integral INSIGHT FOR AN EVOLVING WORLD

City of Carmel-by-the-Sea

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

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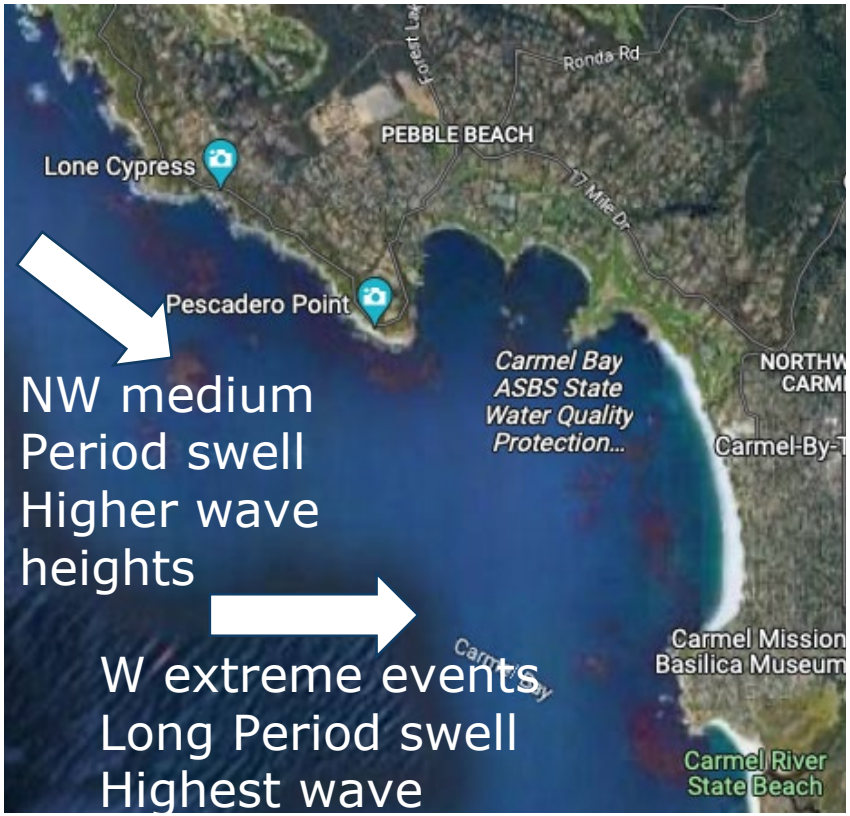
8/10/2023

