CITY OF CARMEL-BY-THE-SEA
JOINT PLANNING COMMISSION & FOREST AND BEACH COMMISSION AGENDA

Planning Commissioners Mel Ahlborn, Erin Allen, Stefan Karapetkov, Michael LePage, Stephanie Locke
Forest and Beach Commissioners Sarah Berling, Kelly Brezoczky, Tamara Michie, Harry Ross, and Neal Rutta

All meetings are held in the City Council Chambers
East Side of Monte Verde Street
between Ocean and 7th Avenues

Special Meeting
Thursday, January 29, 2026
3:00 PM

HYBRID MEETING ATTENDANCE OPTIONS

This meeting will be held in person and via teleconference ("hybrid"). The public is welcome to attend the meeting in person or remotely via Zoom, however, the meeting will proceed as normal even if there are technical difficulties accessing Zoom. The City will do its best to resolve any technical issues as quickly as possible. To view or listen to the meeting from home, you may also watch the live stream on the City's YouTube page at: https://www.youtube.com/@CityofCarmelbytheSea/streams. To participate in the meeting via Zoom, copy and paste the link below into your browser.

https://ci-carmel-ca-us.zoom.us/j/83752396141?pwd=ChDGy3ab3hbCBVvAMV8f0CiidfwhjF.1 To attend Zoom webinar via telephone, dial +1 (669) 444-9171, Webinar ID: 837 5239 6141, Passcode: 001916

HOW TO OFFER PUBLIC COMMENT

The public may give public comment at this meeting in person, or using the Zoom teleconference module, provided that there is access to Zoom during the meeting. Zoom comments will be taken after the in-person comments. The public can also email comments to sgorman@ci.carmel.ca.us. Comments must be received at least 2 hours before the meeting in order to be provided to the legislative body. Comments received after that time and up to the beginning of the meeting will be made part of the record.

CALL TO ORDER AND ROLL CALL

PUBLIC APPEARANCES

Members of the public are entitled to speak on matters of municipal concern not on the agenda during Public Appearances. Each person's comments shall be limited to 3 minutes, or as otherwise established by the Chair. Persons are not required to provide their names, however, it is helpful for speakers to state their names so they may be identified in the minutes of the meeting. Under the Brown Act, public comment for matters on the agenda must relate to that agenda item and public comments for matters not on the agenda must relate to the subject matter jurisdiction of this legislative body. If a member of the public attending the meeting remotely violates the Brown Act by failing to comply with these requirements of the Brown Act, then that speaker will be muted.

ANNOUNCEMENTS

ORDERS OF BUSINESS

1) Carmel Sea Level Rise Draft Adaptation Pathways Report

FUTURE AGENDA ITEMS

2) Next Regular Meeting of the Planning Commission: February 11, 2026

3) Next Regular Meeting of the Forest & Beach Commission: February 12, 2026

ADJOURNMENT

This agenda was posted at City Hall, Monte Verde Street between Ocean Avenue and 7th Avenue, Harrison Memorial Library, located on the NE corner of Ocean Avenue and Lincoln Street, the Carmel-by-the-Sea Post Office, 5th Avenue between Dolores Street and San Carlos Street, and the City's webpage (http://www.ci.carmel.ca.us) in accordance with applicable legal requirements.

SUPPLEMENTAL MATERIAL RECEIVED AFTER THE POSTING OF THE AGENDA
Any supplemental writings or documents distributed to a majority of the Planning Commission regarding any item on this agenda, received after the posting of the agenda will be available at City Hall located on Monte Verde Street between Ocean and Seventh Avenues during regular business hours.

SPECIAL NOTICES TO PUBLIC
In compliance with the Americans with Disabilities Act, if you need special assistance to participate in this meeting, please contact the City Clerk's Office at 831-620-2000 at least 48 hours prior to the meeting to ensure that reasonable arrangements can be made to provide accessibility to the meeting (28CFR 35.102-35.104 ADA Title II).

CITY OF CARMEL-BY-THE-SEA
Staff Report

January 29, 2026

ORDERS OF BUSINESS

SUBMITTED BY: Mary Bilse, Environmental Programs Manager

APPROVED BY: Anna Ginette, AICP, Director of Community Planning and Building

SUBJECT: Presentation of the Carmel Beach Adaptation Pathways Report — Sea Level Rise and Coastal Hazard Planning for Carmel Beach

Application:
Block & Lot: N/A
Location: N/A
Applicant: N/A

APN: N/A

Owner: N/A

Recommendation:

Receive a presentation from Integral on the Carmel Adaptation Pathways Report and provide feedback on adaptation strategies, priorities, and policy ideas that may inform future planning efforts, including updates to the Local Coastal Program (LCP).

Summary, Background, and Project Description:

The Carmel Adaptation Pathways Report (**Attachment #1**) evaluates how sea level rise and coastal hazards may affect Carmel Beach over time and outlines a flexible, long-term approach for responding to those changes. The report was developed with extensive community outreach and reflects strong public interest in protecting what people value most about Carmel Beach, including public access, recreation, natural habitat, and its iconic white sand, while planning ahead for increasing coastal risks.

The report uses an “adaptation pathways” approach, which allows actions to be phased and adjusted over time as conditions change. This joint meeting provides the Forest & Beach Commission and Planning Commission with an opportunity to review the report and provide input on how the City should move forward with policy and implementation development.

Key Findings

Public outreach, including workshops, surveys, and public hearings, highlighted several consistent themes. Community members expressed strong support for nature-based solutions and emphasized the importance of early, proactive planning rather than relying on emergency or reactive fixes. Maintaining public beach access and recreational opportunities was identified as a high priority, along with protecting the natural look, feel, and character of Carmel Beach.

Adaptation Pathways Framework
Adaptation strategies in the report are organized by three planning areas: North Beach and North Dunes, Del Mar Dunes and Central Beach, and South Beach and Scenic Road. Within each area, recommended actions are tied to projected sea level rise conditions rather than fixed dates. These include immediate actions anticipated around 2026, near-term actions associated with approximately one foot of sea level rise (around 2050), mid-term actions associated with two feet of sea level rise (around 2070), and long-term actions associated with four feet of sea level rise (around 2100).

Adaptation Strategies
The report identifies three main approaches:

1. Nature-Based Solutions

- Restoring and expanding dunes
- Planting native vegetation
- Using driftwood to help stabilize sand
- Beach nourishment to maintain beach width

2. Engineered Approaches

- Seawalls, revetments, and wave deflectors where needed to protect key infrastructure
- Exploring nearshore reefs or shore platform enhancements to reduce energy

3. Managed Retreat

- Gradually relocating or modifying infrastructure in high-risk areas
- Avoiding new development where long-term risks are high

Challenges
The Carmel Adaptation Pathways Report also identifies several challenges associated with implementation. Finding compatible sand sources for beach nourishment can be difficult and is subject to significant regulatory oversight. Balancing public access, environmental protection, and infrastructure needs often requires tradeoffs. In addition, engineered solutions and nourishment projects tend to be costly and involve complex permitting processes.

Staff Analysis:

The Carmel Adaptation Pathways Report recommends the following near-term actions:

- Conduct sediment source and nourishment feasibility studies
- Develop a Beach and Dune Management Plan
- Establish a Coastal and Beach Monitoring Plan with defined triggers
- Enhance public communication and coordination with regulatory agencies

Planning-level cost estimates in the report include:

- Beach nourishment: $2–4 million (small projects) to $30 million (larger efforts)
- Nearshore reefs: approximately $43.5 million
- Wastewater infrastructure: approximately $2.5 million (retreat) or approximately $3 million (armoring)

The Carmel Adaptation Pathways Report provides a practical, community-driven roadmap for planning ahead as sea levels rise and coastal hazards increase. Input from both the Commissions will help staff refine priorities, identify policy updates, and guide future implementation efforts while protecting the special character of Carmel Beach.

Other Project Components:

ATTACHMENTS:

1. Carmel Adaptation Pathways Report_DRAFT

Carmel Adaptation Pathways

Adaptation Alternatives, Priorities, and Triggers

Prepared for
City of Carmel-by-the-Sea
Public Works
P.O. Box CC
Carmel-by-the-sea, California, 93921

Prepared by

Integral Consulting Inc.
200 Washington Street
Suite 201
Santa Cruz, CA 95060

December 2025

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ACRONYMS AND ABBREVIATIONS

CAWD	Carmel Area Wastewater District
CDP	coastal development permit
CEQA	California Environmental Quality Act
City	City of Carmel-by-the-Sea
LCP	local coastal program
NbS	Nature-Based Solutions
NEPA	National Environmental Policy Act
SLR	sea level rise
USACE	U.S. Army Corps of Engineers

GLOSSARY

Armoring (coastal)	Hard protection structures, such as seawalls and revetments, that are built to prevent erosion
Backshore	The extreme inland limit of the beach
Basal unit	The lower geologic formation of a cliff (sandstone in Carmel)
Bluff	Soft, unconsolidated materials found in marine terrace deposits
Bluff top	The location where there is an identifiable break from the steeper cliff and bluff to the gently sloping inland areas
Cliff	Hard, consolidated rock beneath the bluff
Dry-sand beach	The portion of the beach that is landward of the mean high-water mark
Dunes	Areas that are landward of the beach where wave action and onshore winds have led to sand deposition
Erosion (coastal)	1) For cliffs, the long-term loss or removal of land due to coastal or terrestrial processes; 2) for beaches, either the long-term, short-term, or localized removal of sediments from the beach
Littoral cell	A relatively self-contained coastal compartment within which sand is transported between sources, transport zones, and depositional sinks, such as beaches, dunes, or submarine canyons
Living shorelines	Are a nature-based approach to reducing coastal erosion. Living shorelines use natural materials, like native plants, to stabilize shorelines. In many cases, these techniques can be combined with structural components such as rock, driftwood, or fiber rolls to stabilize the shoreline.
Nature-based solutions	Are a broad category of strategies that work with nature to build coastal resilience
Nourishment	The placement of sand to offset erosion or increase beach width
Revetment	A sloped structure of rock or concrete to absorb wave energy and protect landward areas
Scour (beach)	The process by which waves and currents remove sediment from the beach (usually localized)
Shoreline	The region where water typically meets the land; the wet–dry line (in this report)

Splash	The instance when waves break seaward of the coastal armoring, or where the armoring is high in relation to the wave height, and overtopping is a concentrated stream of water droplets
Toe of the cliff	The location where the dry-sand beach meets the base of the cliff

EXECUTIVE SUMMARY

This Adaptation Pathways Report provides a flexible roadmap to address sea level rise and coastal hazards at Carmel Beach. The development of this report was guided by extensive community outreach, public hearings, and a survey of residents and visitors. Outreach findings demonstrate a strong desire to maintain safe and reliable beach access and to protect recreational, scenic, and ecological qualities of Carmel Beach. Community members expressed a clear preference for nature-based solutions where feasible, favored early proactive planning rather than emergency response, and emphasized the importance of maintaining the quality of the beach's distinctive white sand.

This report evaluates a broad suite of adaptation strategies, including beach and dune management, engineered shoreline protection, and the phased relocation of vulnerable assets. Adaptation pathways are tailored to three planning areas of the shoreline: North Beach and North Dunes, Del Mar Dunes and Central Beach, and South Beach and Scenic Road. For each area, the report describes appropriate actions for immediate, near-term (one foot of sea level rise), mid-term (two feet), and long-term (four feet) conditions. Cost considerations, regulatory feasibility, and integration with public safety and access goals inform how and when each strategy might advance.

Across the entire beach, immediate needs include maintaining and restoring the sand ramps and beach access stairways through access-focused repairs. The City can improve its storm readiness by re-establishing a sediment management program, implementing nature-based solutions, and enhancing shoreline monitoring to better track changes in beach width, erosion hotspots, and storm impacts. Stronger monitoring will also support public communication, funding pursuits, and the timely and transparent application of adaptation triggers.

In planning for future sea level rise, the City will face two major strategic decisions. The first concerns whether and how to implement beach nourishment. This strategy has strong potential to preserve beach width, but it depends heavily on identifying compatible sand sources within the regulatory context of Carmel Bay. The second involves the alignment of Scenic Road and the infrastructure beneath it. As erosion progresses, the City must weigh the secondary consequences between expanded coastal protection or pursuing selective retreat and realignment of upland development. A summary of some of the key adaptation strategies and the triggers for implementation is outlined below:

Table ES1. Summary of Adaptation Triggers and Strategies by Horizon

SLR Scenario	Adaptation Trigger(s)	Adaptation Strategies
Immediate	• Depth of sand at the sand ramps • Bedrock exposure duration • Condition of armoring and stairways	• Beach and dune management • Maintenance of coastal armoring • Targeted repair and improvement of stairways and sand ramps

Near-Term (1-ft SLR)	• Above + • Repair costs • Summer beach widths and beach recovery • Overtopping frequency at seawalls	• Implement NbS including woody material for toe protection and vegetation to trap sand • Pilot program for shore platform enhancement, sand retention, and current defectors
Mid-Term (2-ft SLR)	• Above+ • Frequency of waves reaching the dune toe • Availability of suitable sand sources	• Beach nourishment • Extend and raise coastal armoring • Nearshore reefs and wave tripping structures
Long-Term (4-ft SLR)	• Above+ • Distance between upland development and the dune or bluff rest	• Managed retreat and realignment of upland development and infrastructure

1 INTRODUCTION

This report is part of the City of Carmel Coastal Engineering and Adaptation Planning Project. Specifically, it fulfills the deliverable requirements for Phase 2, Task 4, "Adaptation Pathway Development." The scope of Task 4 focuses on the development of adaptation pathways for Carmel Beach—the region extending from Pescadero Canyon in the north to Carmel Point in the south—within the city of Carmel-by-the-Sea.

Adaptation pathways are frameworks that help navigate the uncertainties associated with climate change by laying out feasible adaptation approaches in a series of steps to be implemented over time. With this approach, instead of requiring a strategy to be implemented by a certain year, the community monitors a set of easily observable changes; when a specific trigger is met, planning then begins for the next phase of adaptation with enough lead time to avoid projected damages. Throughout all phases of the project, Integral Consulting Inc. and EMC Planning Group have had ongoing discussions with City staff, stakeholders, and regulators on site-specific vulnerabilities, immediate needs, and desires for longer-term adaptation to inform adaptation pathway development.

The adaptation pathways outlined in this report serve as high-level planning directions for Carmel Beach. Pathways are laid out for the entire beach and each of its planning areas (See Figure 3 in Section 1.3 for a map). They include strategy descriptions, rolled-up cost estimates, relevant triggers for considering new adaptation approaches, and recommendations for a monitoring program. This framework allows the City of Carmel-by-the-Sea (City) to consider both systemwide and site-specific adaptation strategies that address local shoreline characteristics. Adaptation strategies are organized by time horizon from the immediate term (0 ft of sea level rise [SLR] or 2025) to the near term (1 ft of SLR or ~2050), midterm (2 ft of SLR or ~2070), and long term (4 ft of SLR or ~2100) (OPC, 2024).

This adaptation pathway report serves as a bridge between the project's 1) coastal hazards and vulnerability assessment completed in Phase 1 (Integral 2024), and 2) upcoming policy updates to the City's local coastal program (LCP) (Phase 2, Tasks 5–7). It also expands on a range of feasible SLR adaptation approaches that were developed under Phase 2, Task 1. These approaches were evaluated and ranked using a set of screening criteria and vetted through regulatory consultation, City input, and community outreach. Descriptions of these adaptation strategies—including their potential, secondary benefits and consequences—are detailed in Sections 1.5–1.7.

In addition, this report builds on the project's Phase 2, Task 3, "Socio-Economic Analyses," which included 1) adaptation preferences that were informed by an outreach survey, 2) an analysis of visitation patterns using cellphone data, and 3) a travel cost model for a broader understanding of the non-market value of a beach visit. This report found that among survey participants, the areas of greatest concern are 1) coastal, storm-related cliff and dune erosion, 2) damage to coastal access stairs and sand ramps, and 3) the loss of the sandy beach area.

The respondents also expressed a preference for nature-based adaptation approaches over armoring strategies, despite their better familiarity with armoring approaches. They were generally satisfied with the City's maintenance of Carmel Beach (e.g., sand management and maintenance at the Del Mar Parking Lot, debris cleanup), but they were less satisfied with the City's emergency storm response. Survey respondents called for an improved storm response as well as the development of a more proactive and structured maintenance program to avoid and more quickly mitigate future damage.

This work is also intended to meet the requirements laid out in SB 272, which requires local jurisdictions to integrate sea level rise planning into planning processes and LCP updates. Among the requirements of this legislation is to develop a suite of recommended adaptation strategies that reduce risks from coastal hazards, identifying the entities responsible for planning and implementation, and establishing a timeline for adaptive measures based on evolving sea level projections. In subsequent phases, the project team will refine the adaptation pathways in this document into actionable policies, funding mechanisms, and permitting strategies that will support the City's goal of implementing proactive adaptation solutions to meet coastal resilience goals.

1.1 ADAPTATION PATHWAYS FOR SEA LEVEL RISE

An adaptation pathway allows the City to visualize a sequence of adaptation actions while accounting for lead times associated with planning and other efforts, such as outreach, permitting, design, funding, and construction. Because of the uncertainty over future physical conditions, natural variability, and changing societal values, an adaptation pathway should remain flexible. Appendix A includes a more detailed discussion of adaptation planning principles.

The core premise of an adaptation pathway is planning for future needs; this planning should be triggered by predetermined triggers. Adaptation triggers are measurable thresholds that indicate when management actions must begin to avoid or limit coastal risks. The incorporation of these triggers into the LCP will help ensure that policy updates and permitting decisions remain adaptive, transparent, and consistent with evolving shoreline conditions. Triggers are typically developed by working backward from tipping points or thresholds where damages go from mild to significant. These indicators may include physical metrics (e.g., beach width, bluff retreat, overtopping frequency); social metrics (e.g., access disruption, safety hazards); or economic metrics (e.g., unsustainable maintenance costs, higher insurance claim costs).

The identification of adaptation triggers requires sustained monitoring, which provides the data needed to verify when thresholds are reached and guides the timing of future adaptation actions. A consistent monitoring program will allow the City to track shoreline changes, assess the effectiveness of implemented strategies, and adjust the management of measurements as conditions evolve. Overall, monitoring should be affordable and repeatable, and it should be

integrated into existing City operations. A monitoring program should rely on field observations, data from maintenance activities, and information from community partners. Modern tools, like shoreline cameras, are helpful in that they allow for the low-cost, continuous tracking of shoreline conditions and public use. Collecting higher-quality and more frequent data will improve the ability of the City and its contractors to evaluate conditions to determine if triggers are reached, and their conclusions will form the basis for adaptation decisions and budgeting. A more detailed explanation of specific triggers and monitoring approaches for Carmel Beach can be found in Appendix B.

1.2 ADAPTATION APPROACHES

Adaptation approaches to coastal hazards can be divided into separate components, beginning with project-level strategies and policies that can facilitate the implementation of specific initiatives. The goal of this project is to identify the types of approaches that 1) the community prefers, and 2) are deemed feasible for further investigation so that subsequent policy updates can be integrated into the City's LCP.

Following the establishment of project-level goals, adaptation strategies can be implemented horizontally and vertically in various zones (Figure 1). Within each zone, adaptation strategies can be divided into categories based on how they affect the physical processes and hydrodynamics that cause erosion (i.e., whether they stop or reduce erosion).

Figure 1. Horizontal and Vertical Zones for Coastline Adaptation Strategies

Some adaptation strategies have been previously implemented by the City; one such strategy is armoring the coast. Other strategies include measures that dissipate wave energy and reduce localized longshore currents or mimic natural defensive habitat functions. Erosion-reduction strategies can also include more nature-based approaches that utilize natural materials—such as driftwood and vegetation—to guide human uses and reduce the magnitude of physical processes that cause erosion. These different adaptation strategies are on a spectrum of "gray to green" (Figure 2). Gray approaches use engineered protection structures, such as seawalls and revetments, to stop erosion. Green approaches—including sand

management, beach nourishment, dune restoration, and living shorelines—use natural processes to build elevation and widen beaches, thereby reducing erosion and providing a buffer against storm waves. Carmel has historically relied on a combination of engineered protection strategies, including seawalls and revetments, to stop erosion. It has also relied on nature-based approaches, such as sand management, to reduce erosion.

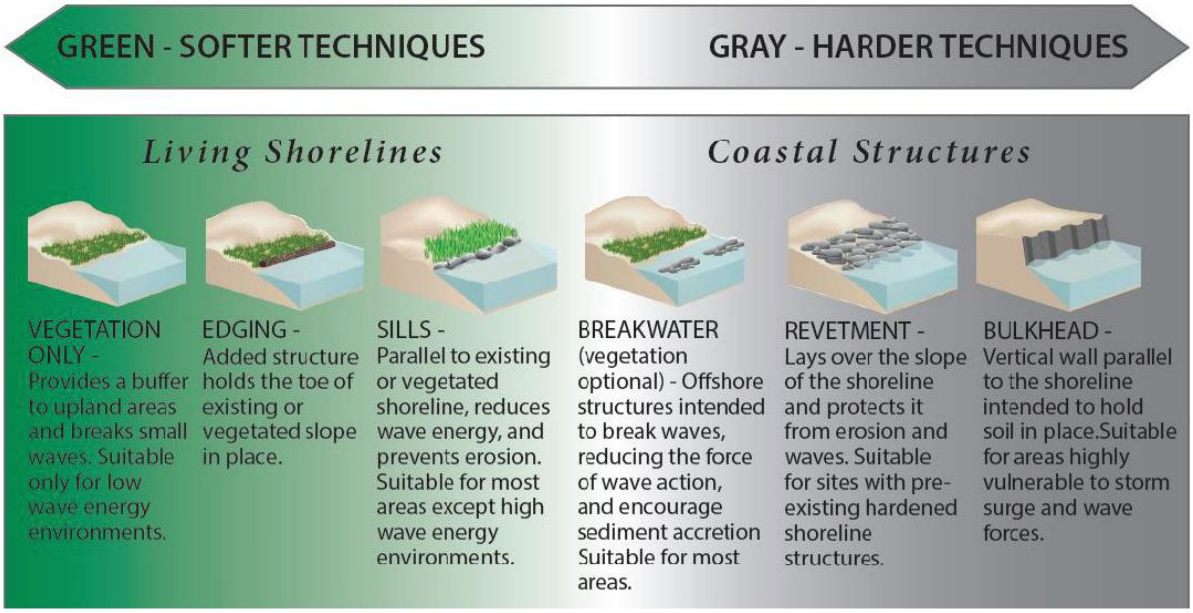

Figure 2. "Gray to Green" Adaptation Strategies for Erosion or Flood Mitigation (NOAA and USACE 2015 & NOAA 2025)

These adaptation strategies differ in their approach to erosion mitigation. For example, engineered protections at the back of the beach, such as seawalls and revetments, are intended to stop erosive wave energy at the backshore to stop erosion and protect upland development. Conversely, nearshore protections, such as reefs, disrupt wave energy before reaching the beach and backshore, thereby reducing the forces that drive erosion. In addition, sand, dune, and vegetation strategies are intended to primarily reduce erosion by increasing dry-sand beach areas, providing root stabilization, and trapping sediment in place (Figure 2).

Another strategy avoids coastal hazards by retreating or relocating upland infrastructure and development away from high-risk areas while limiting new construction. This managed-retreat approach is not an evacuation; rather, it is a gradual moving away from high-hazard areas. It is guided by policies, land-use designations, and zoning ordinances that support the gradual removal of upland development and infrastructure. Early steps include 1) requiring real estate disclosures for property transactions that list coastal hazards and SLR impacts, and 2) limiting City liability for land-use decisions. The development of an equitable acquisition program is also important for the relocation of private development based on the community's vision of maintaining access to Carmel's beaches and coast. Over time, this approach becomes the most

cost-effective option compared to the maintenance of erosion control structures, and it ensures that retreats occur through a planned, controlled process that maximizes public and private benefits.

Some strategies are not practical for the project. For example, some strategies accommodate coastal hazards by modifying upland development (e.g., elevating structures or increasing setbacks, accommodating flood depths or accelerated erosion while reducing damages). Given the City's existing development patterns, however, which are relatively built out, most of the accommodation strategies are not applicable to the project. Section 1.6 details the range of feasible coastal adaptation strategies for the project, and Section 2 describes where and when these approaches may make the most sense.

The implementation of adaptation strategies requires lead times to plan, permit, design, finance, and implement the effort; adaptation efforts often blend these approaches across different locations and time frames. In addition, these potentially feasible adaptation strategies will require more technical work and community dialog. Immediate and short-term strategies (and potentially mid-term measures) that align with community preferences should be identified in policy updates to streamline financing and implementation in an updated LCP, as well as to meet California's Senate Bill 272 requirements, so that the City will be positioned for funding. Mid-term strategies that are currently identified will require additional technical work, consultations with regulatory agencies, ongoing dialogs with the community, and consistent monitoring to help identify transparently when it is time to decide which adaptation strategy should be pursued. These efforts should be based on evolving community vision, scientific information, and observable changes that reduce the existing uncertainty about future conditions.

1.3 STUDY AREA

This report focuses on the City-managed portion of Carmel Beach, from Pescadero Canyon in the north to Carmel Point in the south. The study area comprises three planning areas: North Beach and North Dunes, Central Beach and Del Mar Dunes, and South Beach and Scenic Road (Figure 3, left). These planning areas are based on prior work from a climate change vulnerability assessment report (Carmel-by-the-Sea 2021) and from Phase 1 (Integral 2024). For this study, some boundaries between sections have been modified slightly from prior work, and both North Beach and North Dunes have been combined into one section. Their details are provided below:

- North Dunes and North Beach include the armored private properties on the cliffs at the north end of the City as well as the mostly natural and unarmored North Dunes area. This section includes three sand ramps (used for beach access) and the Del Mar Avenue parking lot.

- Central Beach and Del Mar Dunes include the mostly unarmored dunes and private properties between 8th Avenue and the Del Mar Parking Lot. At 8th Avenue and Scenic Road, there is a coastal access stairway and an emergency access sand ramp that is currently closed because of erosion damage.
- South Beach and Scenic Road include the mostly armored cliffs and vegetated bluffs along Scenic Road that are south of 8th Avenue. This section includes eight coastal access stairways from 9th Avenue to Martin Way.

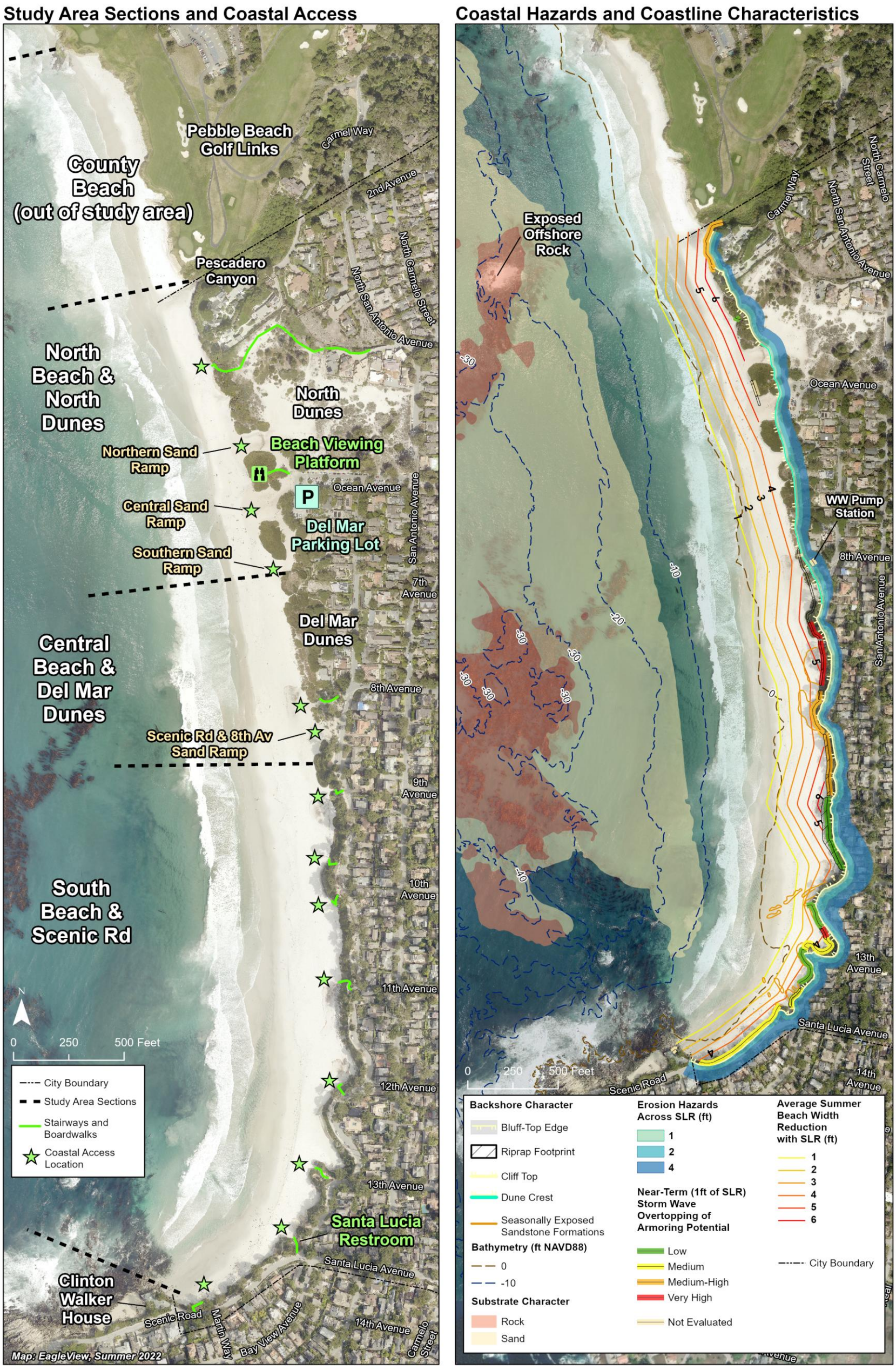

Figure 3. Carmel Beach Study Area and Adaptation Pathway Subareas (left); Coastal Erosion Hazard Zones and Areas of Concern for Wave Overtopping and Important Geomorphic Characteristics of the Upland Backshore, Nearshore, and Offshore Regions (right)

1.3.1 Existing Conditions

The City's existing approach to coastal erosion is the use of seawalls and riprap rock (revetments) to stop the erosion of the cliff and bluff. While this strategy has protected the backshore, it will have limited effectiveness as a long-term strategy with increasing sea levels, as it will eventually lead to the loss of the beach and a corresponding loss in natural resources, coastal recreation, and economic benefits. Naturally, Carmel Beach has the potential to maintain a wide and accessible beach despite the presence of extensive coastal armoring due to its relatively unique littoral cell setting. It forms a pocket beach that maintains a stable sand volume that is supported by retaining headlands, like smaller littoral systems found along the Oregon coast. As the sea level rises, this stability could be sustained through periodic beach nourishment.

Carmel Beach has distinctive sand that is derived from the abrasion of the granitic material found on the Monterey Peninsula (Appendix C). The sand has a fine texture and light color that is notably different from the coarser sand just to the south at Carmel River State Beach (Figure 4). A key challenge in planning for nourishment is identifying a compatible sand source. The most likely potential sources lie within Carmel Bay; however, extraction and placement may be limited by regulations of the Marine Protected Area and Monterey Bay National Marine Sanctuary.

