Stinson Beach Nature-Based Adaptation Study

Can dunes protect Stinson Beach from sea level rise?

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Coastal Conservancy

COUNTY OF MARIN

ESA 50 YEARS 1969-2019

Executive Summary

1. Introduction

With a grant from the State Coastal Conservancy, Marin County Community Development Agency (CDA) contracted with Environmental Science Associates (ESA) to examine the feasibility of a nature-based green infrastructure project at Stinson Beach.

In 2014, the Marin County Community Development Agency (CDA) commenced "Collaboration: Sea-Level Marin Adaptation Response Team" (C-SMART) to develop adaptation solutions for West Marin. To date, C-SMART has produced two major deliverables: the ***Marin Ocean Coast Sea Level Rise Vulnerability Assessment*** (2016) and ***Marin Ocean Coast Sea Level Rise Adaptation Report*** (2018) with the support of ESA. The Vulnerability Assessment documents the exposure of Pacific coast communities in the County to sea-level rise based on coastal flooding and erosion hazard maps produced by the US Geological Survey (USGS) and ESA respectively. The Vulnerability Assessment concluded that 200 to 400 of Stinson Beach's homes may be exposed to flooding by 2030, potentially increasing to nearly 600 by the end of the century while beaches are vulnerable to coastal squeeze and may disappear by the end of the century. In addition, beaches may disappear by 2050 (3.3 feet of sea-level rise). The Adaptation Report identifies several conceptual adaptation alternatives along the Pacific shoreline of Stinson Beach including nature based alternatives such as dune restoration that could have multiple benefits in providing habitat, recreation and flood protection. This Stinson Beach Nature-Based Adaptation Feasibility Study
(Study) is part of CDA's continued efforts to develop innovative sea-level rise adaptation solutions for West Marin.

The project goal and objectives were confirmed during the project kickoff meeting between ESA and Marin CDA on October 8, 2019.

Project Goal: Assess the feasibility of a nature-based green infrastructure project at Stinson Beach to develop a resilient beach and dune ecosystem that enhances existing habitats and public access, supports vibrant recreational opportunities for users of all socioeconomic circumstances, and provides feasible flood and erosion protection for public and private assets against existing coastal hazards and future sea level rise under future scenarios consistent with state guidance for adaptation planning.

Project Objectives for this Study include the following:

1. Understand sediment transport along Stinson Beach's shore.
2. Characterize historical and modern shoreline change trends.
3. Identify sand sources and sand grain size at candidate sand source sites.
4. Assess the performance of nature-based adaptation alternatives relative to flood and erosion hazards at Stinson Beach.

5. Quantify expected life of nature-based adaptation alternatives for a range of SLR scenarios, and life-cycle costs (first cost and reconstruction after storms), in terms that inform feasibility as well as support a broader long-term adaptation plan.
6. Assess the performance of nature-based adaptation alternatives relative to evaluation criteria (design life analysis, geomorphic and coastal habitat benefits, environmental impacts, recreation, costs, regulatory considerations, storm/SLR protection levels, public access, constructability and possibly others), compared to a more traditional/engineered approach.
7. Support County staff in engaging local residents and beach users in the decision-making process through presenting and soliciting input on project alternatives.
8. Identify existing regulatory barriers to implementation and identify possible regulatory pathways.

The following sections in this report summarize the feasibility study and are supported by multiple study memoranda that are included as appendices:

> **Chapter 2 Existing Conditions** describes the study area and existing conditions including historic context and coastal processes (see Appendix 1);
>
> **Chapter 3 Climate Scenarios and Adaptation Criteria** defines the climate scenarios and adaptation criteria used in the study (see Appendix 2);
>
> **Chapter 4 Adaptation Alternatives** documents the development and evaluation of sea-level rise adaptation alternatives for the Pacific shoreline of Stinson Beach (see Appendix 3);
>
> **Chapter 5 Regulatory and Policy Considerations** describes relevant regulatory issues pertinent to implementation of nature based adaptation alternatives as well as policy considerations (see Appendix 4);
>
> **Chapter 6 Conclusions and Next Steps** draws conclusions from the study analysis and proposes next steps towards nature based adaptation for sea-level rise at Stinson Beach.

2. Study Area Characterization

The Stinson Beach study area is located within Bolinas Bay, situated on a sand spit that extends from its eastern end at the Marin hills to its west end at the mouth of Bolinas Lagoon. Stinson Beach was formed by waves building up a beach and low sand dunes along the front of Bolinas Lagoon and subsidence associated with seismic events on the San Andreas Fault that passes under the west end of the study area.

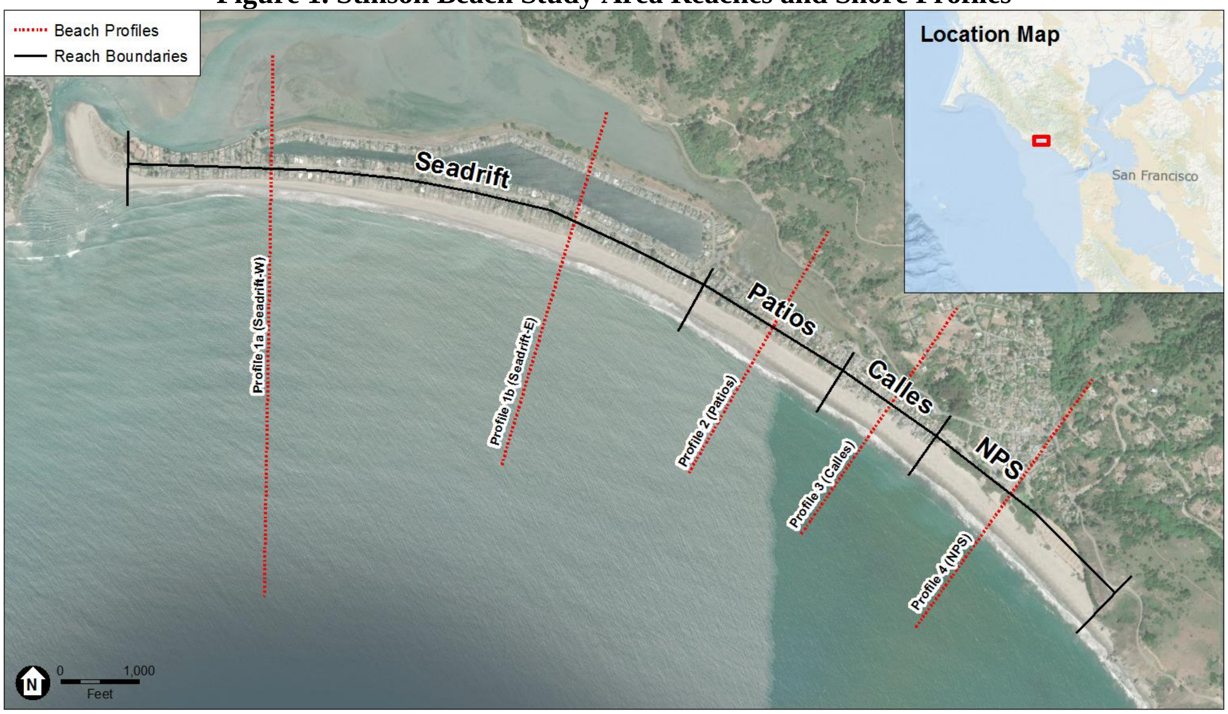
Today, development along the western spit (Seadrift) occupies low areas that were previously foredunes that experienced frequent wave overtopping as well as periodic subsidence as a result of fault activity on the San Andreas fault that passes below the west end of Seadrift. At the eastern end of the spit, development occupies much of what was once a wetland and lagoon complex sustained by freshwater overflows from Easkoot Creek and saltwater from wave overtopping and tides in Bolinas Lagoon.

