City of Santa Cruz Beach Vulnerability and Adaptation Strategy

November 6, 2019

Central Coast Wetlands Group
City of Santa Cruz
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Appendices

Santa Cruz Beach Management in the Face of Climate Change

Introduction

To understand the incremental effects of coastal adaptation policy on coastal resources (beaches, coastal access and use, visual and recreation) the City of Santa Cruz initiated this evaluation of adaptation options for beaches within the city limits to inform a more strategic and iterative approach to coastal climate adaptation. This beaches adaptation and management planning effort will include qualitative, quantitative, socioeconomic and geospatial analysis methods to assess the vulnerability of beach resources from sea level rise and identify policy and strategies to increase resiliency of coastal resources and public access. The evaluation will focus on policies and strategies to support coastal adaptation, (i.e., those called out in the City's Administrative Draft LCP, 2018 Climate Adaptation Plan Update and those recommended in the Coastal Commission Sea Level Rise Policy Guidance) for identified hazards along coastal beach sections of the City of Santa Cruz.

This evaluation will also:

- Support city staff selection of 3 initial adaptation strategies and pathways that will be considered to address predicted risks for each of the 4 beach segments
- Identify secondary consequences to each of the initial adaptation strategies selected. (e.g., impacts to recreation, tourism, affordable housing of low income communities, etc.)
- Identify fiscal, policy and engineering strategies to mitigate any secondary consequences of the 3 alternative adaptation strategies
- Recommend triggers/thresholds (i.e. repetitive loss leading to infrastructure removal and retreat) that initiate next phase adaptation strategies (adaptation pathway)
- Evaluate and identify public finance options and innovative funding to mitigate secondary consequences of adaptation strategies.

These strategies, their costs, tradeoffs, and funding mechanisms will then be presented to decision makers and the public to evaluate equitable cost share strategies. The evaluation will support the integration of policies and programs (seawall mitigation funds, beach nourishment programs, defined coastal retreat areas) needed to maintain beaches, coastal access and recreation for all that live and visit Santa Cruz.

Previous Study: 2017 Sea Level Rise Vulnerability Assessment

A Sea Level Rise (SLR) hazard evaluation was completed in 2017 for the City of Santa Cruz, intended to provide a chronology of projected future risks to benefit local coastal planning and foster discussions with state regulatory and funding agencies. Estimates of the extent of beach area and access assets at risk of various climate hazards were made using best available regional data. The report was intended to enable city staff and stakeholders to understand the full range of possible impacts that can be reasonably expected based on the best available science, and build an understanding of the overall risk posed by potential future sea level rise.

Coastal Climate Change Hazards

The 2017 coastal climate change vulnerability analysis, conducted by CCWG for the City of Santa Cruz, uses the Coastal Resilience hazard model developed by Environmental Science Associates (ESA) and funded by the State Coastal Conservancy.[1] An important limitation of the original ESA hazard layers was addressed within the 2017 focus effort for the City of Santa Cruz. CCWG modified the hazard layers to account for reductions in potential hazards provided by current coastal protection infrastructure. This refinement of this coastal hazard analysis helped to better understand the future risks Santa Cruz may face from each individual coastal hazard process.

The 2017 vulnerability analysis evaluates the impacts of each individual coastal climate change hazard process (rising tides, coastal storm flooding, and erosion) for time horizons 2010 (existing), 2030 (.3ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR) on beach resources. Definitions of each of these hazards are discussed below. More information about the method used and the 2017 SLR assessment can be found in the City of Santa Cruz 2018 Climate Adaptation Plan Update (City of Santa Cruz, 2018).

Rising Tides

These hazard zones show the area and depth of inundation caused simply by rising tide and ground water levels (not considering storms, erosion, or river discharge). The water level mapped in these inundation areas is the Extreme Monthly High Water (EMHW) level, which is the high water level reached approximately once a month.

Coastal Storm Flooding

These hazard zones depict the predicted flooding caused by future coastal storms. The processes that drive these hazards include (1) storm surge (a rise in the ocean water level caused by waves and pressure changes during a storm), (2) wave overtopping (waves running up over the beach and flowing into low-lying areas, calculated using the maximum historical wave conditions), and (3) additional flooding caused when rising sea level exacerbate storm surge and wave overtopping. These hazard zones also take into account areas that are projected to erode, sometimes leading to additional flooding through new hydraulic connections between the ocean and low-lying areas.

Coastal Erosion

These layers represent future cliff and dune (sandy beach) erosion hazard zones, incorporating site-specific historic trends in erosion, additional erosion caused by accelerating sea level rise and (in the case of the storm erosion hazard zones) the potential erosion

[1] The Coastal Resilience model developed by ESA in 2014 mapped hazard zones at various sea level rise scenarios for each of the individual coastal hazards (rising tides, coastal storm flooding, and coastal erosion). The Coastal Resilience hazard layers are available for viewing through the online mapping viewer at www.coastalresilience.org.

impact of a large storm wave event. The inland extent of the hazard zones represents projections of the future crest of the dunes, or future potential cliff edge, for a given sea level rise scenario and planning horizon. The extents of these hazard zones were modified by CCWG to take into account existing coastal armoring through the year 2030.

Key Findings from City of Santa Cruz 2017 SLR Vulnerability Study

The SLR hazard assessment prepared for the City of Santa Cruz 2018 Climate Adaptation Plan Update (City of Santa Cruz, 2018) offered several key findings as they relate to beaches:

2030-2060 Planning Horizon

- Much of West Cliff and some of East Cliff are protected by sea walls and rip rap, mitigating much of predicted erosion hazards and leading to coastal squeeze and other impacts to beach resources.
- New structures will need to be constructed for portions of West Cliff and East Cliff (Seabright) where no structures currently exist if we are to maintain the same level of service (auto, bike and pedestrian) along the coast. This would further reduce beach areas.
- Storm Flooding is predicted in the Beach Flats area due to waves overtopping the coastal infrastructure on Beach Road yet these impacts are assumed to be managed by current storm water pumps along the San Lorenzo River levee.
- Pocket Beaches that remain along West Cliff are predicted to be lost between higher tides and protected back shores.

2060-2100 Planning Horizon

- Main Beach is predicted to be reduced by approximately 50% due to rising tides.
- Predicted flooding risks from rising tides to areas of Lower Ocean, parking lots in Beach Flats, and natural areas of Neary Lagoon are assumed to be managed by current storm water pump infrastructure.
- Houses and roads along West Cliff between Woodrow and Lighthouse Field are vulnerable to coastal erosion leading to debris risks to inland infrastructure.
- The first block inland of Beach Street is vulnerable to waves and storm flooding which may require the construction of protective infrastructure on or adjacent to the beach.

This hazard evaluation exercise confirms that coastal erosion and flooding along Natural Bridges, West Cliff, Main Beach and Seabright will be a continued challenge for the City of Santa Cruz. Much of the most vulnerable coastal infrastructure is owned and operated by the City. Establishing sound coastal adaptation and protection policies early will likely best enable the long-term implementation of these policies and ensure long term sustainability for the coastline.

New State SLR Guidance

State guidance (Ocean Protection Council, 2018) suggests that “a Bayesian probabilistic framework” can support improved decision making and probabilistic projections represent consensus on the best available science for sea-level rise projections through 2150. With continued advances in sea-level rise science, it is expected that probabilistic projections will change in the future. However, within the Monterey Bay, probabilistic models are not yet available. To respond to state guidance, the Coastal Resilience hazard models (developed by ESA in 2014) were cross-walked with the probabilistic based-scenarios referenced within the most recent guidance (Table 1). For clarity, this report focuses the hazard analysis on a subset of those scenarios (red text in table 1).

Table 1. Comparison of OPC 2013 Guidance Document and 2018 Update’s Probabilistic SLR projections

SCENARIO BASED PROJECTION: TIME HORIZON	SCENARIO BASED PROJECTION: EMISSIONS SCENARIO	SCENARIO BASED PROJECTION: SLR	PROBABILISTIC PROJECTION: EMISSIONS SCENARIO	PROBABILISTIC PROJECTION: LIKELY RANGE*: 66% PROBABILITY SLR IS BETWEEN…	PROBABILISTIC PROJECTION: 1-IN-200 CHANCE**: 0.5% PROBABILITY SLR MEETS OR EXCEEDS…	H++ SCENARIO***
2030	Med	4 in	High	**3.6 – 6 in**	9.6 in	12 in
2060	High	28 in	Low	6 – 14.4 in	**27.6 in**	45.6
			High	8.4 – 16.8 in	31.2 in	
2100	High	63 in	Low	10.8 – 27.6 in	**66 in**	121.2
			High	18 – 39.6 in	82.8 in	

*Notes: * low risk aversion projection, **Medium-high risk aversion projection, ***Extreme risk aversion projection*

The goal of scenario-based analysis for sea level rise is to understand where and at what point sea level rise and the combination of sea level rise and storms, pose risks to coastal resources or threaten the health and safety of developed and natural areas. This approach allows planners to understand the full range of possible impacts that can be reasonably expected based on the best available science, and build an understanding of the overall risk posed by potential future sea level rise.

State guidance recommends evaluating the impacts of the highest water level conditions that are projected to occur in the planning area. In addition to evaluating the worst-case scenario, planners need to understand the minimum amount of sea level rise that may cause impacts for their community, and how these impacts may change over time, with different amounts of sea level rise.

Scenario Selection for Planning

Projected future hazard zones can be interpreted as areas of the coast where various climate impacts (rising tides, erosion and coastal storm flooding) are likely to occur in the future. The expected future event horizon can be expressed as a predicted time horizon (e.g., 2030, 2060, 2100) or for a future ocean elevation range (e.g., 4 in, 28 in, 63 in). Therefore, future adaptation pathway triggers can be either based on a future predicted date or other financial (e.g., inability to meet costs of a certain strategy) or physical (e.g., predicted sea elevation) triggers. The use of physical triggers like sea level rise is useful because they don’t initiate actions prematurely but rather wait for the particular financial or physical phenomena to occur.

For ongoing management of beach and coastline resources, considerations regarding predicted time horizons should be taken when decisions as to if and how to adapt are made. Specifically, new infrastructure built within hazard zones should be designed to withstand the predicted hazards while accommodating the appropriate level of uncertainty regarding the scale of the hazard (i.e. water elevation) and the predicted time horizon when these hazards will occur (i.e. 2030 through 2060). Red text (Table 1) highlight corresponding probabilistic sea level rise predictions with those used for modeling coastal and beach hazards (scenario-based model). Because such probabilistic projections (66% and 0.5%) have not yet been integrated with predictions for storm intensity and wave height and for changes in rainfall, and future emissions scenarios are extremely uncertain, it is likely inaccurate to assume the predicted impacts have less than a 1% chance of occurrence by 2060.

Coastal Resource Goals of this Study

Coastal Resource Goals for City of Santa Cruz

The technical team worked with City Planning Staff and Coastal Commission staff to develop overarching beach resource management goals to help direct adaptation strategy identification and selection. This report documents the significant coastal resources and visitor access opportunities that are projected to be vulnerable to climate change. While all coastal visitor serving resources (i.e. access, beach area, natural habitat areas, viewshed) will be difficult to retain in the face of climate change, this adaptation strategy evaluation process will help to ensure that the City of Santa Cruz retains or enhances coastal resources where feasible and prioritized. Coastal resource goals to address sea level rise include:

1. Maintain/protect beach width where feasible.
2. Ensure sufficient city beaches along the length of the city coastline remain accessible in order to minimize increases in visitor densities on specific beaches and preserve public and private visitor serving facilities in collaboration with other agencies holding jurisdiction (e.g. Harbor District, State Parks).
3. Maintain a distribution of beach access points by encouraging a variety of multi-mode transportation along the entire city coastline.
4. Minimize coastal habitat loss and maintain ecological connectivity.
5. Address needs of underserved people of the community[2], both local residents and visitors with respect to housing, little to no cost access and recreation, day use parking, multi-mode transportation, cultural and spiritual uses, and jobs.
6. Maintain public safety on beaches and when accessing beaches.
7. Accommodate a diversity of recreational activities for a range of users.
8. Maintain and enhance water quality to the extent feasible.
9. Encourage, enhance and maintain regional sediment supply to the coast.

[2] Under-represented members of the community include those who are living with disability, advanced age, poverty, language limitations, and crime (as identified by the 2017 Social Vulnerability Assessment as well as other groups including but not limited to LGBTQ+, tribes, those living without housing and racially diverse members of our community.

Coastal Management Goals

City and Coastal Commission staff have also identified coastal management goals for coastal adaptation to SLR, including:

1. Minimize coastal armoring.
2. Reduce beach area loss from placement footprint of shoreline protection structures.
3. Prioritize living shoreline adaptations.
4. Monitor coastal access infrastructure and beach width long term and in response to extreme storm events; monitor how coastal change is impacting coastal use.

Adaptation Strategy Development

The technical team has completed a draft summary of potential engineered and policy-oriented adaptation alternatives best suited to address the identified hazards. Next steps for this planning process will include estimating the relative costs and potential mechanisms to support the implementation of a subset of preferred actions.

Inventory of Adaptation Alternatives

A number of adaptation guidance documents have been developed to help local municipalities link current and future hazards with alternative adaptation strategies. Strategies are often classified as being within one of three categories (accommodate, protect, retreat) with many methods to achieve these objectives.

Several guidance documents selected for use in this adaptation evaluation and prioritization include the Georgetown Adaptation Tool Kit (2011), the Center for Ocean Solutions Coastal California Adaptation Policy Briefs (2018), the ABAG Regional Resilience Toolkit (2019), and the California Coastal Commission Residential Adaptation Policy Guidance (2018). Each of these documents provides valuable information and useful recommendations regarding the applicability, challenges and legal and financial constraints that should be considered when selecting adaptation options.

An adaptation strategy summary table (Appendix A) includes reference to hazard response actions (accommodate, protect, retreat) and the needed policies, legal actions, programs and funding mechanisms to implement the described actions. The various actions can be used to address projected hazards. Adaptation strategies were selected from these resources that will be considered for inclusion in the three adaptation pathway alternatives for each of the beach sections identified for this project. These strategies were evaluated and individual case studies were prepared that describe the applicability of the strategy to the Santa Cruz beach-specific context and examples of this strategy being used within other coastal communities to address SLR and coastal erosion. (Appendix B). Policies, triggers, programs and funding mechanisms will be identified for the selected adaptation pathways in future project deliverables.

The case studies are intended to provide the project Technical Advisory Committee (TAC), City staff, and other stakeholders with the background information needed to engage in dynamic conversations regarding adaptation applicability and tradeoffs within each of Santa Cruz's four beach areas. Case studies of strategy implementation are intended to provide real world examples of use, cite costs, benefits, and secondary implications of these strategies, and help stakeholders and decision-makers develop preferred adaptation strategies and integrated, multi-strategy adaptation pathways that transition between current and future climate horizons.

Adaptation strategy case studies evaluated are found in Appendix B and include:

- Beach nourishment
- Living shoreline
- Groins
- Sea Walls
- Managed Retreat

These and other adaptation options will be evaluated by the TAC and City staff to address the hazards identified within each beach area. Since no single alternative will likely meet all the coastal resource goals over time, it is anticipated that various adaptation strategies will be selected for specific hazards, within specific beaches for specific time (or climate change) horizons planned and implemented when thresholds for triggers are experienced. By recognizing the secondary implications of each adaptation alternative on coastal resources and under-represented (or frontline) community groups, we intend to demonstrate how the preferred alternative adaptation strategies lead to a resilient city coastline that best meets coastal resource management and community goals.

The City TAC, Staff and stakeholders can reference these various actions to develop three alternate adaptation pathways for each beach segment. An adaptation pathway describes an incremental transition from one coastal management strategy to another as physical conditions change, time horizons are reached or engineering or cost limitations are exceeded.

Once three alternative pathways are selected for each beach area, policies and programs needed to achieve the preferred pathways will be identified. Similarly, costs and benefits of various pathways will be noted as well as impacts to coastal resources and implications to unique and under-represented communities within Santa Cruz. This iterative pathway development process can reference this document and the descriptive appendices to make the necessary difficult decisions regarding prioritization of coastal resources given resource limitations.

As sea levels continue to rise, various engineered and policy adaptation options will likely become obsolete at specific locations and alternative strategies will need to be implemented. Stakeholders, City staff and TAC members will work together to estimate when such transitions are needed and identify temporal, fiscal, environmental or policy “triggers” that will direct new adaptation actions. The team will also evaluate possible policies, programs and funding mechanisms to achieve these transitions (or pathways).

Adaptation Strategy Technical Report Development Approach

The technical team has compiled necessary information regarding beach use, access and amenities, quantified future projected impacts associated with SLR and made initial assumptions regarding special access needs of various community groups. Hazard adaptation strategies were compiled based on state guidance, prioritized based on projected hazards and case studies were drafted documenting the use of these strategies by other coastal communities. The process for developing the (draft) Adaptation and Policy Implication and Response Strategy Evaluation Technical Report is contained in Figure 1.

Visual representations of potential coastal change and various coastal adaptation strategies were developed to aid discussions among stakeholders and are shown in Appendix C. These visual depictions of shoreline resource distribution and existing and future protective infrastructure alignment help to visually display the benefits and impacts associated with various strategies.

Several alternative response strategies (i.e. adaptation pathways) were then drafted that describe a future "pathway" that describes a set of transitions from one adaptation strategy to another. Each alternative pathway prioritizes a different set of coastal resource management goals. In future deliverables, these alternatives will be used as example pathways from which to build beach specific alternatives based on local hazards, coastal resources at risk and identified beach specific resource management goals.

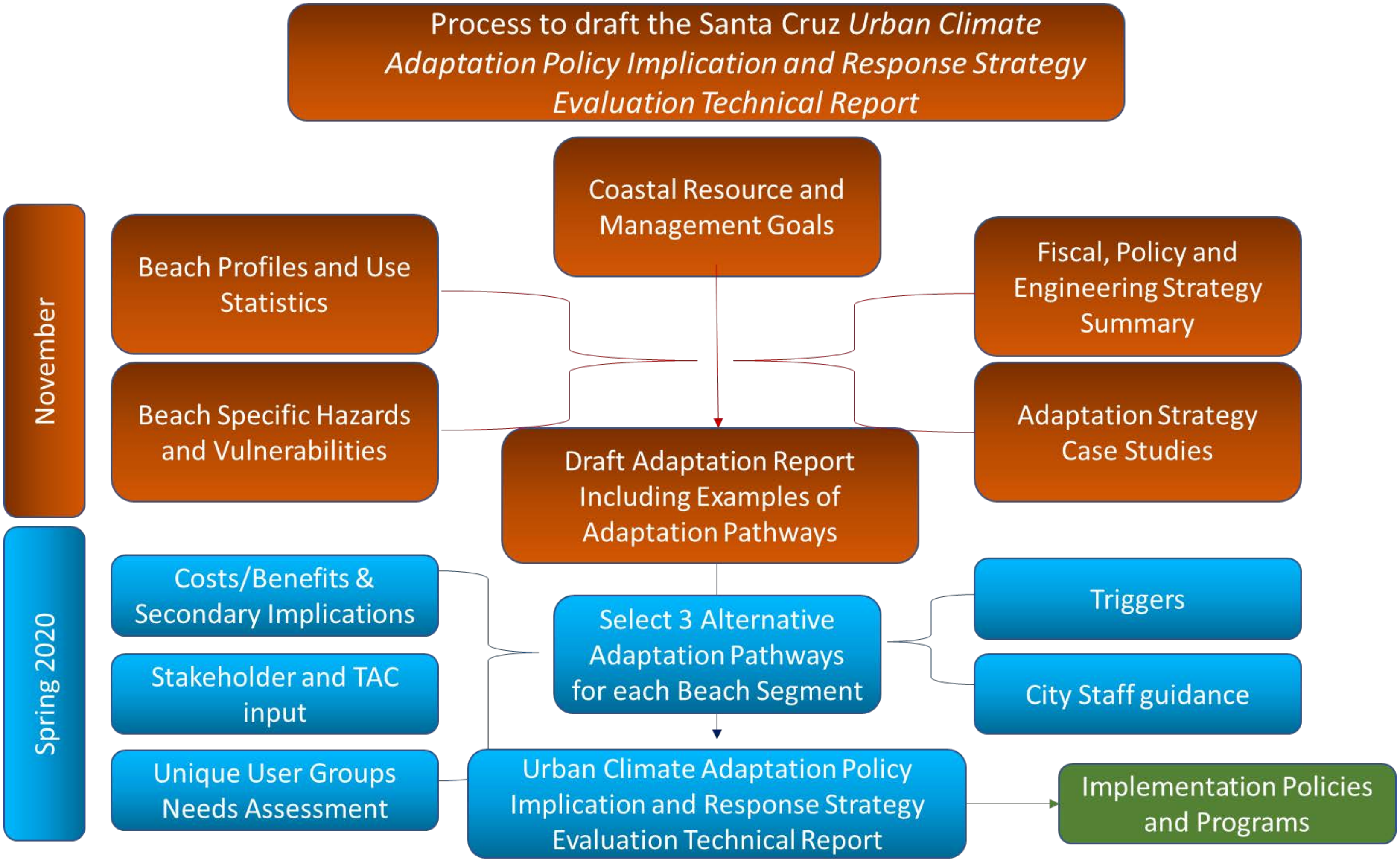


Figure 1. Diagram of process to complete the Climate Adaptation Policy Implication and Response Strategy Evaluation Technical Report

Santa Cruz Beach Segments

For this planning exercise, the City of Santa Cruz beaches have been segmented into four areas to aid planning and identify site specific strategies (Figure 2). These segments are: 1) Seabright Beach between the Santa Cruz Harbor and the San Lorenzo River, 2) Main and Cowells Beaches spanning from the San Lorenzo River to Bay Avenue, 3) pocket beaches of West Cliff, and 4) Natural Bridges State Beach. Each segment has adapted to coastal flooding and erosion differently and future hazards pose unique challenges to each of these segments.

Adaptation pathway selection may include universal policies and strategies as well as segment specific actions. Adaptation strategies defined in those pathways may also be different within segments, as needed to meet local coastal resource and management goals and regulatory requirements and respect private property rights and concerns. Background information on each beach segment is provided below to help quantify impacts, report on current visitor serving amenities and reflect use by various coastal visitor groups.

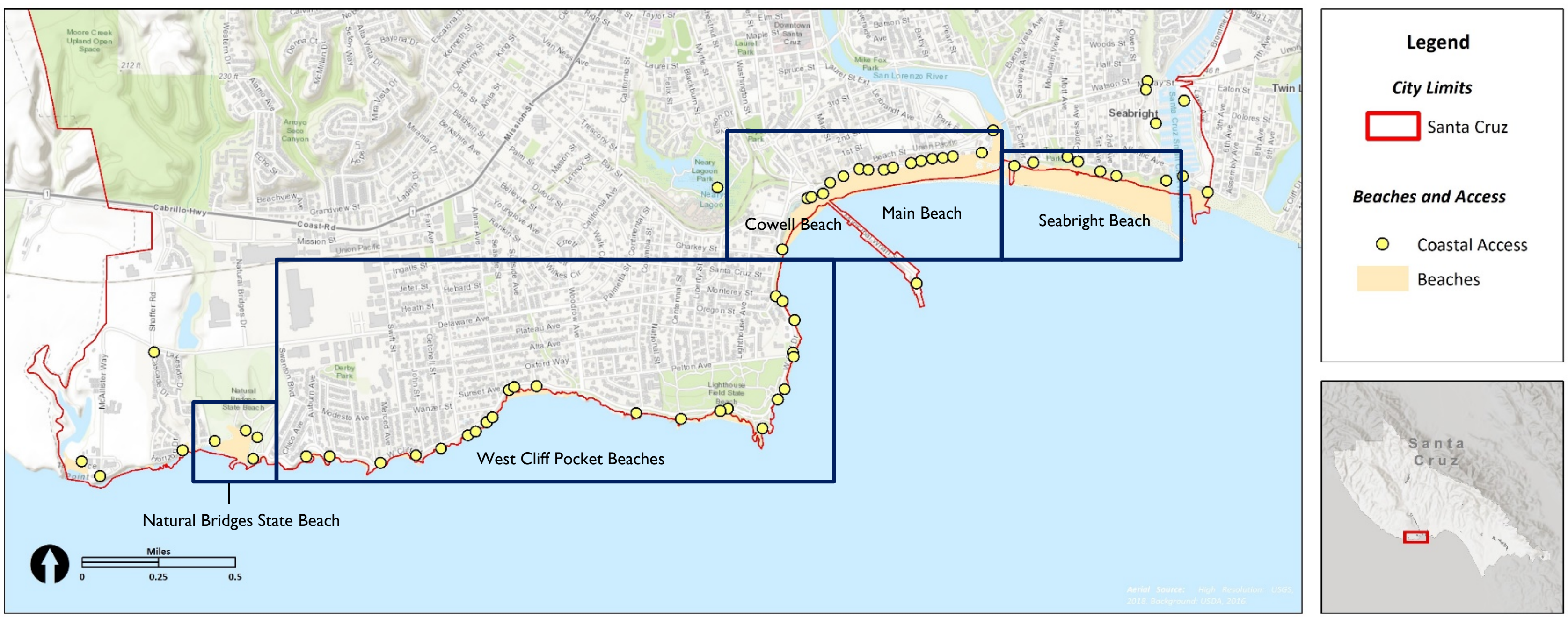
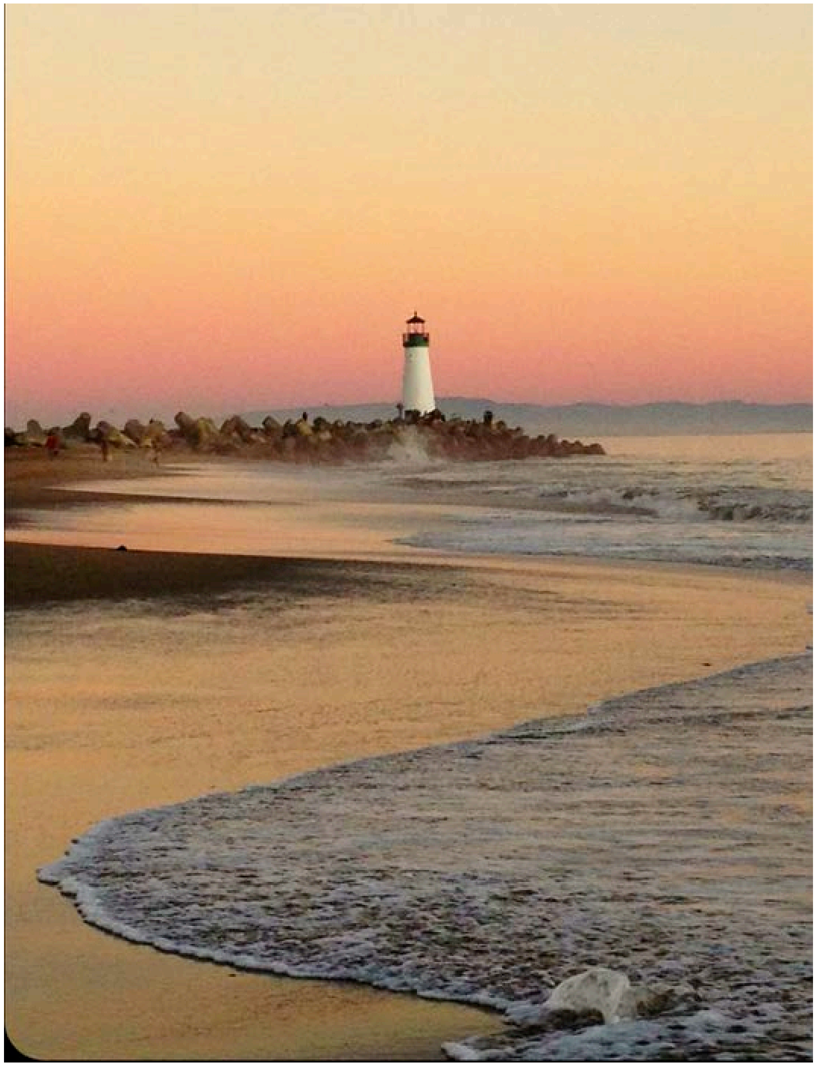


Figure 2. Beach segments included in evaluation and planning process

Seabright Beach



Description

Seabright State Beach (also known locally as Castle Beach) is part of Twin Lakes State Beach and managed by State Parks staff. It is a popular beach that spans a wide stretch of sand from the Santa Cruz Yacht Harbor entrance and West Jetty to a narrow natural rock wall that juts out into the surf at the mouth of the San Lorenzo River. At the bottom of this rock wall is a small rock arch opening that lets river water pass through. Shifting sand sometimes closes up the arch, but at times it's possible to crawl through and wade the river water to reach Main Beach. People are no longer allowed to walk the trail on top of this narrow fin, but many locals jump the fence and go out on the rock wall despite the "area closed" signs.

The Walton Lighthouse is at the end of the Santa Cruz Harbor's West jetty where a paved walking path allows residents and visitors to walk out and look back at Seabright Beach. Parking and beach access are available at the west end of East Cliff Drive near Alhambra Avenue, Mott Avenue, and at the end of 3rd Avenue.

This area has received extensive restoration, spearheaded by Groundswell Coastal Ecology beginning in 2011, to enhance back dune and jetty habitat. Most of this work has occurred on CA State Parks and Port District properties with a small portion on City of Santa Cruz land.

Amenities and Use

Seabright Beach provides a variety of coastal recreational opportunities including swimming and boogie boarding, beach picnicking and evening bonfires. Most beach access and amenities are managed by State Parks staff. The lists of amenities and uses below are compiled from the Friends of Santa Cruz State Parks website, observational surveys conducted by the City of Santa Cruz, and local knowledge of the project team.

Amenities

- Public bathrooms
- Public transit nearby
- Lifeguards (1 lifeguard tower active during summer months)
- Firepits
- Free parking in the neighborhood surrounding the beach.

Coastal Uses

- Shallow water play
- Sunbathing
- Boogie boarding
- Surfing (river mouth and jetty, sandbar dependent)
- Fishing
- Volleyball
- Dog walking
- Harbor access
- Jetty/lighthouse access
- Sunset viewing
- Walking
- Kite-flying

A site and time specific observational survey conducted by the City of Santa Cruz in the summer of 2019 helped to document the numbers of people participating in certain activities at a specific place and time (Figure 3 and Figure 4).

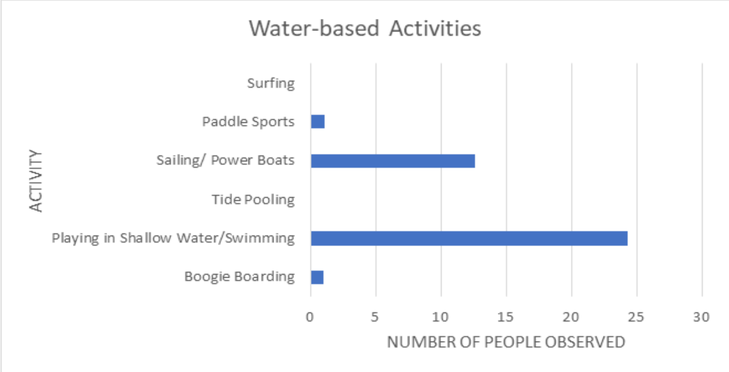


Figure 3. Average numbers of people observed participating in water-based activities at Seabright Beach.

