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

Stinson Beach Nature-Based Adaptation Study

Executive Summary

1. Introduction

With a grant from the State Coastal Conservancy, Marin County Community Development Agency (CDA) contracted with Environmental Science Associated (ESA) toto examine the feasibility of a nature-based green infrastructure project at Stinson Beach (Federal ownership) and Upton Beach Park (County ownership).

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;

Chapter 3 Climate Scenarios and Adaptation Criteria defines the climate scenarios and adaptation criteria used in the study;

Chapter 4 Adaptation Alternatives documents the development and evaluation of sea-level rise adaptation alternatives for the Pacific shoreline of Stinson Beach;

Chapter 5 Regulatory and Policy Considerations describes relevant regulatory issues pertinent to implementation of nature based adaptation alternatives as well as policy considerations;

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.

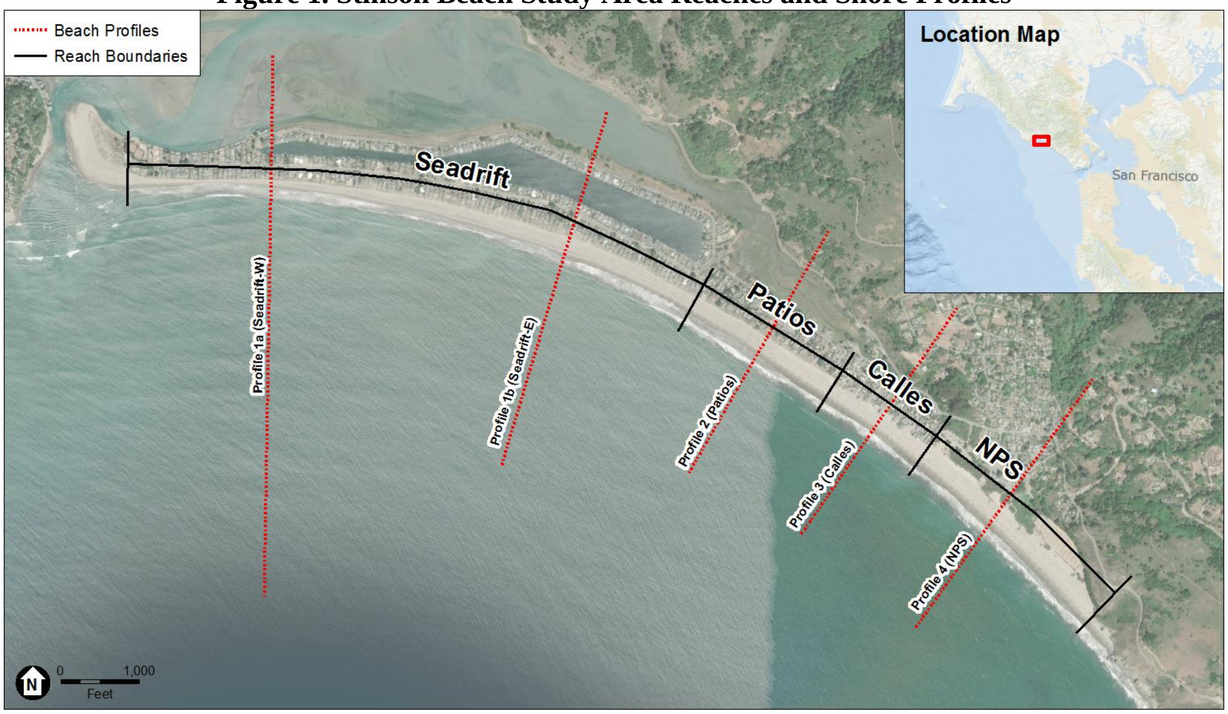
Today, development along the western spit (Seadrift) occupies low areas that were previously foredunes that experienced frequent wave overtopping as well as periodic subsidence as a result of fault activity on the San Andreas fault that passes below the west end of Seadrift. At the eastern end of the 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

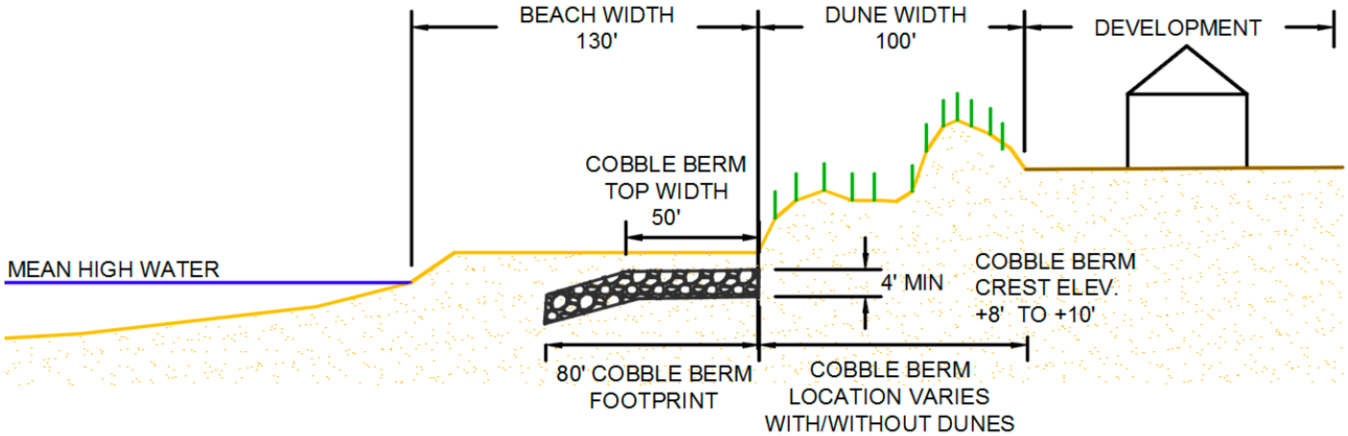
A cobble berm can act as a soft revetment whether buried under dunes or constructed by itself. During a coastal storm event, a constructed gravel/cobble berm can buffer the backshore from flooding but not without eroding and flattening from the wave power. Thus there is a minimum amount of elevated cobble 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: o 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)

Chapter 2
Existing Conditions

This chapter presents the background literature and describes existing conditions at Stinson Beach for the Nature-Based Adaptation Feasibility Study (study). It is broken into the following sections:

1. Project Description, Goals and Objectives.
2. Literature Review
3. Study Reach Definitions
4. Ecological Characterization
5. Reference Sites
6. Shore Dynamics Characterization
7. Sediment Characterization

1. Project Description, Goals and Objectives

The study will assess the feasibility of a nature-based green infrastructure project at Stinson Beach (Federal) and Upton Beach Park (County) 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 flood and erosion protection for public and private assets against existing coastal hazards and future sea level rise. The nature-based project alternatives developed in this feasibility study will be compared to a traditional engineered shoreline protection approach. 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 Project Goal and Objectives 1 to 3 are addressed throughout this existing conditions memorandum.

2. Literature Review

Several studies and reports were reviewed to inform 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 below along with key information relevant to this Feasibility Study.

In 1984, the Pacific Northwest Laboratory investigated the damage from the winter storm of 1982-83 at Stinson Beach Park (NPS reach in this study), as well as its contributing physical processes, beach recovery, and shore protection measures feasibility to reduce future risk. This study was documented in the ***Investigation of Stinson Beach Park Storm Damage and Evaluation of Alternative Shore Protection Measures*** report (Ecker and Whelan, 1984). Over the winter of 1982-1983, the beach was almost completely eroded and wave run-up eroded the foredunes and flooded the backshore at Stinson Beach Park. The study summarized local wind and wave climate, including details on the various storms that occurred during the 1982-1983 winter. The largest 6-hour significant wave height of 25 feet (12.2 second period) was observed on January 26, 1983 at the Farallon Island wave gauge. Using the energy-flux-method-based program by Perry and Street (1969), this study estimated potential longshore sediment transport at Stinson Beach Park to equal about 310,000 cubic yards per year, directed almost exclusively to the northwest. The study evaluated shoreline protection alternatives for Stinson Beach Park in comparison to no action: foredune development/enhancement, riprap revetment and nearshore artificial seaweed beds. The lowest cost alternative was determined to be limited riprap revetments only around existing structures at Stinson Beach Park (lifeguard station, restrooms, parking lot).

In the ***Measuring Key Physical Processes in a California Lagoon*** paper (DeTemple et al., 2000), Philip Williams & Associates (PWA) conducted a data collection and analysis program at the Bolinas Lagoon as part of the USACE feasibility study for protection and restoration alternatives in the lagoon. A wide range of physical processes including tidal hydrology, tidal current, wave climate, and inlet channel morphology were measured during April-May and October-November of 1998. This study is one of several reports developed for the USACE.

The Bolinas Lagoon Ecosystem Restoration Feasibility Project was conducted in 2006 by PWA and WRA, Inc. for the Marin County Open Space District, to review the historical evolution and develop a 50-year projection evolution of Bolinas Lagoon and its habitats (PWA, 2006). Analysis of sediment cores collected in Bolinas Lagoon (Byrne et al., 2006) revealed that sediment accumulation has averaged approximately 43,000 CY/yr between 1906 and 2004, to which the littoral beach sands from Stinson Spit and silt eroded from the Bolinas Bluffs contributed about 33,000 CY/yr, and the alluvial processes contributed about 10,000 CY/yr.

O’Connor Environmental, Inc. (OEI) prepared the ***Stinson Beach Watershed Program Flood Study and Alternatives Assessment*** for the Marin County Flood Control and Water Conservation District in 2014 (OEI, 2014). The study examined existing creek and floodplain conditions of Easkoot Creek in the community of Stinson Beach with respect to peak storm runoff and long-term sediment deposition as well as SLR effects on these processes. Ten feasible alternatives that provide benefits for flood protection, habitat restoration and emergency access were assessed, among which Alternatives 9 and 4 that include dredging were shown to be more significant for flood mitigation. Dredged materials from the Easkoot Creek are a potential opportunistic source for use in the adaptation alternatives developed for the current study. OEI proposed removing 3,100 cubic yards of sediment from 2,300-foot reach of Easkoot Creek between Arenal Avenue and Calle del Arroyo and constructing supplemental sediment removal structures with a capacity of about 290 cubic yards.

