developing adaptation pathways over time
- Local Coastal Program Policies and Implementation Language updated to reflect community vision and adaptation directions.



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El Niño Effects

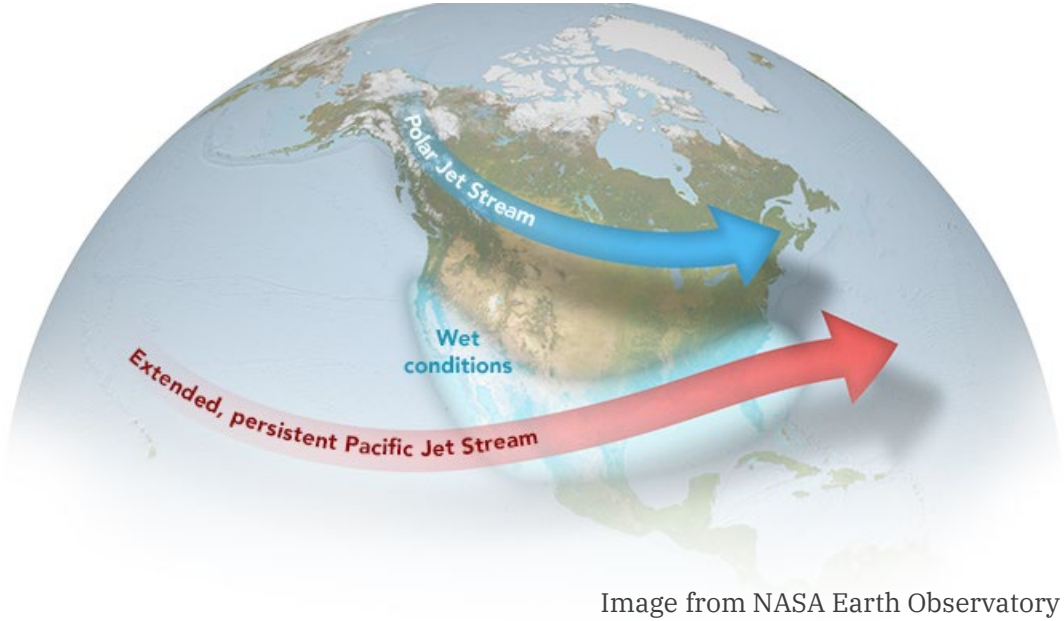
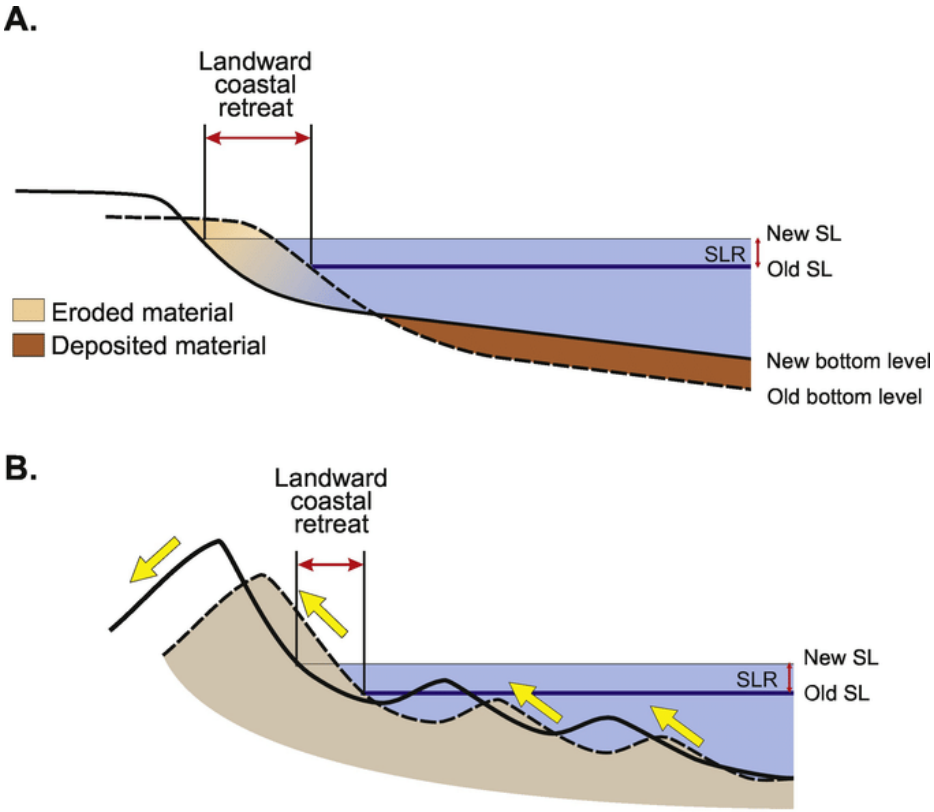


Image from NASA Earth Observatory

Dune Erosion Methods

- Projected dune erosion using FEMA guidance and a *"marching back"* of the shoreline position
- If no sediment is available, *"coastal squeeze"* occurs
- Projected dune erosion out to 1 foot of sea level rise, then transitioned to cliff erosion processes as underlying cliff exposed



Cliff Erosion Methods

- Multiple model approach similar to USGS cliff erosion tool that use historical erosion rates as a baseline
- We modeled **unarmored** and **armored** conditions, and **high**, **medium**, and **low** assumptions on historical erosion rates.
- For the **armored** scenario, the frequency of wave attack above the top of armoring leads to an acceleration of erosion rates into the future
- For the **unarmored** scenario, a decreasing surf zone width and more wave energy on the cliff drives erosion