Figure 4. Carmel Beach and Carmel River State Beach Locations (left); Carmel Beach (top) and Carmel River State Beach (bottom) Images (center); Carmel Beach (top) and Carmel River State Beach (bottom) Sand Colors (right)

1.3.2 Coastal Uses and Access

Carmel Beach supports a wide range of coastal uses that contribute to the community's identity and quality of life. User surveys have indicated that passive recreation, such as dog walking and nature watching, are top priorities for visitors and residents. Although active recreation—such as running, beach volleyball, fishing, and surfing—was less frequently mentioned in the outreach surveys, a dedicated group of users regularly engage in it. All these uses highlight the need to maintain safe and accessible areas for various recreational activities.

The most frequently used access points for the beach include the Del Mar Parking Lot, sand ramps, and the 8th Avenue sand ramp and stairs. The Del Mar Parking area and the Scenic Road Beach Bluff Pathway are among the most heavily used sections of the beach, which highlights their importance for beach access, recreation, community gathering, and socializing.

1.3.3 Vulnerabilities to Sea Level Rise

SLR vulnerabilities along Carmel Beach vary by location. They are also shaped by seasonal beach widths, coastal wave exposure, and the location of upland development. Under current and near-term SLR conditions, beach access infrastructure—such as the sand ramps and beach access stairways, which are adjacent to the active beach—are exposed to coastal hazards. In the mid-term (1–2 ft of SLR), vulnerabilities are driven by progressive beach narrowing, increased coastal wave exposure, and accelerated coastal erosion. In this horizon, upland development—including the Scenic Road Beach Bluff Pathway, Scenic Road, and utilities like wastewater and water lines—is vulnerable. In long-term (4 ft of SLR), upland development becomes increasingly vulnerable, and private property and public infrastructure, such as the Del Mar Parking Lot, are at risk of coastal erosion. Table 1 summarizes the timing and areas of highest risk under progressive SLR scenarios; it identifies where early management attention is most critical. The right-hand image in Figure 3 provides spatial context for the hazards described in Table 1.

Table 1. Projected SLR Vulnerabilities with No Adaptation Measures and Current Armoring

SLR (ft)	Areas with High Overtopping Risk	Development at Risk from Erosion	Winter Beach Widths at Risk	Summer Beach Widths at Risk
0	Not applicable	All beach access stairways and sand ramps; all stormwater infrastructure along coastal bluffs and dunes	Not applicable	Not applicable
1	9th to 10th Avenue	Scenic Road Beach Bluff Pathway and a water line near Martin Way from 12th to 13th Avenue and 9th to 10th Avenue	12th Avenue south to the end of the beach	Not applicable
2	Above+8th to 13th Avenue; Martin Way; 4th Avenue to Pescadero Canyon	The entire length of the Scenic Road, including the pathway, street parking spaces, utilities, and the road; wastewater pipe under the Del Mar Dunes and the lift station near 8th Avenue	The area described above; the 10th Avenue headland impedes lateral access	Not applicable
4	Most of the cliff-backed shoreline	The areas described above; 44 homes along Scenic Road in the South and at North Beach; the Del Mar Parking Lot and associated utilities	All but small pockets of the beach	Narrow width for the whole beach; little dry-sand beach recovers at the extreme southern and northern (county) portions

1.4 ADAPTATION GOALS

Adaptation goals describe the long-term vision for the shoreline and guide how management decisions are made to balance public access, habitat, recreation, and the protection of coastal infrastructure. For this project, the goals were informed through engagement efforts with community members, public works employes, and survey respondents, and they reflect the community vision for Carmel Beach.

Overall, the project team received 307 complete surveys. The survey included questions about beach visitation preferences and opinions on coastal adaptation. In addition, the project team also presented the project at eight city council and Forest and Beach Commission hearings to answer questions and solicit feedback on tasks. Feedback and comments from the city and the community at large emphasized several key priorities for adaptation:

- Pursue nature-based strategies that enhance natural resilience and ecological function.
- Take early and proactive action (rather than waiting for damage to occur).
- Promote environmental education and public awareness about coastal change.
- Support a managed retreat, where feasible, to allow for inland beach migration.
- Preserve the City's coastal identity by maintaining the existing quality of beach sand and recreational uses.
- Maintain public safety, create safe and accessible transitions to the beach (safe landings), and ensure lateral access along the beach.

1.5 EVALUATION OF ADAPTATION STRATEGIES

The evaluation and vetting process for the Carmel Beach adaptation strategies considered technical and political feasibility as well as broader tradeoffs for the community and the environment. Each strategy was screened based on criteria that included regulatory, financial, ecological, and social factors, and feasibility was judged based on cost, regulatory/legal factors, and secondary consequences. Each strategy was then assigned a priority index score balancing all these factors.

The scoring system ranked each criterion based on three levels: low, medium, and high. Regulatory viability was assessed as either viable, likely, less likely, or unlikely. The various secondary impacts were evaluated on a three-point scale, with "+1" for a favorable consequence, "0" for no effect, and "-1" for a negative impact. These scores allow strategies to be compared consistently across criteria and identify which adaptation strategies are most feasible; they are presented in Section 1.7 (Table 3).

The following sections detail the categories used to rank each strategy, and they summarize the range of strategies considered most feasible.

1.5.1 Timing for Implementation

The timing of implementation of coastal adaptation strategies varies based on public acceptance, feasibility, lead times, and constraints like costs. The highest priorities for early implementation include many of the more nature-based approaches—including beach, dune, and vegetation management strategies—while monitoring and maintaining the existing engineered strategies. More complex strategies that require additional technical studies and regulatory consultations—such as beach nourishment or nearshore reefs—fall into the mid-term category, as they require significant study, planning, permitting, and design. Longer-term strategies include realignment, relocation, and retreat strategies, as they require significant effort and collaboration among numerous stakeholders.

1.5.2 Cost

The cost category is divided into initial construction costs and ongoing maintenance costs. Construction costs are consolidated, providing an order of magnitude estimate for the implementation of an adaptation strategy, while maintenance costs reflect routine ongoing costs, such as periodic nourishment, monitoring, and repairs.

To ensure consistency across strategies, cost estimates were assigned using the following scale:

$	=	<$100,000
$$	=	$100,000–$500,000
$$$	=	$500,000–$1,000,000
$$$$	=	$1,000,000–$5,000,000

These symbols appear in the evaluation table and the adaptation pathways in Section 2 to allow comparisons across strategies based on initial construction and ongoing maintenance costs (the actual cost of a strategy is typically based on bids, which are influenced by many economic factors and can vary widely). Nature-based approaches—such as dune restoration, vegetation planting, and the beneficial reuse of sand—typically have low to moderate construction costs (beach nourishment being the exception) as well as moderate, consistent ongoing maintenance costs and monitoring needs. Engineered protection measures—like seawalls, revetments, and offshore breakwaters—tend to have high upfront construction costs and potentially moderate to high long-term maintenance costs and secondary impacts.

In addition to initial and ongoing costs, project planning must also account for the potential costs of inaction as well as indirect economic considerations, including potential economic impacts on tourism, beach access, and city revenue. Strategies that maintain wide, accessible beaches tend to offer long-term cost savings by reducing the need for frequent maintenance and protecting economic interests. However, these indirect economic factors were not

comprehensively assessed in prior phases of the work and need to be examined in greater detail in future stages of adaptation planning.

1.5.3 Regulatory Viability

Coastal adaptation projects in Carmel must comply with a range of state and federal regulations and coordinate approvals across multiple agencies (see Appendix A for more details). Larger projects may require coastal development permits (CDPs) and environmental reviews under the California Environmental Quality Act (CEQA) or National Environmental Policy Act (NEPA), but they are less likely to trigger federal review unless a disturbance occurs below the mean high-tide line. Carmel Bay has multiple marine protections and a variety of regulatory agencies. Depending upon the specific location of adaptation, primarily above or below MHW, the following special designation and their regulatory agency would require additional consultations: NOAA, who oversees the Monterey Bay National Marine Sanctuary, the California Department of Fish and Wildlife, who oversees the Carmel Bay State Marine Conservation Area, and the State Water Resources Control Board, who oversees the Carmel Bay ASBS State Water Quality Protection Area (note that the Carmel Pinnacles State Marine Reserve lies just offshore of this critical coastal area).

For projects like beach nourishment, permitting will also include U.S. Army Corps of Engineers (USACE) Section 404 permitting, while offshore structures, such as reefs, must be reviewed under the National Marine Sanctuaries Act.

Projects within the coastal zone either fall within the City's LCP jurisdiction or within the California Coastal Commission's (CCC) retained jurisdiction. A project may also require approval from the State Lands Commission and require federal permits under the Clean Water Act, Rivers and Harbors Act, Endangered Species Act, and National Marine Sanctuary Act. One major benefit of updating the City's LCP is to align with the CCC's adaptation priorities so that strategies above mean high tide line (MHTL) can be permitted by the City, leading to expedited implementation.

Regulatory details for specific approaches are described below:

- Dune and sand management approaches, such as dune restoration, generally have fewer regulatory barriers, lower construction costs, and stronger alignment with state guidance encouraging nature-based adaptation.
- Engineered infrastructure can be permitted by City if above MHTL. Note that certain engineered options may be deemed inconsistent with the Coastal Act's policies, especially when they contribute to coastal squeeze or a loss of public beach, and may be appealed to CCC. Strategies below MHTL must be permitted by CCC.
- Retreat or relocation strategies are socially and politically challenging, but they often encounter fewer regulatory obstacles with the CCC because they reduce long-term hazard exposure and are generally aligned with the California Coastal Act. The major

obstacles to these strategies are public acceptance, political will, and coordination with multiple agencies overseeing various lands and utilities. These strategies often have high upfront costs associated with planning and implementation.

1.5.4 Beach Widths

Adaptation strategies vary in their influence on beach width. Nature-based approaches, for one, vary in their scoring. Beach nourishment receives a positive score, as it maintains or widens the beach while enhancing storm buffering. In contrast, approaches like dune creation might take up space that otherwise could be used for beach recreation. Hard structures like seawalls and revetments receive a negative score, as they typically result in beach narrowing over time from passive erosion and coastal squeeze. Short-term strategies, such as opportunistic sand reuse, can provide temporary beach width increases but require ongoing maintenance. The strategy of managed retreat has a positive score, as it allows for the erosion of the backshore, giving space for the beach to migrate inland.

1.5.5 Environmental and Habitat Impacts

Nature-based strategies typically provide the highest levels of recreational and ecological benefits. Dune and vegetation restoration strategies enhance native habitat and biodiversity; thus, they have a positive score when weighing priorities. Beach nourishment is harder to judge, as this practice can help sustain coastal habitat and maintain sediment supply but may temporarily disturb ecological communities during construction, especially in intertidal zones, and thus receive a neutral score. The long-term ecological effect depends on sediment compatibility, placement timing, and frequency of nourishment cycles. Finally, hard protection structures tend to degrade habitats through passive erosion and increase nearshore currents and wave reflection; thus, their strategies have a negative score.

1.5.6 Public Access and Safety

Most strategies aim to balance hazard reduction with maintenance of beach access. Dune restoration and beach nourishment enhance access and safety by preserving beach widths and reducing wave energy at beach access points; thus, receiving a positive score. Strategies such as winter storm berms can temporarily improve storm safety, but lateral and vertical beach access may be affected, and it may require frequent rebuilding. Hard protection measures protect upland development, but they will eventually limit lateral movement along the beach, reducing accessibility during wintertime and high tides; thus, they received a negative score.

1.5.7 Secondary Consequences of Coastal Armoring on Beach Widths

Wherever a hard structure is built along a shoreline undergoing long-term net erosion due to SLR, there will be a gradual loss of beach in front of a seawall or revetment. Over time, as the

water deepens and the shore face of the beach moves landward, the beach will eventually disappear (Figure 5). While upland development may be protected, the coastal recreation and habitats are lost. This process is known as *coastal squeeze*, and it occurs when the shoreline is fixed along an otherwise eroding stretch of coast. It will eventually lead to a loss in the recreational amenities associated with the beach unless the shoreline is continually replenished. At Carmel Beach, existing seawalls and revetments already limit the natural landward erosion of the shoreline, creating conditions of coastal squeeze.

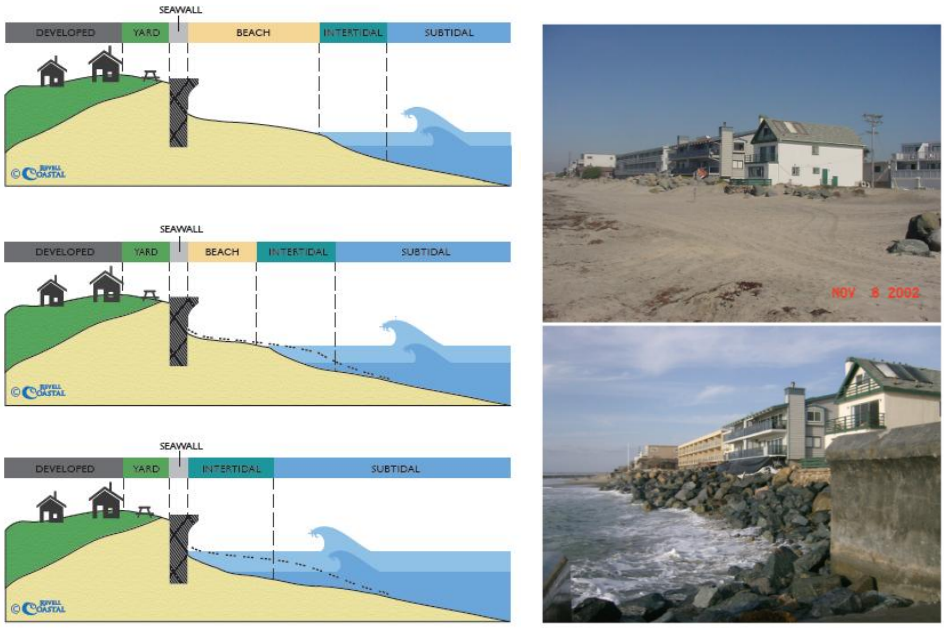

Figure 5. In-Place Backshore Fixing and Coastal Squeeze (left); Photographs from 2002 and 2012 at Imperial Beach Demonstrating Coastal Squeeze (right)

While Carmel has a unique littoral cell with a relatively stable volume of sand, as the sea level rises, Carmel Beach is projected to narrow significantly. In Phase 1, Task 2, the project team evaluated this coastal squeeze and projected the future summer beach narrowing with SLR. Results indicate a significant narrowing of beach widths after 3 ft of SLR (see Figure 3 for a map of beach widths), and in longer-term horizons, the recovery of the summer beach in its northern and southern ends may be limited, thereby limiting vertical and lateral access (Table 2).

Table 2. Typical Summer Dry-Sand Beach Remaining with SLR

SLR Elevation (ft)	Summer Beach (acres)	Percentage of Historical Summer Beach (1984–2021)
0	34.2	100%
1	27.4	80%
2	20.7	61%

Table 2. Typical Summer Dry-Sand Beach Remaining with SLR

SLR Elevation (ft)	Summer Beach (acres)	Percentage of Historical Summer Beach (1984–2021)
3	14.1	41%
4	7.6	22%
5	2.6	8%

Note: The baseline year for SLR 2020. Summer dry-sand beach acreage is representative of the 75th percentile beach width from 1984 to 2021.

1.6 RANGE OF COASTAL ADAPTATION STRATEGIES CONSIDERED

The coastal adaptation strategies deemed most feasible—based on an alignment with community priorities and regulatory viability—are grouped into three categories: dune and sand management (green strategies), engineered protection (gray strategies), and managed retreat or relocation (Table 3). Together, these strategies provide various options that can be combined or phased over time into an adaptation pathway to enhance resilience and maintain the beach and access over time.

1.6.1 Dune and Sand Management

Nature-based strategies strengthen the natural defenses of the beach and dune system while maintaining habitat and recreational value. These approaches to reduce erosion use vegetation, sand placement, and natural materials like driftwood to absorb wave energy, support dune formation, and sustain beach width over time. By maintaining beach widths, the amount of erosive wave energy reaching the base of the cliffs and dunes can be reduced. These strategies result in a more resilient backshore and better buffer, even when the beach is scoured during severe winter storms.

The following sections describe the range of feasible dune and sand management strategies. Given the unique sand on Carmel Beach and the high priority placed on the beach by the community, additional studies will be necessary to further evaluate the feasibility and longevity of these strategies.

1.6.1.1 Sacrificial Winter Storm Berm (reduce erosion)

For winter storms, a low storm berm along the beach can reduce wave impacts on the backshore. The berm will erode naturally during winter storm events and can be rebuilt as needed with locally sourced sand. This strategy is not applicable where there are narrower beaches, and it is unnecessary where coastal armoring is already in place. Primary locations for implementation are likely to be along the dune-backed shoreline between 4th and 8th Avenue.

Figure 6. Winter Storm Berm at Carpinteria City Beach Protecting a Low-Lying Neighborhood

1.6.1.2 Driftwood for Dune Stability (reduce erosion)

Driftwood that is strategically placed along the upper beach or back beach can trap sand and encourage dune formation. When combined with native vegetation, this method creates a self-sustaining natural barrier that enhances resilience and habitat value while maintaining a natural beach appearance. The City decided several years ago to leave driftwood in place on the beach, except where large logs pose a risk of damaging staircases or other infrastructure (Figure 7). In those cases, public works staff relocated these logs to the top of the 8th Avenue maintenance ramp or to the back of the beach (Culver and D'Ambrosio, personal communication, 2025). Driftwood placed on the dune ramps can direct access routes and reduce the dune ramp deflation caused by excessive trampling.

Figure 7. Driftwood near 8th Avenue Sand Ramp (left); Natural Driftwood on the Beach near 8th Avenue (right)

Dunes constructed with driftwood core and vegetation could be designed and implemented along the existing dune-backed shoreline. For dune restoration and expansion, this work can be accomplished using earthmoving equipment, such as front-end loaders and bulldozers, to move sand into the dune areas. The equipment would sculpt the dunes in place to mimic the natural dune contour, and revegetation of the site would then follow (Figure 8; Figure 9). Suitable areas would be dune-backed areas, such at the 8th Avenue Sand Ramp, and the northern sand ramp areas.

Figure 8. Rio del Mar State Beach in Aptos, California: Driftwood Logs Pinned Vertically and Cross-Braced to Form the Core of a New Dune Site (left); Sand Placed over the Logs (center); Post-Construction with Dune Vegetation Establishment (right)

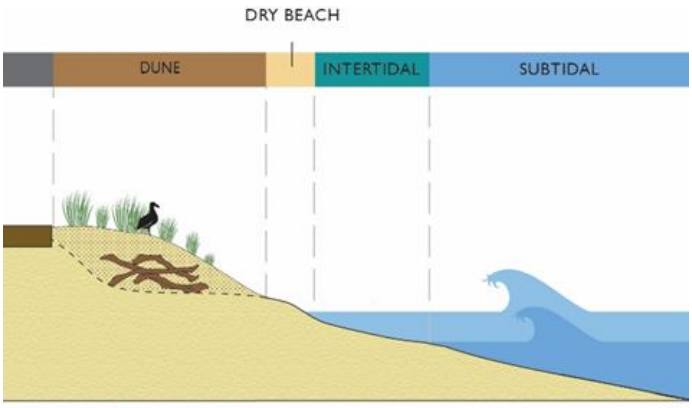

Figure 9. Driftwood-Cored Dune and Living Shoreline

1.6.1.3 Dune Restoration (reduce erosion)

The restoration of native dune areas focuses on building low, hummocky dunes along the existing dune-backed shoreline. Areas with extensive ice plants can be reshaped and stabilized using native plants to restore their natural form, and these actions will improve coastal habitat quality. This measure also improves visual quality while reducing erosion along the upper beach. Some restoration efforts to reduce impacts from access trampling may include terracing and the use of rice straw bales or jute netting on the dunes for contouring and

protection to support long-term slope stability. The recommended location for this strategy is the Del Mar Dunes.

1.6.1.4 Vegetation and Landscaping to Reinforce and Protect Terrace Soils (reduce erosion)

Native vegetation and soil-stabilizing landscaping use the plant root networks to enhance the stability of the terrace and bluff soils and manage surface runoff. This method may also include terracing and the use of erosion fabric on the bluff to retain soil. Feasible locations for such a strategy would be along the backshore and terrace to the south of 8th Avenue.

Figure 10. Restoration Work along Bluff Area near West Cliff Drive, Santa Cruz in 2018 (left) (Groundswell Ecology 2018); Restored Bluff Section with Native Vegetation in 2025 (orange circle) (right)

1.6.1.5 Beneficial Reuse of Sand or Opportunistic Beach Nourishment (reduce erosion)

The beneficial reuse of sand includes the placement of small volumes of beach-compatible sand on Carmel Beach or at the top of the sand ramps once such material becomes available from nearby construction projects, utility work, flood control activities, or maintenance activities. Historically, these sands have been offloaded to the dump or sold off for landscaping purposes.

Placement typically occurs by truck and is generally modest in volumes that supplement the natural sand supply. These sediments must pass a specific set of tests to ensure sand compatibility, cleanliness, and quality. The City of Monterey and several jurisdictions in southern California have implemented these programs, which are also called sand compatibility and opportunistic use programs.

While it does not substitute large-scale nourishment, this type of program provides a cost-effective and low-impact tool to support routine beach maintenance and maintain sand supply. As described in Section 3, a program for the opportunistic placement of sediment will strengthen resilience by identifying compatible sand, screening it for suitability, and ensuring that suitable material is beneficially reused on Carmel Beach whenever feasible. This practice helps ensure that sufficient sand is available to maintain the sand ramps.

Figure 11. Opportunistic Beach Nourishment at Goleta Beach in Santa Barbara, California (BEACON 2019)

1.6.1.6 Sand Management and Harvesting (reduce erosion)

Another adaptation strategy that falls under dune and beach management is active sand harvesting—i.e., the movement of sand from the foreshore to the back beach and backshore. This strategy widens the beach, potentially up onto the dune ramps, and has been implemented in the past. From the 1960s until 2015, the City conducted routine sand redistribution in late spring and early summer from Pescadero Canyon south to Marin Way. This work involved bulldozing sand from the lower beach (above the high-tide line) to the upper beach, and it was intended to improve public safety and compensate for sand that was naturally pushed downslope by visitors. Starting in 1984, the sand redistribution plan expanded, and the City contracted out the work (typically with Monterey Peninsula Engineers) to push sand up from just below the mean high-tide line (not into the surf zone) to the sand ramps and fully cover the revetments. The total sand redistribution volume varied between 50 and 100,000 cy, depending on conditions (mild winters required less sand movement than severe winters) (Shonman and D'Ambrosio 2003; Culver, personal communication, 2025) (Figure 12; Figure 13).

From the 1980s until the early 2000s, the sand redistribution plan involved moving sand from lower on the beach landward. This action created a lowered area or depression behind the beach berm (Figure 13). Subsequent wave overtopping deposited sand into this depression, with the water then seeping out through the beach during lower tides. This process could still

be considered sand harvesting, given the time of year when the winter nearshore sandbars were returning back to the beach. It is uncertain, however, what changes this practice may have caused, but recreating the practice—and conducting monitoring—could be a pilot project approach.

Ultimately, the City's larger-scale sand management program was discontinued, largely due to funding constraints (Culver and D'Ambrosio, personal communication, 2025). Today, the City performs smaller-scale sand management in house to maintain the sand ramps. Typically, this practice only lasts one season, before wind and foot traffic moves the sand away. The City also moves sand into the volleyball courts when it gets low (Culver and D'Ambrosio, personal communication, 2025). Sand redistribution could be restarted and would assist the natural recovery of the beach following large winter storms. More sand volumes on the beach could buffer some of the impacts from winter storms and help maintain the investments in coastal access stairways and sand ramps. The entire beach would be a suitable location for this strategy.

Figure 12. Active Sand Management near Del Mar Parking Lot (Kenneth & Gabrielle Adelman, Coastal Records Project 2003)

Figure 13. Sand Management with Sand Bulldozed over Riprap Revetments near 13th Avenue (Kenneth & Gabrielle Adelman, Coastal Records Project 2003)

1.6.1.7 Beach Nourishment (reduce erosion)

Traditional beach and dune nourishment involved placing sand directly on the beach, while shoreface nourishment, which became common after the 1990s, relies on using natural marine processes to gradually move submerged sand landward to create a wider beach over time. Larger-scale nourishments distribute sand across the nearshore and dune system, allowing both marine and wind-driven processes to reshape the beach in cross-shore and alongshore directions. This approach provides a temporary (multiyear) direct protection of upland resources and widens the beach for improved recreational use.

The implementation of beach nourishment requires large volumes of compatible sand (usually from an offshore source) to be placed along the beach to restore or maintain beach widths. There are numerous challenges associated with beach nourishment at Carmel Beach including regulatory viability and sand compatibility. More information on this can be found in Section 3 and in Appendix C.

In Carmel, an additional placement at the top of the existing sand ramps could improve regulatory viability. This placement avoids many of the ecological impacts to the beach and may reduce permitting and regulatory hurdles. Potential locations are at the top of the sand ramps at North Dunes, Del Mar Avenue, or 8th Avenue.

Beach nourishment is a cyclical ongoing maintenance approach and needs to be repeated. A nourishment cycle is based on the timing needed between nourishments. As the rate of SLR accelerates, the time between nourishment cycles will decrease. The optimal time to conduct this work would be during the spring. Benefits of doing the work at this time are that the sand

can be placed before summer visitation increases, and can be available throughout the high-use beach season (summer).

Benefits

The benefits of this strategy are as follows:

- It maintains wider beaches, thereby benefitting coastal recreation.
- It mitigates adverse effects of coastal squeeze from engineered protection strategies on environmental and coastal access resources.
- It provides an additional buffer against wave attacks at the base of the dunes and bluffs.
- It results in limited sediment losses in the downcoast direction, which could prolong nourishment benefits.

Challenges

The challenges of this strategy are as follows:

- It requires the identification of a suitable source and volume of compatible sand.
- It is subject to regulatory approvals.
- CEQA and NEPA environmental permitting processes are required with regard to sediment placement and impacts on nearshore and marine species.
- It requires marine sanctuary approval (recent changes to Sanctuary regulations regarding opportunistic nourishment need to be further evaluated).
- There is a high potential cost of sand and unknown potential funding sources.
- It will require multiple nourishment cycles over time with high recurring costs.

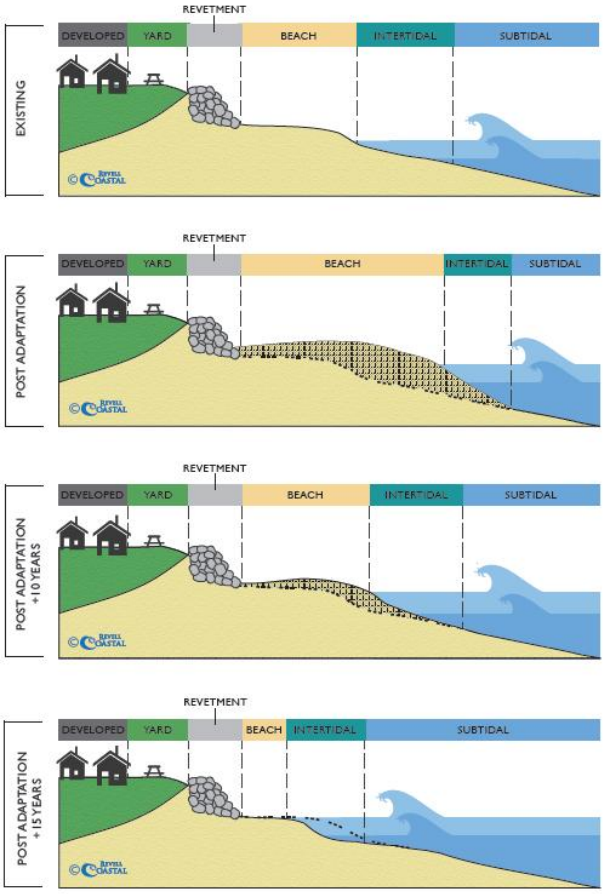

Figure 14. The Nourishment Cycle

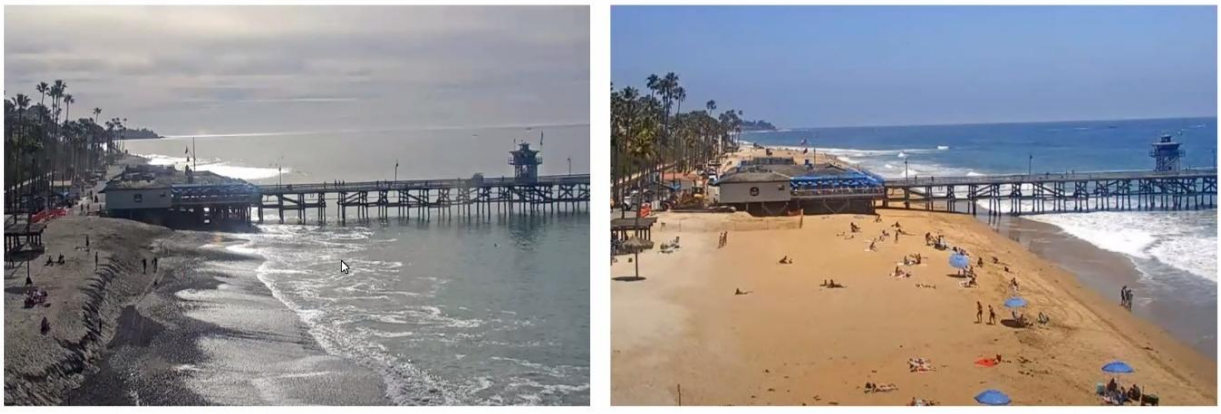

Figure 15. San Clemente, California, Before (left) and After (right) Beach Nourishment (City of San Clemente, 2025)

Note: The volume of sand added to the beach was approximately 251,000 cy, and the project footprint is 3,214 ft long.

1.6.1.8 Restoration of Kelp Ecosystems

Another approach is to investigate opportunities for programs and partnerships centered on kelp restoration and its potential to enhance both ecosystem health and coastal resilience. Kelp forests are naturally found in nearshore waters, and healthy kelp forests provide multiple benefits, including improved biodiversity and enhanced fisheries habitat. Kelp also contribute to improved sequestration and the cycling of carbon and oxygen, and they increase ecosystem productivity. Kelp restoration provides significant ecological and water-quality benefits.

Kelp restoration effects on erosion reduction, however, is poorly substantiated. There is scientific evidence that kelp reduces small, low-wave-height energy, but there is not much evidence for kelp's ability to reduce large, erosion, storm-wave energy—for this reason, it is not included in the list of feasible adaptation strategies (Table 3). However, combination of kelp restoration and other adaptation strategies, such as nearshore reefs, may provide appropriate and suitable mitigation.

Further studies should evaluate the feasibility of artificial reefs for the project. The City can conduct the necessary research by partnering with research institutions, nonprofits, and regulators to identify potential pilot restoration sites and develop best practices for kelp forest recovery in Carmel. Currently, the Giant Giant Kelp Restoration Project (2025) is underway at Tanker's Reef in Monterey, and it has identified areas within Carmel Bay that are suitable for restoration. Permitting from state agencies can be a significant challenge in Carmel Bay, and permitting requires significant investments in studies as well as alignment with the broader marine management goals of regulatory agencies.

Figure 16. Restoration Efforts at Tanker's Reef in Monterey in 2021 (Schmalz 2024)

1.6.2 Engineered Coastal Protection

Engineered infrastructure strategies use structural measures to protect the shoreline and reduce the erosion of bluffs and beaches. These approaches can preserve existing development and public access but generally require higher maintenance and more complex permitting than nature-based solutions such as living shorelines.