A similar restoration project was conducted in 2016 at the Cardiff Beach ***- The Cardiff Beach Living Shoreline Project*** (Moffatt & Nichol, 2016), which aimed to develop a natural SLR adaptation approach to protect a vulnerable segment (2,900 feet) of Cardiff Beach by beneficially reusing export materials generated from the San Elijo Lagoon Restoration Project (SELRP) or another opportunistic sand source. The SELRP began in 2017 and through 2019 was estimated to yield ~one million CY of export material. Three alternatives were considered for Cardiff Beach living shoreline designs, including 1) exposed cobble dune (5,000 CY of sand + 15,000 CY of cobble), 2) sand dune (20,000 cy of sand), and 3) buried cobble under dune (10,000 CY of sand + 10,000 CY of cobble). While this report is not relevant to existing conditions at Stinson Beach, this project provides examples of adaptation measures that could be evaluated in this study. The constructed alternative included upgrade of existing rip rap to an engineered revetment, existing cobble reconfigured into a dune core, a sand dune created with native habitat, and pedestrian improvements created along HWY 101.

The Sonoma-Marin Coastal Regional Sediment Management Report was prepared by the Greater Farallones Association in 2018 (George et al. 2018). The Greater Farallones National Marine Sanctuary (GFNMS) led a process financially supported by the State of California to develop coastal sediment management recommendations for the Sonoma and Marin County outer coasts (340 miles, including Tomales Bay). This report summarized sediment sources and sinks in the study area from the literature and identified potential sediment sources for future coastal restoration activities. Key findings relevant to our study are summarized below.

- In the literature, sediment sources are not well constrained because of widespread data gaps. The largestindividual sediment sources to the Sonoma-Marin coast include the Russian River (900,000 tons/yr, Milliman and Farnsworkth, 2011), Gualala River (270,000 tons/yr, Milliman and Farnsworkth, 2011), San Francisco Bay (1,200,00 tons/yr total export, Erikson et al., 2013), Cliffs such as Bolinas bluffs (5,100 tons/yr, Ritter, 1973) and slides such as the Lone Tree Slide (1,800,000 tons, Komar, 1998) afterthe 1989 Loma Prieta earthquake.

- Sediment sinks are only quantified in three areas in the literature, including Bodega Harbor (6,300 tons/yr, Conner et al., 2006), Tomales Bay (2,828 tons/year, Rooney and Smith, 1999), and Bolinas Lagoon (5,180 tons/yr, PWA, 2005). Two dams erected on the Russian river and culverts under Highway 1 and county roads that prevent free flow of sediment to the coast also function as sediment sinks.

- Potential sediment sources include dredged materials from San Francisco shipping Channel (about 300,00 CY/yr) currently placed near Ocean Beach, offshore sand deposits at the Bolinas Graben (volumes not provided), and accumulated sediment in Bolinas Lagoon.

The Natural Shoreline Infrastructure: Technical Guidance for the California Coast (TNC, 2018) provided guidance and design criteria crucial to inform natural shoreline infrastructure planning process, based on a more in-depth paper (Newkirk et al. 2018) from the California's Fourth Climate Change Assessment. This guidance discussed six Natural Shoreline Infrastructure Measures – Vegetated Sand Dunes, Cobble Berm, Marsh Sill, Tidal Bench, Oyster Reef, and Eelgrass Bed, among which the Vegetated Sand Dunes and Cobble Berm are suitable for our site at Stinson Beach. To implement the Vegetated Sand Dunes, the design parameters that need to be considered include seaward edge of the dune, landward limit of zone/space available for a dune field, and appropriate alongshore length. Key design parameters that should be determined for a Cobble Berm site include: alongshore length of constructed berm, crest elevation, slope and layer thickness and volumes. In addition to the space needed for constructing such features, space for lateral beach access and property boundaries must also be considered.

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 used coastal flooding and erosion hazard maps produced by the US Geological Survey (USGS) and ESA, respectively, to determine exposure of the Stinson Community and other Pacific coast communities to sea-level rise. 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. The Adaptation Report identified several conceptual alternatives for adaptation 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 is part of CDA's continued efforts to develop innovative adaptation solutions for West Marin.

3. Study Reach Definitions

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 and are described below. Existing beach dimensions provided below are based on a topographic survey conducted on October 16, 2019. Beach width is defined as the distance from the MHW shoreline to the backshore (dune or armoring toe, or development). One characteristic profile was surveyed for each reach except for Seadrift which has two profiles. Figure 1 below shows the Stinson Beach study area with reaches, including nearby wave and wind gauge locations that were accessed for this analysis. Note the beach profiles extend offshore to approximately -35 feet NAVD to capture the full active beach profile. The location of this depth is further offshore at the Bolinas lagoon mouth (due to the sand shoal there, which forms from ebb tide sediment export from the lagoon) and closer to shore near the headlands on the east side of Stinson.

Large format plan figures of each study reach are provided in **Appendix A**.
Photos taken at each shore profile location are provided in **Appendix B**.
Representative shore elevation profiles for each reach are plotted in **Appendix C**.

SOURCE: ESA, Marin County 2018 Imagery, ESRI

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Figure 1
Stinson Beach Study Reaches

Reach 1: Seadrift – Lagoon mouth to 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 3,800 feet and eastern 1,200 feet of shore, while the central portion of the structure is buried by sand with dune vegetation. The beach width in October 2019 ranged from approximately 50 to 250 feet, while the minimum documented beach width was 29 feet. The basemap for this reach is shown on Figures A-1 to A-3. Reach photos taken from the October 2019 shoreline and back of beach at each survey profile are shown on Figures B-1 and B-2. Noble Consultants (Noble et al 2007) has documented armoring conditions along Seadrift for the past few decades. After the 1983 El Nino, over 35,000 tons of rock riprap along the Seadrift shoreline for the protection of 125 property owners and residences, expanding upon an emergency structures built along the western and eastern portions of Seadrift during the 1978 and 1980 winters respectively. This structure was constructed to a 2.5:1 (horizontal: vertical) slope with a toe elevation of approximately +7 feet MLLW (Mean Lower Low Water) and a crest elevation of +17.5 feet MLLW. After 1998 El Nino, 5,500 tons of new stone was placed for repairs. An additional 3,000 tons were placed in 2004 and 700 tons of repair work was done in 2006. Due to the existing protection afforded by the rock revetment that spans the Seadrift Reach, the relative need for natural infrastructure is lower compared to the other study reaches.

Reach 2: Patios – Seadrift/Walla Vista to Calle Del Embarcadero/Occidente (2,080 feet long). This reach has the greatest width of beach and foredunes seaward of residential property. The beach width in October 2019 ranged from approximately 210 to 275 feet, while the minimum documented beach width was 73 feet. The basemap for this reach is shown on Figure A-4. Reach photos taken near the survey profile are shown on Figure B-3.

Reach 3: Calles – Calle Del Embarcadero/ Occidente to Calle Del Pinos (1,460 feet long). Homes closer to shore, encroaching on beach. The beach width in October 2019 ranged from approximately 240 to 295 feet, while the minimum documented beach width was 80 feet. The basemap for this reach is shown on Figure A-5. Reach photos taken from the October 2019 shoreline and back of beach on the survey profile are shown on Figures B-4.

Reach 4: NPS – Calle Del Pinos to Stinson boulders (3,040 feet long). National Park beach and dunes fronting parking. The beach width in October 2019 ranged from approximately 240 to 300 feet, while the minimum documented beach width was 56 feet. The basemap for this reach is shown on Figure A-6. Reach photos taken from the October 2019 shoreline and back of beach on the survey profile are shown on Figures B-5.

Representative beach profiles were surveyed by ESA and Merkel on October 16, 2019 to establish existing geometry and sediment characteristics (see Section 7). The opportunities and constraints for nature-based adaptation alternatives will depend on available space and backshore elevations along the study area. Table 1 lists documented beach widths for each reach since the 1920s; the greatest beach widths are typically observed in the fall and minimum widths occur in the late winter/spring. The beach width is defined as the distance between the backshore (toe of dune or armoring, or development edge) and the mean high water line (5.1 feet NAVD based on NOAA tide gauge 9415020 at Point Reyes). ESA timed the existing conditions topographic survey in October 2019 before the first winter storms occurred in order to document the widest beach conditions. The average minimum beach widths reported in Table 1 were determined by available LiDAR from April 1998, May 2010 and May 2016.

TABLE 1
RECENT BEACH GEOMETRY FOR STUDY REACHES

Reach	Name	Length (feet)	October 2019 Average Beach Width, feet [with range per reach]*		1920-2019 Average Minimum Beach Width, feet [with range per reach]*		October 2019 Average Beach Berm Elevation, feet NAVD	October 2019 Intertidal Slope, from MLLW to MHHW
1	Seadrift	**7,610**	**156**	[47 to 243]	**71**	[26 to 127]	10.3	2.4 to 2.5%
2	Patios	**2,080**	**250**	[210 to 274]	**102**	[73 to 128]	9.3	2.4%
3	Calles	**1,460**	**267**	[242 to 295]	**104**	[80 to 142]	9.0	2.5%
4	NPS	**3,040**	**264**	[241 to 298]	**130**	[56 to 197]	9.5	2.4%
All	-	**14,190**	**205**	[47 to 298]	**92**	[29 to 197]	9.8	2.5%

** Averages and ranges of beach width are based on 50-foot spaced transects along the study shoreline.*

4. 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, etc. By understanding these physical-ecological links, future shoreline projections can be related to existing ecology functions and to evaluate the ecological implications for shoreline adaptation alternatives. This section presents an overview of available historical information about the natural topography and vegetation at Stinson Beach prior to residential development (early 20th century) followed by discussions for onshore and offshore ecological conditions as observed in Fall and Winter of 2019 by the ESA team.

4.1. Historical Foredune and Backshore Conditions at Stinson Beach

The natural features we hope to utilize for coastal adaptation at Stinson Beach evolve over long time periods. The historical conditions of Stinson Beach before significant development were studied to develop an understanding of the natural evolution of the beach-foredune spit that is Stinson Beach. The historic conditions provide an indication of the natural maintenance potential of implemented nature-based adaptation measures. The photograph below provided by the Stinson Beach Historical Society shows an undeveloped sand spit in 1910.