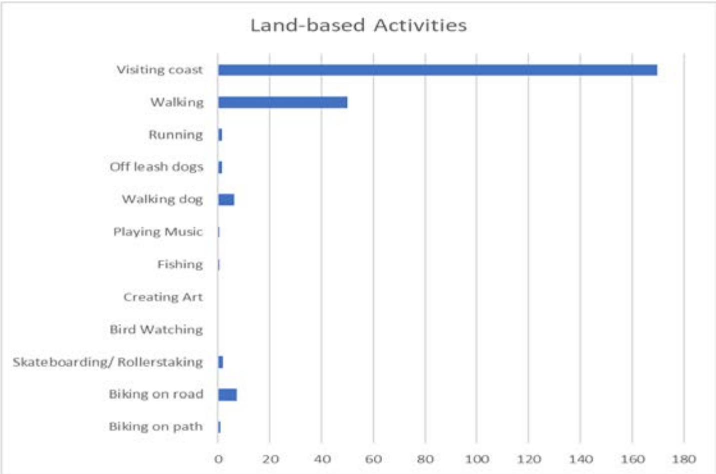


Figure 4. Average of numbers of people observed participating in land-based activities at Seabright Beach.

Coastal Hazards

Historical and Existing Condition

Prior to the construction of the jetties at the Santa Cruz Small Craft Harbor in 1963, the 2,500 foot length of Seabright Beach was very narrow, even in the summer months (Figure 5). Waves often attacked the bluffs during the winter months, and sometimes during summer high tides.

Figure 5. 1953 historical photo shows narrow beach width and bluff erosion at Seabright Beach. source: UCSC Digital Commons

The beach is backed by bluffs that are 35 to 40 feet in height consisting of Purisima Formation capped by up to 15 feet of weaker terrace deposits. Erosion rates determined from aerial photographs averaged 6 to 18 inches/yr during the decades prior to harbor construction (Griggs and Haddad, 2011). A number of private seawalls and bluff stabilization structures were constructed by private land owners prior to construction of the harbor.

The harbor jetties trapped littoral drift sands moving down coast beginning in 1963 and Seabright Beach gradually widened. Over the next 20 years, beach width reached 300 feet at the west end near San Lorenzo Point and about 600 feet next to the jetty. With this wide sandy buffer, wave attack and erosion of the bluff has been reduced significantly. Bluff failure at the west end of Seabright Beach occurred during the Loma Prieta earthquake.

Depending upon the rate and magnitude of future SLR, Seabright Beach will gradually narrow and the waves will again reach the base of the bluffs in the winter and erosion will begin again. The lowest elevation along this stretch of coastline is at the main access path to Seabright Beach at the end of Cypress Avenue. High tides and storm waves do occasionally wash this far inland, carrying logs and other debris.

Habitat restoration efforts that include native plantings have been incredibly effective at improving coastal dune habitat condition adjacent to the Seabright Beach entrance (Pilkington Creek) and adjacent to the harbor jetty.

Projected Coastal Hazard Maps

The projected hazard zones for rising tides, coastal storm flooding, and bluff erosion can be found in Figure 6, Figure 7 and Figure 8 below.

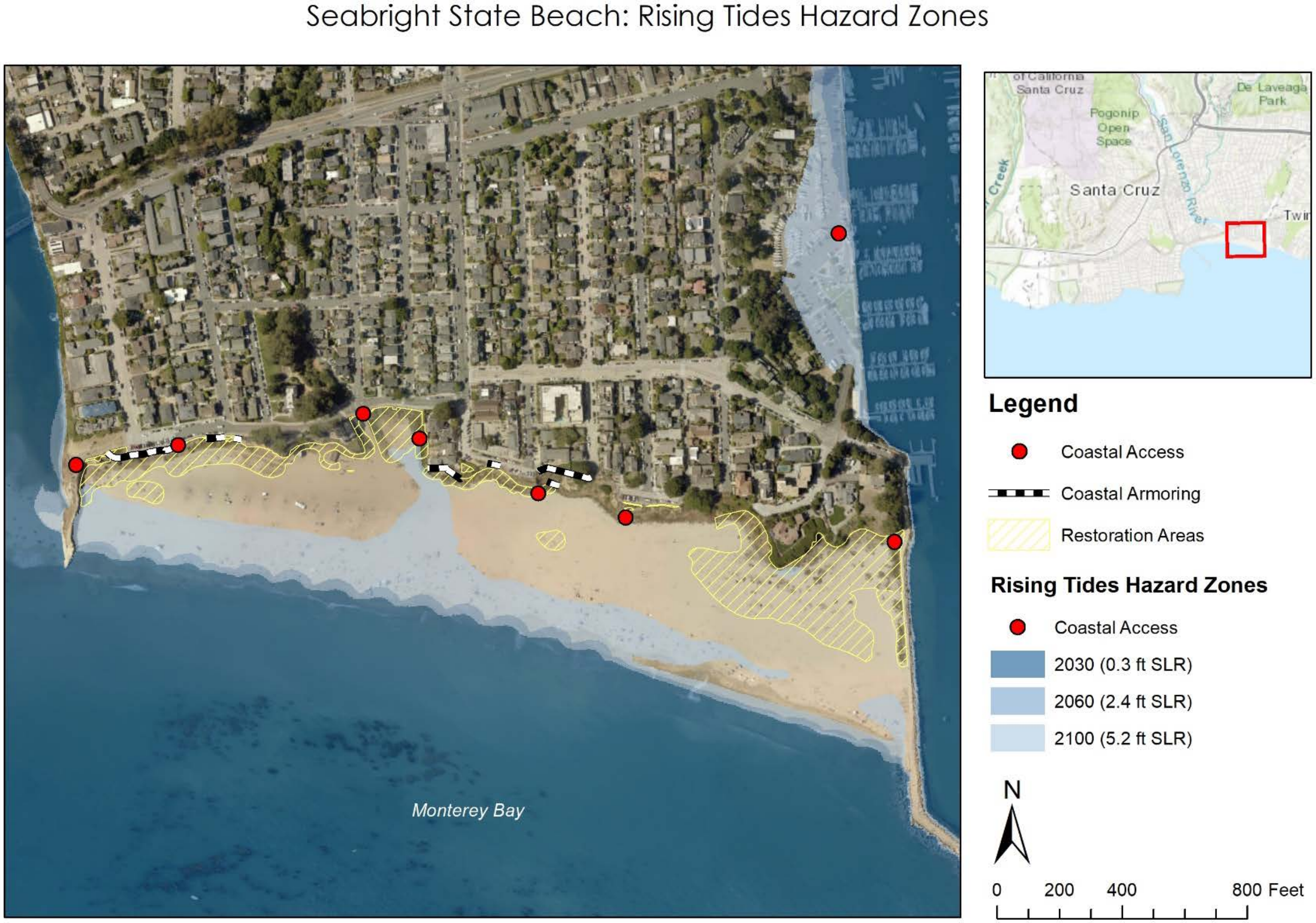


Figure 6. Rising tides hazard zones at Seabright Beach for time horizons 2030 (0.3 ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR).

Seabright State Beach: Coastal Storm Flooding Hazard Zones

Figure 7. Coastal storm flooding hazard zones at Seabright Beach for time horizons 2030 (0.3 ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR).

Seabright State Beach: Erosion Hazard Zones

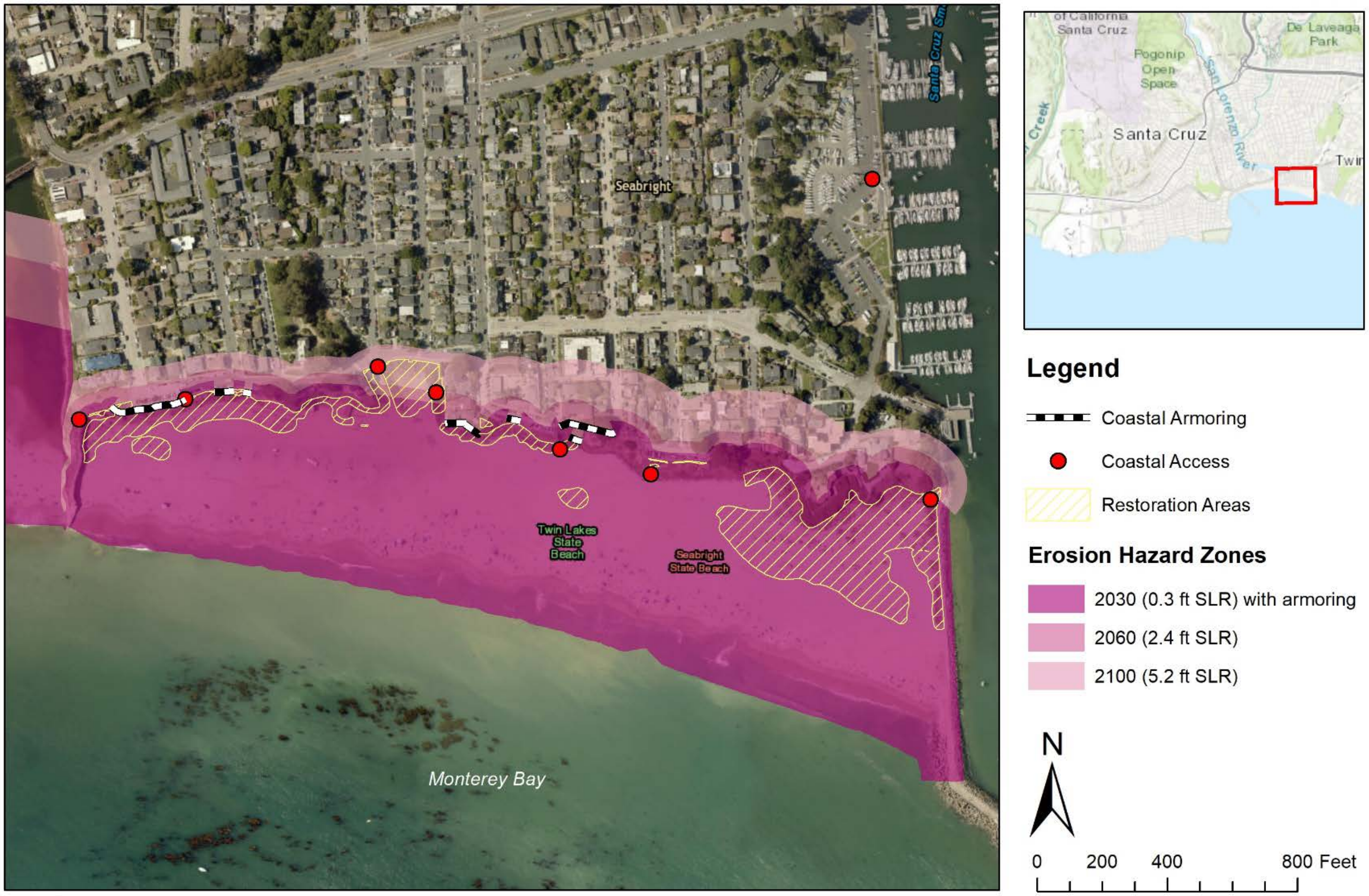


Figure 8. Coastal erosion hazard zones at Seabright Beach for time horizons 2030 (0.3 ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR). Existing armoring is accounted for (restricting erosion) through 2030 but assumed to fail to restrict erosion past that time horizon.

Projected Coastal Impacts

- Coastal Storm Flooding (CF): By 2030 all of beach may be inundated during large storm events.
- Rising Tides (RT): By 2030 the beach may be reduced by 10%, and by 2100 the beach may be reduced by 30-50%.
- Bluff Erosion (ER): Bluff erosion may impact coastal access ways and back beach dune habitat by 2030 and roadways and private homes by 2060. Aging storm drains may exacerbate bluff erosion during discharge events.

A summary of assets that are projected to be impacted by future coastal hazards is shown in Table 2.

Table 2. Assets projected to be impacted by coastal hazards at Seabright Beach.

Severity characterized as Low-short term impacts with minimal rebuild required, Moderate-some infrastructure replacement required, High- significant impact to infrastructure requiring significant replacement.

Asset	Hazard	Time horizon	Severity
Access Ways	CF ER	2030 2030	Low Moderate
Bathroom	CF	2030	Low
Fire Pits	CF	2030	Low
Habitat	ER CF	2030 2030	Moderate Low
Volleyball	CF	2030	Low

Problem Statement

Seabright beach is the widest beach within the City of Santa Cruz because sand accumulates behind the Santa Cruz Harbor Jetty. Winter waves are predicted to impact the bluff face leading to bluff erosion and potential loss of adjacent habitat, sidewalks, roadway, homes and the remaining portions of East Cliff Dr and sidewalk. Management decisions regarding how to retain certain levels of access will need to prioritize the protection of private property and coastal access (auto, bike, pedestrian and parking). New bluff protective structures may be needed to protect portions of East Cliff (Seabright) where no structures currently exist or alternative adaptations strategies that prioritize beach resources may require revisions to inland infrastructure alignment. By defining structural (Management) and non-structural (Resource) goals, adaptation alternatives can be evaluated to select preferred alternatives.

Management & Resource Goals

Future coastal bluff erosion will place the road and homes at risk and may require upgrades or new sea wall construction if protection is a preferred adaptation response. Where protective measures are inappropriate, actions can be selected that achieve identified resource goals. Seabright specific resource and management goals defined by the city include:

- To the extent possible, work to maintain existing beach width; but at a minimum, retain pre-harbor beach width through 2100.
- Maintain and enhance native back beach vegetation.
- Focus on living shoreline adaptations.

- Retain or enhance beach amenities including restrooms and fire pits.
- Establish 2100 beach management goals and bluff erosion strategies.
- Work with the Harbor District on dredge management and jetty maintenance and ensure that coastal adaptation strategies and harbor adaptation strategies are integrated.
- Address storm drainage issues causing bluff erosion.
- Retain lateral coastal access along blufftop for multi modal transportation where beach sand can be considered as a secondary access.

Adaptation Strategies

Based on an initial evaluation of predicted hazards at Seabright Beach and the various adaptation options available to address predicted wave induced flooding and erosion, a number of adaptation strategies have been identified (Figure 9). Descriptions of each strategy begin on page 44.

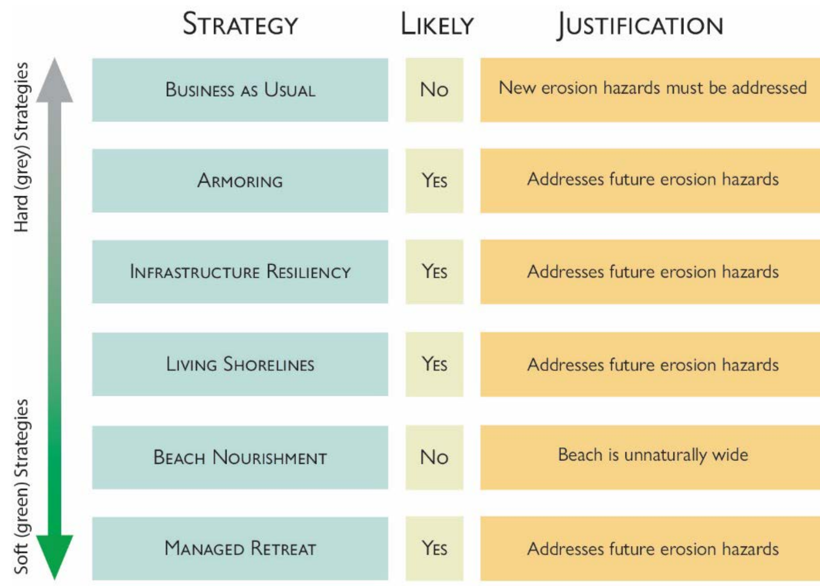
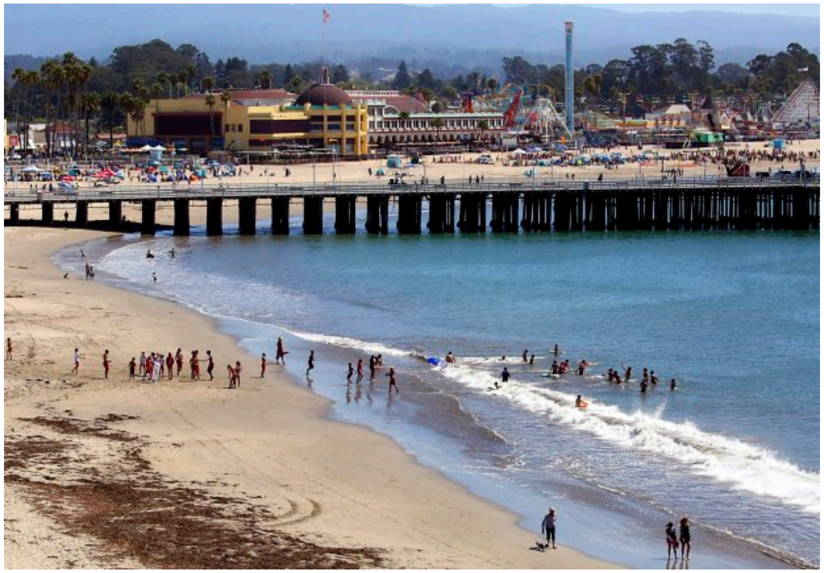


Figure 9. Potential Adaptation Options for Seabright Beach

Main Beach and Cowell Beach



Description

Cowell Beach is located west of the Municipal Wharf pier. The Dream Inn is located behind Cowell Beach. Surfing is popular at Cowell Beach when conditions are right – it's known as a beginner's wave. Persistent water quality problems are reported at Cowell.

On the other side of the pier is the larger more popular Santa Cruz Main Beach. Main Beach is known as Boardwalk Beach because of the amusement park that spans the length of this beach. Main Beach is a south-facing beach that stretches from the mouth of the San Lorenzo River to the Santa Cruz Municipal Wharf wooden pier. Volleyball is popular here and there are many sand courts available. This large beach gets quite crowded with tourists and locals on sunny days. The shops and attractions along Beach Street and the Santa Cruz Boardwalk are a popular place for tourists to visit. Lifeguards are commonly on hand at Main Beach making it a safer place for families to play in the waves. Parking is available on the streets nearby and on the Santa Cruz Wharf.

The San Lorenzo River mouth has a sand bar that periodically closes the river mouth and creates a lagoon at the east end of the beach where a narrow rock fin wall extends into the surf.

Little restoration activity has occurred on Main Beach despite ample open space. The city recently installed a small bioswale near the Cowell's Beach Parking Lot and an unknown entity planted coastal species adjacent to the east side of the Dream Inn foundation.

Amenities and Use

Main and Cowell beaches provide a variety of coastal recreational opportunities including swimming and surfing, beach picnicking and other water sports, and a summer junior guards' program. These beaches are also a primary tourist destination and visitors often enjoy the Wharf and Beach Street businesses. Evening concerts and beach movies occur throughout the summer months in from of the Boardwalk. The lists of amenities and uses below are compiled from the City of Santa Cruz website, observational surveys conducted by the City of Santa Cruz, and local knowledge of the project team.

Amenities

- Public bathrooms
- Public transit nearby
- Lifeguards
- Beach and water sport rentals
- 16 Volleyball Courts

Coastal Use

- Surfing and surf schools (Cowell Beach)
- Volleyball
- Boardwalk and arcade
- Boogie boarding
- Sunbathing
- Shallow water play
- Art

A site and time specific observational survey conducted by the City of Santa Cruz in the summer of 2019 helped to document the numbers of people participating in certain activities at a specific place and time (Figure 10 and Figure 11).

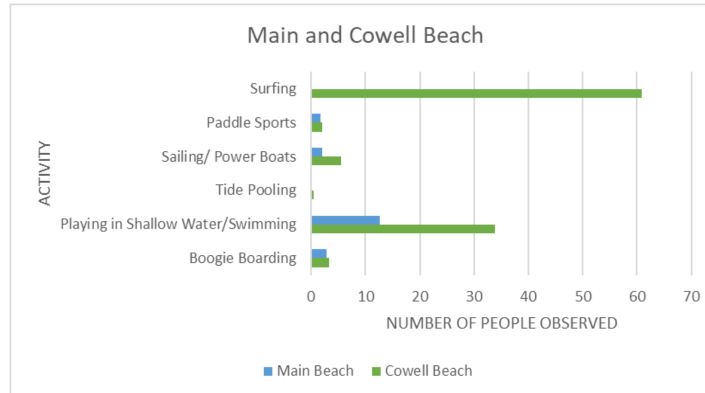


Figure 10. Average numbers of people observed participating in water-based activities at Main Beach and Cowell Beach

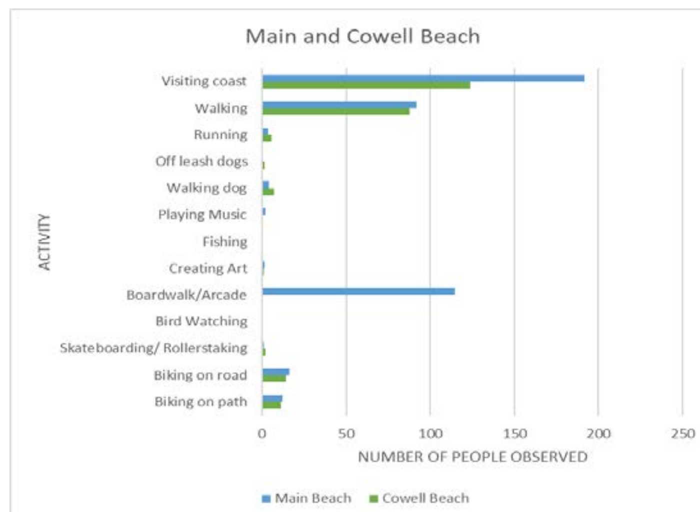


Figure 11. Average numbers of people observed participating in land-based activities at Main Beach and Cowell Beach

Coastal Hazards

Historical and Existing Condition

The entire 3,700 feet of shoreline from the Dream Inn to the San Lorenzo River mouth, including the Boardwalk, has been protected for decades with a low concrete support wall. The top of the wall is at an elevation of about 14 feet; so while the beach itself will gradually narrow as sea level rises in the decades ahead, erosion risk is lessened because of the presence of the boardwalk concrete support wall. A significant change in the storm wave climate and the rate of sea level rise could lead to the overtopping of these walls (Griggs and Haddad, 2011).

Figure 12. Severe storm went through Santa Cruz, causing flooding. February 13, 1926. Source: SF Chronicle

Several times a year, a sand bar builds at the mouth of the San Lorenzo River, creating a lagoon that pools water in front of the Boardwalk, threatening the historic site (Figure 13).

Figure 13. Flooding in front of the boardwalk due to large winter storm in 2012. Source: Santa Cruz Sentinel, Dan Coyro.

Projected Coastal Hazards

The projected coastal hazard zones at Main and Cowell Beaches for rising tides, coastal storm flooding, and bluff erosion can be found in Figure 14, Figure 15, and Figure 16 below.

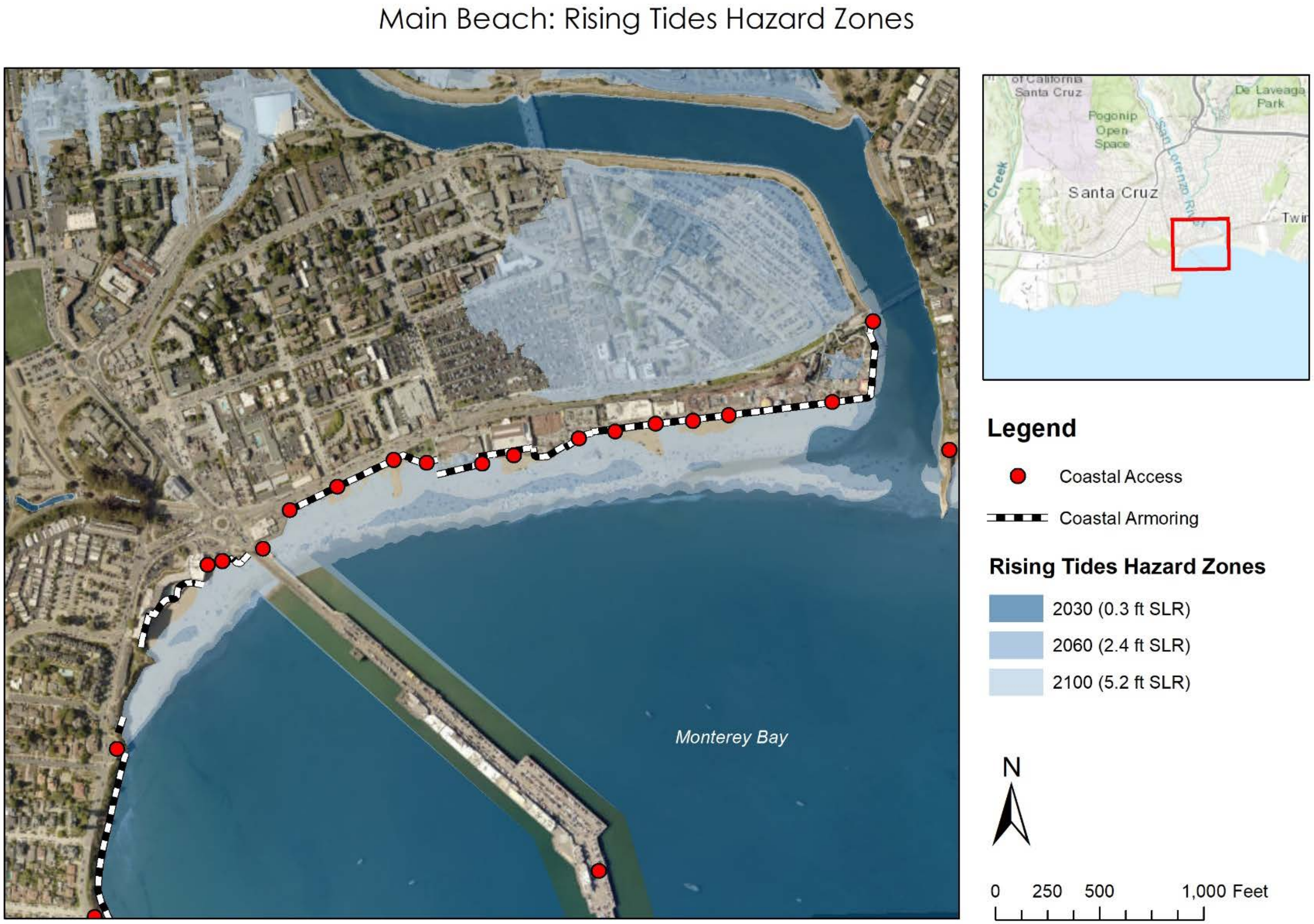


Figure 14. Rising Tides hazard zones at Main and Cowell Beaches for time horizons 2030 (.3 ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR).

Main Beach: Coastal Storm Flooding Hazard Zones

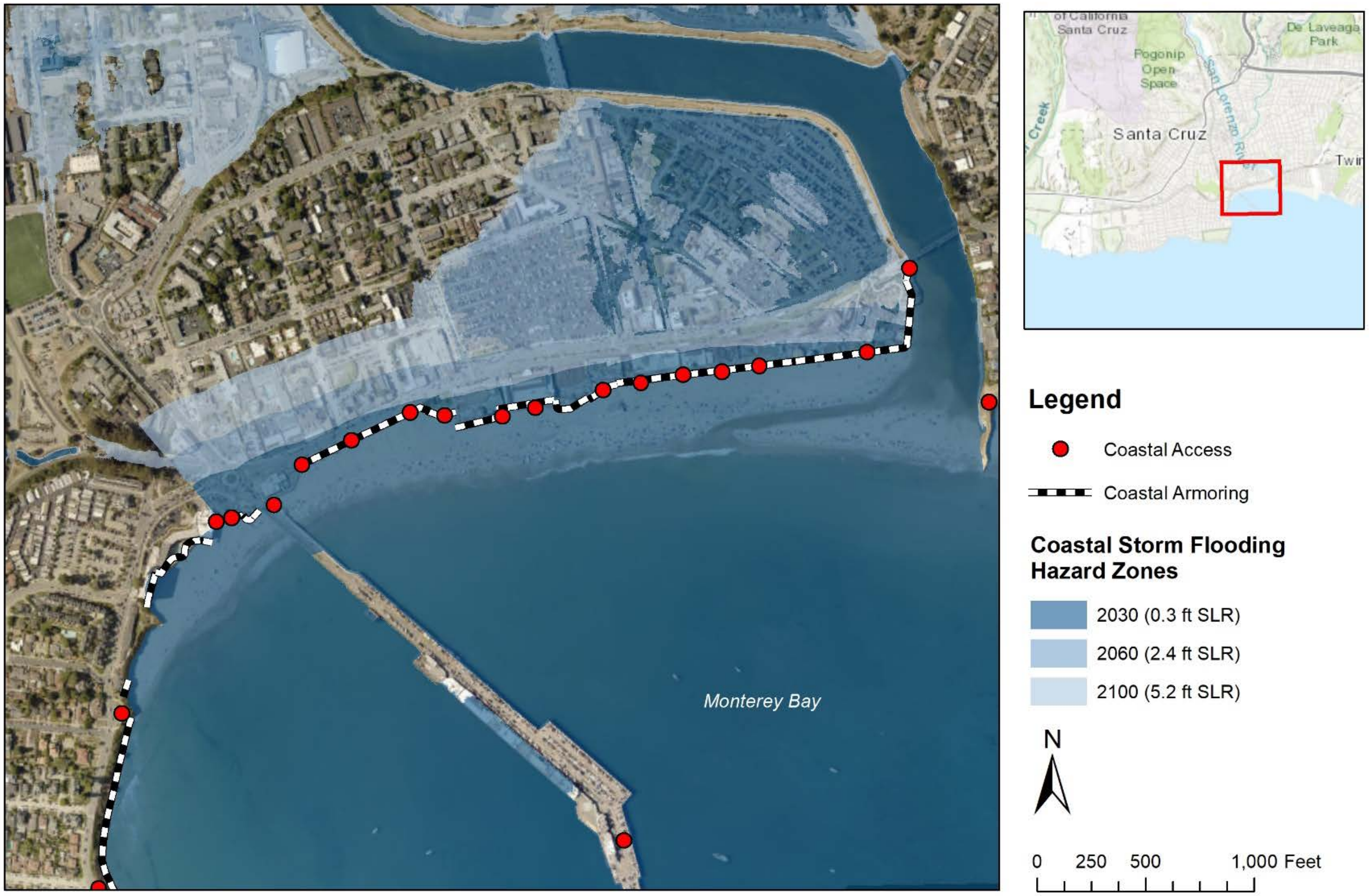


Figure 15. Coastal storm flooding hazard zones at Main and Cowell Beaches for time horizons 2030 (.3 ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR).

Main Beach: Erosion Hazard Zones

Figure 16. Coastal erosion hazard zones at Main and Cowell Beaches for time horizons 2030 (.3 ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR). Existing armoring is accounted for (restricting erosion) through 2030 but assumed to fail to restrict erosion past that time horizon.