1.6.2.1 Integration of Wave Deflectors in Access Improvements

Currently, during winter storm events, localized currents accelerate erosion and wave run-up. As a mitigation tactic, the City has already seen some benefit by integrating wave and current deflectors into some of the beach access staircases (Figure 17). These deflectors are protrusions at the base of beach stair foundations that deflect wave energy and reduce current velocities. Access repairs and any future access enhancements or replacements should integrate these deflectors into their design to reduce erosion.

Figure 17. Wave Deflectors at the Base of a Beach Access Stairway

1.6.2.2 Elevation of Riprap and Seawall (stop erosion)

Phase 1, Task 3, identified locations of increased wave overtopping over four SLR horizons and found that, with increasing sea levels, many areas of coastal armoring will see significant threats from wave overtopping. A strategy to combat this threat includes restacking and raising revetments, raising the crest of seawalls, and building infill walls at unarmored backshore locations (Figure 18). This approach provides added protection to the underlying cliff and bluff terrace against increased wave overtopping with SLR. Potential project areas for this approach include all coastal protection areas south of 8th Avenue.

Figure 18. Conceptual Image of Raising Crest Elevations of Seawalls or Elevating and Restacking Riprap

1.6.2.3 Soil Nail Wall or Tie Back Wall to Protect the Bluff Terrace (stop erosion)

A soil nail or tie back wall can stabilize the bluff terrace and prevent an upper-slope bluff retreat in areas where erosion threatens upland development. These walls are typically finished with textured shotcrete to blend with the surrounding landscape, similar to the system used at Pebble Beach Golf Links (Figure 19). Candidate locations include the headlands, especially where the terrace is more exposed to wave energy and where there are fewer conflicts with existing trees and vegetation.

1.6.2.4 Replace Riprap with Vertical Seawalls (stop erosion)

Existing revetments in Carmel, based on Phase 1, Task 1, are typically about 10–20 ft high and built at a 1.5 to 2:1 slope, occupying roughly 15–40 ft of beach. The replacement of these structures with vertical seawalls or soil nail walls reduces the footprint of shoreline armoring and can widen the usable beach area. This approach improves lateral (along the beach) access while maintaining coastal protection.

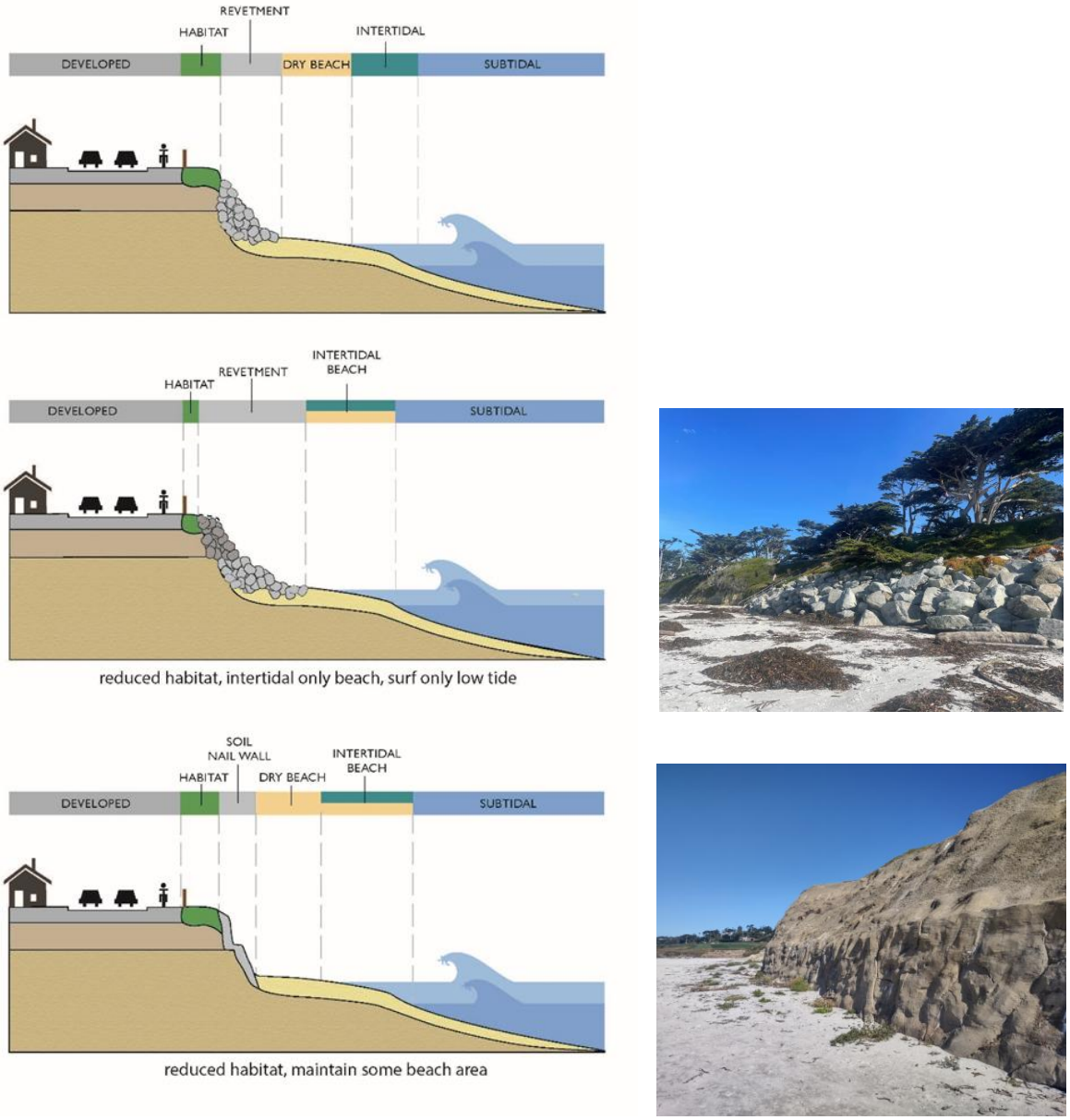

Figure 19. Passive Beach Erosion with Riprap Removal for Soil Nail Tie Back Wall over the Cliff and Bluff Terrace (left); Existing Riprap Revetments and Existing Soil Nail Tie Back Wall near 10th Hole of Pebble Beach Golf Links (right)

1.6.2.5 Low-Crested Structures to Reduce Erosion and Scour (reduce erosion)

As identified in Phase 1, Task 2, the existing engineered protection structures accelerate some of the localized currents, particularly in the south of Carmel Beach in gaps amidst the mudstone and sandstone outcrops. Low-crested structures, similar to sills, can be integrated into exposed shore platforms to break up waves and reduce nearshore currents (Figure 20). By dissipating wave energy before it reaches the bluff or beach, these structures reduce wave

energy, erosion, and scour and can be color and texturized to preserve the natural appearance of the sandstone exposed in the winter and along the backshore.

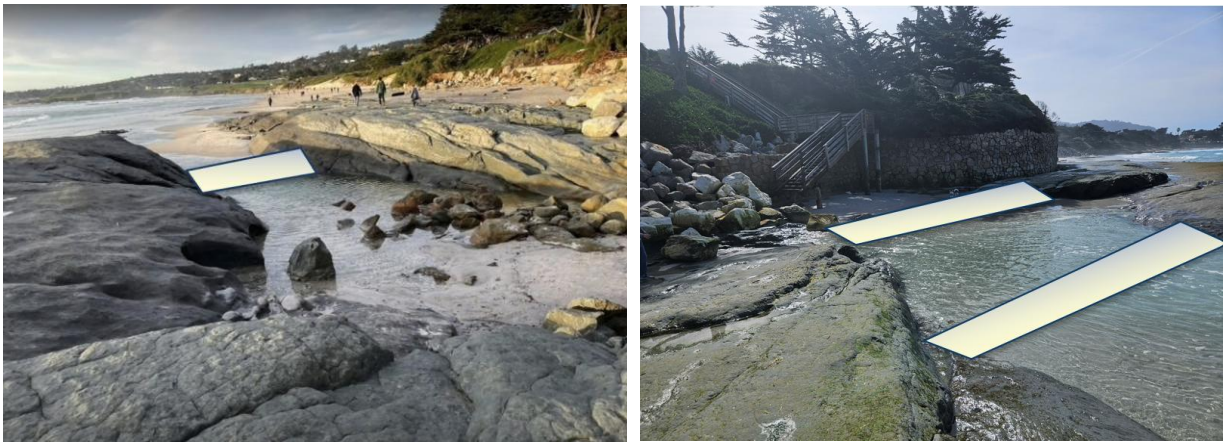

Figure 20. Illustrated Locations Where a Low-Crested Structure Could Provide Resiliency
Note: These structures could be in back-beach areas with gaps in the shore platform, where wave exposure is high.

1.6.2.6 Shore Platform Enhancement (reduce erosion)

Over time, the sandstone outcrops and existing shore platforms are eroding and decreasing in elevation, thereby reducing natural wave dissipation. With erodible textured concrete, these platforms can be augmented or extended using the existing shore platforms (also known as wave-cut terraces) to increase wave energy dissipation and reduce erosion. The features can be constructed using cemented sediments designed to match the color and composition of the existing sandstone and mudstone outcrops, thereby maintaining a natural appearance while improving coastal stability. These enhancements can also include lateral and vertical access considerations to maintain safe landings from access stairways and allow for some winter passage around traditionally challenging locations, such as 12th and Santa Lucia Avenue.

Benefits

Benefits of this strategy include the following:

- It reduces the wave energy impacting the backshore and likely depositing sand.
- It minimizes potential aesthetic impacts along cliffs and bluffs.
- It enhances habitat complexity and supports marine biodiversity.
- It promotes sediment retention and reduces local scour.
- It can be integrated with other nature-based measures, such as nearshore reefs.
- It provides an adaptive alternative to enhance lateral and vertical beach access.

- Appropriate cementation and texture could result in compatible sand material to be eroded over time while augmenting a small percentage of sand volume.

Challenges

Challenges of this strategy include the following:

- An evaluation of benefits is more complex than traditional approaches and would likely require pilot projects with detailed monitoring to quantify performance and ecological effects.
- Regulatory pathways and permitting requirements are still evolving and may vary depending on the project scale and materials used.
- Long-term maintenance needs and ecological interactions remain uncertain without extended study.
- Construction requires specialized materials and techniques to match local geological and hydrodynamic conditions.

Figure 21. Illustration of Shore Platform Enhancement

1.6.2.7 Nearshore Artificial Reefs (reduce erosion)

Around the Monterey Peninsula, natural nearshore reefs and offshore rocks provide important marine habitats and dissipate wave energy before it hits the shoreline. Offshore rock platforms and reefs also provide stable substrate to support kelp forests. Carmel Beach already has a

prominent and often photographed offshore rock that affects breaking wave patterns (Figure 22). A nearshore reef adaptation strategy could consider the construction of a series of submerged artificial reefs that are designed as rubble mounds or concrete structures with a crest at or below the waterline. These reefs, which would have multiple benefits, could dissipate wave energy and change erosion and accretion patterns. They could also focus wave patterns on armored sections of coast and promote sand retention, enhance marine habitats, and (depending on the design) improve surf recreation.

Benefits

Benefits of this strategy include the following:

- It reduces wave energy and coastal erosion.
- It enhances marine habitat and biodiversity.
- It promotes sediment deposition and stabilization near the shore.
- It may support recreational activities, such as snorkeling, diving, fishing, and surfing.
- It can complement kelp habitat restoration and other nature-based adaptation measures.

Challenges

Challenges of this strategy include the following:

- It requires detailed bathymetric and coastal modeling studies, as well as engineering, to identify suitable locations.
- Regulatory viability would be complex, challenging, and time consuming.
- Construction in the near-shore environment is challenging and costly relative to other nature-based approaches.
- Alterations to existing hydrodynamics would affect sediment transport and need to be carefully designed.

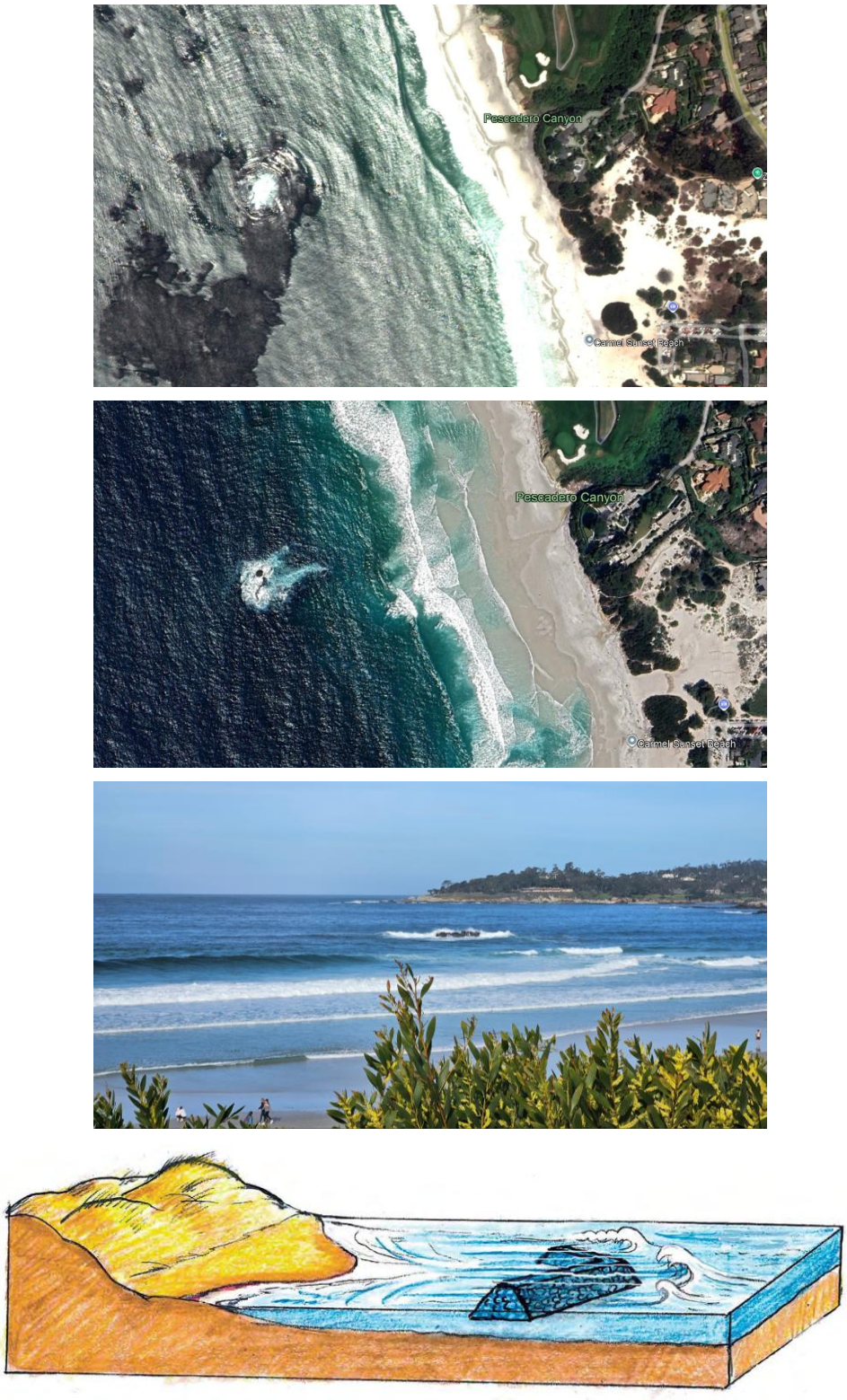

Figure 22. Offshore Rock near Pescadero Canyon on the Beach's North End (top three images); Illustration of a Submerged Nearshore Reef Structure (bottom)

1.6.3 Retreat or Relocation

There are two retreat or relocation strategies that are considered feasible for the project.

1.6.3.1 Transportation Realignment (avoid erosion)

Transportation realignment refers to realigning pedestrian and vehicular corridors away from hazardous areas. This strategy focuses on Scenic Road, which currently operates as a narrow one-way southbound road. The narrow nature of this path and roadway limits opportunities to shift alignments within the existing right-of-way as erosion continues, and it may necessitate creative solutions, such as dead ends with turnarounds.

Figure 23 illustrates how transportation realignment could unfold. In the early phases, the roadway and multiuse path can continue functioning in their current configurations; however, pathway-adjacent vegetation area may be lost. As erosion continues, the City will reach a decision point regarding how to balance competing priorities, which include the maintenance of parking and vehicular traffic, multimodal circulation, and safe pedestrian access. Potential adjustments at this stage include narrowing or removing travel lanes, modifying parking, or rerouting vehicular and pedestrian access to a new inland corridor, where feasible. Each stage would need to evolve with community dialog based on observed changes in shoreline and erosion conditions, and it must balance local resident access to homes with public access to the coast.

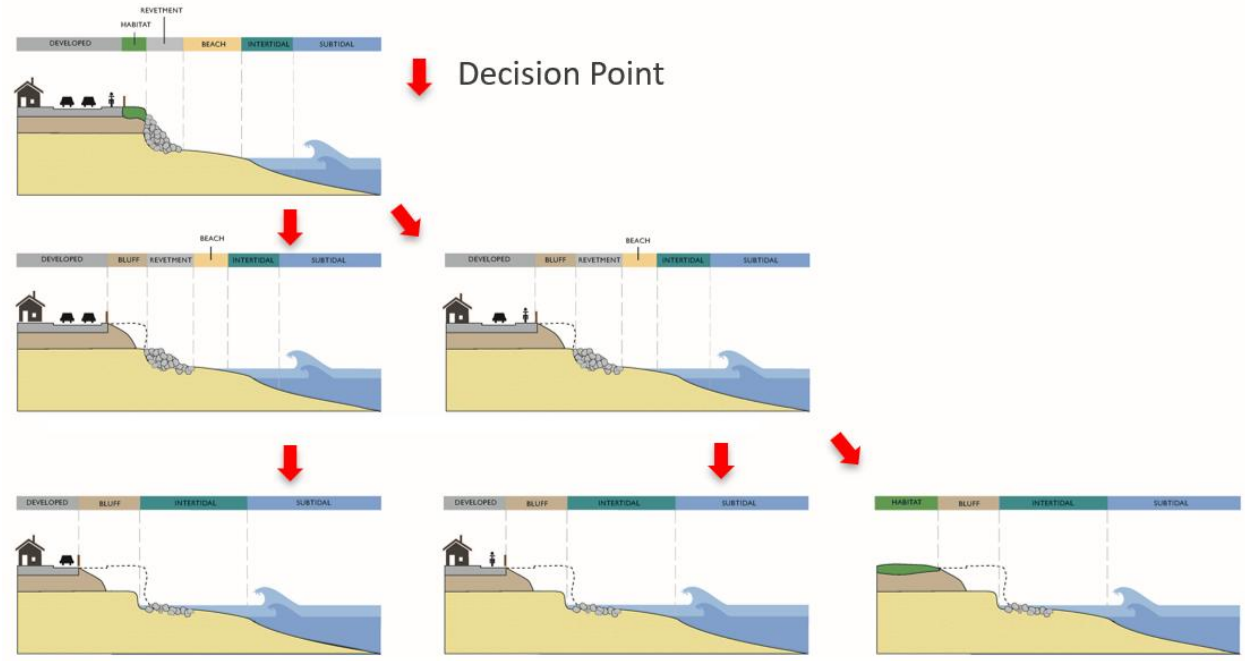

Figure 23. Transportation Realignment Pathways Considering Priorities of Vehicle and Pedestrian Access Along the Narrowing Upland Corridor

The examples below are from Santa Cruz County.

Figure 24. Grand Avenue at Depot Hill in Capitola, California in 1993 (left) and 2025 (right); Example of Former Continuous Road Transitioned to Continuous Lateral Access for Pedestrians Via Coastal Trail (vehicle access to ocean-fronting homes is afforded through alleyways from side streets)

Figure 25. Third Avenue and East Cliff Drive at Seabright Beach in Santa Cruz, California, in 1931 (left) and 2025 (right); Example of Former Continuous Road Transitioned to T-Shaped Turnaround with Parking for Bikes and Vehicles and Continuous Lateral Access for Pedestrians Along a Coastal Trail

Figure 26. Armored Pathway Along West Cliff Drive in Santa Cruz, California.

Note: Continued bluff erosion had led to the closure of these portions of the cliffside walkway and bike trail. Given that there was limited room to retreat the pedestrian path inland, the pathway was built up vertically from the bluff.

1.6.3.2 Relocation of Critical Infrastructure (avoid erosion)

The relocation of critical infrastructure refers to strategically moving vulnerable public and private assets away from high hazard areas to avoid damages, thus avoiding cleanup and emergency repair costs. Relocation may start with smaller assets—such as signage, garbage bins, and benches—that are easy to relocate. As erosion progresses, more substantial infrastructure relocation will be required for bluff-adjacent infrastructure, such as coastal access staircases, storm drains, and lighting. In the long term, critical utilities managed by other entities, including the Carmel Area Wastewater District (CAWD), California American Water, and Pacific Gas & Electric Company, may need to be relocated. Many of these utilities represent high-cost assets, with limited flexibility for relocation. As part of Phase 1 Tasks 3 and 4, the numbers and lengths of critical assets exposed to erosion hazards were reported. A summary of these findings by 4 ft of SLR includes the following:

- 2,149 ft^2 of the Del Mar parking lot, threatening at least 15 parking spaces as well as the vehicular turnaround area that supports circulation and emergency access
- 3,463 linear ft of Scenic Road, equivalent to roughly 96,067 square feet of roadway, with multiple buried utilities at risk
- 4,390 ft of wastewater main beneath Scenic Road and the Del Mar Dunes
- 805 ft of forced main near 8th Avenue
- 2,072 ft of water main located beneath Scenic Road
- 59 private residences along Scenic Road and Carmel Way.

Note: These findings assume no adaptation measures are in place by 4ft of SLR.

1.7 FEASIBLE ADAPTATION STRATEGIES TABLE

Table 3 lists the range of strategies described in Section 1.6 and outlines the results of the vetting process described in Section 1.5. This screening informs the range of actions that have advanced into the adaptation pathways described in Section 2.

Table 3. Carmel Beach Range of Potential Adaptation Strategies

Carmel Beach - Range of Potential Adaptation Strategies										
			Priorities		Cost		Regulatory Viability	Secondary Impacts		
Strategy Category	***Strategy***	***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*
Dune & Sand Management	Vegetation and landscaping to reinforce/protect terrace soil	Planting and landscaping of bluff areas to reduce bluff erosion (typically due to stormwater). May include terracing or erosion fabric on the bluff with landscaping to retain soil and vegetation	**Immediate**	**18**	**$**	**$$**	**Viable**	**=**	**+**	**=**
Dune & Sand Management	Dune restoration	Creation of native low hummocky dunes along existing dune-backed shoreline	**Immediate**	**18**	**$**	**$$**	**Viable**	**+**	**+**	**=**
Dune & Sand Management	Beneficial reuse of sand	Locally sourced sand available from nearby construction or dredging projects, or capture of sediment	**Immediate**	**20**	**$**	**$$**	**Viable**	**+**	**+**	**=**
Dune & Sand Management	Living shorelines - utilize driftwood expanded dunes	Dunes with driftwood core and vegetation along existing dune-backed shoreline	**Immediate**	**19**	**$**	**$$**	**Viable**	**+**	**+**	**+**
Dune & Sand Management	Beach nourishment of upland dune ramps	Upland sand nourishment at high priority access locations that would erode onto the beach	**Short-term**	**20**	**$$**	**$$**	**Viable**	**+**	**+**	**+**
Dune & Sand Management	Beach nourishment	Sourcing and placement of sand directly along the beach usually from offshore or navigation sources	**Short-term**	**18**	**$$$**	**$$$**	***Depends***	**+**	**+**	**+**
Dune & Sand Management	Sacrificial berm	Creation of low berm(s) at the backshore along the dune-backed beach. Can work with sand management/harvesting	**Short-term**	**16**	**$**	**$$$**	**Likely**	**+**	**+**	**+**
Dune & Sand Management	Sand management/harvesting	Active harvesting and movement of sand from the foreshore to the back beach and backshore to widen the beach	**Short-term**	**15**	**$**	**$$$**	**Likely to Less Likely**	**+**	**-**	**+**
Engineered Protection	Monitoring and maintenance of existing structures	Program to monitor and maintain existing seawalls	**Immediate**	**17**	**$**	**$$$**	**Viable**	**-**	**-**	**+**
Engineered Protection	Integrate wave deflectors into access improvements	Concrete protrusions at the base of beach stair foundations to deflect wave energy	**Short-term**	**17**	**$$**	**$$**	**Likely**	**=**	**-**	**+**
Engineered Protection	Replace revetments with seawalls	Replacing existing revetments with vertical seawalls	**Mid-term**	**16**	**$$$**	**$$**	**Likely**	**+**	**=**	**=**
Engineered Protection	Wave tripping low structures on bedrock	Similar to a sill, built into exposed beach bedrock to reduce currents and wave energy	**Mid-term**	**13**	**$$**	**$$$**	**Less Likely**	**=**	**-**	**+**
Engineered Protection	Raise crest and redesign of seawalls	Raising the crest of seawalls to reduce wave overtopping, or seawall redesigns including recurved walls to redirect overtopping wave/spray	**Mid-term**	**12**	**$$$**	**$$$**	**Likely**	**-**	**-**	**+**
Engineered Protection	Shore platform enhancement	Augmentation and extension of exposed shore platforms (wave cut terraces)	**Mid-term**	**12**	**$$**	**$$**	**Less Likely**	**-**	**-**	***Depends***
Engineered Protection	Raise riprap	Adding more armoring stone to existing revetments to reduce wave overtopping	**Mid-term**	**11.5**	**$$$**	**$$$**	**Likely**	**-**	**-**	**+**
Engineered Protection	Infill seawalls	Adding seawalls to currently unarmored sections of backshore	**Mid-term**	**12**	**$$$**	**$$**	**Less Likely**	**-**	**-**	**+**
Engineered Protection	Soil nail wall or tie back wall to protect bluff terrace	Shotcrete textured wall similar to the one at Pebble Beach Golf Links	**Mid-term**	**12**	**$$$**	**$$**	**Less Likely**	**-**	**-**	**+**
Engineered Protection	Nearshore reefs	A rubble-mound or concrete structure(s) with the crest below the water line to reduce wave energy	**Mid-term**	**13**	**$$$**	**$$$**	**Less Likely**	**+**	**=**	**+**
Retreat/Relocation	Transportation Realignment (pedestrian path)	Plan and implement a strategy for accommodating erosion in relation to pedestrian and vehicular access along Scenic Rd.	**Long-term**	**17.5**	**Varies ($$)**	**$**	**Likely**	**+**	**+**	**+**
Retreat/Relocation	Retreat/Relocation	Plan and implement a phased relocation of infrastructure, parking lots, access ways, roadways, and homes from vulnerable locations. Includes policy on triggers related to repetitive losses, repairs, or other criteria	**Long-term**	**17**	**Varies ($$$+)**	**$**	**Likely**	**+**	**+**	**+**

1.8 PLANNING LEVEL ENGINEERING COST ESTIMATES

Planning-level cost estimates were developed to support the comparison of adaptation strategies and provide an order-of-magnitude understanding of potential investment needs for coastal adaptation at Carmel Beach (Table 4). These estimates are intended for planning purposes only. The project team has attempted to provide rolled-up costs accounting for design, permitting, and construction, but actual project costs may vary based on site conditions, regulatory requirements, available contractors, and market conditions at the time of implementation.

Costs were developed using a combination of industry-standard references, using comparable California coastal projects and professional judgment. For each strategy, a reference is provided for the cost estimate along with cost comparisons, when available. Estimated costs were developed for the primary adaptation strategy types identified in this study.

Table 4. Planning-Level Engineering Cost Estimates

Cost estimate table to completed after review from the Integral Engineering Team and consultation with the City of Carmel. This table has been excluded from this draft, but will be included in the final version of the report.

2 ADAPTATION PATHWAYS

This section describes the high-level adaptation considerations for the entire beach. It also provides adaptation pathway graphics and descriptions for each of the three planning area sections of the City's coastline. For the entire beach, there is a description of key decisions that will influence longer-term adaptation pathway decisions related to beach nourishment and sand management. Thereafter, this section outlines immediate, near-term, mid-term, and long-term strategies—along with requisite studies, plans, and potential triggers—for the three sections of the beach described in Section 1.3:

- The North Beach and North Dunes area includes the Del Mar Parking Lot and adjacent dune habitat, where adaptation focuses on access maintenance, stabilization of the sand ramps, habitat restoration, and recreation.
- The Del Mar Dunes and Central Beach area contains the Del Mar Dune complex and the 8th Avenue Sand Ramps, where adaptation emphasizes maintaining emergency access, dune restoration, and infrastructure protection or realignment.
- The South Beach and Scenic Road Pathway area marks the southern end of the shoreline, which is characterized by narrower winter beach widths and an armored backshore. Here, adaptation efforts prioritize safe beach access, coastal erosion protection, and long-term planning for the retreat of vulnerable infrastructure and upland development.

The discussion of each area lists goals and considerations that were informed by 1) discussions with the City during site visits, and 2) community outreach events and surveys. These goals and considerations inform the City of how and where to apply the adaptation strategies. The approaches recommended in this section should remain flexible and responsive as strategies are tested, SLR science evolves, community priorities shift, and real-world conditions are monitored. Additional technical studies—including engineering feasibility and management studies—will be required before deciding which pathway approach, particularly in the mid-term, makes the most sense among the many adaptation strategies described herein.

2.1 ENTIRE BEACH

Historically, the City's adaptation strategy has been seawalls and revetments to stop erosion, and a yearly sand redistribution program to maintain beach widths and facilitate beach access. While the larger-scale sand management program was in place (up until the mid 2010s), it demonstrated effectiveness in accelerating beach width recovery and retaining more sand on the beach and sand ramps into the fall and winter. The protection approach of seawalls and revetments currently protects the backshore from existing erosion threats; however, it will have limited effectiveness as a long-term strategy, and it will eventually lead to a loss of the

beach and a corresponding loss in natural resources, coastal recreation, and economic benefits. A new set of strategies will be necessary to address these concerns, and ongoing community outreach and involvement will be essential to ensure that the process aligns with the City's goals and evolving community vision. Key adaptation goals currently include the following:

- Maintaining safe and reliable vertical and lateral beach access
- Maintaining sandy environments for recreation (e.g., volleyball) and erosion buffering
- Maintaining existing coastal protection
- Promoting community participation in adaptation planning and monitoring
- Promoting proactive planning for gradual adaptation toward nourishment, protection, or managed retreat when triggers are reached
- Improving response times to repairing damaged accessways.

In the immediate and near term, the City can continue to maintain its current infrastructure, build winter-storm readiness, and strengthen monitoring capacity. Building winter-storm readiness involves actions such as beach and dune management and living shoreline techniques, such as driftwood placement and dune enhancement. The strengthening of monitoring capacity actions typically includes enhancing data collection programs and integrating regular public works maintenance activities into active monitoring programs. Other priorities should also include improving public communication and outreach about coastal projects, updating key policies (like the LCP), and pursuing funding opportunities for pilot projects. This work will serve as a solid foundation for adaptive management as the City works toward mid- and long-term adaptation strategies. Many of those strategies are outlined in the beach-specific section below.

The following sections expand on questions concerning two adaptation planning mechanisms: beach and dune management and beach nourishment.