Stinson Beach circa 1910, showing undeveloped sand spit. (Stinson Beach Historical Society)

Primary sources of information on Stinson beach and foredune morphology, landforms, and dynamics include descriptive geomorphic and vegetation accounts by W.S. Cooper's monograph of California coastal dunes, and interpretation of historical photographs. Cooper (1967) provided only brief descriptive accounts of Stinson Beach as having "rudimentary" dune development, like Doran Beach, based on his coastal California dune surveys of the 1930s. This description is consistent with the historical early 20th century photographic images of Stinson Beach showing most of the spit supporting a wide geomorphically young washover terrace dotted with relatively uniform distribution of low-relief vegetated dune mounds across the entire barrier beach profile. The early 20th century Stinson Beach dune field exhibited no traces of older remnant dune vegetation or landforms, indicating the area is a frequently overtopped and experiences limited natural dune accretion.

Stinson Beach was affected by subsidence of the eastern side of the San Andreas Fault in Bolinas Lagoon following the 1906 earthquake: wave overtopping of the spit became frequent and apparently widespread after the earthquake (Lawson 1908:81-82). Plate 6B of the "California Earthquake of April 18 1906" (Lawson 1908) shows a view of Stinson Beach from Wharf Road in Bolinas immediately after the earthquake. Seadrift appears to be a low, wide uniform overtopped terrace, which would be expected if co-seismic subsidence lowered the spit and thus it's elevation threshold for storm wave overtopping. Geologist G.K. Gilbert (a pioneer in barrier spit geomorphology) recorded his own and local resident observations of Stinson Beach's change in wave overtopping frequency following the 1906 earthquake:

> The overflow of the spit by waves during the past winter had washed a considerable amount of sand down the north slope, and this sand suffocated large tracts of Salicornia and other plants…[quantified estimated subsidence of adjacent McKinnon Island of 10 inches] appears sufficient to account for the overwashing of the spit, (G.K. Gilbert, in Lawson 1908:83)

> Various residents are of opinion that the sand-spit, except at its extreme western end, is lower than formerly. A lady who has lived at Dipsea Inn several years states that before the earthquake the spit was overtopped by waves only during storms with heavy winds, but that since the earthquake waves frequently wash over it. It will be observed that all this testimony, with the single exception of Mr.

> Morse's observation of water-levels near his house, tends to show a general sinking of the land east of the fault, and a general rising of that to west of it. (G.K. Gilbert, in Lawson 1908:82)

The Stinson-Seadrift spit is situated above the San Andreas fault which passes under the western end of Seadrift and northwards up Bolinas Lagoon. Thus the Stinson spit may be subject to future subsidence during earthquakes along the fault.

Looking down Bolinas Lagoon and Bay toward the Golden Gate, village of Bolinas in foreground (H.W.F.). Plate 6 B. Andrew C. Lawson, The California Earthquake of April 18, 1906. Report of The State Earthquake Investigation Commission. Carnegie Institution of Washington Publication No. 87, Volume I, Part I.

The east/west fault scarp uplift and subsidence pattern that rejuvenated Stinson Beach by wave overtopping was marked by a visible, measurable transient fault scarp boundary on “Pepper Island” (original name of Kent Island) and its adjacent lagoon flats of Bolinas Lagoon. Gilbert and botanist W.S. Jepson (Lawson 1908) made direct measurements of transient fault scarps on “Pepper Island” sands and muds following the earthquake, estimating an average of 1 ft (up to 1.5 ft) subsidence on the NE side of the fault (Lawson 1908:72). Recent sediment cores (Reidy and Byrne 2006) indicate significant net co-seismic subsidence of the lagoon flats up to 2.7 m during the last two millennia of the late Holocene (after AD 400), unevenly balanced by tidal and fluvial sedimentation during gradual sea level rise.

Therefore, the geomorphic evolution of the dune field at Stinson Beach during the 20th century should be interpreted as sequential, gradual stages in long-term recovery following abrupt seismic subsidence of the spit and intensification of wave overtopping. The limited foredune growth that occurred by the time of post-War residential development (1950s) suggests that even under relatively slow sea level rise during the 20th century and favorably wide backshore conditions, Stinson Beach dune building rates are relatively slow compared with west-facing Pacific dune fields oriented onshore to dominant westerly winds (e.g. Dillon Beach, Ocean Beach). Previous earthquakes documented in 1695 and 1776 north of the Golden Gate suggest a shorter, time interval (130–210 yr) between major earthquakes here than has been previously documented (Hall and Niemi 2008).

The extreme eastern end of Stinson Beach, where back-barrier wetlands where non-tidal freshwater pond, swamp (riparian woodland), and marsh, were apparently not impacted by wave overtopping following the 1906 earthquake, and persisted in historical photographs of the 20th century (see below) until most of them were drained and filled. Significant repeated storm wave overtopping of seawater there would likely have caused persistent brackish wetland conditions and associated dieback of salt-sensitive freshwater riparian scrub or woodland dominants, such as willow, waxmyrtle, and red alder. Well-developed, steep foredunes and anomalous wetland dune scrub vegetation were evident in the east end of the spit, where the backbarrier wetlands formed a freshwater non-tidal "lagoon" or dune pond, instead of the tidal lagoon salt marsh. This area corresponds with the approximate location of the modern County Park and GGNRA shoreline and backbarrier parking lots (referred to as NPS reach in this study), where wetland scrub foredunes and emergent groundwater exist today (see historic T-Sheet below).

View west from hills above NPS Reach showing historic lagoon in foreground in the location of the existing dirt parking lot. (Stinson Beach Historical Society)

Marram (European beachgrass; Ammophila arenaria) was first collected from "Bolinas Lagoon" in 1931, and subsequent multiple herbarium collections from the 1930s-1940s at Stinson Beach indicate that this was the "Bolinas" locality. Marram was introduced to San Francisco and extensively established to form stabilized large mobile dune systems in the 1870s, and Stinson Beach is the nearest backshore dune habitat north of San Francisco. All west Marin dune localities north of Bolinas had established significant marram cover by the 1930s (Cooper 1967). It is very likely that marram dominated foredune geomorphic processes and topography of Stinson Beach during the entire 20th century, prior to residential development.

The T-sheet excerpts in Figure 2 below show the extent of fill and development along the sand spit in the 20^{th} century. Development along the western spit backshore were constructed in low foredune areas that experience 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.

SOURCE: USGS 1897 and 1993

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Figure 2
Excerpts of US Geological Survey T-Sheets 1897 (Tamalpais, top)
and 1993 (Bolinas, bottom),

4.2 Onshore Characterization

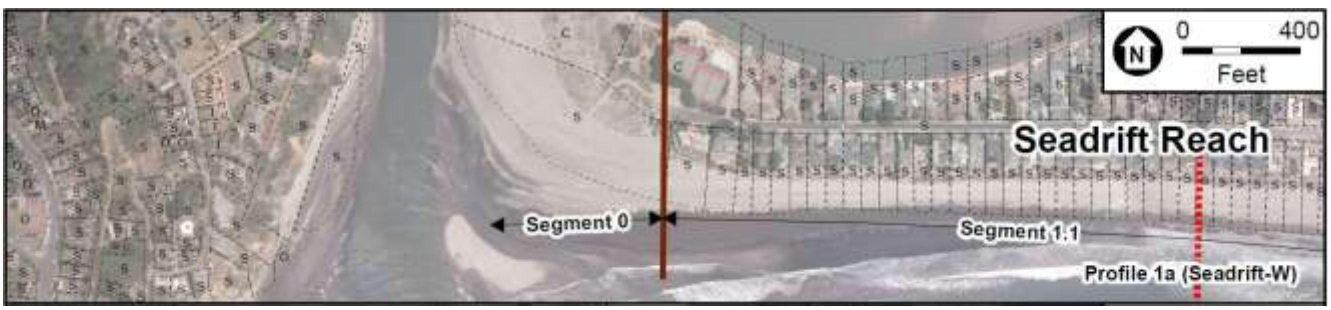
Onshore beach and foredune conditions at Stinson Beach were surveyed by Dr. Peter Baye on December 20, 2019. The description in the following subsections draw from observations made during this survey as well as prior observations made over the past decade. The main focus of the beach and dune assessment is on indicators of ecological and geomorphic interactions between (a) wave and wind transport of sand, (b) beach and foredune vegetation, and (c) patterns and processes of short-term and long-term erosion and deposition, and backshore (beach and dune) landforms resulting from their interactions. The assessment is presented as continuous segments that comprise the coast. Reaches defined fort this study align with and are represented by one or more ecological segments

4.2.1. Shoreline Segments

The artificially filled and developed Stinson Beach shoreline today has distinct segments with high contrasts in the development of existing foredunes, and backshore beach space available for either incipient ("embryo") foredunes or post-storm recovery of scarped (wave-cut) foredune profiles. For description purposes, the shoreline was classified based on the seaward extent of residential structures and presence of a shore armoring structure or continuous sand beach-foredune backshore transition. Based on these criteria, review of aerial photography, and field observations, 8 distinct shoreline segments were identified along Stinson Beach from the Bolinas Lagoon mouth to the eastern end of the spit at the Stinson Boulders. These segments are described below within the context of the shoreline reaches defined for this feasibility study.

Seadrift Reach

Segment 0 (Figure 3): Beyond the west end of the Seadrift reach is the end of the Seadrift spit. The area is a low foredune terrace and that borders the Bolinas Lagoon tidal inlet. This low-relief foredune terrace is dominated by a non-native marram (European beachgrass, Ammophila arenaria), with patches of native foredune and beach vegetation including beach wildrye (American dunegrass, Leymus mollis; syn. Elymus mollis). Due to forces from tidal currents from the lagoon mouth and waves, this area to cycles of erosion and recovery of the sandy spit and sandbars (as shown in Figure 3), but the foredunes have likely experienced infrequent wave overtopping given its sheltered position relative to the overall shoreline.



SOURCE: ESA, Marin County 2018 Imagery

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Figure 3
Shore Segment 0

Segment 1.1 (Figure 4): Approximately 60 oceanfront lots at the west end of Seadrift are armored by a rock revetment and the beach profile was essentially a low tide terrace (bar and trough inshore) and narrow intertidal beach face up to the toe of the revetment. There was wave reflection off the revetment at mid-tide, and little or no backshore berm profile in the vicinity at the time of the visit. The base of the concrete/rock stairways within the revetment ranged from 0 to 5 feet above the intertidal beach face, indicating significant long-term loss of beach backshore elevation. This segment has essentially no significant remaining foredunes, and no geomorphic space for them either now (December 2019) or in any season in any year shown in recent aerial photographs in Google Earth. This suggests that utilizing foredunes as natural infrastructure in this reach may not be feasible, especially without the space to construct them.

