City of Carmel-by-the-Sea

Carmel Beach

Sea Level Rise Adaptation and Resiliency Strategies

Integral Consulting
David Revell, PhD
Matt Jamieson, MFA
Ashley Ellenson, PhD

EMC Planning
Anastazia Aziz, AICP

March 12, 2025
Planning Commission

Project History

- Carmel Climate Committee prioritized work on sea level rise, coastal hazards, and adaptation
- City funded Phase 1, then CCC funded Phase 2 (City later approved a separate coastal engineering study)
- History of storm damages and responses have led to armoring
- Community identity is partially tied to Carmel's unique beach conditions
- Changes in beach and coastal management occurred in the mid-2000s - monitoring, maintenance, and beach/sand management
- Damaging storms affecting beach and emergency access including dune ramps and vertical staircases
- Requirement (and funding) to update coastal planning documents

Background/Project Scope

Local Coastal Program = Land Use Plan and Implementation Plan

Why the Update?

- CCC requires that LCPs be updated to consider sea level rise
- Current LCP does not consider SLR or include adaptation policies
- The Consultant team reviewed several **key documents** to develop the project scope including:
  - 2001 Coastal Development Permit for Scenic Road Armoring Repairs
  - 2003 Shoreline Management Plan (Shonman and D'Ambrosio)
  - 2016 Carmel Shoreline Assessment Update
  - 2016 Assessments of Shoreline Improvements at Carmel Beach (Easton Geology)
  - 2022 Climate Adaptation and Climate Action Plans

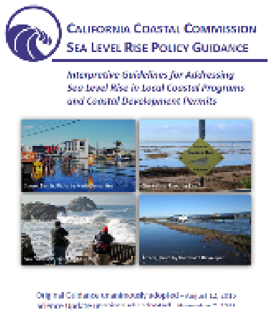
Background/Project Scope

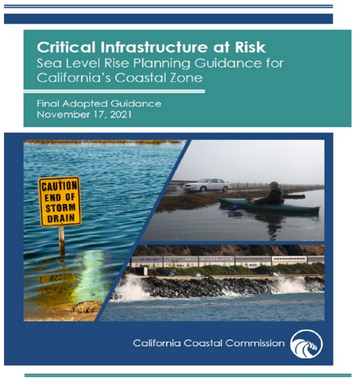
Certified Local Coastal Program (LCP) is required by the Coastal Act

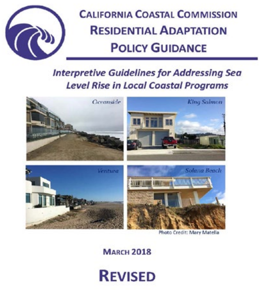
- Carmel's LCP—**Certified 2004**

Coastal Commission LCP Guidance

- *Planning for Accelerated SLR along the California Coast*—1989
- *CCC Sea Level Rise Policy Guidance*—2015, 2018, 2024
- *CCC Residential Adaptation Policy Guidance*—2018
- *Critical Infrastructure at Risk* - 2021







Coastal Hazards Local Coastal Program Update Process


integral

Work Plan

- **Phase 1, Tasks 1 – 4 All Tasks Completed** ✓
  - 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
- **Phase 2**
  - Tasks 2 and 3 – Public Outreach and Engagement – **In Progress**
  - Tasks 1 and 4 – Adaptation Feasibility (**Nearing Completion**) and Pathway Development
  - Tasks 5 and 6 – Coastal Hazards Review and Policy Recommendations
  - Task 7 – LCP Amendments

Important Considerations

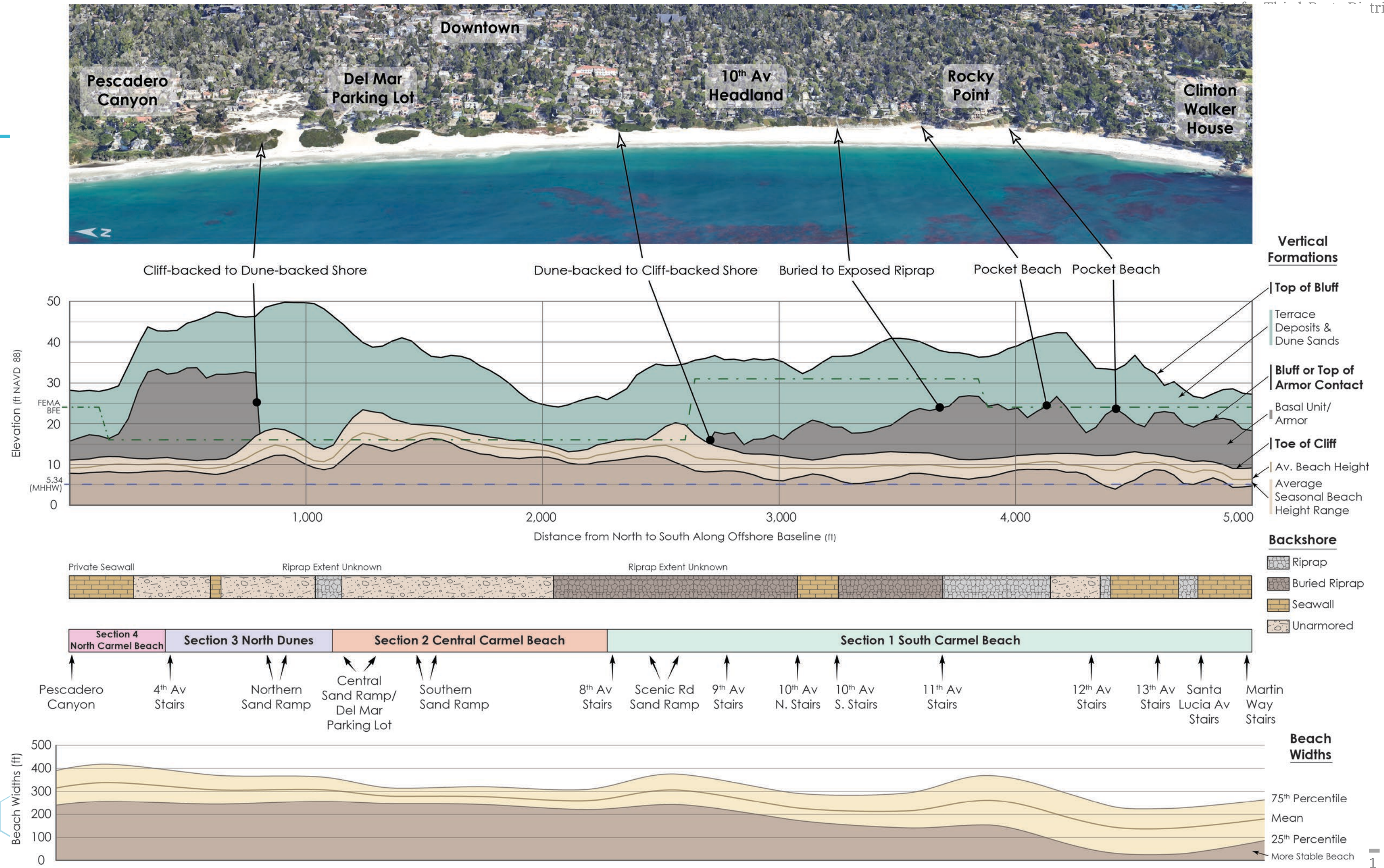
- Vision for the Future – How important is the beach vs the current upland?
- What kind of adaptation strategies is the City willing to consider?
- When to transition from one adaptation strategy to the next?
  - Lead time, Monitoring, Triggers
- Beach and Sand Management
  - Carmel Beach sand is unique and difficult to find. If the beach disappears with sea level rise, at what point will a change in sand quality become palatable?
- How to move away from the ocean gracefully?
  - Relocating critical infrastructure
  - Rerouting Scenic Rd, Del Mar Parking Lot
- How is the City going to pay for adaptation over time?

integral

Task 1: Coastal Engineering and Protection Assessment

Suggestions for Coastal Engineering Scope of Work

- Monitoring and Maintenance Plan for all coastal armoring structures
- Feasibility of adding additional crest height to existing structures
- Geotech analysis of Dune Ramps to determine where the underlying cliffs/bluffs are located (data gap)
- Integrate wave deflectors into any new or repaired beach accesses
- Consider previously permitted designs from 2000s that lacked funding