Existing conditions along the study area are characterized from existing data and literature as well as recent aerial imagery, topographical and ecological surveys. Several studies and reports were reviewed to develop an understanding of existing and historic conditions at Stinson Beach as well as relevant example projects that may provide insight to this Feasibility Study. Notable studies and reports are summarized in Appendix 1 along with key information relevant to this Feasibility Study. The following sections summarize the delineation of study reaches.

2.1 Study Reaches

The Stinson-Seadrift study area was divided into four distinct reaches for the purposes of the study. The reaches span from the Bolinas Lagoon mouth at the north-west end to the Stinson Beach Boulders at the southeast end of the study area as described below. One characteristic shore profile was surveyed for each reach except for Seadrift which has two profiles. Figure 1 shows the study reaches and shore profiles. Large format plan figures, shore profiles and photos of each study reach are provided in **Appendix 1 along with a detailed assessment of long term, seasonal and storm-induced shoreline changes, sediment characterization**.

Figure 1. Stinson Beach Study Area Reaches and Shore Profiles



Reach 1: Seadrift – The Seadrift reach stretches from the west end of Seadrift Road to Van Praag/Walla Vista (7,610 feet long). The backshore homes are currently armored with rock revetment shoreline protection structure that was constructed after the 1982-1983 winter. This shoreline protection structure is exposed along the western and eastern ends while the central portion of the structure is buried by sand with dune vegetation. Due to the existing protection afforded by the rock revetment that spans the Seadrift Reach, the relative need for protective natural infrastructure is lower compared to the other study reaches. This reach is discussed in terms of Seadrift West and Seadrift East given the overall reach length and beach width differences between the west (narrow beach) and east (wider beach). The beach is essentially absent along the western boulder revetment in the Seadrift Reach, and a steep beach profile (with an apparent inshore intertidal or subtidal trough) leaves no space for foredune evolution. The central Seadrift foredunes appear to have almost no over-winter backshore space needed for foredune initiation nor the

sufficient wind-driven sand accretion to regenerate and recover wave-eroded foredune scarps. The exposed eastern revetment indicates low potential for natural foredune development along this segment of Seadrift.

Reach 2: Patios – The Patios reach stretches from Van Praag/Walla Vista to Calle Del Embarcadero/Occidente (2,080 feet long). The Patios Reach is characterized by set-back homes that appear to have allowed the entire beach profile to migrate landward, leaving geomorphic space for foredunes as well as post-storm recovery of the dune morphology and ecology. It has some potential feasibility for natural infrastructure management actions, though is constrained by apparently low natural onshore wind-driven sand transport and foredune accretion rates even with a wide beach.

Reach 3: Calles – The Calles reach stretches from Calle Del Embarcadero/ Occidente to Calle Del Pinos (1,460 feet long). The Calles Reach has alternating residential lots that project directly onto the beach with no foredune morphology and set-back lots with some limited foredunes seaward of them. The reach also appears to have no geomorphic space available for foredune growth in a backshore that remains temporarily stable long enough to support them.

Reach 4: NPS – The NPS reach stretches from Calle Del Pinos to the Stinson boulders (3,040 feet long). It includes the GGNRA park, beach and dunes fronting parking. The foredune wetland scrub and marsh vegetation associated with high groundwater seeps and springs in the beach along the west NPS Reach are hydrologically and geomorphically unique features along the Central Coast of California. The high groundwater saturating the backshore and foreshore would strongly influence vegetation management here. The GGNRA overflow parking foredunes have almost unrestricted potential undeveloped space for landward transgression, but are apparently restricted by intermittent or past parking lot road maintenance grading and spoil disposal of onshore-blown dune sand. The wide, gently sloped backshore, prevalence of finer medium sand, and greater exposure of the NPS reach to dominant westerly winds makes it the most conducive to potential natural foredune accretion and transgression with shoreline retreat given limited development in the reach.

2.2 Ecological Characterization

Existing and historical ecological conditions along the Stinson Beach study area were studied to inform the development and evaluation of nature-based adaptation alternatives. Site ecology (wildlife and vegetation) is linked to physical characteristics such as beach width and elevation, sediment grain size and other attributes. By understanding these physical-ecological links, future shoreline conditions can be related to existing ecology functions and to evaluate the ecological implications for shoreline adaptation alternatives.

Wildlife at Stinson Beach primarily consists of invertebrates that live on or under the sand surface, shorebirds and the occasional fish or sea mammal nearshore. Western snowy plovers are present as a wintering population at Stinson Beach, and they occur in the foreshore and backshore within some reaches of the Stinson Beach study area. They are expected to occur in the shoreline segments with the widest profiles. They are less likely to occur within the study area during the breeding season (spring-summer). This federally listed species is highly inconspicuous, and frequently forages and rests in upper intertidal zones with footprints, and adjacent wider backshore beach zones with surface litter or other sparse cover. Snowy Plovers have been seen nesting at the western tip of the sand spit as well as along the

Seadrift Reach but are not likely to nest along the more traversed eastern reaches but have been observed foraging along the shoreline as recently as December 2019.

Vegetation conditions at Stinson Beach reflect the constraints of "coastal squeeze" caused by recent shoreline erosion events combined with fixed positions of armoring or residential development from the mid/late 20th century. Where backshores are absent in the winter (storm season) beach, only scarped foredunes occur, with no significant post-storm recovery (sand accretion or vegetative regeneration). Marram is the most efficient sand-trapping and dune-building vegetation, so locations where it fails to initiate or support foredune recovery in current conditions (lack of over-winter backshore areas) strongly indicates a major constraint for any purely nature-based (native vegetation management) approaches, too. The inherent lack of consistent annual onshore sand transport by wind – a function of both backshore width and shoreline orientation to dominant sand-transporting winds – is the apparent relevant physical constraint for natural foredune vegetation recovery and dune building. The wide beach surveyed in October 2019 indicate space is available to construct natural infrastructure but any features built along Stinson Beach would require robust monitoring and management plans to maximize their effectiveness and longevity.

Offshore habitats are an important consideration for coastal adaptation activities on Stinson Beach. The offshore portion of the study area is within the Greater Farrallones National Marine Sanctuary. As part of the topographic survey and sediment sampling for the study, Merkel and Associates mapped nearly 1,200 acres of subtidal habitat offshore of Stinson Beach in October 2019. Offshore habitats are comprised primarily of sandy seafloor (90 percent) with transient features such as longshore storm bars and rip current chutes with coarser sand and shell hash. Further details on offshore habitats mapped along the study area are presented in Appendix 1.