SOURCE: ESA, Marin County 2018 Imagery, ESRI

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Figure 4
Seadrift Reach - Shore Segment 1.1

Western rock revetment in Seadrift reach, December 20, 2019. Intertidal beach face is revealed at low tide, the surf zone reaches the revetment at high tide with no backshore. An apparent foreshore trough with visible longshore currents lies close inshore near the beach face. (P. Baye)

Segment 1.2 (Figure 5): Along the central foredunes of the Seadrift reach (~2,300 feet), the rock revetment is completely buried along approximately 38 oceanfront lots. This segment is characterized by low and apparently relict and stabilized foredunes with persistent decaying leaf litter at the surface, with minimal indicators of recent (1-2 years) wind-driven sand accretion, and many indicators of recent net erosion (scarped dune faces and exposure of older vegetation at the scarp crest). Homes are landward of the foredunes. This segment has a wider beach than Segment 1.1, which could provide space to construct foredunes as natural infrastructure. However, the existing rock revetment that spans the Seadrift reach provides some backshore protection and reduces the relative need for additional protective infrastructure at Seadrift in the near term compared to the eastern reaches.

SOURCE: ESA, Marin County 2018 Imagery, ESRI

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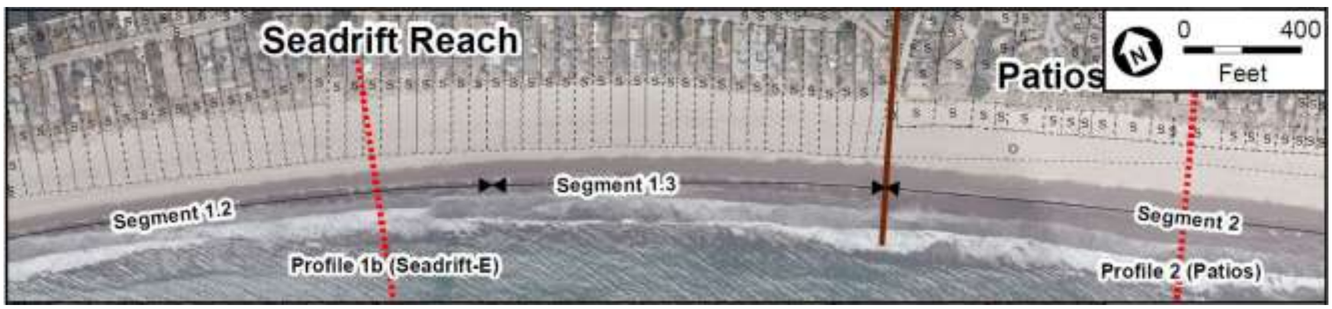
Figure 5
Seadrift Reach - Shore Segment 1.2

Central Seadrift foredune segment, typical profile with a relatively wide backshore, persistent drift-lines (potential embryo foredunes) and a foredune scarp with extensive recovery of perennial vegetation and slight but significant sand accretion on the seaward slope. December 20, 2019. This profile indicates some backshore persistence over winter for more than 1 year. (P. Baye)

Segment 1.3 (Figure 6): Along the eastern end of Seadrift reach, approximately 22 oceanfront lots have relict foredunes with exposed rock revetment. Homes are landward of the revetment and relict foredunes. The foredune vegetation in most of this segment is apparently sand-starved, erosional at the seaward face (scarped dune faces are prevalent), and dominated by marram, iceplant and various ornamental landscaping specimens. The west end of this segment, however, exhibited the greatest sand accretion (a precursor to foredune formation) and widest backshore areas near its west end. Some of the eastern boulder revetment had been buried by marram-vegetated foredunes accreted to the height of the revetment in past years, burying and obscuring the revetment but has been recently re-exposed by erosion. Relatively young marram foredunes in some locations are perched on the revetment, protected from wave erosion below. However, there is no indication of recent (1 year or older) backshore vegetation seaward of the revetment. This inconsistent pattern suggests alternation between complete erosion of the backshore, and phases of temporary beach recovery and sand accretion, with trapping of sand in the only persistent perennial vegetation perched atop and protected by the revetment. In other words, the only geomorphic space apparently available for persistent foredunes is that which is provided behind the rock revetment given the current range of shoreline positions. In summary, this segment also has a wide beach that could accommodate the construction of foredunes as natural infrastructure. However, the existing rock revetment that spans the Seadrift reach provides some backshore protection and reduces the relative need for additional protective infrastructure at Seadrift in the near term compared to the eastern reaches.



SOURCE: ESA, Marin County 2018 Imagery, ESRI

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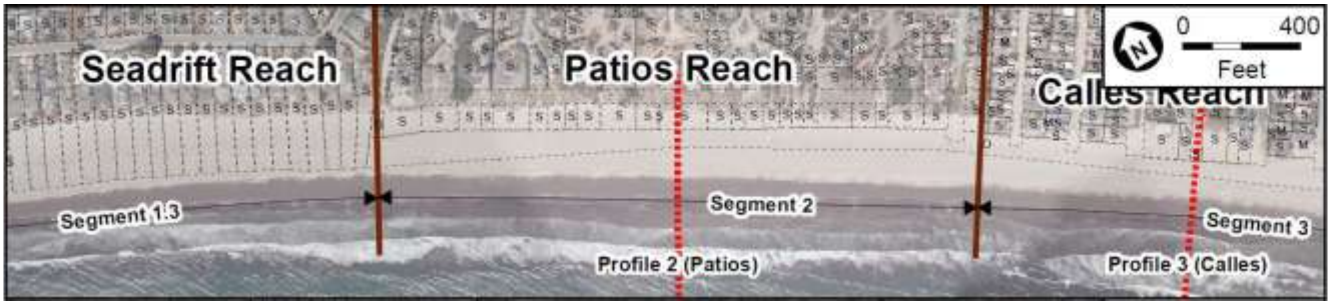
Figure 6
Seadrift Reach - Shore Segment 1.3

Eastern end of Seadrift rock revetment, December 20, 2019. The boulder revetment here varies between exposed boulders with recent unvegetated wind-deposited sand ramps (SE-oriented) and mixed marram foredunes perched in the revetment, partially eroded or persistent. This profile indicates alternation between severe erosion to the revetment, and episodes of backshore beach and dune accretion. There is currently no significant annual or perennial beach vegetation in the backshore seaward of the revetment. (P. Baye)

Patios Reach

Segment 2 (Figure 7): The Patios reach is comprised of foredunes and a wide beach. West of Calle del Embarcadero (Calle del Occidentale) to Walla Vista are relict foredunes seaward of homes. Relict foredunes here exhibit strong long-term and short-term (recent) erosion indicators, and no indicators of recent significant wind-driven sand accretion.



SOURCE: ESA, Marin County 2018 Imagery, ESRI

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Figure 7
Patios Reach - Shore Segment 2

Patios reach, December 20, 2019. All foredunes exhibit "sand-starved" persistent linear scarps, with exposed older graying marram leaf litter at the sand surface. There is no sand burial of attached, matted gray leaf litter, no tapered mounds of wind-blown sand around vegetation patches (sand shadows) in the scarp or above its crest. There is no significant annual or perennial backshore vegetation seaward of the scarp. (P. Baye)

Calles Reach

Segment 3 (Figure 8): The Calles reach is primarily beach-top residential. The extreme eastern lots along County roads (Calle del Embarcadero to Calle del Pinos) project seaward of the adjacent foredune lines and backshore beach zones, located directly over (pile-supported homes) or on (seawall-protected homes) the beach, with recent swash lines landward of the structures. The setback older homes between them also appear to be positioned seaward of the nearby willow scrub foredunes of the NPS Reach to the east (See Leymus mollis account below).

SOURCE: ESA, Marin County 2018 Imagery, ESRI

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Figure 8
Calles Reach - Shore Segment 3

Calles reach, December 20, 2019. Homes are located on the active foreshore and backshore (swash zones of fair-weather and storm beach profiles); eroded foredunes, where they persist, are landward and between the prominent homes. (P. Baye)

NPS Reach

Segment 4.1 (Figure 9): The National Park Service Reach backshore is comprised of freshwater wetland scrub foredunes influenced by seep and distributary channels including Easkoot Creek.

SOURCE: ESA, Marin County 2018 Imagery, ESRI

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Figure 9
NPS Reach - Shore Segment 4.1

Very distinct and regionally rare wetland scrub foredunes (effectively small precipitation dune ridges; Cooper 1967) occur locally between the Calles and the west end of the National Park Service (GGNRA) overflow parking lot, where high groundwater emerges seasonally at the surface as perennial backshore beach seeps. This is one of the only examples of freshwater wetland-dominated foredunes left on the Central California coast. This segment also contains two seasonal stream distributary mouths connected to Easkoot Creek and Stinson Beach. The eastern small stream mouth breaches the stabilized wetland foredune ridge and drains a disconnected floodplain backwater swamp thicket landward of the wetland-vegetated foredune. The backdune wetland consists of freshwater riparian scrub and marsh dominated by willows (Salix lasiolepis, Salix spp.), waxmyrtle (Morella californica), sedges (Carex obnupta, Scirpus microcarpus), rushes (Juncus lescurii), and many freshwater marsh forb species, including water-parsnip (Oenanthe sarmentosa). This wetland foredune is apparently a descendent of the original backdune pond (freshwater lagoon) at the spit’s eastern end, either a remnant of the original complex or reassembled from it. The western seasonal stream mouth drains an intermittent overflow distributary channel (bank breach) of Easkoot Creek through an unstabilized public pathway to the beach. The foredune vegetation itself consists of an older salt spray wind-flagged willow-waxmyrtle thicket that traps a dune precipitation ridge, and a younger low marsh-foredune terrace composed of mixed freshwater and brackish marsh vegetation, including coast bulrush (Schoenoplectus pungens), saltgrass (Distichlis spicata), and Vancouver wildrye (Leymus xvancouverensis). The younger marsh-foredunes alternate between accretion and erosion among years. The backshore in the wetland foredune zone is often eroded down to a seasonal stream channel (down to intertidal foreshore) saturated to the surface with freshwater (emergent groundwater). A lens of stream gravel, or wave-reworked stream gravel, sometimes outcrops in the backshore where seep-fed rill erosion and wave erosion expose it. The buried backshore gravels are likely a mechanism of efficient shallow subsurface freshwater discharge from backdune to beach. Little long-term net foredune growth has been observed here since 2011. Storm wave run-up appears to cyclically remove accreted foredune sand where the beach is perennially saturated with shallow groundwater.