Projected Coastal Impacts

- Coastal Storm Flooding (CF): By 2030 all of the beach is projected to be inundated during large storm events.
- Rising Tides (RT): By 2030 the beach may be reduced by 5%, by 2060 it may be reduced by 30%-50%, and by 2100 most of beach is projected to be inundated during high tides.
- Bluff Erosion (ER): Erosion is projected to begin impacting the beach, coastal access ways, and amenities as early as 2030.
- A summary of assets that are projected to be impacted by future coastal hazards is shown in Table 3.

Problem Statement

Storm flooding is predicted to impact low lying areas including the Beach Flats community as higher waves overtop the coastal infrastructure on Beach Street. Wave impacts to adjacent buildings and flooding of low lying areas is anticipated to increase over time as sea level rises and storm intensity increases. Loss of beach infrastructure (volleyball courts, access ramps to boardwalks) is likely to become more frequent.

Table 3. Assets projected to be impacted by coastal hazards at Main and Cowell Beaches.

Severity characterized as Low-short term impacts with minimal rebuild required, Moderate-some infrastructure replacement required, High- significant impact to infrastructure requiring significant replacement.

Asset	Hazard	Time Horizon	Severity
Access Ways	CF RT ER	2030 2100 2030	Low Moderate Moderate
Bathroom	CF ER	2030 2060	Low Moderate
Volleyball courts	CF RT ER	2030 2100 2030	Low Moderate Low
Wharf entry	CF RT ER	2030 2100 2060	Moderate Moderate Severe
Boardwalk	CF ER	2030 2060	Moderate Severe
Habitat (San Lorenzo River Mouth)	CF RT ER	2030 2030 2060	Low Moderate Low

Management and Resource Goals

Coastal Storm impacts will place Beach Street, historic and cultural landmarks, and adjacent businesses and homes at risk of flooding. Flood management and wave protection may require upgrades or construction (e.g., horizontal levee, pumps) if protection is a preferred adaptation response. Beach resource and management goals include:

- To the extent possible, work to maintain existing beach width but at a minimum, retain pre-harbor beach width through 2100
- Ensure risks to residents and visitor serving businesses are considered when developing adaptation alternatives.
- Maintain diverse recreational opportunities (picnics, beach volleyball, surfing, kayaks, etc.) at Main and Cowells beaches for visitors of all socioeconomic levels.
- Retain easy access via multimodal transportation to the coast for use by residents and visitors of all socioeconomic levels to beaches, wharf and boardwalk.
- Maintain and, where feasible, improve flood protection infrastructure, e.g., pumps, levee and river mouth culvert, within Beach Flats and lower Ocean Street to safeguard residents, visitors, and assets.
- Retain safe access to the extent possible to the wharf and beaches through upgrades to access infrastructure by increasing their resiliency to winter storm events.
- Maintain structure of Santa Cruz Wharf as an important means of coastal access.
- Ensure river and beach management are coordinated.

Adaptation Strategies

Based on an initial evaluation of predicted hazards at Cowell and Main Beaches and the various adaptation options available to address predicted wave flooding and erosion, the options listed in Figure 17 should be considered for adaptation options. Descriptions of each strategy begin on page 44.

Figure 17. Potential Adaptation Options for Main and Cowell Beaches

West Cliff Pocket Beaches

Description

Santa Cruz's west side coastline is studded with a number of small to mid-size beaches distributed along the 2.7miles of coastline. Beaches of note include from large to small, Its (Lighthouse) Beach, Mitchell's Cove, several smaller beaches between Fair and Swift streets, and Pyramid Beach close to Natural Bridges (Figure 18).

Its Beach is a south-facing beach below the bluff on the west side of Lighthouse Field. State Parks manages the beach and the adjacent open space park across West Cliff Drive from the beach. Stairs at Its Beach and Mitchell's Cove provide easy access to the beach and are frequented by boogie boarders and dog owners.

Restoration opportunities within the pocket beaches along West Cliff are somewhat limited due to intense winter swell. However, small restoration projects have been implemented along the first terrace of the bluff on several locations along West Cliff.

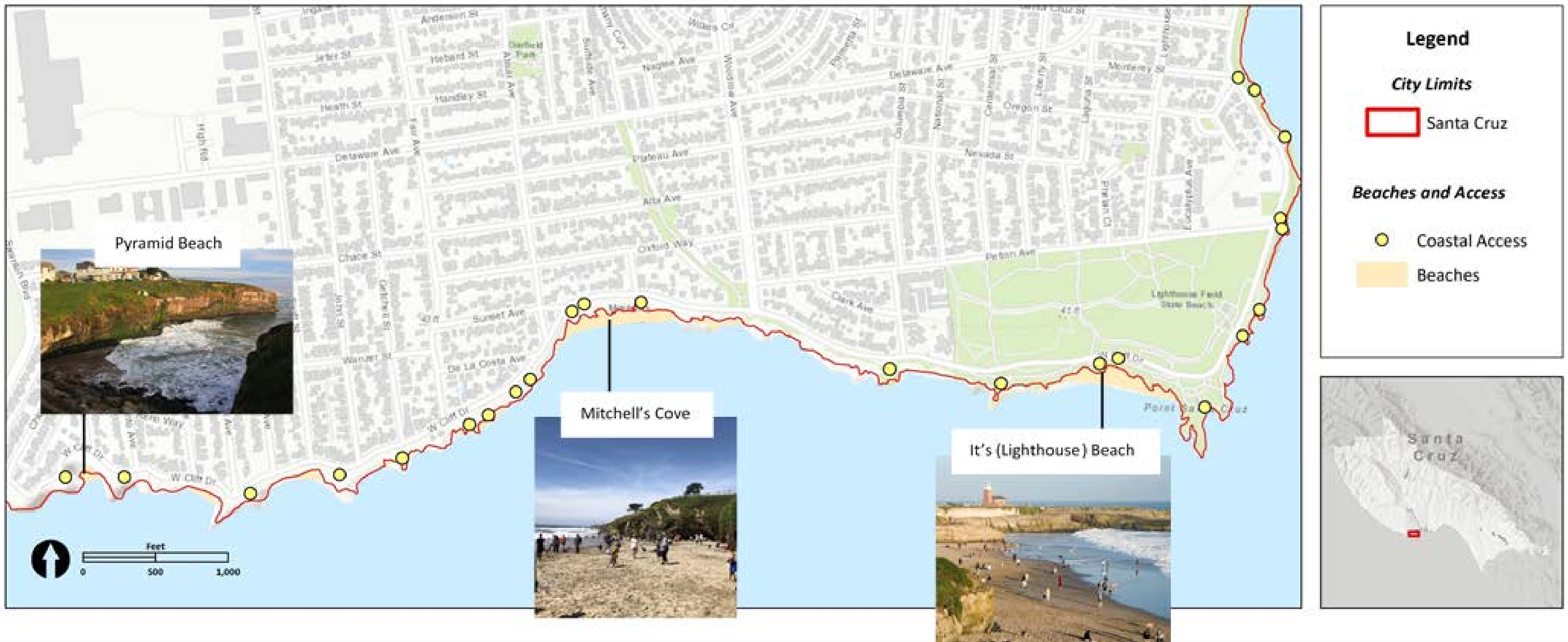


Figure 18. Popular pocket beaches along West Cliff Drive

Amenities and Use

The lists of amenities and uses below are compiled from the City of Santa Cruz website, observational surveys conducted by the City of Santa Cruz, and local knowledge of the project team.

Amenities

- Overlooks
- Walking/Bike path
- Benches

Coastal Use

- Tide pooling
- Fishing
- Art
- Dog walking
- Off leash dog
- Surfing
- Walking
- Sunset viewing
- Boogie Boarding

A site and time specific observational survey conducted by the City of Santa Cruz at Its Beach during the summer of 2019 helped to document the numbers of people participating in certain activities at a specific place and time (Figure 19 and Figure 20).

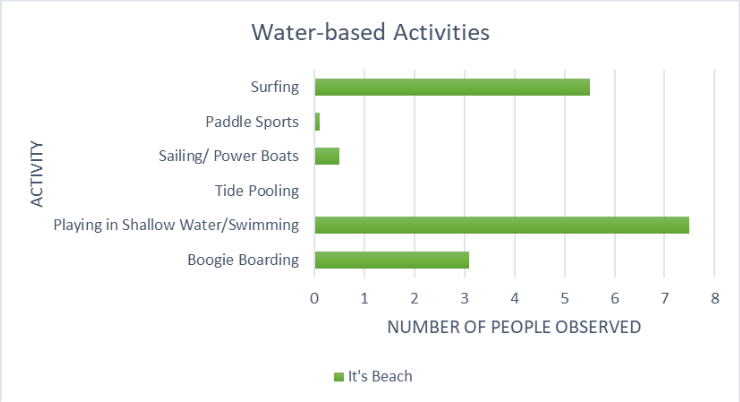


Figure 19. Average numbers of people observed participating in water-based activities at Its Beach

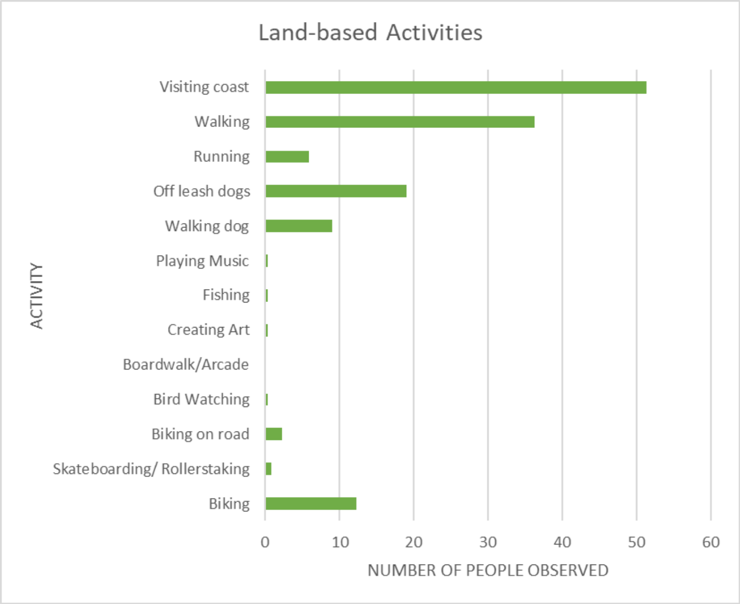


Figure 20. Average numbers of people observed participating in land-based activities at Its Beach

Coastal Hazards

Historical and Existing Condition

The coastline extending along West Cliff Drive consists primarily of 25 to 40-foot high bluffs that front an uplifted marine terrace. The bluff backed coastline is broken up by small pocket beaches, with Its (Lighthouse) Beach and Mitchell's Cove being the largest and most intensively used. Many of the smaller pocket beaches are backed by riprap so that as sea level continues to rise, these narrow beaches will gradually narrow even further (Griggs and Haddad, 2011).

Its Beach is the most intensively used beach along West Cliff during the summer months. During the winter, storm waves lower the beach sand level and attack the bluffs at high tides. Monitoring of Its Beach during the 1997-98 El Niño documented that the 150-foot wide beach present in October was completely eroded by February and the sand had dropped about eight feet in elevation (Griggs and Haddad, 2011), demonstrating the dynamic fluctuations in beach width and elevation. There is no armor backing the beach so as sea level has risen historically, the bluffs have gradually retreated, but a narrow and heavily used beach has persisted. Overall, the low bluffs have changed very little over the past century. An increasing sea level rise will progressively narrow the summer beach and lead to more frequent and severe winter wave attack, which even now overtops the bluff (Griggs and Haddad, 2011).

Projected Coastal Hazards

The projected hazard zones for West Cliff pocket beaches for rising tides, coastal storm flooding and bluff erosion can be found in Figure 21, Figure 22, and Figure 23 below.

Projected Impacts of Focus for this Report

- Coastal Storm Flooding (CF): By 2030 all pocket beaches are projected to be inundated during large storm events
- Rising Tides (RT): Between 2010 and 2060 pocket beaches around West Cliff are projected to be reduced up to 30%
- Bluff Erosion (ER): Erosion is projected to impact coastal access way, Lighthouse Point, and bluff habitat by 2030.
- A summary of assets that are projected to be impacted by future coastal hazards is shown in Table 4.

Table 4. Assets projected to be impacted by coastal hazards at West Cliff pocket beaches.

Severity characterized as Low-short term impacts with minimal rebuild required, Moderate-some infrastructure replacement required, High- significant impact to infrastructure requiring significant replacement.

Asset	Hazard	Time Horizon	Severity
Access ways	ER	2030	Moderate
Bird nesting habitat	CF ER	2030 2030	Moderate Moderate
Intertidal habitat	RT	2060	Low
Lighthouse Point	ER	2030	Severe

Problem Statement

Most of the pocket beaches along West Cliff have been lost due to the deposit of riprap to protect West Cliff Dr. Its Beach and Mitchell's Cove are the two largest "pocket beaches." Pyramid beach and the smaller pocket beaches at the end of Swift Street are projected to be lost by 2030 due to sea level rise interacting with coastal armoring. By 2060 all pocket beaches will be lost except for Mitchell's and Its Beach, which will retain some of their beach area.

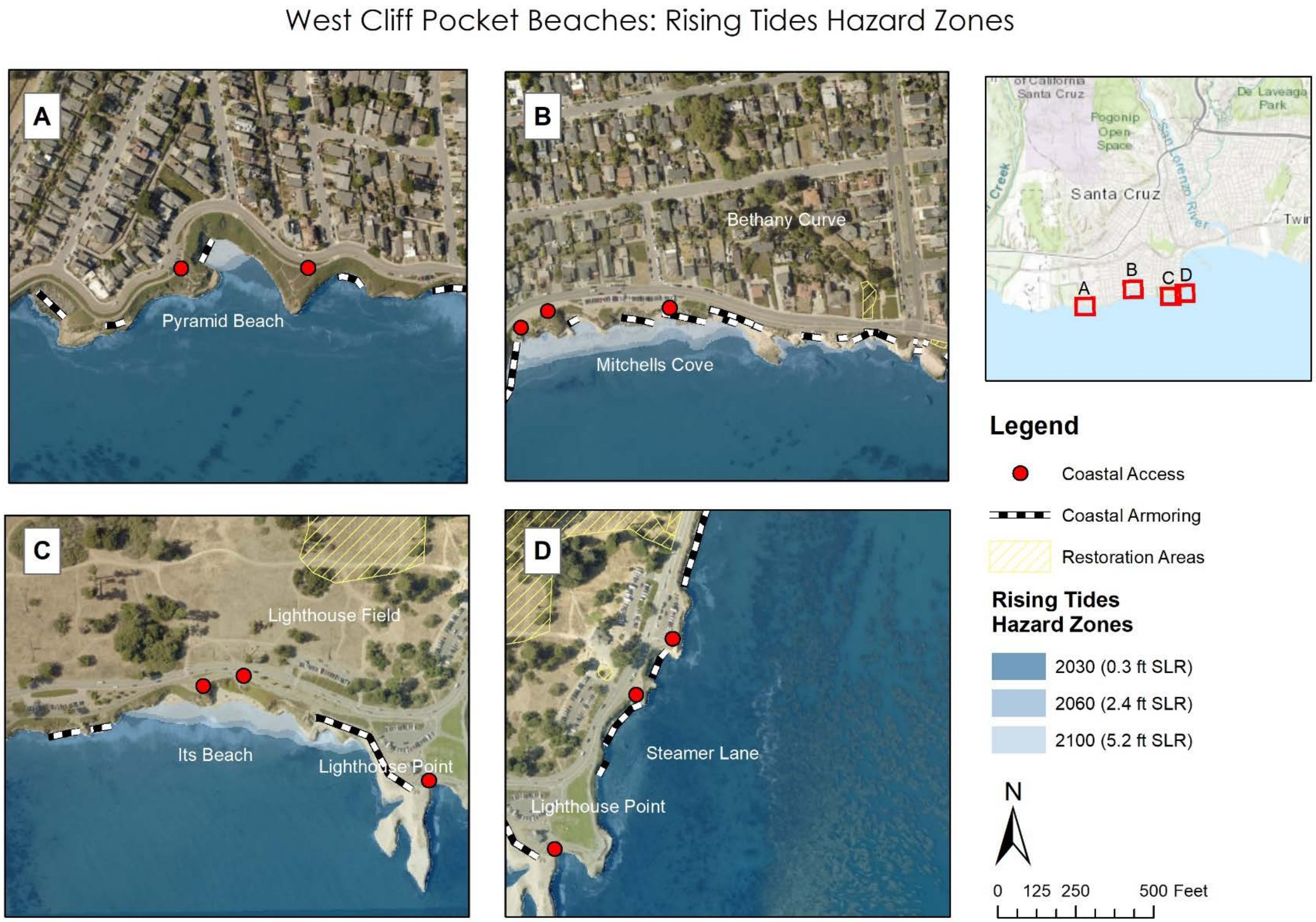


Figure 21. Rising Tides hazard zones at along West Cliff pocket beaches for time horizons 2030 (.3 ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR).

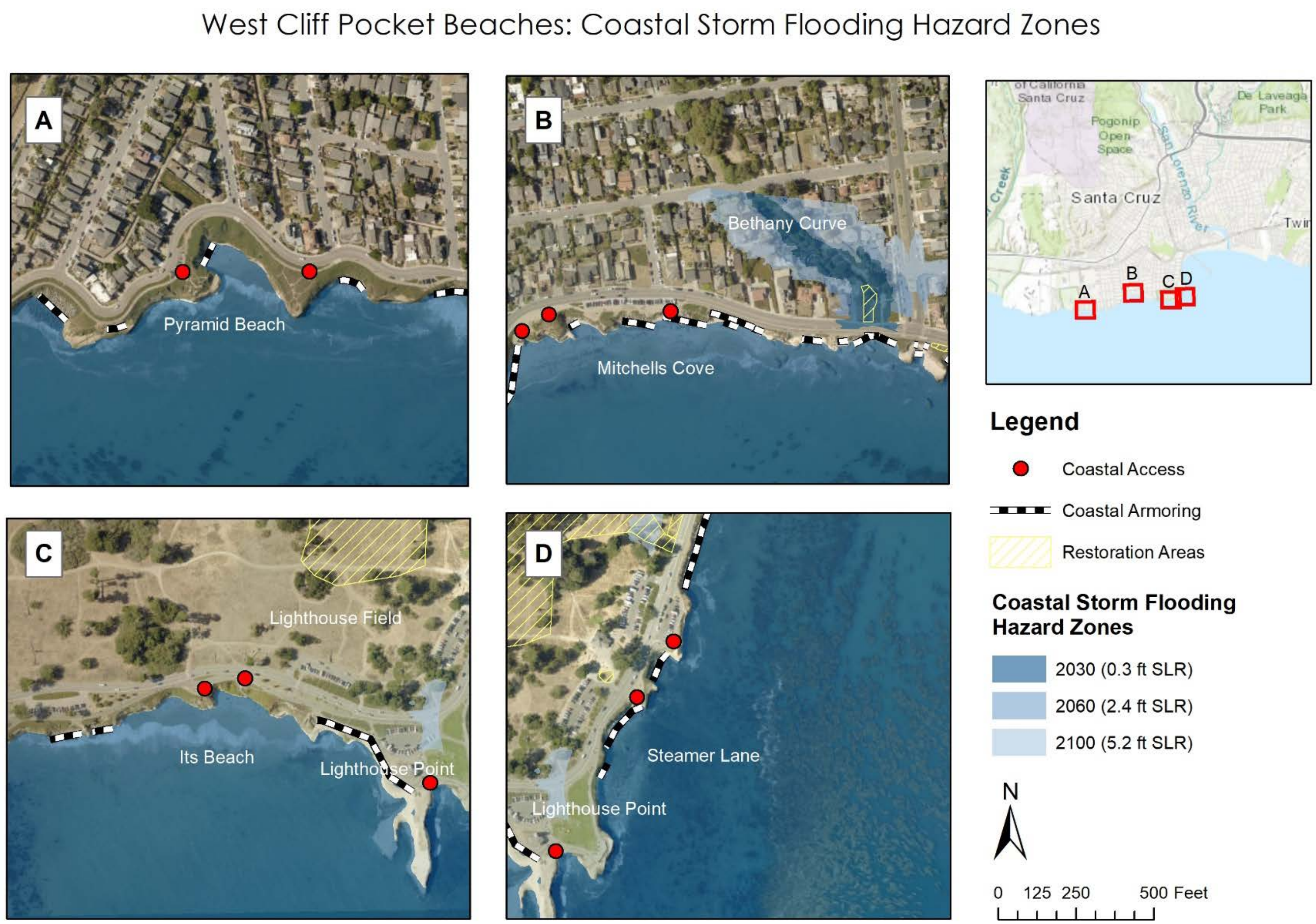


Figure 22. Coastal storm flooding hazard zones along West Cliff pocket beaches for time horizons 2030 (.3 ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR).

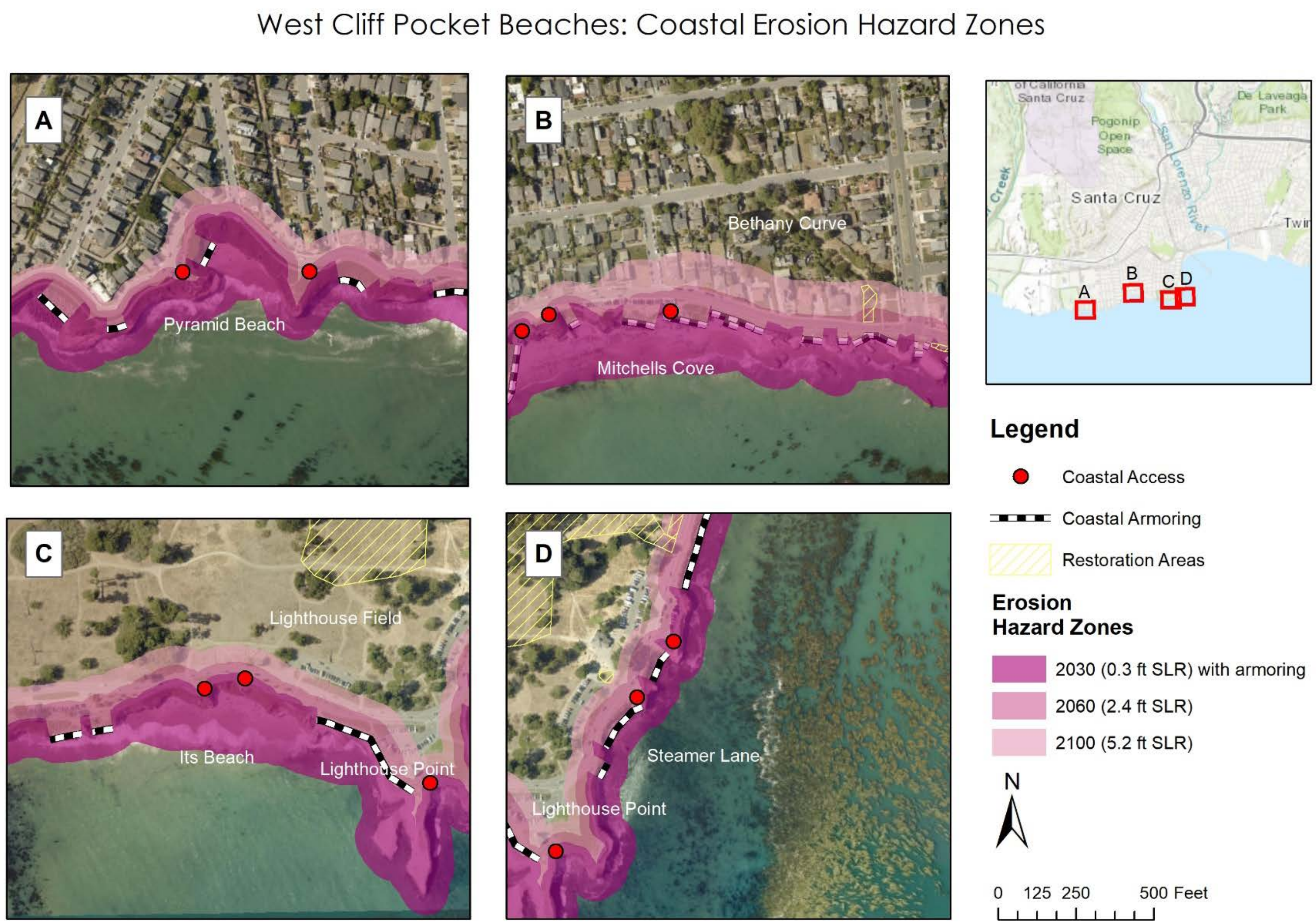


Figure 23. Coastal erosion hazard zones along West Cliff pocket beaches for time horizons 2030 (.3 ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR). Existing armoring is accounted for (restricting erosion) through 2030 but assumed to fail to restrict erosion past that time horizon.

Management and Resource Goals

The pocket beaches (including Its Beach and Mitchell's Cove) are vulnerable to significant loss of area due to SLR as early as 2030. Bluff failure may require upgrades or construction of shoreline protection devices if selected as a preferred adaptation response. Adaptation options outlined within the West Cliff planning effort may support retention/enhancement of select pocket beaches (managed retreat, removal or enhancement of riprap, upgrades to sea walls, and sand nourishment with geologic groin extensions). Goals selected for this beach segment include:

- To the extent possible, retain access to some pocket beaches including Lighthouse and Mitchell's Cove through 2100.
- Manage public safety (on beach and bluff) with respect to bluff failure and access ways
- Retain level of multi modal beach access adjacent to priority pocket beaches.
- Identify options for continued access along the coast even where beaches are lost (through blufftop trails, parks, etc. and/or access features along seawalls).

Adaptation Strategies

Based on an initial evaluation of predicted hazards at West Cliff pocket beaches and the various adaptation options available to address predicted wave flooding and erosion, the options listed below in Figure 24 should be considered for adaptation options. Descriptions of each strategy begin on page 44.

Hard (grey) Strategies

Strategy	Likely	Justification
Business as Usual	Yes	Addresses future erosion hazards
Armoring	Yes	Addresses future erosion hazards
Infrastructure Resiliency	Yes	Addresses limited/unsafe access
Living Shorelines	No	Limited space and unlikely effective in high energy area
Beach Nourishment	Yes	Increases beach area and provides additional littoral resources
Managed Retreat	Yes	Addresses future erosion hazards

Soft (green) Strategies

Figure 24. Potential Adaptation Options for West Cliff pocket beaches

Natural Bridges

Description

Natural Bridges State Beach is a 65-acre California State Park. The Park features a natural bridge across a section of the beach. It is also well known as a hotspot to see monarch butterfly migrations. The State Beach is open to year-round recreation including swimming, surfing, hiking, nature walks and picnics. The beach is small and sheltered. The afternoon winds attract kite flying and wind surfing. The beach is open to surfing and is busiest during the winter when large swells wash up onto the shores of Natural Bridges State Beach.

Hiking trails pass through the Moore Creek estuary and the Monarch Butterfly Nature Preserve.

Motor access to the beach is at the end of West Cliff Dr. with road traversing the eastern bluff before meandering through the park to the parking area north of the beach. Secondary access for parks staff is available from Delaware and is far from projected hazard areas.

State Parks has drafted a management plan for Natural Bridges that addresses flooding and beach erosion and outlines habitat restoration activities prioritized for this beach. Habitat restoration has occurred near the entrance to the park, replacing ice plant and other non-native species with native plants. The Moore Creek lagoon is a valuable fresh/brackish water habitat that supports tidewater gobies and other special species.

Natural Bridges State Beach contains a diverse array of ecological alliances. Here restoration activities have focused on the dunes and bluffs on the east side of the beach. Groundswell Coastal Ecology has worked with CA State Parks and the California Native Plant Society Habitat Restoration Team over the past five years to plant native dune species and restore habitat for bluff nesting seabirds. This work has included fencing to focus and enhance access as well as protect dune habitat.

Amenities and Use

The lists of amenities and uses below are compiled from the Friends of Santa Cruz State Parks website, observational surveys conducted by the City of Santa Cruz, and local knowledge of the project team.

Amenities

- Hiking trails
- Bathroom
- Picnic Area
- Visitors Center
- Lifeguard
- There is a free parking lot next to an ocean/beach overlook

Coastal Use

- Tide pooling
- Shallow water play
- Surfing
- Boogie boarding
- Sunbathing
- Kite flying
- Whale watching
- Art

A site and time specific observational survey conducted by the City of Santa Cruz in the summer of 2019 helped to document the numbers of people participating in certain activities at a specific place and time (Figure 25 and Figure 26).

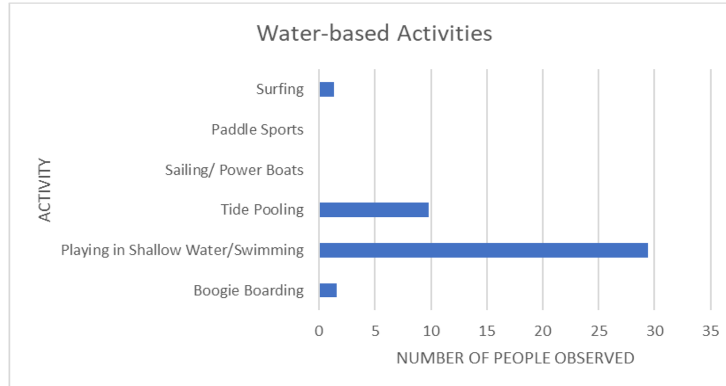


Figure 25. Average numbers of people observed participating in water-based activities at Natural Bridges Beach

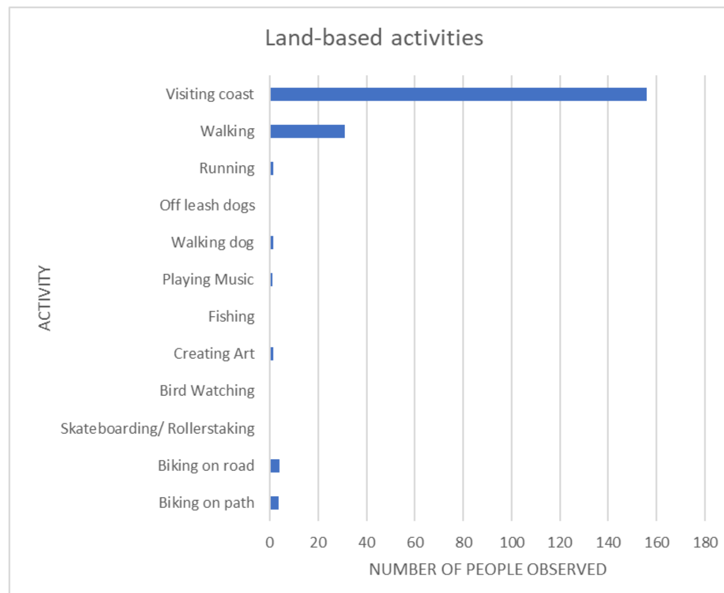


Figure 26. Average numbers of people observed participating in land-based activities at Natural Bridges Beach

Coastal Hazards

Historical and Existing Condition

Natural Bridges State Beach is named for the naturally occurring mudstone bridges that were carved by the Pacific Ocean into cliffs that jutted out into the sea. Wave erosion carved the arches and then cut away the cliffs, leaving only islands. Of the three original arches, only the middle one remains. The outermost arch fell during the early 20th century and the inner arch collapsed during a storm in 1980. The middle arch is in danger of collapsing as well due to erosion by wind and waves. Visitors were formerly permitted to climb up, walk and even drive from the bridges. Now the arch is closed to public access.