Additional information on ecological conditions along the study area is presented in Appendix 1.

2.3 Reference Sites

Reference sites were selected to develop a baseline understanding of (1) geomorphology and (2) to native foredune vegetation in similar coastal systems to Stinson Beach. Reference sites provide a natural context for the existing conditions at Stinson Beach and inform the designs of nature-based adaptation alternatives that are selected for evaluation. Local and regional reference sites are summarized below.

Geomorphology: sites with similar orientation and wave exposure include the embayed sand spit-foredune backshores at Stinson Beach, Doran Beach and Limantour Beach.

Vegetation: native foredune vegetation reference sites include the eastern (landward) end of Stinson Beach GGNRA (NPS reach), west Kent Island inside the Bolinas Lagoon tidal inlet, the restored Abbot's Lagoon foredunes in Point Reyes, foredunes at Doran and Muir Beaches, foredune and cobble terrace in Pacifica State Beach (historic and restored) and the embryo foredunes and cobble beach terrace at Waddell Creek in Santa Cruz County.

Additional information on reference sites is presented in Appendix 1.

2.4 Shore Dynamics Characterization

Shore dynamics at Stinson Beach are a function of tides, storm surges, waves and wind climate. Shore dynamics were characterized to inform design criteria for development protection, project life and maintenance requirements (e.g., reconstruction of dunes after erosion) and limiting potential adverse effects (e.g., sand deposition in the inlet). This section summarizes the wind and wave climate, quantifies potential longshore sediment transport and calculates recent and long term shoreline evolution.

Ocean waves are primarily responsible for the formation of the Stinson-Seadrift sand spit and thus play an important role in the development and feasibility of nature-based adaptation alternatives along the shore. Wave action and tidal currents influence the movement of sand, which in turn leads to changes in beach morphology. Changes to the width, elevation, slope and orientation of the beach occur over the long- and short-term in response to the seasonality and year-to-year variations in wave climate. In general, energetic winter waves (short period waves generated by local storm winds and the Northern Pacific) erode sand from the beach face to subtidal bars immediately offshore. During summer and fall, more organized waves (long period waves coming from southern hemisphere storms) gradually transport sand onshore and build up the beach. In response to these seasonal wave patterns, beaches at Seadrift and Stinson usually vary in width and elevation in response to the seasonality of wave conditions. Extreme winter storms associated with El Nino conditions have even greater impacts to beach widths and upland assets, as discussed below.

The primary purpose of evaluating the nearshore waves is to assess nearshore wave behavior to support sediment transport analysis and evaluate the coastal flooding and erosion along the study area. ESA developed a wave transformation model in order to improve our understanding of the nearshore wave climate at Stinson Beach. The Storm Waves Affecting Nearshore (SWAN) model was developed, which used local tide and wave data collected from stations near the site. The modeled nearshore wave conditions along the study area were used to compute a historic record of water levels and detailed wave run-up for extreme events as well as refined estimates of longshore sediment transport. Details on the input data, methods, and results of the shore dynamics characterization are provided in **Appendix 1**.

2.5 Sediment Characterization

In the spirit of nature-based adaptation at Stinson Beach, any given project would ideally have limited adverse impacts on the local ecology both during construction and over time. Therefore, it is important to source sediments that adequately match the characteristics (e.g. grain size, fines content) present along Stinson Beach. From a regulatory perspective, imported beach sediment should have at least 80% sand (less than 20% fines) and be free of contaminates and organics.

Sediment samples were collected along the study area, including 25 samples (5 along each study profile) taken from the back of beach to offshore limit of the active shore. These samples were analyzed to determine the grain size distributions at Stinson Beach so that potential sources can be evaluated in future phases of work. Sampled sediments ranged from coarse to medium sand with a high sand fraction and low silt content. Beach sediment samples collected along the Stinson study area in October 2019 were mostly sand (95-100 %) at all locations from the back of beach to outside of the surf zone, with median grain sizes ranging from 0.25 mm to 1 mm. Details on sediment sampling methods and results are provided in Appendix 1.

Building natural infrastructure at Stinson Beach will require clean, appropriately sized sediments. Dune features would likely also be constructed with clean beach quality sand although a wider range of characteristics may be acceptable. Coarser, more erosion resistant sediments are needed for cobble-gravel berm features. The sediments that could be beneficially reused for constructing natural infrastructure at Stinson Beach fall into three sediment classes (per ISO classification[1]):

- Sand: medium to coarse sands for dune features and mixing into cobble-gravel berm when needed, sediment grain size ranges from 0.2 mm to 2 mm
- Gravel: fine to coarse gravels to mix into cobble-gravel berms (to fill voids between cobbles), size ranging from 2 mm to 63 mm
- Cobble: coarser, erosion resistant material to be used in buried cobble-gravel berms and lags, sediment grain size ranges from 63 mm to 200 mm.

Potential sediment sources for nature-based adaptation features at Stinson Beach include regional maintenance dredging sites, offshore deposits and local watershed sources. Based on an initial assessment of sediment sources, it appears that there is a fairly significant volume of sediment that could be made available for a resilience/restoration project at Stinson Beach. However, additional research is needed to determine timing of availability and potential regulatory issues that need to be resolved (see Chapter 5). Potential sediment sources that may be suitable and available for use at Stinson Beach include maintenance dredging sites (shipping channel and harbor dredging), offshore deposits in the region and local watershed sources. Additional information on potential sources is provided in Appendix 1.

3. Climate Scenarios and Adaptation Criteria

Climate scenarios and adaptation criteria serve as the parameters to determine whether natural infrastructure is a feasible coastal adaptation alternative for Stinson Beach. Climate scenarios represent near to mid-term sea level rise with and without potential coastal storm impacts. Adaptation criteria provide the foundation for developing location specific design parameters and action thresholds for natural infrastructure at Stinson Beach.

3.1 Climate Scenarios for Stinson Beach

Climate scenarios are used to define the potential future conditions that a project may experience during its design life. For this study, climate scenarios are used to understand the progressive coastal flooding and erosion impacts that may occur along Stinson Beach due to sea-level rise. The climate scenarios selected for this study provide a basis for the design and maintenance criteria for adaptation alternatives. Along with site-specific analysis, climate scenarios allow us to determine how long adaptation alternatives will function and can indicate when future adaptation pathways must be taken to maintain the Stinson community's resilience.

The primary climate factors that pertain to this study include long-term sea-level rise and event-based coastal storm impacts. For this study, a climate scenario is defined as a sea-level rise amount and storm

[1] International Organization for Standardization (ISO) 14688-1:2002, establishes the basic principles for the identification and classification of soils on the basis of those material and mass characteristics most commonly used for soils for engineering purposes.

scenario. Together, the scenarios represent the range of future conditions that are considered when evaluating the functional life and performance of nature-based adaptation alternatives for Stinson Beach.