2.1.1 Beach and Dune Management

The dominant adaptation priority identified by the community was maintaining beach access and recreation. As described in Section 1.6.1, up until the 2010s, the City had an active sand management program (formerly called a sediment redistribution program) that moved sand from the foreshore to the back beach and backshore. As this program was scaled back, some noticeable changes have occurred along the beach. For instance, historical elevation data indicate a deflation in the sand ramp elevation of 1–3 ft since the sand management program was terminated. This trend suggests that access trampling and erosion have resulted in a loss of sediment from this system; it also indicates that City sand management activities have not kept up with sand loss from the ramps (Figure 27).

It is important for the City to reinvest in beach and dune management activities as an immediate and near-term adaptation strategy. There are many varieties of dune and beach management approaches (see Section 1.6). In addition, a beach and dune management plan can provide clear direction on when, where, and how sand management actions can occur across the entire beach. Along the entire beach, there are unique sand management actions identified in the individual section adaptation pathways; however, there is an important component of all adaptation strategies that will require actions that allow the mechanized movement of sand on the beaches and dunes to maintain access and enhance coastal resilience.

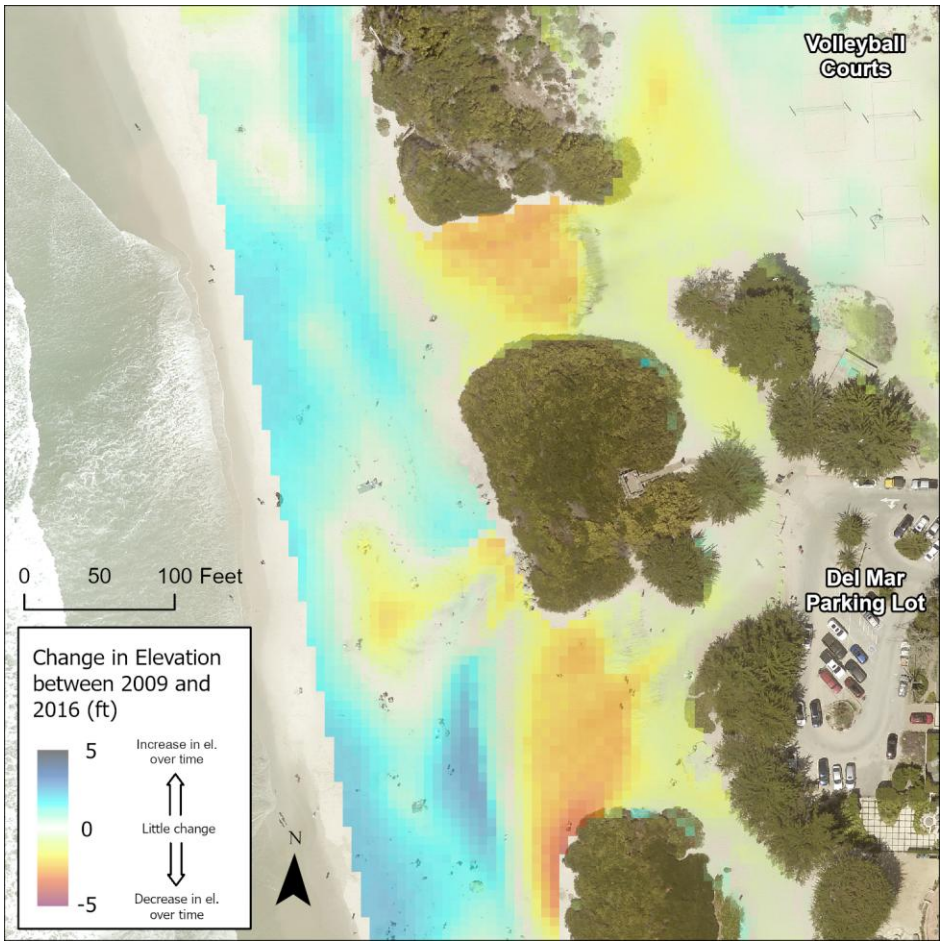

Figure 27. Elevation Change at Sand Ramps near Del Mar Parking Lot

Note: The sand ramps have experienced a deflation in elevation of 1–3 ft since 2009.

Some of the specific beach and dune management actions include the following:

- Movement of sand back onto the sand ramps
- Dune vegetation planting with guided access for dune stability and erosion reduction
- Cover revetments

- Repair and maintenance of the 8th Avenue emergency access area
- Enhancement in the safety of the vertical access landings
- The integration of driftwood and vegetation with sand into nature-based approaches.

Beach and dune management actions will likely play a role at all stages of the adaptation pathway future to maximize access and recreation, regardless of what other mid- and long-term strategies are adopted.

2.1.2 Beach Nourishment Feasibility Study

Previous work from Phase 1, Task 2, showed that Carmel Beach functions as a closed pocket-beach system with a generally stable total sand volume. A stable sand volume does not mean the beach width stays the same all year; instead, the width changes seasonally as sand shifts. The beach widens in the summer and narrows in the winter when sand moves offshore into near-shore bars. The beach typically begins rebuilding in the spring, with the rate of recovery depending on winter wave energy. Overall, the stability of the total sand volume suggests that the long-term average beach width is also likely to remain relatively stable. This stable volume means that—even with extensive coastal armoring and a backshore facing coastal squeeze as the sea level rises—Carmel Beach could conceivably be maintained by augmenting sand into the littoral beach system.

As noted in the public engagement and described in Section 1.3, the sand quality in Carmel is unique, and the distinctive bright-white native sands (fine and quartz- and feldspar-rich) are highly valued by the community. Any potential additional sand resources must therefore match this unique grain size, color, mineralogy, and shell content. The most likely source would be nearby offshore sand deposits that have been created from the same abrasion and erosion of the Monterey Peninsula granodiorite, and these deposits will require sand source investigations. Furthermore, even if a source of sand is identified, many of the most promising offshore areas lie within overlapping regulatory jurisdictions that protect marine resources, including California Marine Protected Areas and Areas of Special Biological Significance. They also lie within the Monterey Bay National Marine Sanctuary, further complicating feasibility.

If an offshore source of sand to nourish Carmel Beach is identified, and if nourishment is deemed regulatorily feasible, then the City may be able to sustain beach width and storm-buffering capacity for a longer period, thereby preserving adaptation options like beach management, dune enhancement, and hybrid nature-based strategies. However, if nourishment from an offshore source is infeasible, the City may need to investigate other sediment sources and discuss whether having a change in beach sand quality would be preferred over potentially not having a beach at all. If all sediment-dependent strategies are removed from consideration, it would mark a significant fork in the adaptation pathway, and the City would need to consider a range of erosion-reduction, backshore-protection, and earlier managed-retreat or relocation strategies.

To better understand potential sand sources, an initial analysis using available scientific data and published reports was conducted. Initial findings show that some offshore areas in Carmel Bay may contain sediment with a compatible texture and mineralogy (see the areas in green between a depth of 10m and 30m in Figure 28). Details of this initial screening are further described in Appendix C.

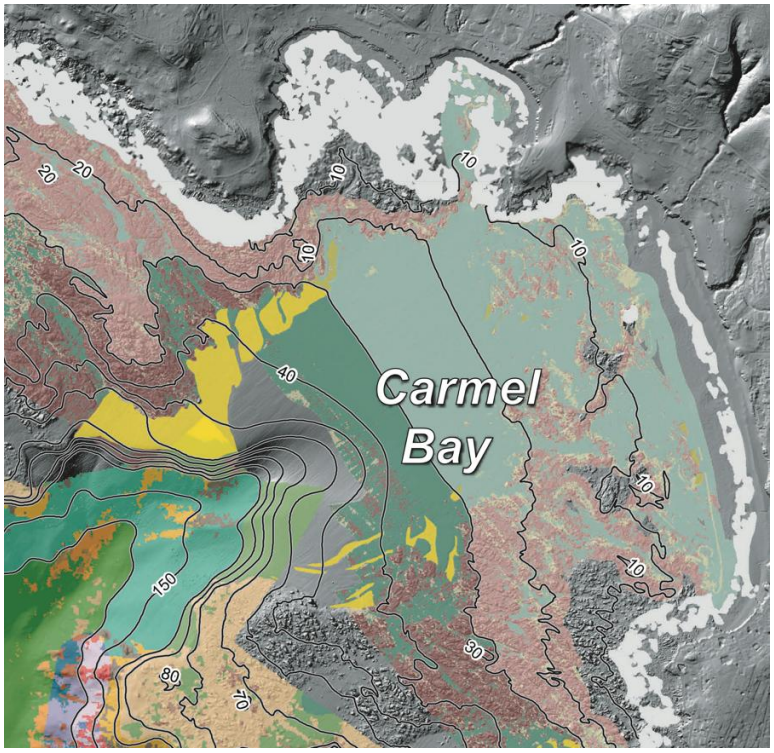

Figure 28. Seafloor Character Offshore of Monterey Map Area, California (Johnson et al. 2016)

Identifying a suitable sand source, and determining whether it can be legally obtained and placed, is a critical step in the process. To confirm whether a compatible and permissible source exists, more detailed sampling and sub-bottom profiling will be required. Close coordination with regulatory agencies will also be essential to understand the feasibility of both acquiring the sand and placing it on the beach. It is also possible that sand from other locations could meet the necessary criteria and support alternative placement methods, but these options would need further evaluation as well.

Note that with accelerating SLR, beach nourishment will eventually reach physical and financial limits, and the consideration of different sand sources or managed retreat will be necessary.

2.2 NORTH BEACH AND NORTH DUNES

North Beach and the adjacent North Dunes support the highest levels of public use of the beach. This area supports the largest public parking area along Carmel Beach, and it also

contains the City's largest dune complex. The Del Mar Parking Lot functions as the primary access point, linking beach goers via sand ramps. The shoreline reach is popular for family visits and ocean-viewing, and it also supports organized and informal beach sports, such as volleyball. The Del Mar Parking Lot is at the end of Ocean Avenue, near downtown, and is the location most used by out-of-town recreators for beach access.

Figure 29. Del Mar Parking Area and Sand Ramps (Kenneth & Gabrielle Adelman, Coastal Records Project 2024)

Two private properties are located at the north end of this area, and existing armoring structures in front of those parcels are maintained by the owners. Future actions will require coordination with those owners on maintenance responsibilities, design standards, and consistency with public access goals.

Figure 30. North End of Subarea with Two Private Properties off Carmel Way (Kenneth & Gabrielle Adelman, Coastal Records Project 2024)

Within North Dunes is a stormwater outfall and seawall (Figure 31). This structure has been deteriorating and needs improvement.

Figure 31. 4th Avenue Seawall and Outfall

Stormwater runoff from the Del Mar Parking Lot and adjacent uplands contributes to erosional scour; small improvements to grading, landscaping, and stormwater could reduce these impacts. Wind exposure mobilizes sand from the North Dunes and sand ramp, then sends sand into the parking lot, which is a concern for visitors and for city maintenance. The City has noted that the Acacia plant acts as a wind barrier, and any future work should consider impacts on wind exposure (Culver, personal communication, 2025).

An offshore rock formation emerges near the mouth of Pescadero Canyon and offshore of the 4th Avenue stairway. This feature can affect local wave focusing and currents during storms (see Section 1.6.2).

Primary amenities for this section are as follows:

- Four beach volleyball courts
- An ocean-viewing platform with signage near the Del Mar Parking Lot
- Sunbathing areas and spaces for family-oriented beach use
- The Del Mar Parking Lot, with 122 parking spaces (Shonman and D'Ambrosio 2003)
- Coastal access at multiple sand ramps and one beach access stairway at 4th Avenue

- A restroom at the Del Mar Parking Lot
- Ecologically beneficial areas of the North Dunes, including sand storage areas, habitat for native vegetation and birds, and natural buffering areas for storm waves.

2.2.1 Adaptation Goals and Considerations

Adaptation goals for North Beach and North Dunes are focused on sustaining both recreational and ecological values while protecting beach access and the parking lot from erosion. Maintaining a balance between the needs of visitors and the preservation of ecological function and wildlife habitat in North Dunes should remain a priority. Residents have expressed support for maintaining wide beach areas, and future planning should weigh these preferences against practical limits in sand availability, staffing and equipment availability, and long-term maintenance costs.

A long-term goal should be to preserve and maintain the viewing platform and beach access under future SLR conditions. The dunes could be managed as a dynamic and living system, one that is capable of migrating inland with erosion. To maintain a scenic overlook at this location, the viewing platform can be designed to be movable, so it can easily retreat as the dune crest moves inland. The tops of the sand ramp should be managed as a repository of sand that can make its way down the ramps and onto the beach. Under long-term threats from erosion, parking and infrastructure should be relocated inland. If parking spaces are reduced beyond an acceptable threshold, the City may want to investigate alternatives, such as remote parking with shuttles.

The key adaptation goals are twofold:

- Enhancing dune habitat in the North Dunes through restoration efforts, native vegetation planting, and fencing while promoting community participation in dune restoration and monitoring
- Protecting the Del Mar Parking Lot and associated infrastructure from erosion.

The strategies for these goals are illustrated in Figure 33 and described below.

2.2.2 Immediate Strategy

The immediate timeframe should focus on maintaining current beach recreational amenities and dune conditions while addressing sand ramp deflation and the condition of the 4th Avenue outfall and seawall. Deflation of the sand ramps occurs seasonally as visitors trample sand downslope, and every year, the City pushes sand back onto the ramps. The recommended management actions in the immediate term are intended to extend the life of existing infrastructure and ensure continued recreational uses. The strategy outlined below represents the first step in the adaptation pathway for North Beach and the North Dunes and provides the

foundation for either future nourishment, hybrid protection, or retreat strategies as SLR accelerates:

- Guide access and maintain sand on existing sand ramps to sustain safe beach access and reduce deflation of the sand ramp.
- Restore and expand native dune vegetation to improve sand trapping and dune stability, and implement small-scale public access improvements in the North Dunes to guide visitors away from sensitive vegetation areas.
- Repair and improve the 4th Avenue outfall and seawall to improve drainage performance and reduce the chances of failure in the future. Consider the current redesign to allow for future alterations, such as adding a vertical access point, if the adjacent sand ramp is eroded or is no longer a viable access point.
- Develop a coastal armoring monitoring and maintenance plan that includes conducting regular inspections of the 4th Avenue seawall and revetments near the stormwater outfalls to assess conditions and implement restorative actions promptly.

This strategy's triggers are as follows:

- The depth of sand at the sand ramps and exposure of the underlying consolidated material
- Bedrock exposure
- The percentage of time the revetments are exposed
- Erosion scarp at the toe of the sand ramp
- Conditions relative to an established baseline for summer beach widths.

Aside from the repair of the 4th Avenue outfall and seawall, these actions are low cost, and all are achievable in the immediate term. They are intended to maintain public access and dune stability while building readiness for future adaptation measures that may involve nourishment, protection, or relocation of infrastructure.

2.2.3 Near-Term Strategy (1-ft SLR)

The near-term phase builds on current maintenance activities by introducing small-scale opportunistic nourishments at the top of the sand ramps. It also involves monitoring—via the installation of staff plates to gage sand depths—and pilot efforts for driftwood and vegetation as part of nature-based solutions. These actions aim to protect the habitat of the North Dunes, maintain safe beach access, and collect the data necessary to guide future adaptation. The focus is on 1) proactive, low-cost interventions that enhance the natural system's ability to recover from seasonal erosion while preparing for a potential larger nourishment program, or 2) alternative hybrid protections for higher sea levels.

The near-term strategy is as follows:

- Opportunistically nourish the top of sand ramps using locally available sand to maintain safe and functional beach access.
- Start a sediment management program to offset seasonal sand loss and sustain beach widths.
- Implement living shoreline features that integrate woody material to enhance sand trapping and dune toe protection.
- Design and construct a movable viewing platform that can be relocated or elevated as dune morphology changes.
- Develop a monitoring program to better understand beach visitation and seasonal beach width dynamics.

This strategy's triggers are as follows:

- The availability of suitable local sediment sources for opportunistic nourishment
- The depth of sand at the sand ramps
- Bedrock exposure duration
- Dune vegetation coverage levels below a target density
- Average summer beach widths narrowing beyond 75 percent of baseline conditions
- The erosion scarp height of the sand ramp beyond safety or design thresholds
- A distance between the viewing platform and the dune crest that indicates progressive dune retreat.

These near-term measures provide a foundation for data-driven management and adaptive decision-making. Aside from the design and construction of a new viewing platform, they are relatively low-cost to implement and will maintain the recreational importance of this area, and they will improve the City's understanding of beach width dynamics, supporting timely transitions to larger-scale interventions for SLR adaptation.

Figure 32. Sand Ramps at Del Mar Parking Lot (left); Underlying Consolidated Sand and Sandstone to Emerge with Sand Ramp Deflation (right)

Note: The 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.

2.2.4 Mid-Term Strategy and Alternatives (2-ft SLR)

The mid-term phase represents a transition point where a reduction in beach widths may mean that the existing sand ramps may no longer provide sufficient functionality. This period focuses on evaluating long-term sustainability, identifying when to phase away from sand ramp maintenance, and implementing either nourishment to widen the beach and maintain the sand ramps or some other beach access strategy.

The mid-term strategy is as follows:

- Determine when to abandon the sand ramps as a coastal access strategy based on cost, maintenance effort, and safety thresholds.
- Establish clear triggers for ongoing maintenance cost and the level of effort to ensure cost-effective adaptation.

As a partial alternative, there is a retreat strategy that can be employed in the mid-term known as Alternative 2A. Early retreat is an option for the North Dunes part of this section, as there is limited vulnerable upland development in the mid-term horizon. This alternative shifts away from the continued sediment placement and management of the sand ramps, and it shifts towards an engineered approach, such as beach access stairways or a ramp. The strategy for Alternative 2A is to investigate and prepare for alternative coastal access methods (e.g., engineered stairways or ramps). Triggers for initiation are as follows:

- The depth of sand on the sand ramps
- Bedrock exposure duration

- Average summer beach widths narrowing beyond 50 percent of baseline levels
- Erosion scarp heights of the sand ramp beyond safety or design thresholds
- The frequency of waves reaching the dune toe
- The cost of repairs and maintenance of the beach access, including the sand ramps and the 4th Avenue Beach access stairs.

The retreat strategy moves away from sand ramps and towards an engineered beach access. This pathway emphasizes reduced sand management, which may come with high upfront costs, but lower ongoing costs associated with maintaining sand on the sand ramps.

Similarly, there is another alternative, Alternative 2B, that uses beach nourishment. This strategy focuses on maintaining a wide, accessible beach and sustaining the sand ramps through sediment and vegetation management. The strategy is as follows:

- Nourish the beach using suitable sand sources to sustain sand volumes and beach widths to maintain recreational and protective functions of the beach.
- Manage and restore dune vegetation to stabilize nourished sand.
- Integrate woody material for living shoreline dune toe protection.

Beach nourishment has high upfront and ongoing costs that reflect dredge, transport, mobilization, demobilization, and permitting expenses. This option sustains current beach widths and recreational benefits but requires ongoing financial commitment and consistent monitoring to ensure effectiveness.

Alternative 2B's triggers for initiation are as follows:

- An indication from state or federal regulations for a regulatory pathway for nourishment
- Suitable sediment sources that make nourishment feasible
- Average summer and winter beach widths narrowing beyond performance thresholds
- Difficult or expensive maintenance of sand ramps, indicating accelerated erosion and a need for imported sand.

Finally, Alternative 2C is a protection alternative strategy to delay and reduce seasonal beach scouring. This option focuses on the dissipation of wave energy and protection of the upland development. The strategy is as follows:

- Prioritize the sand ramp maintenance for as long as feasible and continue opportunistic nourishment at the top of the ramps if sediment is naturally available.
- Implement living shoreline features while incorporating woody material for sand ramp protection. When this action is no longer feasible, implement an engineered strategy for beach access.

- Evaluate and consider wave energy dissipation measures, including nearshore reefs or substrate enhancement.
- Consider vertical access stairs or a similar solution if the underlying cliffs become exposed.

The protection and wave dissipation strategy would also incur high upfront costs, but these costs could be highly variable and dependent on wave energy dissipation strategies, if any. The implementation of nearshore reefs is expensive, reflecting high permitting, design, and construction expenses. Smaller-scale wave dissipation strategies, such as shore platform enhancement, would be less expensive.

Triggers for Alternative 2C are as follows:

- Depth of sand on the sand ramps
- Bedrock exposure duration
- Feasibility and performance of wave dissipation approaches
- Average summer and winter beach widths declining below critical thresholds
- Increasing frequency of wave exposure at the dune toe
- Erosion scarp height beyond designed safety levels.

2.2.5 Long-Term Strategy (4-ft SLR)

The long-term SLR horizon anticipates significant shoreline change and an eventual tipping point where ongoing maintenance of existing infrastructure and sand management practices may no longer be sustainable. At this point, planning for retreat should become the priority. The City will also want to work collaboratively with private property owners at the north end of this section to identify potential retreat options for at-risk areas of their parcels (these larger lots may allow for inland retreat within the same parcel). At this horizon, the City may consider implementing open-space improvements in the North Dunes to accommodate reduced beach widths and provide safe areas for recreation in the winter (when beach widths are narrow).

The long-term strategy is as follows:

- Plan for the retreat of at-risk areas within the Del Mar Parking Lot area, including associated upland infrastructure, such as lighting, electrical systems, irrigation networks, and the two underground cisterns.
- Develop plans for alternative or emergency beach access at Del Mar Avenue if the 8th Avenue access location is no longer a viable option.
- Consider offside parking with shuttles to compensate for lost parking in the Del Mar Parking Lot.

This strategy has the following triggers:

- The distance between the parking lot and an established dune crest decreasing below a defined safety or slope stability threshold
- Rising costs of sand management and maintenance to levels above feasible budget constraints
- Summer beach widths narrowing to 25 percent of the baseline
- Bedrock exposure duration
- Winter beach width narrowing to a threshold
- Increasing frequency of overtopping at the north end of the beach, which threatens private homes.

The long-term strategy has high upfront costs. These expenses reflect coordinated capital investment for infrastructure relocation and site transformation. As a benefit, however, this strategy results in reduced ongoing maintenance costs, as less infrastructure is at risk. These actions mark a transition toward managed retreat, prioritizing safety in response to long-term SLR.

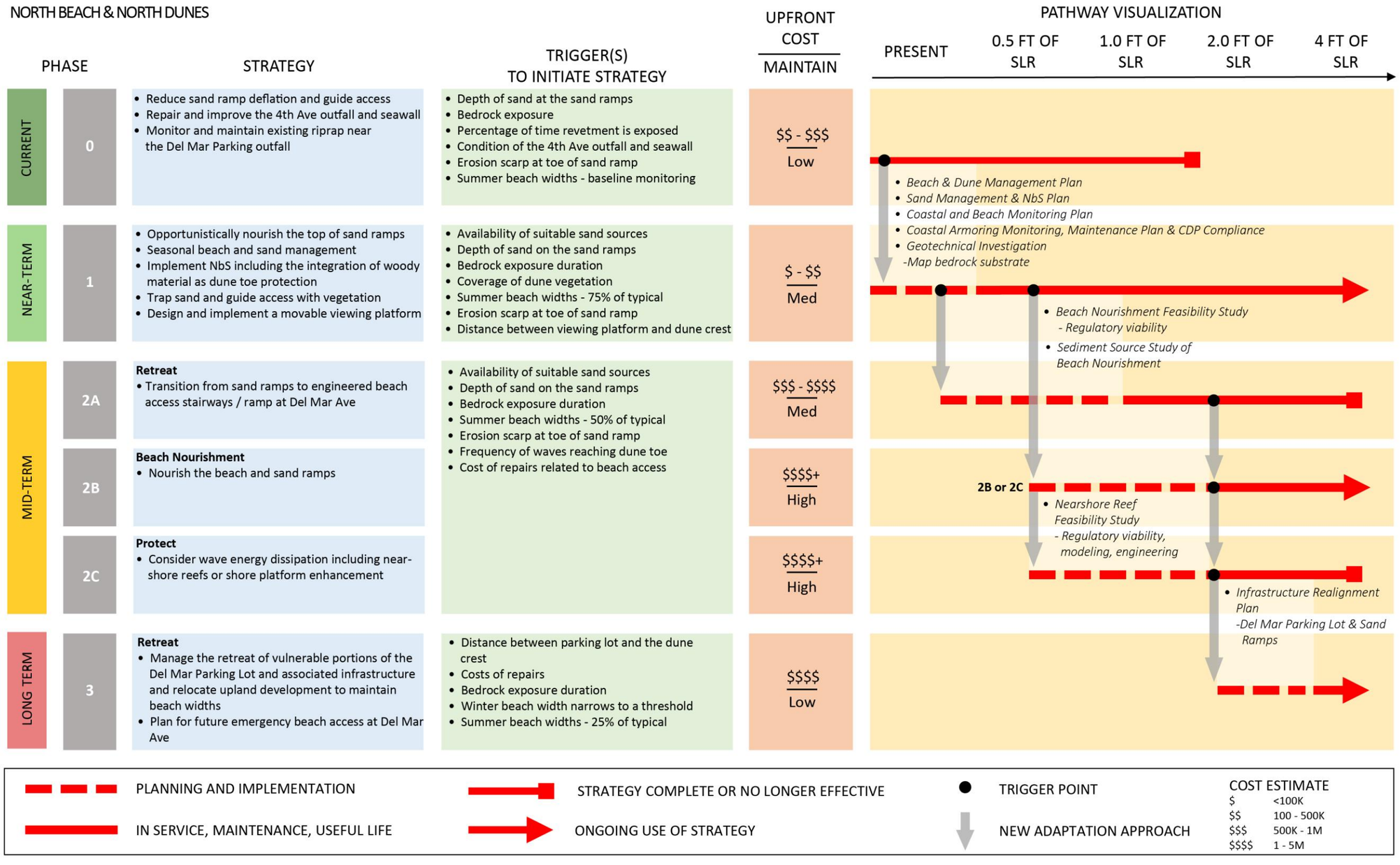

Figure 33. Adaptation Pathway for North Beach and North Dunes

2.3 DEL MAR DUNES AND CENTRAL BEACH

Located in the middle of the Carmel Beach system, the Del Mar Dunes and Central Beach area connects the wide, recreational beaches of the north with the narrower, armored shoreline to the south. This area provides both significant ecological and recreational value, and the dunes provide natural protection for upland infrastructure, including wastewater utilities. The 8th Avenue access location serves as a key emergency vehicle access location, and it provides pedestrian access to the beach. It is also one of the most popular beach access locations for local residents.

Figure 34. Del Mar Dunes and 8th Avenue Sand Ramp and Stairs

2.3.1 Adaptation Goals and Considerations

Future adaptation in the Del Mar Dunes and Central Beach area should balance dune restoration and habitat protection with the need to maintain safe beach access and protection of critical infrastructure. The goals are threefold:

- Maintain, restore, and enhance the Del Mar Dunes to improve sand retention, improve habitat quality, and create a natural erosion buffer.
- Prioritize nature-based solutions that use vegetation, driftwood placement, and sand management to reduce wave energy at the backshore and stabilize the back beach.
- While working with CAWD, consider the projected exposure to wastewater infrastructure, including exposure to the pump station and conveyance pipe.

The strategies for these goals are illustrated in Figure 37 and described in the following sections.

Private property owners front the Del Mar dunes in this area, which introduces some challenges for adaptation planning, particularly for water and wastewater services. Coordination with these landowners will be essential to ensure that adaptation strategies are compatible with private property rights. Future adaptation actions—such as dune enhancement, armoring, or utility relocation—should be designed in consultation with private property owners while progressing broader shoreline resilience goals and community visions for the beach.

The 8th Avenue sand ramp has historically been the primary access for emergency services. This access has experienced significant erosion following major El Niño events in 1983–1984, 1997–1998, and in more recent years. Current damages sustained in January 2023 have created eroded conditions such that the ramp no longer serves as a location for emergency vehicle access. A visual storyline of the loss of this access point is documented in Figure 35.

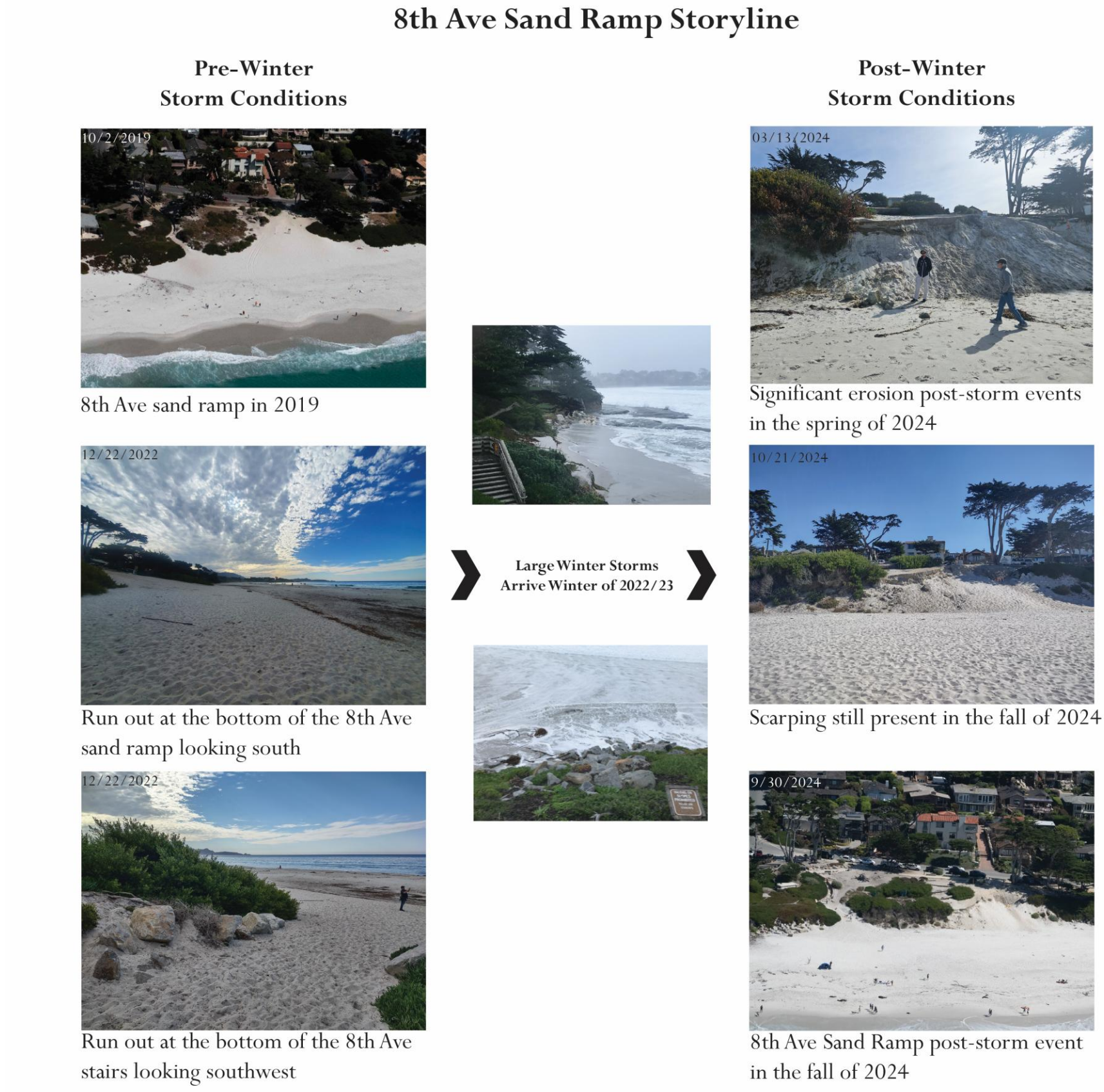

Figure 35. 8th Avenue Sand Ramp Storyline, 2019–2024

2.3.2 Immediate Strategy

Immediate actions should focus on restoring emergency access and functionality at the 8th Avenue sand ramp for continued, safe use under current conditions. Repair of this accessway would likely qualify under emergency permit conditions for the California Coastal Commission and may also be a CDP decision at the City's discretion under its existing LCP.