Projected Coastal Hazards

The projected coastal hazard zones for Natural Bridges Beach for rising tides, coastal storm flooding, and bluff erosion can be found in Figure 27, Figure 28, and Figure 29 below.

Projected Impacts of Focus for this Report

- Coastal Flooding (CF): By 2030 all of the beach is predicted to be inundated during large storm events
- Rising Tides (RT): By 2030 beach width may be reduced by 10%, by 2100 the beach width may be reduced by 30-50%.
- Bluff Erosion (ER): Erosion is projected to impact coastal access ways and habitat areas as early as 2030.
- A summary of assets that are projected to be impacted by future coastal hazards is shown in Table 5.

Table 5. Assets projected to be impacted by coastal hazards at Natural Bridges Beach.

Severity characterized as Low-short term impacts with minimal rebuild required, Moderate-some infrastructure replacement required, High- significant impact to infrastructure requiring significant replacement.

Asset	Hazard	Time horizon	Severity
Access Driveway	CF ER	2030 2060	Moderate Severe
Habitat: Intertidal	CF ER	2030 2030	Moderate Moderate
Habitat: Lagoon	CF ER RT	2030 2060 2060	Low Moderate Severe
Habitat: Nesting bird habitat	ER	2030	Moderate

Problem Statement

Natural Bridges State Beach is a large beach area at the west end of the City that provides beach access to many. The eastern bluff and adjacent parking and access road are vulnerable to coastal erosion and sea level rise is predicted to flood large portions of the beach. Back bluff erosion may lead to loss of parking and picnic areas and may impact coastal habitat areas including Moore Creek lagoon.

Natural Bridges State Beach: Rising Tides Hazard Zones

Figure 27. Rising tides hazard zones at Natural Bridges Beach for time horizons 2030 (.3 ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR).

Natural Bridges State Beach: Coastal Storm Flooding Hazard Zones

Figure 28. Coastal storm flooding hazard zones at Natural Bridges Beach for time horizons 2030 (.3 ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR).

Natural Bridges State Beach: Erosion Hazard Zones

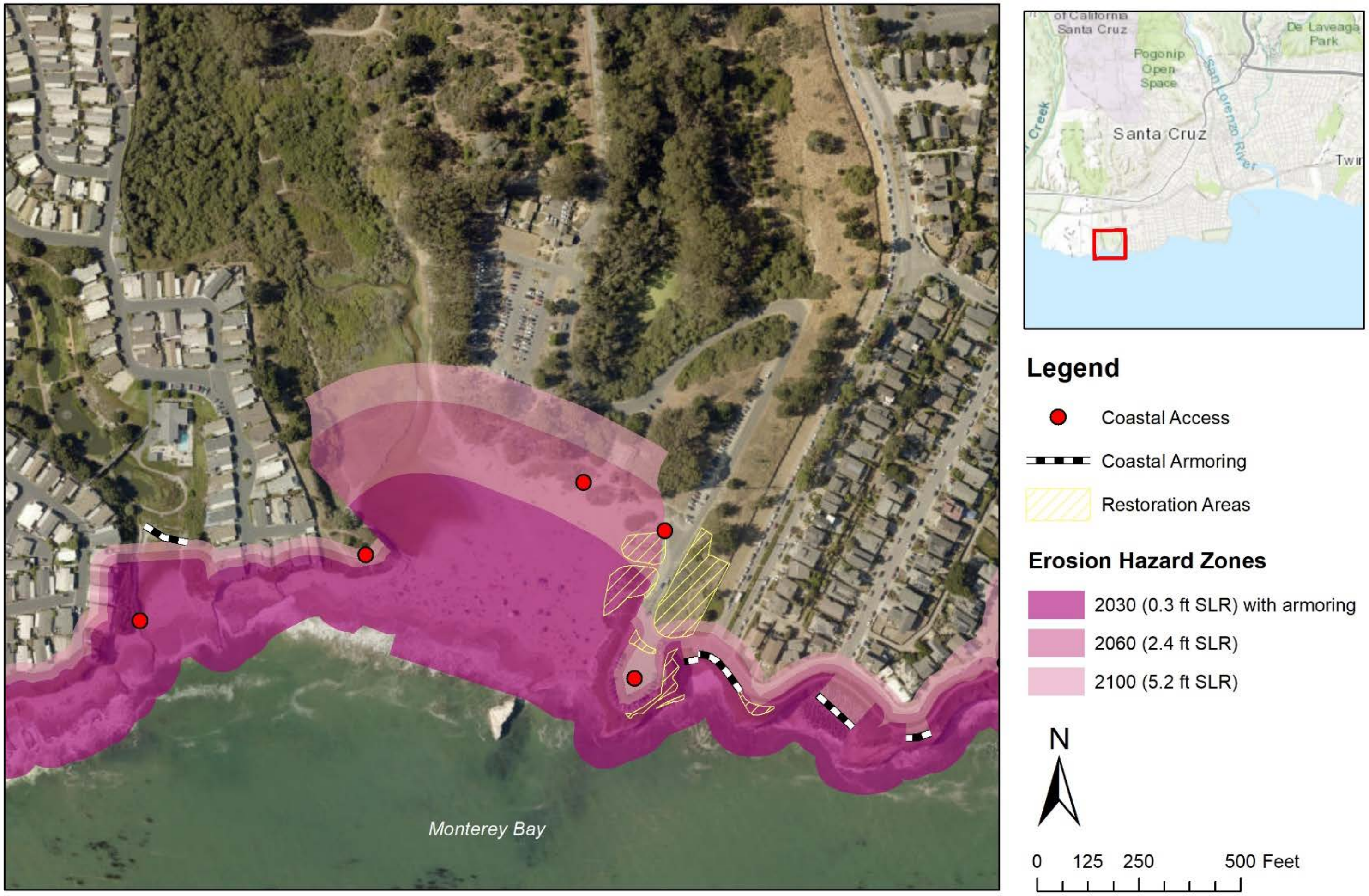


Figure 29. Coastal erosion hazard zones at Natural Bridges Beach for time horizons 2030 (.3 ft SLR), 2060 (2.4 ft SLR), and 2100 (5.2 ft SLR). Existing armoring is accounted for (restricting erosion) through 2030 but assumed to fail to restrict erosion past that time horizon.

Management and Resource Goals

Sea Level Rise and increased water elevations within the adjacent lagoon will lead to loss of much of the beach by 2060. Erosion is predicted to impact the back beach bluff and parking lot. Erosion of the back beach area and adoption of managed retreat is likely a feasible strategy that could help maintain beach width and is aligned with State Parks policies. Goals selected for this beach segment include:

- Maintain or increase beach area for public recreation
- Work with State Parks on managed retreat plan that meets beach width goals, considers unique aquatic habitat (e.g., tidepools, lagoon etc.), and supports habitat restoration objectives.
- Investigate alternative access ways to Natural Bridges outside of erosion and flood hazard zones, so as to maintain multimodal access
- Focus on living shoreline adaptations.

Adaptation Strategies

Based on an initial evaluation of predicted hazards at Natural Bridges and the various adaptation options available to address predicted wave flooding and erosion, the options listed below in Figure 30 should be considered for adaptation planning. Descriptions of each strategy begin on page 44.

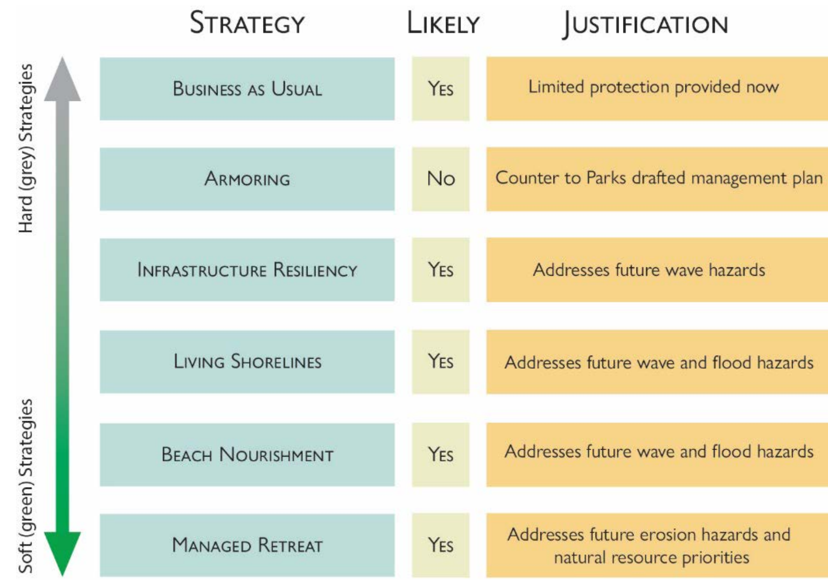


Figure 30. Potential Adaptation Options for Natural Bridges Beach

Development of Adaptation Pathways

Process

The next step to complete an adaptation strategy prioritization effort will be for City staff, the technical team, the TAC and stakeholders to begin the process of identifying preferred adaptation options. The selection process will need to weigh the costs and benefits of each alternative, define mitigation actions to minimize impacts to access and beach resources, and identify policies, programs and funding mechanisms needed to implement the preferred strategies.

Key considerations when assessing each adaptation strategy for prioritization are:

- Who pays?
- Who wins and who loses?
- How do we balance public trust lands and private property needs?
- What thresholds (triggers) do we consider for when a strategy is implemented?
- What programs and policies are needed to guide the transition from one strategy to another?
- What do we want our coastline to look like and who shall it serve in 2060 and on through 2100?
- Can we adopt a set of adaptation strategies that maintains a range of coastal accesses and resources through space and time?

The technical team has compiled information on various adaptation alternatives (Appendix A) aimed at helping address the above listed considerations. Examples of how these alternatives have been implemented elsewhere are provided in the case studies document (Appendix B) and graphical examples of adaptation alternatives have been drafted to provide a visual interpretation of impacts and benefits (Appendix C).

Several examples of how general adaptation strategies can be used along the City coastline are described below. Three examples of adaptation pathways (describing the transition from one strategy to another) are also presented to demonstrate how a systematic transition can be selected to achieve specific resource outcomes and meet selected coastal goals.

Moving forward, City staff and stakeholders will be asked to use the described strategies, referenced case studies, and triggers and policy information to draft three adaptation pathway alternatives for each segment of Santa Cruz beaches. The pathways describe predetermined strategies to transition from one coastal management strategy to the next. The pathways will identify costs and benefits of each approach, reference legal and financial challenges to implementation, discuss programs and partners needed to implement those programs and identify mitigation actions needed to address unavoidable implications of each pathway on coastal resources and unique segments of the community.

Adaptation Strategy Alternatives

Strategy: Business as Usual (Protect)

The City has, since the 1980s, responded to periodic bluff erosion through the placement of and improvements to rock revetments and sea walls (Figure 31).

As those structures become damaged by repeated wave impacts, new material is added to retain their effectiveness. The City has completed a number of emergency and planned upgrades and repairs to coastal revetment, often using emergency permitting processes that later require follow up actions. Funding for these emergency activities are often allocated through budget amendments to the Public Works Dept. (see West Cliff revetment cost evaluation in the Draft West Cliff Management Existing Conditions report).

As sea levels rise, these structures will likely need to be fortified and/or elevated more frequently to continue to provide the expected protections to inland resources. The Business as Usual strategy requires long term emergency response funding, periodic renewal of complex permits, and will likely lead to the further loss of beach areas adjacent to these structures. The consequential failure of the revetment and bluff edge during winter storms is also likely to threaten inland infrastructure.

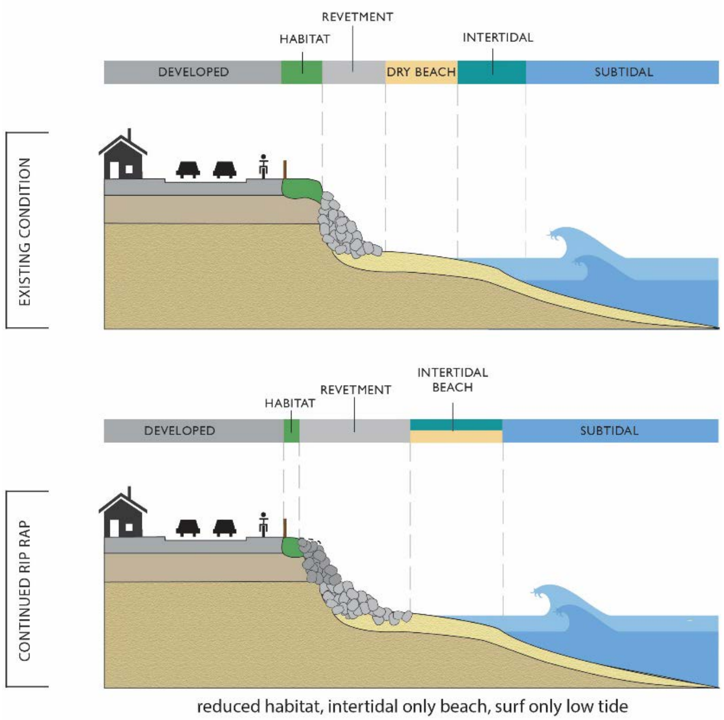


Figure 31. Depiction of Business as Usual: Placing additional Rip Rap to respond to periodic failures or reduction in protection.

Strategy: Hardened Structures

Armoring (Protect)

City bluffs have seen periodic erosion since development was first established. As early as 1948, bluff erosion had led to the loss of sections of East Cliff and West Cliff drives, leading to the relocation of West Cliff and the loss of portions of East Cliff in the Seabright area. As homes became vulnerable, armor was installed by property owners at several locations along East Cliff and later, when West

Cliff Dr. and the pedestrian/bike lane became vulnerable, the City began to construct riprap protections.

Looking forward, new riprap, sea walls and other structures can be installed to reduce wave impacts to vulnerable portions of the bluff (Figure 32). This strategy can be implemented piece meal over time or through completion of a shoreline characterization and prioritization study that estimates future bluff failure potential and identifies structural replacements (sea walls) needed to make various portion of the coastline more resilient and achieve other coastal management goals. Upgrades to existing infrastructure (for maintenance or enhancement) can be completed prior to failure, limiting inland impacts associated with catastrophic failures, reducing construction costs and reducing permitting challenges associated with emergency permits (See Business as Usual strategy).

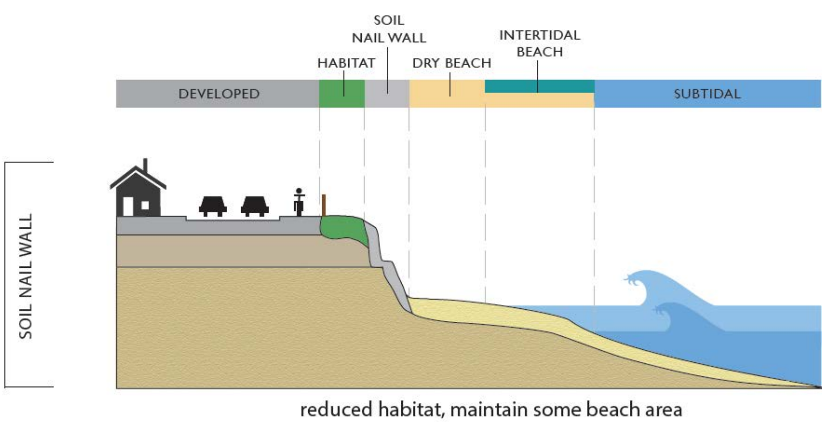


Figure 32. Depiction of SLR induced coastal bluff erosion halted through construction of a soil nail wall.

Through completion of a coastline characterization study prior to an emergency situation, the City can develop more refined adaptation strategies that rely on a combination of hard (armor) and soft (living shorelines) strategies that address the hazards and resulting risks facing specific resources and infrastructure.

Groins (Protect)

Groins are hard engineering structures which are installed perpendicular to the shore in order to interrupt longshore drift and impede the flow of sediment along a shoreline (Figure 33). This causes nearshore sand and sediment to accrete on the updrift side of the structure until the capacity of the groin is reached. Groins function similarly to the natural geologic headlands that span the Santa Cruz coastline. Artificial groins are able to trap sand and create beaches where they previously did not exist or be used to stabilize or widen existing beaches.

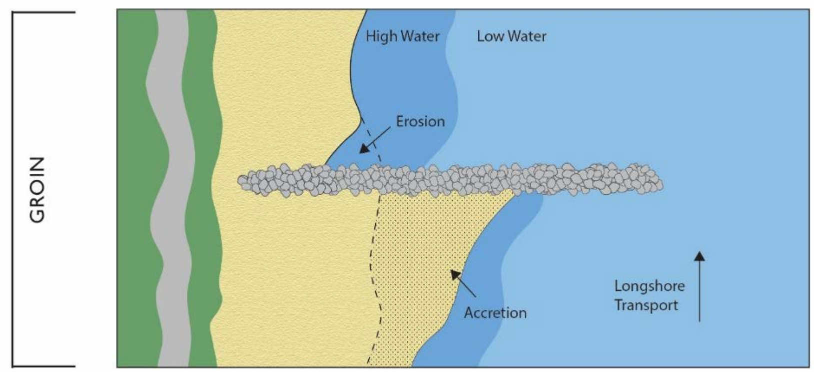


Figure 33. Depiction of groin along a beach

The accretion of sand caused by groin installations can diminish the sediment supply to downcoast areas, leading to accelerated erosion. This may be mitigated by artificially nourishing the groin (beach nourishment) after construction is complete. Groins are seen as a structural tool to increase the longevity of local beach nourishment projects.

Strategy: Infrastructure Resiliency (Accommodate and/or Protect)

There is a significant amount of coastal infrastructure located along the City beach front. Parking, roads, bike and pedestrian pathways, stairs, and overlooks provide visual and direct access to the coast.

To ensure that vital infrastructure and critical access accommodations are maintained or enhanced, infrastructure can be modified, rebuilt, or relocated to increase its resiliency to projected hazards (Figure 34). Infrastructure enhancement strategies can be integrated into future operations and maintenance efforts by the City and State Parks.

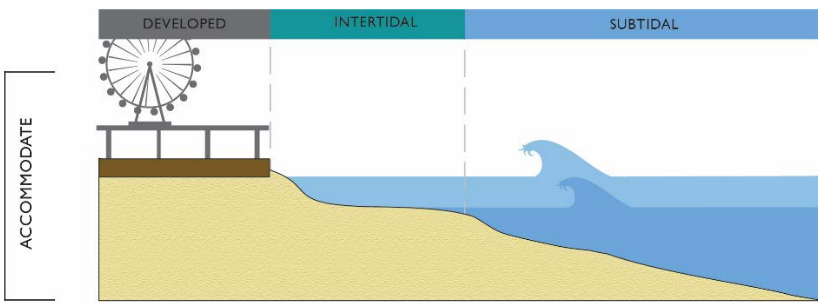


Figure 34. Depiction of infrastructure raised on piers to accommodate for flooding during extreme high tides or storm events.

The redesign or relocation of beach access infrastructure can help ensure levels of service are maintained, repetitive replacement costs are reduced and infrastructure upgrades are absorbed (as feasible) into ongoing operations and maintenance budgets.

Strategy: Living Shorelines

The term 'Living Shorelines' is a relatively new concept which encompasses many different strategies and techniques surrounding the use of coastal ecosystems. The central approach is linked to efforts to incorporate natural habitats into shoreline stabilization designs. Applications of living shorelines range from the use of natural features, such as natural shoreline vegetation; to more hybrid approaches where such natural assets are paired with additional hardened features such as sills or breakwaters.

Back Dune Enhancement (Protect)

More resilient back beach dune habitat can be established that will hold and possibly accrete sand for years until high waves erode those areas. Dependent on the needed level of protective certainty, back beach dunes can be constructed to include a base layer of wood, rock or other material that will withstand impacts once the dune habitats have eroded (Figure 35). These sacrificial dunes can be reestablished after winter storms have ended.

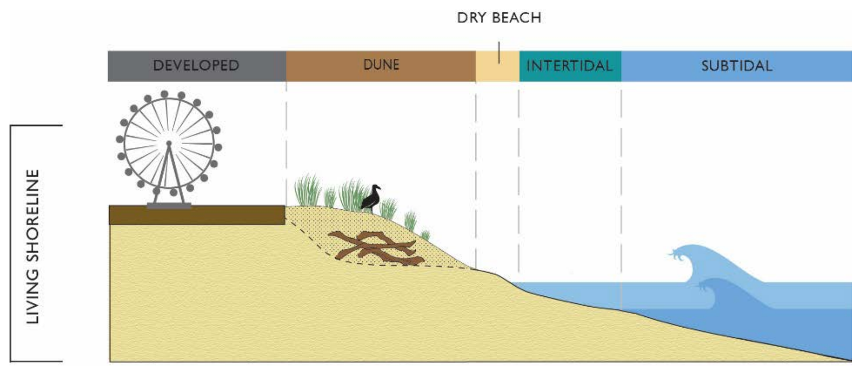


Figure 35. Depiction of living shoreline being used to protect inland infrastructure.

Living Bluff Faces (Protect)
Areas of the bluffs that back Santa Cruz beaches range in condition and stability. Some areas where land has already been lost, the bluff face angle is more set back, includes vegetation (native and iceplant) and appears to be more resilient to further bluff failure. Some areas where bluff top infrastructure is vulnerable, armoring and sea walls have been constructed (with various levels of engineering sophistication) that may leave the bluff more vulnerable to future failure if storm waves impact the structure or substrate below them. Enhanced bluff face contouring and habitat revitalization may work in concert with other select managed retreat efforts to increase the resiliency of Santa Cruz bluffs (Figure 36).

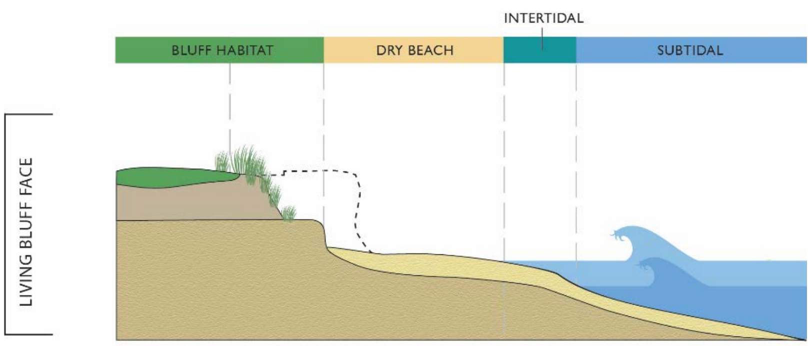


Figure 36. Depiction of bluff erosion mitigated by native plantings along bluff face and terrace

A number of non-sanctioned access ways leave the bluffs more vulnerable to future impacts and could be upgraded/retired to increase bluff resiliency in concert with revegetation of adjacent areas.

Beach Contour Management (Protect)
Managed sand placement on beaches (beach scraping) has been used as a temporary protection of back beach resources during winter storms. Sand can be piled in mounds (similar to that employed in Capitola) to act as a sacrificial barrier to waves. Such actions can be repeated between storm events if needed.

Strategy: Beach Nourishment (Protect)
Beach nourishment is the process of artificially placing sand (or other aggregates such as gravel) on or near a coastline in order to restore an existing beach or construct a new one (Figure 37). This intervention differs from beach contour management in that sediment is added from outside the system, normally from a ‘borrow site’, while sand scraping relies on the redistribution of existing sand.

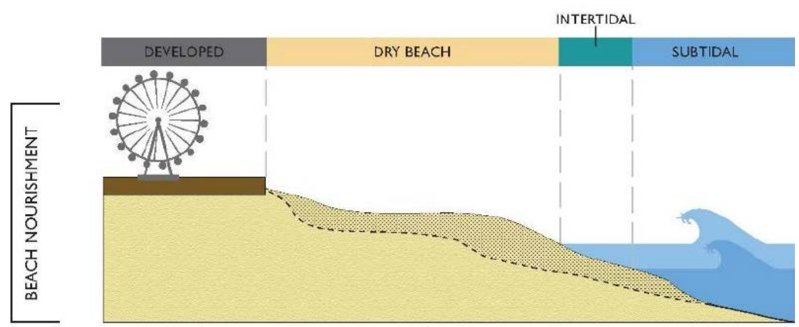


Figure 37. Depiction of beach nourishment

Beach nourishment is often undertaken as a strategy to combat coastal erosion and to augment the natural buffering action of beaches against storm surge. It is increasingly being seen as an important adaptation tool in combatting sea level rise which threatens to inundate beaches and accelerate and exacerbate erosion and coastal storm flooding. Nourishment can be used with other adaptation strategies such as sand scraping, dune restoration, hard engineering (groins), and development set-backs. It is often referred to as a soft adaptation strategy (green), similar to wetland and dune restoration.

There is a certain degree of uncertainty as to the long-term effectiveness of beach nourishment projects. In some cases, storms can quickly remove sediment. In order to be truly effective, nourishment projects need to be planned carefully to account for the limited temporal effectiveness of this strategy and the long term hazards projected for coastal assets.

Strategy: Managed Retreat (Retreat)

Managed Retreat implies the shifting of assets, activities and people away from coastal hazards. Activities can entail removal or relocation of existing structures in hazard prone coastal areas. The term "managed realignment" is also used, as well as "managed or planned relocation" (Figure 38). Managed retreat can be seen as a reclaiming of public resources and access as private infrastructure becomes threatened. The term "managed" suggest that planning has been undertaken to address the logistical, financial and legal implications of this transfer of use.

Managed retreat plans and policies can encompass aspects of other adaptation strategies. Retreat can therefore be conceptualized as a broad suite of adaptation options. There have been cases where coastal hazards including coastal flooding or storm damage have created the impetus for retreat from defined hazard areas.

Managed retreat options will differ dependent on the type of infrastructure which must be relocated and the owner of that property. For much of Santa Cruz, the coastline is owned and managed by the City or State Parks. City owned properties along Seabright provide several key public access functions. Two way traffic is provided for approximately half of East Cliff Drive within the Seabright area and for all of West Cliff Drive.

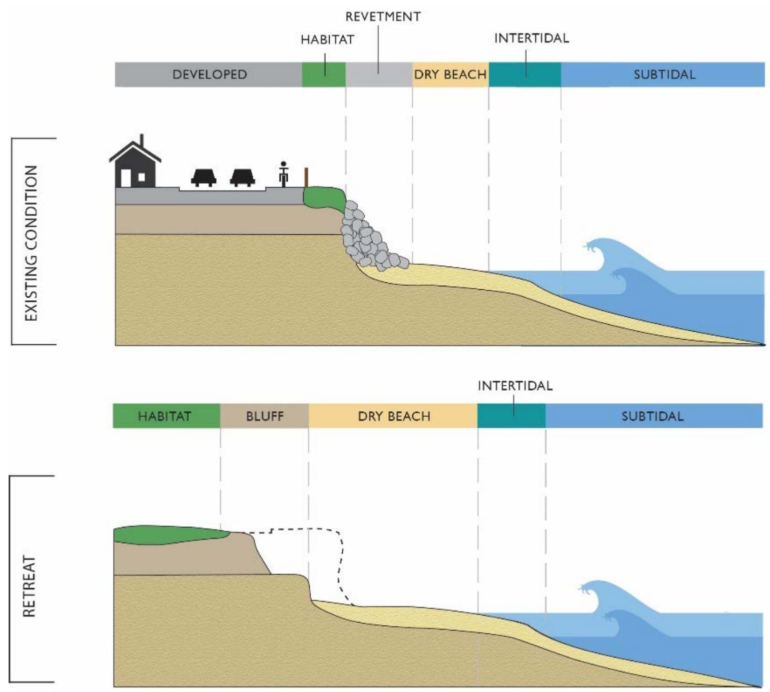


Figure 38. Depiction of managed retreat

Because of the high density development along the Santa Cruz coastline, managed retreat of private property is challenging and costly. Such sacrifices could lead to an increase in public access and recreation if such a transition could be done legally and supported fiscally by the community. Examples of this private to public transition have been achieved in Pacifica where the City partnered with the Pacifica Land Trust and Coastal Conservancy to fund the acquisition of several private homes and surrounding land at the cost of $2.2 million dollars.

Example Adaptation Pathways

Adaptation pathways describe logistical transitions from one management strategy to another. The benefit of developing adaptation pathways is that the community has an opportunity to discuss and select the preferred future for their coastline and identify funding needs, legal hurdles and necessary implementation programs needed prior to implementation of any adaptation strategy transition. Private property owners (and city staff) also benefit from an understanding of the long term plan for how future coastal impacts will be addressed.

Similarly, by integrating these strategies into city policies, plans and funding operations (Capital Improvement Plan), as climate related impacts occur, the city is prepared to take action based on sound planning. Similarly, FEMA, the California Coastal Commission and other agencies will be prepared for proposed infrastructure changes (and needed funding) by referencing the selected pathways in state and federal planning documents (Local Hazard Mitigation Plan, Local Coastal Plan).

Specific adaptation pathways will be developed in partnership with City staff and community stakeholders for consideration and discussion. Depending on selected goals for various beach areas and their back shore infrastructure, various adaptation strategies may be employed over time. Three example pathways have been developed to provide conceptual understanding of the challenging planning exercise before us (Figure 39, Figure 40, and Figure 41). Each descriptive pathway includes possible triggers, time horizons, ocean elevations, fiscal considerations (repetitive loss), protective and adaptive adaptation strategies, a temporal navigation from one strategy to the next, and coastal resource costs and benefits.

Selecting defined triggers is important to the implementation of climate adaptation pathways. An adaptation pathway is a decision strategy that provides a vision for managing climate risks through a sequence of steps over time, each of which is triggered by a change in social, economic and/or environmental conditions. Adaptation pathways which use triggers help to describe what/if/when scenarios that help the public and city staff understand how to respond to future effects of climate change on coastal areas. The table below provides examples of various categories of triggers that can be used to help develop adaptation pathways (Table 6).

Table 6. Example Triggers

Temporal	Environmental	Structural	Fiscal
Duration of temporary loss	Flood elevations	Repetative loss	Cost/Benefit exceedences
Future time horizon	Ocean levels	Bluff failure	Willingness to pay
Infrastructure resiliency	Salt water intrusion	Loss or condition of protective structures	
Past permitted use	Habitat impacts or response	Loss of service or uses	
Cumulative loss of use or access	Beach width	Prescriptive setbacks	
	Hazardous conditions		
	Loss of public use or access		

Pathway Example 1: Protect in Place

This pathway implements actions intended to protect important city/community infrastructure and resources that cannot or will not be relocated or removed. The pathway relies on increased coastal resiliency through beach nourishment and back shore adaptations including sea walls. Described coastal impacts and benefits are related to the transition from use of riprap to sea walls that can be designed to include elements that enhance the visual appeal of the bluffs and provide public access amenities (Figure 39).