Climate scenarios are selected to maintain consistency with C-SMART efforts to date while also consider recent State of California Sea Level Rise Guidance 2018 Update (published by the California Natural Resources Agency and Ocean Protection Council).

Given the extensive coastal housing development present along Stinson Beach, this study utilizes the sea-level rise projections for **medium-high risk aversion**. This risk aversion projection (corresponding to a 1-in-200 chance of sea-level rise exceedance) is appropriate since the underestimation of sea-level rise hazards could have high consequences for the Stinson community (State guidance recommends medium-high risk aversion projections for community-scale sea-level rise planning and analysis).

TABLE 1
CLIMATE SCENARIOS PROPOSED FOR STINSON BEACH NATURE-BASED ADAPTATION FEASIBILITY STUDY

Scenario	Storm	Sea-level rise	Timing (by Risk Aversion)[1]
1	no storm[2]	0.8 feet (25 cm)	2040 low / 2030 med-high
2	20- year storm		
3	no storm	1.6 feet (50 cm)	2064 low / 2045 med-high
4	20- year storm		
5	no storm	3.3 feet (100 cm)	2098 low / 2068 med-high
6	20- year storm		

[1] *Timing interpreted from low and medium-high risk aversion sea-level rise projections in CalNRA & OPC 2018.*
[2] *Average conditions without storm impacts (regular tidal inundation and long term erosion)*

This feasibility study focuses on the near- to mid-term sea-level rise and considers a 20-year coastal storm in addition to average conditions. Potential impacts from a 100-year coastal storm event are described, but this study's evaluation and the ultimate feasibility of each nature-based adaptation alternative will focus on the 20-year storm. Such a storm is more likely to occur within the expected functional timeframe for nature-based adaptation and we anticipate that a 100-year storm would overwhelm the alternatives examined in this study. Longer term vulnerabilities to sea-level rise and storms will be addressed in terms of future potential adaptation pathways that may stem from the preferred alternative(s) analyzed in this study. Additional background information and details regarding climate scenarios for Stinson Beach are covered in Appendix 2.

3.2 Adaptation Criteria for Stinson Beach

Adaptation criteria were used to evaluate the performance of adaptation alternatives as well as determine when additional adaptation actions are needed. The criteria include shore characteristics such as beach, dune and cobble berm width and physical forces such as sea-level rise amount and wave run-up intensity. Relevant studies, reference sites and existing conditions along the study area inform the criteria used to evaluate adaptation alternatives. Thresholds for action were established based on observed seasonal shoreline fluctuations and storm erosion at Stinson Beach.

Marin Ocean Coast Sea-Level Rise Vulnerability Assessment (C-SMART 2016) highlights the flooding and erosion risks to the Stinson community. Due to the low-lying nature of the sand spit that comprises the study area, beyond 2 feet of sea-level rise, nature-based adaptation along the beach will not be enough to fully protect the Stinson community against the rising sea-level. In addition to impacts from wave-driven flooding and erosion on the Pacific coastline, the community is also at risk to tidal inundation and storm surge from Bolinas Lagoon as well as storm flooding from Easkoot Creek. Higher sea-levels may overwhelm the protection afforded by constructed natural infrastructure on the Pacific shoreline. Therefore, additional adaptation actions for areas outside of the backshore can be expected with as little as 2 feet of sea-level rise. The adaptation alternatives analysis will describe potential future adaptation pathways that may apply to these areas but does not explicitly analyze their feasibility. The evaluation criteria used to develop and evaluate the adaptation alternatives are discussed below. Further details including thresholds for adaptation action are included in Appendix 3.

Sea-level Rise

For the purpose of the adaptation alternatives evaluation in this study, sea-level rise amount is the independent variable with which the evaluation criteria described here are analyzed in addition to storm impacts following the climate scenarios described above. It is important to note that nature-based adaptation along the Pacific shore can only addresses a portion of overall adaptation needs of the Stinson-Seadrift community: Other adaptation measures will be needed to address flood impacts from Easkoot Creek and Bolinas Lagoon with sea-level rise (see community-wide sea-level rise thresholds summarized in Appendix 2).

Wave Run-up Intensity

The action of wave run-up and overtopping has influenced the formation and evolution of the Stinson sand spit over time. A geomorphic interpretation is that the Stinson–Seadrift landform is a littoral spit that was likely reinforced by sand delivered by wave run-up and overtopping. Prior studies have also identified that the landform is likely to settle following strong seismic events, and requires sand from the ocean to rebuild (PWA 2006, Alt & Hyndman 1975, Alt & Hyndman 2000). Nature-based types perform best when sited to accommodate and survive, at least partially, extreme coastal storm events while providing protective services to development. For the adaptation alternatives evaluation wave run-up intensity for the 20-year storm was modeled as an indicator of wave run-up reduction. Potential wave run-up intensity for the 100-year was analyzed for context, but it did not inform the maintenance scheduling of nature-based adaptation alternatives in this study. Wave run-up intensity was also used to determine the crest elevation of cobble berm features.

Beach Width

For this study, beach width is defined as the beach above mean high water (MHW) that extends landward to where the beach meets the edge of development, toe of dune or armoring structure. Wave run-up dissipates with distance traveled over a beach, hence wider beaches result in lower wave run-up and less erosion on upland features and development. Conversely, a narrow (or absent) fronting dry beach offers little protection to adjacent uplands. Without the buffering effects of a wide beach, more wave energy reaches the uplands which results in greater run-up, erosion of dunes and bluffs, and wave loading on coastal armoring structures. Wider beaches also provide increased recreational and ecological values.

Conceptually, a resilient beach at Stinson could accommodate seasonal changes as well as a typical coastal storm erosion event and while retaining a nominal beach width at its narrowest (spring). An important consideration when thinking about beach width is that repairs or expansions of dunes or other natural features in the future will require space on the beach to work and build the feature(s). Thus, it will be prudent to maintain a minimal beach width so that after (or during) extreme winters, the ability to build/maintain natural infrastructure is maximized while limiting impacts to the intertidal beach and nearshore (a National Marine Sanctuary)., Beach width at Stinson Beach has remained relatively stable in recent history, but extreme coastal storms have caused significant shoreline erosion and damages to coastal development. Sea-level rise could cause shoreline recession that reduces the beaches over time, further exposing development to greater storm impacts. Beach width was modeled together with dune and cobble berm width where applicable to evaluate the performance of adaptation alternatives (Chapter 4). Beach width outputs from the modeling were interpreted to evaluate habitat benefits, environmental impacts, and public access implications of each adaptation alternative.