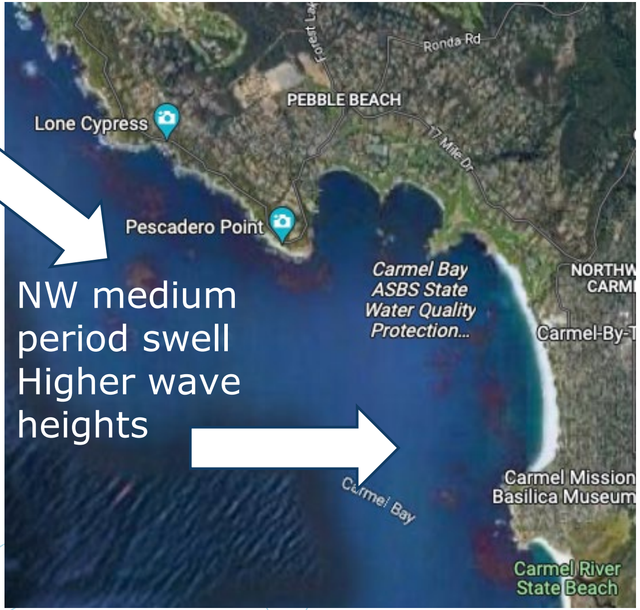
Downtown
Pescadero Canyon
Del Mar Parking Lot
10th Av Headland
Rocky Point
Clinton Walker House
Cliff-backed to Dune-backed Shore
Dune-backed to Cliff-backed Shore
Buried to Exposed Riprap
Pocket Beach
Pocket Beach
Vertical Formations
Top of Bluff
Terrace Deposits & Dune Sands
Bluff or Top of Armor Contact
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

integral

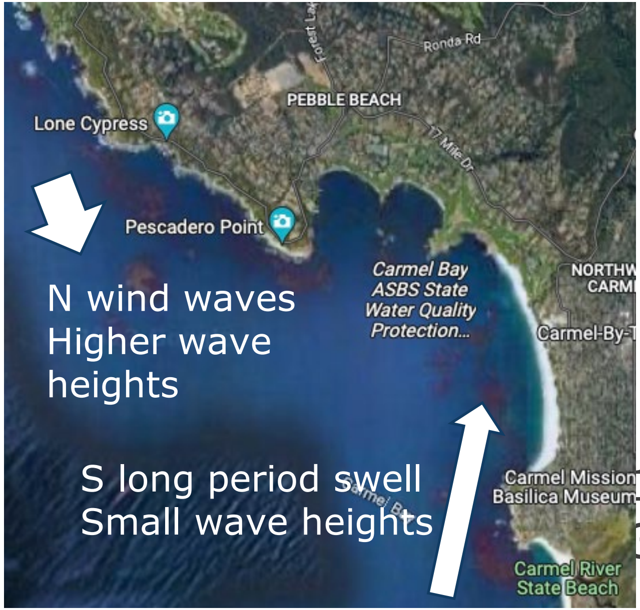
Task 2: Shoreline and Beach Change Analysis: Seasonal and Long-Term

Winter vs Spring Waves

Winter
Erosion Dominant



Spring
Accretion Dominant



13

integral

Processes Driving Erosion

Coastal Processes:

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

Local Conditions:

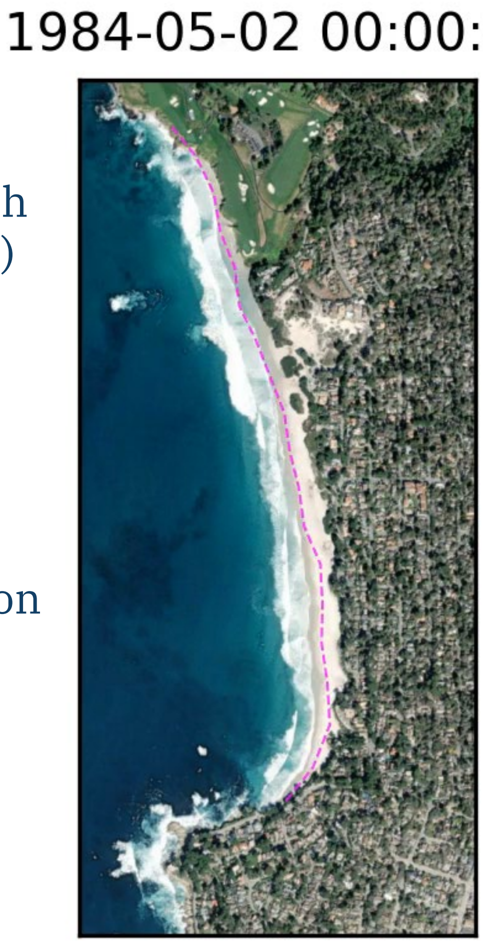
- Geomorphology
- Coastal armoring
- Cliff/bluff substrate
- Localized currents generated by waves
- Other factors including stormwater runoff and anthropogenic factors

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

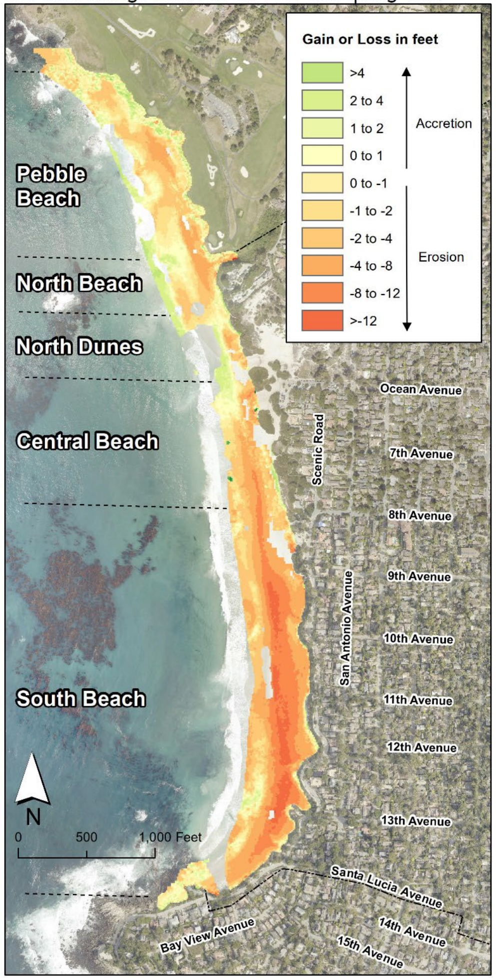
integral

Summary of Task 2

- Beach volume - relatively stable over time
- Major El Niño years led to the largest beach width reductions (1992, 1998, 2009, 2011)
- In 1997-98
  - ~300,000 cubic yards of sand was moved offshore
  - Maximum beach scour was ~14 feet (in vertical loss)
- Variability is highest in South Beach section
- North Dunes area saw the smallest trend with sediment moving into the foreshore



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



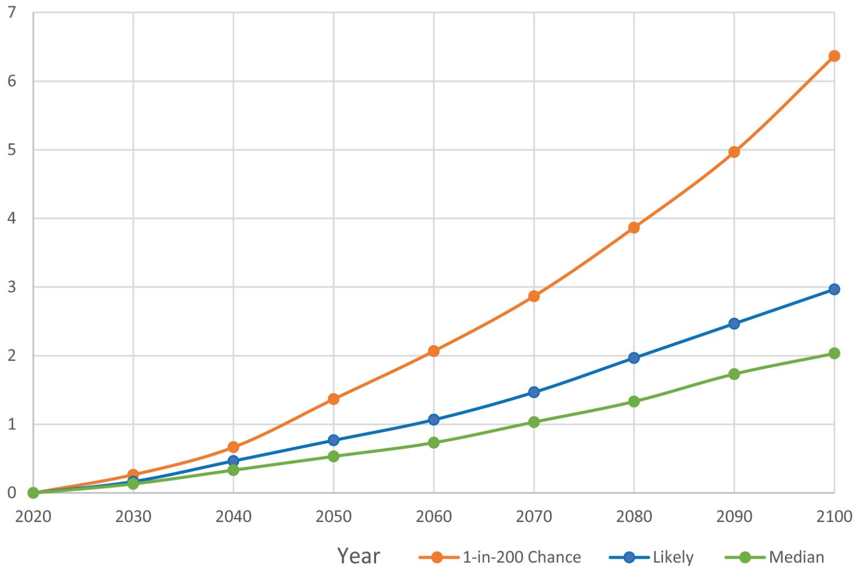
integral

Future Sea Level Rise Projections

Task 3: Cliff and Dune Erosion and Beach Changes
Task 4: Vulnerability Assessment to Infrastructure and Development 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 update
- Sea level rise scenarios considered medium-high risk aversion (.5% likely) to low-risk aversion (66% likely):
  - Current conditions, **2020 baseline**
  - Near-term, **1** ft of SLR / **2045 - 2060**
  - Medium-term, **2** ft of SLR / **2060 – 2080**
  - Long-term, **4** ft of SLR / **2080 – 2100+**



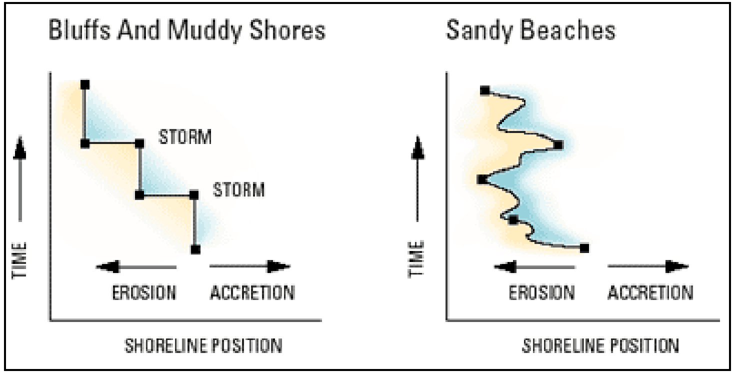
Above: SLR curves from the (2018) OPC guidance

*Current (2024) guidance indicates 4.6’ of SLR by 2100 (Int-High Scenario)

integral

Cliff Erosion vs Dune Erosion

- Storm erosion differs based on backshore
- Bluffs and cliffs **do not recover**
- Dunes erode and **can recover**
- Carmel has a multitude of backshore conditions:
  - Del Mar Dunes and North Dunes
  - Unarmored cliffs
  - Seawalls and riprap, primarily in the South



integral

Cliff and Dune Overtopping and Erosion
With Coastal Armoring

Erosion and Overtopping Short Term (1 ft: 2045 - 2060)

Overtopping:

- Highest risk between 8th and 10th Avenues

Erosion:

- High risk 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

integral

Cliff and Dune Erosion Medium Term (2 ft: 2060 – 2080)