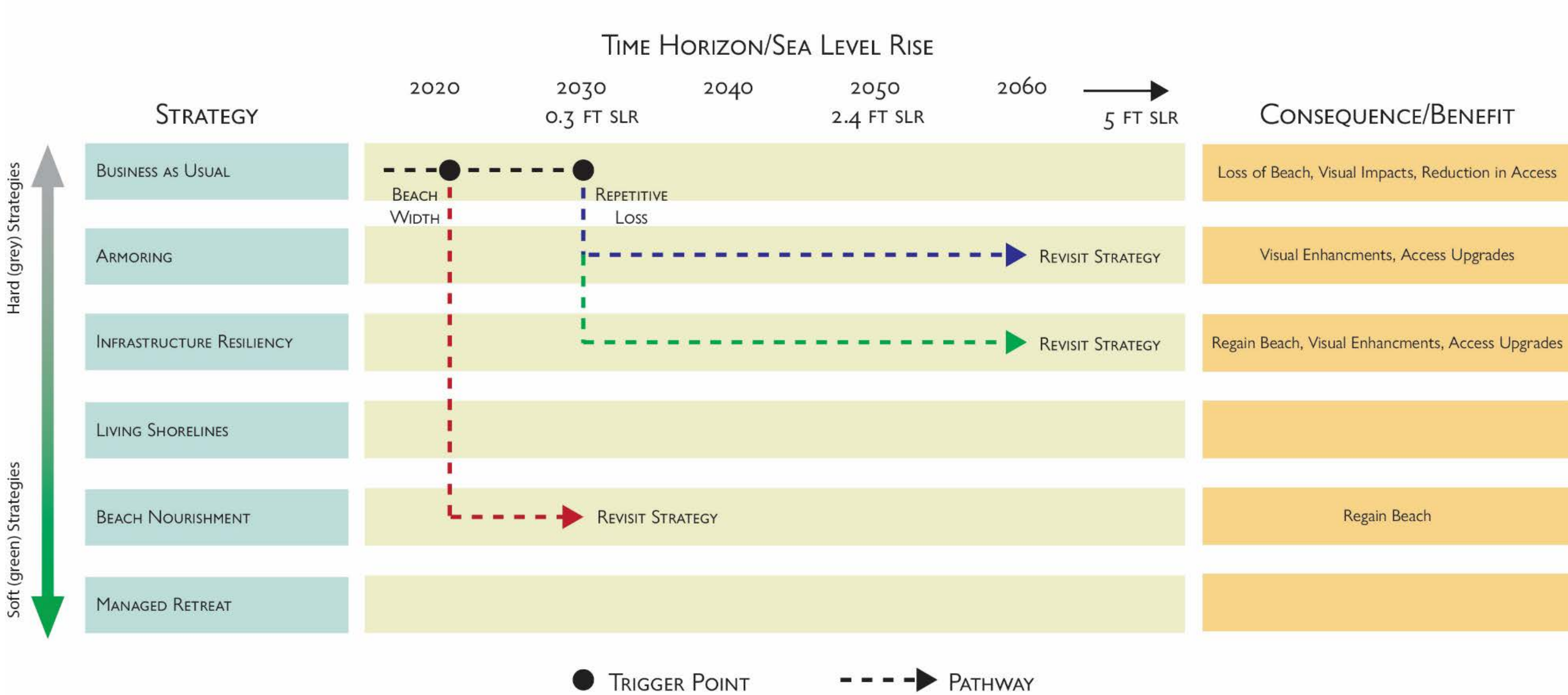


Figure 39. Example Pathway: Protect in Place

Example 2: Protect (soft), Accommodate and Retreat

This pathway implements actions intended to reduce the reliance on coastal armoring through use of "soft" coastal resiliency efforts (e.g., beach nourishment, dune creation) with the expectation that once these strategies are no longer feasible (physical and/or fiscal) inland infrastructure will be rebuilt to withstand projected hazards or removed/relocated out of harm's way. Predicted coastal impacts and benefits are based on use of beach nourishment and living shoreline techniques that can enhance beach resources. As seas rise these strategies may become ineffective (environmental trigger) and a transition to a strategy of incremental replacement of structures with more resilient infrastructure and/or relocating vulnerable buildings and infrastructure elsewhere (Figure 40).

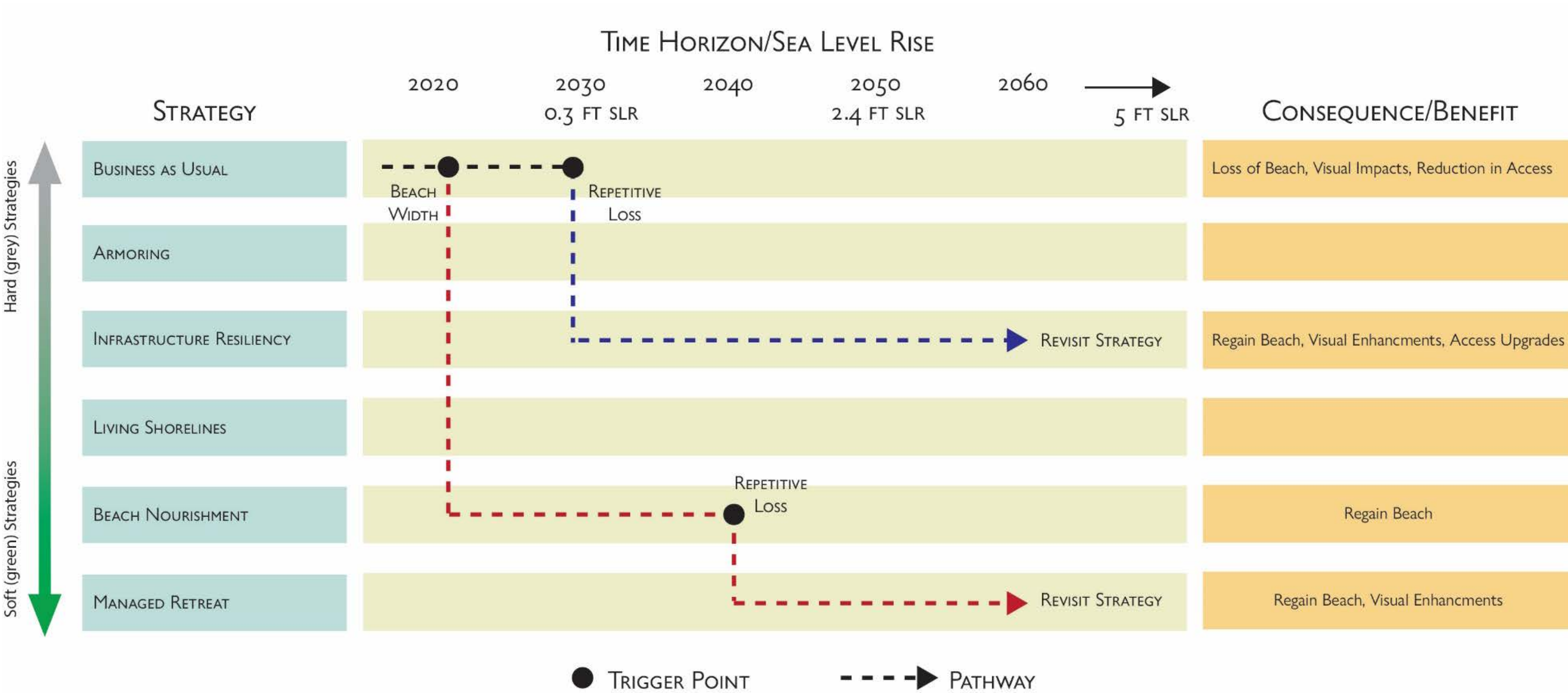


Figure 40. Example Pathway: Accommodate and Retreat

Example 3: Restrictions on Coastal Armoring

This pathway implements actions intended to restrict the use of coastal armoring through transition to "soft" coastal resiliency efforts (beach nourishment, dune creation) with the expectation that once these strategies are no longer feasible (physical and/or fiscal), inland infrastructure will be removed/relocated out of harm's way. Predicted coastal impacts and benefits are based on use of beach nourishment and living shoreline techniques that can enhance beach resources and the incremental removal of vulnerable buildings (Figure 41).

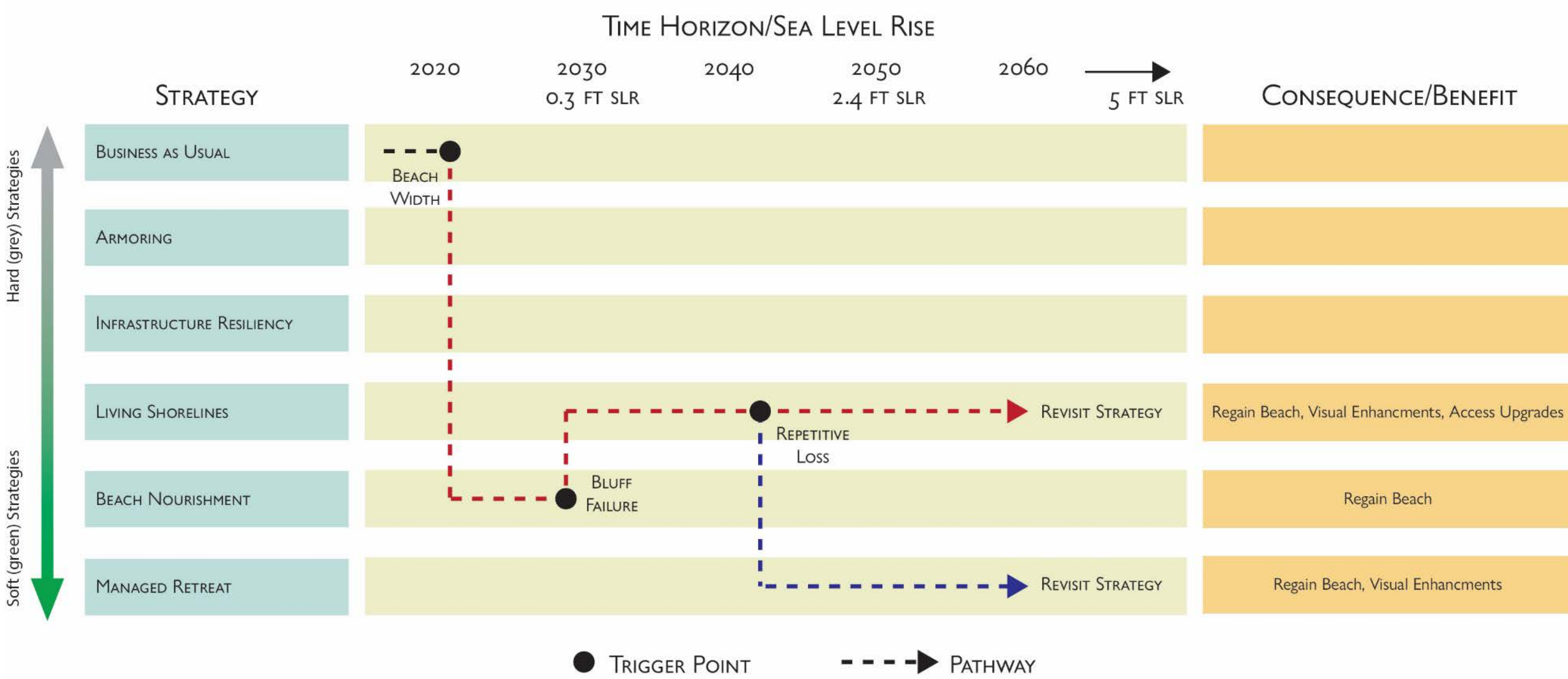


Figure 41. Example Pathway: Restrict Coastal Armoring

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Appendix A:

Adaptation Strategy Summary Table

Accommodate: Accommodation strategies refer to those strategies that employ methods that modify existing developments or design new developments to decrease hazard risks and thus increase the resiliency of development.

Protect: Protection strategies refer to those strategies that employ some sort of engineered structure or other measure to defend development (or other resources) in its current location.

Retreat (Realign): Retreat strategies are those strategies that relocate or remove existing development out of hazard areas and limit the construction of new development in vulnerable areas.

Strategy	Type of Tool	Accommodate	Protect	Retreat	Description	Comments & Examples
Elevating Structures	Regulatory	x	x		Design requirements related to building type and hazard zone type are common in Federal Emergency Management Agency (FEMA) flood zones. Local governments could adopt similar policies in LCPs to require elevating structures, floodproofing designs, or siting structures in ways that accommodate flooding and erosion	In California, Marin County attempted to prompt the use of this strategy through updates to its local coastal program. There are many ad hoc examples of this strategy in California and elsewhere, usually prompted by FEMA requirements.
Beach Nourishment	Soft Adaptation		x		Beach nourishment is the process of artificially placing sand (or other aggregates such as gravel) on or near a coastline in order to restore an existing beach or construct a new one.	Four recent nourishment projects took place in Southern California, including Torrey Pines, Imperial, Cardiff and Solana beaches. Other examples from Encinitas and Solana Beach, Ocean Beach in SF, Santa Cruz (dredging of the Santa Cruz Harbor and sand replacement at Twin Lakes Beach) , and Morro Bay. US Database incl. costs and maintenance - http://beachnourishment.wcu.edu/ Plans for opportunistic nourishment have been developed for California and selected areas such as Monterey Bay
Dune Restoration	Soft Adaptation		x		Dune rehabilitation is an engineered process whereby native plant revegetation, non-native plant removal, organic dune thatching, and dune fencing are used to stabilize dunes and propagate enduring dune recovery.	Dune restoration project at Monterey State Beach and Salinas River State Beach. Abbotts Lagoon coastal dune restoration project at Point Reyes is another example. The Surfer’s Point managed retreat project also incorporated dune restoration to a large degree.

Strategy	Type of Tool	Accommodate	Protect	Retreat	Description	Comments & Examples
Living Shorelines	Soft Adaptation		x		Applications of living shorelines range from the use of natural features and species, such as natural shoreline vegetation; to more hybrid approaches where such natural assets are paired with additional hardened structures to mitigate erosion. Other alternative techniques include utilizing salt marsh and oyster reefs to stabilize shorelines.	San Francisco Bay Living Shorelines Project , Salinas River State Beach Dune Restoration project and Cardiff Beach Living Shoreline project are some examples in California. Living shorelines can encompass hybrid and grey infrastructure, oyster reefs and dune restoration.
Riprap	Hard Adaptation		x		Traditional approaches to managing coastal erosion and flood risk have often relied on hard armoring of the shoreline. The type of armoring chosen (e.g., riprap, revetments or seawalls) depends on geomorphic context.	Riprap is the most common armoring strategy on California's coastline. Can be found along over 50% of West Cliff Drive for example. Other examples include Broad Beach in Malibu.
Seawalls	Hard Adaptation		x		Seawalls are near vertical, shore parallel structures which are normally built to protect landward development against storm waves. They can be installed as a result of degradation or loss of natural protective buffers due to coastal erosion.	Multiple seawall examples in California – e.g. O'Shaughnessy Seawall in Ocean Beach, San Francisco, the Elliott Bay Seawall in Seattle and the East Cliff Drive Parkway and Bluff Protection Project, Santa Cruz.
Groins	Hard Adaptation		x		Groins are hard engineering structures which are installed perpendicular to the shore in order to interrupt longshore drift and impede the flow of sediment along a shoreline.	Groins have mainly been used in different areas of Southern California such as Ventura Santa Monica as well as in Santa Cruz and Orange County. The Capitola groin has been successful at creating and maintaining the beach after the construction of the Santa Cruz Harbor.

Strategy	Type of Tool	Accommodate	Protect	Retreat	Description	Comments & Examples
Wetland Restoration	Soft Adaptation		x	x	Conserving areas for wetlands to migrate landward is a strategy embraced by state agencies, for dealing with sea level rise. Wetland restoration can be a less-expensive alternative to competing "gray" armoring alternatives that can also provide additional ecosystem services.	Multiple examples throughout California: Dune restoration was an important component of the first phase of the Pacifica Beach managed retreat project.
Acquisitions and Buyout Programs	Spending Tool			x	By accumulating a funding reserve for anticipated future needs, a special district can provide the financial resources necessary for adaptation approaches that extend beyond a single parcel. Typically, these entities can borrow from lenders or issue bonds with very attractive credit terms.	Suffolk - USDA Emergency Watershed Protection-Floodplain Easement Program. Limited examples elsewhere. A number of buyout initiatives were implemented to encourage retreat after Hurricane Sandy in NJ.
Conservation Easements/ Rolling Conservation Easements	Spending Tool			x	An easement is a property right that allows access or use of a property to a third party. Conservation agreements can range from an outright ban on development to the preservation of sensitive habitat on one portion of a property. Rolling easements can lead to the removal of structures that are designed and approved with managed retreat triggers (e.g., based on surveys of minimum beach width or mean high tide line).	In 2013, a first-of-its-kind "coastal resilience" easement was created in Maryland as a response to sea level rise

Strategy	Type of Tool	Accommodate	Protect	Retreat	Description	Comments & Examples
Geologic Hazard Abatement Districts	Regulatory		x	x	Geologic Hazard Abatement Districts (GHADs), County Service Areas (CSAs) and other similar entities could provide a potential means for funding sea level rise adaptation measures on a neighborhood scale. A GHAD or CSA can provide the financial resources for adaptation approaches that extend beyond a single parcel by pooling contributions from its members and accumulating a funding reserve for anticipated future needs	There are currently thirty-five GHADs organized in California. Most of these are concentrated in the SF bay area and coastal LA County. Santa Cruz also manages a GHAD. Malibu created a GHAD in order to nourish Broad Beach but have had many technical and financial issues implementing it.
Transferable Development Credits/ Transfer of Development Rights	Tax and Market Based Tool	x		x	Transfer of development rights (TDR) is a market-based tool that can help implement phased retreat from shoreline hazard zones. TDR programs enable individual transactions to transfer development rights from privately owned parcels (i.e., sending sites) to areas that can accommodate additional growth (i.e., receiving sites).	The California Coastal Commission has used TDR markets to retire antiquated subdivision lots in the coastal zone. E.g. Santa Monica Mountains. Malibu's Local Coastal Program also includes procedures for transferring development credits.
Development Moratoria	Regulatory			x	Development moratoria are restrictions or outright bans on development in an area. They are normally a temporary measure. When implemented they will likely face opposition from affected property owners wishing to develop their parcels.	Marin County instituted a development moratorium for areas of Stinson Beach while it finalized an update to its Local Coastal Program.
Overlay Zones	Regulatory	x		x	Sea Level Rise Overlay Zones can be useful tools for overall, long-term adaptation strategies to trigger downzoning, redevelopment restrictions, structure removal.	Cities along the California coast are considering or have already utilized overlay zones for flood-prone and environmentally sensitive areas. E.g. the City of Goleta is evaluating overlay zones as part of their suite of future coastal adaptation strategies

Strategy	Type of Tool	Accommodate	Protect	Retreat	Description	Comments & Examples
Rebuilding and Redevelopment Restrictions	Regulatory	x		x	These strategies can prompt planned retreat from a coastal region by incrementally restricting new and modified structures in an affected area. They can also accommodate sea level rise by requiring that redeveloped or rebuilt buildings be elevated to a certain height or incorporate other resilient engineering approaches	The California Adaptation Strategy recommends that local governments consider restricting rebuilding "when structures are damaged by SLR and coastal storms.
Public Trust Doctrine	Spending Tool			x	Under the public trust doctrine, California has a duty to protect and sustain its coastal tidelands and submerged lands for public purposes	Protecting the public's interest in shared resources of the coastal zone from current and foreseeable future harm is a central tenet of the public trust doctrine.
Coastal Adaptation and Takings Law / Eminent Domain	Spending Tool			x	Eminent domain powers can also be used to condemn properties to prevent against hazards to health, safety, and welfare.	All takings analyses for actions undertaken by the State of California must be consistent with both federal and state takings requirements. Ideally, local governments will be able to choose policies that financially burden their constituents the least while still achieving their long-term planning and coastal adaptation objectives.
Setbacks and Buffers	Soft Structure/Regulatory	x		x	Setbacks are building restrictions that establish a distance from a boundary line where landowners are prohibited from building structures. Buffers require landowners to leave portions of their property undeveloped.	The EPA recommends use of setbacks as a "soft" adaptation option. LCPs must establish buffer areas for new development that protect coastal waters, estuaries, wetlands, streams, and environmentally sensitive habitat areas. The City of Santa Cruz incorporates a fixed setback from the center line of wetland areas.

Strategy	Type of Tool	Accommodate	Protect	Retreat	Description	Comments & Examples
Subdivisions and Cluster Development	Regulatory	x		x	Governments can use clustered development programs to ensure that new development is more resilient to SLR. Subdivision ordinances could be used to encourage the concentration of development in upland areas at lower risk of impacts and to restrict development in low-lying areas vulnerable to erosion and flooding.	The California Adaptation Strategy encourages clustering new development in areas considered to have a low vulnerability to sea-level rise
Tax and Other Development Incentives	Tax and Market Based Tool	x		x	By altering this form of taxation, governments can use tax incentives to encourage preferred development patterns including becoming more resilient to coastal climate hazards.	The 'South Carolina Omnibus Coastal Property Insurance Reform Act' provides a tax rebate to homeowners who purchase supplies to retrofit homes to be more resilient to storms.
Real Estate Disclosures	Tax and Market Based Tool	x		x	Governmental bodies (e.g., state or local agencies) could compile data, erosion maps, inundation models, and other relevant information and make this information accessible to potential property buyers and developers	Laws could be enacted to require disclosure concerning property that is vulnerable to flooding and erosion from SLR. Implementation of this policy could be in the form of : Government dissemination where Governments compile data and other relevant information and make this information accessible to potential buyers and developers. 2. Mandatory private disclosures - sellers would be required to disclose to potential buyers that a property is located in an area vulnerable to SLR.

Information Adapted from:

Center for Ocean Solutions, Stanford Woods Institute for the Environment, Coastal California Adaptation Policy Briefs (2018).

Georgetown Climate Center Adaptation Tool Kit for Sea-Level Rise and Coastal Land Use (2011)

Appendix B:

Adaptation Strategy Case Studies

MANAGED RETREAT

Description

Managed Retreat can be described as the shifting of assets, activities and people away from coastal hazards. This can entail removal or relocation of existing structures in hazard prone coastal areas [1]. The term 'managed realignment' is also used, as well as managed relocation. Managed retreat plans and policies can encompass aspects of other adaptation strategies. Retreat can therefore be conceptualized as a broad suite of adaptation options. [2]
Some of these relevant and enabling strategies are listed in Table 1 below:

Table 1: Managed Retreat Strategies

Setbacks	Soft Engineering*	Buyout programs
Conservation easements	Floodplain regulations	Property acquisition
Real estate disclosures	Rebuilding restrictions	Setbacks and buffers
Transferable Development Rights	Removal of structures	Zoning

* such as beach replenishment and dune restoration [3]

According to Plastrik and Cleveland [3], retreat can occur in different ways and be led by different driving factors. These include retreat strategies driven by:

- disasters where infrastructure and land are destroyed and people are forced to relocate
- financial fears in markets linked to losses due to climate change (which is anticipated to happen in the future) which leads to disinvestment and abandonment of assets
- community planning in anticipation of unavoidable climate risks.

Managed retreat is still a relatively new concept and has not been widely documented in the US. There have been cases where coastal hazards such as coastal flooding or storm damage have created the impetus for retreat such as after Superstorm Sandy in New York and Hurricane Katrina in New Orleans. Managed retreat may be very difficult to implement in the absence of external factors such as these. Once an event has occurred there is also a limited window in which stakeholders may be open to voluntary relocation. Hence prior planning, long-term community engagement and buy-in is critical for successful implementation. [4]

Case Studies

Pacifica/ Linda Mar State Beach

Faced with the long-term impacts of recurring hazards, the City of Pacifica has been developing a managed retreat strategy to address coastal flooding and erosion as well as habitat loss. Prior to this, hard engineering such as coastal armoring and channelization were utilized but this was thought to have exacerbated erosion. In 1990, the city developed the Pacifica State Beach Master Plan which outlines a number of retreat options. It called for the acquisition and demolition of two homes, demolition of existing restrooms which would be reconstructed elsewhere, and the relocation of a restaurant from vulnerable areas of the beach. This would create the space to utilize soft stabilization techniques such as sand dune restoration and watershed restoration with the goals of reducing flooding threats, preserving the beach, and improving steelhead habitat [5]. The plan also called for new beach access, reconfiguration of parking facilities and facilities such as a bike path and extended coastal trail. The project was completed in 2004, providing protection for over 300 homes [6] (See Figure 1).

The City partnered with the Pacifica Land Trust and Coastal Conservancy to fund the acquisition of the private homes and surrounding land at the cost of $2.2 million dollars. 4,000 cubic yards of sand were also sourced in order to rebuild dunes and restore four acres of beach and the nearby estuary [7]. The overall cost of the project was approximately $10 million [6].

Surfer’s Point

Beach erosion and wave overtopping in the late 1980’s and early 1990’s continually damaged the parking lot and bike path at Surfer’s Point in the City of Ventura. Initial proposals to construct a seawall were rejected by the Coastal Commission who suggested stakeholder engagement to find a solution. A working group was formed with important stakeholders including representatives from the City of Ventura, the Surfrider Foundation, and several state agencies. The Surfrider foundation in particular helped to prioritize the importance of the beach and surf breaks over the installation of hard engineering [8].

The primary goals of the project were to relocate the damaged parking lot and bike path and to increase resilience and offset risk from future storms and sea level rise, while maintaining access and other coastal resources. This approach was also complemented by the construction of a cobble beach which then allowed for beach nourishment and dune restoration and revegetation, adding additional protection and ecosystem services. Phase one of the project was completed in 2011 which included relocation of portions of the bike path and parking lot landward. Phase two of the project will focus on refining aspects of the design of phase one, investigating alternatives and allowing for the relocation of the remaining sections of the parking lot and bike path [9]. See Figures 2 & 3.

There are indications that the approach has been successful so far. A report by the ESA in 2016 shows that wave runup was limited and damage was avoided during high wave conditions over the 2015-2016 winter period.

The Buyout and Acquisition Programs (NYS)

Retreat was utilized after Superstorm Sandy in 2012 in the areas of New York and New Jersey. Hurricane Sandy was one of the most destructive storms with losses of over $71 billion dollars, $19 billion from New York alone. Critical infrastructure such as roads, utilities and subways were flooded and thousands of residents lost their homes.

A number of buyout initiatives were implemented to encourage retreat after the disaster. Eligibility depended on hurricane related damage and property location [4]. Restrictions were placed on the vacated land which was earmarked for open space, recreation or wetland restoration. Targeted buyouts also attempted to ensure that adjacent properties could be acquired to minimize the risk associated with holdouts [4].

Lifespan/Effectiveness

The timeframe needed for managed retreat projects should consider that the planning and design phases can be lengthy. Both the Surfer's point and Pacifica projects had long gestation periods dating back to the 1990's which were driven by local stakeholders and took a long period of time to gain acceptance. The plans and policies, the legal and regulatory compliance needed as well as the funding and implementation may take many years to secure, as well as the engagement with the local communities [3].

There are challenges with acquisition of private property, and voluntary measures facilitated by incentives such as buy-back programs may see the most success. In many cases it may be more feasible to implement early stages of managed retreat projects by focusing on critical public infrastructure (such as hospitals, wastewater facilities and electrical generation facilities) and land as opposed to private property [10].

Stakeholders should also be given proper alternatives, including information such as suitable areas in which to relocate. State and County long range plans can be updated to consider areas suitable for retreat and prioritization for other use such as conservation [10].

New laws may have to accompany managed retreat plans and projects in order to aid in implementation and enforcement. This may be along the lines of restricting or prohibiting coastal armoring, increasing existing setbacks, requiring real estate disclosures as well as looking at the possibility of easements and transfers of development rights [10]. Local Government may also look at the possibility of withdrawing some essential services in order to foster coastal retreat but this may have to be conducted with a sound strategy to avoid violating the Takings Clause. There are some examples of this been done in California in terms of utility lines, parking spaces, parkland and bike and walking trails [11].

A recent study investigating managed retreat in the US put forward a number of lessons that cities should encompass when planning for managed retreat. These include the need to plan for the emotional and social aspects of managed retreat during the community engagement process; the need for cities to accurately and transparently report climate risk and vulnerabilities in their assessments; frame retreat as a long term positive vision; begin with the relocation of essential public infrastructure in order to set precedents for new development and to consider the potential impacts on already existing disparities which many exist in the economic and social makeup of the city. [3]

Consensus will be very important, especially when dealing with homeowner interests. A significant majority of those affected will have to agree to managed retreat in order to avoid holdout scenarios. Agreement on the vision as well as the implementation and outcomes are also essential. [4]

The use of voluntary measures, as opposed to eminent domain may also result in fewer legal challenges. This approach has fostered success in coastal neighborhoods in Staten Island, New York with voluntary buyout programs. [4] The creation of legally binding hazard maps, integrating risk-based land use planning and relocation plans in advance can help to facilitate proactive managed retreat. [12]

One important factor when planning managed retreat is that is it difficult to convey different scenarios to communities when there has not been a prior disaster or hazard. Oftentimes that is what creates the impetus for communities to act and there is a short period of time or window of opportunity that occurs after a disaster which can facilitate retreat strategies. However, if communities do not regularly experience damage or if they have unrealistic ideas about longer term impacts such as sea level rise then they may ultimately choose to remain and not relocate. [4]

Cost

Costs for managed retreat vary greatly depending on the scale, timeframe as well as additional adaptation strategies and technologies which may be involved. Analysis should be done beforehand to look at the cost of removing and/or relocating infrastructure as well as the potential need to acquire property. Estimates for Surfer's Point are around $5.5 million dollars for phase 1 and $10.9 million for the entire project, including monitoring costs.

The Environmental Services Associates group has implemented projects which encompass retreat of coastal development. These costs ranged from $4.5 Million to $45 Million per acre of beach. The wide disparity is due to the removal of low hanging public assets versus high value utilities. The group recommends the use of property values and different compensation mechanisms such as easements and purchases in order to determine costs. Non-market values and benefits should also be taken into condition [13]. Lease back options can also be employed together with acquisitions so that Cities can recover portions of its investment [14].

The use of fees and taxes can also be used to try to recoup costs. In Pacifica, the City council approved the use of new fees for parking as a way to pay for beach restorations and maintenance [15]. Cities will have to look at the tradeoffs and conduct costs benefit analysis and mapping exercises in order to understand which areas are the most important to protect and which may be too costly to do so over the long term This may result in strategies such as one developed by the City of Norfolk in 2016, where a general reduction in development intensity was recommended wherever possible. [3]

Secondary Impacts

The lack of consensus on managed retreat can lead to long drawn out legal challenges which may impede the success of managed retreat projects. This can also lead to holdouts which can negatively influence the implementation of a retreat policy and be expensive to service [4].

Managed retreat can end up inadvertently attracting more development pressure on the coast if development is not disincentivized or if development moratoriums are not enforced or implemented.

Also, while managed retreat will reduce the vulnerability of assets which are relocated landward, it may also increase the vulnerability of certain areas by removing structures such as seawalls and allowing coastal processes to continue unimpeded. This would mean that these areas would be susceptible to ongoing hazards such as flooding and erosion in the future.

One disincentive for retreat is the high value of land and infrastructure in the coastal zone. This means that it may be cost prohibitive to try to relocate dense privately owned coastal residential areas. These areas would also serve as important tax bases for the local City or Government and this may have a knock-on effect of reducing local tax revenue if these areas are demolished or abandoned [4].