Dune Width

Dunes provide a natural buffer to flooding and erosion landward of beaches. Dunes naturally erode and nourish the beach during coastal storm events and over the long term as the shoreline moves landward due to natural erosion trends and/or sea-level rise. Dunes constructed for nature-based adaptation ideally would be sized to accommodate the potential erosion, wave run-up and overtopping from an extreme coastal storm event. Depending on the available space in a given area, a constructed dune would ideally be built wider than the design storm erosion distance in order to accommodate long term erosion and delay the need for maintenance. Dune width was tracked over time to determine when reconstruction is needed to maintain the level of protection of the dune or when a change in the adaptation pathway is warranted. Prior studies and observed conditions at Stinson Beach and reference sites provide examples of design dimensions for dune features. Minimum desired dune widths for implementation are 100 feet. The dune width threshold for maintenance or other action ranges along the study reaches from 45 feet at Seadrift reach to 65 feet at NPS reach. The thresholds are based on the potential erosion distance associated with the 20-year storm. Constructed dune dimensions will be determined for each Stinson Beach reach based on available space, type of dune, and wave run-up intensity and extents. These minimum thresholds will be used to determine timing of additional maintenance of constructed dunes and may be refined during the alternatives evaluation analysis.

Cobble Berm Width

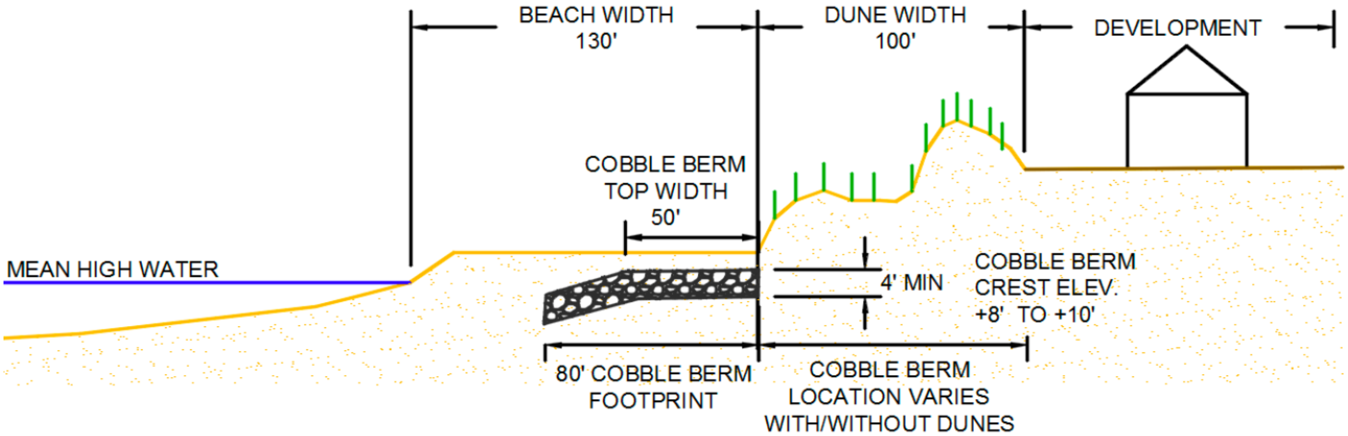
A cobble berm can act as a soft revetment whether buried under dunes or constructed by itself. During a coastal storm event, a constructed gravel/cobble berm can buffer the backshore from flooding but not without eroding and flattening from the wave power. Thus there is a minimum amount of elevated cobble berm width that should be maintained to provide adequate protection. The maintenance threshold was determined to be 30 feet, at which other actions could be taken. The design cobble berm width was determined based on prior studies/guidance, existing conditions and wave run-up exposure at Stinson.

Criteria Summary

The existing shore geometry at Stinson Beach is compatible with natural shore infrastructure approaches that employ cobble berms and vegetated sand dunes, and is expected to remain compatible through at least mid-century, with the exception of the Seadrift reaches which have limited beach space available. In order to maintain beaches and natural infrastructure for the purpose of recreation, ecological function and hazard reduction, thresholds were established for each reach.

The minimum desired dimensions for implementation of natural infrastructure types are provided schematically in Figure 8. These dimensions will be used to select alternatives by reach, and may be revised after analysis of alternatives and community input.

Using the criteria mentioned above and desired natural infrastructure dimensions, the design and maintenance scheduling were determined for adaptation alternatives (see Chapter 4).



SOURCE: ESA 2020

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 8
Conceptual Desired Dimensions for Natural Infrastructure Elements at Stinson Beach

4. Adaptation Alternatives

To evaluate the feasibility of using with natural infrastructure for adaptation at Stinson Beach, the project team developed two nature-based alternatives and evaluated them along with a traditional armoring alternative. This Chapter summarizes the types of natural infrastructure that are applicable to Stinson Beach, the selected adaptation alternatives, and the various evaluations performed

The nature-based alternatives draw upon the adaptation strategies presented in the C-SMART Adaptation Report (Marin County 2018). The natural infrastructure types and combinations considered for application at Stinson Beach are listed below. This preliminary list was developed considering the C-SMART work to date as well as existing conditions along the study area (including seasonal shoreline changes and potential storm impacts). Additional information is provided in Appendix 3 (ESA 2021).

- **Foredunes** – a natural Pacific Coast sand dune geometry with native vegetation and low-relief mounds and hummocks, typically found on the landward side of a beach, and sometimes fronting larger mature dunes.

- **Foredunes and cobble-gravel berm** – Foredunes with a buried cobble-gravel berm for increased erosion protection.
- **Dune embankment** – a linear sand embankment that is landscaped to form a protective barrier to wave run-up and erosion during extreme events. Dune embankments are taller and narrower than foredunes and can be widened or combined with foredunes, if space allows.
- **Dune with cobble-gravel berm** – a dune embankment with a buried cobble-gravel berm for increased erosion protection.
- **Cobble-gravel berm** – a cobble-gravel berm buried just below dry beach elevations. Cobble-gravel berms are naturally formed by waves and can be found near creek mouths and other bluff locations such as Steep Ravine. A variant is a "lag deposit" geometry which is a wider, lower elevation cobble apron that is only exposed during extensive beach scour or erosion typically associated with rare events.

Adaptation alternatives were developed for the study area by selecting a natural infrastructure type for each reach. Suitability of the natural infrastructure types was determined by comparing the minimum desired widths for each natural infrastructure type with actual beach widths in each reach (based on recent surveys and observed seasonal fluctuations). Two nature-based adaptation alternatives were developed for each study reach by combining the most suitable natural infrastructure types. The baseline armoring alternative and nature-based alternatives are described below:

Alternative 0 – A traditional armoring adaptation alternative, whether rock revetment, reinforced concrete seawall or other method.

Alternative 1 – The "more natural" of nature-based infrastructure types, consisting of foredunes where there is sufficient space and dune embankments where space is limited (or cobble berm in the case of Seadrift West).

Alternative 2 – More structural versions of nature-based infrastructure, including cobble-gravel berms with dunes where there is sufficient space, and only a cobble-gravel berm in the Seadrift West and East reaches where there is limited space.

By applying the adaptation criteria discussed above, the two nature-based and one traditional armoring adaptation alternatives were evaluated in terms of design life and engineering cost, storm protection levels, coastal habitat benefits, regulatory considerations, public access and constructability. These evaluation categories are summarized below, further information is presented in Appendix 3.