The strategy is as follows:

- Regrade and repair the 8th Avenue access location to restore safe emergency and maintenance access on historic alignment. Perform sand management and sediment redistribution to ensure continued, safe use and reduce potential future beach scour and erosion.
- Monitor the emergency access ramp to document damages and the level of maintenance effort to maintain emergency access.
- Monitor and maintain the existing revetment near the 8th Avenue outfall to ensure structural integrity.

Triggers to initiate this strategy are as follows:

- Depth of sand at the sand ramps
- Bedrock or revetment exposure duration
- Percentage of time the revetment is exposed
- Erosion scarp at the toe of the sand ramp
- Establish baseline for summer beach widths.

2.3.3 Near-Term Strategy (1-ft SLR)

The Del Mar Dunes area will face increasing exposure to erosion and wave impacts that threaten both the 8th Avenue emergency access location and the wastewater infrastructure. Near-term actions should focus on restoring the 8th Avenue access location until damages recur and the City spends what is deemed an excessive amount on maintenance.

Pending the City's evaluation of the potential for beach nourishment, this area may warrant further technical evaluation of erosion causes and an alternative plan to protect or realign the emergency beach access location. This could involve inland realignment of the sand ramps (Figure 36). Any improvements in this area should also implement public access improvements and restoration of vegetation to improve sand trapping and stabilize the dunes.

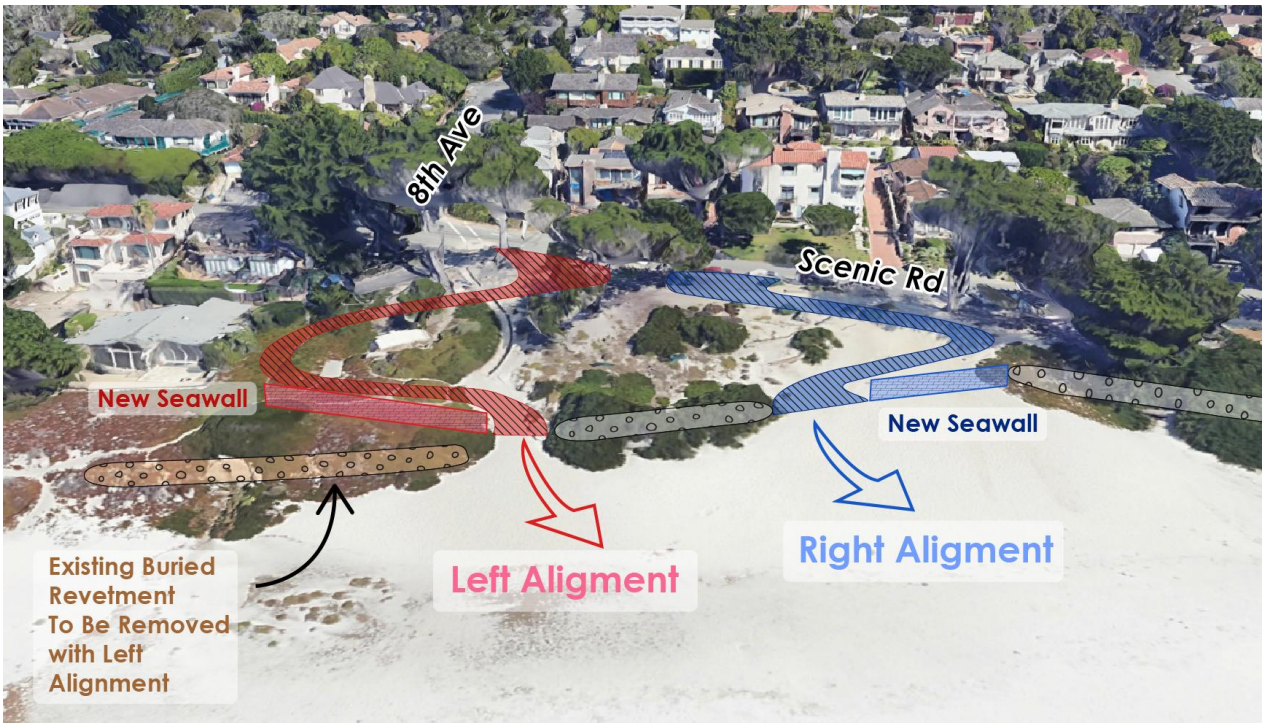

Figure 36. Possible Alternative Alignments for 8th Avenue Emergency Access Location

Notes: Red represents moving the alignment 200 ft to the north, which would serve a dual purpose of providing beach access and protecting the wastewater pump station in place, but this option would require movement of the existing coastal access stairway. Blue represents the alignment that would use the existing sand ramp location but would be stepped back to limit exposure to coastal erosion.

A wastewater pipe and pump station are also at risk in this area in the mid-term horizon. Planning for the protection or relocation of this critical infrastructure will involve significant effort and require substantial lead time, and it will need to involve CADW and targeted outreach to nearby Scenic Road property owners. Early in this process, the City should determine community preferences on whether to 1) pursue armoring to protect the wastewater line and pump station, or 2) retreat the infrastructure and transition to ejector pumps that connect homes to the wastewater line upslope on Scenic Road. Throughout this process, potential funding sources should be investigated, and responsibilities should be clarified for how costs would be shared among property owners, the City, and CAWD.

The near-term strategy is as follows:

- Maintain an improved 8th Avenue emergency and vehicular access location that provides safe and reliable coastal entry. If triggers are met, plan, design, and implement an improved, more resilient configuration for the 8th Avenue access location.
- Use seasonal sediment management to maintain beach widths and support dune recovery.

- Implement nature-based solutions, such as integrating dune toe protection to reduce erosion and vegetation restoration to enhance bluff or dune stabilization.
- Work with CAWD to begin the investigation for the protection or potential retreat of wastewater infrastructure behind the Del Mar Dunes.

Triggers to initiate the near-term strategy are as follows:

- Bedrock exposure duration
- Distance between the wastewater pipe and the dune crest reducing beyond acceptable thresholds
- Depth of sand at the sand ramp
- Percentage of time the revetment is exposed
- Average summer beach widths narrowing beyond 75 percent from baseline monitoring
- Erosion scarp height of the sand ramp exceeding safety or design thresholds
- Damages and costs of repairs at the 8th Avenue access location

2.3.4 Mid-Term Strategy (2-ft SLR)

In the mid-term, increasing dune erosion and wave exposure are expected to threaten the wastewater infrastructure under the Del Mar Dunes. At this stage, proactive coordination with affected homeowners and agencies becomes essential to identify feasible adaptation choices and establish clear trigger points for transitioning from business as usual to beach and dune nourishment or protection.

There are two viable mid-term strategies for this area; they are described below:

- Beach Nourishment Alternative:
  - Maintain existing 8th Avenue sand ramp access location or examine alternative alignments (as illustrated in Figure 36).
  - Implement nature-based solutions, such as dune toe stabilization and bluff reinforcement, to support habitat and natural sediment exchange during the transition period.
- Protection Alternative: Implement armoring to protect the wastewater line to extend the useful life of the wastewater line.
  - Extend and raise the crest of the existing revetment to protect the wastewater line and pump station.
  - Plan for and implement additional armoring where the wastewater line is vulnerable.

– Design and implement an integrated vehicular access ramp with coastal protection for infrastructure and public access (as illustrated in Figure 36).

The protection alternative will delay the need for retreat; however, it involves high upfront costs and ongoing maintenance to remain effective under increasing SLR. It is intended as an interim measure, and the implementation of new armoring will require substantive regulatory efforts that likely need to be combined with a future removal and retreat strategy (or sunset clause). If protection is deemed infeasible or too costly, the city may consider retreat of the wastewater infrastructure and transition to ejector pumps, as described in long-term strategy section below.

Triggers to initiate either nourishment or protection strategy are as follows:

- Findings from a preliminary study, as well as from public and stakeholder outreach, that indicate a direction towards protection, nourishment, or alternatively, retreat
- Feasibility and availability of funding these strategies
- Depth of sand on the sand ramp
- Bedrock exposure duration
- Average summer beach widths narrowing beyond 50 percent from baseline widths
- Erosion scarp height of the sand ramp beyond safety or design thresholds
- Frequency of waves reaching the dune toe
- Frequency of overtopping of seawalls
- Costs of repairs related to beach access
- Damages to 8th Avenue access.

In summary, mid-term adaptation strategies represent a decision point between two fundamentally different pathways that are partially dependent on the feasibility of beach nourishment: the beach nourishment alternative represents maintaining wide beaches and using nature-based solution to protect existing infrastructure, and the protection alternative represents extending protection measures to maintain the current infrastructure so long as it is feasible. If neither of these strategies is deemed feasible, then the retreat strategy outlined in the next section should be evaluated. The preferred approach should be determined through stakeholder engagement and a cost–benefit evaluation.

2.3.5 Long-Term Strategy (4-ft SLR)

In the long term, continued SLR and dune retreat are expected to significantly reduce beach widths, and the Del Mar Dunes may experience significant erosion. At this stage, adaptation measures should transition toward managed retreat for long-term resilience as well as the reconfiguration or relocation of the 8th Avenue coastal access location and Scenic Road.

The retreat strategy provides long-term resilience and reduces future maintenance liabilities but requires significant early planning and community support. In addition, it will have a high upfront cost associated with higher logistical efforts. The effort will require a reliance on coordinated funding, property-level agreements, and technical feasibility studies for the ejector pumps.

The long-term strategy is as follows:

- If dune erosion threatens the wastewater infrastructure, and protection strategies are not viable, work with CAWD and property owners to plan and implement ejector pumps to relocate wastewater service upslope to Scenic Road. Either retire the wastewater equipment in place or remove the existing pipes and pump station infrastructure from the dunes.
- Implement a managed retreat plan for the private properties backing the Del Mar Dunes. Identify at-risk parcels, establish appropriate trigger points for action, and coordinate with property owners on relocation or structural modification options that preserve parcel homes while reducing the exposure to erosion to an acceptable risk threshold.
- Prioritize and maintain emergency access to the beach. If the 8th Avenue emergency vehicle access location becomes increasingly threatened by coastal erosion, move the emergency vehicle access location to the Del Mar Parking Area.

Triggers to initiate this strategy are as follows:

- Distance between the upland development and infrastructure and the dune/scarp crest reaching a defined distance, allowing for the implementation of the select strategy
- Maintenance or repair costs of the 8th Avenue coastal access location becoming unsustainable
- Bedrock exposure duration
- Frequency of waves overtopping the armoring
- Summer beach widths narrow to 25 percent of the baseline width.

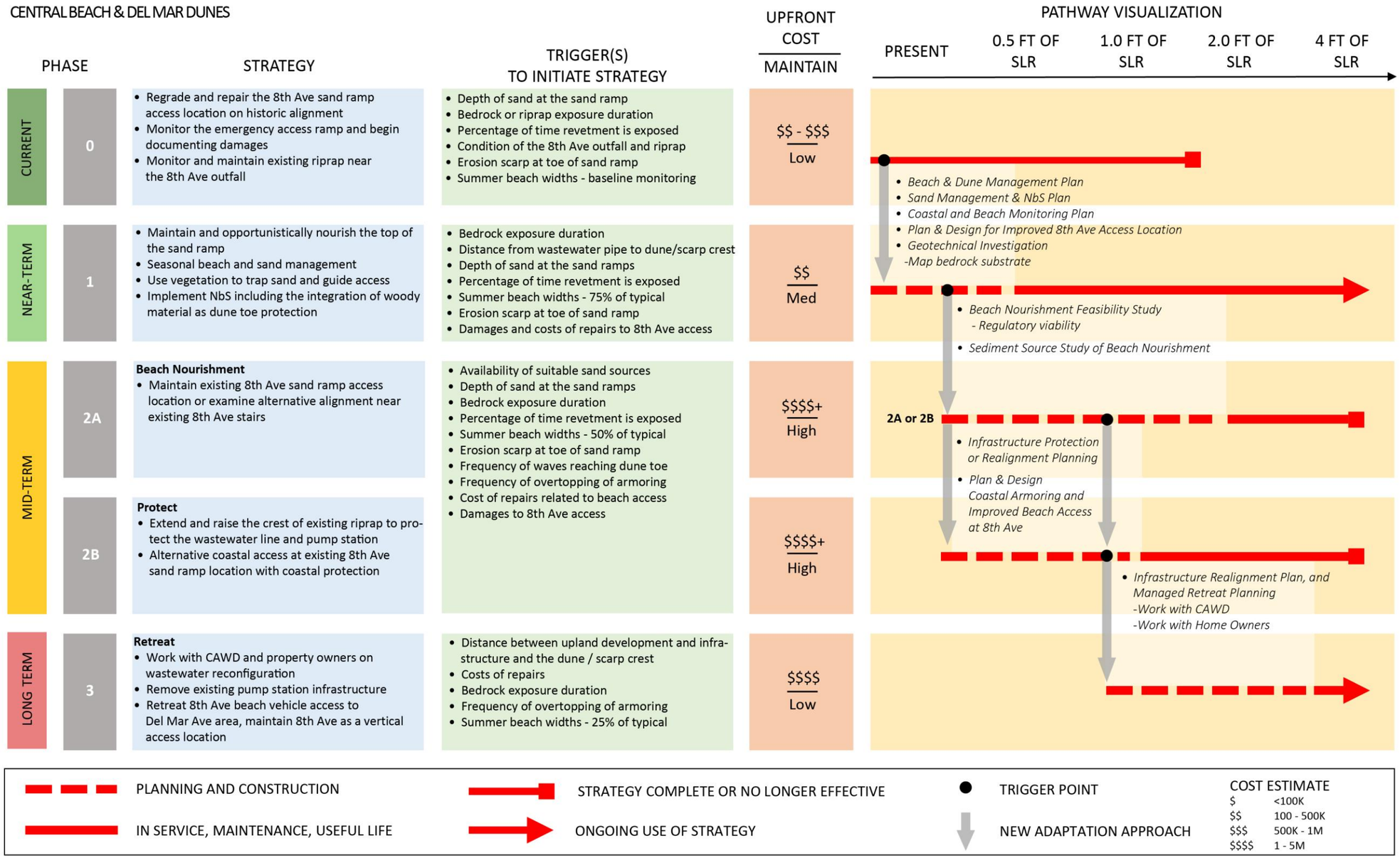

Figure 37. Adaptation Pathway for Del Mar Dunes and Central Beach

2.4 SOUTH BEACH AND SCENIC ROAD

The South Beach area transitions to a narrow beach that is backed by armored coastal cliffs. This area has historically seen the widest fluctuations in beach widths following major storm events, and seasonal sand loss in the winter regularly exposes the underlying sandstone and mudstone geology (also called *shore platforms*). When the beach is removed, wave energy can splash above the current seawall crest elevation, thereby wetting the erodible softer terrace deposits and driving longshore currents that accelerate erosion and scour the base of seawalls and revetments. These eroded winter conditions limit lateral access along the beach, particularly around the 12th and 13th Avenue rocky point outcrops. However, the eroded winter beach condition also exposes a series of tidepools that draw locals and residents alike. Collectively, these seasonal changes and recreational, scenic, and ecological qualities make South Beach an important community and environmental asset.

The Scenic Road corridor atop the cliffs above South Beach is one of the most heavily visited and distinctive parts of Carmel Beach. It provides an important public amenity with opportunities for recreation, relaxation, and coastal viewing, and it has numerous beach access locations. The restroom at Santa Lucia Avenue supports year-round public use, and the free streetside parking along Scenic Road makes this segment easily accessible for both residents and visitors. There are parking spaces for 127 vehicles on Scenic Road between 8th Avenue and Martin Way (Shonman and D'Ambrosio 2003).

Figure 38. Narrow Road Width of Scenic Road Causing Use Challenges Between Vehicle Traffic, Parking, and Pedestrians

The history of Scenic Road traces the history of coastal bluff erosion at Carmel Beach. When the road was first constructed, it allowed vehicles to travel in both directions. Starting in the 1960s, vehicles driving between 8th and Santa Lucia Avenue were restricted to just one-way

southbound travel. In 1988, following a large project to improve stormwater drainage and coastal access following the El Niño storms of 1982/83, the road was further narrowed to provide more space for the Beach Bluff Pathway and landscaping (Shonman and D'Ambrosio 2003). In the future, the pressures from coastal erosion, public use, and desires for lateral and vertical access for both pedestrians and vehicles will necessitate creative thinking.

Figure 39. South Beach Area Between 10th and 13th Avenue (left); South Beach Area Between 13th Avenue and Martin Way (right) (CRP 2024)

2.4.1 Adaptation Goals and Considerations

The goals for the South Beach segment focus on maintaining safe and reliable public access, protecting vulnerable coastal infrastructure, and preserving the recreational and scenic value of the shoreline and Scenic Road.

As seasonal sand levels fluctuate, the beach often narrows or even disappears entirely during the winter months. Adaptation efforts should focus on reducing the wave energy and longshore currents while retaining the area's aesthetic and recreational qualities. Maintaining and improving stormwater drainage infrastructure, as well as reducing wave overtopping at the seawall, should be prioritized because saturated soils can accelerate bluff erosion. The goals are threefold:

- Protect and maintain the coastal armoring and plan and implement improvements (i.e., strategies) to reduce both scouring currents and wave overtopping.
- Maintain the Scenic Road Beach Bluff Pathway.
- Maintain both vertical and lateral beach access for as long as feasible.

Figure 40. Examples of Sandstone Impeding Lateral Access When the Beach Is Scoured in the Winter

The South Beach segment presents several key considerations that will shape future adaptation and management strategies. Historically, the revetments along this portion of the shoreline were seasonally covered with sand through the City's sand redistribution program. Community feedback has indicated a preference to continue this program because sand-covered rock improves the recreational experience and maintains the natural visual character of the beach. Some of the riprap are over-steepened and need maintenance to avoid injuries or structural failure.

The strategies for this area are illustrated in Figure 43 and detailed below.

2.4.2 Immediate Strategy

Coastal access stairways have experienced significant damages in the past two winter storm seasons, leading to stairway closures. As stairways are repaired, the City should design and implement strategies to remedy the drop-offs or gaps at the bottom of stairways. These gaps are a source of concern, as scouring can make beach access difficult, even when stairs are still safe for use (Figure 41).

Figure 41. Gap at Bottom of 12th Avenue Stairs (Easton Geology 2016)

The immediate strategy is as follows:

- Fix stairways that are currently closed and implement stairway improvements, including wave energy deflectors and safe landings at the base of stairways.
- Monitor and maintain coastal armoring, stormwater infrastructure, and stairways.
- Survey the extent and elevations of the shore platforms and geology underlying the beach at the end of the winter, during beach scoured conditions.
- Restore bluff vegetation and control access.

2.4.3 Near-Term Strategy (1-ft SLR)

In the near term, the Scenic Road Beach Bluff Pathway and utilities (e.g., the water line running under Scenic Road) will become increasingly threatened by erosion. Some of the most vulnerable areas to erosion and overtopping are at the southern end of the beach by Martin Way, and at the lower-lying areas from 8th to 11th Avenues. In addition, beach width reductions will lead to longer periods of lateral access constraints around the headland at 12th Avenue, where the underlying sandstone can create a barrier along the beach.

The City should develop a coastal public access improvement plan that studies both horizontal and vertical beach access. This plan should help prioritize strategies for each coastal access location and a set of triggers for each. To improve horizontal beach access, strategies may

include building steps along the backshore (which traverses headlands) and obstructions for continuous horizontal beach access. For vertical beach access, possible strategies include the improvement, removal, and relocation of stairways as well as the transition to temporary or retractable stairways that are installed in the summer and removed in the winter.

To mitigate the impacts of nearshore wave energy and lateral scouring currents, the City should also study the potential of shore platform enhancement, low-crested structures, sand retention structures, or current deflectors where existing headlands and the substrate would make them effective. This study can build off geotechnical investigations and requires a pilot program to test the effectiveness of these methods.

In summary, the near-term strategy is as follows:

- Add public access improvements into the Coastal Access and Recreation Element that is informed by public outreach.
- Conduct seasonal beach and dune management to manage summer beach width recovery and winter preparedness.
- Implement a pilot program for shore platform enhancement, low-crested sand retention structures, or current deflectors. These solutions would be unique to Carmel Beach, and further study would be required.
- Through public outreach efforts and discussions with City officials, discuss the acceptance of seawall design aesthetics, including the continued use of golden granite rock or other alternatives.
- If flooding triggers are reached, implement floodproofing to the public restroom on the bluffs at Santa Lucia Ave.
- Extend and raise the crest of existing armoring as needed.

Figure 42. Former Stone Stairway near 12th Avenue, Remnants of Which Run Perpendicular to Backshore

Note: If built out further into the shore platform, this type of structure could function to disrupt lateral scouring currents.

The triggers to initiate this strategy are as follows:

- Repair and maintenance costs for beach access and armoring
- Distance from the Scenic Road Beach Bluff Pathway to the bluff edge, accounting for bluff face erosion and soil loss in areas where the bluff edge is adjacent to the pathway
- Summer beach recovery reduction and winter bedrock exposure duration
- Frequency of beach access closures
- Frequency of overtopping of revetments and seawalls
- Summer beach widths narrowing beyond 75 percent from baseline monitoring.

2.4.4 Mid-Term Strategy (2-ft SLR)

In the mid-term, without beach nourishment, there will be a significant reduction in summer beach width recovery and increased wave exposure during winter storms. This reduction is expected to create significant erosion risks to Scenic Road, upland development, and infrastructure. The mitigation of these impacts will necessitate either regular beach nourishment, wave energy dissipation, or significant improvements to coastal armoring; otherwise, wave overtopping may become unmanageable.

There are two mid-term strategies the City can employ. The first is a protection alternative:

- Extend and raise the crest of existing armoring. Where the raising of armoring is not viable, develop a plan to either 1) redesign coastal armoring to increase overtopping protection, or 2) implement additional coastal armoring to protect the softer terrace deposits.

- Investigate infill armoring at the 12th Avenue promontory.
- Implement lateral access improvements in the shore platforms/underlying geology.
- Install nearshore reefs and wave tripping structures.
- Shore platform enhancement.

The other alternative is beach nourishment. This strategy can involve an investigation to extend the headland at the southern end of the beach to better retain sand that may be moving around Carmel Point and escaping the littoral cell.

Triggers to initiate either strategy are as follows:

- Repair costs for beach access and armoring
- Distance from Scenic Road Pathway to the bluff edge
- Winter bedrock exposure duration and summer beach recovery reduction
- Frequency of beach access closures
- Frequency of overtopping of revetments and seawalls
- Summer beach widths reducing by 50 percent from baseline.

2.4.5 Long-Term Strategy (4-ft SLR)

SLR of 4 ft will narrow the beach because of coastal squeeze. It will also accelerate the wave overtopping of existing coastal armoring, thereby causing bluff erosion and increasing maintenance costs. At this stage, the Scenic Road Corridor—including the pathway, landscaping areas, parking spots, and roadway—will be increasingly exposed to erosion, and the maintenance of existing infrastructure through protection alone may no longer be sustainable. Adaptation should shift toward managed retreat and the relocation of vulnerable infrastructure and utilities to avoid emergencies and catastrophic damage.

Long-term adaptation measures should aim to protect and maintain Scenic Road and the critical infrastructure beneath the road for as long as feasible. However, once triggers have been observed, the City should work with private homeowners and other stakeholders on a managed retreat plan for the road and highly vulnerable properties. It may be possible to retreat portions of the road while realigning utilities connections to San Antonio Avenue. If this method is feasible, highly vulnerable portions of Scenic Road may transition to a no-through road. Santa Cruz has some examples of the managed retreat of roadways with public access pathways and private homes remaining in place (Section 1.6.3; Figure 24–Figure 26).

The long-term strategy is as follows:

- Develop a plan for the realignment of Scenic Road and the Beach Bluff Pathway.

  - Integrate managed retreat planning into future updates to the LCP and capital improvement program, including limitations of City liability and real estate disclosures.
  - Work with utility providers and property owners to plan for a phased relocation or realignment of Scenic Road and underground utilities further inland.
  - Identify alternative routes for transportation connectivity and emergency access.
- Identify areas where vertical beach access can be maintained.

The triggers for this strategy are as follows:

- Distance between the bluff edge and Scenic Road or critical utilities reaching a minimum safety threshold
- Repair costs—especially recurrent maintenance or stabilization costs for the roadway or bluff protection—exceeding sustainable levels
- Summer beach widths reduce by 25 percent from the baseline
- Winter bedrock exposure duration
- Erosion events resulting in repeated losses of public access or failures of shoreline armoring at multiple locations.

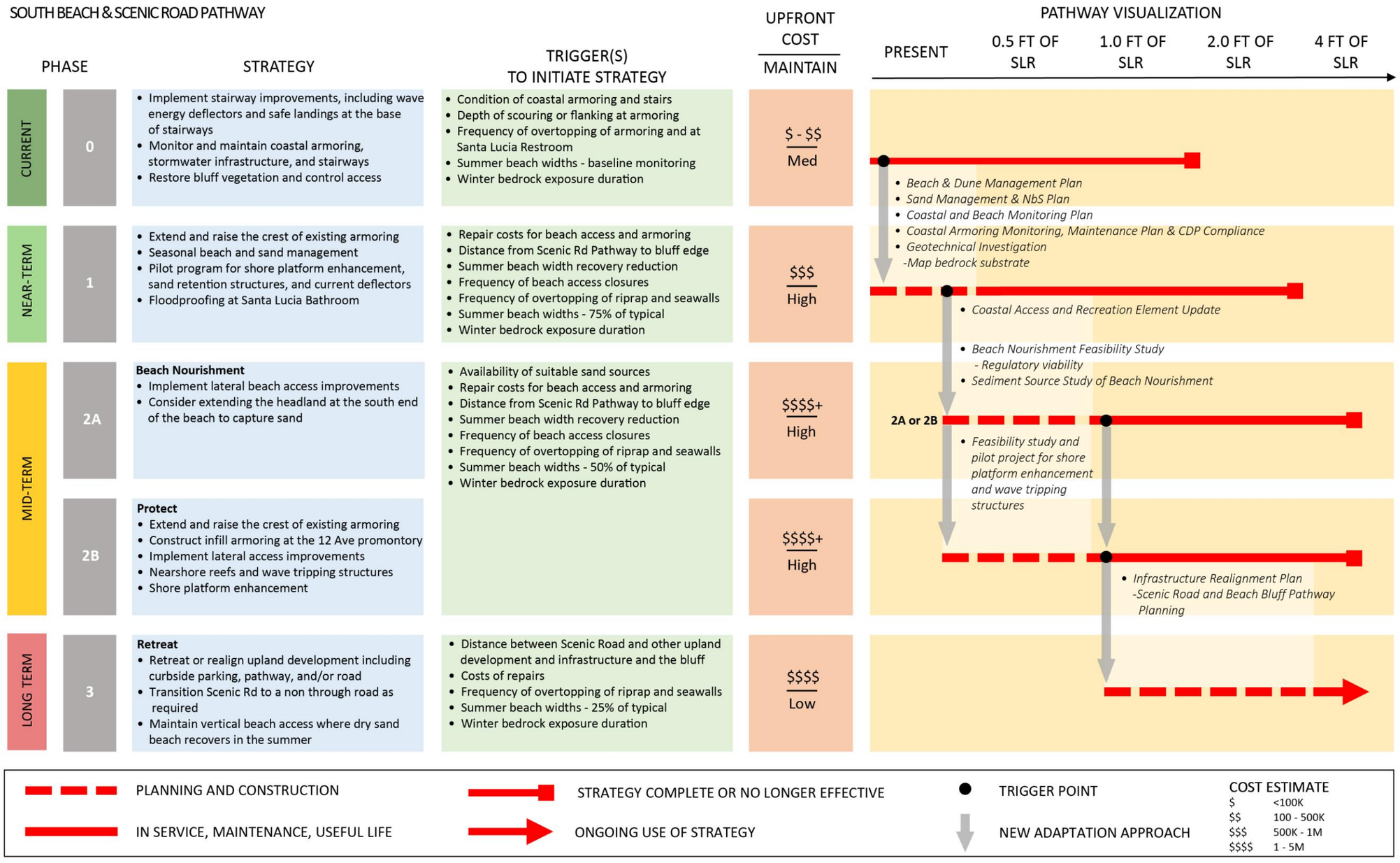

Figure 43. Adaptation Pathway for South Beach

2.5 COSTS ASSOCIATED WITH ADAPTATION

Adaptation costs are tied to the various parts of the beach and the implemented strategies. This section discusses the costs for the entire beach and compares the alternative mid-term strategies for each area.

2.5.1 Beach Nourishment

Beach nourishment represents a potential strategy for extending the beach width and buffering against erosion. Nourishment volumes would depend on sediment source proximity, placement method, and mobilization constraints. As a point of reference, San Clemente in Orange County had a cost quote of approximately $15 million (2025 dollars) for the City, with the federal government accounting for the remaining half for a total of $30 million (San Clemente 2025). The project involves moving ~200,000 cy of sediment every 5–6 years from offshore sources. Preliminary estimates to nourish the area from Arrowhead Point to Carmel Point could be on a similar order of magnitude, however a smaller scale nourishments could cost between $2 million to $4 million per.

2.5.2 Nearshore Reefs

Regarding the implementation of nearshore reefs, San Clemente serves as a suitable example. There, rolled-up costs amounted to $89 million for one structure, including $45.5 million for nourishment behind the structure for a sand salient. Removing the nourishment component, the structure alone cost $43.5 million (Moffatt & Nichol 2025).

2.5.3 Protection or Retreat of the Wastewater Infrastructure at the Del Mar Dunes

CAWD (2024) estimates that the implementation of ejector pumps costs approximately $50,000 per home. There are 20 homes along this stretch, making the cost for the City approximately $1 million based on the CAWD estimation. Furthermore, CAWD (2024) estimates that the cost to remove the existing wastewater infrastructure and restore the dunes would be approximately $1.5 million, making the total cost for the city approximately $2.5 million.

Assuming the cost to implement hybrid revetments with dunes to be $5,000 per linear foot, armoring approximately 600 ft of vulnerable wastewater infrastructure via the protection strategy would cost approximately $3 million.

3 RECOMMENDATIONS AND NEXT STEPS

This section outlines recommended actions the City can take now and in the near term to support long-term coastal resilience. The recommendations provide guidance for monitoring, maintenance, and updates to the LCP. They are intended to bridge the technical findings with the practical steps needed to implement adaptation measures, secure additional funding, streamline permitting for key near-term strategies, and facilitate repairs following future storm impacts.

Early action should focus on improving monitoring; maintaining existing coastal armoring; repairing access; enhancing winter storm preparedness; restoring bluffs, dunes, and vegetation; and performing maintenance. If thresholds are exceeded, or if maintenance becomes unsustainable, other measures—such as beach nourishment, wave dissipation, or expanded coastal protection—should be considered.