Some of the willow-dominated foredunes near the west end of this segment have their seaward faces trampled down to bare sand, which destabilizes the dune face, and also makes it more conducive to vertical growth and landward retreat by enabling efficient onshore sand transport by wind and waves from the beach to the crest. The lack of trampling on the shaded, brushy landward slope maintains sand trapping capacity there, at least currently.

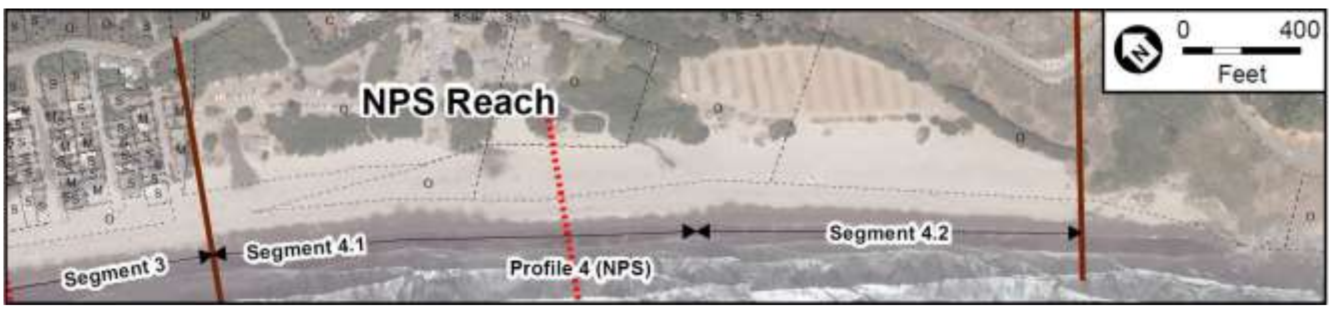
Freshwater marsh vegetation and riparian scrub vegetation dominate foredune area associated with high emergent groundwater (freshwater seeps) between the backdunes and backshore beach. June 17, 2011 (left; willow-waxmyrtle scrub and rush marsh) and April 2, 2013 (right; Vancouver wildrye). (P. Baye)

A perennial to seasonal freshwater channel draining the backdune wetlands supports dominant freshwater marsh vegetation in the foredunes, including broadleaf cattail (Typha latifolia), coast bulrush (Schoenoplectus pungens) and salt rush (Juncus lescurii), excluding typical terrestrial foredune vegetation. This is one of the only examples of freshwater wetland-dominated foredunes left on the Central California coast. April 3, 2015. (P. Baye)

Freshwater seeps and emergent groundwater can dominate the entire backshore profile in wet years with high groundwater, saturating the beach from the toe of the willow-waxmyrtle wetland foredune to the intertidal zone. Seep/spring erosion rills and wave erosion (intensified wave backwash in saturated sand) locally expose outcrops of buried stream gravels. March 6, 2014. (P. Baye)

Seasonal freshwater stream discharge from the willow-waxmyrtle wetland foredunes saturates the backshore and foreshore beach below the stabilized stream mouth breach in the foredunes. March 6, 2014. (P. Baye)

Segment 4.2 (Figure 10): Along the GGNRA overflow parking lot, the backshore is comprised of semi-artificial foredunes. This feature serves as a local example of foredune creation at Stinson Beach that could be evaluated for this study, as it shows the greatest signs of natural foredune accretion of all the shore segments.



SOURCE: ESA, Marin County 2018 Imagery, ESRI

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Figure 10
NPS Reach - Shore Segment 4.2

The east end of the sand spit supports a semi-natural foredune that is partially derived from occasional (or past) maintenance removal of blown foredune sand from the unpaved GGNRA overflow parking lot, and placement of mixed dune sand and parking lot soil/gravel (spoils) in berms at the edge of the parking lot's seaward roadway. The segments of spoil berms become linear nuclei for new foredunes as they become vegetated with a mix of roadside weeds (dependent on soil admixture enriching nutrient-poor, moisture-poor dune sand) and native and non-native foredune plants (dispersed by storm waves and tidal litter on the seaward side). The berm vegetation subsequently traps and accretes dune sand, and evolves into naturalized linear foredune ridges. The degree of naturalization of the berms to foredunes depends on the extent of sand burial. The landward sides of the berms generally have more surface exposure of mixed soil/sand, and support high proportions of weeds, especially ripgut brome (*Bromus diandrus*). The seaward and crest slopes tend to be thickly covered with accreted dune sand, and support one of the largest colonies of perennial pink sand verbena (taxonomically intermediate, variable population, close to the rare *Abronia umbellata* var. *breviflora*, introgressant with *A. umbellata* var. *umbellata*). The associated foredune species here include scattered colonies of Vancouver wildrye (*Leymus* x*vancouverensis*), beach-bur (*Ambrosia chamissonis*), and yellow sand-verbena (*Abronia latifolia*). Isolated willows also occur in this area, indicating shallow seasonal freshwater groundwater, but less so than the freshwater marsh-dominated foredunes in Segment 4.1.

This easternmost foredune segment contains the richest source of native foredune species populations on the sand spit, and has the strongest indicators of frequent significant onshore transport of wind-blown sand. It also rarely exhibits wave-eroded foredune scarps, in contrast with the rest of Stinson Beach. These distinctive features correspond with the beach orientation, profile, and sand texture at the east end of the sand spit: wide, dissipative low tide terrace and beach face dominated by finer (medium) sand, a wide backshore (provides a dry sand fetch), and orientation of the shoreline with greater exposure to westerly onshore winds.

Graded berms of mixed blown sand and parking lot "dirt" fill (gravel, soil, angular pebbles) are placed at the seaward edge of the overflow parking lot, develop sand-trapping vegetation, and become mantled with accreted dune sand. Sept 20, 2013. (P. Baye)

The landward slopes of the eastern berm-nucleated foredunes often have thin or no accretion of dune sand, and expose mixed sand/soil spoils at the surface, which support annual weed-dominated vegetation, mixed with native foredune plants. April 17, 2015. (P. Baye)

The accreted dune sand on berm-nucleated foredune crests inhibits dominance of annual weedy grasses, and selects for prevalence of native foredune vegetation. The eastern-most Stinson Beach shoreline is oriented with greater exposure to dominant westerly winds compared with central and western shorelines of the spit, and has a wide backshore with finer (medium) sand. These interactions promote vigorous growth of native foredune vegetation. April 5, 2013 (left) and April 17, 2015 (right). (P. Baye)

Perennial colonies of pink sand-verbena (Abronia umbellata) occur extensively in the berm-nucleated foredunes bordering the overflow parking lot. June 17, 2011. (P. Baye)

4.2.2. Vegetation and drift-lines

Existing vegetation observed in December 2019 is further elaborated upon in this section to provide context for nature-based approaches utilizing dune vegetation. The vascular plant species richness (number of species) and diversity (evenness of species' relative abundance) in the study area foredune and beach (high tide beach; backshore) were very low compared with Kent Island's west beach and the proximal end (GGNRA) of Stinson Beach. The dominant and most frequent plant in the foredune zone in all Stinson Beach shoreline segments was marram (European beachgrass; *Ammophila arenaria*), occurring throughout in naturalized populations, and probably some planted ones as well. The next most frequent and locally abundant plant in foredunes and on boulder revetments was iceplant (*Carpobrotus chilensis*, *C. edulis* x *chilensis*). One native foredune plant, beach wildrye, occur in small, sparse colonies in a few foredune locations, some evidently planted recently, but most apparently naturally established. Sea-rocket (*Cakile maritima*), a ubiquitous introduced annual or short-lived perennial forb on sand beaches of Central Coast region, was infrequent. Most of the native foredune and beach flora present at Kent Island, GGNRA Stinson Beach (East), was either absent or rare and not detected. Other cultivated, non-native ornamental plants were present in the foredune zone, probably as a result of foredune scarp erosion and retreat landward into older plantings (e.g., Monterey cypress, *Hesperocyparis macrocarpa*; acacia or green wattle, *Acacia decurrens*) that were originally farther landward from the shoreline.

***Cakile maritima* (sea-rocket)**. The common pioneer non-native beach weed, sea-rocket (*Cakile maritima*) is frequent on all West Marin beaches that are not severely trampled or eroded and wave-overtopped during the growing season. At Stinson Beach, however, *Cakile* was almost absent from the beach except along the foredunes in the center of Seadrift Reach and western terminal spit (Segment 0). Along the Patios reach, it was present only within the foredune scarp (near-vertical eroded slope), apparently where wave run-up deposited seeds. *Cakile's* significance here is as an indicator of beach erosion and disturbance, and potential for foredune succession, rather than a weed management issue per se. (*Cakile* is not a beach weed management priority, since it seldom conflicts with native beach plants). *Cakile* colonies indicate the zone where ecological succession can proceed between storm drift-lines (containing seeds, vegetative propagules, and organic debris), new and accreting foredunes can occur. Thus, *Cakile* is a useful feasibility indicator and zonal indicator for where embryo foredunes may be established. The extreme scarcity of this prolific pioneer colonizer of beach drift-lines at Stinson suggests that the beach profile space available for backshore deposits of seeds and drift-lines in winter, where they can be left undisturbed by waves or trampling during the subsequent growing season, is highly constrained under existing conditions. Even in highly trampled urban beaches like Ocean Beach, San Francisco, *Cakile* colonies are common except where the beach is graded.

Two factors are likely to contribute significantly to the extremely limited abundance and distribution of *Cakile* at Stinson Beach. First, the diffuse, intensive human trampling pressure along the beach is high because of the continuous distribution of residential access along the beach. Typically, beach trampling tapers rapidly from concentrated points of access, such as parking lots or boardwalks, so that reduction of beach vegetation is limited to the immediate access area. Related to the diffuse, intensive beach trampling pattern is the general compression of the backshore between high tide lines and either steep erosional foredune scarps or steep shoreline armoring. The "coastal squeeze" of the backshore likely confines wave run-up during high tides and high swell episodes, such that the highest, most landward drift-line colonies of *Cakile* (and other beach pioneer plant colonies initiated in winter) are subject to saltwater flooding and wave disturbance (erosion, burial) during the summer growing season. The presence of *Cakile*, in association with some native foredune species such as beach wildrye (*Leymus mollis*) in the central Seadrift Reach, where a low-angle foredune gradient occurs at the landward end of the beach profile instead of armoring or a steep scarp, suggests that beach steepness and width limit pioneer establishment of beach and foredune vegetation in most shoreline reaches of Stinson Beach.