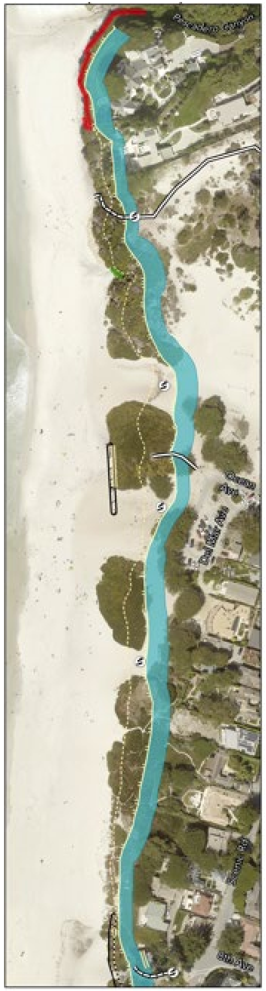
Overtopping:

- Overtopping is 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

North



Central

South

Overtopping Potential:

Low
Medium
Medium-High
Very High

Erosion hazard area

Cliff and Dune Erosion Long Term (4 ft: 2080 – 2100)

Overtopping also includes:

- 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)

North Central South

Overtopping Potential:

Low
Medium
Medium-High
Very High

Erosion hazard area

integral

Task 4: Vulnerability Assessment to Cliff and Dune Erosion with armoring
Assuming no Adaptation in the Future

Current Vulnerabilities

- **Stormwater** conveyance
- All **beach access stairways** and the **Del Mar Overlook**
- **Restroom** near Santa Lucia Avenue, located at ~24 ft, same elevation of FEMA FIRM base flood elevation
- Wave splash (not green water associated with overtopping) may exceed the bluff crest of the armored coastline at multiple locations:
  - Between 9th and 12th Aves
  - 13th Ave to Martin Way
  - At the private seawall near Pescadero Canyon

Stormwater infrastructure

Restroom near Santa Lucia Ave

integral

Short Term (1 ft SLR, 2045 - 2060)

- **Scenic Road** is exposed in 6 locations from 8th Avenue to 11th Avenue
- **Wastewater mains** are exposed at:
  - Martin Way
  - Between 9th and 10th Avenues
  - Under the dunes between 7th and 8th Aves
- **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

integral

Medium Term (2ft SLR, 2060 - 2080)

- **Scenic Road**: entire length exposed, including underground water and sewer infrastructure
- **Water main** between 8th and 10th Avenues
- An additional 0.3 acres of **dune habitat**
- During 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

integral

Long Term (2-4ft SLR, 2060 - 2100)

- With armoring - 44 homes along Scenic Road and Pescadero Canyon
- Without armoring - 59 homes along Scenic Road and Pescadero Canyon
- Del Mar Parking Lot including two water storage tanks
- 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
- Wave overtopping during storm events is more frequent south of 8th Ave

Worst case high erosion scenario:

- Restroom at Del Mar Parking Lot
- Volleyball Courts

integral

Range of Possible Adaptation Strategies

Range of Adaptation Choices

Do Nothing

Accommodate

Setback

Elevate

Hybrid

Grey

Green

Protect

Managed Retreat

Before - 2002

After - 2005

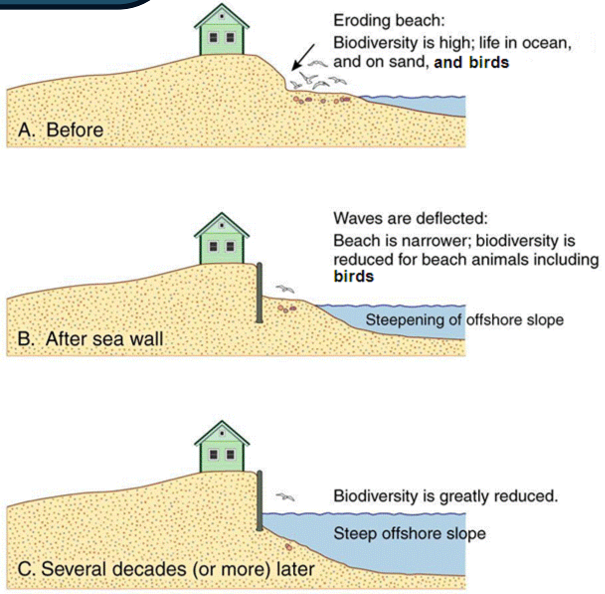
Adaptation Projects vs. Policy Approaches
Green vs Grey

integral

Secondary Consequences

- Construction Costs
- Escalating Maintenance Costs
- Access
- Ecology
- Recreation
- Views
- Aesthetics
- Displacement of underrepresented communities
- Loss of low-cost recreation
- Loss of tourism-related revenues

How should we adapt, and what are the trade-offs?



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

integral

Beach Width Narrowing with Existing Coastal Armoring without Adaptation (Phase 1, Task 3)

Beach widths wider in the north than the south

Summer beach widths narrow ~**50 - 60** feet for each foot of sea level rise

integral

Beach Width Narrowing: Short term (2045 - 2060)

- A typical summer beach still exists
- Southern section becomes "squeezed" especially at 12th avenue headland
- By **1 ft** of sea level rise, typical summer dry sand beach reduced by **20%**

North

0 - 1 ft of SLR

South

0 - 1 ft of SLR

integral

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

1 - 2 ft of SLR

South

1 - 2 ft of SLR

integral

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

3 - 4 ft of SLR

South

3 - 4 ft of SLR

integral

Beach Width Narrowing with up to 5’ 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%

Assumes existing coastal armoring is maintained

North

4 - 5 ft of SLR

South

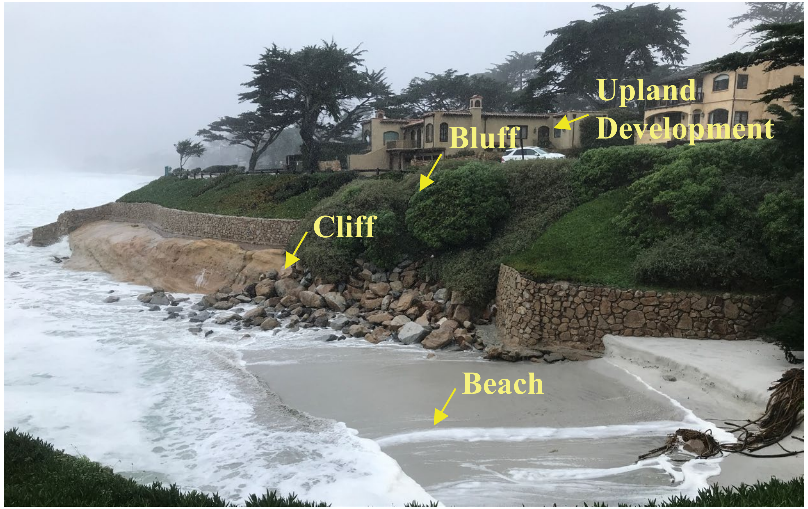
4 - 5 ft of SLR

integral

Full Range of Feasible Strategies

Based on professional experience and consultation with City and Coastal Commission Staff

Adaptation Areas



Stop, Reduce, or Avoid Erosion

Stop = loss of beach protect upland – increasing costs

Reduce = balance beach and recreation – routine costs

Avoid = maintain beach, realign upland – high upfront costs

integral

Adaptation Evaluation Criteria

Immediate, Short (5-20 yr), Medium (10-30 yr), Long (30+ yr)

- **Criteria includes:**
  - Reduce, Stop, or Avoid Erosion
  - Construction Cost/Maintenance of the Investment
  - Effectiveness
  - Regulatory Viability
- **Co-benefits and Secondary Consequences including:**
  - Beach widths
  - Water/surf/sand quality
  - Ecological impacts
  - Public access and safety

Strategy Category	*Strategy*	Timing for Implementation	Priority Index Score (Balancing Effectiveness, Cost, and Other Criteria)	Construction	Maintenance (Including Cost Savings)		Beach Width Impacts	Environmental and Habitat Impacts: Water/Surf Quality and Ecological	Public Access and Safety
		Immediate, Short-term (5-20yr), Mid-term (10-30yr), Long-term (30yr +)	*Index Score (0 - 20)*	*Low - $, Medium - $$, High - $$$*	*None to Low - $, Medium - $$, High - $$$*	*Viable, Likely, Less Likely*	*Negative, No Effect, Positive*	*Negative, No Effect, Positive*	*Negative, No Effect, Positive*
Dune & Sand Management	Vegetation and landscaping to reinforce/protect terrace soil	**Immediate**	**18**	**$**	**$$**	**Viable**	=	+	=
Dune & Sand Management	Dune restoration	**Immediate**	**18**	**$**	**$$**	**Viable**	+	+	=
Dune & Sand Management	Beneficial reuse of sand	**Immediate**	**20**	**$**	**$$**	**Viable**	+	+	=
Dune & Sand Management	Living shorelines - utilize driftwood expanded dunes	**Immediate**	**19**	**$**	**$$**	**Viable**	+	+	+
Dune & Sand Management	Beach nourishment of upland dune ramps	**Short-term**	**20**	**$$**	**$$**	**Viable**	+	+	+
Dune & Sand Management	Beach nourishment	**Short-term**	**18**	**$$$**	**$$$**	***Depends***	+	+	+
Dune & Sand Management	Sacrificial berm	**Short-term**	**16**	**$**	**$$$**	**Likely**	+	+	+
Dune & Sand Management	Sand management/harvesting	**Short-term**	**15**	**$**	**$$$**	**Likely to Less Likely**	+	-	+
Engineered Infrastructure	Monitoring and maintenance of existing structures	**Immediate**	**17**	**$**	**$$$**	**Viable**	-	-	+
Engineered Infrastructure	Integrate wave deflectors into access improvements	**Short-term**	**17**	**$$**	**$$**	**Likely**	=	-	+
Engineered Infrastructure	Replace revetments with seawalls	**Mid-term**	**16**	**$$$**	**$$**	**Likely**	+	=	=
Engineered Infrastructure	Wave tripping low structures on bedrock	**Mid-term**	**13**	**$$**	**$$$**	**Less Likely**	=	-	+
Engineered Infrastructure	Raise crest and redesign of seawalls	**Mid-term**	**12**	**$$$**	**$$$**	**Likely**	-	-	+
Engineered Infrastructure	Wave cut terrace augmentation	**Mid-term**	**12**	**$$**	**$$**	**Less Likely**	-	-	***Depends***
Engineered Infrastructure	Raise riprap	**Mid-term**	**11.5**	**$$$**	**$$$**	**Likely**	-	-	+
Engineered Infrastructure	Infill seawalls	**Mid-term**	**12**	**$$$**	**$$**	**Less Likely**	-	-	+
Engineered Infrastructure	Soil nail wall or tie back wall to protect bluff terrace	**Mid-term**	**12**	**$$$**	**$$**	**Less Likely**	-	-	+
Engineered Infrastructure	Nearshore reefs	**Mid-term**	**13**	**$$$**	**$$$**	**Less Likely**	+	=	+
Retreat/Relocation	Transportation Realignment (pedestrian path)	**Long-term**	**17.5**	**Varies ($$)**	**$**	**Likely**	+	+	+
Retreat/Relocation	Retreat/Relocation	**Long-term**	**17**	**Varies ($$$+)**	**$**	**Likely**	+	+	+