Each strategy should be tied to measurable triggers—such as erosion distance, beach width, or overtopping frequency—to ensure timely decision-making and an efficient use of resources. Triggers help to reduce the uncertainty associated with future climate changes and the projected impacts; they are easily observable. Triggers require community agreement and monitoring for transparency, the process of which also opens an opportunity for engaged community members to get involved in citizen science. There are many active community groups that can assist with studies, monitoring, and work on the ground. The community and these groups should be brought along as engaged stakeholders. Some of these groups include the following:

- Carmel Cares
- Senior centers
- Local dog groomers
- Women’s voting groups
- Annual surfing events
- Nonprofits, such as the Giant Giant Kelp Restoration Project.

The overarching goal is to sustain a resilient and accessible shoreline that continues to serve the community, visitors, and the natural environment under future SLR conditions.

3.1 RECOMMENDED TRIGGERS AND THRESHOLDS BY BEACH AREA

The triggers and thresholds in Table 5 identify when adaptation strategies should transition from the current management phase to a near-term or subsequent phase. These measurable

conditions define the points at which existing approaches may no longer be sufficient and new strategies should be initiated.

Table 5. Near Term Adaptation Triggers and Thresholds by Beach Section

Area	Beach Width	Erosion Distance	Maintenance Cost Threshold	Other Indicators
North Beach and North Dunes	<75% of dry-sand beach width by the summer	Dune crest to Del Mar Parking Lot	$1,000,000 in cumulative stairway, seawall, and outfall maintenance within 5 years	Depth of sand along the sand ramps
Del Mar Dunes and Central Beach	<75% of dry-sand beach width by the summer	Dune crest to wastewater line	$1,500,000 in dune restoration or sand movement costs within 5 years	Condition and damages to the 8th Avenue access
South Beach and Scenic Road	<75% of dry-sand beach width by the summer	Bluff face or cliff failure; Pathway to blufftop edge	$10 million in stairway, wall, or drainage repair costs within 5 years	Seawall overtopping more than three times or 10 hours/year; duration of bedrock exposure

Notes:

These triggers align with the transitions shown in the pathway figures.

In the pathways, triggers change from near-term and beyond as conditions change.

3.2 OVERVIEW

In the near-term the City must 1) commit to long-term monitoring, 2) maintain existing coastal armoring and accesses, 3) investigate the feasibility of beach nourishment and additional sources of compatible sand, and 4) develop a beach and dune management plan that supports winter-storm readiness and access improvements.

Actions that build monitoring capacity include the enhancement of data collection programs as well as the integration of regular public works maintenance activities into active monitoring programs. Building winter-storm readiness involves actions such as sediment redistribution and living shoreline techniques, such as driftwood placement and dune enhancement. Other priorities should also include ongoing public communication and outreach about adaptation and coastal projects, updating key policies in the LCP, and positioning and diversifying funding opportunities for adaptation. All this work serves as a foundation for adaptive management in the immediate and near term as the City works toward identifying the feasibility of mid- and long-term adaptation strategies.

Recommendations for next steps are organized into three categories—namely, studies, plans, and policies—to align with the City's coastal resilience planning.

3.3 STUDIES

For all of the studies listed in this section, the City should conduct an evaluation of socio-economic and environmental trade-offs between a do-nothing approach, and the various adaptation alternatives. The City should perform the following studies:

3.3.1 Sediment Source Study of Beach Nourishment

Beach nourishment is a strategy to offset coastal squeeze impacts by widening the beach as sea levels rise, thereby providing a buffer to wave energy while preserving recreational and environmental value. It also complements other forms of adaptation to provide multiple layers of protection along the coastline. Even relatively small volumes of sand could result in a lasting benefit, as Carmel Beach is a semi-contained littoral cell in between headlands with lower rates of sediment loss. Developing a more robust sediment budget would be a fundamental goal of this study to help determine how much sand would be needed to nourish.

The City should begin a beach nourishment feasibility study as soon as possible due to the long lead times associated with identifying and permitting suitable sand sources. Early efforts should focus on conversations with regulators on permit conditions and feasibility. If these conversations signal that beach nourishment is feasible, future investigations should assess potential compatible sand sources and evaluate how sand placement would influence coastal processes and beach conditions along the entire shoreline. Appendix C provides a premilitary investigation of nearby offshore sediment sources; however, further investigations are required to assess the feasibility, sediment compatibility, and environmental implications of any specific beach nourishment activity.

Even relatively small volumes of sand could result in a lasting benefit since Carmel Beach is a semi-contained littoral cell in between headlands, resulting in lower rates of sediment loss. Nourishment projects should not be considered one-time events but should instead include planned maintenance and subsequent nourishment efforts. Any planning efforts for nourishment activities should also be conducted in collaboration with the County of Monterey, which is responsible for the beach north of Pescadero Canyon, as well as the Pebble Beach Golf Links.

3.3.2 Nearshore Reefs Feasibility Study

The City should also investigate the feasibility of establishing or enhancing nearshore reefs to support coastal resilience, habitat diversity, and surf recreation. An evaluation of the technical, ecological, and regulatory feasibility of such projects can determine their potential role in

Carmel's adaptation strategies. While limited examples exist on the Central Coast, nearshore reefs are being considered in Oceanside under the REBEACH study[1], and San Clemente is studying a hybrid breakwater/reef in Orange County (Moffatt & Nichol 2025). Both of these projects have had initial support from key regulatory agencies.

The unique marine environment and protections in Carmel Bay require further study and consultation to assess regulatory feasibility. If the reef strategy is feasible, future modeling and engineering studies should investigate potential reef configurations, ecological compatibility, impacts on sediment, and long-term maintenance needs of any constructed features to ensure that the reefs provide both habitat and protective benefits without unintended impacts on adjacent shorelines.

For reference, the California Department of Fish and Wildlife is currently leading the California Artificial Reef Program (CARP). This program—anticipated for 2026—will include guidance on artificial reef materials, design, siting, function, and general performance standards, and it will build on lessons learned and feedback received from stakeholder outreach. This guidance is expected to be released in 2026; however, they are primarily focused on the biological enhancements of reefs, however, not the secondary effects for coastal adaptation. The City may consider engaging elected officials to expand this focus.

3.3.3 Shore Platform Enhancement Study and Pilot Project

Shore platform enhancement can restore and bolster the underlying sandstone and mudstone rock to provide erosion protection. This strategy would be a novel approach to living shorelines that, while currently lacking established standards and guidelines, could prove to be an important element of long-term climate resilience. The design of enhancement features would need to be fine-tuned to mimic the different nearshore rocky substrate types and account for sediment retention, public safety, and coastal access considerations. A detailed geotechnical study and modeling will be necessary to characterize material properties and evaluate stability under wave and current conditions.

3.4 PLANS

Implementations of larger-scale actions should be planned to ensure a good return on the investment in time and resources. They also ensure that strategies are aligned with City and community goals—such as maintaining the recreational, ecological, and scenic value of the shoreline—while reducing exposure to coastal hazards over time.

[1]More information can be found at: https://www.rebeach.org/

3.4.1 Coastal Armoring Monitoring, Maintenance Plan and CDP Compliance

The California Coastal Commission typically requires the submittal of a coastal armoring monitoring and maintenance plan for any new structure. However, even with existing armoring structures, a certified CDP is beneficial. Once such a plan is approved, repairs and maintenance for coastal armoring and stairways are allowable without further permitting requirements. It is recommended that the City develop such a plan and gain appropriate regulatory approvals.

Any necessary maintenance of an existing coastal protection structure or stairway access provides an opportunity to incorporate additional protective capacity to account for projected SLR, provided that the improved structure remains in compliance with the Coastal Act and other local hazard mitigation policies. Structures that cannot be retrofitted for the higher total water levels will likely require replacement to protect against increased coastal hazard exposure. In addition, a thorough assessment of any bluff stabilization infrastructure improvement project will be required to ensure compliance with relevant state and local policies, and these assessments will be required to consider the potential trade-offs associated with armoring projects.

The City should integrate plan activities into existing public works efforts—which should be updated routinely in the coastal infrastructure and data management systems—to ensure consistent tracking and coordination across departments. Activities—such as the maintenance of grout on seawalls, rock restacking, and repairs in response to wave damage—will be more streamlined and cost effective over time and reduce the risk of any coastal armoring failure. A coastal armoring monitoring and maintenance program will support timely identification of coastal change and help inform adaptive management decisions.

3.4.2 Maintenance and Targeted Improvement of Coastal Infrastructure

Continued maintenance or targeted improvement of coastal infrastructure will be an important component of mitigating coastal storm damage and bluff erosion. Many of the existing engineered bluff protection structures will continue to be effective under near-term conditions, provided that they are regularly inspected and maintained to ensure ongoing protective functions.

The monitoring of storm drains and outfalls will help identify when maintenance is required, ensure effective drainage during high-water events, and reduce localized erosion that can accelerate dune or bluff instability. Monitoring actions include checking for blockages following heavy rainfall, assessing whether outfalls become buried or exposed by seasonal sand movement, and documenting any damage caused by wave impacts or overtopping during winter storms.

Financially tracking the frequency and cost of these repairs will also support long-term planning and budgeting. It will also help determine when relocation or redesign of infrastructure should be considered under future conditions.

3.4.3 Coastal and Beach Monitoring Plan

The city should develop a coastal and beach monitoring plan to establish baseline monitoring conditions for adaptation triggers using a combination of remote sensing technologies, observations, daily maintenance logs, annual reporting, and citizen science. In the 1980s and 1990s, beach width surveys were conducted twice yearly between 9th and Santa Lucia Avenue, and surveyed benchmarks were established as part of the process. These surveys were conducted in both the spring and fall; however, budget constraints eventually ended the effort, and they were discontinued (D'Ambrosio 2025, pers. comm.). The City should locate this data and consider these locations for future beach width monitoring to ensure consistency with prior efforts. In addition, as a near-term goal, the City should reenact the beach monitoring program as identified in the land use plan (Carmel-by-the-Sea 2003).

Additionally, advances in technology since the 1990s could make restarting and maintaining this effort more achievable. As part of the coastal monitoring plan, the identification of specific locations, frequencies, and measurements is crucial. It will also be important to incorporate routine maintenance actions, such as sand movement onto volleyball courts, inspections of storm drainage infrastructure and beach access stairways, budgeting, and assessments of clean-up costs, and or damages along the dunes, bluffs, and upper beach. This work should correspond with the development of a centralized database and public-facing dissemination tool so that this information can be more easily communicated to City staff and the public, which would further assist with public works, marine safety, and engaging the public in citizen science, the last of which helps continue the dialog on adaptation approaches.

In addition to measurements, it is recommended to track staff time and total expenses related to beach maintenance and coastal adaptation projects. This tracking includes larger expenses, such as the purchase of a skid steer for repair work or fixing and maintaining coastal access stairways. These data will demonstrate the City's history of work and help inform future decisions, such as the potential relocation of assets that are damaged repeatedly.

In summary, coastal and beach monitoring efforts could look like the following:

- Identify data collection and storage framework applications to integrate routine City activities into long-term monitoring.
- Incorporate drone or unmanned aerial vehicle measurements routinely with LiDAR (light detection and ranging) or structure from motion (SfM) photogrammetry surveys to measure shoreline position, beach width, and dune volume while monitoring erosion by tracking changes in beach and bluff elevations over time. This information could support field surveys to help document detailed responses to storm events.

- Deploy beach cameras along the coastline to capture continuous visual records of beach conditions, wave activity, and visitor use according to best practices (Surfline 2025). The footage can be used to track shoreline change, document storm impacts, estimate visitation trends to support future socioeconomic evaluations, document habitat and species, and support the early detection of erosion or flooding events.
- Utilize satellite-derived imagery (e.g., USGS and UNSW 2025) to assess regional shoreline trends and supplement local data collection.
- Encourage citizen science participation for beach and vegetation observations as well as post-storm documentation, as done by UNSW and NSW (2025).
- Develop a public-facing monitoring website and visualization products to communicate long-term monitoring results to support adaptation triggers and pathway implementation.
- Install base plates or survey benchmarks along the sand ramps to measure changes in sand depth over time.
- Coordinate with ongoing research institutions to align local monitoring with regional coastal change studies.
- Share lessons learned and monitoring program development with the regional partners through venues such as Central Coast Climate Collaborative.

These coordinated monitoring efforts will provide a robust foundation for evaluating adaptation triggers, supporting planning updates, and tracking the effectiveness of implemented strategies (see Appendix B for additional details on triggers and monitoring systems)

3.4.4 Beach and Dune Management Plan

The City's shoreline management plan is part of its overall LCP (Carmel-by-the-Sea 2003), and the Del Mar Master Plan (Carmel-by-the-Sea 2010) provides a plan for the North Dunes and Del Mar Dunes. Together, these plans aim to manage coastal resources through specific policies and recommendations. The City should build on these documents with a unified beach and dune management plan.

First, the City should integrate field measurements into standard beach maintenance activities and document remediation variables (e.g., volumes and frequencies of sand moved, sand accumulation in the parking lot or other maintained areas following wind events). Using the City's preferred work management software, new data entry columns should be added to help track this information. Data collected through monitoring should be used to guide nourishment and sand placement practices, helping the City maintain the minimum beach width required for safe access and erosion buffering (see Section 3.4.1).

As part of this plan, the City should also continue targeted sand management actions that support public access. These works include periodic dune grading to maintain a stable and healthy dune system while reducing erosion. They also include the placement of sand over exposed revetments (when conditions allow) and prioritization of sand ramp maintenance by adding sand to offset seasonal deflation. Documentation of the timing, sand depths, and sand volumes of these activities will help evaluate long-term sustainability as sea levels rise and will provide a clearer basis for determining when alternative access or shoreline strategies may be needed.

3.4.5 Sand Management and Nature-Based Solution Plan

Nature-based solutions provide an adaptive, self-sustaining approach to coastal protection that enhances ecological function. A nature-based solution plan can help the City identify, prioritize, and coordinate projects that use natural processes to reduce coastal hazards, improve resilience, and maintain and improve the scenic character of Carmel Beach. Nature-based measures can also complement engineered protection and nourishment efforts, providing a hybrid approach to sustaining beach access and width, while enhancing ecological function.

A nature-based solution plan could also outline opportunities for integrating efforts for vegetation planting, dune enhancement, the replanting of native vegetation on cliffs, and driftwood placement into ongoing beach maintenance and management activities. It should define suitable sites, design parameters, and monitor metrics for each action in congruence with the Beach and Dune Management Plan.

The implementation of a nature-based solution plan would also establish clear guidelines for design, permitting, and adaptive management. These guidelines should ensure consistency with the Coastal Act, Monterey Bay National Marine Sanctuary regulations, and local environmental objectives. Some of these elements may include the following actions:

- Identify priority areas for dune and vegetation establishment.
- Evaluate potential co-benefits, such as improved public access, scenic value, and biodiversity.
- Establish monitoring protocols to track dune stability, vegetation cover, and dune reliance during storms.
- Coordinate with community groups and academic partners for implementation and stewardship.
- Integrate projects into existing capital improvement and coastal management programs.

3.4.6 Infrastructure Realignment Plan

In the near- to mid-term horizon, the City should develop an infrastructure realignment plan to identify appropriate triggers for the retreat or relocation of critical infrastructure and upland development, such as the Scenic Road Beach Bluff Pathway, Scenic Road, and associated infrastructure. This plan should identify what triggers would indicate moving toward abandonment and retreat and identify appropriate funding strategies. This study should also assess economic feasibility and funding mechanisms for realignment.

3.5 POLICY

Effective adaptation requires policy tools that guide future development, ensure consistency with SLR science, and provide a clear framework for integrating climate change into long-term decision-making. Policies help align private and public actions, reduce exposure to coastal hazards, and create predictable pathways for redevelopment, maintenance, and adaptation over time. Policy approaches also help manage expectations of residents and developers, and they limit the City's liability. The following policy approaches can support the City in managing risk, increasing resilience, and ensuring that adaptation strategies remain coordinated across departments and regulatory agencies.

3.5.1 Encourage Adaptation Action Through Policy

The City can encourage proactive adaptation through targeted policy measures that make resilient, low-impact strategies easier and more attractive to implement. Nature-based and low-impact adaptation measures can be supported through incentives or streamlined permitting pathways. For example, it would be beneficial to develop an opportunistic sediment reuse policy that allows sand recovered from construction or landscaping activities to be beneficially reused on Carmel Beach, when it is compatible. A preference for nature-based solutions or the maintenance of existing coastal armoring helps reduce conflict in permitting. For example, if beach nourishment, for example, is deemed feasible with a suitable sand source, then a policy prioritizing that adaptation strategy would help direct City funds or justify mitigation fees to be applied to the strategy implementation.

3.5.2 Establish In-Lieu Fees or Direct A Percentage of Existing Funding Streams to Support Coastal Access Maintenance and Dune and Beach Management

The City may also benefit from an in-lieu fee program that is tied directly to CDPs or conditions of approval whereby activities that may affect the beach could result in a fee. The California Coastal Commission currently assesses in-lieu fees typically tied to coastal armoring structures, such as a lost recreational value fee and a sand mitigation fee for the loss of sand

supply. Alternatively, if the City establishes a parking fee structure, funding from that fee could support access and sand management activities.

3.5.3 Adopt a Coastal Hazard Overlay Zone

A coastal hazard overlay zone can serve as a policy tool for guiding long-term adaptation by identifying areas with elevated exposure to future SLR. Establishing an overlay zone ensures that City development decisions, permit reviews, and public disclosures reflect the best available science and clearly communicate coastal risks.

The overlay zone should be based on the completed hazard mapping from Phase 1 of this project. Furthermore, it should be reviewed every 5–10 years to incorporate the emerging scientific understanding of SLR and coastal hazards as well as regional approaches to adaptation planning.

A coastal hazard overlay zone could trigger the following:

- Real estate disclosures associated with each land transaction for coastal hazards (described below)
- Requirements for a site-specific coastal hazard and SLR report as part of a coastal development permit application, which evaluates the specific risks to a proposed development for the life expectancy of the project
- Implement development constraints for new projects and expansions, including construction standards or development setbacks from hazardous coastal areas.
- Assumed liability by property owners for future coastal hazards and costs before permit approval is granted.

3.5.4 Develop Real Estate Disclosures

The development of real estate disclosures requires that, for any real estate transaction, buyers of properties in coastal hazards zones (Section 3.5.3) are made aware of potential hazards to their property. This disclosure informs buyers that they may face hazards, such as erosion or coastal wave flooding because of climate-induced impacts like SLR. This type of real estate disclosure would be like the flood insurance disclosure, which is already a part of hazard disclosures if a property is within a creek flood hazard zone. The education of landowners and potential buyers is important for a general understanding of the risk of owning property in a hazardous area.

In addition, real estate disclosure could acknowledge that the City may not always be able to provide access and some public services to the property. In that manner, it provides some liability protections for the City.

3.5.5 Continue Existing Armoring Policies Under the Coastal Act and LCP

The City should continue the existing armoring policies outlined in the Coastal Act and the certified LCP. Developing a certified Coastal Armoring Monitoring and Maintenance Plan for all the City's coastal armoring will expedite repairs and reduce the regulatory permitting burden for maintenance activities. Furthermore, the development of a certified coastal armoring monitoring and maintenance plan for all the City's coastal armoring will expedite repairs and reduce the regulatory permitting burden for maintenance activities.

Any request for new or modified armoring should include a detailed, site-specific coastal hazard analysis that evaluates anticipated SLR, erosion rates, wave runup, and potential impacts on beach width, habitat, and public access. This analysis should demonstrate that armoring is necessary to protect existing development and that alternatives—such as relocation, dune restoration, or hybrid solutions—have been fully considered while also identifying the design life of the armoring structure to ensure consistency with the City's long-term adaptation pathway.

3.5.6 Link Permit Renewal or Redevelopment Approvals to Updated Coastal Hazard Assessments and Adaptation Triggers

Permit renewal and redevelopment should be tied to updated coastal hazard assessments and the City's adaptation triggers to ensure that project decisions reflect the best available SLR and erosion science. Updated analyses for each major permit action provide a consistent checkpoint such that development remains safe and appropriate under future conditions. To support this method, the City should standardize the planned design life of all new development and redevelopment, so it aligns with projected SLR timelines and long-term adaptation planning.

3.5.7 Update the LCP to Integrate SLR Triggers

The City should update its LCP to formally integrate SLR triggers so that adaptation actions are tied to measurable and observable measurements rather than fixed arbitrary dates. This approach helps manage the uncertainty with the timing of impacts. By embedding these triggers in the LCP, residents, staff, decision-makers, and regulatory agencies will be aligned on timelines for specific adaptation steps, and there will be a transparent and predictable framework for long-term planning. As part of this update, the City should also incorporate managed retreat policies that outline when and how relocation or removal of at-risk development would be considered once trigger thresholds are met. The inclusion of both SLR triggers and managed retreat policies in the LCP will help the City transition from reactive responses to proactive, planned adaptation consistent with future coastal conditions.

3.5.8 Update Building Codes

The City's should update its building codes to incorporate coastal hazard resilience standards that reflect projected SLR and erosion conditions. Updates could include 1) definitions for appropriate foundation types in hazard zones that may allow for the relocation of structures, 2) requirements for the use of flood- and corrosion-resistant materials, and 3) the integration of design life expectancies that are consistent with the City's adaptation timeline. These updates ensure that new and redeveloped structures are built to withstand future coastal conditions and reduce long-term maintenance and safety risks. These building codes may also apply to access ways so that repairs can increase resiliency or add additional design features over time. building codes may also apply to access ways so that repairs can increase resiliency or incorporate additional design features over time.

3.6 PRIORITIZED ADAPTATION POLICIES, PLANS, STUDIES, AND ACTIONS

Table 6 summarizes the prioritized adaptation policies, plan, studies, and actions for the project.

Table 6. Studies, Plans, and Policies to Be Prioritized in the Near-Term by Adaptation Pathway

No.	Description
	Studies
1	Sediment Source Study of Beach Nourishment
2	Nearshore Reefs Feasibility Study
3	Shore Platform Enhancement Study and Pilot Program
	Plans
4	Coastal Armoring Monitoring, Maintenance Plan and CDP Compliance
5	Maintenance and Targeted Improvement of Coastal Infrastructure
6	Coastal and Beach Monitoring Plan
7	Beach and Dune Management Plan
8	Sand Management and Nature Based Solutions Plan
9	Infrastructure Realignment Plan
	Policy
11	Encourage Adaptation Action Through Policy
12	Establish In Lieu Fees or Direct a Percentage of Existing Funding Streams to Support Beach and Dune Management
13	Adopt a Coastal Hazard Overlay Zone
14	Develop Real Estate Disclosures
15	Maintain Existing Armoring Under the Coastal Act and LCP
16	Link Permit Renewals or Redevelopment Approvals to Updated Coastal Hazards Assessments and Triggers
17	Update LCP to Integrate SLR Triggers
18	Update the Building Codes

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Appendix A.
Adaptation Planning Principles

As sea level rise adaptation advances, focused analysis on the feasibility and effectiveness of specific strategies should be conducted. The State of California has developed guidance documents to direct local municipalities through the adaptation planning process. These documents provide valuable information and useful recommendations regarding the applicability, challenges, and legal and financial constraints that should be considered when selecting adaptation options. For the City of Carmel-by-the-Sea, one of the most applicable is the California Coastal Commission Residential Adaptation Policy Guidance (2018/2020)[1] , which provides policy guidelines for addressing sea level rise in local coastal programs and coastal development permits.

The following draft planning principles are suggested for incorporation into policy development for the City. These guiding principles are derived from the requirements of the Coastal Act and complement the priorities outlined in the State of California's climate adaptation strategy, the 2014 Safeguarding California plan. The following are some high-level planning principles to consider:

- Remain flexible to change and changing conditions
- Find a balanced approach with co-benefits
- Maintain ecosystem services whenever possible
- Prioritize nature-based solutions that do not need extensive maintenance over time
- Require new coastal development to plan for coastal storm and sea level rise hazards
- Maintain consistency with the General Plan and other Management Plans
- Conserve, maintain, and when necessary, restore beaches and access to beaches for the enjoyment of future generations, flora, and fauna.

High Level Questions for Decision-Makers

There are many challenges to adaptation planning that decision-makers must consider. Answering these questions will require a combination of community dialogue, stakeholder engagement, detailed technical evaluation, numerical modeling, economic analyses,

[1] Document can be found here: https://documents.coastal.ca.gov/assets/climate/slr/vulnerability/residential/RevisedDraftResidentialAdaptationGuidance.pdf

engineering design and costing, and political will. This section is intended to provide a list of questions that need to be considered at a high level as well as more detailed considerations for cost–benefit analyses and inclusion of social equity:

1. Does the strategy buy decision-making time to incorporate the evolving science of sea level rise?
2. Does the strategy increase flexibility and not lock the community into a single long-term solution?
3. Does the strategy incentivize good practices and adaptation (e.g., reward early actors and avoid maladaptation)?
4. How do we take a holistic adaptation approach that considers safety, coastal resources and habitats, and community identity?
5. Does the strategy support the protective role of ecosystems and sustain their physical processes?
6. Does the strategy allow for the evolution from one adaptation approach to the next?
7. How much sea level rise will the strategy accommodate?
8. How much does the strategy cost to implement initially?
9. Does the strategy require increased maintenance costs over time, and who bears the costs and responsibilities for maintenance and success?
10. Does the strategy avoid high costs and demonstrate a strong net benefit over time?

Ensure That the Plan Is Actionable

The Capital Improvement Plan (CIP) is an important planning process that outlines budget expenditures to address current needs and long-term capital needs. Many of these expenditures relate to public facilities, infrastructure, and amenities. Incorporating the probability of sea level rise and coastal hazards into the CIP process would be an effective way to ensure public projects are accounting for future hazard risks. These projects also present opportunities to include strategies to build adaptive capacity into coastal resources where feasible.

Public Education and Outreach

Public education and outreach programs can be utilized as a form of planning-level sea level rise adaptation within the City. These programs aim to enhance community understanding of potential sea level rise hazards and their potential impacts on coastal resources within the City. Community workshops serve as an effective platform for outreach and education related to sea level rise. Multiple workshops have already been conducted as part of this project, and future workshops may be necessary in response to

significant adaptation projects such as beach nourishment or following coastal hazard events that raise community concern.

Understanding physical and Ecological Implications of Coastal Armoring

Selecting among adaptation options requires understanding the secondary consequences associated with each strategy. Some strategies entail high construction or maintenance costs, while others may have temporary environmental or social impacts. Structural measures may protect upland infrastructure but reduce habitat or recreational opportunities over time. Conversely, nature-based approaches often provide ecological and aesthetic benefits but may offer less immediate protection to developed areas. Others may inhibit access to the beach, or affect the aesthetics or views of the coast. Selecting the appropriate strategy therefore requires weighing trade-offs between coastal habitat preservation, public access, recreation, and protection of upland development. In many cases, hybrid or combined strategies such as pairing dune restoration with targeted structural protection can balance these competing objectives. The decision-making process should remain adaptive, allowing the City to adjust priorities as monitoring data, funding opportunities, and regulatory guidance evolve.

Active Erosion

Active erosion from coastal armoring refers to interactions between coastal armoring and the physical processes that increase erosive forces. Some of these processes include wave reflection; positive wave interference, which causes waves to get bigger before breaking; increased beach scouring; and “end effects”. In some cases, armoring may increase longshore currents, which increases the rate of beach loss in front of the structure, and in turn escalates the erosion effects at the “ends” of adjacent, unarmored sections of the coast. Active erosion is typically site-specific and dependent on the length of the structure, sand supply, wave direction, specific design characteristics, and other local factors.

Figure A1. Lateral currents near the headland at 13th Avenue

Placement Loss

Wherever a hard structure is built, there is a footprint of the structure. The footprint of this structure results in a loss of coastal area known as placement loss. This inevitable impact

can bury the beach beneath the structure and reduce the usable beach for recreation or habitat purposes. For example, a 20-ft high revetment may cover up to 40 horizontal feet of dry sand beach. A vertical seawall typically has a smaller placement loss than a riprap revetment.

Limits to Access

Typically, vertical beach access (the ability to get to the beach) on a cliff-backed coast can be limited unless there are beach access stairs. Additionally, if passive erosion occurs, lateral (along) beach access can also be impacted.

Ecological Impacts

A study by Dugan et al. (2008) has shown that armoring reduces habitat, causes biodiversity loss, and is associated with a reduction in kelp deposition on the beach and a resultant loss of sand crabs, shorebirds, and certain species of fish. Given the negative ecological impacts of coastal armoring, more attention is now being focused on the implementation and effectiveness of natural, green, or soft solutions for shoreline protection. Soft solutions involve the creation or restoration of shoreline ecosystems using nature-based solutions. These solutions rely on natural physical, biological, or geologic processes to enhance the natural ability of coastal landforms to buffer erosion and flooding. Nature-based features can be designed, engineered, and constructed to mimic nature and may include sediment management and redistribution. When implemented correctly, soft solutions can be more self-sustaining after an initial establishment phase, possibly resulting in lower ongoing maintenance costs. Soft options may be required as mitigation for the construction of hard structures, are more favorably looked upon by permitting agencies, and offer added benefits, such as water filtration, wildlife habitat, and recreational opportunities. However, certain beach management practices, such as mechanical grooming or frequent sand redistribution, can also disrupt ecological processes by compacting sediments, removing wrack that supports invertebrates and shorebirds, and altering the natural exchange of sand between the beach and dune system. These benefits will be considered in the future cost–benefit analysis of prioritized adaptation strategies.

Safety Considerations

In the long term, design elements should consider public safety related to coastal access and recreation. Coastal structures, such as revetments or stairs, must include appropriate signage, barriers, or design features that reduce the risk of injury from falling or accidental entry into hazardous areas. It is also essential that emergency access to the beach remains viable, and communication systems remain functional and clearly marked. In Carmel, recent erosion near key beach entry points, such as the Del Mar parking lot ramp and the 8th Avenue ramp, has already reduced the reliability of emergency vehicle access, highlighting the need for proactive design and maintenance measures to ensure continued safety and response capability during future storm and high-water events.

Maladaptation

According to the Intergovernmental Panel on Climate Change, maladaptation inadvertently increases vulnerability to sea level rise and related hazards and can result from poorly planned adaptation actions or decisions that prioritize short-term benefits over long-term resilience. An example of maladaptation in Carmel would be the installation of hard protection structures, such as a seawall or revetment, in front of the Del Mar Dunes. While such a measure may temporarily protect existing development behind the dunes, it would accelerate beach narrowing and loss of recreational and ecological value over time, ultimately increasing community exposure to coastal hazards as wave reflection and scour intensify.

Avoiding maladaptation requires applying a long-term, systems-based approach that accounts for cumulative effects, future sea level rise, sediment dynamics, and social equity. Continuous monitoring, adaptive management, and alignment of project-scale measures with regional adaptation plans are essential to ensure that near-term interventions contribute to sustained resilience rather than increased vulnerability.

Regulatory Viability/Consideration/Feasibility

The primary federal laws that coastal projects must comply with are the Clean Water Act, National Environmental Policy Act, Coastal Zone Management Act, and Rivers and Harbors Act. The primary state laws and regulations include the California Environmental Quality Act, California Coastal Act, California Endangered Species Act, California Ocean Plan, California Department of Fish and Wildlife Code, California Public Resources Code, and the Porter-Cologne Water Quality Control Act.

State and Federal agencies involved in conducting, reviewing or approving, and permitting potential projects identified in this plan include the U.S. Army Corps of Engineers (USACE) and the Carmel Bay State Marine Conservation Area (under the authority of the California Department of Fish and Wildlife). The U.S. Environmental Protection Agency and USACE are the two main agencies involved in regulating discharges of fill and dredged material.