4.1 Design Life Analysis

The functional life of constructed natural infrastructure depends on seasonal shoreline fluctuations, long term shore evolution with sea-level rise and event-based coastal storm erosion. The design life of each alternative was estimated using models that track erosion of the shoreline, dune and cobble features over time with sea-level rise and storm events.

To conduct the analysis, initial shore conditions were established for each alternative including starting beach widths, the constructed widths of natural infrastructure or armoring as applicable. The initial conditions are based on analysis of existing and historic shoreline conditions along the study area and correspond to construction of the alternatives during fall when beaches are widest. Second, long term evolution of the adaptation alternatives was modeled considering sea-level rise amounts discussed above. The long term evolution considers the shore changes due to sea-level rise only. Sensitivity of the natural infrastructure widths to seasonal changes and storms was also considered. Erosion impacts were estimated for moderate coastal storm events that occur every 20-years on average. While the long term shore evolution analysis indicates natural infrastructure could persist with up to 3.3 feet of sea-level rise under average conditions, the probability of extreme coastal storms indicates that interim repairs of natural infrastructure could be needed to maintain their protective functions. Current State guidance on sea-level rise recommends that 3.3 feet of sea-level rise be considered to occur by 2067; there is a 235% probability of a 20-year storm event occurring during this timeframe (from 2020). The cost of each alternative was estimated using the outputs of the design life analysis considering the construction, long term maintenance requirements with sea-level rise and storm event maintenance. Construction and maintenance costs for the two nature-based alternatives ranged from $48M to $55M (Alt 1 and 2 respectively) compared to the armoring baseline of $155M (Alt 0).

Appendix 3 describes the methods of the design life analysis, construct and maintain alternatives up to 1 meter (3.3 feet) of sea-level rise. The natural infrastructure width outputs (beach, dune and cobble width) computed for the design life analysis were then used to evaluate storm protection, coastal habitat, public access and recreation benefits provided by the nature-based alternatives compared to traditional shore armoring.

Storm Protection Levels

Storm protection levels were analyzed for the alternatives by modeling the wave run-up extents for two representative extreme coastal storm events: the 1982-83 and 2015-16 El Ninos. The alternatives were sized to provide storm erosion protection from a moderate storm event represented by the 2015-16 El Nino winter impacts that were observed along the study area. The 2015-16 “design storm event” was evaluated as the primary indicator of storm protection performance for each alternative considering the constructed conditions and future conditions with 3.3 feet of sea-level rise. The natural infrastructure alternatives were found to reduce wave run-up extents compared to the armoring baseline.

Coastal Habitat Benefits

Nature-based adaptation alternatives increase the resiliency of a dune and beach system compared to traditional shoreline armoring approaches. Under a traditional shoreline armoring approach that places armoring structures in front of development, future shoreline erosion from storms and/or sea-level rise can lead to more rapid beach loss in front of the armoring structure compared to an erodible shore form. Nature-based approaches to reduce erosion and flooding exposure can provide benefits to beach geomorphology and ecology by harnessing the dissipative effects of natural infrastructure. Specific benefits provided by dunes and cobble berms are described below.

Dunes: Dunes provide protection to development while maintaining beach width longer compared to traditional armoring approaches. Sand eroded from the dunes dissipates wave energy, reduces beach erosion, and nourishes beaches with sand, thereby making the sandy beach relatively higher, wider and more persistent than without dunes. The sand provided by dunes maintains beach ecology functions as well. Foredunes can be more resilient to wave run-up than a dune embankment. While both types of dunes can increase resiliency of beaches, lower foredunes are a more natural form of protection with greater ecological benefits provided by vegetation and their dissipative slopes. Vegetation native to California can thrive in and reinforce development of foredunes, thereby creating a basis for increased ecology benefits. In comparison, taller embankment dunes with steeper slopes will lead to more frequent erosion scarps on the dunes that are less favorable for maintenance of high native plant diversity.

Cobble: While cobble berms reduce erosion and flooding behind them, they become exposed during winter and effectively reduce the available sandy beach area during mid- to late-winter. However, a lens of sand may persist on the top of the cobble berm for wintering shorebird habitat, depending on the elevation of the berm in relation to sea level and how stormy each winter is. See examples from Surfer's Beach in Ventura County and Pacifica State Beach below. Similar to sand and gravel beaches, native invertebrates and insects can survive in cobble shores, providing food for other fauna and an overall ecological benefit that is not found with engineered boulder revetments. The cobble berm also facilitates sand beach recovery and protects sand dunes behind it from waves, thereby increasing ecology benefits relative to seawalls and boulder revetments. These functions are further advanced by the capture of organic materials (seaweed, kelp, large wood) on the cobble berm crest. There are however some tradeoffs for ecological and geomorphic benefits with cobble berms. Seasonal or chronic exposure of cobble berm at or near the sand surface would likely restrict the colonization and establishment of native foredune and backshore vegetation, and select for species with plant functional traits that are less efficient at trapping sand and naturally rebuilding foredunes. Deep long-term burial of cobble berms by thick sand deposits (beach or dune) would reduce the potential inhibitory impact of cobble berms on regeneration of foredune vegetation (i.e. burying a cobble berm within a dune would limit the berms effects on native vegetation establishment until the dune is eroded and cobble berm is exposed.

Ecological benefits (or impacts) of these natural infrastructure landforms to native foredune vegetation depends in part on the duration of their intermediate erosional states, and the disturbance intervals associated with maintenance or reconstruction. The foredune designs are more likely to provide net ecological benefits to native plant populations if relatively prolonged intervals of low-energy winter storm conditions (multiple consecutive years of low erosion and disturbance) follow construction and vegetation establishment, and ample winter rainfall. This sequence would enable vegetative to establish and accumulate before storm erosion occurs. However, low storm intensity may be associated with winter drought conditions that are unfavorable for initial foredune vegetation post-transplant survival and establishment. Wet, stormy winters following construction and revegetation of artificial foredunes are likely to cause erosion before bud banks and seed banks accumulate to sizes that effectively recolonize eroded beach and foredune zones. If erosion intervals recur frequently, with short post-storm recovery (beach accretion) intervals, foredune vegetation recovery periods may be insufficient to restore or enhance resilient biological diversity. Over a decade or more, if the constructed foredune system exists in prolonged post-erosion partial recovery states, it may likely require supplemental repair or maintenance (sediment replacement and replanting).

Since sea level rise rates and the frequency of major coastal storm erosion events are likely to increase within the next few decades, the likelihood of substantial net ecological benefits of constructed foredunes is likely to depend on external climate variables and related intensification of maintenance and repair actions.

Additional discussion on the ecological benefits and consequences of the adaptation alternatives is provided in Appendix 3.

Constructability

The nature-based alternatives formulated for this study are intended to be constructed at the back of the beach, whether in front of existing dunes, existing armoring structures or unarmored development. Construction would ideally occur in the late fall when beach recreation has slowed but beaches are still wide. Natural infrastructure would be constructed on the landward side of the dry beach to avoid impacts to the intertidal beach and nearshore. Specific constructability considerations are summarized below.