Short-term Management Strategies

	Priorities		Cost		Regulatory Viability	Secondary Impacts		
Strategy	Timing for Implementation	Priority Index Score (Balancing Effectiveness, Cost, and Other Criteria)	Construction	Maintenance (Including Cost Savings)		Beach Width Impacts	Environmental and Habitat Impacts: Water/Surf Quality and Ecological	Public Access and Safety
	Immediate, Short-term (5-20yr), Mid-term (10-30yr), Long-term (30yr +)	*Index Score (0 - 20)*	*Low - $, Medium - $$, High - $$$*	*None to Low - $, Medium - $$, High - $$$*	*Viable, Likely, Less Likely*	*Negative, No Effect, Positive*	*Negative, No Effect, Positive*	*Negative, No Effect, Positive*
Vegetation and landscaping to reinforce/protect terrace soil	Immediate	18	$	$$	Viable	=	+	=
Dune restoration	Immediate	18	$	$$	Viable	+	+	=
Beneficial reuse of sand	Immediate	20	$	$$	Viable	+	+	=
Living shorelines - utilize driftwood expanded dunes	Immediate	19	$	$$	Viable	+	+	+
Beach nourishment of upland dune ramps	Short-term	20	$$	$$	Viable	+	+	+
Beach nourishment	Short-term	18	$$$	$$$	*Depends*	+	+	+
Sacrificial berm	Short-term	16	$	$$$	Likely	+	+	+
Sand management/harvesting	Short-term	15	$	$$$	Likely to Less Likely	+	-	+

- Continue Monitoring and Maintenance of Existing Structures

integral

Vegetation, Dune, and Sand Management

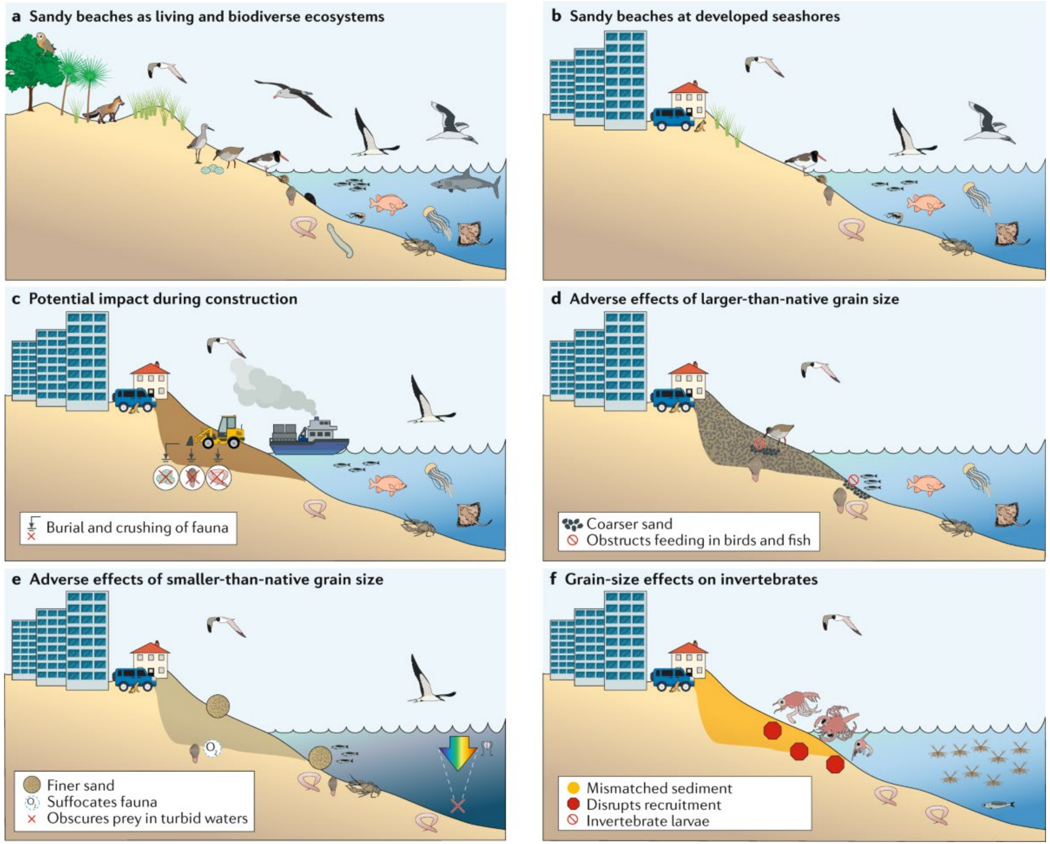
- Sacrificial Winter Storm Berm
- Living Shorelines - Utilize Driftwood to Expand Dunes
- Dune Restoration
- Vegetation and landscaping to reinforce and protect terrace soils
- Beneficial Reuse of Sand or Opportunistic Beach Nourishment
- Sand Management/Harvesting
- Beach Nourishment
- Dune Ramp Nourishment

integral

Challenges with Sand in Carmel

- Testing and Compatibility
  - Clean
  - Size, Color
- Placement methods
  - At once
  - Continuous
- Sorting
  - Different Grain Sizes
- Transporting
  - Truck
  - Dredge

size class	diameter range (mm)	microns
gravel	2.00 +	
v. coarse sand	1.0 - 2.0	
coarse sand	0.5 - 1.0	
medium sand	0.25 - 0.5	250 - 500
fine sand	0.125 - 0.25	125 - 250
v. fine sand	0.0625 - 0.125	63 - 125
coarse silt	0.031 - 0.0625	31 - 63
silt	0.0039 - 0.031	3.9 - 31
clay	< 0.0039	



integral

Sacrificial Winter Storm Berm

In the fall, construct a low berm along the backshore to reduce wave impacts at the back of the beach

Potential Location

At the **back beach** in areas without seawalls – along the dune-backed shoreline from 8th to 4th

integral

Living Shorelines - Utilize Driftwood to Expand Dunes

- Dunes with driftwood core and vegetation along existing dune-backed shoreline

Potential Location

Dune-backed areas, esp. at the
8th Avenue Sand Ramp
Northern Sand Ramps

Living Shoreline Construction in Aptos

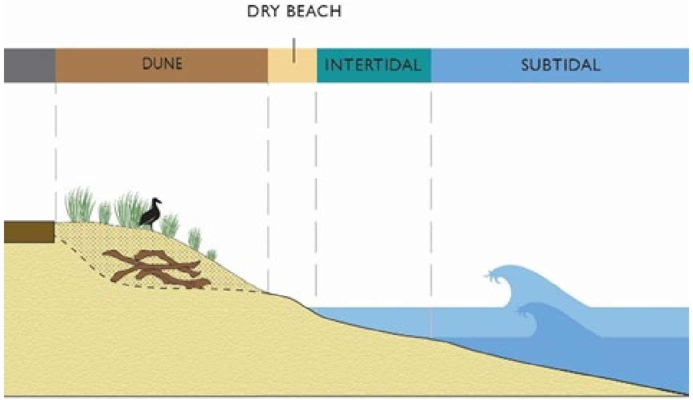
integral

Dune Restoration

- Restoration of native dune areas.
- Low hummocky dunes along the existing dune-backed shoreline.
- Can correspond with a program for the beneficial reuse of sand from local sources and incorporate driftwood material.

Potential Location

Back beach area of the Del Mar Dunes



Dunes at Seabright Beach in Santa Cruz

integral

Vegetation and landscaping to reinforce and protect terrace soils

Planting and landscaping of bluff areas to hold soil in place and reduce bluff erosion. This may include terracing and the use of erosion fabric on the bluff with landscaping to retain soil

Potential Location

Along the **backshore** and terrace south of 8th Ave

These efforts can coincide with:

- Trail and access improvements
- Stormwater improvements
- Controlling access (signage, fencing etc.)