Forest and Beach Commission

Winter vs Spring Waves

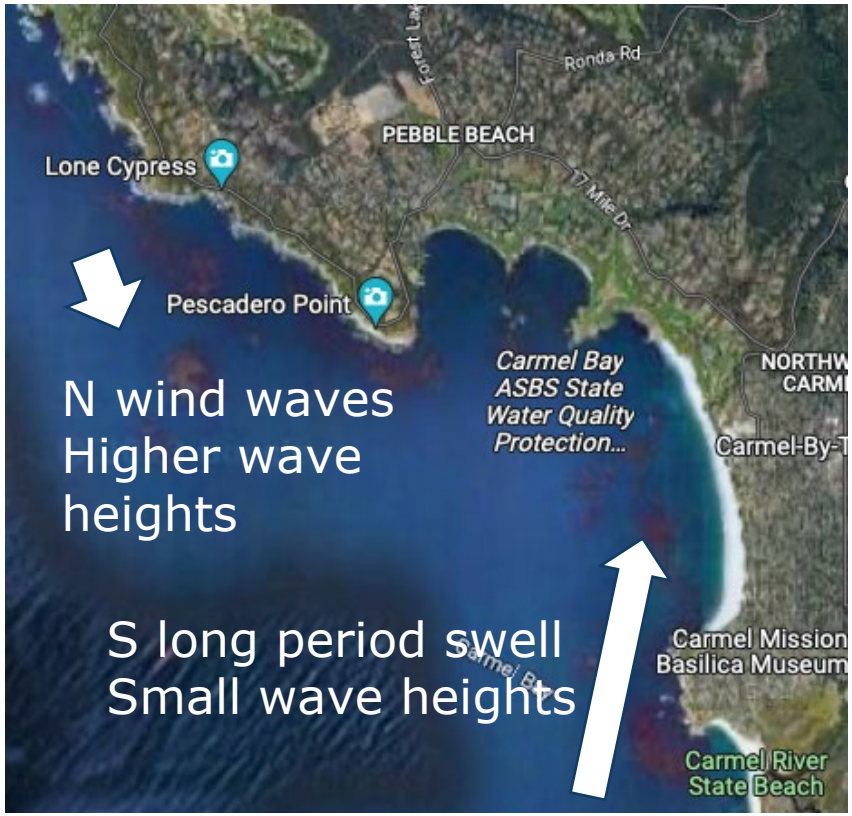
Winter

Erosion Dominant



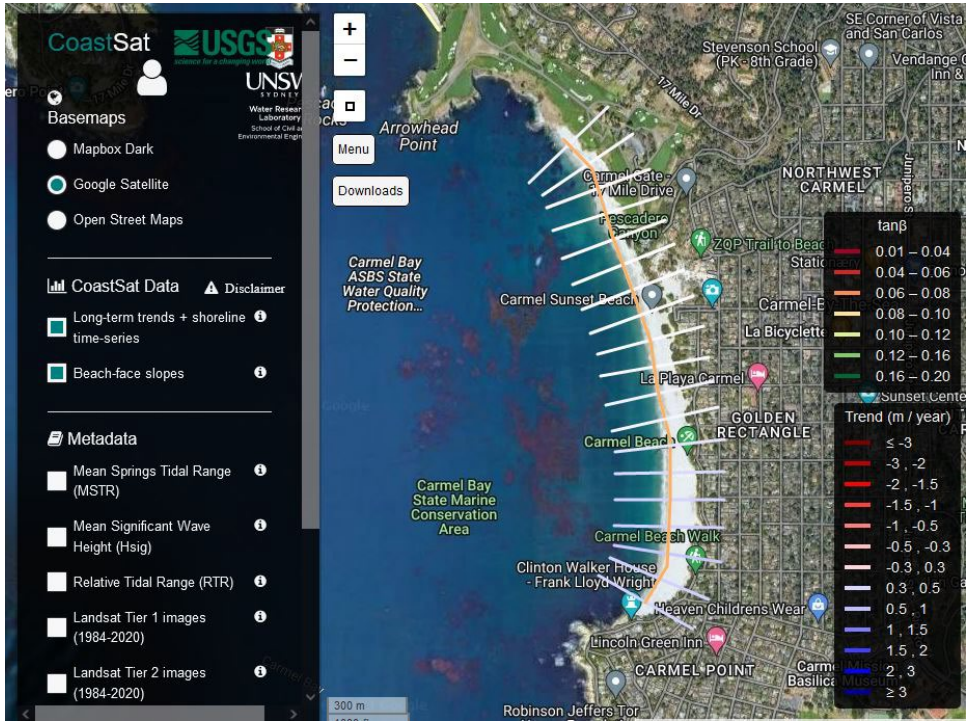
Spring

Accretion dominant



Datasets used for Seasonal and Long-term Change Analysis

- NDBC Buoys (waves)
- USGS Waves 1980s to 2100
- CoastSat (University of New South Wales and USGS) - ~monthly from 1984 - 2021
- 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 transects

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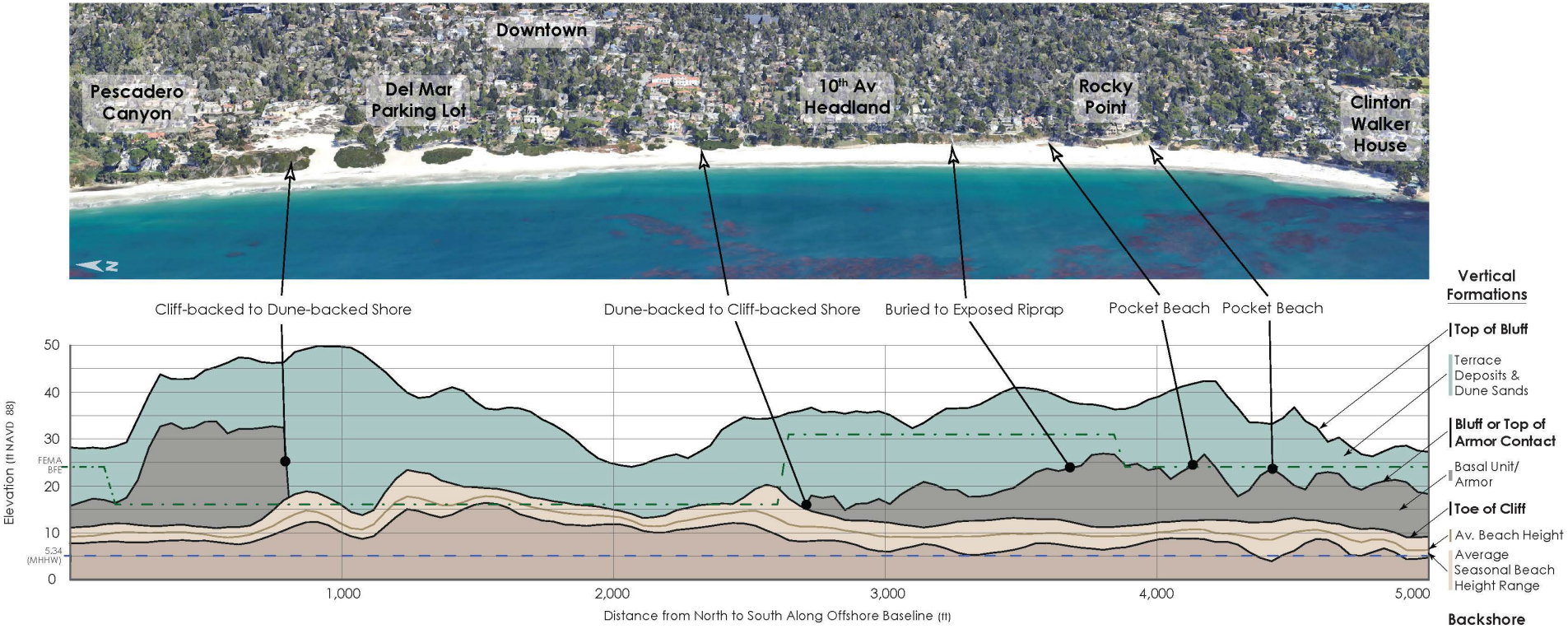
BEACH CHARACTER



Bluffs

Range from 25-48 ft. Contact elevation with underlying sandstone is higher south of 11th Av.

Dunes

Up to 50 ft high. Location and elevation of the underlying sandstone is unknown

Armoring

Seawalls and revetments protect ~68% of the City's shoreline

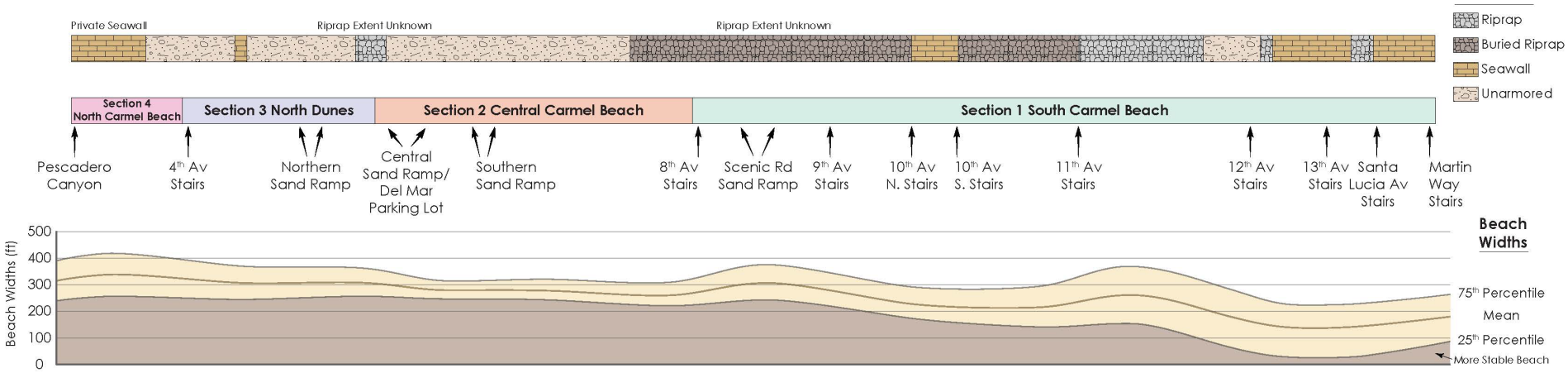
Armoring is located in areas with the highest variability in beach width