Construction of beaches, dunes and cobble berms is relatively straight-forward placement of imported natural materials with conventional construction equipment. The primary constraints are:

1. Acquiring desired sand and cobble (sizes and other characteristics)
2. Delivering the sand and cobble to the site
3. Establishing native vegetation which requires management of foot traffic.

The traditional engineering armor baseline alternative is more complicated to construct than a cobble berm or dune, whether a rock revetment or reinforced concrete seawall (or other) structure is used. For dunes and cobble berms, sourcing and delivering desired quality sand and cobble will be the greatest obstacles. Further study of sediment sources and characteristics is needed to properly assess the constructability of these alternatives (ESA 2020a). Otherwise, dune features require vegetation planting and public access management techniques to reduce impacts to vegetation. Foot-traffic management approaches add elements to the construction of either natural or engineered alternatives, but are not overly-complicated. For low foredunes, simple roped paths could be used to manage foot traffic through the dunes, while taller dune embankments require more substantial elements such as wooden stair cases down the face. These public access features are discussed further in Section 6.7.

Environmental Impacts

Construction and maintenance of the proposed natural infrastructure typologies (cobble, foredunes, dune embankments) in Alternatives 1 and 2 likely will result in three types of ecological impacts to sandy beach shorebirds: 1) impacts related to initial construction/installation; 2) impacts resulting from repeated maintenance; and 3) conversion of existing habitats into other habitat types.

The probability of the ecological impacts depends on how the construction is performed and the overall space (beach width) available at the time of construction. If there is any heavy machinery on the wet/semi wet beach, there could be indirect mortality from crushing. The nature-based alternatives were designed to be constructed at the landward side of the dry beach in part to minimize these impacts. Any implemented natural infrastructure should optimize construction timing and limit the work area to the most landward and highest beach areas to minimize these ecological impacts.

Installation of natural infrastructure alternatives will convert existing dry beach habitat into new types (foredunes, dune embankments and periodically exposed cobble berms), reducing the amount of gently sloping beach and steepening the overall profile.

Other environmental impacts of the adaptation alternatives may stem from suboptimal sediment source quality; construction of dune features should utilize beach quality sands that match the conditions at Stinson Beach as closely as possible to minimize ecological impacts.

Under the armoring alternative (Alt 0), ecological impacts will be caused by failure to mitigate the climate effects of sea-level rise and erosion which will result in much lower quality habitat over time. Existing hard armored shoreline areas will be exposed at a much earlier date, exacerbating the negative ecological impacts caused by hard armoring. New armoring constructed to protect development would broaden the extent of negative ecological impacts. These impacts include loss of the high intertidal zone, lower trophic diversity, and changes in wrack deposition (Dugan et al. 2017).

Regulatory Considerations

The alternatives evaluated in this Feasibility Study, while nature based, would still require extensive construction activities including excavation and placement of sediment. Due to the nature of the proposed activities, geographic location of the site, environmental sensitivity of beach and dune habitat, and multiplicity of jurisdictions and regulations involved, the permitting process for either Alternative 1 or 2 would require an extensive effort to obtain agency approval. However, for comparison, the more traditional approach of using hard armoring to protect the back shore (Alternative 0) would present a much larger permitting challenge and would likely not be approved due to environmental impacts and the fact that less ecologically damaging alternatives exist.

Alternatives 1 and 2 would require close collaboration with a number of permitting and resource agencies during the project planning and regulatory compliance process. Appendix X, Regulatory and Policy Considerations, includes a detailed overview of the required permits and approvals, involved agencies, and necessary actions required for the permitting process. Beyond the procurement of permits, the overall regulatory compliance process consists of environmental review (pursuant to CEQA), followed by permitting and/or agency approvals, and concludes with compliance review and documentation. Permits and/or approval would be required from: U.S. Army Corps of Engineers (USACE); U.S. Environmental Protection Agency (EPA); U.S. Fish and Wildlife Service (USFWS); Greater Farallones National Marine Sanctuary (GFNMS); National Marine Fisheries Service (NMFS); California Coastal Commission (CCC); California Department of Fish and Wildlife (CDFW); Regional Water Quality Control Board (RWQCB); California State Lands Commission (CSLC), and; County of Marin.

Public Access

Public access across and along the Stinson shoreline is important to maintain; the beach is visited by millions of people annually including local residents. Public access is discussed in terms of potential impacts during construction, considerations for long term shore evolution with sea-level rise and potential impacts during coastal storms.

Construction period - Construction of natural infrastructure for adaptation would ideally occur during late fall when beaches are wide and recreation is reduced. Nonetheless, cross-shore access would be limited during construction of natural infrastructure or traditional armoring alternatives. Depending on the beach widths when alternatives are constructed, alongshore beach access could be maintained seaward of the active construction area as features are be built along the back of the beach.

Long term access implications with sea-level rise - Overall, natural infrastructure alternatives provide benefits to access by maintaining dunes and beaches over time compared to a traditional armoring baseline. As detailed in Table 4, beach width is expected to be substantially reduced with sea-level rise, and the natural infrastructure alternatives result in wider beach widths.

Access during storm events - Access along the shoreline and beach is dangerous during coastal storm events. Traversing along the top of a traditional armoring structure where the beach is absent can be treacherous during storms because waves are likely to run-up along the structure. Natural infrastructure alternatives can provide benefits to coastal access during and after storm events. In comparison to the traditional armored shoreline described above, the top of a dune or cobble berm may provide a relatively safer place for lateral access during a coastal storm event but beachgoers must exercise caution at the beach at all times especially during extreme events. Compared to hard armoring that reflects wave energy and magnifies beach erosion during storms, natural infrastructure can respond to wave impacts during a storm, erode, and provide room for the beach to respond such that beach widths are not depleted completely during the storm and facilitate post-storm access along the shoreline even at high tides.

5. Regulatory and Policy

The alternatives evaluated in this Feasibility Study, while nature based, would still require extensive construction activities including excavation and placement of sediment. Due to the nature of the proposed activities, geographic location of the site, environmental sensitivity of beach and dune habitat, and multiplicity of jurisdictions and regulations involved, the permitting process for either Alternative 1 or 2 would require an extensive effort to obtain agency approval. However, for comparison, the more traditional approach of using hard armoring to protect the back shore (Alternative 0) would present a much larger permitting challenge and would likely not be approved due to environmental impacts and the fact that less ecologically damaging alternatives exist.

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Additional information on regulatory issues are discussed in Study Memorandum 5. Regulatory and Policy Considerations.

6. Conclusions and Next Steps

We evaluated two nature-based adaptation alternatives along with a traditional armoring baseline (Alternative 0). The two natural infrastructure alternatives consist of a more natural Alternative 1 that prioritizes foredunes and an enhanced Alternative 2 that incorporates cobble berms and taller dune embankments to increase protective services.

Natural infrastructure implementation at Stinson Beach is a feasible alternative to traditional shoreline armoring approaches for near term sea-level rise (up to ~3.3 feet). The exception is in the Seadrift reaches where the existing beach is narrow, providing limited space for dunes seaward of the existing rock revetments: In this location, sand placement would need to be more frequent and may not provide the ecologic benefits of a natural system.