Opportunistic Beach Nourishment or Beneficial Reuse

- Placement of small volumes of sand acquired from nearby sources during construction or flood control maintenance activities and placed directly on the beach (Placement is usually by truck)
- Policy recommendation - Develop a program requiring beach compatible sand to be placed on beach or upland dune ramps

integral

Sand Management/Harvesting

Active harvesting and movement of sand from the foreshore to the back beach and backshore to widen the beach

Potential Location

The entire **beach**. May conducted at high-priority access locations including those at 4th Ave and the Del Mar Sand Ramps

integral

Beach Nourishment

- Large volume of sand usually from an offshore source and pumped to the beach

integral

Dune Ramp Nourishment

- Placement of sand at the top of the existing sand ramps, avoids many of the permitting and regulatory hurdles with sand delivered to the beach during erosion events

Potential Location

Sand ramps at Del Mar and 8th Ave

Engineered Infrastructure

- Stop or Reduce Erosion
  - Riprap and Seawall Improvements
  - Raise Crest of Existing Structures
  - Protect Upper Bluff Terrace
  - Replace Riprap with Vertical Seawalls
  - Low Crested Structures to Reduce Erosion and Scour
  - Shore Platform Enhancement
  - Integrate Wave Deflectors in Access Improvements
  - Nearshore Reefs
- Requires monitoring and maintenance
- Challenging to permit but feasible if tied to protecting public infrastructure or improving/maintaining access
- Easier to permit if multiple benefits – access, habitat, recreation

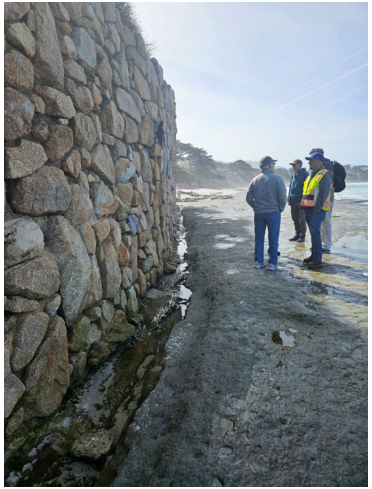
Short to Medium Term Engineered Strategies

- **Stop** erosion vs **reduce** erosive processes
  - **Stop** erosion likely to protect upland longer but cause beach loss faster
  - **Reduce** erosion likely supports longer beach and recreation

	Priorities		Cost		Regulatory Viability	Secondary Impacts		
Strategy Description	Timing for Implementation	Priority Index Score (Balancing Effectiveness, Cost, and Other Criteria)	Construction	Maintenance (Including Cost Savings)		Beach Width Impacts	Environmental and Habitat Impacts: Water/Surf Quality and Ecological	Public Access and Safety
	Immediate, Short-term (5-20yr), Mid-term (10-30yr), Long-term (30yr +)	*Index Score (0 - 20)*	*Low - $, Medium - $$, High - $$$*	*None to Low - $, Medium - $$, High - $$$*	*Viable, Likely, Less Likely*	*Negative, No Effect, Positive*	*Negative, No Effect, Positive*	*Negative, No Effect, Positive*
Monitoring and maintenance of existing structures	Immediate	17	$	$$$	Viable	-	-	+
Integrate wave deflectors into access improvements	Short-term	17	$$	$$	Likely	=	-	+
Replace revetments with seawalls	Mid-term	16	$$$	$$	Likely	+	=	=
Wave tripping low structures on bedrock	Mid-term	13	$$	$$$	Less Likely	=	-	+
Raise crest and redesign of seawalls	Mid-term	12	$$$	$$$	Likely	-	-	+
Wave cut terrace augmentation	Mid-term	12	$$	$$	Less Likely	-	-	*Depends*
Raise riprap	Mid-term	11.5	$$$	$$$	Likely	-	-	+
Infill seawalls	Mid-term	12	$$$	$$	Less Likely	-	-	+
Soil nail wall or tie back wall to protect bluff terrace	Mid-term	12	$$$	$$	Less Likely	-	-	+
Nearshore reefs	Mid-term	13	$$$	$$$	Less Likely	+	=	+

Stop erosion

- Riprap and Seawall Improvements
- Raise Crest of Existing Structures
- Protect Upper Bluff Terrace
- Replace Riprap with Vertical Seawalls



integral

Riprap and Seawall Improvements

Includes restacking and raising riprap, raising the crest of seawalls, and building infill walls at unarmored backshore locations

Potential Location

From 8th Av south

integral

Soil nail wall or tie back wall to protect bluff terrace

Shotcrete textured wall similar to the one at Pebble Beach Golf Links

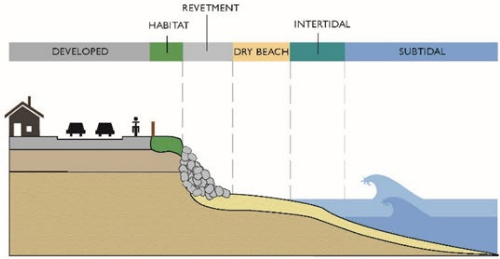
Potential Location

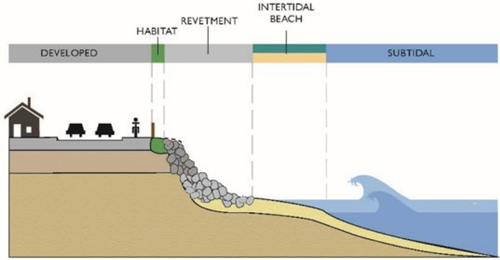
From 8th Av south. Especially where the terrace is more exposed to wave energy and where there are no conflicts with existing trees and vegetation.

Shotcrete wall at Pebble Beach Golf Links

Replacement of Riprap with Vertical Seawalls

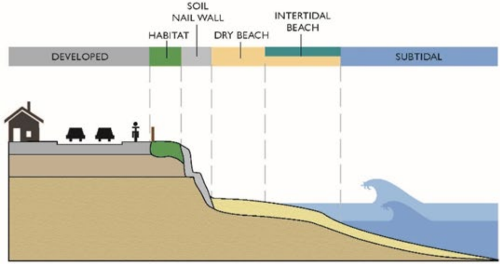
Revetment is about 40 feet high built at a 2: 1 slope. Footprint of the armoring occupies 80 feet of beach





reduced habitat, intertidal only beach, surf only low tide

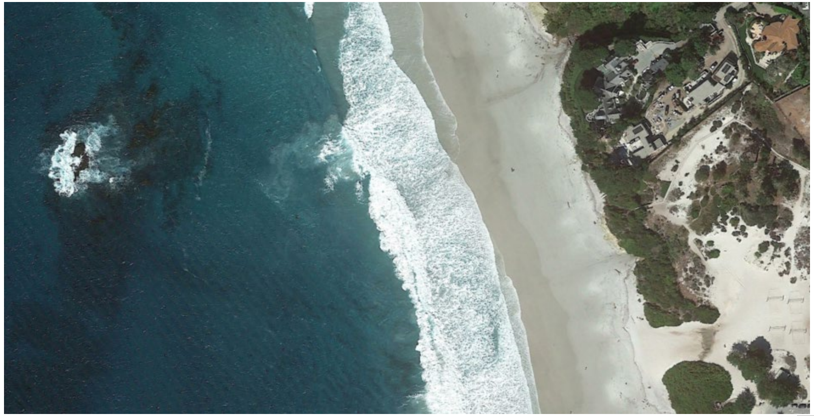
Vertical seawalls or soil nail walls have a smaller footprint and temporarily widen the beach by removing a revetment



reduced habitat, maintain some beach area

Reduce erosion

- Low Crested Structures to Reduce Erosion and Scour
- Shore Platform Enhancement
- Integrate Wave Deflectors in Access Improvements
- Nearshore Reefs



integral

Low Crested Structures to Reduce Erosion and Scour

Similar to a sill, built into exposed shore platforms to reduce currents and wave energy

Would consist of cemented sediments to retain the same color and material composition as the existing sandstone and mudstone outcroppings

Potential Location

In **back beach** areas with gaps in the shore platform where wave exposure is high

integral

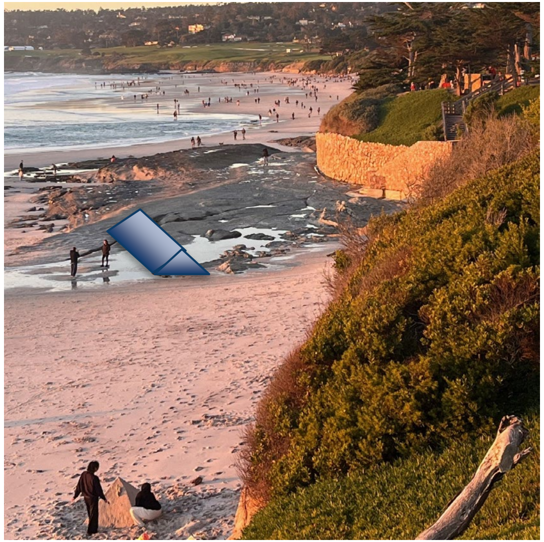
Shore Platform Enhancement

Augmentation and extension of shore platforms (or wave-cut terraces) to improve wave attenuation.

- Would consist of cemented sediments to retain the same color and material composition as the existing sandstone and mudstone outcroppings.