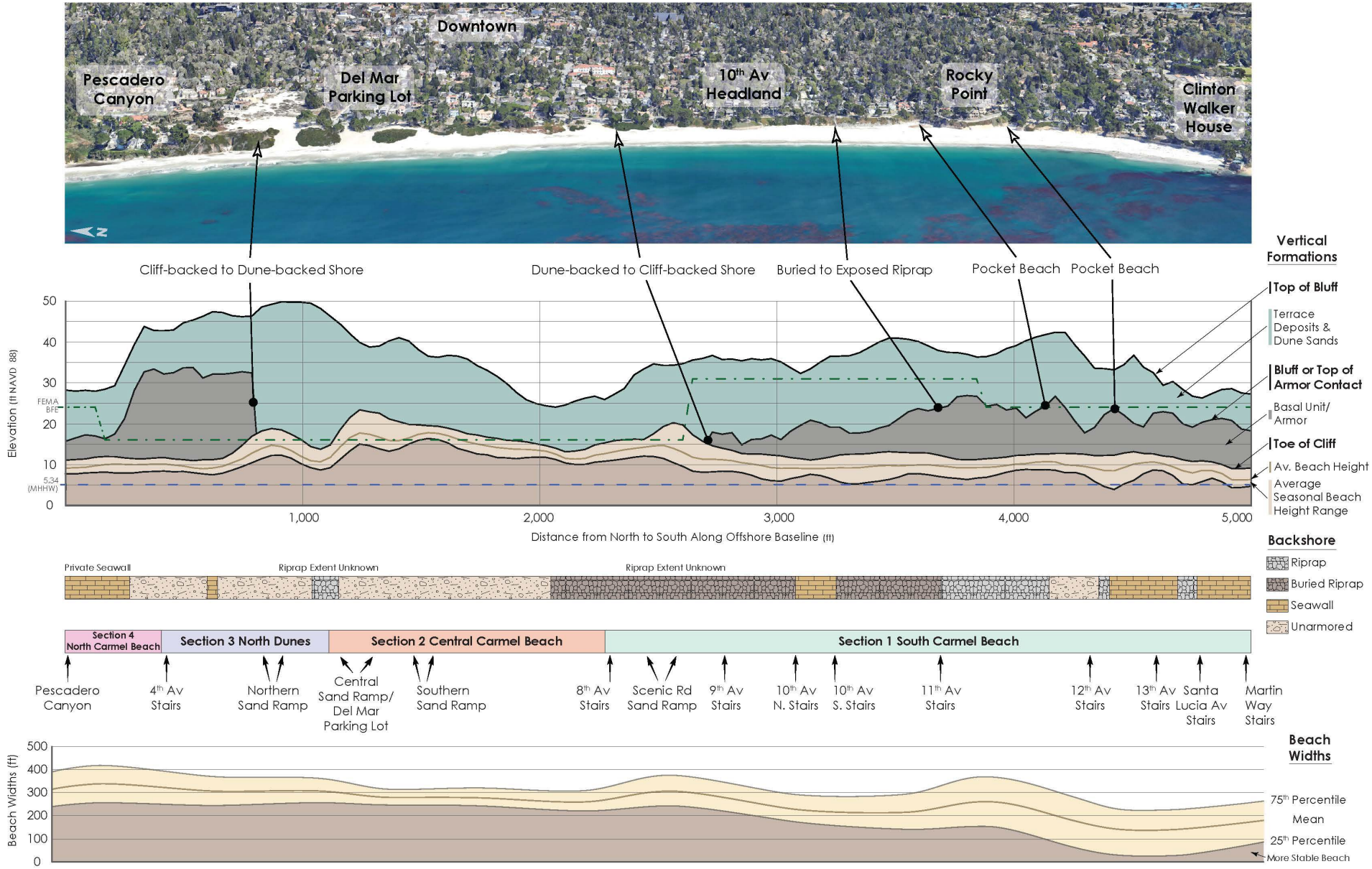
Beach

Most stable beach sections are the Del Mar Dunes and North Dunes. Beach widths (250-300 feet).

Highest beach widths are in the central and northern sections of Carmel Beach, with beach widths ~300 feet.

Sections that experience the greatest scouring also experience the greatest recovery.




Downtown
Pescadero Canyon
Del Mar Parking Lot
10th Av Headland
Rocky Point
Clinton Walker House
N
Cliff-backed to Dune-backed Shore
Dune-backed to Cliff-backed Shore
Buried to Exposed Riprap
Pocket Beach
Pocket Beach
Vertical Formations
Top of Bluff
Terrace Deposits & Dune Sands
Bluff or Top of Armor Contact
Basal Unit/ Armor
Toe of Cliff
Av. Beach Height
Average Seasonal Beach Height Range
Elevation (ft NAVD 88)
50
40
30
FEMA BFE
20
10
5.34 (MHHW)
0
1,000
2,000
3,000
4,000
5,000
Distance from North to South Along Offshore Baseline (ft)
Backshore
Riprap
Buried Riprap
Seawall
Unarmored
Private Seawall
Riprap Extent Unknown
Riprap Extent Unknown
Section 4 North Carmel Beach
Section 3 North Dunes
Section 2 Central Carmel Beach
Section 1 South Carmel Beach
Pescadero Canyon
4th Av Stairs
Northern Sand Ramp
Central Sand Ramp/ Del Mar Parking Lot
Southern Sand Ramp
8th Av Stairs
Scenic Rd Sand Ramp
9th Av Stairs
10th Av N. Stairs
10th Av S. Stairs
11th Av Stairs
12th Av Stairs
13th Av Stairs
Santa Lucia Av Stairs
Martin Way Stairs
Beach Widths
Beach Widths (ft)
500
400
300
200
100
0
75th Percentile
Mean
25th Percentile
More Stable Beach