Benefits

Managed retreat can benefit cities by reducing the vulnerability of the coastal population to climate impacts such as coastal flooding, erosion and sea level rise and thereby prevent future injuries and loss of life. Relocating business and infrastructure can avoid disruption in the long term and avoid larger economic impacts and losses due to avoided costs from repeated and increasingly severe coastal hazards. Retreat scenarios can also have important benefits to the coastal ecosystems as they are allowed to naturally evolve as opposed to being impacted by hard engineering such as seawalls which may fragment ecosystems and disrupt coastal processes, resulting in narrower beaches over time [3]. Retreat can also encourage and facilitate habitat restoration, water quality improvements and improve coastal recreation. Retreat can also prioritize access to the coast and realignment of infrastructure such as roads, paths and parking spaces can help to facilitate this [10].

Properly planned and managed retreat can also assist in preventing adhoc and forced migration following disasters. It can also help to ensure that Cities can cater for the needs of its disadvantaged and low-income residents when considering sources of funding for relocation but also by ensuring access to services and to the coastal assets in the long term [3].

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Figures:

Figure 1. Managed retreat at Pacifica State Beach pre (2002, top) and post (2013, bottom) (photo source: Adelman & Adelman 2013)

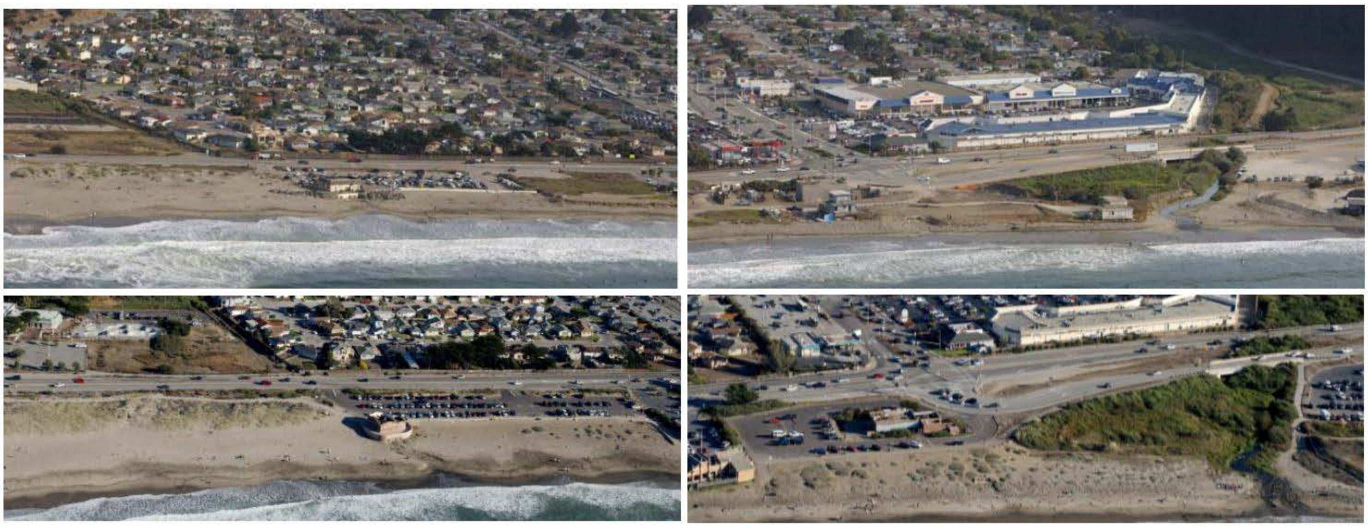

Figure 2. Surfer's Point: Before and After – source U.S. Geological Survey

Figure 3: **oject.**

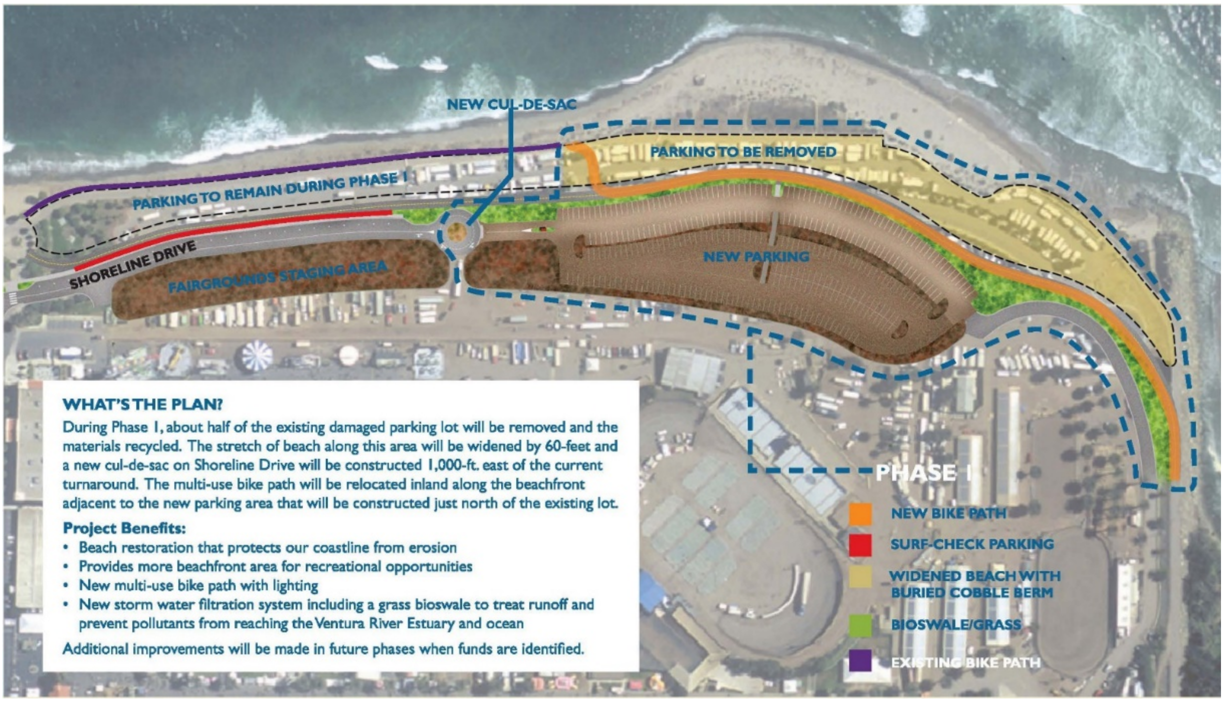

Figure 1 Areas completed in phase 1 outlined in Blue - Image source: Paul Jenkin, adapted from a map created by the City of Ventura.

LIVING SHORELINES

Description

The term 'Living Shorelines' is a relatively new concept which encompasses many different strategies and techniques surrounding the use of coastal ecosystems. The central approach is linked to efforts to incorporate natural habitats into shoreline stabilization designs. Applications of living shorelines range from the use of natural features and species, such as natural shoreline vegetation; to more hybrid approaches where such natural assets are paired with additional hardened features such as sills, breakwaters and biologs [1] [2]. Researchers, practitioners and private entities have also developed other alternative techniques such as utilizing salt marsh and oyster reefs to stabilize shorelines [3]. These efforts have multiple benefits such as maintaining connectivity between aquatic, intertidal and terrestrial habitats (which might otherwise be segmented by use of only traditional hard structures such as seawalls). Living shoreline approaches can help to minimize the effects of implementing shoreline stabilization on estuarine and coastal ecosystems and in many cases can also help to create new habitat [1].

Other terminology which encompasses the use of living shorelines is the use of nature or nature-based solutions. The use of features such as beaches and coastal dunes can help to dissipate wave energy over the surf zone and provide protection against coastal storms and inundation from future sea level rise. These existing features can be augmented by the use of beach replenishment and/or use of natural vegetation. If the geomorphology and coastal processes are suitable then features like dunes may even be constructed where not previously found. Even if dunes erode, they may still provide an important sediment source for beach recovery [4]. The terms ecosystem-based management and ecosystem-based adaptation also bear similar meanings and mirror similar approaches to living shorelines.

A useful graphic from the National Oceanic and Atmospheric Administration (NOAA) pulls together a continuum of different strategies including natural, hybrid and hard structures which help define where living shorelines may fall as part of an overall shoreline stabilization approach [3].

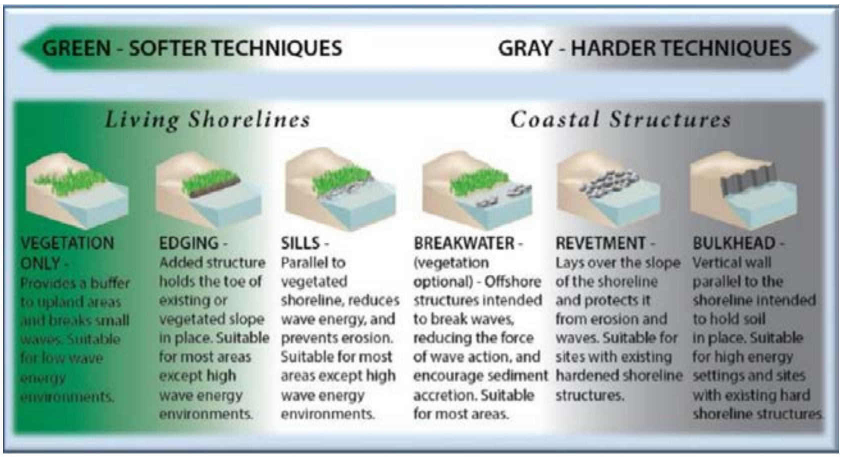

Figure 1: Guidance for Considering the Use of Living Shorelines (NOAA 2015)

In different parts of the US such as Maryland, Virginia and areas of the Gulf region, the use of wetlands, marsh lands, plants and stones have all been used as components of a protective strategy involving small bays and estuaries. However local geomorphological conditions play a major role and some of these interventions may not be feasible in high-energy wave areas present in large parts of California [5]. Some of the living shoreline concepts which have been trialed or implemented in California to date include native Olympia oyster reefs, eelgrass beds, tidal wetlands revegetation, upland ecotones, sand beaches, and coastal dune restoration projects. Additional habitats which may have important roles in future living shoreline approaches include coastal islands and boulder fields, kelp forests, rocky intertidal areas, and coastal bluffs [6].

Case Studies

San Francisco Bay Living Shorelines Project

The goal of the San Francisco Bay Living Shorelines project was to examine how creating and enhancing native ecosystems such as oyster reef and eelgrass beds can be used to minimize coastal erosion and maintain coastal processes while enhancing natural habitat. The project focused on a one-acre area, 200 meters offshore from the San Rafael shoreline with a variety of intertidal, nearshore and soft bottom habitats. A number of public and private entities were involved including the Environmental
Protection Agency, San Francisco Estuary Partnership, NOAA, the United States Geological Society and the Nature Conservancy, who provided the use of the land in 2012 [7].

As part of the main project interventions, Pacific oyster shell-bag mounds were used to encourage oyster recruitment to approximate a reef-like structure which could provide wave attenuation services. Eel grass was also planted both to provide additional biodiversity but also for its sediment stabilization properties. Both oyster reefs and eelgrass were situated in separate plots as well as in plots where they were combined. These were compared to control plots to understand the role of the different species in reducing coastal erosion. An additional experiment was run to look at the potential for different substrate types for oyster recruitment. These included reef balls, oyster blocks, and layer cakes composed of a mixture of cement, sand, shell, and rock called 'baycrete' [7].

Olympia oysters recruited quickly to both shell bag mounds and the baycrete structures with the shell mounds having a higher recruitment, likely due to their increased surface area and size. Although there was some initial sinking and sediment accumulation, the bags were stable after 5 months. Eelgrass density was highest when planted alone but also survived well when planted with shell mounds and resulted in higher biodiversity at the sites once there was sufficient space available [7].

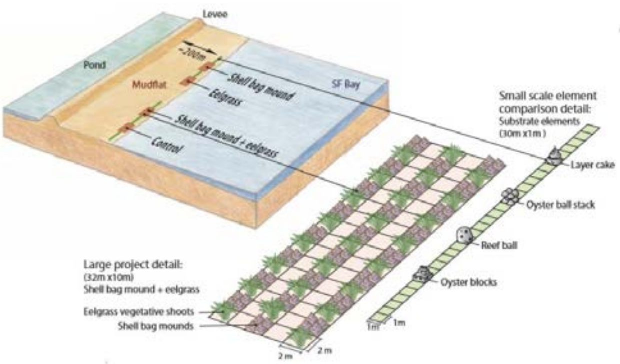

Figure 2. Schematic showing experimental design for large experiment and small experiment. Image credit ESA

Following continual hydrographic monitoring and wave modeling the project demonstrated that the combined oyster-eelgrass plots showed a 30% wave energy reduction effect as compared with control plots. The installation of the oyster reefs and eelgrass beds was also shown to have a positive effect on habitat, food resources and biodiversity with increases in certain fish species and wading birds which used the areas for foraging [7]. Over a one-year period over 2 million oysters were recruited to the structures [8].

The project cost was 2.5 million for the first five years, with allocations for design and permitting, construction and intensive post construction monitoring. The results of the project will be useful for informing future interventions of a similar nature in California and other areas of the US Coastline [6].

Salinas River State Beach Dune Restoration

The dune restoration project at Salinas River State Beach (SRSB) focused on enhancing the storm resilience of the local dune system. The SRSB dune system forms a continuous buffer, protecting the Moss Landing community, nearby estuaries and low-lying agricultural land in Salinas Valley from coastal storm flooding and erosion. The project goals included enhancing the resilience of the dunes by establishing native plants and eradicating invasive plants, including iceplant (*Carpobrotus edulis*). Iceplant is an invasive species that undermines the dune's physical integrity and ecological functions. As a result, the capacity of the dune ecosystem to act as an effective barrier to sea level rise and erosion is compromised. The project was funded the State Coastal Conservancy through the Climate Ready Grant Program with an approximate cost of $300,000 [9].

The project team lead by the Central Coast Wetlands Group and other state and local partners, including Coastal Conservation and Research Inc., California State Parks, and 'Return of the Natives', restored 20 acres of dune habitat. This was done through a combination of iceplant eradication, strategic planting of dune grass and the installation of hay bales and driftwood in order to facilitate the capture of sand and increase the resiliency of the dune face. Iceplant was mainly removed by herbicide treatment and hand removal. Treated iceplant was not removed from the dune so that it might serve as a natural mulch. In total, approximately 20,000 native plants were propagated, using seeds sourced from the dune system, during the 2016/2017 and 2017/2018 planting season. The project also upgraded local trails in order to reduce foot traffic throughout the sensitive dune habitat and prevent further erosion [9].

High resolution mapping was conducted before, during and after project implementation using differential GPS, Unmanned Aerial vehicles and Terrestrial Laser Scanners, this continued over a four-year period. Results show that while the dune habitats remained stable, the upper profile of the beach changed significantly; indicating accretion and erosion of sand as a result of local processes. These results seem to support the theory that removal of iceplant and replantation of native species has a positive effect on the profile of the dune, forming a more gradual slope which is less prone to erosion. The addition of hay bales and wooden features also appears to have encouraged sand accumulation and overall enhanced dune resilience (figure 4) [9].

Figure 3. Installation of drift wood and hay bales along the foredune help capture sand and increase dune roughness. Credit: SRSB Dune Restoration Project Final Restoration and Monitoring Report

The results of the study will help to inform future restoration efforts. Some of the final project recommendations include:

- That removal of iceplant over time has a positive effect and is more efficient through the use of herbicide treatment. Allowing dead iceplant to remain in place has the benefit of providing mulch for native species but also dissuading new iceplant recruitment.
- The need for long term monitoring of both plant health and dune dynamics to capture longer term changes and not just short-term natural cycles.
- The need to develop a Dune Rapid Assessment Method (DRAM) to create a cost-effective standardized monitoring strategy for dune restoration projects.

City of Encinitas, Cardiff Beach Living Shoreline Project:

The Cardiff Beach Living Shoreline project was implemented in 2018 with the goal of reducing the vulnerability of San Diego County's Highway 101 to flooding, primarily by creating dune habitat. The project was funded by grants from the California State Coastal Conservancy and led by the City of Encinitas and other partners, including the California Department of Parks & Recreation, U. S. Fish and Wildlife Service, and the San Elijo Lagoon Conservancy [10].

In total, the project constructed around 3 acres of new dune habitat. Existing un-engineered rip-rap at the site was reconfigured, together with a cobble core as the foundation for the sand dunes. This was designed with the intention that the rock would act as a last line of defense in cases of extreme waves and tides. Over 29,000 cubic yards of sand, imported from the annual dredging of the neighboring San Elijo lagoon, was used to form dunes which covered the rip-rap/cobble core. These were then planted with a mixture of native species in order to further stabilize the new dunes. One of the goals of the project was to ensure that the dune systems would persist for approximately 50 years and help protect the highway from future sea level rise and coastal flooding. This would be periodically maintained and augmented by additional planting and beach nourishment from the opportunistic use of the San Elijo dredge material. New pedestrian paths were also installed to reroute public access and parking facilities were realigned. The project will serve as an important pilot to assess the use of dune systems for coastal resilience [10].

The project was funded through a combination of grants from the California State Coastal Conservancy, the California Ocean Protection Council, the U.S. Fish and Wildlife Service and the San

Diego Association of Governments, totaling $2.5 million dollars. The project was completed in July 2019, although a five-year monitoring program will continue [11].

Lifespan/Effectiveness

As living shorelines are a relatively new approach there may some barriers to their widespread implementation. Other states such as North Carolina have less requirements in their regulations and permits for traditional armoring such as bulkheads when compared to living shoreline approaches. Living shorelines tend to require more extensive review by other agencies and can have other site-specific conditions. This makes it more difficult to encourage property owners to employ living shorelines due to extra time and costs involved [1].

Additional challenges include that few designers and engineers are familiar with nature-based techniques for coastal protection. Coastal communities and key stakeholders will have to be actively engaged for effective project implementation and to successfully manage expectations [3].

Some states are staring to include legislation and policies which promote the use of living shorelines as the preferred alternative for erosion control, especially in protected areas. This may help to make the environment for development of these technologies more conducive [3]. Non-structural interventions focusing on polices, zoning, building codes, plans and regulations should also help to enable further implementation.

States such as Virginia have comprehensive spatial mapping tools which recommend different natural interventions, including living shorelines, depending on the habitats and features already present. The Virginia Shoreline Management Model uses the presence or absence of natural buffers such as beaches and marshes, nearshore bathymetry, wave exposure, bank height, existing defenses and infrastructure as its main data inputs [12].

Due to their relatively recent development and implementation, there is some level of uncertainty in assessing the long-term effectiveness of living shorelines in addressing aspects of climate change such as storm surge and sea level rise. Strategies such as oyster reefs may have some resilience to rising seas as they can accrete vertically in place. However, they will most likely play similar roles to low crested breakwaters and will be unlikely to attain the vertical heights which can be more quickly achieved by seawalls and other hard structures. This makes them less effective in defending against high energy waves and storm surge [13].

Cost

Costs for living shorelines are varied depending on the type of ecosystem restoration involved, whether the approach will be a hybrid approach together with hard structures or focus more on actions such as replanting, the scale of the project area and permits required. Overall costs tend to be lower than hard adaptation alternatives, both in terms of installation and maintenance. Costs can vary from less than $1000 to $5,000 per linear foot with annual maintenance costs of less than $100 per linear foot being the norm [14].

Secondary Impacts

- The term living shorelines can be rather nebulous in some cases and different hard or hybrid structures may be termed 'living shorelines' where they may not significantly incorporate natural systems or may not have any positive effect on natural ecosystems in the area.
- Concepts involving the use of hard structures to facilitate the conditions for vegetation growth may also have unintended effects. These approaches may cause disruption of the natural habitats if they were not already suited to such vegetation due to local conditions and processes [15].
- New species which colonize an area after a structure such as a hybrid breakwater is installed may have negative effects if the species are non-native or have other adverse effects on the existing ecosystems [15].
- Living shorelines may provide a variety of different ecosystem services, however some care would have to be taken to ensure that utilization of one service does not reduce the value of others. One example is that oyster reefs will have value as both shoreline stabilization structures as well as provide for increased oyster habitat. Traditional destructive oyster harvesting practices would most likely result in damage to the reefs and in turn reduce their potential to buffer erosion. New practices may have to be initiated, such as using divers to harvest oysters in a strategic manner and timeframe so that other ecosystem services can still be sustained [16].
- There are also challenges with obtaining a steady supply of material with which to construct certain types of living shorelines such as oyster reefs [13]. Shell recycling programs have been advocated to fill these gaps. Sustainable sources of sand are also becoming challenging to locate and are often accompanied by high transportation costs. This may result in making beach and dune restoration as well as maintenance challenging going forward.
- Each type of living shoreline intervention will have its own level of impact on the immediate environment where it is installed. Table 1 below collates the potential effects of different shoreline stabilization methods on estuary habitat in North Carolina [17].

Table 1: Possible habitat changes as a result of different stabilization methods, North Carolina Division of Coastal Management (2006)

Land Planning	Vegetation Control	Beachfill	Sills	Groins	Breakwaters	Sloped Structure	Vertical Structure
Continued erosion with loss of upland	Reduces sediment and nutrient input into estuary	Changes from estuarine/sandy bottom to upland	Reduces sediment and nutrient input into estuary	Reduces sediment and nutrient input into estuary	Reduces sediment and nutrient input into estuary	Reduces sediment and nutrient input into estuary	Reduces sediment and nutrient input into estuary
	Reduces erosion landward	Reduces erosion landward	Reduces erosion landward	Reduces local erosion landward	Reduces erosion landward	Reduces erosion landward	Reduces erosion landward
		Could change sediment size distribution	Creates hard structure for non-mobile marine life	Creates hard structure for non-mobile marine life	Creates hard structure for non-mobile marine life	Creates hard structure for non-mobile marine life	Creates hard structure for non-mobile marine life
		Buries local shoreline type with sand	Fill resulting in wetland or upland	Sand trap or fill results in wetland or upland	Sand trap or fill results in wetland or upland	Could eliminate intertidal habitat or environment	Could eliminate intertidal habitat or environment
			Creates a new, lower energy environment	Increased erosion downdrift	Creates a new, lower energy environment	Reduces sediment to depositional areas downdrift	Reduces sediment to depositional areas downdrift
			Fragments habitat	Starves sediment depositional areas	Fragments habitat	Deepens water	Deepens water
			Increases habitat complexity	Increases habitat complexity	Increases habitat complexity	Increases habitat complexity	Concentrates turbulence
						Concentrates turbulence	

- Additional factors and stressors may have an important role in determining the success of different natural infrastructure interventions. Rainfall patterns can affect the growth of vegetation used to replant dunes, and water quality levels and outbreaks of disease can have an impact on the growth of oyster reefs. Aspects of assessing ecosystem health should be built into long term monitoring programs for living shorelines.

Benefits

- Oyster and coral reefs, seagrass, mangroves, dunes and other natural and enhanced coastal and marine ecosystems have the potential to attenuate waves, stabilize shorelines, and buffer storm surge in ways that match or surpass traditional hard stabilization efforts [3].
- In addition to reducing erosion, living shoreline approaches can also be important in improving marine habitat and spawning areas, improving water quality, and filter stormwater runoff [12]. For strategies like oyster reefs additional benefits include seashore stabilization, carbon sequestration, habitat provisioning for mobile fish and invertebrates, increased fish production, habitat for epibenthic fauna, increased epibenthic faunal production and biodiversity, diversification of the landscape and increased oyster production [16]. However, there may be tradeoffs depending on which services are prioritized over others.
- In the long term, hard adaptation approaches may be less cost-effective than ecosystem restoration, especially considering the negative potential influence of traditional armoring on ecosystem services such as reduction in sediment transport. Research has shown that in some settings, natural and enhanced shorelines may be more resilient to storms and recover faster after inundation [3].
- Living shorelines can provide a variety of benefits and ecosystem services to coastal communities in the form of:
    - food and livelihoods from fisheries (assessments of the economic value of enhanced fish production indicate that a hectare of oyster reef can yield approximately $4,000 in commercial landings [2].
    - protection from coastal hazards,
    - opportunities for recreation and tourism,
    - carbon storage and sequestration,
    - human health and well-being [3].
    - increased property values. Can also be used to satisfy zoning and permitting requirements for waterfront development projects.
    - opportunities for education such as the installation of signage and interpretation at project sites
    - improved public access to waterfront through recreational activities such as fishing, boating and birding [18].

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BEACH NOURISHMENT

Description

Beach nourishment is the process of artificially placing sand (or other aggregates such as gravel) on or near a coastline in order to restore an existing beach or construct a new one [1]. The intervention differs from sand scraping in that sediment is added from outside the system, normally from a 'borrow site', while sand scraping relies on the redistribution of existing sand [2]. Other terms such as 'beach replenishment', 'beach restoration' and 'beach fill' are often used interchangeably to describe the process [1]. Beach nourishment is often undertaken as a strategy to combat coastal erosion and to augment the natural buffering action of beaches against storm surge. It is increasingly being seen as an important adaptation tool in combatting sea level rise which threatens to inundate beaches and accelerate and exacerbate erosion and coastal storm flooding. Nourishment can be used with other adaptation strategies such as sand scraping, hard engineering, building codes, set-backs as well as in tandem with, or as a precursor to dune restoration [3]. It can be implemented as part of 'protect', 'hold the line' or 'advance the line' coastal management and adaptation pathways. It is often placed under the category of soft adaptation/engineering strategies alongside wetland and dune restoration.

Case Studies

Beach replenishment has been undertaken in many different countries throughout the world, dating back to the early 1900's with Coney Island being the first example in the USA in 1922 [4]. Other examples from the USA include Florida, the Gulf Coast, areas of the East Coast such as New Jersey and many parts of the West Coast including Southern California. Other countries include the Netherlands, the United Kingdom and Australia. Some recent examples are listed below:

California Examples

A recent study reviewed the impacts of beach nourishment at four beaches in Southern California. These beaches received between 68,000–344,000 m^3 of imported sand spanning 500–1500 m (see table 1 below) [5]. These include the Torrey Pines Beach which was nourished in 2001 and the Imperial, Cardiff and Solana beaches which were nourished in 2012. The grain size selected for Torrey Beach was similar to the native sand conditions while at the other three beaches a coarser grain size was used in comparison to the sand native to each beach. The sand placed at Torrey Beach was washed offshore after a short duration during a relatively mild storm whereas the sand placed at the other three beaches remained, even in the face of more energetic wave conditions. After an especially erosive 2015-2016 El Nino event all four sites recovered. The subsequent energetic 2016-17 winter events caused lower levels of dry sand at Torrey Pines whiles the other sites remained relatively stable. At Torrey Pines it appears that over a 16 year period since the last re-nourishment an overall loss of about 300,000 m^3 of sand took place, about 20,000 m3/yr. In contrast long term trends for the other three beaches have been harder to determine due to the relatively shorter time series [5].

It was noted that at Imperial Beach, placement of sand was effective in mitigating coastal flooding, however it may have exacerbated groundwater flooding by elevating the water table [5]. It appears that shortly after the original nourishment took place at Imperial Beach residents were subjected to pooling water on the landward side of the dry beach which threatened to undermine residential structures and foundations. A number of residents have filed a lawsuit against the SANDAG contractors for not properly considering the beach slope when conducting the replenishment [6].

Table 1: Beach nourishment statistics for four Southern California projects (Ludka et al., 2018)

Nourishment statistics.

Beach	Native Grain Size [mm][a]	Nourishment Grain Size [mm][b]	Nourishment Volume [m^3][c]	Subaerial Survey Area [m^2]	Jumbo Survey Area [m^2]
Torrey	0.23	0.2	187,000	171,715	1,094,546
Imperial	0.25	0.53	344,000	252,358	1,610,518
Cardiff	0.16	0.57	68,000	95,499	629,437
Solana	0.15	0.55	107,000	104,968	1,213,960

[a] D_{50} at MSL. Torrey, Imperial and Cardiff from Ludka et al. (2015). Solana from Group Delta Consultants (1998).
[b] D_{50}. Torrey from Seymour et al. (2005). Imperial, Cardiff, and Solana from Coastal Frontiers (2015).
[c] Coastal Frontiers (2005, 2015).

There were also problems associated with impacts to surfing locations, recreational activities such as swimming and beach access [7]. There have also been issues with project sand potentially contributing to blocking the mouth of the Tijuana River, threatening riverine ecosystems and wildlife and leading to stagnant and anoxic conditions [8].

The nourishment of the Torrey Pines beach was part of a regional nourishment of twelve San Diego beaches, totaling $17.5 million [5]. The Cardiff, Solana and Imperial beaches were part of a project involving five other beaches at a cost of $28.5 million [9].

Opportunistic Beach Nourishment

California's Coastal Sediment Management Workgroup and the San Diego Association of Governments facilitated the development of the Sand Compatibility and Opportunistic Use Program Plan for implementing opportunistic beach replenishment across California [10]. "Opportunistic beach nourishment uses sand that is extracted from a flood channel, debris basin, navigation channel, harbor area, a byproduct of construction or other source, where the main reason for extracting the sand is not to use it for beach nourishment" [11]. The use of nearby opportunistic sources can provide a cost saving alternative to the transportation of sand over large distances, whether by land or via dredging from offshore sources. It also provides a useful purpose to extracted sand which might otherwise have just been dumped offshore and potentially lost to the submarine canyons [11]. Opportunistic beach nourishment has provided the majority of sand historically used for beach nourishment in southern California [12].

The Sand Compatibility and Opportunistic Use Program Plan was crafted to streamline regulatory approval of small beach nourishment projects using opportunistic sources and materials [10]. As part of the development of the plan pilot nourishment projects were implemented in areas of northern San Diego County within the Oceanside littoral cell.

The plan advocates for a number of requirements and criteria for conducting beach replenishment, including but not limited to:

- The need for source materials to be free of harmful chemical or biological contaminants and be free of free of trash and debris.
- That the grain size distribution of the potential source must lie within a suitable envelope in an effort to best match conditions at the receiver site.
- That the sediment color must reasonably match the color of the receiver site after natural color changes occur. If not possible, then material can instead be placed in the surf zone [10].

A plan has also been developed for opportunistic nourishment in Monterey Bay. This plan identifies inland sources of sand and potential sites where sand can be stockpiled in preparation for future nourishment. This is in response to eroding sand dunes and undercutting of structures such as at Ocean Harbor House. The California Coastal Commission has expressed concern about environmental implications such as inundation of biota and has warned that these efforts are likely to only have temporary benefits and that relocation of assets may have to be planned for in the future [13].

Opportunistic nourishment also takes place in Santa Cruz in the form of harbor bypassing. This relies on the accretion of sediment at the Santa Cruz harbor mouth due to retention by the Seabright jetties. This sediment is dredged on a yearly basis and the sand is pumped out onto Twin Lakes Beach to allow for it to re-circulate into the system and feed downdrift beaches and littoral cells. This amounts to about 250,000 cubic yards of sand annually at a cost of roughly $2/cubic yard [14].