Native beach and foredune plants.

There is a small native flora beach and foredune plants native to the Central Coast, which have been present at Stinson Beach since the earliest botanical locations for "Bolinas Bay" (19th century) and "Stinson Beach" (1930s and later) were recorded. The Consortium of California Herbarium and Calflora were searched for the following species, which are still present at Kent Island and the GGNRA shoreline at east Stinson Beach, as well as the Doran Beach reference system (Bodega Bay).

> *Abronia latifolia* (yellow sand-verbena). Not found along any Stinson Beach shoreline segment. Infrequent as a pioneer in beach drift-lines, common in foredunes of West Marin where marram is not dominant. No local source populations are known.

Abronia umbellata (intermediate between *A. u*. var. *umbellata* and the rare *A. u.* var. *breviflora*; Marin-Sonoma populations from the same locality have been treated as both). Colonies are present along the eastern GGNRA beach reach, and at southwest Kent Island, where they rapidly expanded spontaneously during the restoration project there, after 2012. A. *umbellata* may be present at the western spit terminus, but it is apparently absent along the residential shorefront.

Ambrosia chamissonis (beach-bur). This species was not observed along armored or foredune-scarped residential shoreline segments of Stinson Beach. This is the most common native perennial pioneer beach and foredune forb in the Central Coast region. It may occur in the central foredune reach, but was not detected during winter (leafless or nearly so). Large colonies would have been detectible. It is present at Kent Island, GGNRA Stinson Beach, and at the western spit terminus, so local propagules (seeds; buoyant drifting dry fruits) are present in the littoral cell.

Atriplex leucophylla (whiteleaf saltbush). This is the most common and widespread native pioneer beach plant of the Central California coast. It is present at Kent Island, and at Limantour Spit, but it was not found along the residential shoreline segments of Stinson Beach. It would be expected to occur among *Cakile* in drift-lines of the backshore, but not in accreting foredunes.

Leymus mollis (beach wildrye) and *L. xvancouveresis* (Vancouver wildrye). Sparse colonies of *L. mollis* occur at about three locations in the central foredune reach, and more colonies occur at the western spit terminus foredunes. Compared with foredune colonies at Limantour Spit and Abbott's Lagoon in Point Reyes, the *L. mollis* at Stinson Beach backshore and seaward foredunes appears to grow at significantly lower density, and with shorter shoots. Environmental factors that may influence the lower density, height, and vigor of Stinson Beach *L. mollis* may include sand grain size (slightly coarser sand, lower moisture availability), low rates of organic drift-line debris deposition (nutrient, moisture retention capacity), and beach elevation relative to the fresh-brackish groundwater table surface elevation (high groundwater seaward of perched, non-tidal Abbott's Lagoon, and at low elevations near washover flats composed of medium sand at western Limantour Spit). The significance of the relatively low height and density of naturalized, unmanaged *L. mollis* at Stinson Beach foredunes is its role in generating sufficient surface roughness to trap wind-blown sand. Sparse, low shoot canopies of dune grasses are less efficient at trapping wind-blown sand than taller, denser shoot canopies.

One set-back residence on a lot at the eastern beach-top residential reach has a recently planted (about 1-2 yr) stand of *L. mollis* on what appears to be a low constructed sand bank (image below). The vegetated low (2-3 ft high above backshore) bank appears to be highly wind-sheltered by the adjacent lots with structures placed seaward, on or over the beach. The vegetated bank appears to be eroding at the seaward edge, and exhibits no sand accretion patterns on top.

The natural hybrid *L. xvancoverensis* occurs at both Kent Island (co-occuring with *L. mollis*) and in the vicinity of freshwater seep-influenced willow thicket foredunes at the GGNRA Stinson Beach, but it was not observed in the residential Stinson Beach shorefront. In the absence of high groundwater or finer sand, it would be expected to grow and spread less vigorously than *L. mollis*. *L. mollis* shoot canopy density and height can be increased by addition of nutrient-rich macroalgal (kelp) tidal litter in the backshore, over spreading root zones.

Beach wildrye was apparently planted on sand embankments placed in front of set-back residences within the Calles reach. The sand embankments and wildrye are mostly eroding by undercutting from wave action. (P. Baye)

Vancouver wildrye grows in both "marshy" foredunes (freshwater seep-influenced foredunes near high groundwater and wetland scrub) and well-drained accreting foredunes along the GGNRA overflow parking shore, where it often associated with pink sand-verbena (2011-2015). (P. Baye)

Non-native dune-building vegetation

Marram (marram grass, European beachgrass; *Ammophila arenaria*) is globally the most efficient dune-building grass of temperate zone coastal dunes. Its capacity to build and stabilize mobile dunes is a function of its extreme high tolerance to sand burial, high rates of growth and lateral spread despite high burial rates, and its ability to develop vigorous, dense, tall, upright stands of flexible, strong shoots that tolerate high wind-stress and sand abrasion.

High vigor of marram grass depends on periodic burial by sand accretion; in the absence of annual sand accretion, marram stands decline in density (number of shoots per unit area) and vigor (shoot size and growth rate), increase in mortality, and accumulate decaying leaf litter. The accumulation of decaying marram leaf litter at the base of shoots, at the sand surface, is a reliable indicator of recent dune surface stability, and the absence of significant sand accretion. Leaf litter more than one year old begins to disintegrate and turn from straw to gray in hue.

With the exception of the foredunes in the central Seadrift reach, all marram stands at foredune crests and even within scarps exhibited abundant accumulation of gray leaf litter at the dune surface. This indicates surface stability or slight surface erosion of foredunes and scarps for at least the past year. Minimal sand- buried litter was observed in the seaward zones of the central foredune reach. This key observation is consistent with local short-term geomorphic indicators of very low-level wind-driven sand accretion: little or no development of sand shadows in the lee of plants or other wind-obstacles (driftwood, debris, etc.) in the backshore.

Typically, back beach ramp accretion resumes during episodes of onshore winds above the threshold velocity for wind transport of sand, weeks or months after foredune scarp erosion by storm wave run-up. Sand deposition in the scarp/ramp profile initially occurs at the toe of the scarp face and slumping blocks of marram, and then proceeds up to the foredune crest as the back-beach sand ramp profile fills in. Only minor sand shadows and limited development of wind-driven sand ramps were observed in the central Seadrift and Patios reaches (maximum estimated local sand burial depth during the 2019 growing season less than 5-10 cm). For comparison, Doran Beach foredune marram was inspected on the same day as Stinson. The clear signature of recent SE onshore wind deposition of sand in foredune and embryo foredune marram was evident at all shoreline segments of Doran Beach except the farthest eastern end (where the backshore is extremely narrow, and sand is coarser). Both Doran and Stinson foredune marram experienced the same basic coastal winds this past year (growing season), but Stinson foredune marram exhibits almost no accretion, while Doran exhibits low to moderate accretion (burying basal marram leaf litter) in the seaward foredune slope.

Foredunes at Patios Reach, marram-dominated foredune scarps exhibit minimal post-storm recovery of vegetation and wind-driven ramp sand accretion; exposed roots, leaf litter unburied by sand dominate the surface of the slope, and there is almost no vegetative regeneration seaward of the scarp toe. December 20, 2019. (P. Baye)

Marram represents the upper limit of potential shoot height and density in the foredune vegetation canopy (maximum sand trapping capacity of vegetation canopy). All other native vegetation canopies would have somewhat lower sand-trapping capacity. Differences in sand-trapping capacity between marram and native foredune canopies are less significant at very low levels of onshore wind sand transport and vertical accretion rates. At low levels of onshore sand transport, marram tends to trap blown sand narrowly at the seaward edge of the dense canopy, forming a steep, narrow foredune ridge. Beach wildrye mixed with other species tends to trap onshore blown sand over a wider, gently sloping zone.

Iceplant (*Carpobrotus chilensis* and hybrids with *C. edulis*). Mats of iceplant are established in patches on some eroded foredunes and segments of boulder revetments. Iceplant has a low, flat leaf canopy and slow shoot emergence rates following sand burial; it builds low, broad mounded foredunes at slow rates, because the canopy saturates with sand at low levels of deposition. No iceplant mats were observed with accreted sand, and all iceplant mats exhibited retained old gray leaf litter (unburied) in the canopy. Iceplant apparently has no significant recent role in trapping wind-blown sand along residential shorefront lots at Stinson Beach. Iceplant vigor was usually low (reddish leaves, sparse growth) where it was rooted in interstitial soil or sand fill among boulders in revetments.

Iceplant occurs in scattered patches along eroding foredune scarps, interspersed with marram, or in single-species stands. Patios foredunes, December 20, 2019. (P. Baye)

4.2.3. Wildlife

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. This section provides a background on shorebird occurrence and beach ecology in the Stinson Beach region and describes recent shorebird observations.

Pacific Coast sandy beaches provide important habitat for shorebirds for migration and wintering and also provide breeding habitat for a few species. Sandy beaches are shaped by waves and vary by slope, width and sand grain size as a result. These characteristics influence the macroinvertebrate community and wider flatter beaches tend to have greater abundance and diversity of macroinvertebrates. Another factor that contributes to beach macroinvertebrate community is the presence of kelp wrack. Consequently, robust invertebrate community supports a greater abundance and diversity of shorebirds. The two most abundant shorebirds on sandy beaches are sandpipers and plovers.

Shorebird Occurrence and Beach Ecology in the Stinson Beach Region

The best available information on the ecological relationships between shorebird occurrence and sandy beach characteristics in the Stinson Beach region comes from the North-Central Marine Protected Area baseline characterization, conducted in 2010 and 2011 (Nielsen et al. 2013). Stinson Beach was not included in the more detailed assessment, but the covered adjacent beaches in the region that included Limantour Beach and Drakes Beach. However, it should be noted that, unlike Limantour and Drakes Beaches, most of the Stinson Beach backshore is developed and the beach is heavily used by humans, reducing the quality of the sandy beach habitat at Stinson for shorebirds. Another important factor affecting patterns of shorebird occurrence at Stinson is the very close proximity of Bolinas Lagoon, a 445 hectare seasonal estuary, which supports a large diversity and abundance of migratory and wintering shorebirds (Stenzel and Page 2018).