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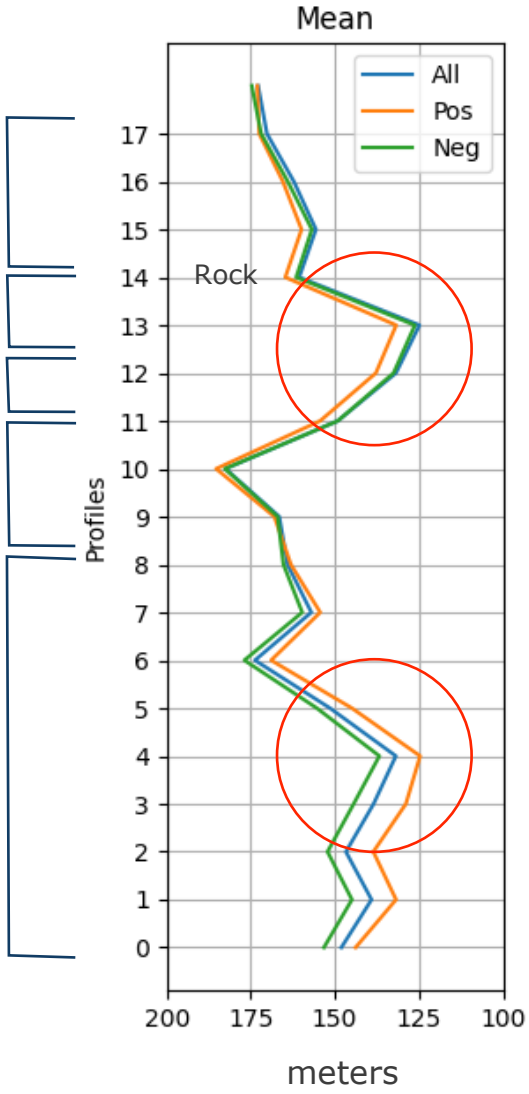
SEASONAL CHANGES

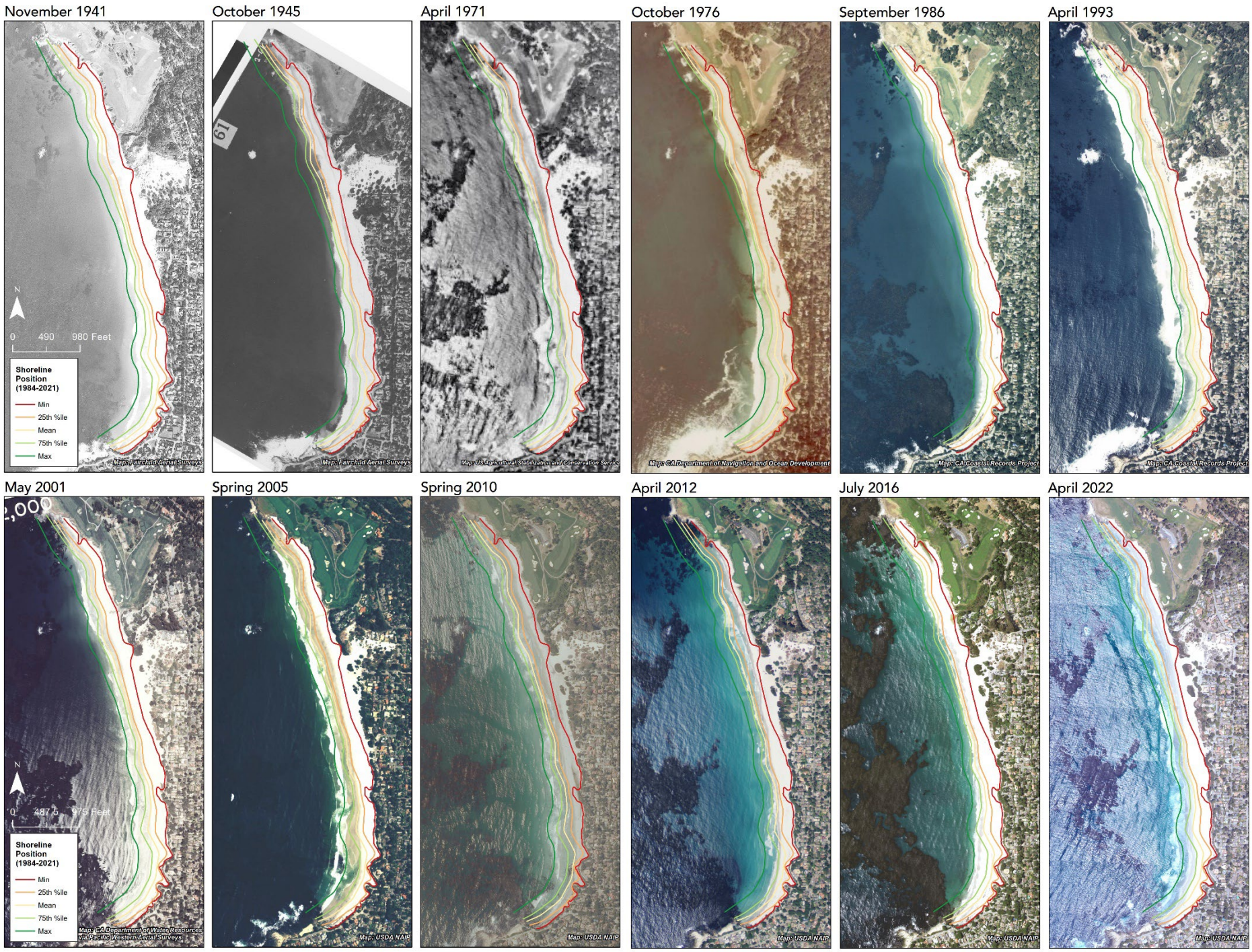
Seasonal/Long-term Change Determined from CoastSat Shoreline Change Analysis

› CoastSat

- 1,100 images with shoreline position
- 19 Shoreline Transects
- ~ monthly 1984 to 2021