Mega-Nourishment: The 'Sand Engine' in the Netherlands

Another relatively recent approach to beach nourishment is to undertake 'mega-nourishment' which is designed to redistribute sediment over a much longer period as opposed to smaller nourishment projects which would have to be maintained more frequently over time. This approach depends heavily on natural processes to transport sediment. One of the best examples of this is the Dutch 'Sand Engine' initiative, now named DeltaDuin [15].

This 90 million dollar project aims to widen beaches by 10-20 km over a period of 20 years with little outside intervention as opposed to smaller scale replenishment projects where additional re-nourishment would be needed at regular intervals. A large amount of sediment is placed on the shoreface and the natural wave energy and circulation distributes the sand (See Figure 1). This provides a large beach area for coastal recreation as well as significant natural buffers against wave erosion. The need for less maintenance also reduces the impact and disturbance to local ecosystems by reducing the frequency of re-nourishment [15].

The aim of the sand engine was to provide long term flood protection in the face of increasing river discharges and accelerated sea-level rise. Many parts of the coastline of the Netherlands are already below sea-level and are vulnerable to rising seas [16]. The idea is that a single large (21.5Mm^3) locally concentrated nourishment would be able to feed adjacent areas of the coastline over time.

Lifespan/Effectiveness

There is a certain degree of uncertainty as to the long-term effectiveness of beach replenishment projects. In some cases, storms can quickly remove sediment and accelerate downstream loss [3]. Poor project design which does not account for local coastal processes can also contribute to replenishment projects having a limited lifespan. The use of the appropriate grain size when selecting sand sources is also vital in determining how the beach profile will evolve.

The inherent uncertainties surrounding sea level rise projections will also have an effect on long term planning and maintenance when implementing replenishment projects. Rising seas may mean that previously viable borrow sites may no longer be accessible and that access and availability of aerial sand is restricted [3]. Beach nourishment is also unlikely to be effective unless deployed alongside other strategies such as use of groins, or other structures which will retain the sand. This is due to high littoral drift rates characteristic of much of California's coast which will encourage additional sand to be moved alongshore [12].

The entire 'active profile' of the shoreline should be considered, including the dry or subaerial portion of the beach as well as the submerged or nearshore area. The two are connected and replenishment will affect the entire profile. In order to be truly effective, nourishment projects need to be planned carefully to address either short term sediment imbalances versus long term sea level rise and larger deficits in the sediment budget. A flexible monitoring scheme which considers long term erosion, morphology, bathymetry, beach sediment characteristics, sediment budgets and storm impacts will better inform nourishment practices and their associated maintenance [17].

Cost

Costs for beach nourishment can vary significantly based on the high transportation costs involved in moving sand from a borrow site to the project location. This can be in the form of overland vehicles and heavy machinery or other methods such as dredging of offshore sand sinks. Beaches also must be re-nourished periodically. Ocean City Beach in New Jersey has been re-nourished 22 times between 1952-1995 at a cost of over $83,104,502 [18]. A study by Leatherman et al., 1989 [19] indicates that costs are very site specific and based on the rate per cubic yard of material. In terms of dredging offshore sand, costs are predicted to rise approximately $1.00 per cubic yard per mile farther offshore as near-shore supplies are diminished [19].

Some costs may be offset by taking advantage of dredging which is already planned such as in federal navigation routes and harbors. This includes all federal harbors along the coast including the San Francisco Bay entrance channel, Santa Cruz and Monterey, as well as other sources such as through river maintenance. The sand compatibility and opportunistic use program plan developed for the San Diego Association of Governments and the California Coastal Sediments Management Workgroup details these opportunities and provides specifications and guidance [20]. Some examples of costs can be found in the study done by T.D. Clayton, 1991 [21] and in the online database developed by the Program for the Study of Developed Shorelines at Western Carolina University (http://beachnourishment.wcu.edu). Some costs from the East Coast can be found in Table 1 [22].

Secondary Impacts

Environmental Effects

Depending on where the sand is sourced and the method used to extract and transport sand and sediment from the borrow sites, beach replenishment can have serious implications for the health of the marine and nearshore ecosystems. This can include disturbance to flora and fauna including changes to species feeding patterns. Shorebirds and endangered species such as sea-turtles which rely on beaches for nesting are likely to be heavily affected in the early stages. One change that may occur is that beach profiles may become much steeper resulting in turtles making false crawls or abandoning nesting efforts [1]. Changes in nearshore climates due to modification of the local bathymetry can have knock-on effects on intertidal and sessile communities. Replenishment can also result in elevated turbidity levels as the newly introduced sand is either pumped onshore or delivered by heavy machinery [1].

It is also important that the necessary studies be done on the sediment to be acquired from borrow sites. This includes investigating the potential for the borrow sediment to house contaminants such as heavy metals. One such occurrence took place when the US Navy attempted to utilize sand from a dredging project for a replenishment project in San Diego. Unfortunately, the sand was found to contain munitions and chemical contamination. Careful analysis and planning should take place beforehand to avoid this [18].

Development

One concern is that although beach replenishment provides increased areas for recreation and buffers against coastal flooding it may result in incentivizing further coastal development in high hazard areas. This may be because of the false sense of security a wider beach may provide in terms of buffering effects against storm waves and wind [18]. A combination of strategies should be considered alongside replenishment including hard engineering, overlay zones and setbacks as well as tax incentives.

Retreat policies may also have to be considered in long-term planning strategies. This is particularly true in sparsely developed, rapidly eroding coastlines and where the long-term cost of maintaining nourished beaches are extremely high [18].

Benefits

Public Access

It will be important to ensure that replenishment projects result in equitable access to beach areas and that access is not sacrificed solely for the protection of commercial buildings and infrastructure. This should include convenient perpendicular access at well-marked access points and the provision of adequate support facilities such as parking, shuttle services, restrooms, and food services [18]. Access is important for many coastal livelihoods such as fishing as well as coastal recreation and tourism.

Beach nourishment can provide larger areas for ecosystems to migrate including coastal vegetation and dune systems. If carefully planned then turtles and shorebirds may benefit from increased coastal habitats.

In addition to its use as a tool for combating coastal erosion, beach replenishment has also been advocated because it:

- Tends to be less expensive and easier to construct as opposed to hard engineering,
- Is aesthetically more pleasing and thought to be more environmentally sensitive
- Provides a source of sand for wind-created or artificially created dunes
- Utilizes opportunistic products from dredging or construction projects
- Contributes to the littoral sediment budget and may help to feed down-drift locations
- Can create habitat for biota [1]

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Additional Resources

Beach Nourishment Viewer - http://beachnourishment.wcu.edu/ - Program for the Study of Developed Shorelines – Western Carolina University - This database lists primary funding source, funding type, volume of sediment emplacement , length of beach nourished and cost and inflated cost for 2,054 identified beach nourishment episodes dating back to 1923.

Figures and Tables

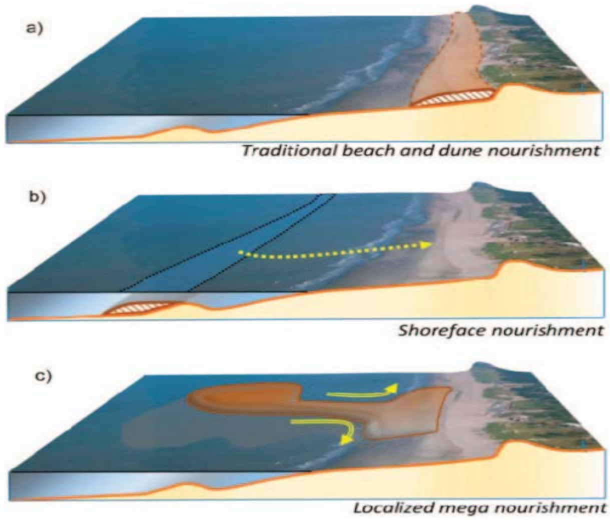

Figure 3. Conceptual diagram displaying different nourishment strategies. (a) Traditional beach and dune nourishments, used frequently from the 1970s onward, place sand directly on the beach and dunes. (b) Shoreface nourishments, initiated in the 1990s, make use of natural marine processes to redistribute the sand that is placed under water in the cross-shore direction and gradually create a wider coastal defense over time. (c) Concentrated mega-nourishments, as introduced here, exploit both marine and aeolian processes, to redistribute the sand both in cross and alongshore directions.

Figure 1. Conceptual diagram displaying different nourishment strategies (Stive et al. 2013)

Table 1. Estimated cost to nourish the entire length of developed shoreline along four states over a 10 year period, based on assumptions of episode life span and average cost per mile of shoreline. From Leonard, L., Clayton, T. & Pilkey, O. (1990)

Location	Miles	Cost/mile	Life span	10-Year cost
New Jersey	90	3.5 million	2 years	$1,575 million
North Carolina	138	2.0 million	4 years	$690 million
South Carolina	60	1.0 million	3 years	$200 million
Northeast Florida	113	2.5 million	5 years	$565 million
Southeast Florida	175	2.5 million	7 years	$625 million
Gulf Coast Florida	160	2.7 million	6 years	$720 million
Total Florida	448			$1,910 million
Total all locations	736			$4,375 million

Figure 4. Time lapse of Seacoast nourishment project (top: 2010 pre, middle: 2012 during, bottom: 2019 post. Google Earth)

GROINS

Description

Groins are hard engineering structures which are installed perpendicular to the shore in order to interrupt longshore drift and impede the flow of sediment along a shoreline. This causes nearshore sand and sediment to accrete on the updrift side of the structure until the capacity of the groin is reached. Once the different segments of a groin are filled, then sand can continue to bypass the structure and feed downstream coastal cells. Single groins may be installed in strategic locations to protect the coastline or multiple groins or fields may also be utilized. The accretion of sand caused by groin installations can diminish the sediment supply to downcoast areas, leading to accelerated erosion. This may be mitigated by artificially nourishing the groin on completion and allowing sediment to bypass the groin [1], [2].

Groins have been compared to artificial headlands in the way that they function. They are able to trap sand and create beaches where they previously did not exist or they can be used to stabilize or widen existing beaches. They are important tools in reducing short and long-term beach erosion [3]. Groins have been successfully used at a limited number of locations in southern California but have often been lumped with the much larger breakwaters and jetties as structures that have had major secondary or negative downdrift effects [3].

Case Studies

There are examples of groin installations in southern California where the aim was to stabilize or widen existing beaches. These include groin fields at Ventura, Malibu, Santa Monica, and Newport Beach and single installations such as the one in Capitola.

Santa Monica Groins

Installation of the six Bel Air Club groins in Santa Monica Bay has had positive effects on the initially narrow beaches. The concrete groins had the effect of extending the effects of the existing rock reefs [4]. The result was that a wider and more stable beach was created. The shoreline appears to now be in equilibrium and the impact on sediment transport to down drift beaches appears to be minimal.

Las Tunas Groins

The Las Tunas Groins are some of the oldest groin field in California. The structures consist of 13 groins constructed from steel sheet piles capped with concrete. The main purpose of the groin field was to widen the beach and protect coastal infrastructure and residents. Despite low littoral drift rates, the groins performed well initially. Over time, the integrity of the groins deteriorated, leaving jagged metal projections protruding from the shoreline which led to safety concerns, lawsuits and proposals for removal and the construction of new groins [5]. This prompted the Coastal Commission to approve a proposal to remove five of the groins. One groin was capped and restored. This may be a useful indicator of the lifespan of such structures. Low littoral drift may also lower the effectiveness of groins in their ability to trap sand [6].

Capitola and Seabright

The groin in Capitola was constructed after the Santa Cruz Harbor was installed and had the negative effect of impeding sediment from travelling down the coast (See Fig 1). This caused the loss of the pocket beach in Capitola which was an important tourism asset [7]. The groin was constructed in 1970 and filled with approximately 45,000 m^3 of sand. This initial fill helped to mitigate the downcoast effect on nearby beaches and the groin has been successful in trapping enough sand to form a wide public beach during summer months. At present sand is dredged annually from the Santa Cruz Harbor in order to maintain the channel depth and also to allow sediment to bypass the harbor and continue downcoast. The Harbor's jetty has also played a similar role to a groin and has been responsible for the formation of a wide permanent beach at Seabright as well as contributed to the expansion of Main Beach [3].

Imperial Beach

Erosion at Imperial beach was attributed to sediment loss from the damming of the Tijuana River. This has resulted in a lack of flood flows since 1944, reducing the overall sediment available to the nearshore. Private persons installed stone revetments and the Corps of Engineers was authorized to construct five groins in the area. The construction of two of the five groins proved ineffective however as the groins' compartment did not fill and further work was deferred [8]. The general failure of such groins can be attributed to the structures being too short in length or to the installation being in locations having a zero or near zero net longshore sand transport environment [6]. Local conditions are also very important as it appeared that onshore-offshore transport, rather than longshore transport played a more important role in determining loss of material at Imperial Beach [8].

West Newport Beach, Orange County

Eight rock and sheet pile groins were installed in West Newport Beach in the 60's and 70's in order to prevent the shoreline from receding. Their role in reducing erosion appears to be unclear. Sediment losses from damming of rivers upstream, as well as the length of the groins may have resulted in the structures being less efficient. Additional efforts in terms of multiple nourishment projects and the creation of an offshore mound using sediment from the Santa Ana River appear to have helped to widen and stabilize the shoreline. However southern swells, potentially exacerbated by climate change still pose a threat to coastal development. [9]

Lifespan/Effectiveness

As a short-term strategy, groins may be an important tool to stabilize beaches along California's coast [3]. However, the overall sediment supply in a particular region should be considered before installing groins. This includes looking a sediment sources such as rivers and ensuring that dams are not impeding transport. Other sediment retention structures which have been installed nearby, such as jetties and harbors may also impact sediment transport. Local coastal processes such as rip tides may also reduce the ability of a groin to trap sand over the long term. The cost of sand in the future may be an important factor in deciding whether to artificially nourish groin compartments.

Coupling beach nourishment projects with groins has been shown to significantly increase their lifespan and effectiveness in retaining sediment and preventing loss from the nearshore zones. This approach may result in larger capital costs but could reduce the amount of future nourishment needed to maintain beach width as sea level rises. [10]

Sea level rise may impact the effectiveness of groins in certain ways. Submergence of the groin can lead to overtopping by longshore currents and a retreating dune line due to rising seas may cause groins to be flanked on the landward side as well, allowing sand to bypass the groin and be lost [2].

The materials used as well as the placement and design of groins are critical factors to ensure success. Locations should be areas with high, mainly uni-directional littoral drift so that the groins can be recharged throughout the year, especially following winter scour and erosion. This appears consistent with much of California's coast [3]. Material composition as well as site specific information such as littoral cell positions also influence groin effectiveness [10].

Some important design considerations and precautions include: "height, length, location, material, spacing, and orientation of groins, location within a littoral cell, as well as the sand volumes needed to fully charge the area upcoast of groins following construction [3], [6].

In California, the most effective existing structures appear to be located where the coast is oriented between 240 and 310 degrees, and where there is a substantial net longshore sand transport rate. Structures on west facing parts of the coast appear to be less effective [6]. (See Figure 3 showing effectiveness of different groins in Southern California)

In the face of significant sea level rise existing groins would have to have their crest raised, have additional beach fill to counter submergence or be extended inland. Groins may help to control erosion which may be exacerbated by sea level rise but will not directly control the resulting shoreline recession [11].

Cost

Groin cost can vary greatly depending on foundation used, the design dimensions, materials used and the strength specifications of the structure. Costs can range from under $100 to over $1000 per linear foot with the lower estimates for minor projects, while the higher costs represent extensively engineered groins in a severe wave climate. [12]

Groins have been constructed from a variety of material including concrete and wood sheet piling, concrete blocks, or timber cribs filled with stone. On the Atlantic Coast of Delaware installed wood pile groins had an estimated cost of $984/m ($300/ft) in 1975. Typical 1980 costs per foot of shoreline for groins could vary from $100 to $1,500 depending on criteria such as: level of wave attack, whether or not beach fill will be placed, and beach slope [11].

Secondary Impacts

- Groins have inherently different purposes, and unlike seawalls or revetments, are not designed to protect back shore development or infrastructure (except perhaps indirectly) as opposed to retaining sand.
- They may restrict access to the beach for recreation use such as walking and jogging and also may create difficulties involving horizontal beach access, such as for disabled persons. Due to their nature to drastically change the coastal vista and compartmentalize the beach, public support for groins may be difficult. [8] [10]
- There is an ongoing debate about impact of surf breaks. Some groins have been shown to create new surf breaks whereas other have been blamed for degrading or destroying surfing areas.
- Interruption of longshore transport by groins may affect downcoast areas as well as benthic habitat and animals
- Public safety is also an important consideration, lawsuits can be filed if groins are shown to pose a hazard to beachgoers, for example due to poor maintenance. Groins can often create rip currents that can pose a danger to swimmers [13]. The use of appropriate signage and design can help to minimize the risk of injury and limit public liabilities [3].

Benefits

- Groins can assist in providing wider and more stable beaches for both recreational use and coastal protection
- By impeding sediment loss in strategic locations, groins can help retain sand on beaches before it is permanently lost in areas outside of coastal cells, such as in submarine canyons
- They can be of variable length and height and do not require annual maintenance or dredging [3]. They can also be constructed in phases and help to create a buffer to allow for removal of other structures such as seawalls or for longer term strategies such as managed retreat.
- By filling groin compartments on completion of the structures, erosion impacts on downcoast beaches can be minimized.
- There may be opportunities to complement or extend existing natural features such as headlands and rock reefs to fulfill similar roles as man-made groins.
- In certain areas, groins may be able to create new surfing conditions
- If a groin is effective then it may greatly reduce the need for additional shoreline armoring

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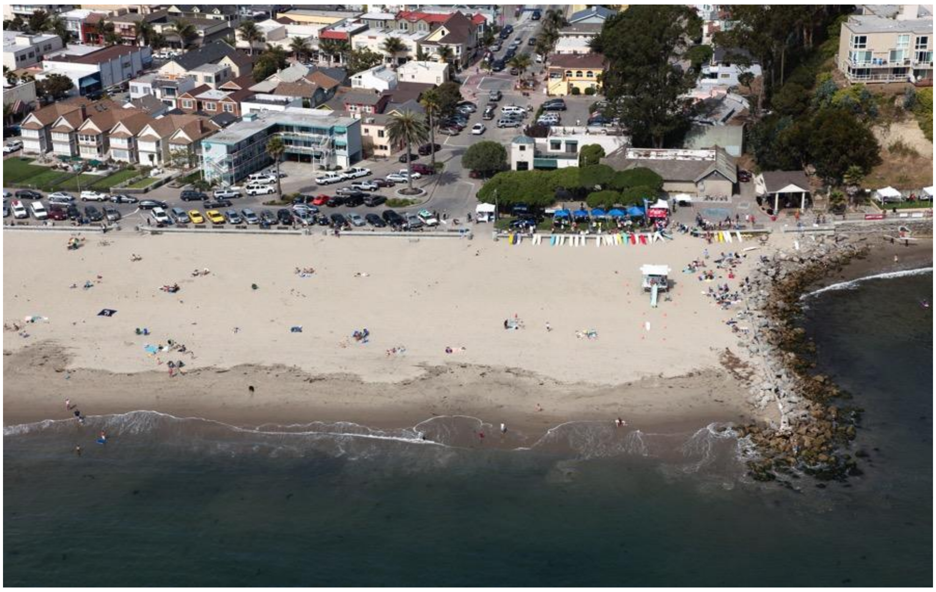

Figure 5: Capitola Groin, 2009 California, Coastal Records Project. Copyright © 2009 Kenneth & Gabrielle Adelman. All rights reserved.

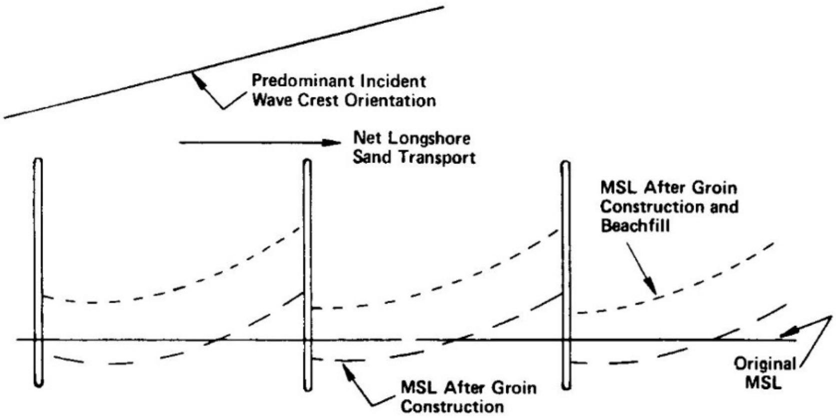

Figure 6. Schematic of typical groin field (Sorenson et al 1984)

Table 2. Summary of upcoast beach performance for existing groins in Southern California (Everts Coastal 2002)

Groin Location	Number of structures	Effectiveness in retaining a fillet beach	Reason
Imperial Beach	2	Ineffective	Too short
Coronado (Hotel del Coronado)	1 (curved structure)	Effective before 1946; relatively ineffective after 1946 **(no downcoast impact at present)**	1946 beach enhancement reduced effective groin length; structure now functions more like an offshore breakwater
Ocean Beach	1	Ineffective	Zero Q_n environment
San Luis Rey River, Oceanside	1	Possibly effective **(downcoast impact not defined)**	Q_n controlled by Oceanside Harbor breakwater and sand bypassing
San Juan Creek, Dana Point	1	Moderately effective **(downcoast impact not defined)**	Q_n controlled by Dana Point Harbor breakwater
West Newport, Newport Beach	8	Ineffective	Too short for near zero net longshore sediment transport environment
El Segundo, Chevron Groin	1	Effective **(downcoast impact required a revetment)**	Moderate Q_n environment
Playa del Rey	2	Ineffective in 1985-87	Too short
"LA Groin", Playa del Rey	1	Effective in the past; probably ineffective today **(downcoast impact not defined)**	Moderate Q_n environment
Venice	2	Ineffective	Too short
Will Rogers State Beach, Santa Monica	4	Effective **(downcoast impact mitigated by fillet retained upcoast of the Santa Monica salient)**	High Q_n environment
Sunset Blvd., west Santa Monica	1	Effective **(downcoast impact mitigated by revetment that protects a restaurant parking lot)**	High Q_n environment
US Navy, Point Mugu	3	**Effective (adverse downcoast impact required a revetment)**	High Q_n environment
Ventura	7	Effective **(downcoast impact partly mitigated by Ventura Harbor breakwater and salient)**	High Q_n environment

SEAWALLS

Description

Seawalls are an example of a hard adaptation measure. They are prominent around the California coastline along with other types of hard engineering such as rip-rap. Seawalls are near vertical, shore parallel structures which are normally built to protect landward development against storm waves [1]. They can be installed as a result of degradation or loss of natural protective buffers due to coastal erosion [2]. Whereas groins and beach nourishment help to expand the beach, seawalls do not usually facilitate accretion and are constructed to halt cliff, bluff and dune erosion and protect infrastructure and development above the high tide line [3]. (See Fig 1.)

Seawalls as well as other coastal armoring vary widely in the type of material used in their construction and in their engineering design [3]. This can have an impact on their relative success as well as the maintenance required to upkeep the structure in the future. The main types of concrete seawalls are gravity walls which are self-supported by their large mass, cantilever walls which require a deep foundation, and tie-backwalls which are braced by cables or rods and anchored on the landward side of the structure. Designs may incorporate vertical or conical faces which assist with reflecting wave energy back out to the ocean [4].

Case Studies

O'Shaughnessy Seawall, Ocean Beach, San Francisco

The O'Shaughnessy Seawall in San Francisco is an example of a carefully engineered structure which has lasted over 75 years without needing major repair [5]. The seawall was built in 1915 along San Francisco's Ocean Beach. The structure incorporates designs which are still relevant today and includes elements that reduce typical weaknesses and causes of failure. An example of this is that the wall incorporates the adjoining concrete sidewalk and a layer of impervious clay to prevent spray and runoff from seeping behind the wall. Water also drains quickly through oversized drainage holes to prevent pooling on top of the wall. These examples of surface and subsurface drainage designs help to increase the lifespan of hard structures like seawalls in the long term [4].

One of the reasons why the seawall had persisted so long may have been the regular maintenance which was conducted on the structure. Before 1960, regular work was done on the wall in the form of filling cracks and gouges and replacing rebar. However, at some later point this was halted due to budget constraints. This resulted in degradation such as exposed steel reinforcing rods at the northern end of the wall which have become increasingly vulnerable to rust [4]. Regular maintenance appears to have continued after 2016 with funding from an oil spill settlement.

Sand buildup and overflow also appears to be an issue with the O'Shaughnessy Seawall as the sediment is prevented from accreting naturally inland (See Fig 2). About 50% of the original structure is buried in sand, affecting stairwells, promenades and parking lots with accretion appearing greatest at the northern end of the beach [6]. In 2015, 42,000 tons of sand were moved by the San Francisco Public Utilities Commission as part of the Ocean Beach Sand Management Project to erosion hotspots in other areas of the beach [7]. This appears to have become necessary again in 2018 [8].

A present-day cost estimate for this seawall is around $5000 per linear foot [4]. More recent extensions of the seawall have cost over $7000 per linear foot [5]. Under the Ocean Beach Master Plan there are designs to create additional public space, parking, public amenities and native planters in the area bordering the seawall.

Elliott Bay Seawall Project, Seattle

The Elliott Bay Seawall in Seattle was completed in 2017 over the course of four years. The seawall replaced an older structure originally built in 1916 which was deemed to be vulnerable to seismic hazards, wind driven storms and storm surge. The new seawall incorporates multiple components including environmental and recreational aspects. The final design included the creation of intertidal habitat, including an artificial beach, the installation of crevices and ledges in the seawall face to allow for invertebrates and algae and the addition of glass blocks to allow for natural lighting to improve productivity and salmon habitat under the structure, spanning 3,700 ft [9] (Fig 3). The new seawall is designed to last for 75 years, the majority of which was funded by a voter approved bond [10]. The seawall has been constructed in order to cope with the worst sea level rise projections up to 2100. At 2100 projections the wall should still be at least three feet above water levels. Final costs approached over $350 million dollars for this first phase. Future phases will focus on additional areas of seawall and recreational areas such as a promenade.

East Cliff Drive Parkway and Bluff Protection Project, Santa Cruz

Regular cliff failure due to wave induced erosion at East Cliff Drive in Santa Cruz necessitated the repair of the local road and bluff and the restriction of traffic to a one-way direction. Local stakeholders saw the need to preserve and maintain regular use of this popular recreational area in the long run, especially for pedestrians, visitors and cyclists. This resulted in plans to construct a generous public walkway and bike path, safety railings and landscaping and improvements to the local park including reconfiguring parking. In order to facilitate this, work first had to be focused on the stabilization of the eroding coastal bluff. This consisted of the use of concrete “soil-nail” seawalls (a type of retaining wall made out of shotcrete) which were sculpted and designed to mimic the color of the surrounding bluff [11] (See Fig 4).

The project involved three phases, which focused on 2 bluff protection structures (one at ‘The Hook’ and the other between 33rd and 36th Avenue) and the third focusing on the Parkway area. As part of the project new access points were constructed in the form of stairways at Pleasure Point and concrete rubble and rock rip-rap were removed from the beach. Road and path improvements, as well as improved drainage were also incorporated into the project. Although other alternatives such as groins were considered, the full bluff armoring scenario was chosen as it maximized access and parkway and transportation improvements [11].

The County of Santa Cruz also reviewed the implications of a ‘do nothing’ alternative. Studies commissioned by the County indicated that a large percentage of the roadway would become unsafe within a short time period due to regular and unpredictable erosion of the bluff. This would also affect public utilities such as an important waterline within as little as two or three storm cycles [11].

Although the project qualified for federal funding, initial review by the Coastal Commission did not find that the project was consistent with the California Coastal Management Program [12]. As such, the project was funded by the Santa Cruz Redevelopment Agency and County Department of Public Works. The project was approved by the Coastal Commission in 2007 and work was finalized in 2012 [12]. Initial estimates by the Army Core of Engineers for the seawall component of the project were around $7 million [13].

As part of the permit application the Coastal Commission mandated that monitoring be undertaken to evaluate the project's influence on the quality of surfing waves, by recording changes in the patterns of wave energy within the study area [13]. This is most likely due to the recreational and cultural importance of surfing at the adjacent Pleasure Point site.

Lifespan/Effectiveness

In order to be sustainable in the long term, seawalls and other types of armoring must be able to survive overtopping by storm waves, undermining by coastal processes and scour and direct impacts from waves, sediment and debris [3]. Seawalls will have to be constructed to withstand the upper limit of these hazards and the design and materials used will influence the lifespan of the project. However, it may be becoming more difficult to obtain permits for new structures as both coastal cities and the Coastal Commission now appear to be stricter at reviewing the long-term vulnerability of coastal infrastructure and weigh multiple costs, both environmental and economic in their decisions.

Under the Coastal Act, new coastal armoring is only allowed to protect existing structures and new buildings must be setback from the coast to avoid erosion. The Coastal Commission, in coordination with local coastal planning agencies, provides permits for coastal protection structures. However ambiguous language in the Act has not dissuaded homeowners from striving to protect their property on their own [3]. It appears that the Commission may be revising their internal guidelines, passing resolutions stating that seawalls should only be permitted if necessary and if no other alternatives remain [14]. Recent events have shown that beachgoers and public access are being considered more strongly by the Commission and property owners who construct seawalls may be fined for damaging the beach [14].

Another example of this evolving view and the possible implications for private landowners can be seen at Del Monte Beach in Monterey. Facing ongoing property damage through coastal erosion, wave impact and storm surge, local homeowners applied for a permit to construct a seawall to protect the Ocean Harbor House condominiums at Del Monte Beach. This permit was granted by the City, although the Environmental Impact Report stated that the structure would restrict public access to the beach and cause loss of the beach through passive erosion. Conditions were built into the permit to provide access to the public through private land and to ensure the seawall matched the aesthetics of the surrounding landforms. On review of permit by the California Coastal Commission, a sand replacement mitigation fee was mandated to mitigate the loss of about 1 acre of beach area, amounting to a fee of $5,300,000. Homeowners disagreed with the additional requirements, viewing it as akin to an unconstitutional taking, and filed a lawsuit. Ultimately the

Court upheld the mitigation fee as mandated by the Commission [15]. The final stages of the wall were competed in 2008.

Cost

During to their varying construction methods and material used, seawall costs can vary greatly. Approximate costs per linear foot are around $7,200 in northern California and $6,250 in southern California, although the amount can vary due to location and the engineering profile and design. Annual costs for maintenance approximate to 2.5% of the capital cost of construction [1]. Despite their durability, seawalls are often not used due to their high cost [5].

Secondary Impacts

Passive and Active Erosion

Many of the impacts surrounding seawall installations revolve around the fact that seawalls effectively fix the shoreline at a single point. This creates the effect of an artificial headland as the surrounding areas, such as beaches and cliffs not protected by the seawall, continue to erode. This may eventually mean that the shoreline may retreat landward of the structure, causing the structure to be flanked by the sea. The profile of the beach in front of the seawall may also be affected as the water deepens, resulting in the beach becoming narrower. The updrift side of a wall that extends onto the beach can also function as a groin, contributing to sediment starvation downdrift [2].