The light blue lines indicate the higher water level exposure with sea level rise

Location *From south to north*	Water Levels above the Top of Armoring or Sandstone Cliff *Percentage of days* that the contact elevation is exceeded* Sea Level Rise Horizon, feet (years)			Water Levels above the Crest of the Bluff or Dune *Does wave splash exceed crest elevation? (YES or NO)* Sea Level Rise Horizon, feet (years)		
	1 (2045–2060)	2 (2060–2080)	4 (2080–2100+)	1 (2045–2060)	2 (2060–2080)	4 (2080–2100+)
Section 1 South Beach						
Martin Way to Santa Lucia Ave (Seawall)	4%	8%	21%	YES	YES	YES
Santa Lucia Ave to 13th Ave (Seawall)	6%	16%	23%	YES	YES	YES
13th Ave Headland (Seawall)	1%	3%	10%	YES	YES	YES
13th Ave Cove (Seawall)	4%	10%	22%	NO	NO	NO
13th Ave to 12th Ave (Riprap)	22%	25%	25%	NO	NO	NO
13th Ave to 12th Ave (Seawall)	<1%	<1%	2%	NO	YES	YES
13th Ave to 12th Ave (Unarmored Cliff with Riprap around SW Drain)	2%	5%	17%	NO	YES	YES
13th Ave to 12th Ave (Unarmored Cliff)	14%	21%	25%	NO	NO	YES
12th Ave Cove (Unarmored Cliff)	<1%	1%	5%	NO	NO	NO
12th Ave Cove (Revetment)	1%	2%	6%	NO	NO	NO
12th Ave to 11th Ave (Revetment)	1%	1%	4%	YES	YES	YES
11th Ave to 10th Ave (Buried Revetment)	15%	20%	24%	YES	YES	YES
10th Ave Headland (Seawall)	13%	19%	24%	YES	YES	YES
10th Ave to 9th Ave (Buried Revetment)	24%	25%	25%	YES	YES	YES
9th Ave to 8th Ave (Buried Revetment)	25%	25%	25%	YES	YES	YES
8th Ave Stairs (Buried Revetment)	12%	24%	25%	NO	NO	NO

Section 2 Central Beach						
8th Ave (Buried Revetment under Vegetated Dune)	<1%	3%	23%	NO	NO	YES
8th Ave to 7th Ave (Vegetated Dune)	<1%	<1%	4%	NO	NO	NO
7th Ave (Vegetated Dune)	0	0	<1%	NO	NO	NO
Southern Sand Ramp (Dune)	0	0	0	NO	NO	NO
7th Ave to Ocean Ave (Vegetated Dune)	0	0	0	NO	NO	NO
Del Mar Parking Lot (Dune)	0	0	0	NO	NO	NO
Section 3 North Dunes						
Ocean Ave (Buried Revetment under Vegetated Dune)	0	0	0	NO	NO	NO
Ocean Ave (Vegetated Dune)	0	0	0	NO	NO	NO
Northern Sand Ramp (Dune)	0	0	0	NO	NO	NO
Ocean Ave to 4th Ave (Vegetated Dune and Cliff)	0	0	0	NO	NO	NO
Ocean Ave to 4th Ave (Vegetated Dune and Cliff)	0	0	0	NO	NO	NO
Ocean Ave to 4th Ave (Seawall)	0	0	0	NO	NO	NO
4th Ave Stairs (Vegetated Dune and Cliff)	0	0	0	NO	NO	NO
Section 4 North Beach						
4th Ave to Pescadero Canyon (Unarmored Cliff)	0	0	0	NO	NO	NO
4th Ave to Pescadero Canyon (Seawall)	18%	24%	25%	NO	NO	YES

Coastal Cliff and Dune Erosion Projection With Armoring

Coastal Cliff and Dune Erosion Projection Without Armoring - North Carmel Beach

1 ft of SLR (2045 - 2060) | 2 ft of SLR (2060 - 2080) | 4 ft of SLR (2080 - 2100+)

Projected Bluff Crest Position Across Sea Level Rise Elevations

Most Likely | Best | Worst Case

Notes: *Erosion distances represent projected long-term time-averaged trends in erosion without coastal armoring. Future erosion distances and bluff crest position may vary from these projections.*

Sea level rise elevations and time periods are based on 2018 OPC guidance and refer to a high emissions scenario with 2020 as a baseline.

Shoreline Features

- Boardwalk
- Beach Access Stairway
- Coastal Access Location
- Riprap Footprint
- Seawalls
- Approx. Cliff to Terrace Contact Location
- Bluff-Top Edge

N W E S

0 75 150 Feet

Aerial: EagleView, 2022

Coastal Cliff and Dune Erosion Projection Without Armoring - Central Carmel Beach

1 ft of SLR (2045 - 2060) | 2 ft of SLR (2060 - 2080) | 4 ft of SLR (2080 - 2100+)

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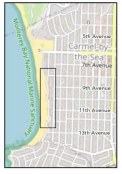

N W E S

0 75 150 Feet

Aerial: EagleView, 2022

Coastal Cliff and Dune Erosion Projection Without Armoring - South Carmel Beach

1 ft of SLR (2045 - 2060) | 2 ft of SLR (2060 - 2080) | 4 ft of SLR (2080 - 2100+)

Projected Bluff Crest Position Across Sea Level Rise Elevations

Most Likely	Best	Worst Case

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N E S W

0 70 140 Feet

Aerial: EagleView, 2022