- Pattern of erosion hotspots – key to consider in adaptation planning




November 1941
October 1945
April 1971
October 1976
September 1986
April 1993
May 2001
Spring 2005
Spring 2010
April 2012
July 2016
April 2022
N
0 490 980 Feet
Shoreline Position (1984-2021)
Min
25th %ile
Mean
75th %ile
Max
Map: Fairchild Aerial Surveys
Map: Fairchild Aerial Surveys
Map: US Agricultural Stabilization and Conservation Service
Map: CA Department of Navigation and Ocean Development
Map: CA Coastal Records Project
Map: CA Coastal Records Project
N
0 487.5 975 Feet
Shoreline Position (1984-2021)
Min
25th %ile
Mean
75th %ile
Max
Map: CA Department of Water Resources via Pacific Western Aerial Surveys
Map: USDA NAIP
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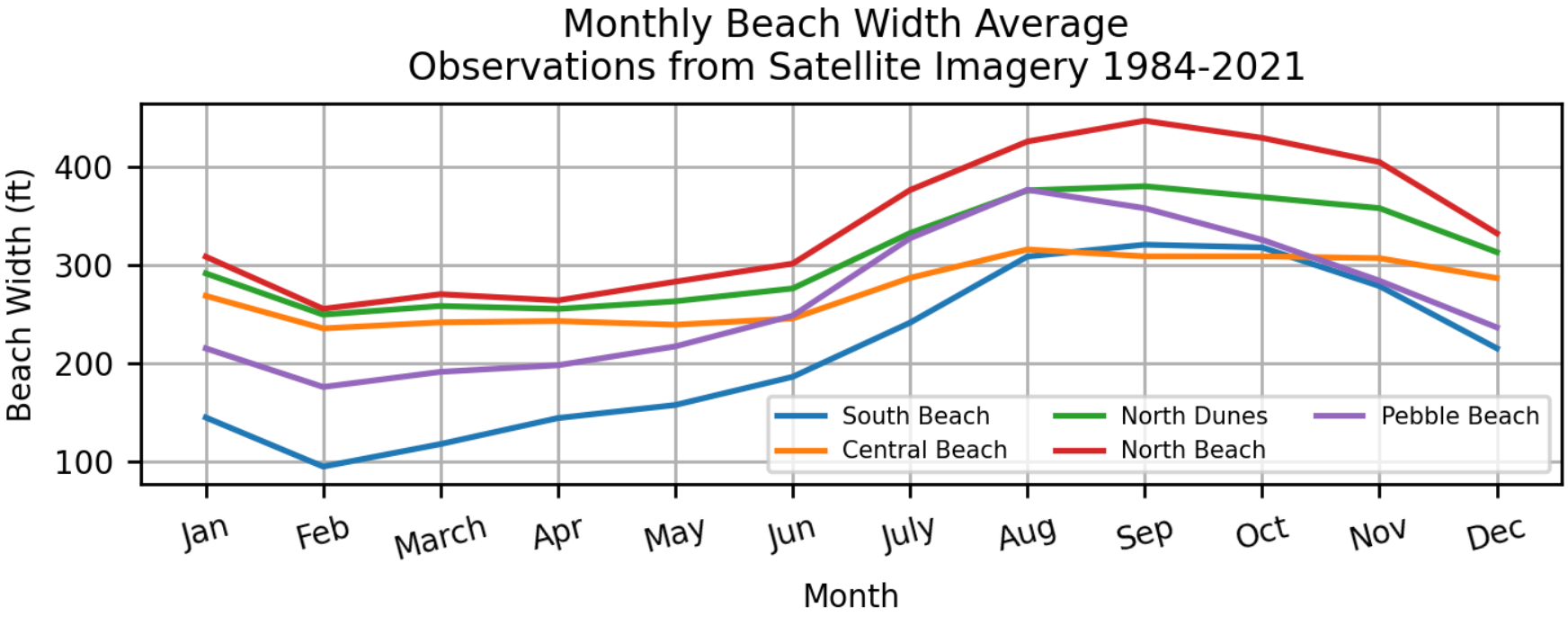
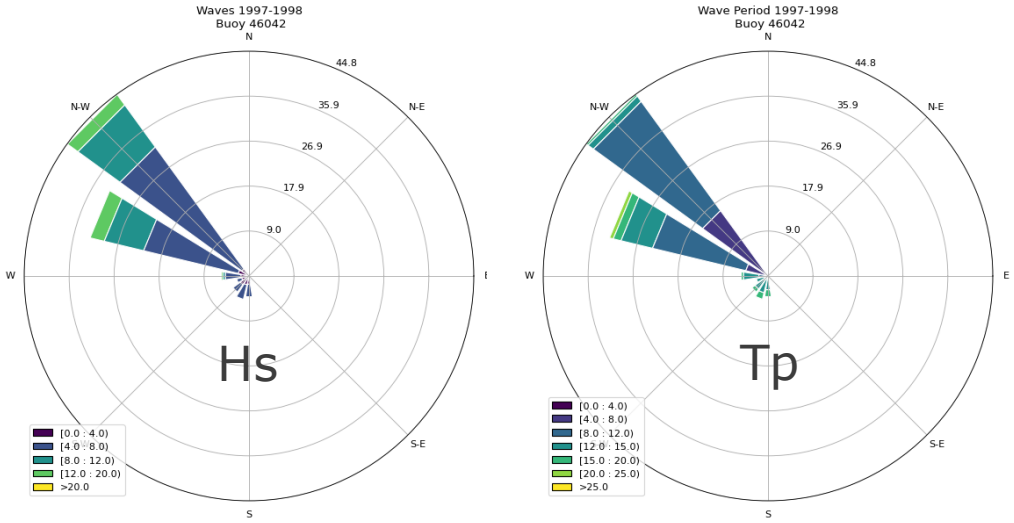
Average Seasonal Beach Width Change