State agencies involved in conducting, reviewing, or approving potential projects include the California Coastal Commission (CCC), California State Lands Commission (CSLC), and the California State Coastal Conservancy (SCC). The agencies with primary regulatory responsibility over shoreline protective structures are CCC and CSLC. SCC is involved with funding coastal adaptation projects, so its involvement may vary depending on funding.

Carmel Bay has multiple marine protections and a variety of regulatory agencies. Depending upon the specific location of adaptation, primarily above or below MHW, the following special designation and their regulatory agency would require additional consultations: NOAA, who oversees the Monterey Bay National Marine Sanctuary, the California Department of Fish and Wildlife, who oversees the Carmel Bay State Marine Conservation Area, and the State Water Resources Control Board, who oversees the

Carmel Bay ASBS State Water Quality Protection Area (note that the Carmel Pinnacles State Marine Reserve lies just offshore of this critical coastal area).

Section 404 of the Clean Water Act

USACE is the chief decision-making agency for beach nourishment projects. For USACE to approve a project, the proponent must demonstrate that the proposed project is the "least environmentally damaging practicable alternative." Additionally, under Section 404 permitting, either an environmental assessment or an environmental impact statement is required for beach nourishment projects. Under Section 404, there are two types of applicable permits that are required: for larger-scale projects with the potential to cause significant impacts, an individual permit is typically required; for activities with minimal potential environmental impacts, a general permit is usually required.

Marine Sanctuary Permits

All hard structures, such as offshore breakwaters or submerged features like artificial reefs that dissipate wave energy before reaching the shoreline, would trigger review by the marine sanctuary. This review is conducted by the Office of National Marine Sanctuaries within the National Oceanic and Atmospheric Administration. The permitting process ensures that any activity proposed within a designated National Marine Sanctuary is consistent with the site's management plan, resource protection objectives, and the National Marine Sanctuaries Act. The review considers potential impacts on seabed habitats, sensitive species, sediment transport, water quality, and the overall ecological integrity of the sanctuary.

Sections 7 and 10 of the ESA

Pursuant to the Endangered Species Act (ESA), the lead agency responsible for environmental review of a proposed project must determine whether any species listed as threatened or endangered are present within the project or plan area and whether the project could result in significant impacts to those species or their habitats. If potential impacts are identified, the project proponent is required to prepare a Habitat Conservation Plan and submit it to the U.S. Fish and Wildlife Service for review and approval.

Marine Mammal Protection Act (MMPA)

The MMPA was the first legislation to mandate an ecosystem-based approach to marine resource management. Under the MMPA, Congress directed that the primary objective of marine mammal management should be to maintain the health and stability of the marine ecosystem and, when consistent with that primary objective, to obtain and maintain optimum sustainable populations of marine mammals. Projects that have a direct or indirect impact on marine mammals would be subject to this act.

California Coastal Commission Development Permits

California Coastal Commission Development Permits (CDPs) are permits required for development projects within California's Coastal Zone. They ensure that development activities, such as construction, grading, or changes in land use, are consistent with the California Coastal Act and the relevant Local Coastal Program (LCP). While local governments often issue CDPs under their certified LCPs, the Coastal Commission retains permitting authority and appeal jurisdiction along Carmel Beach.

Occupational Safety and Health Administration

During implementation, all adaptation measures must adhere to construction safety standards and minimize conflicts with public access and sensitive habitats. This includes compliance with Occupational Safety and Health Administration (OSHA) requirements, local safety codes, and site-specific health and safety plans to manage heavy equipment operation, unstable slopes, and weather-related risks. Construction routes and staging areas should be carefully located to reduce disturbance to beach users and adjacent dune ecosystems.

Appendix B.
Triggers and Monitoring

ADAPTATION PATHWAY TRIGGERS

Adaptation planning relies on the use of triggers, which are measurable thresholds that indicate when a change in management or strategy is required to limit risk. Triggers are established to ensure that adaptation actions are implemented proactively rather than reactively, providing decision-makers with a clear signal for when intervention is needed.

Trigger points are often developed by working backward from a potential tipping point, identifying early warning indicators that provide sufficient lead time for design, permitting, funding, and implementation of the next adaptation step. This proactive approach reduces uncertainty and supports smoother transitions between adaptation phases.

Triggers represent measurable or observable conditions that, once reached, signal the need to reevaluate existing management actions or initiate the next stage of adaptation. Trigger points should be selected to reflect both physical and social thresholds, ensuring that changes in shoreline conditions, infrastructure performance, or community tolerance are all captured within a monitoring framework. Triggers should be regularly reevaluated and updated in the future to capture advances in sea level rise science and changing conditions. Strategies can then be implemented before a trigger threshold is met. The following section outlines several examples of potential trigger points, and describes how each could be monitored.

Measurements

Observable and measurable entities, which may include physical distances, elevations, or rates of change, form the basis of monitoring and trigger evaluation. These measurements provide the quantitative evidence needed to assess progress toward adaptation thresholds and determine when a management response is required.

Common examples include measurements of beach width, bluff retreat, shoreline position, depth of sand, dune elevations, or flood depths recorded during tide events and storm events. Additional parameters, such as wave runup extent, bluff area lost, and associated infrastructure damage, can supplement physical measurements to provide a more comprehensive understanding.

To ensure accuracy and consistency, all measurements should be collected relative to established benchmarks or reference point locations, and using standardized survey or remote sensing methods. Data should be stored in an organized system to support future trend analysis, visualization, and integration into decision-support tools.

Beach Widths

Measuring beach width involves surveying the beach or documenting beach widths using other methods, such as ground-based cameras or remote sensing. A trigger may be when the beach width in the spring is 50 percent narrower than normal for that beach section, then an adaptation strategy such as sediment redistribution or placement should be pursued.

Note that the City of Carmel-by-the-Sea has a history of beach width surveying; however, it no longer actively monitors beach profiles. The City should develop a beach-width monitoring strategy, which may include ground-based cameras, traditional surveying, or remote sensing. Understanding beach width is essential because it influences both recreational use and ecological habitat value. Thresholds for acceptable beach width can be defined according to the size, location, and function of each individual beach.

Recommended Monitoring Method: Conduct biannual beach profile surveys and use automated camera systems (such as Surfline or CoastSnap) to capture daily shoreline position and sand recovery trends.

Erosion Distance

If erosion distance exceeds a defined threshold, it will trigger a corresponding management action. Erosion can be measured horizontally, vertically, or by the volume of material lost. For example, scarping of the sand ramps or dunes at the Del Mar Dunes can be quantified by measuring the height of the exposed scarp, supported by pre- and post-event photographs to document changes over time.

For bluff areas, erosion distance is commonly measured at the top of the bluff edge, while for harder sandstone or consolidated basal material, measurements can be taken relative to the depth of gaps or undercutting adjacent to armoring. Erosion may also be expressed as the remaining horizontal distance between upland development and the bluff edge, which provides a clear indication of remaining buffer space.

Consistent monitoring of these parameters allows for early detection of accelerating erosion trends and supports the timely implementation of adaptive management actions before critical thresholds are reached.

Recommended Monitoring Method: Use high-resolution drone or LiDAR surveys every 5–10 years to measure cliff position change, supplemented with field GPS mapping and photo documentation after major storm events and during maintenance activities.

Depth of Sand

The depth of sand to the underlying mudstone or sandstone is an important parameter for evaluating beach and dune system stability. This measurement is particularly relevant at locations such as sand ramps, where maintaining adequate sand depth is necessary to preserve access, pedestrian safety, and to mitigate erosion of the underlying consolidated material.

A threshold can be established to indicate when sand management techniques, including replenishment and redistribution, are required. For instance, if the sand depth falls below a specified value (such as 2 ft at the top of the sand ramp), it may trigger an action to move sand from lower areas back to the top of the ramp to restore its form and continuity. This approach is especially useful following winter storm events, when high-energy waves can scour and redistribute large volumes of sand.

Recommended Monitoring Method: Set up a staff plate at locations such as the volleyball courts, along the sand ramps, at revetments and seawalls, or at coastal access stairs would be critical for supporting timely maintenance and adaptive management. In addition, regular monitoring of sand depth using probes or even ground-penetrating radar can help identify the depth of sand in locations without staff plates.

Vegetation Cover

Vegetation cover on dunes or bluffs serves as an indicator of surface stability and resilience. A reduction in vegetative cover below a defined percentage threshold may signal increased vulnerability to erosion. Trampling and dune scarping can all contribute to reduced vegetation density and a corresponding decrease in sand volume.

Recommended Monitoring Method: Vegetation cover can be monitored through field surveys or remote methods such as drone-based imagery. Comparing field survey transects data or remotely-sensed imagery over time allows for the detection of spatial patterns of vegetation loss and recovery, supporting targeted restoration or access management actions when thresholds are exceeded. Monitoring should be targeted toward key indicator dune species or species of concern.

Dune or Sand Ramp Erosion

If erosion of the dune exceeds a defined threshold, such as retreat of the dune toe or dune crest by more than 10 ft, then it may trigger a transition to a different management strategy. Potential actions could include adding protection at the toe of the dune using less erodible materials to retain sand, such as armor stone, geotextile bags, drift logs, or another type of coastal structure. Alternatively, soft approaches such as dune restoration and planting may be appropriate depending on site conditions and long-term goals.

A sunset strategy can also be established whereby, if dune erosion exceeds a larger threshold (for example, more than 20–40 ft of retreat), management actions should be initiated to reduce risk to upland development and infrastructure. Clearly defining these thresholds provides a structured basis for decision-making and helps ensure that adaptation actions are implemented before critical losses occur.

Recommended Monitoring Method: Elevations may be captured with an auto-level or total station and tied to a benchmark. Changes in topography can be measured from prior surveys.

Bluff Erosion

Bluff erosion can be monitored using several measurable indicators, including horizontal retreat distance, slope angle, and proximity of critical assets to the bluff edge. If the rate or extent of erosion exceeds a defined threshold—such as when the bluff terrace reaches a certain angle of repose or when the distance between the bluff edge and infrastructure (for example, Scenic Road) becomes critically narrow—management actions should be initiated to reduce risk.

Thresholds should be tailored to site-specific conditions, including local bluff composition, erosion rates, and the design life of nearby structures. In areas where retreat threatens public infrastructure or private property, adaptation measures such as bluff stabilization, drainage improvements, or relocation planning may be warranted. Establishing clear trigger distances or slope criteria helps ensure that intervention occurs before safety risks or significant structural impacts arise.

Recommended Monitoring Method: Site inspections following storm events, and periodic monitoring of bluff conditions.

Public Access and Recreation Reduction

A decline in shoreline accessibility or sustained disruption of recreational use can be monitored, and triggers can be established based on problems reported to the City by the public.

Frequency

Frequency refers to how often a particular event or condition occurs within a given time period. In the context of coastal monitoring, this can include metrics such as the number of wave overtopping hours per season or year, or the duration and recurrence of beach or roadway closures caused by storm-related flooding and erosion. Tracking the frequency of these events helps identify emerging trends in coastal hazard exposure and supports timely adjustments to management and adaptation strategies.

Wave Exposure Frequency

Monitoring the frequency of backshore exposure to wave action is essential for understanding when and how often key features, such as dunes, cliffs, or coastal armoring, are directly impacted. This includes tracking how frequently waves reach the toe of a dune, cliff, or structure, and how often wave runup overtops and saturates the bluff terrace behind the armoring.

Trigger thresholds can then be defined based on the number of occurrences or the duration of exposure that exceeds a set limit within a given year. For example, if wave overtopping or flooding at a specific site occurs more than a defined number of hours or events annually, it may indicate that adaptation measures or design modifications are needed.

Recommended Monitoring Method: To monitor the frequency of flooding and wave exposure, the City should document each coastal flooding event by recording the date, location, type, depth, and severity of the event. Beach cameras and other automated monitoring systems can be programmed to track these occurrences and supplement field observations.

Toe of a Structure or Dune

Monitoring should focus on how frequently waves reach or expose the toe of dunes, seawalls, or revetments, as repeated exposure can cause scour, destabilization, or increased erosion rates.

Top of the Seawall

For coastal armoring, frequency is often measured by the number of hours or events in which waves overtop the seawall. Consistent overtopping may signal that the structure is undersized for future sea level rise conditions and may require modification or supplemental protection.

SEA LEVEL RISE OR FUTURE DATE

Sea Level Rise Elevation or Rate

Carmel Beach is already susceptible to significant coastal wave and erosion hazards that occur during El Niño years, major storm events, and seasonal high tides. Future sea level rise will increase both the frequency and severity of these impacts, and monitoring of sea level rise provides a practical way to track changes and establish quantitative triggers for adaptive management. Triggers can be defined based on specific elevation increases in

sea level relative to present conditions—such as 0.5, 1, or 2 ft of rise—or based on the rate of change over time.

Recommended Monitoring Method: The City should monitor data from the Monterey tide gauge, and this should be compared with modeled projections to assess progress toward identified thresholds. Because sea level varies naturally due to both astronomical tides and atmospheric conditions, use a 6-month averaging period to help filter out short-term variability associated with seasonal and El Niño fluctuations, ensuring that trigger points reflect long-term trends rather than temporary anomalies.

Future Date

This trigger type specifies that by a defined future date (for example, 2030), a particular set of strategies, policies, or programs must be implemented or completed. Future date triggers are most effective as follows: when used to schedule regular reviews or updates of adaptation policies, when they align with permit expiration and renewal timelines, or for more predictable events, such as the end of life of a structure. Establishing clear review dates provides predictability for both the City and regulatory agencies, which often require periodic evaluations to ensure that adaptation approaches remain current with evolving science and local coastal conditions. Note that the limitation of time-based triggers is that unpredictable extreme hazard events or other factors may reduce their reliability.

Cost, Condition, and Feasibility

Damages and Ongoing Maintenance and Repair Costs

The City can track and keep records of storm damage events and information related to storm damage and repair costs. This can also be a collaborative effort between City Public Works staff and residents, involving the collection of photos and videos documenting flood events and damage. Information such as the date, type, location, and severity of flooding, including associated information regarding wave runup and overtopping elevations, as well as any resulting damage, can be compiled into a central database.

The goal is to monitor changes in the frequency, extent, and severity of flooding over time. In the event of significant or extreme flood events, additional storm data (e.g., water levels and wave conditions) can be gathered to help establish risk-based thresholds.

Recommended Monitoring Method: Assets to track for public works staff include beach access stairways and sand ramps, with documentation of the extent of damages and associated costs to maintain. If they are required to be repaired a certain number of times over a 2- to 5-year window, then a transition to another strategy should be considered. Another measure could be to use cost; for instance, once the City spends a certain amount on ongoing maintenance and repair costs, then additional steps need to be taken.

A more nuanced approach to determining cost thresholds is considering costs from a cost–benefit analysis, whereby the benefits for the existing infrastructure or other adaptation approaches are weighed against their ongoing maintenance and repair costs, as well as the costs to the community.

Condition Ratings

By the time a coastal armoring structure has failed, it is too late. Early signs of potential failure include souring, flanking, spalling, dislodged armor stone, and visible cracks. Regular condition assessments are required to identify these early signs of failure, and plans should be set in place for when to sunset structures and transition to the next strategy, which may include eventual replacement of the structure or retreat at that location. The City can identify what actions should take place given structural conditions, which may include repair if the condition is average, replace if the condition is poor, and plan to relocate if the structure experiences repeated issues.

MONITORING

Identifying and monitoring triggers will allow the City to anticipate when management adjustments are needed, prioritize funding and permitting efforts, and remain flexible as conditions evolve. The City and its partners should regularly monitor and evaluate progress toward these thresholds to determine when they are reached. Monitoring indicators may include physical parameters, such as beach width, bluff retreat distance, and storm damage recurrence, as well as social and economic factors, such as public access disruptions or maintenance costs. A monitoring and maintenance plan will be needed to ensure that data collection methods remain standardized and results are comparable over time.

The ideal monitoring system should be low-cost and integrated into the day-to-day activities of the City and the community. Effective monitoring systems are essential for tracking coastal change, verifying adaptation triggers, and guiding future management decisions. They should also be readily observable and agreed upon in advance, and preferably codified into the local coastal program or shoreline management plan. This will ensure transparency, and once a trigger is reached through monitoring, all stakeholders will understand the process and next steps. Monitoring can also encourage citizen science participation, foster community engagement and shared ownership of coastal management. For example, the CoastSnap app (Harley and Kinsela 2022) enables beach users to take repeat photos at the same location via a smartphone cradle and upload them to build a long-term record of shoreline change (Figure 1).

Figure B1. CoastSnap is a phone app that relies on repeated photos at the same location to track how the coast is changing over time. CoastSnap relies on citizen participation, and stations can be set up at coastal overlook location (Harley and Kinsela 2022).

Although monitoring of the beach has been recommended in the City's Shoreline Management Plan, implementation has historically been time intensive and costly, and thus has never been fully established. Regular, structured monitoring is therefore essential to support informed decision-making and efficient budgeting.

Recent advances in technology now make it possible to collect continuous, low-cost data that can greatly enhance coastal monitoring efforts. New tools such as camera systems equipped with machine-learning software can automatically analyze beach use, track visitor numbers, and identify patterns of recreational activity along the cliffs and shoreline. Similar systems are already in use through Surfline's coastal camera networks, which provide real-time imagery and wave data that can be archived and analyzed for beach width, runup, and public use.

Other tools such as GPS-based tracking, can record patterns of movement by beachgoers, cyclists, and drivers, providing valuable insights into how different parts of the coast are used over time (Patsch et al. 2024; Figure 2). These data sources, when integrated with traditional survey and visual inspection methods, can help verify adaptation triggers and guide future management decisions. Together, they offer a flexible and scalable framework for tracking shoreline change, wave conditions, and community use in near real time.

Figure B2. Heat map of hourly visitation, Carpinteria State Beach (Patsch et al. 2024).

The City is advised to make routine inspections of the coastline as well as utilize these new technologies to inform annual maintenance and budget planning.

Recommended monitoring parameters include:

- Vehicular use (parking, types of vehicles, direction, and volume) on Scenic Road and surrounding roadways
- Pedestrian counts on Scenic Road Pathway
- Monthly beach widths
- Visual inspections following any wave event with a recurrence greater than 10 years
- Documentation of Scenic Road and the Bluff Pathway impacts from cliff erosion (location, scale, and repair costs).

The City of Santa Cruz, California, provides a useful example through its Coastal Change Monitoring Network. Through this network, 14 scientific, civic, and community organizations are co-developing a coastal monitoring program that integrates both geophysical and social indicators of coastal change into an analytical dashboard. The program uses affordable and replicable tools to track shoreline dynamics, storm impacts, and community observations. Outputs from the dashboard include visualization products, early-warning notifications, and a communications plan to support public awareness and proactive decision-making.

Another useful example comes from the City of San Clemente in Orange County, which has implemented Surfline camera systems along its shoreline to record and archive visual data for both scientific and public purposes (Figure 3). These systems allow for the automated

monitoring of beach width, wave runup frequency, and nearshore conditions, while also supporting recreational and safety uses. The archived imagery has proven valuable for quantifying coastal change, documenting storm impacts, and informing maintenance decisions.

Figure B3. Stills from a Surfline monitoring camera. Top, Newport Beach in Orange County, Bottom, Redondo Beach in LA County. The camera can provide data on wave heights, surface currents, visitors, beach widths, weather conditions and more. All of this is processed in real-time with cloud archiving and access to an API.

A similar approach could be considered for Carmel Beach, where strategically placed cameras such as near the Del Mar Parking Lot or the Santa Lucia Restroom, could provide consistent visual records to supplement survey-based monitoring. These data could help track the frequency of dune or bluff toe exposure, wave overtopping, and seasonal sand recovery. Some private cameras, such as those operated near Pebble Beach Golf Links, already provide limited views of the coastline and could potentially inform future collaborations or data-sharing opportunities if appropriate privacy and access considerations are addressed.

In addition to physical monitoring, these systems can support collaboration with local environmental groups and academic institutions. Collected imagery and metadata can be shared for ecological monitoring, such as tracking vegetation recovery, wildlife presence, or the effectiveness of dune restoration efforts. Establishing clear data sharing agreements and privacy considerations will be essential to ensure transparency and responsible use of the information collected. Collaborative monitoring partnerships may also help reduce overall costs by allowing expenses for installation, maintenance, and data management to be shared among multiple organizations with overlapping research or management interests. Further research will be required to evaluate system feasibility and confirm suitable locations before implementation.

Implementing a monitoring system to identify when actions should be triggered can involve numerous stakeholders. Monitoring data can be collected by the City during routine maintenance activities, extracted from remote sensing data, or collected in partnership with local research institutions such as the U.S. Geological Survey, National Oceanic and Atmospheric Administration, or nearby research institutions. Ideally, a program that monitors triggers would be integrated into routine City public works activities so that regular data collection forms the basis for adaptation decisions.

Some recommendations for this are further discussed in Section 3.4.

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Harley, M.D., and M.A. Kinsela. 2022. CoastSnap: A global citizen science program to monitor changing coastlines. *Continental Shelf Research* 245, 104796.

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Appendix C.
Initial Offshore Sediment Investigation for Augmenting Sand Supply on Carmel Beach

This appendix section provides an initial screening investigation of possible offshore sand supply for the sediment cell encompassing Carmel Bay and Carmel Beach. Carmel Beach is constrained by two rocky headlands—Arrowhead Point to the north and Carmel Point to the south. As a large pocket beach, the sand volume is mostly contained between the headlands, with minimal sediment exchange beyond the system. Carmel Beach is a picturesque 1.25-mile-long pocket beach that is recognized for its distinctive bright white sand, which gives the shoreline its unique character and is highly valued by the community and visitors alike (Figure C1). This white sand is characterized by its fine, soft texture and color, often likened to powdered sugar. Composed primarily of quartz and feldspar, the grains are small, smooth, and uniform, creating a bright, reflective surface that feels comfortable underfoot and gives beaches a pristine, inviting appearance.

Figure C1. Sand ramp near the Del Mar Parking Lot, which showcases the unique white sand.

As the City contemplates adaptation strategies, augmenting the existing sand volume is a promising approach. This initial investigation examines existing literature and data on the quality and quantity of offshore sand in Carmel Bay that may be compatible with the unique characteristics of Carmel Beach, with particular attention to color compatibility, which is the community's primary concern.

Sand supplied to Carmel Bay comes from several sources. The primary contribution is erosion and abrasion of granodiorite bedrock on the Monterey Peninsula, with transport southeast toward Carmel Bay, as shown in Figure C2 (Storlazzi and Field 2000). Additional inputs include erosion and weathering of shoreline and offshore rocks, and terrigenous debris delivered by the Carmel River and smaller drainages such as San Jose Creek, which Carter (1971) identified as a major source of sedimentary deposits to Carmel Bay. However, both the Carmel River and San Jose Creek channels have been stabilized through armoring of the banks and planting of non-native vegetation. Increased soil runoff in the agricultural areas upstream has effectively reduced these waterways' ability to erode bedrock and create sediment for the littoral environment by choking the channels with fine sediment (Storlazzi and Field 2000).

What many people perceive as the "beach" is only the visible portion of a larger sandshed system, where sediment is constantly moving between the dry beach, nearshore bars, and offshore zones (Figure C3). Sediment movement within the system can occur either north or south (alongshore) or off- and onshore (cross shore) based on seasonal changes in wave energy and direction and in response to large storm wave events. The dry sand beach at Carmel is part of a highly dynamic coastal system that experiences seasonal and event-driven fluctuations. During the winter months, large storm waves, especially those approaching from the west, erode the dry beach, transporting sand offshore and often exposing the underlying bedrock. In contrast, calmer summer wave conditions allow that same sand to return onshore, gradually rebuilding the beach. These seasonal patterns of erosion and recovery are typical for pocket beaches like Carmel, where sediment tends to remain trapped between headlands, resulting in long-term volume stability despite dramatic short-term shoreline and beach changes.

During large storm wave events, sand is removed from the beaches and transported into offshore sandbars. However, recovery after major storm events (such as El Niño winters) can take multiple years, depending on wave direction, wave period, and the depths at which the large storm wave events deposit sand as well as the availability of mobile upcoast sediment. Sediment transport at Carmel Beach will be influenced by sea-level rise and increased storminess, which are long-term factors influenced by climate change.

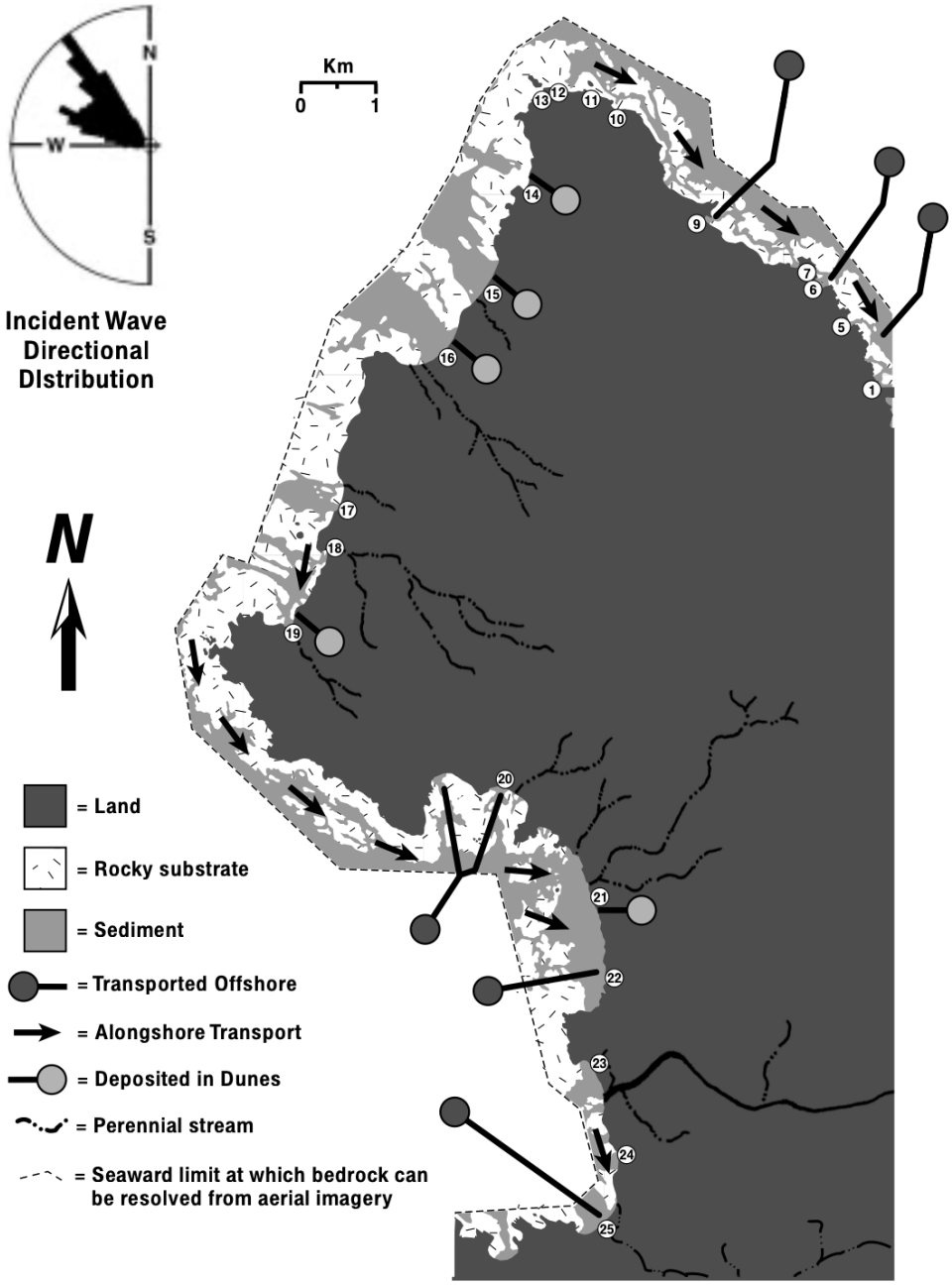

Figure C2. Interpreted sediment distribution overlain by the dominant littoral sediment transport pathways and sinks along the study area. The wave rose for the central coast was compiled from over 12,000 deep-water buoy observations between 1995 and 1998 (Coastal Data Information Program 1998). Note the correlation between transport pathways and sediment patterns (Storlazzi and Field 2000).

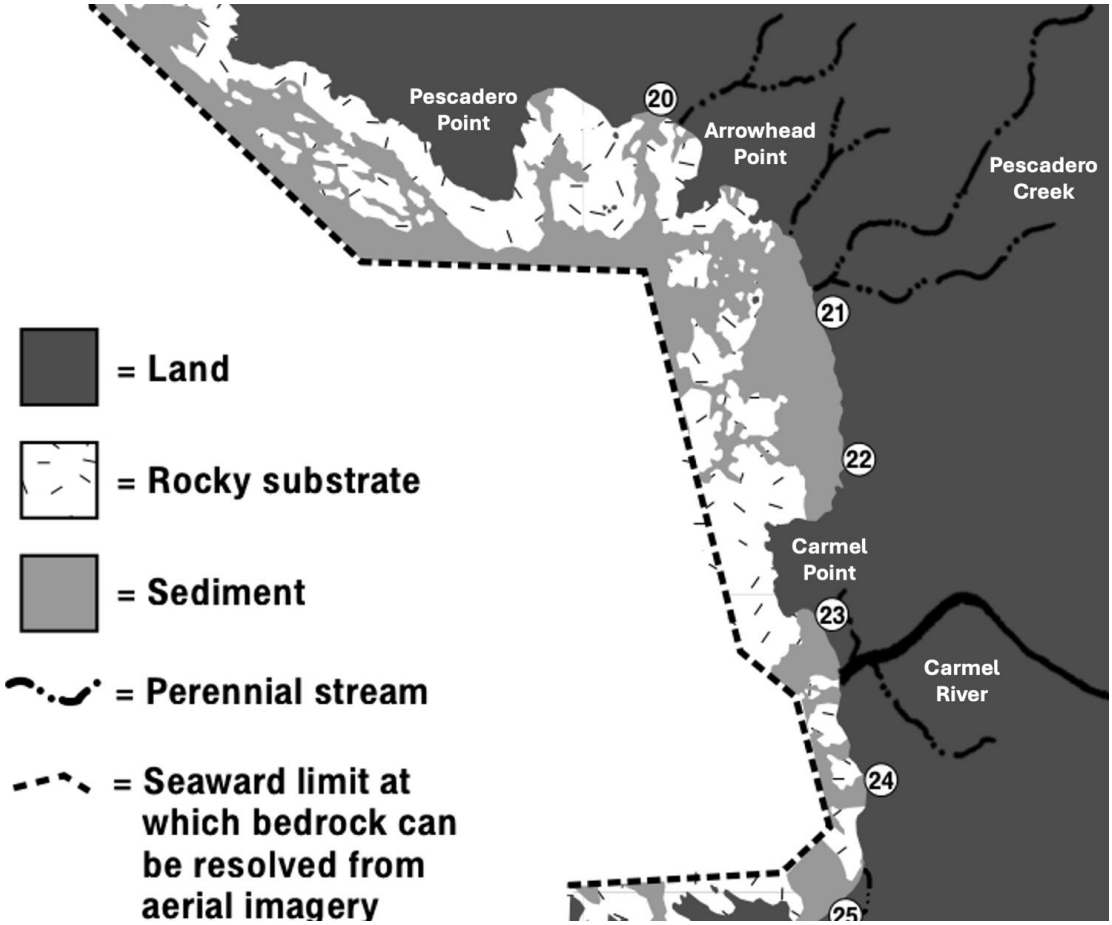

Figure C3. Location of beaches and distribution of sediment and bedrock in the nearshore and inner shelf along the Monterey Peninsula and Carmel Bay (Storlazzi and Field 2000).