Shorebird abundance on sandy beaches in the region peaks in spring and fall, coinciding with migration periods (Nielsen et al. 2013). The most abundant species on sandy beaches in the region are Sanderling, Marbled Godwit and Willet (see Table 2 for species names and mean monthly abundance per kilometer of beach). Sanderling alone account for more than 50% of all shorebird numbers and this numerical dominance by Sanderling is consistent with other studies of sandy beaches in California (Hubbard and Dugan 2003, Neuman et al. 2005, Neuman et al. 2008, Nielsen et al. 2017). The highest maximum and mean densities of shorebirds per kilometer of beach in the region occurred at nearby Drakes and Limantour beaches (maxima of 125-153 shorebirds per km, mean of 25-39 shorebirds per km, respectively; Nielsen et al. 2013). Overall species richness was linked to habitat heterogeneity and proximity to wetlands. A small number of surveys conducted on Stinson Beach over the past decade for the Pacific Flyway Shorebird Survey indicate that Sanderling and Whimbrel are less common there than would be expected based on regional MPA data and patterns at other California beaches (Point Blue unpublished data), probably due to high levels of human-caused disturbance.

TABLE 2
THE TEN MOST ABUNDANT SANDY BEACH SHOREBIRD SPECIES[1] IN THE NORTH-CENTRAL MPA BASELINE STUDY REGION (ADAPTED FROM NIELSEN ET AL. 2013)

Common name	Latin name	Mean monthly abundance per kilometer of beach
Sanderling	*Calidris alba*	11.4
Marbled Godwit	*Limosa fedoa*	3.2
Willet	*Catoptrophorous semipalmatus*	1.6
Western Snowy Plover	*Charadrius nivosus nivosus*	1.0
Killdeer	*Charadrius vociferus*	0.8
Whimbrel	*Numenius phaeopus*	0.6
Black Oystercatcher	*Haematopus bachmani*	0.5
Black Turnstone	*Arenaria melanocephala*	0.3
Semipalmated Plover	*Charadrius semipalmatus*	0.2
Black-bellied Plover	*Pluvialis squatarola*	0.2
All Shorebird Species		20.1

[1] The other species observed included Ruddy Turnstone (Arenaria interpres), Western Sandpiper (Calidris mauri), Spotted Sandpiper (Actitis macularia), and Surfbird (Aphriza virgata)

See **Appendix I** for additional information on shorebirds at Stinson Beach.

Ecological Relationships with Physical Beach Characteristics

The physical characteristics of Stinson Beach, and Limantour and Drakes beaches measured by Nielsen et al (2013) are similar; all three sites are morphodynamically intermediate, meaning they are exposed to waves of 3+ feet, exhibit relatively small sand grain sizes (less than 0.26 mm), are sloped at around ~5% and have wide beach backshores (>240 feet). At Limantour and Drakes beaches, eelgrass is the dominant type of beach-cast wrack in terms of percent cover but kelp wrack are more abundant.

In the region at large, shorebird abundance is correlated with abundance and species richness of macroinvertebrates and macroinvertebrate biomass and diversity is highest at Limantour and Drakes beaches (Nielsen et al. 2013). Thus it is not surprising that the highest numbers of shorebirds in the region also occurs at these beaches. Based on the similarity between the physical characteristics of Stinson Beach and Limantour and Drakes beaches, the patterns of shorebird occurrence at these nearby beaches can be used as a general baseline estimate for Stinson Beach. However, the reduced habitat quality at Stinson resulting from development and high levels of human use must also be taken into account.

In addition to the physical and biological factors mentioned above, many other factors influence shorebird abundance and distribution on Pacific Coast sandy beaches, including tidal state and landscape features and human activity. For example, proximity to wetlands has been shown to influence shorebird abundance and species richness on other Pacific Coast beaches (Colwell and Sundeen 2000, Neuman et al. 2008, Lafferty et al. 2013). Stinson Beach is adjacent to Bolinas Lagoon and this proximity likely influences both species diversity and overall abundance of shorebirds using the beach. Tidal state strongly influences patterns of shorebird behavior and habitat use in estuarine and wetland systems, with most shorebirds foraging on mudflats at low tides when prey availability peaks. On sandy beaches the influence of tide on patterns of occurrence, behavior, and habitat use is less well-studied and the findings are inconsistent among studies. Stinson Beach has high levels of recreational use resulting in a high level of foot traffic and the physical landform has been altered to include areas of hardened and developed shoreline in all but the Patios Reach. These human-caused alterations of the landscape have likely reduced the quality of the sandy beach habitat for shorebirds.

Shorebird Nesting

The federally threatened Western Snowy Plover and the Killdeer are the two primary shorebird species that nest on sandy beaches in the region and are likely to nest along Stinson Beach or at the lagoon side of the north spit of Stinson Beach. Both species are sparsely distributed on beaches in the region and they are less abundant than other sandy beach shorebird species (Nielsen et al. 2013). There is a small nesting population of Snowy Plovers (<60) at nearby Point Reyes National Seashore, where nesting occurs primarily on the north and south sections of the Great Beach (Press et al. 2019). Plovers have nested at Limantour Beach since at least the 1970s (Point Blue unpubl. data) and have nested in some but not all of the past five years (Lau and Press 2019). At Stinson Beach, Snowy Plovers have nested at the northern tip of the spit in two of the past three years (one nest in 2017, two nests in 2018) and along the Seadrift section in 2013 (Point Blue unpubl. data). Historically, Snowy Plovers have occasionally nested on the sandy southern shore of Kent Island within Bolinas Lagoon (Point Blue unpubl. data). It is unlikely that Snowy Plovers nest along the more highly traversed eastern reaches of Stinson Beach.

Recent Shorebird Observations at Stinson Beach and Project Implications

Shorebirds were observed during the December 2019 visit in low numbers (a few dozen) along the outer edge of the swash zone at mid-tide, along the lower beach face. Whimbrels and western sandpipers were the most frequent shorebirds, and a few willets were present. One significant shorebird observation was the presence of at least 6 (possibly 8) western snowy plovers moving between the moist upper and lower beach face, in a zone about 200 feet wide along the Patios Reach. The plovers alternated between foraging movements along the lower beach face, and resting in human footprint depressions along the upper beach face, near but below the narrow dry backshore. The most recent high tide swash lines wetted the upper foreshore within about 5 to 10 feet of the foredune toe. The presence of wintering snowy plovers may be expected at similar locations where relatively wide backshore beach areas are present. At Doran Beach, also during a low tide the same day, over 30 western snowy plovers were similarly distributed (foraging in the lower beach face and resting in footprint depressions along the upper beach face, near the berm crest) in a zone where backshore widths were greatest along the beach. While Snowy Plovers are unlikely to breed at highly populated Stinson Beach, but their presence as wintering groups indicates a need to incorporate project measures to monitor their distribution and movements, and avoid disturbance or adverse habitat modification during any project implementation phases. Potential habitat enhancement could occur through activities that widen the sand berm or beach face, provide heterogeneous beach surfaces (shell, pebble) and maintain very sparse vegetation cover (significantly less than 5%) on most of the backshore where species may occur. Encroachment of backshore by any continuous or dense beach/foredune vegetation would be interpreted as an adverse habitat modification to this species. Specific short-term construction impacts and longer term impacts to shorebirds will be evaluated and described in the alternatives evaluation task of the study.

Western snowy plovers forage in the saturated sand on the lower beach face, and rest cryptically in footprint depressions in the upper beach face above the active swash zone, Patios Reach, late afternoon Dec. 20, 2019. (P. Baye)

Western snowy plovers resting among pebbles and cobbles near the swash uprush limit, and in recent footprint depressions on the upper beach face, Patios Reach late afternoon Dec. 20, 2019. (P. Baye)

4.2.4. Onshore Conclusions

Nearly all of the Stinson Beach shoreline segments exhibit indicators of significant long-term and short-term erosion with minimal post-storm recovery of backshore and foredune vegetation or dune morphology. Backshore annual and perennial vegetation regeneration at the end of the 2019 growing season is extremely limited (mostly absent), compared with extensive establishment at Doran Beach (Bodega Bay), which has comparable levels of intensive public recreational use, but no shoreline armoring to cause "coastal squeeze" of the backshore and foredune zones. The recent trends at Stinson Beach show an eroded foredune scarp-dominated morphology contrast with early 20th century trends of slow recovery of a mounded, low-relief dune field following major wave overtopping after the 1906 earthquake. The existing foredunes in the central Seadrift and Patios reaches appear to be relict features from former shoreline positions and backshore configurations; and do not appear to be maintained by ongoing processes that can be enhanced in current prevailing annual shoreline conditions.

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.

Western snowy plovers (*Charadrius alexandrinus nivosus*), Pacific coast population, 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.

Onshore Ecological Conclusions by Study Reach

Seadrift Reach: The backshore zone 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 seasonal or inter-annual 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.