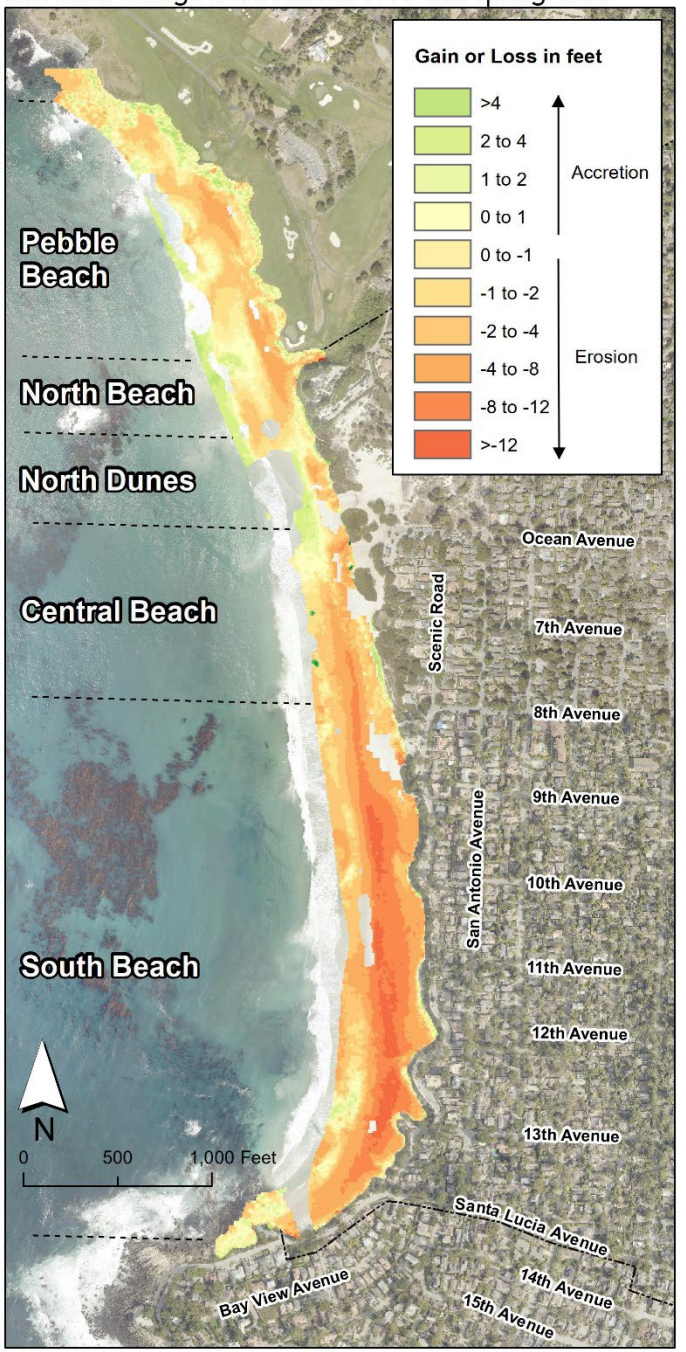
- Beach sections will respond differently throughout the year
- North and south see recovery beginning in late winter, and central areas see recovery beginning more slowly in the spring
- South beach has greatest seasonal beach changes
- Central beach has smallest seasonal beach changes

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



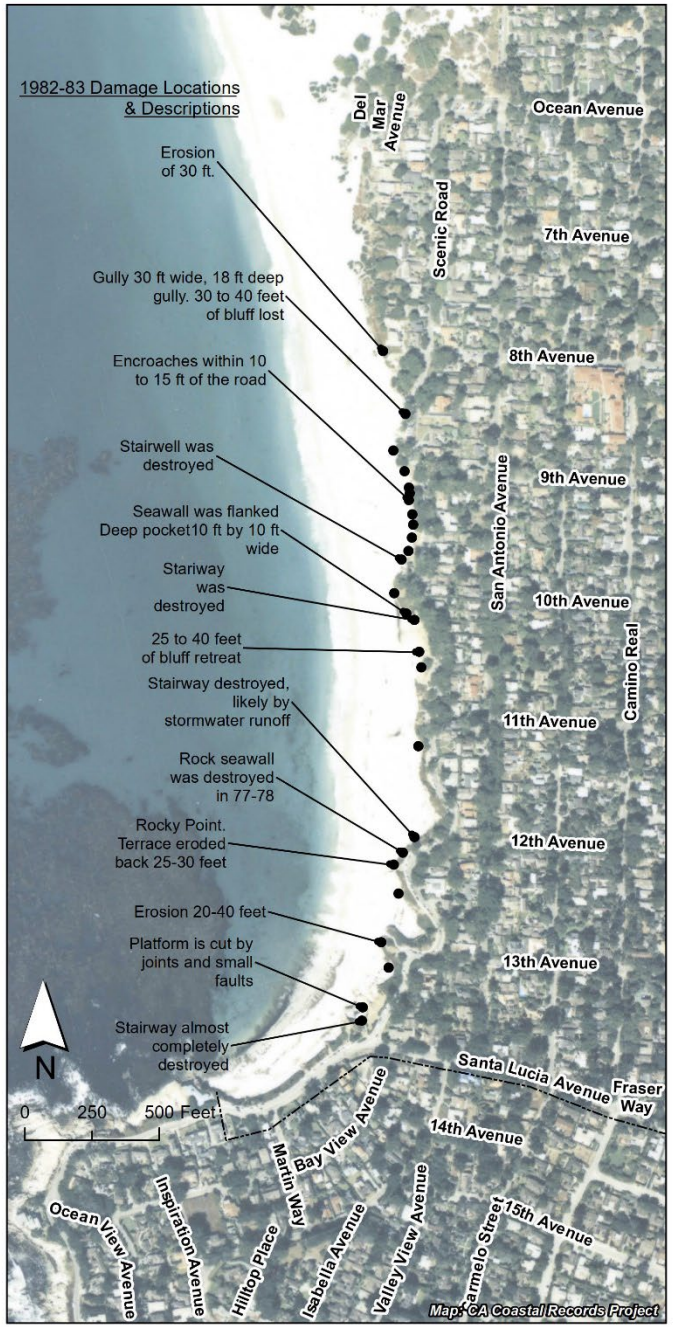
Winter 1997-98 El Niño Shoreline Change
Elevation change between fall 1997 and spring 1998