Table C1 shows that Stillwater Cove (See #20 above) has a relatively coarse mean grain size, comparable to the southern part of Carmel Beach (#22), whereas the northern part of Carmel Beach (#21) is more similar to Carmel River State Beach (#22). The quartz percentage at Stillwater Cove and Carmel Beach is lower, and the feldspar percentage higher than at Carmel River State Beach and Monastery Beach (Storlazzi and Field 2000).

Table C1. Textural and mineralogic properties of the littoral sediments (all mineralogic distributions are % by mass of a 50–100 g sample rounded to the nearest 5%) (Storlazzi and Field 2000).

Site #	Beach Name	Mean (ϕ)	Sorting (ϕ)	Skewness (ϕ)	Quartz (%)	Feldspars (%)	Heavy Mineral (%)	Shell Material (%)
20	Stillwater Cove/ Pebble	1.74	0.42	0.94	40	30	30	<5
21	Carmel Beach (north)	0.57	1.92	-0.44	35	50	15	<5
22	Carmel Beach (south)	1.87	0.52	0.89	40	45	15	<5
23	Carmel River State Beach (north)	0.68	0.83	0.04	60	25	15	<5
24C	Carmel River State Beach (central)	0.96	0.82	0.40	60	30	10	<5
24S	Monastery Beach	-0.87	0.44	-0.56	65	30	5	<5

Carmel Beach is split among northern and southern sections in the study by Storlazzi and Field (Figure C3 and Table C1). We consider the compatible sediment range to reflect the combined properties of both areas. Therefore, suitable sediment for nourishment should have a mean grain size (ϕ) between 0.57 and 1.87, sorting values (ϕ) ranging from 0.52 to 1.92, and skewness (ϕ) between -0.44 and 0.89 (Table C1). This represents a relatively wide range of compatible grain sizes. It is important to note, however, that coarser-grained material generally remains on the beach longer than finer-grained material, which is more easily mobilized and transported offshore. Mineralogically, compatible sediments should contain 35 to 40 percent quartz, 45 to 50 percent feldspar, approximately 15 percent heavy minerals, and less than 5 percent shell material.

DEPTH OF SEDIMENT SOURCES

Based on regional practices and logistical feasibility, sediment for beach nourishment in California is most commonly sourced from depths of less than 30 m. This range balances dredging accessibility, operational efficiency, and environmental permitting. For example, the Sunset Beach nourishment project in San Francisco sourced sediment from depths between 10 and 20 m (USACE 2009), while the SANDAG Regional Beach Sand Project off San Diego sourced material from borrow sites at depths of 15 to 18 m (SANDAG 2005). These cases reflect a broader trend where offshore sand deposits between 15 and 30 m are targeted for their compatibility with native beach grain sizes and manageable extraction costs. Given these constraints, any offshore sediment considered for nourishing Carmel Beach is most likely to come from within this depth range, particularly in bathymetric lows (Figure C4) or paleo-channel features where sand accumulates.

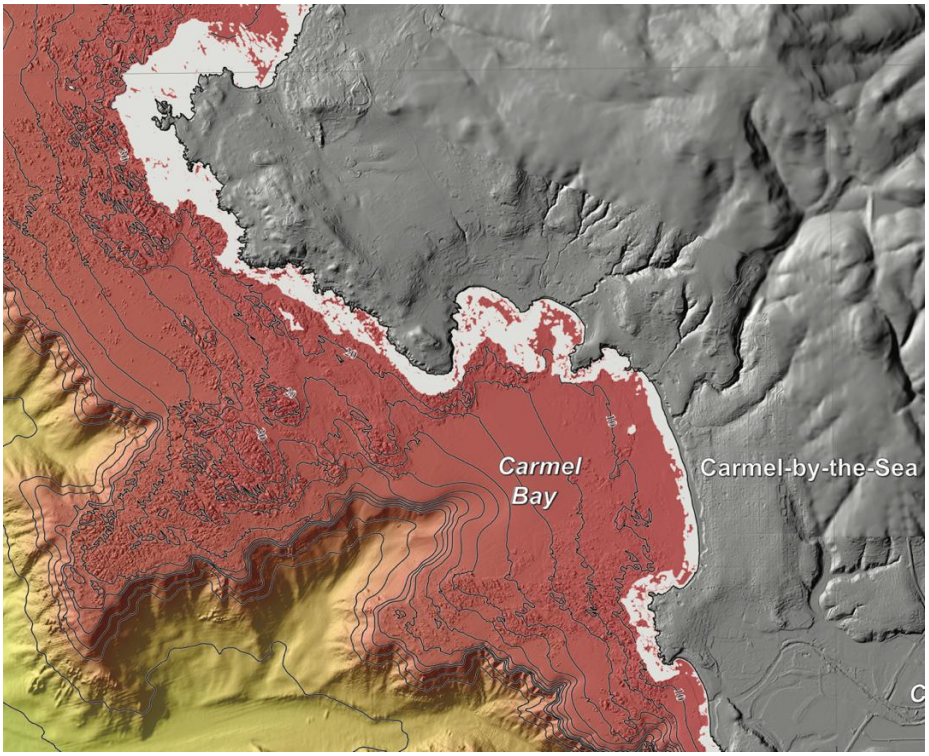

Figure C4. Bathymetric contour intervals: 10 m (Johnson et al. 2016).

Compatible Sediment

Based on the characteristics of Carmel Beach, suitable sediment for nourishment is expected to consist of fine to medium sand with a moderate to high quartz content. This is supported by seafloor character data from the U.S. Geological Survey map series, as shown in Figure C5. In this figure, light green areas represent sandy substrate in depths shallower than 30 m, while dark green areas indicate sandy zones between 30 and 100 m. These regions correspond to areas where the seafloor texture and composition appear most similar to native beach material. While these zones suggest potential compatibility, the interpretation is based on acoustic classification. Ground-truth sampling and laboratory grain size analysis would be required to confirm whether the sediment meets the physical and mineralogical criteria defined in Table C1. Figure C6 shows similar grain size distributions in offshore areas adjacent to Carmel Beach, supporting the possibility that sediment in these regions falls within the acceptable sediment sorting range (expressed on the ϕ scale). However, without direct sampling, the presence of coarse material, fine silts, or excessive shell content cannot be ruled out.

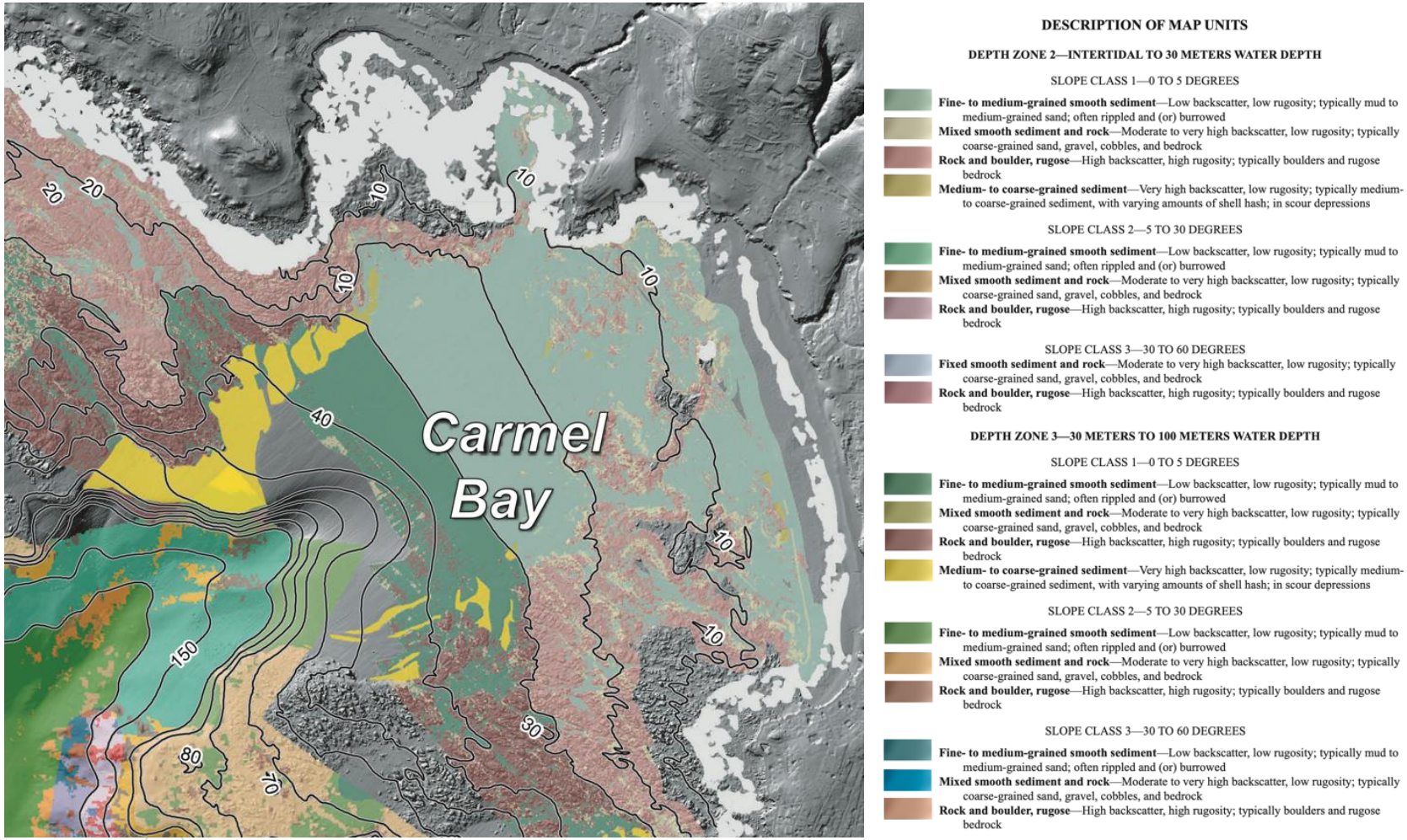

Figure C5. Seafloor Character, Offshore of Monterey Map Area, California (Johnson et al. 2016).

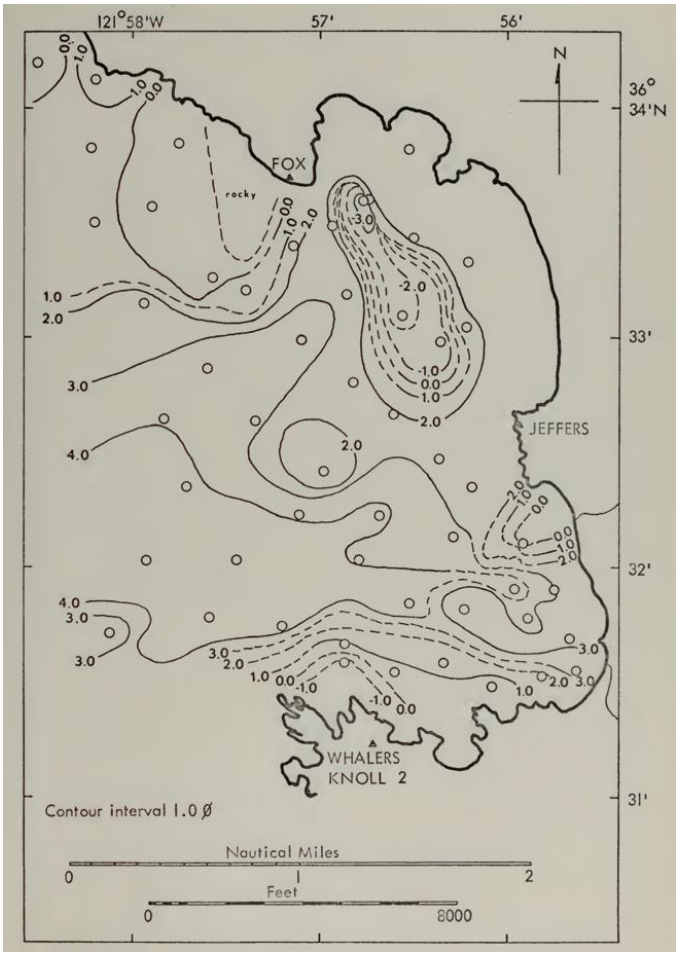

Figure C6. Sediment mean grain-size distribution (Carter 1971).

Shell Content

Shell content is another important factor to consider when evaluating the suitability of offshore sediment for beach nourishment. Excessive shell fragments can alter the visual appearance of a beach, affect compaction and drainage, and potentially reduce recreational or ecological value. For Carmel Beach, the native sediment has been shown to contain less than 5 percent shell material, indicating a preference for mineral-dominated sand with limited shell content. Figure C7, based on Carter's 1971 survey of offshore sediments, presents the spatial distribution of shell content across Carmel Bay. The map shows that much of the offshore area below 30 m depth, particularly zones that contain fine to medium sand, has a shell content ranging from 0 to 49 percent by mass. While this upper range appears high, the data are grouped broadly, and a significant portion of these areas likely fall within the lower end of that range, closer to the target of less than 5 percent. The co-occurrence of suitable grain size and low to moderate shell content in these offshore zones suggests potential compatibility with native beach sediment. However, because the Carter survey is based on surface grabs with limited resolution,

further sediment sampling and laboratory analysis will be necessary to confirm whether specific offshore deposits meet the shell content threshold for nourishment.

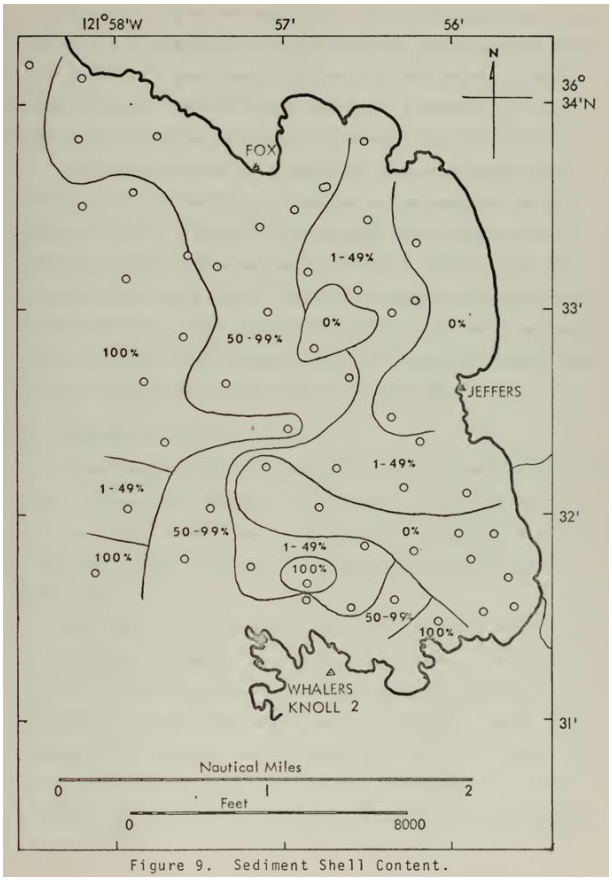

Figure C7. Sediment shell content (Carter 1971).

Table C2. Grainsize and sorting data by location from usSEABED (Buczkowski et al. 2020)

Object ID #	Latitude	Longitude	Grainsize	Sorting
26	36.52113	-121.9672	-2	-99
64	36.52483	-121.9343	1	-99
76	36.52721	-121.9648	-2.5	-99
78	36.52783	-121.9477	1	-99
81	36.5285	-121.9687	1	-99
114	36.539	-121.9617	1	-99
119	36.54002	-121.9698	6	-99
120	36.54033	-121.9493	1	-99
123	36.54134	-121.9637	1.5	-99
137	36.544	-121.9637	1	-99
148	36.54783	-121.9597	1	-99
151	36.54911	-121.9501	1.5	-99
160	36.5515	-121.9423	-3.6	0.9
162	36.55233	-121.9653	1	-99
166	36.55333	-121.9563	-2.5	-99
171	36.55488	-121.9478	1.5	-99
177	36.5565	-121.9458	2.5	-99
178	36.5565	-121.9458	0.3	0.8
187	36.55833	-121.9697	1	-99
191	36.55917	-121.9647	1	-99

Figure C8. Grainsize and sorting data by location from usSEABED (Buczkowski et al. 2020)

Sediment Thickness

In addition to grain size and composition, the thickness of the offshore sediment layer is an important factor when evaluating potential source areas. Figure C9 shows the estimated sediment thickness (in meters) across the Carmel Bay shelf. According to this map by Johnson et al. (2016), the sediment layer begins to exceed 1 m in thickness at around 20 m depth. Between 30- and 40-m depth, the sediment layer increases to approximately 5 m thick in some areas.

While dredging beyond 30 m depth is generally considered less practical because of increased costs, the presence of thicker sediment deposits in these deeper areas may make them worth further investigation. These locations could offer larger volumes of sand with fewer constraints related to patchiness or exposure but would require additional feasibility studies to determine whether extraction is viable and environmentally acceptable.

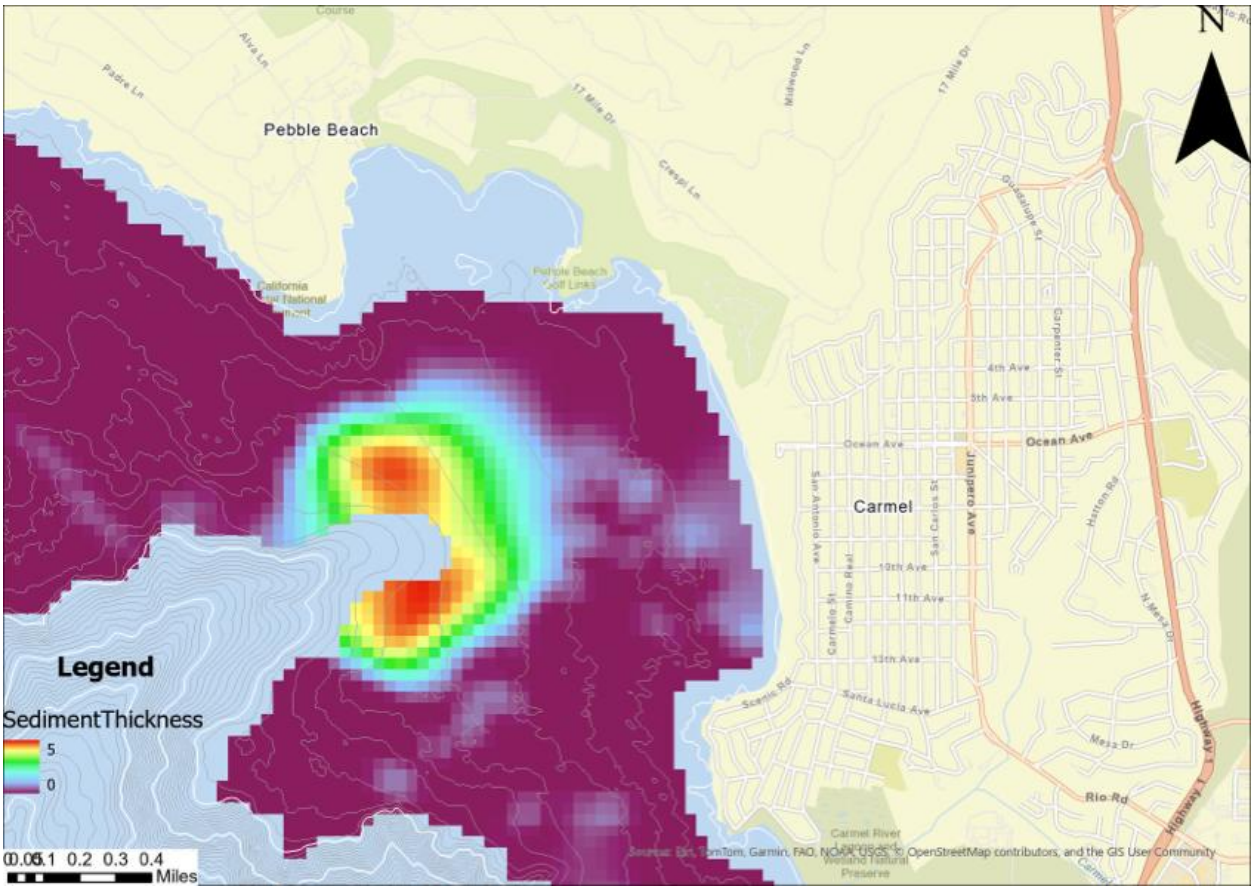

Figure C9. Sediment thickness (meters) with 10-m bathymetric contours shown in gray (Johnson et al. 2016).

PALEO STREAM CHANNELS AS SEDIMENT SOURCE

One of the most important features influencing offshore sediment accumulation in Carmel Bay is the presence of paleo stream channels. These are ancient riverbeds carved into the landscape during periods of lower sea level and now lie submerged on the seafloor. Such features have been documented in the nearshore and inner shelf of the Monterey Peninsula and Carmel Bay, particularly by Storlazzi and Field (2000), who describe them as structurally bounded depressions that function as effective traps for littoral sand.

In regions where the coastline is exposed to the dominant northwest wave direction, sediment tends to accumulate in shore-normal bathymetric depressions interpreted as paleo stream channels that trap littoral sand. These channels often align with former onshore drainage paths and are typically carved into bedrock. As sediment infills these depressions, it creates linear sediment bodies surrounded by rocky substrate, as illustrated in Figure C10 and Figure C11. In areas where stream channels enter the coast perpendicularly and the coastline runs parallel to prevailing wave energy, sediment is distributed both within these shore-normal features and along narrow, shore-parallel ribbons at depths of 2 to 6 m. In contrast, where no major fluvial inputs exist, sediment tends to occur as discontinuous, shore-parallel patches typically found at depths greater than 15 m (shown in Figure C10 as a purple line).

Their typical depth range of 10 to 30 m places them within reach of common dredging equipment, and their location in protected structural lows suggests they could retain high-quality sediment suitable for nourishment. However, their suitability cannot be confirmed without further investigation. Detailed sub-bottom profiling and coring will be required to determine the volume, grain size, shell content, and mineral composition of sediment within these channels, as well as to assess the environmental and geomorphic impacts of potential extraction.

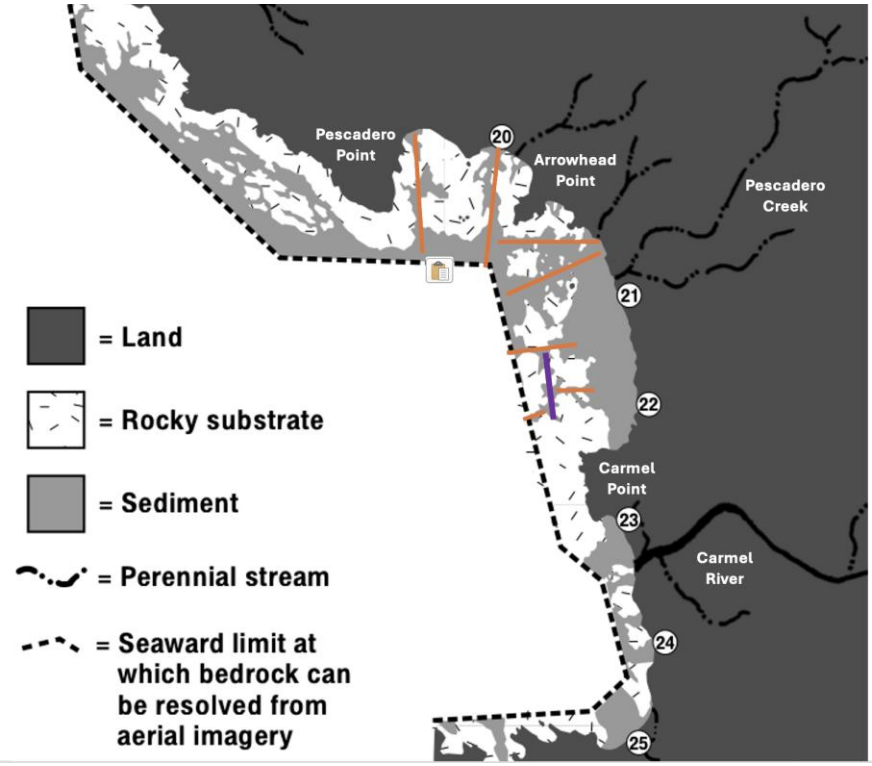

Figure C10. Potential paleo stream channels offshore of the Monterey Peninsula, inferred from sediment-filled depressions bordered by rocky substrate (Storlazzi and Field 2000).

In Carmel Bay, paleo channels are most likely to be found offshore of current and former river mouths. The most promising area is directly offshore of the Carmel River, where bathymetric maps and seismic profiles show a shore-normal depression aligned with the river's historical outflow. Additional candidate locations include the area near Pescadero Canyon, where Simpson (1972) documented sediment pockets up to 22 m thick.

These features are expected to contain fine to medium sand, partially or fully filling the paleo channels. However, sediment sourced from the Carmel River and the adjacent Monastery and Carmel River State Beach sediment cell is compositionally and visually distinct from the native sand at Carmel Beach and is likely a poor compatibility match for nourishment. Any consideration of these offshore deposits should therefore include grain size and mineralogical analyses as well as explicit color evaluation to confirm suitability. Learning from Figure C11, seasonal wave conditions and sediment exchange strongly influence retention of placed sand. Winter storms drive sand offshore and increase the risk that newly placed material is lost to bars, while late summer and fall are characterized by calmer conditions and more frequent onshore transport that favor beach accretion. If this area is selected as a sediment source, scheduling dredging and placement in the fall should maximize stability of the nourishment, reduce turbidity dispersion and rehandling, and avoid early winter storm losses. Under this scenario, dredging the upper region of the deposit in fall is likely the most feasible option, pending permit and biological work

windows. Aligning work windows with seasonal habitat cycles and targeting unconsolidated sand bodies away from rocky reef, kelp, and grass also reduces habitat disturbance, minimizes turbidity exposure, and limits the footprint of temporary impacts.

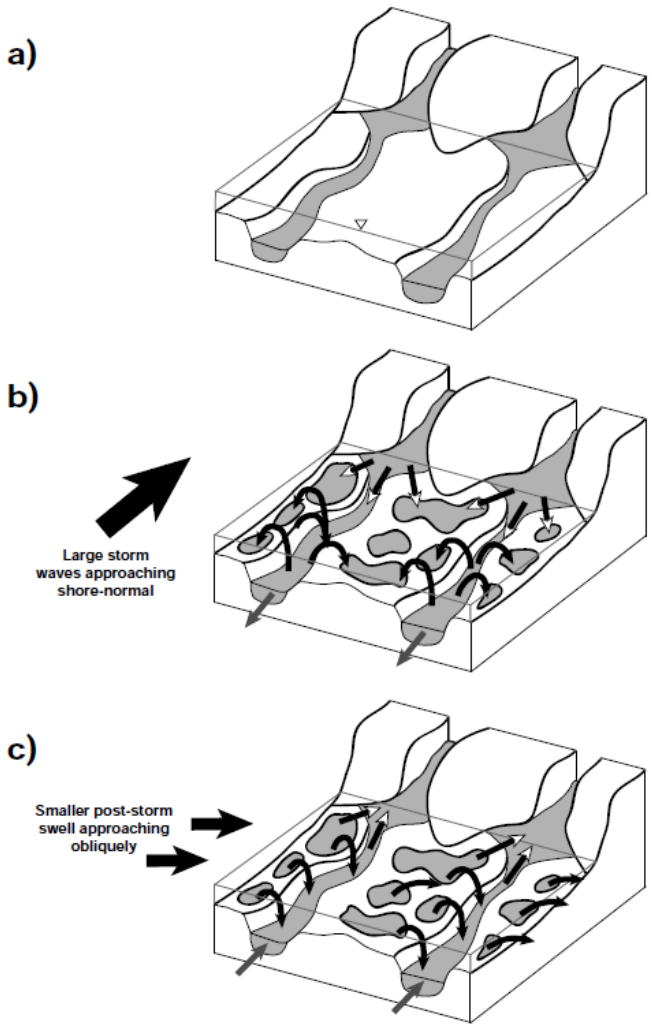

Figure C11. Schematic diagram showing hypothesized model for alongshore sediment transport along a rocky, embayed coastline. (a) Pre-storm: a subaerial beach between headlands and sediment offshore in a paleo-stream channel bounded by subaqueous bedrock ridges. (b) Storm: subaerial beach sediment is eroded and carried offshore (white-tipped arrows), sediment in the paleochannels is suspended and dispersed across shoreface (black-tipped arrows), and a percentage of sediment in the paleo-stream channels is transported farther offshore to the mid shelf (gray arrows). (c) Recovery: smaller short-period waves (moving from left to right) would sweep the bedrock ridges clear of sediment, transporting the sediment either onshore to rebuild the pocket beach (white-tipped arrows) or into the adjacent downcoast paleo-stream channel (black-tipped arrows). The reconstruction of the pre-storm shoreface profile would

then be aided by long period, low-energy swells carrying sediment onshore from greater depths (gray arrows) (Storlazzi and Field 2000).

EXAMPLE OF A MULTICRITERIA SUITABILITY MODEL FOR OFFSHORE SEDIMENT SOURCES

This analysis is provided here for reference. This process uses a multiplicative multicriteria raster overlay to evaluate the suitability of offshore areas for sediment sourcing. Each criterion, such as grain size, shell content, sediment thickness, source depth, proximity to Carmel Beach, and depth of closure compliance, is first normalized on a scale from 0 to 1, with 1 indicating full compatibility. The final suitability score for each raster cell is calculated by multiplying all individual scores. This approach ensures that if a location fails to meet even one of the criteria, its overall suitability becomes zero. As a result, only areas that satisfy all minimum requirements will receive non-zero scores, with values approaching 1 indicating the most compatible zones. This method is particularly useful for strict screening processes, such as identifying offshore sediment sources for beach nourishment under regulatory constraints.

1. Grain size (Johnson et al. 2016).

   Score 1.0 if mean grain size on the phi scale is within 0.57 to 1.87. Values outside this range may be linearly scaled toward 0 if partially compatible.

2. Color

   Score 1.0 when the sand closely matches native Carmel Beach sand. A color scale will be set up

3. Sediment thickness (Johnson et al. 2016).

   Score 0.3 if thickness is at least 1 m, 0.6 if at least 2 m, and 1.0 if at least 3 m.

4. Depth of source (Johnson et al. 2016).

   Score 1.0 if the area lies between the local depth of closure and 30 m. Assign 0.5 for depths between 30 and 45 m. Values outside this range are scaled down or set to 0.

5. Proximity to Carmel Beach

   Use an inverse distance function so areas closer to the placement reach receive higher scores. For example, 1.0 at the shoreline, decaying toward 0 with increasing distance.

6. Depth of closure constraint

If the location lies seaward of the estimated depth of closure, assign a score of 1. Otherwise, assign a score of 0.

7. Shell content (Carter, 1971)

   Score 1.0 if shell content is less than 5 percent. Use 0.9 for 5 to 50 percent, 0.5 for 50 to 75 percent, 0.25 for 75 to 95 percent, and 0 for 95 percent or higher.

Final Suitability Score Calculation

The overall suitability score is calculated by multiplying all individual raster layers:

Suitability, normalized = G × C × S × T × D × P × Z

Where:

G = grain size
C = color
S = shell content
T = sediment thickness
D = depth of source
P = proximity to Carmel Beach
Z = depth of closure compliance

This multiplicative method ensures that all critical conditions must be met for a location to receive a non-zero score. It strongly favors areas that are fully compatible with nourishment requirements, making it well-suited for regulatory screening and high-confidence sediment sourcing.

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