The sand dune elements (foredunes and barrier dune embankment) are more consistent with the setting than the cobble-gravel berms, resulting in concerns about the cobble-gravel degrading access and ecology. However, the cobble-gravel berms provide greater "protective services" in terms of dissipating wave run-up and mitigating landward shoreline movements during elevated wave conditions. Hence, the cobble-gravel berms can be thought of as a natural or dynamic revetment with some attributes of a traditional shore armoring, but with better access and recreation. The cobble-gravel features can be implemented initially or as a future adaptive action.

Natural infrastructure provides ecology and recreation benefits beyond the armoring baseline and does not preclude future implementation of other adaptation measures such as shore armor, beach nourishment, raising homes in place (e.g., on pilings), and relocating homes to higher ground (realignment). While the construction of natural infrastructure converts existing beach area to new habitats (vegetated dunes; cobble berms during winters), the overall shore width of dunes and beaches is maintained longer than with traditional armoring structures. Dunes erode during storms and provide sand to the beach, reducing beach loss and facilitating quicker beach recovery after storms compared to traditional armoring. Cobble berms increase the resilience of the beach and dunes to erosion while being more traversable than traditional armoring structures. By increasing beach and dune resilience with natural infrastructure, public access and recreation are improved over a traditional armoring baseline. Overall beach space is reduced after the initial construction of natural infrastructure but the dunes and cobble berms can provide better cross and alongshore access over time with sea-level rise.

Natural infrastructure could be constructed and maintained with 3.3 feet sea-level rise for approximately one third the cost of a traditional rock revetment as modeled for this study. This estimate assumes two 20-year storms equivalent to the 2015-2016 El Nino occur over the ~50-year timeframe during which this amount of sea-level rise is anticipated to occur in the scenario modeled. Maintenance would be required following each event. Maintenance requirements for all alternatives evaluated may be higher or lower depending on the severity of winters and occurrence of significant coastal storm events and the amount of sea-level rise that occurs.

Natural infrastructure alternatives can provide storm protection levels greater than traditional armoring structures if maintained at adequate widths. This is because a wider beach and dune system dissipates wave run-up and limits the landward extents of flood and erosion risks. Cobble-gravel berms provide even greater wave run-up dissipation, and are more resilient to elevated wave conditions than sand dunes alone. Together, a cobble berm and sand dune system provides an enhanced buffer to elevated wave conditions. An important aspect of successful natural infrastructure project will be a commitment to maintenance after stormy winters or singular events. This study considered the impacts of the characteristic 20-year storm given the timeframe of implementation but greater storms have and may occur at Stinson Beach.

The design life of natural infrastructure depends on the timing of construction and revegetation establishment relative to unpredictable coastal storm events. California foredune dynamics (and elsewhere) are generally dominated by unpredictable infrequent, significant, extreme storm erosion events (single or consecutive storm events), and longer (multi-year) post-storm recovery phases during which beach recovery, vegetation succession, and foredune accretion occur. The ultimate stewards of natural infrastructure built at Stinson Beach for adaptation need to commit to ongoing maintenance program and ready to respond to coastal storm impacts. The management implications are that natural infrastructure investments like this provide a different trade-off between shoreline stabilization and all other ecologic/public benefits of Stinson Beach: instead of more predictable hard armored engineering designs that severely conflict with ecological, esthetic, and recreational benefits that make Stinson Beach valuable, the softer, dynamic nature-based alternatives provide significant but less predictable stabilization benefits while conserving ecological, aesthetic, and recreational benefits of the shoreline for longer periods – a human generation, an important time-scale - until sea level rise overcomes their capacity to function effectively at the current shoreline position. With sea-levels greater than 3.3 feet above existing conditions, additional adaptation actions will be needed to ensure protection of the Stinson Beach community.

The alternatives evaluated in this Feasibility Study, including the armoring included in the baseline, will require permits from a range of environmental regulatory agencies. Due to the nature of the proposed activities, geographic location of the site, environmental sensitivity of beach and dune habitat, and multiplicity of jurisdictions and regulations involved, the permitting process for either Alternative 1 or 2 would require an extensive effort to obtain agency approval. However, the more traditional approach of using hard armoring to protect the back shore (Alternative 0) would present a much larger permitting challenge and would likely not be approved due to environmental impacts and the fact that less ecologically damaging alternatives exist. The use of cobble and gravel along Stinson Beach may raise concerns with regulatory agencies akin to traditional shore armor. A possible exception is at the NPS reach where Easkoot Creek flood flows would naturally transport coarse sediment to and across the beach to the extent it avulses from its sediment-choked channel, and hence placement of these sediments in this location would be consistent with the setting.

- Current regulatory restrictions on beach nourishment to the shore face (nearshore, intertidal to subtidal profile nourishment) limit the alternatives examined for this study to include only backshore actions above the tidal influence. Future potential changes in regulatory restrictions on beach nourishment may open up additional opportunities for shoreface or profile nourishment including intertidal to subtidal. Beach nourishment in the supratidal-intertidal-subtidal gradient is essentially a regulatory consideration, not a physical or ecological feasibility barrier to feasibility other than the potential impacts to Bolinas lagoon mouth by longshore sediment transport (see Study Memorandum 1). Long-term shoreline resilience at Stinson Beach, following the design life of the examined nature-based adaptation alternatives, which excludes intertidal sand placement or drift retention structures (groin field), should be revisited when regulatory policies restricting profile nourishment are reviewed. Long-term adaptive strategies for significantly higher sea-level rise are likely to depend on a sequence of natural infrastructure implementation followed by sediment nourishment and/or managed retreat.

Next Steps

Next steps for implementation of natural infrastructure at Stinson Beach include:

- Develop a preliminary design of an integrated project for the study area. The preliminary design process can facilitate refinements based on analysis as well as community and stakeholder preferences for the types and extents of natural infrastructure, and informed by regulatory and resource agency feedback. The preliminary design can then be subjected to further environmental review and associated refinements.

- The preliminary design scope of work should address the following: ○ Evaluation of sediment sources with consideration of sediment characteristics, availability, requisite studies, and costs of acquiring, transporting and placing. Beneficial reuse of sediments that may become available due to other activities should be considered, consistent with "opportunistic sources" concepts developed by the Coastal Sediment Management Workgroup[1].

    - Coordination with the National Park Service regarding implementation as well as integration with future renovation of the Stinson Beach facility.
    - Public access elements such as boardwalks and fencing through the dunes.
    - Refine analysis of sediment movements away from the placement area, and the response of cobble-gravel berms to elevated wave and water level events.
    - Refine analysis of shore erosion and backshore flooding and damages.
    - Engineer's estimates of likely construction quantities and costs
    - Preliminary construction drawings
    - Renderings (graphic depictions) of the post construction conditions.
    - Implementation funding, potentially including small test projects (Pilot projects)
    - Repeated beach topographical and ecological surveys to better understand seasonal and storm changes (coordinate with ongoing surveys reach by GGNRA staff)