Potential Location

In **back beach** areas on top of shore platforms



integral

Integrate Wave Deflectors in Access Improvements

Concrete protrusions at the base of beach stair foundations to deflect wave energy

Potential Location

Beach stair accessways, primarily those subject to nearshore wave currents

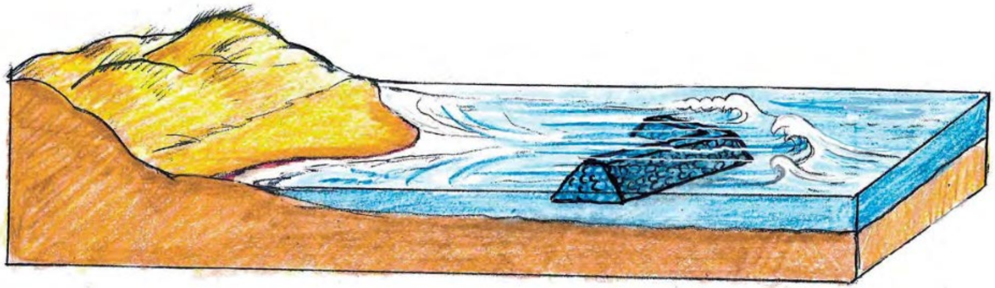
integral

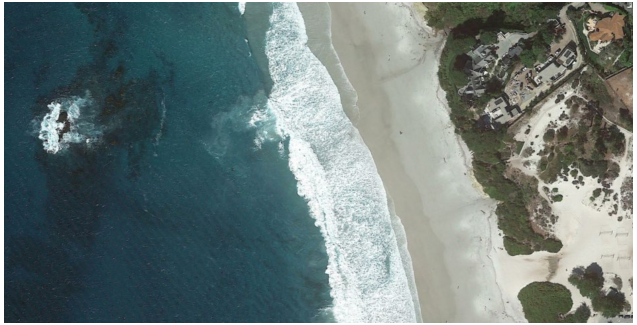
Nearshore Reefs

A rubble mound or concrete structure(s) with a crest below the water line to reduce wave energy

Potential Location

A nearshore reef is currently located offshore from 4th Ave. Could include a series of additional reefs.





integral

Retreat and Relocation

List Retreat and Relocation Strategies

	Priorities		Cost		Regulatory Viability	Secondary Impacts		
Strategy	**Timing for Implementation**	**Priority Index Score (Balancing Effectiveness, Cost, and Other Criteria)**	**Construction**	**Maintenance (Including Cost Savings)**		**Beach Width Impacts**	**Environmental and Habitat Impacts: Water/Surf Quality and Ecological**	**Public Access and Safety**
	Immediate, Short-term (5-20yr), Mid-term (10-30yr), Long-term (30yr +)	*Index Score (0 - 20)*	*Low - $, Medium - $$, High - $$$*	*None to Low - $, Medium - $$, High - $$$*	*Viable, Likely, Less Likely*	*Negative, No Effect, Positive*	*Negative, No Effect, Positive*	*Negative, No Effect, Positive*
Transportation Realignment (pedestrian path)	**Long-term**	**17.5**	**Varies ($$)**	**$**	**Likely**	**+**	**+**	**+**
Retreat/Relocation	**Long-term**	**17**	**Varies ($$$+)**	**$**	**Likely**	**+**	**+**	**+**

integral

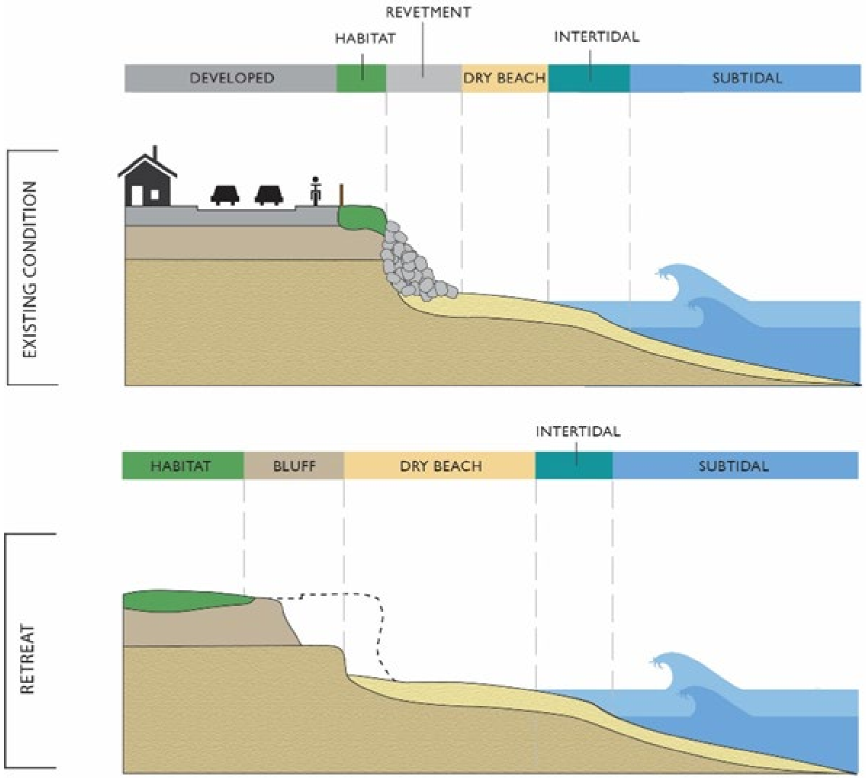
Retreat and Relocation

› Transportation Realignment

- Accommodating erosion in relation to pedestrian and vehicular access along Scenic Rd.

› Retreat and Relocation

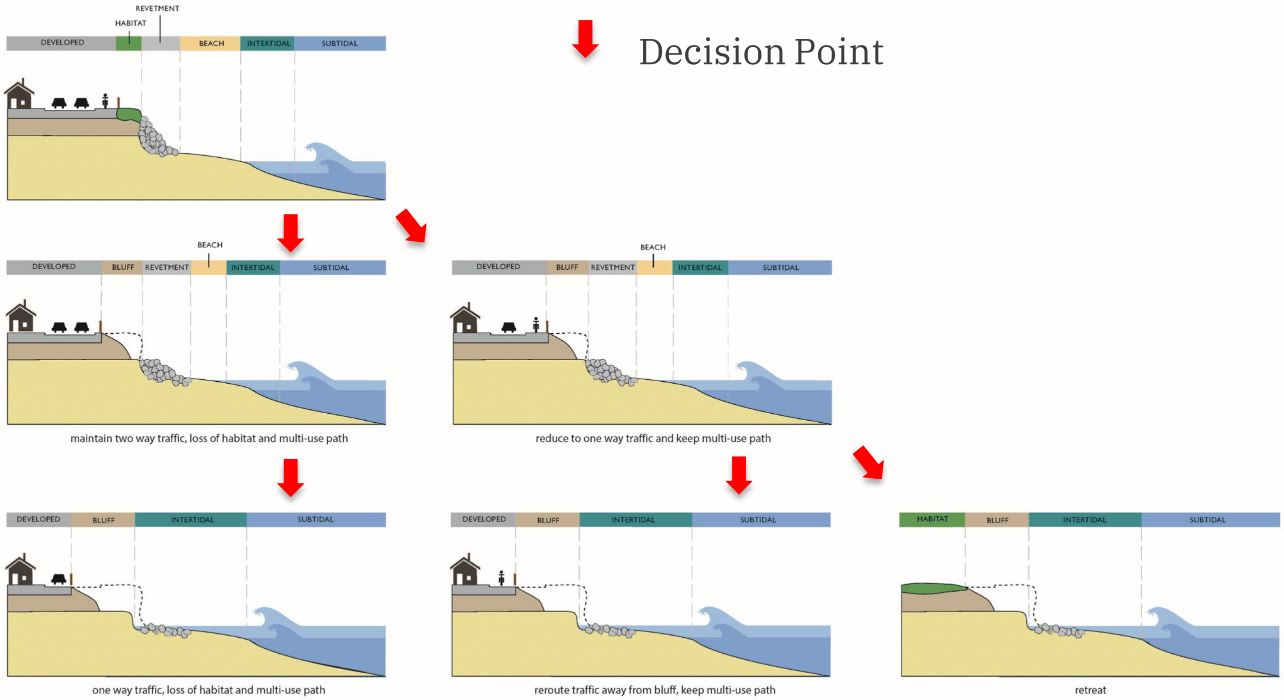
- Phased relocation of infrastructure, parking lots, access ways, roadways, and homes from vulnerable locations



integral

Retreat and Relocation

- Transportation Realignment
  - Cars vs multi-modal uses
  - Residential access
  - Emergency access
  - Coastal Access
- Relocation of Critical Infrastructure
  - Location of other infrastructure