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



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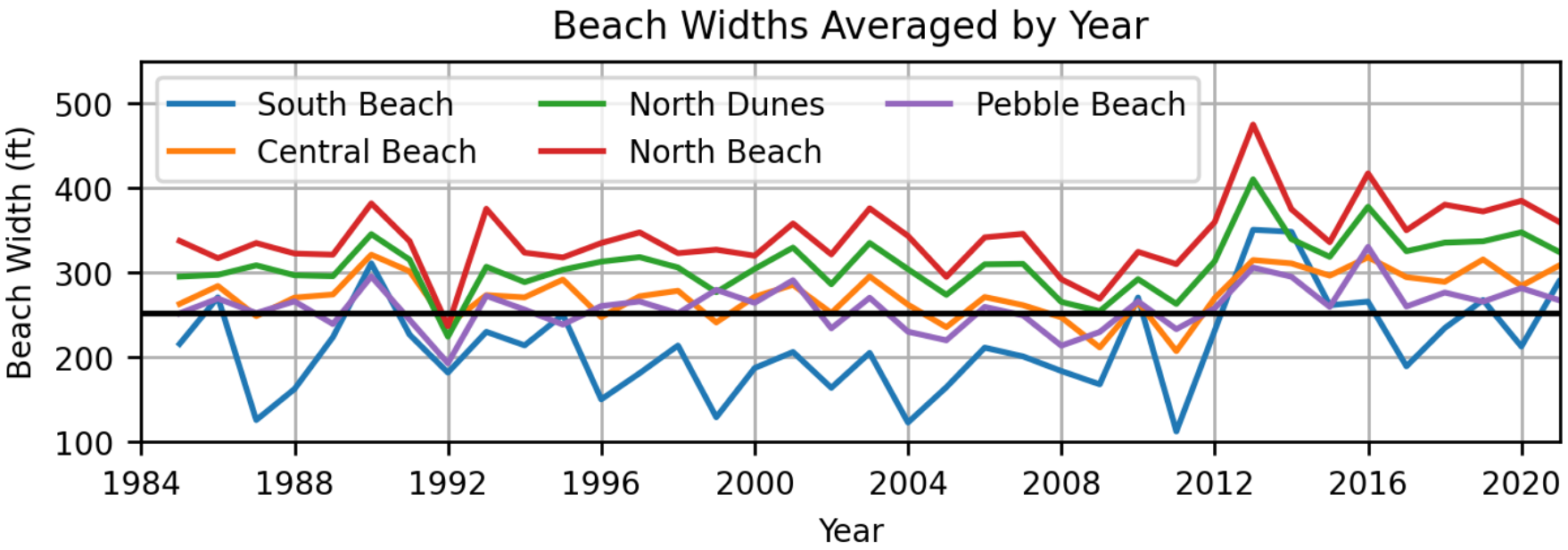
LONG TERM CHANGES

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 (which is likely related to the 1992 El Niño), 2009 and 2011

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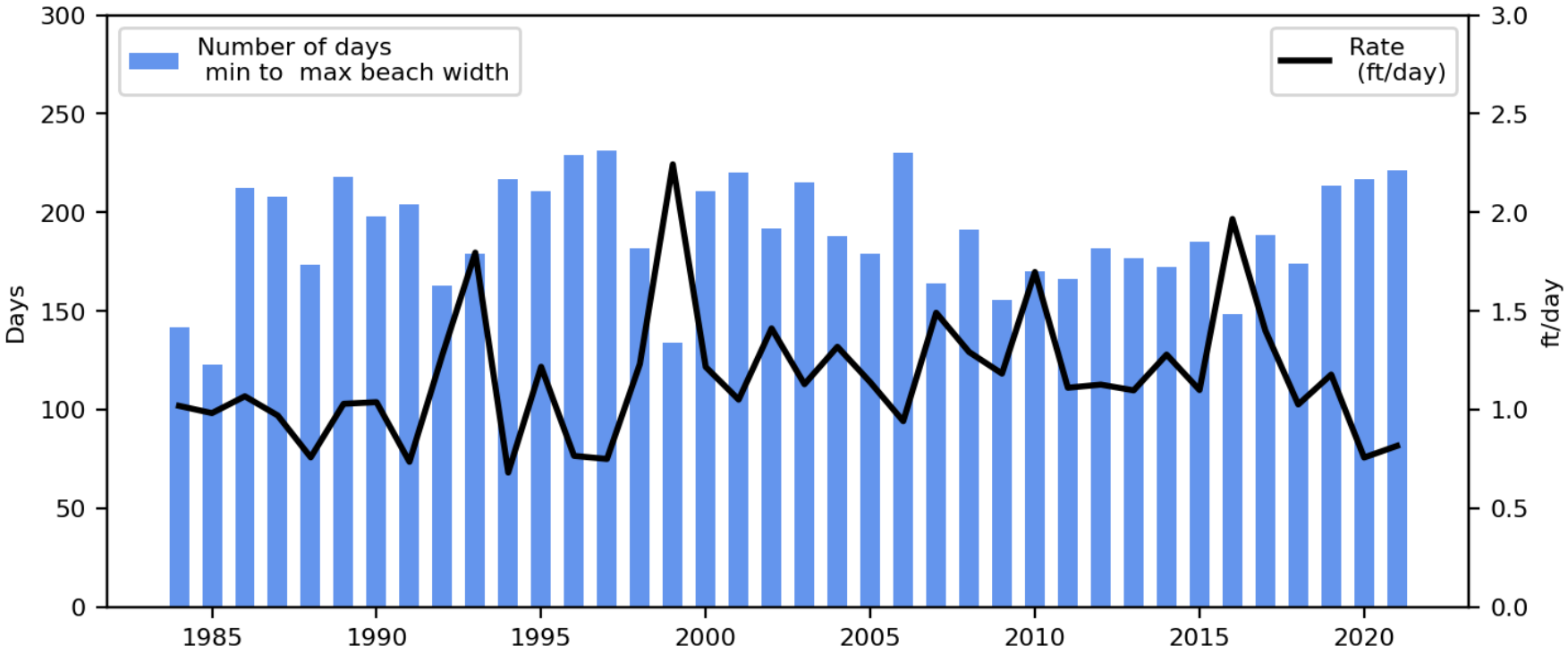
BEACH RECOVERY

Shoreline Recovery Scales and Rates



- Recovery shows how long the beach took to widen from the yearly minimum to maximum
- A faster rate shows that the beach built out faster
- Generally took the beach an average of 150 days (spring-summer)
- Fastest recovery rates around 1.7-2 feet per day and occurred when spring and summer waves were smaller and more oblique (coming from N and S as opposed to W)

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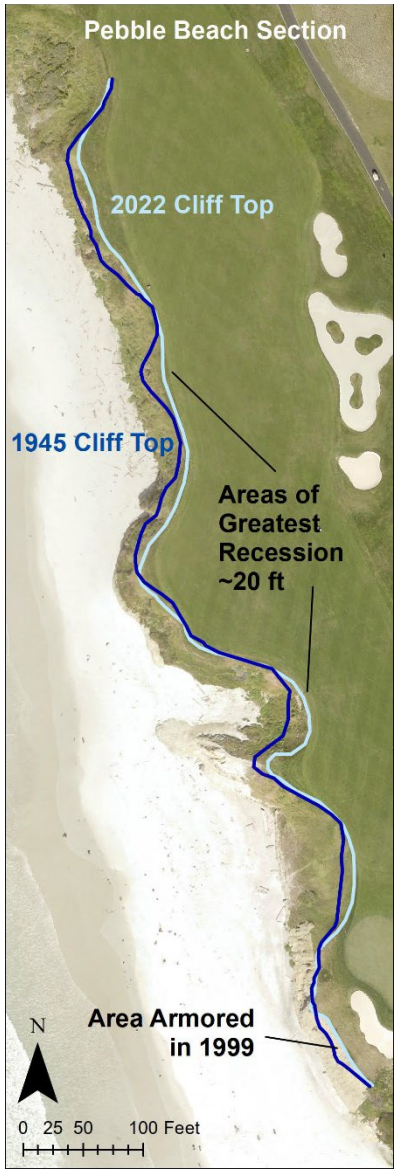
HISTORIC COASTAL CLIFF CHANGE