The wave energy reflecting off of the face of the seawall can also cause scour at the base or toe of the wall, potentially undermining the structure [4]. The end result is that the wall may be weakened by removal of fill from behind and underneath the structure [3]. Recent studies appear to indicate that active erosion caused by the reflection of wave energy off of hard structures does not have as significant an effect as previously thought and that passive erosion is more of a pressing concern [3].

Visual Impacts, Public Access and Downstream Effects

Seawalls drastically affect the aesthetic of coastal areas and are often seen as unnatural and unwelcoming to recreational beach experiences. However, there are some seawall designs which have attempted to mitigate this. The use of materials such as shotcrete (a process where concrete is projected or shot under pressure to form structural shapes) can be used to mimic the color and shape of surrounding cliff and bluff faces, giving a more natural look. An example where this has been used is the wall protecting the cliff behind Cowell's Beach in Santa Cruz [3] (See Fig 5).

Seawalls do invariably take up considerable space on the coastline, potentially restricting public access and displacing areas of the beach where they are immediately installed. This is termed placement loss or impoundment. However, the design of most seawalls makes them preferable to rip rap in this respect as they have a smaller footprint and have less of a visual and physical presence on the beach [3].

Seawalls and other armoring also prevent the natural erosion of landforms which would ultimately contribute to the sediment supply. This can reduce the supply of sand which feeds nearby beaches and influence erosion of cliffs and bluffs downcoast [3].

Biological Effects

Installation of coastal structures such as seawalls can directly smother and kill organisms during the construction phases as well as cover up and/or displace vital habitats for fish, algae and invertebrates [16]. On the other hand, these structures may also create space for new and potentially invasive species to settle. Allowing coastal structures to mimic existing landforms with their corresponding micro-habitats could help avoid loss of natural diversity [3]. Revetments may also be an alternative which may have less impacts on intertidal flora and fauna [2].

Removal of Structures

Although costly and expensive, existing hard structures can be removed if they have failed or have considerably degraded. This may be an opportunity to create new habitat or transition to soft adaptation measures. One example of this is in Puget Sound, Seattle, where a portion of a seawall was removed and beach replenishment used to form a pocket beach and habitat for migrating salmon [17].

Benefits

- Although seawalls are not designed to protect and restore beaches, they are effective at protecting land and homeowners from coastal flooding, storms and sea level rise within their design limits.
- They are relatively simple to construct and maintain and have a smaller footprint in comparison to revetments.
- Although traditionally seen to be visually and aesthetically unappealing, many structures have become local icons and have accrued cultural and heritage value, even serving dual functions as boardwalks and promenades [18].
- New seawall designs are attempting to increase resilience to coastal processes, reduce maintenance, create habitat and allow for recreational use in the design of the seawall [2].
- They can be used in areas where there is no beach, e.g. at the base of coastal cliffs and they can be designed to mimic the color and shape of natural features. This may help to create buy-in from local stakeholders who want to preserve the natural aesthetics of an area.
- Concrete seawalls appear to be one of the most durable types of coastal protection. Although expensive compared to structures such as rip-rap, if well designed then maintenance costs can be reduced [4].
- Seawalls can be installed as part of a wider array of adaptation strategies such as use of groins and rip-rap.

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Figures

Figure 1: Example of Seawall in Aptos, Santa Cruz, California Coastal Records Project.

Figure 2. Partial burial of O'Shaughnessy Seawall, SF, California Coastal Records Project.

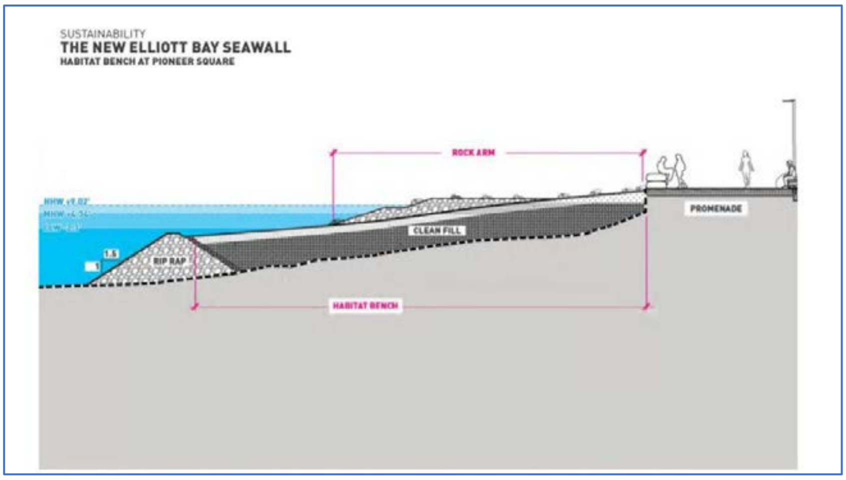


Figure 3: Elliott Bay Seawall Design Cross Section [19]

Figure 4: Hard infrastructure mimicking existing cliff face at The Hook, Capitola, California Coastal Records Project. *[Copyright © 2005 Kenneth & Gabrielle Adelman. All rights reserved.]*

Figure 5: Cliff stabilization designed to mimic cliff face, Cowell's Beach, Santa Cruz. From R. Stamski. (2005).

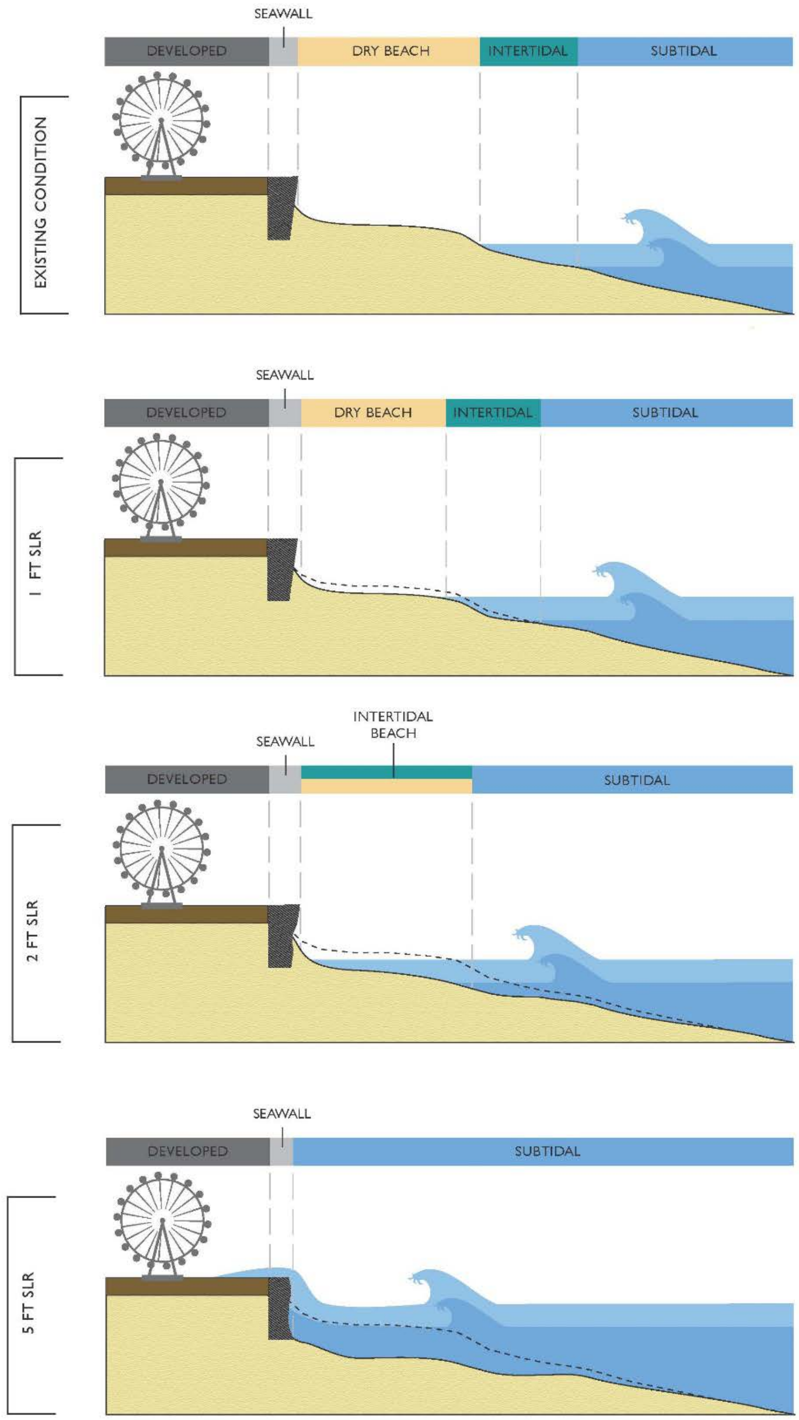
Appendix C:

Diagrams of Coastal Change

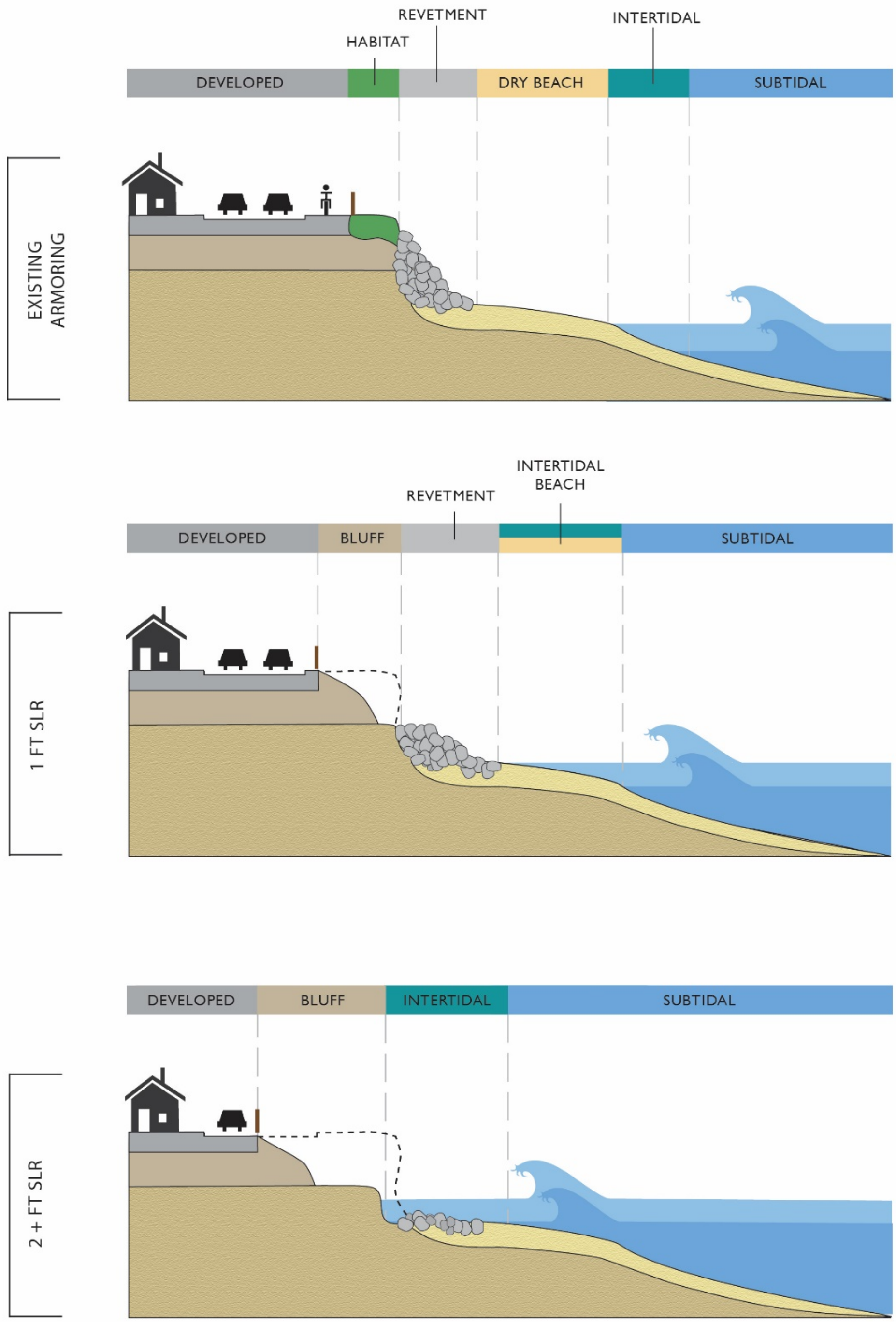
&

Common Adaptation Strategies

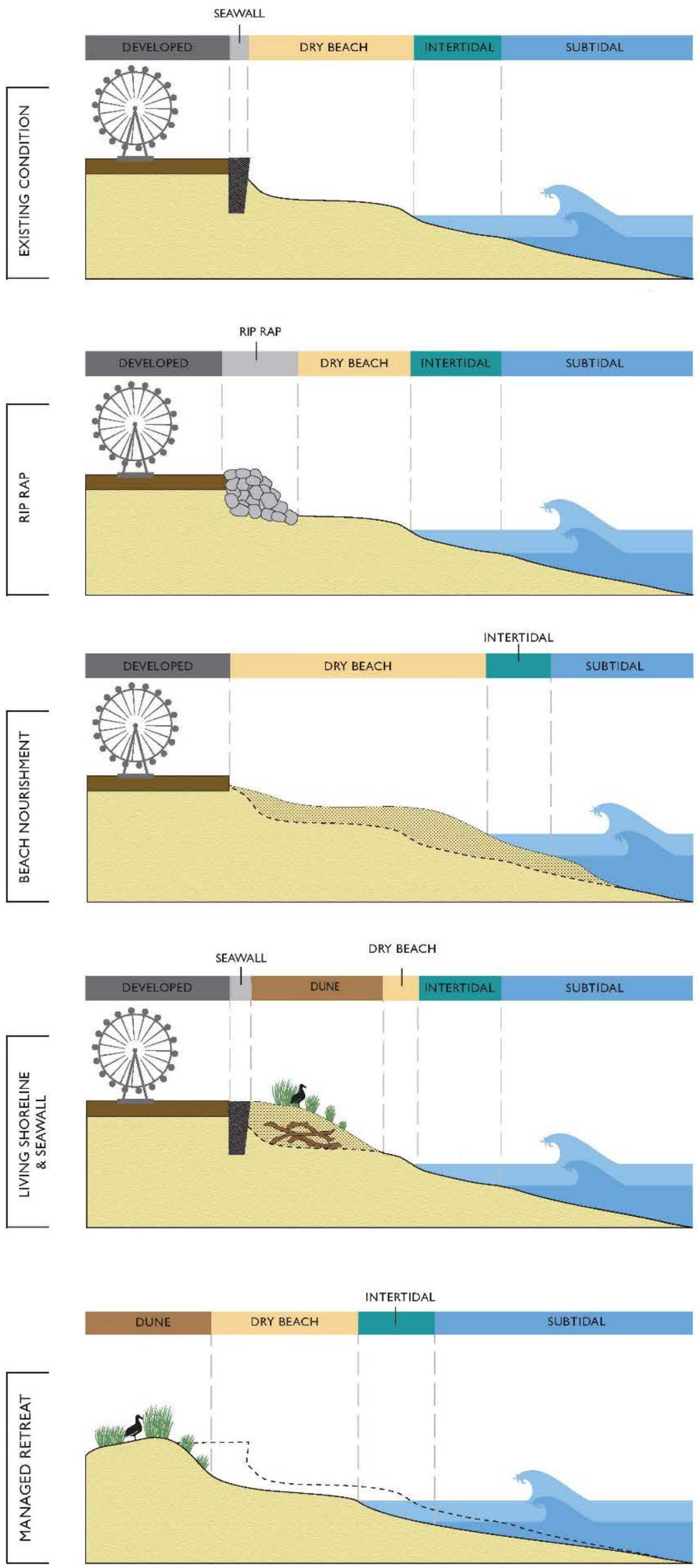
BEACH COASTAL CHANGE: DO NOTHING



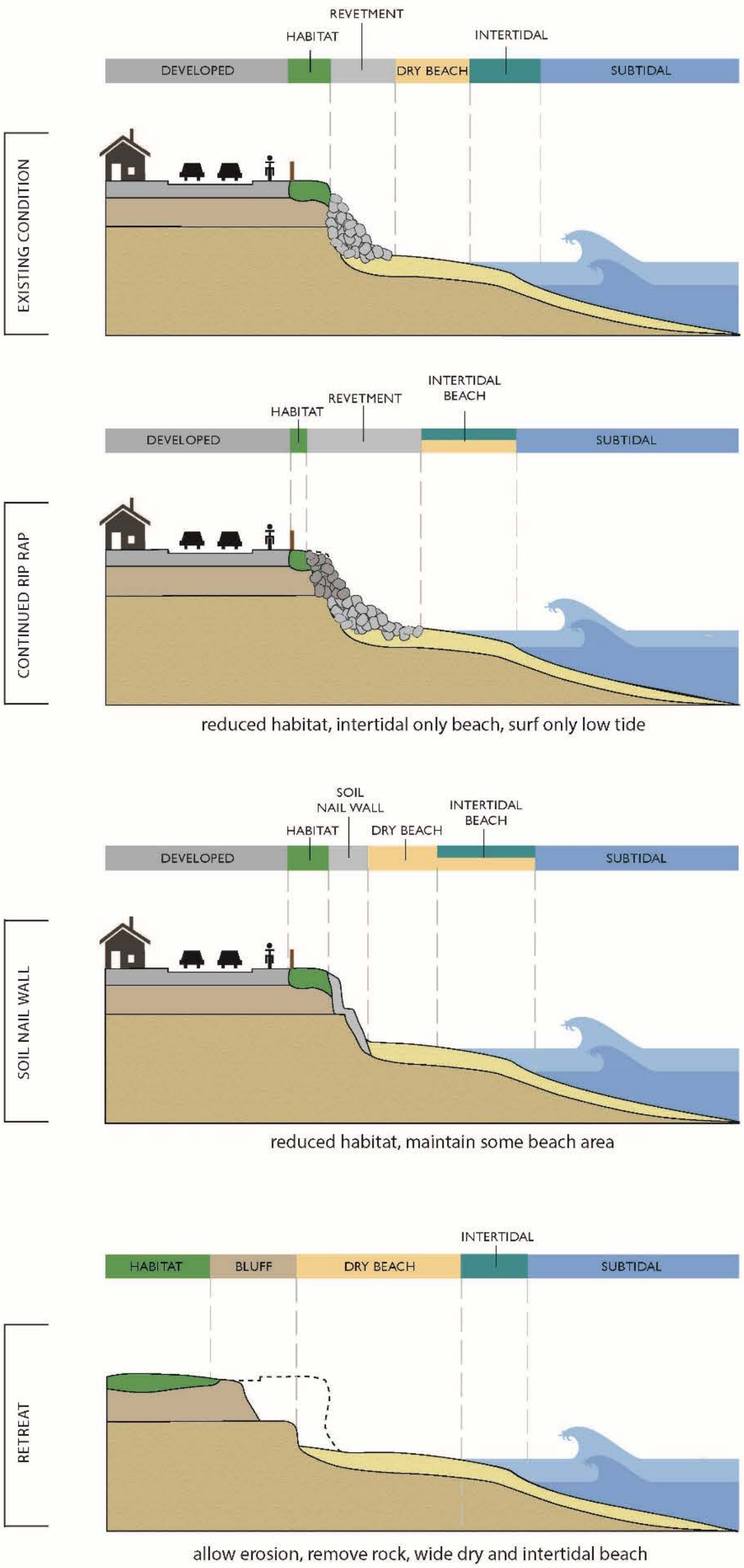
BLUFF COASTAL CHANGE: DO NOTHING



BEACH EROSION & FLOODING: COMMON SOLUTIONS



BLUFF EROSION: COMMON SOLUTIONS



Appendix D:

Draft Socially Vulnerable Populations Impact Analysis

Neighborhood Demographics

West Cliff Drive (WCD) and Santa Cruz beaches are utilized by a variety of community groups from a wide range of socioeconomic backgrounds. As the WCD Management Plan and the beach specific sea level rise policies develop it is important to identify the types of stakeholder and beachgoer groups that face unique challenges when traveling to and accessing the coast and beaches. There are many ways to self-identify, and many users self-identify within several categories. However by integrating information gleaned from various user groups through their participation in focus groups along with city input, statistics from the Census, and intercept survey responses, the project team identified unique coastal access and use needs.

While not comprehensive, this effort attempts to further the work in the 2017 City Social Vulnerability Assessment to expand upon the needs of socially and economically unique user groups that should be considered as adaptation strategies are developed for the City. With an eye to equity in developing adaptations that impact all community members especially those on the front line of climate impacts, throughout the duration of the project, City staff and consultants will continue to meet with unique, under-represented and socially vulnerable user groups to discuss and refine this section.

Differences in how socially vulnerable and under-represented groups use the following coastal resources are considered in this evaluation:

- Beach and Coastal access ways: ramps, stairs, paths, climbing
- Clifftop access: bike paths, parking, walkways, dirt trails
- Beaches: beach name, total sand area, uses
- Businesses: hotels, restaurants, shops, recreational
- Viewshed: overlooks, viewing areas
- Recreational: bikes, surfing, beach going, running, walking, ocean access
- Transportation: multi-modal corridors, roads, paths, parking
- Habitats: intertidal, beaches, roosting, upland

1.1 Community Forums

Beginning in July 2019 and continuing through early 2020, the project team conducted over 700 intercept surveys to date along the coast line aimed at understanding coastal uses and values. In the late summer and fall of 2019, the City of Santa Cruz hosted eight (8) focus groups focused on understanding different community groups' use of, concerns for, and interest in the coastal areas of Santa Cruz. University of California Santa Cruz Coastal Science and Policy graduate students assisted in developing the focus group structure and facilitation. One hundred twenty five (125) one-on-one interviews conducted by City staff and San Jose State University instructors and graduate students took place through November, 2019 with the front line Beach Flats and Lower Ocean neighborhoods. Dialogs are scheduled for December and early January that will focus on specific socially vulnerable or under-represented groups within the community intended to further define unique needs and uses of our coastline along with understanding how adaptations considered might impact these groups. Until the interviews and dialogs are completed and analyzed, initial information regarding unique access and use needs within the community (not categorically defined) can be elucidated from the focus groups and existing survey data by comparing common/universal use and access responses with those less common (i.e. unique) access needs and uses.

1.2 Commonalities among many social groups

Many within the community focus groups responded similarly to their use of and access to the beaches and coastline of Santa Cruz. Common responses regarding coastal activities enjoyed by the community include sporting activities (swim, surf, run, bike, volleyball, kayak, and stand up paddle boarding), passive activities (walking, watching surf, walking dogs on Its Beach, observing wildlife, picnics, creating art, fishing, viewing sunset/sunrises), and visiting the Wharf/Boardwalk (i.e. exhibit and Sanctuary Exploration Center, movies nights, environmental events, dining and shopping). Amenities that improved/enhanced access to and enjoyment of the coast include the weather, the variety of available activities, room to accommodate activities, bike accommodation (lanes, racks, and jump bikes), and Open Streets events.

Challenges to access and coastal enjoyment noted by many include overcrowding (traffic issues, parking, rude people, bike/pedestrian conflict, keeping transportation affordable), pollution (waste/trash, Water quality, vehicle noise and emissions, plastics, dog feces, lack of garbage cans), lack of police presence (safety), and conflicts among user groups (bikes, pedestrians, cars, children, dogs).

1.3 Variance in use and access among many social groups

Dissimilarities among respondents highlight the concerns, needs and values of subpopulations of coastal visitors. For example, focus groups indicate a clear inter-group and interpersonal disagreement on impacts that the Jump bike share has on the coast. Some participants enjoy the convenience of Jump bikes for transportation, while others noted concerns regarding the speed of Jump-bike bikers and the clutter when people park/leave Jump bikes along walk areas, specifically how to deal with pedestrian/bicyclist conflict on West Cliff.

1.4 Under-Represented User Groups and Use of Coastal Resources

This section, building on the 2017 Social Vulnerability to Climate Change Assessment, defines under-represented groups socially vulnerable to climate change impacts, how they use coastal resources as informed by outreach and studies to date, and how coastal change and adaptation efforts might impact each group. This section will support future project efforts after refinement based on additional dialog with under-represented users of the coast to verify how users self-define and how each group may be impacted by coastal change and various adaptation efforts. Refinements will be included in the future project deliverables.

The 2017 Social Vulnerability Assessment identified 5 distinct drivers of social vulnerability using data from a combination of Census data and 2015 City crime data. These user groups included elderly (>65 years old), those that spoke English as a second language, those with low income, persons with disability, and those that lived in areas with high crime rates (violent and property crime). Some users may self-identify with more than one of these groups. While the social vulnerability assessment only focused on residents identifying with one or more of these groups, it is also acknowledged that out-of-town visitors may also identify with one of these groups.

While vulnerable and under-represented peoples mostly use the coast in similar ways as the broader community, with perhaps a few variations and accommodations required, these peoples' ability to cultivate awareness, prepare for, safely evacuate and recover from flood, extreme erosion events, and coastal storm may be hindered. The descriptions below are an initial attempt to highlight how each vulnerable or under represented group uses the coast, what unique needs they have and (in some cases) how they might be impacted by coastal change as projected in Chapter 9 of the West Cliff Drive Adaptation and Management Plan. The next step in this project occurring in December 2019 and January 2020 is to ground truth these initial assumptions with the groups themselves and further understanding of use patterns and on how possible coastal adaptations may affect these groups with the intent toward minimizing impacts.

People living in areas with high crime (violent and property crime): According to the 2017 social vulnerability assessment, there are several high crime census block groups adjacent to the coast. High crime areas include the sea caves near Mitchell's and David Way, which are known hot spots for drug use. Areas of high crime may prevent some residents from using certain areas of the coastline.

Low Income: Census block groups experiencing the highest poverty are also located near the coast in many cases. Those experiencing poverty utilize the free to low-cost amenities along the coast and beaches.

Elderly (>65 years of age): The elderly often have limited mobility and fixed incomes particularly in some of the mobile home parks such as near Natural Bridges State Park. Elderly people benefit from having a range of coastal accessibility options, open views of the coastline from sidewalks, parking areas, benches and overlooks, restaurants and areas for flat leisurely walks, and locations with ramps, staircase access and handrails.

English as a second language: The non-native English speakers often feel linguistically isolated with much of the coastal signage solely in English. Amenities that benefit non-English residents and visitors include multi language informational signage, including symbolized directional signage, street crossing signage and bike and pedestrian signage. This user group tends to use the coast in similar ways as all users (see 1.2).

Those with disabilities: Disabilities can include mobility challenges or other physical limitations, chronic medical conditions, emotional and mental illness, hearing or visual impairments. Those with disabilities utilize coastal amenities such as American with Disabilities Act (ADA) access infrastructure including sidewalk ramps, wheel chair access to the beach, unobstructed views of the coastlines, consistent curbs, tactile paving, and other amenities that allow for unobstructed access to businesses and services. Furthermore, several adaptive surf events and camps are organized at Santa Cruz beaches each year for those with disabilities (e.g. Shared Adventures, Operation Surf, Waves of Impact).

OTHER CATEGORIES

In addition, to the socially vulnerable groups identified in the 2017 Social Vulnerability Assessment, the Project Team has identified several other user groups commonly found using the Santa Cruz coast..

Lower income out of town overnight visitors: Like other user groups, this important visitor group is drawn to the beaches and tourist attractions including the Boardwalk, Sanctuary Exploration Center, and the Wharf. However, these visitors typically seek low cost coastal amenities including easy access to the beaches, affordable overnight accommodations, low or no cost parking, affordable restaurants and shops, bike and pedestrian infrastructure. Many of these visitors come from outside the County and some could be considered climate refugees coming to the coast for cooler temperatures during sweltering inland heat waves.

Out of town day visitors: Like other user groups, this visitor group is drawn to the beaches, tourist and other attractions including the Boardwalk, Sanctuary Exploration Center, and the Wharf. However, they often come more frequently and participate in a wider range of activities including surfing, coastal and beach recreation, whale watching, nature watching, biking and walking, or to attend events, such as triathlons, volleyball tournaments, wharf or Boardwalk events and other local Santa Cruz activities. Many of these visitors drive over from San Francisco Bay and Silicon Valley for the day and come from a variety of income levels. Specific coastal amenities they rely on include, available and affordable parking, transit, walking and biking transportation options, and coastal and ocean access.

Local work force for coastal businesses: Some local residents live paycheck to paycheck and live and work around the city beach front also relying on it for recreation and exercise. Specific coastal amenities they rely on include parking, transit, biking or driving as a commute option, affordable housing.

Subsistence fisher people: This group relies on the natural resources and safe access to the ocean from the beaches, Wharf, and West Cliff Drive coastline.

Below medium income residents of Santa Cruz: More affordable neighborhoods are located near Downtown, lower Ocean Street, and the Beach Flats area. This group includes residents such as food service workers, tourism industry service workers, artists, aspiring entrepreneurs, and students attending University of California Santa Cruz. The community depends on this low wage earning workforce. Specific coastal amenities they rely on include available overnight parking, low cost restaurants and community services, and multi-modal transportation options.

Youth: Youth utilize the West Cliff Drive corridor for recreation, transportation and educational purposes.

People Experiencing Homelessness: Santa Cruz has over 2,000 people experiencing homelessness. City observations identify those that are living out of vans or recreational vehicles are often occupying parking spaces along West Cliff Drive throughout the day and are often exceeding posted parking durations and violating overnight regulations. City observations also indicate some of these people are vending goods from their vehicle, which is a legal practice and a source of livelihood. Specific coastal amenities they rely on include free parking and public restrooms.

Immigrants– Immigrants are more broadly defined to be inclusive of people from other cultures or locations who have become residents of Santa Cruz. For most immigrants English is a second language and they may not have full identification or documentation. They also may have yet to develop strong community connection that offer support or generate awareness of coastal related issues. These people may also find themselves in times of unstable housing and jobs. However, immigrants utilize the coast and its amenities similar to the broader population aside from potentially having language constraints alleviated by bilingual signage.

Tribal Bands: West Cliff Drive and surrounding beaches is traditional and unceded territory of the Uypi Tribe of the Awaswas Nation. Today these lands are represented by the Amah Mutsun Tribal Band who are the descendants of the Awaswas and Mutsun Nations whose ancestors were taken to Mission Santa Cruz and Mission San Juan Bautista during Spanish colonization of the Central Coast. The West Cliff Drive area may hold additional cultural, archeological and ecological significance to these tribal groups, known or yet to be discovered. It may also be integral to the Land Trust's relearning efforts.

People of Color: As a group of people who a have been historically marginalized, people of color face challenges due to both economic and housing inequality, and experiences with community segregation. There are no differences in how people of color use coastal amenities from the broader population.

Sexual orientation, gender identity: Lesbian, gay, bisexual, transgender, and gender fluid persons are historically under-represented and marginalized during local government decision making processes. Some of these people do not have consistent forms of identification. There are few to no differences in how people of varying sexual orientation or gender identities use coastal amenities from the broader population. One example of a difference could include the need for gender neutral public restroom facilities.