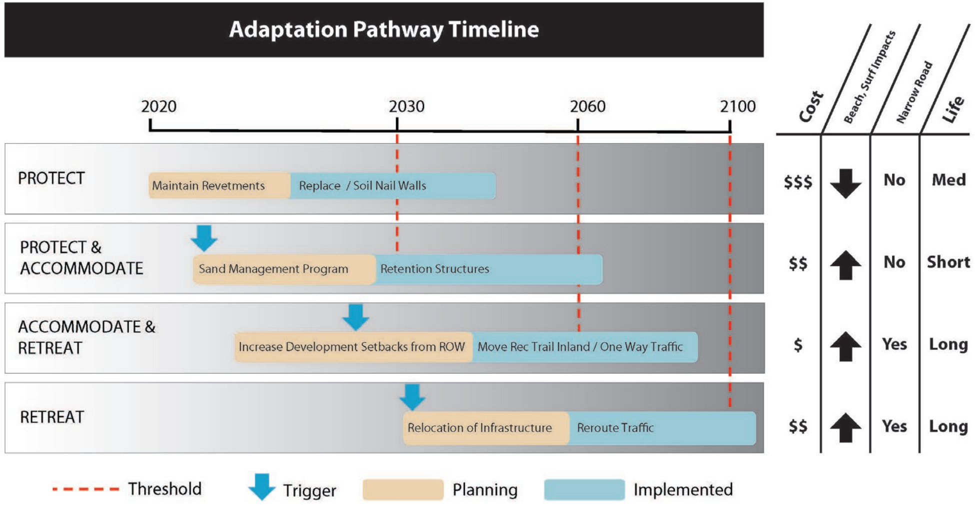


integral

Next Steps

Upcoming Work on this Project

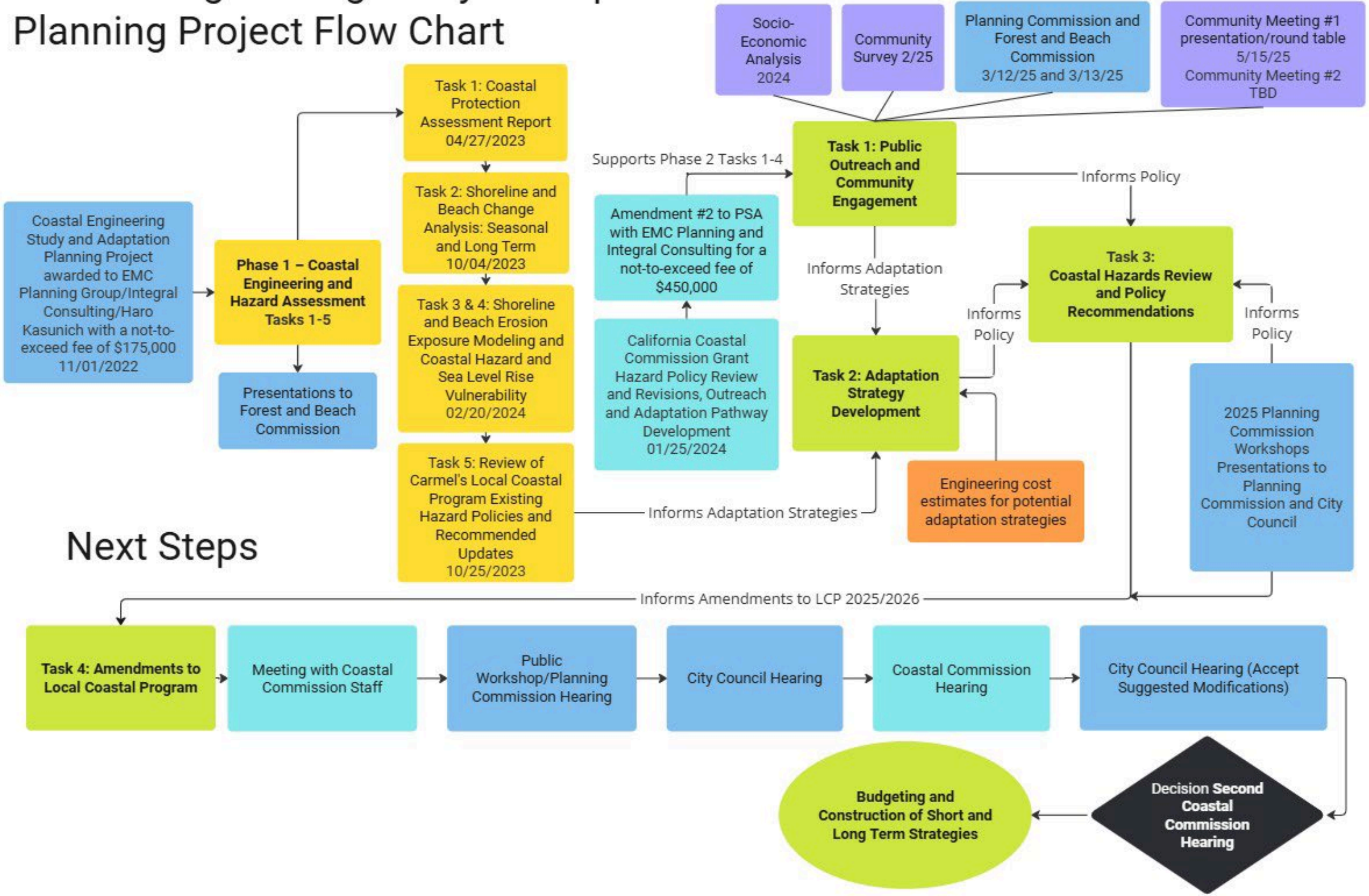
- Continued Public Outreach
- Socio-Economic Analysis
  - Survey and cell phone data analysis
  - Visitation patterns
  - Non-market beach and coastal recreational use values
  - City revenue streams, asset values
- Detailed Evaluation of Adaptation Options
  - Benefit cost analysis (BCA)
  - Identify high-priority projects
  - Cost estimates for construction and maintenance costs
- Adaptation Pathway Development
- Identify Adaptation Funding Sources
- Coastal Hazard Policy Recommendations and LCP Policy Revisions
- Future Grant Writing



***Above**: Example of an adaptation pathway.*

One adaptation pathway will be developed for each of the four sections of the City's coastline - North Beach, North Dunes, Central Beach, and South Beach

Coastal Engineering Study & Adaptation Planning Project Flow Chart



Next Steps

integral

David Revell

831.576.2884

drevell@integral-corp.com

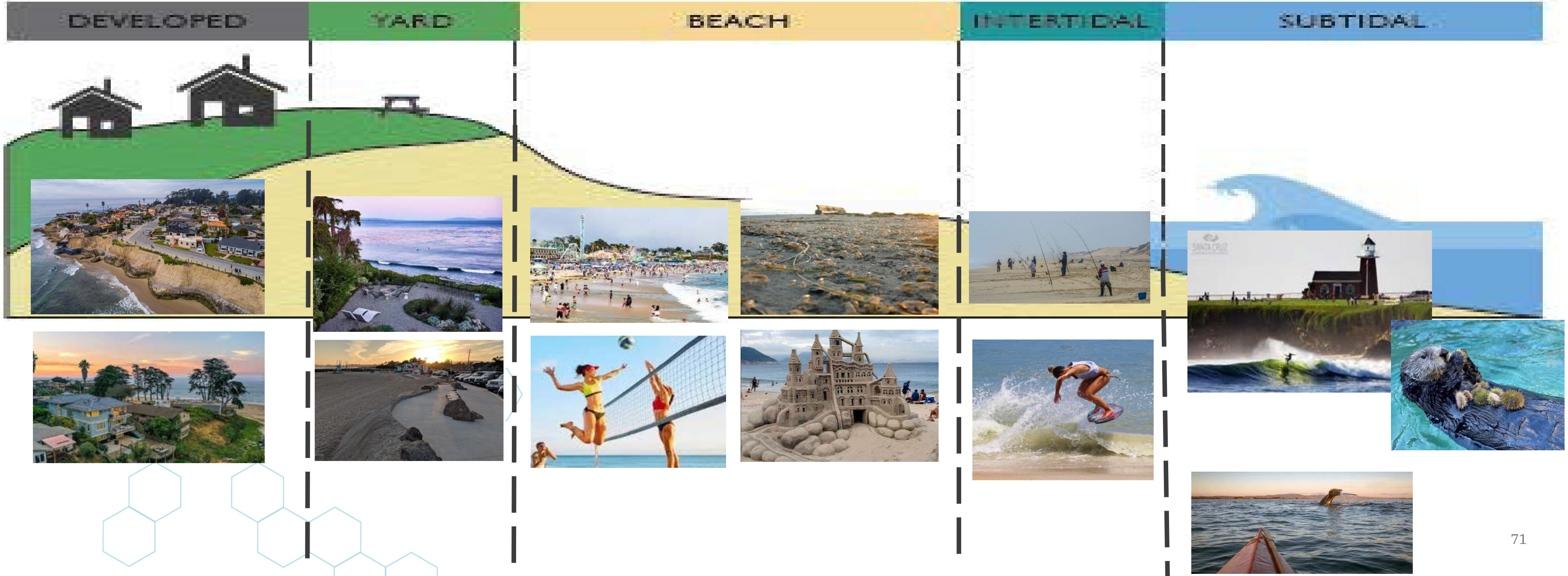
Adaptation Pathway Development

What needs to be considered?

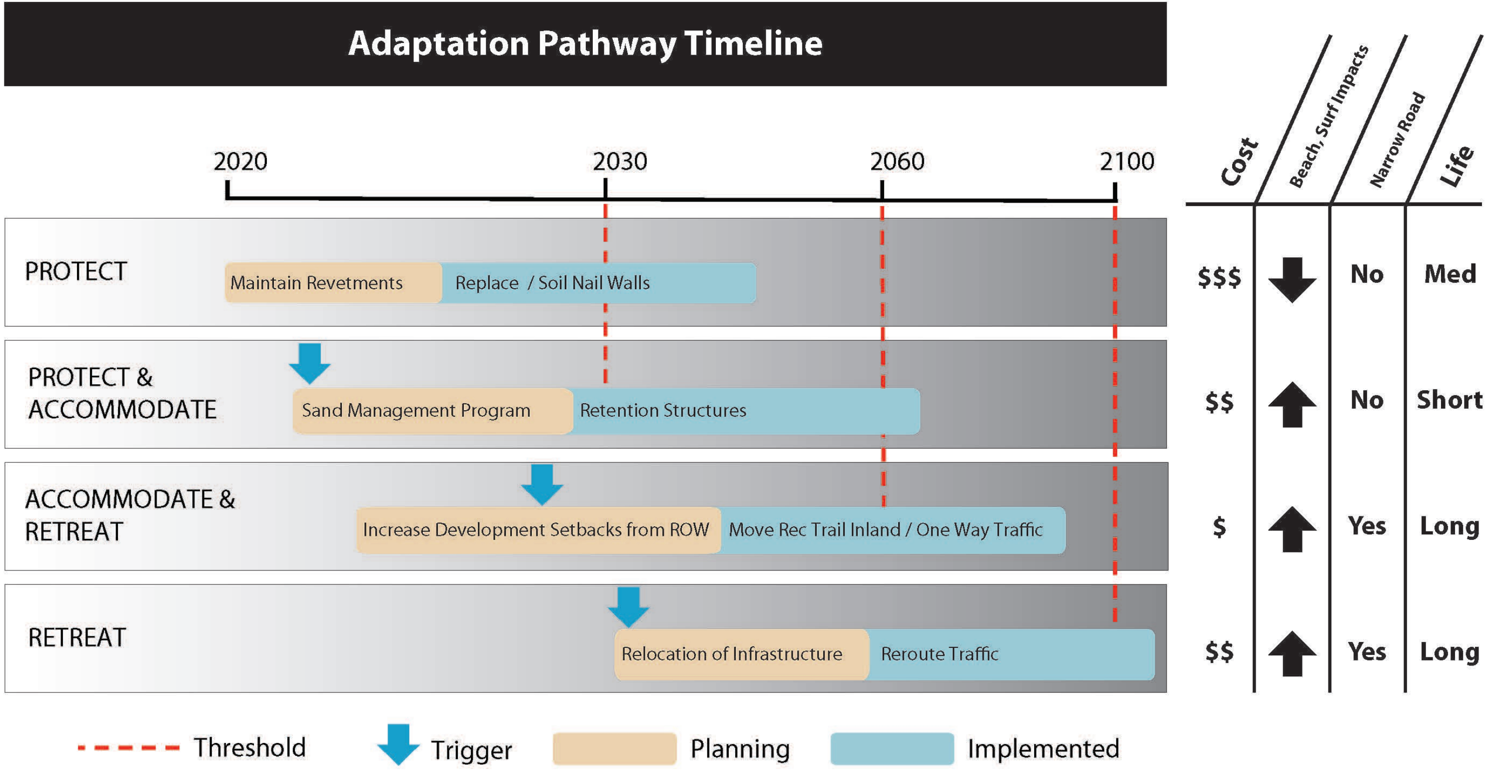
Upland Development, and Infrastructure

Vs.