Historic Cliff Erosion Rates (literature)

- UC San Diego and Scripps Historical Coastal Erosion Study. No data for the City Beach, Pebble Beach only.
  - Negligible erosion from 2010 – 2016
- USGS Statewide Assessment. Section from Point Piños to Gorda
  - **11.8 in/yr** from 1930s – 2002
- Rodger E. Johnson Study 1908 - 1983
  - **4.8 in/yr** in the northern portion of the beach
  - **3.6 – 8.4 in/yr** in the southern portion of the beach
- Integral. Pebble Beach only
  - **1.14 in/yr** from 1945 – 2022
  - Highest observed **~3 in/yr**



Cliff Erosion Event Observations

- From Rodger E. Johnson and Associates:
  - 1982-3 Storm Event Erosion Hotspots:
    - **30 feet** of bluff between 8th-9th Avenues
    - **25-40 feet** of bluff between 9th -10th Avenues
    - **20-40** of bluff between 10th – 11th Avenues
    - **30 feet** of bluff near Santa Lucia Avenue
- From Integral Analysis
  - Largest loss observed at Pebble Beach: **20 feet** near 10th Fairway (1945-2022)

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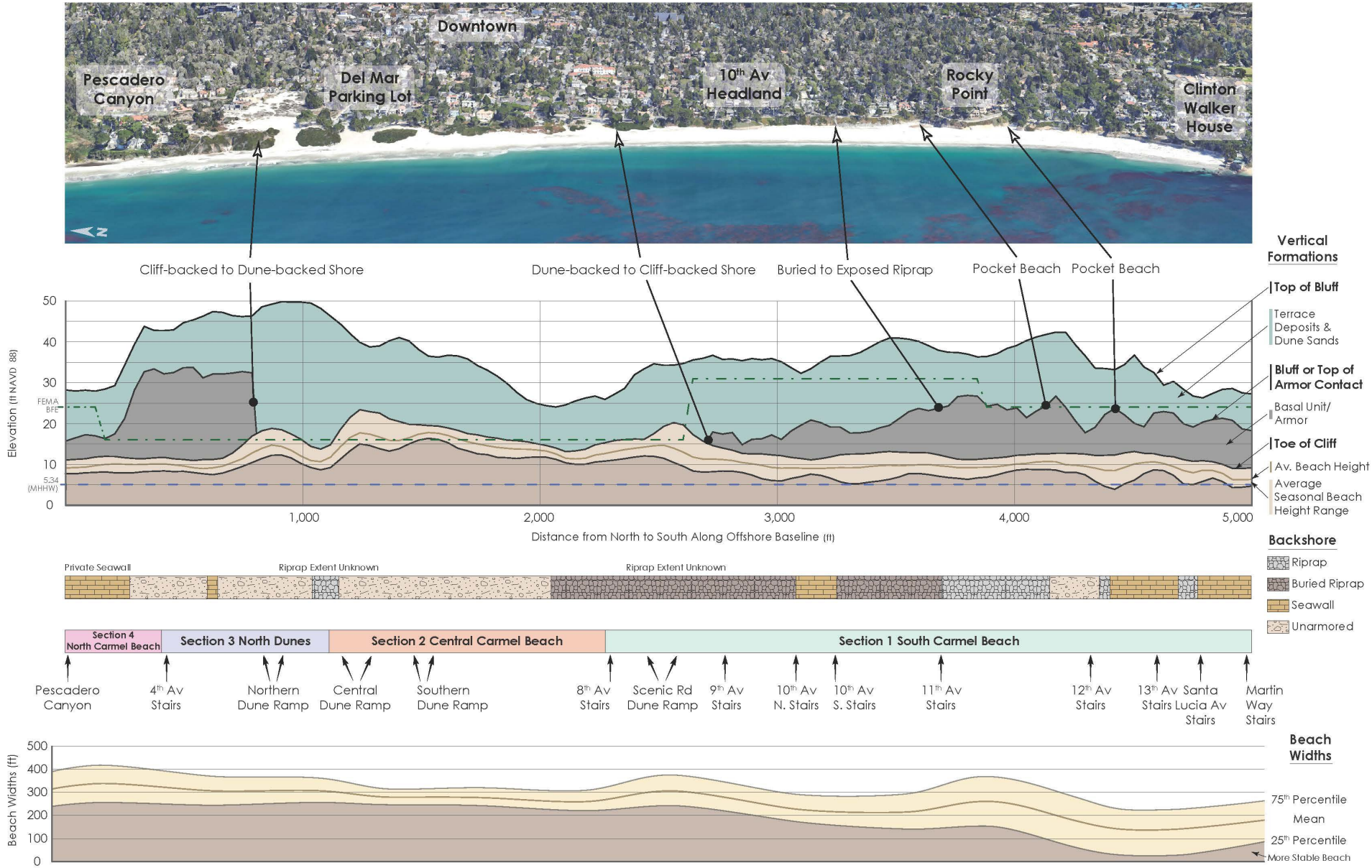
FUTURE HAZARD MODELING

Future Hazard Modeling

- Determine future **beach** widths for:
  - **Average** winter and summer conditions
  - **Stormy** winter (eroded) and summer (recovered) conditions
- Determine future **bluff crest** position
  - **With armoring**
  - **Without armoring**
- Determine future **dune crest** position
  - Eroded scarp position

Vulnerability Assessment

- Dry Sand Towel space availability
  - Future likelihood by season and time
- Threats to assets and infrastructure
  - Timing / Sea Level Rise
  - Extent of hazard
  - $ Damages (Phase 2)
- Potential assets at risk
  - Stormwater, wastewater, water
  - Parcels and structures
  - Recreation space, coastal access/stairs, sidewalk
  - Coastal armoring
  - Streets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Extra Slides