Coastal Resources, and Recreation



Adaptation Pathway



Example Triggers

- **By sea level rise elevation** – trigger planning stages, study requirements
- **By rate of sea level rise** – after a certain rate, erosion will not keep up with sea level rise and beaches will be lost without further adaptation
- **By time** – specify that by 2025, some long-range study identifying appropriate strategies must be complete (e.g. wastewater or transportation) planning
- **By exposure** – how frequently does Scenic Rd get exposed to wave action and require cleaning? Do something different if 5x a month
- **By distance** – what is the distance between the trail and the cliff edge
- **By damages** – structure removed when damaged by 50% or multiple damage claims
- **By cost** – once the City spends $XX, then additional steps need to be taken

Protect

› **Green**

- Sediment Management
- Dune Restoration
- Beach Nourishment
- Cobble Nourishment

› **Grey**

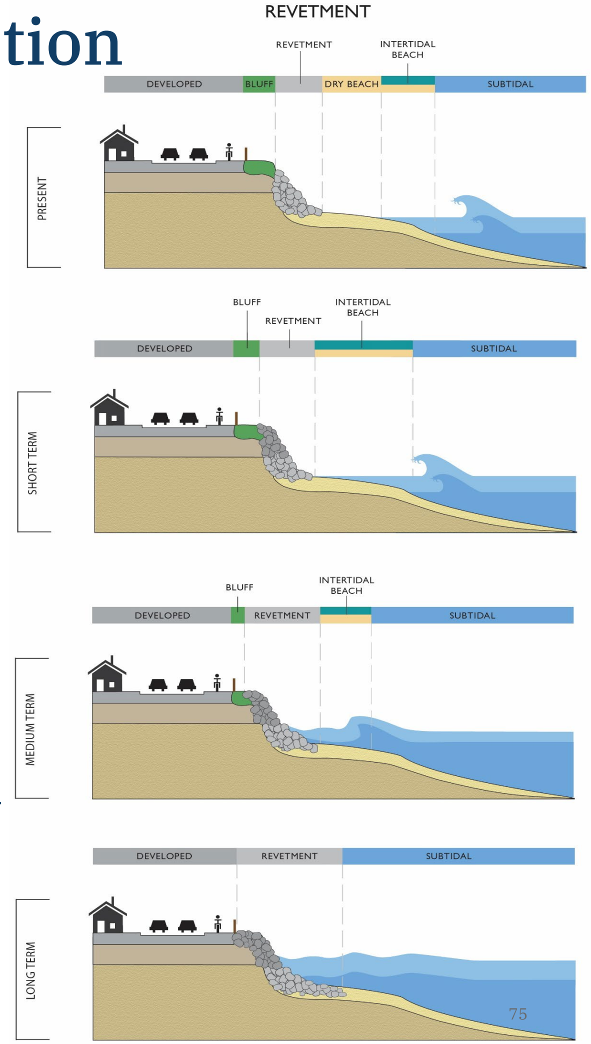
- Seawalls
- Revetments
- Jetties
- Artificial Reefs

Secondary Consequences

Adaptation Challenge with Coastal Protection

+ Temporarily protects infrastructure and development with associated property values, and tax base

- Armoring footprint occupies space on beach
- Armoring holds backshore in place reducing erosion and sediment supply. As sea levels rises, coastal squeeze narrows the beach, reducing recreation, access, surf breaks, and habitats.
- Narrower beaches reduce less wave energy resulting in higher maintenance costs for coastal protection

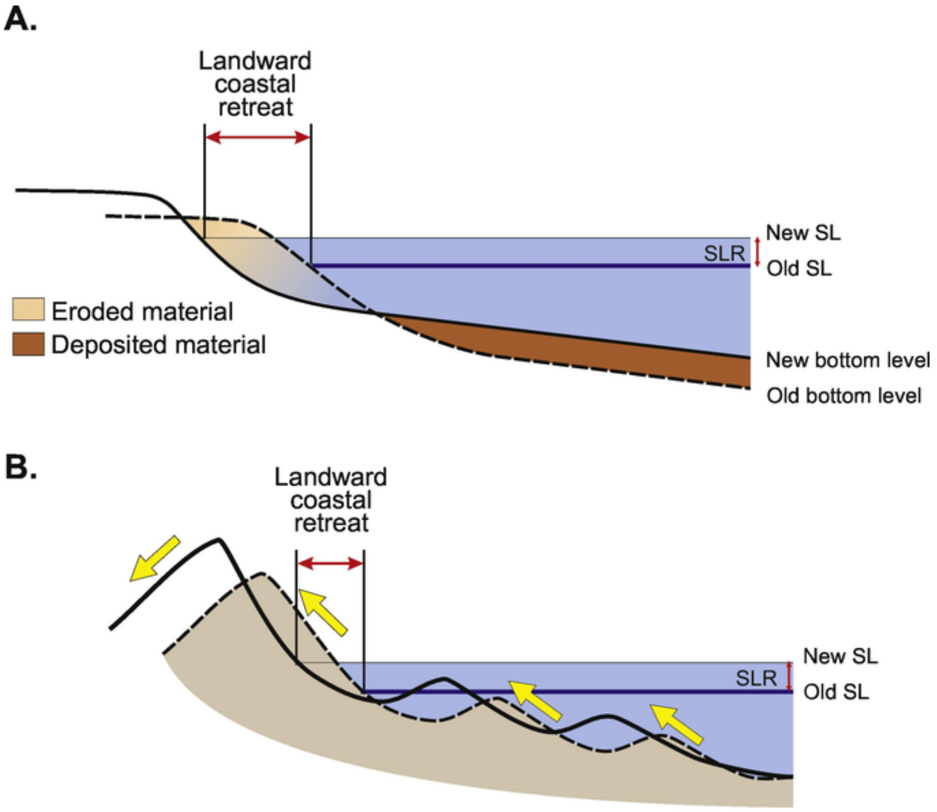


integral

Erosion Methods

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



integral

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

integral

Overtopping and Erosion Results

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**

integral

Coastal Cliff and Dune Erosion Projection With Armoring

Projected Bluff Crest Position Across Sea Level Rise Elevations

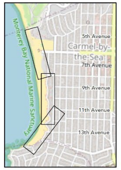
- 1 ft (2045 - 2060)
- 2 ft (2060 - 2080)
- 4 ft (2080 - 2100+)

Shoreline Features

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

Notes: *Erosion distances represent projected long-term time-averaged trends in erosion with 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.



integral

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

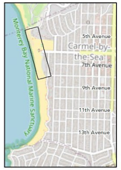
Most Likely | Best | Worst Case

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+)

Projected Bluff Crest Position Across Sea Level Rise Elevations

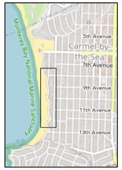
Most Likely | Best | Worst Case

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 - 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

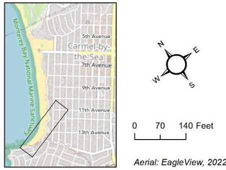
Most Likely | Best | Worst Case

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



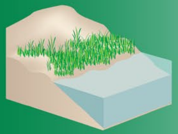
Aerial: EagleView, 2022

integral

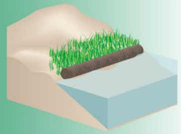
HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GREEN - SOFTER TECHNIQUES | **GRAY - HARDER TECHNIQUES**

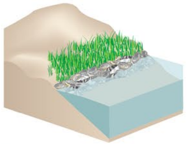
Living Shorelines



VEGETATION ONLY - Provides a buffer to upland areas and breaks small waves. Suitable for low wave energy environments.

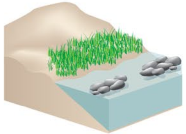


EDGING - Added structure holds the toe of existing or vegetated slope in place. Suitable for most areas except high wave energy environments.

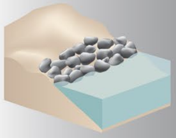


SILLS - Parallel to vegetated shoreline, reduces wave energy, and prevents erosion. Suitable for most areas except high wave energy environments.

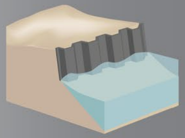
Coastal Structures



BREAKWATER - (vegetation optional) - Offshore structures intended to break waves, reducing the force of wave action, and encourage sediment accretion. Suitable for most areas.



REVETMENT - Lays over the slope of the shoreline and protects it from erosion and waves. Suitable for sites with existing hardened shoreline structures.



BULKHEAD - Vertical wall parallel to the shoreline intended to hold soil in place. Suitable for high energy settings and sites with existing hard shoreline structures.