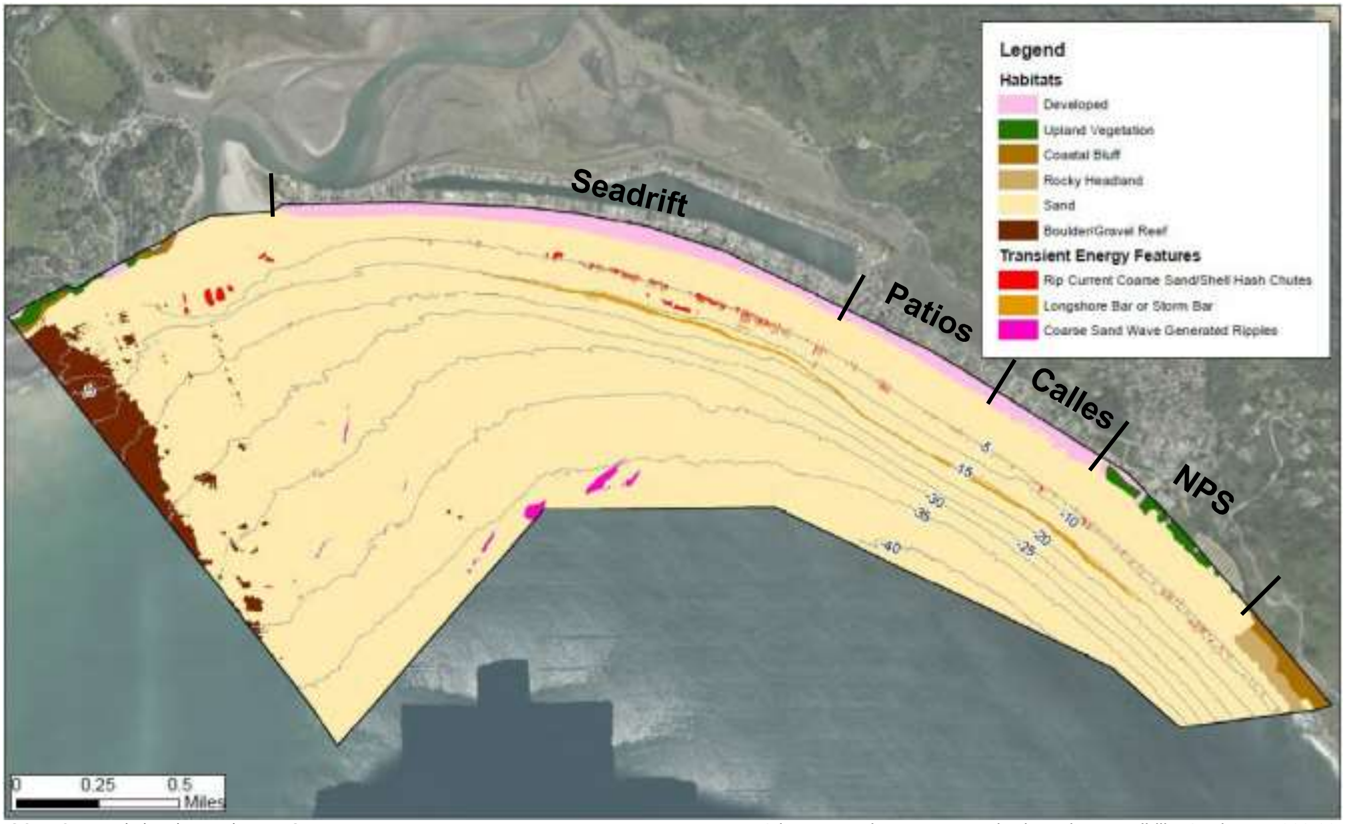
Patios Reach: The Patios Reach is characterized by set-back homes that appear to have allowed the entire beach profile to migrate landward, leaving geomorphic space for foredunes as well as post-storm ecological and geomorphic recovery. It has some potential feasibility for “living shoreline” management actions, though is constrained by apparently low natural onshore wind-driven sand transport and foredune accretion rates even with a wide backshore.

Calles Reach: 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 embryo foredune persistence or growth in a backshore that remains temporarily stable long enough to support them.

NPS Reach: 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.

4.2 Offshore

Offshore habitats are an important consideration for 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 conducted subtidal habitat mapping offshore of Stinson Beach in October 2019. Figure 11 shows the habitat types and transient features observed during the survey. Offshore habitat photos are provided in **Appendix D**.



SOURCE: Merkel and Associates, ESRI

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 11
Benthic Habitat Features Along Stinson Beach

The offshore survey covered a total of 1,197 acres of acoustically mapped subtidal habitat. Areas not mapped by acoustic means were generally restricted by being too shallow for vessel operation, interference by air entrained in waters of the surf zone, or as a result of being out of the water at the time of the survey. In order to provide seamless habitat coverage across the marine/terrestrial interface, mapping was expanded with ESA topographic survey data to include the shoreline margin along the marine habitat mapping area. This expanded the study area to a total of 1,303 acres.

The offshore survey noted five habitat types within the survey area. There were six habitat types mapped by aerial interpretation and acoustic survey. These included upland features and two subtidal marine features including sand bottom and boulder gravel reef. Sand extended from subtidal environments to supratidal environments so this habitat occurred in both terrestrial and marine environments, while the boulder/gravel reef was restricted to subtidal and intertidal environments.

In addition to mapped habitats there were also three transient sand features that were discernable in the acoustic data set. These included longshore or storm bars, rip·current coarse sand/shell hash chutes, and coarse sand wave generated ripples. In most habitat mapping programs, extracting these features is not done as they are not indicative of persistent conditions. However, for the present investigation, it was deemed useful to map energy driven conditions as they provide insights into the physical processes affecting this segment of the coastline. Upland habitats mapped are generic features that provide context to the interface area. The marine habitats are described below and example acoustic images are provided in **Appendix D**.

Boulder/Gravel Reef – This habitat consists of a gradient of features from large unconsolidated boulders to fine gravels that have been derived from the erosion of the bluff shoreline of Bolinas. The study area does not appear to include much, if any of the bedrock of the larger Duxbury Reef off Duxbury Point that defines the sheltering hooked headland to the west of the study area. However, the material size class of the reef material generally diminishes from south to north along the western margin of the survey area such that gravel and cobble dominates the areas of reef nearest the Bolinas Lagoon mouth and large boulder dominates the area towards Duxbury Reef.

Sand – This habitat feature dominates the subtidal and intertidal landscape of Stinson Beach, occupying more than 90 percent of the total mapped habitat. In general, the sand bottom is a relatively featureless bottom with minor sand rippling in deep water and more pronounced rippling with sharper ridges occurring in shallow water. Sharp ridges in the sand ripples denote more recent development of the features, while smoother ridges occur as the features weather with age. Within the sand habitat there were noted several energy features that could be mapped as discrete elements. While they have been mapped, they are transitory features more indicative of coastal processes influences on the geomorphology of the seafloor than being unique habitat features that are biologically separable from sand bottom over prolonged periods. These features are:

> **Rip Current Coarse Sand/Shell Hash Chutes** – These features form within and immediately below the surf zone as a function of wave drain·out from the shoreline at localized points. The highest concentration of rip current features occurs near Seadrift East about midway down the beach. A second feature that has been classified together with rip current chutes is a scour feature in the ebb bar outside of Bolinas Lagoon. These features are generally developed differently from the archetypical rip current chute in that these are thalwegs of drainage courses on the surface of the ebb bar that tend to concentrate ebb tide energy due to slight depression of the bed form along the channels. These features shift around and will disappear and reform based on many factors influencing the ebb bar.
>
> **Longshore Bar or Storm Bar –** Along the shore margin at about ·10 feet near the more protected western end of Stinson Beach and at about ·15 feet towards the more exposed eastern end of the study area there is a narrow and relatively small longshore bar located offshore of the beach. These bars form seasonally and as a result of storm events. They are an unconsolidated temporary feature where beach sand is deposited following erosion from the upper beach face and typically occur immediately outside ofthe surf zone. The bar at Stinson Beach was notably small and non·descript in October 2019, which is typical of a seasonal minimum bar geometry post constructive summer wave conditions.
>
> **Coarse Sand, Wave Generated Ripples** – These features are not to be confused with widespread minor sand rippling that occurs in shallow waters near shore where the bottom exhibits small and highly transitory rippling due to high frequency wave influence. Rather the ripples that are mapped under this energy feature are long·period deeper water features that depict evidence of large storm influence and directionality of storm waves. The largest of these features occur below ·35 feet and are likely the result of concentrating swell energy by the Duxbury Reef headland. Smaller features also occur in waters between ·20 and ·30 feet towards the western end of the study area. These are similarly likely the result of swell energy being focused by Duxbury Reef as it enters Bolinas Bay and are likely sand transport pathway (see Section 6).

5. Reference Sites

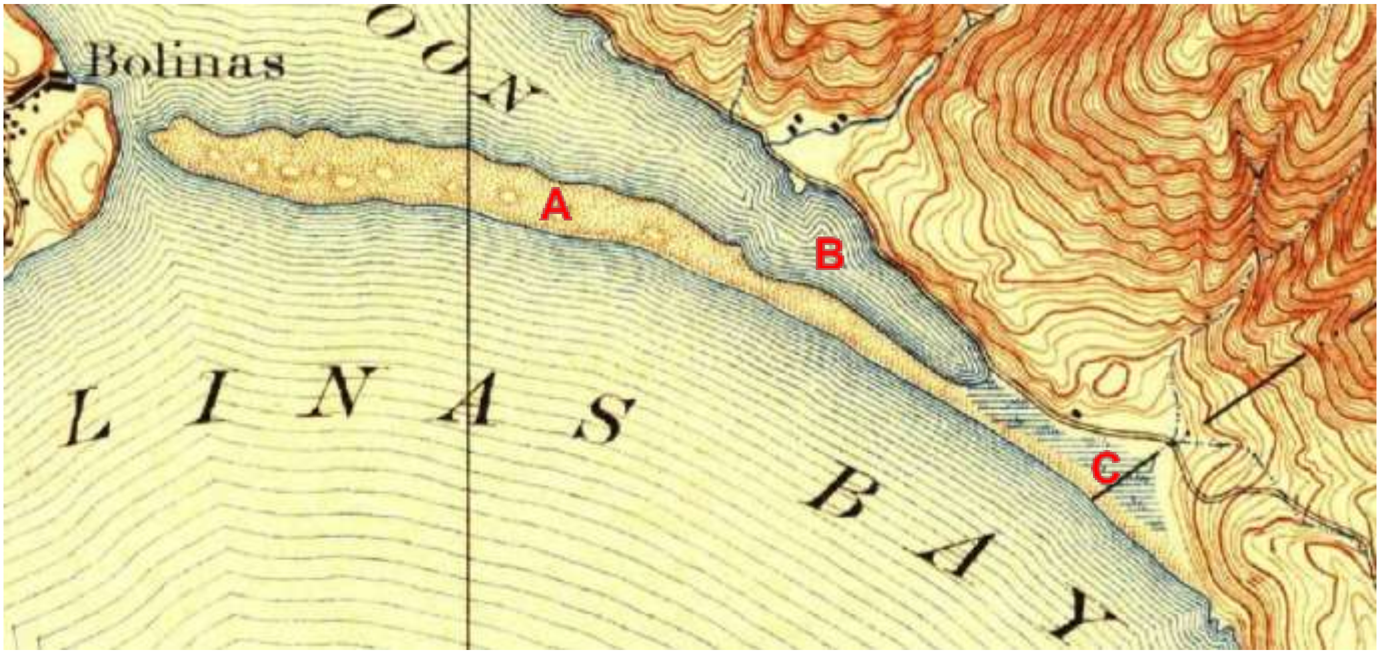
Reference sites were selected to develop a baseline understanding of (1) geomorphology and (2) to native foredune vegetation in similar coastal systems to Stinson Beach. Reference sites provide a natural context for the existing conditions at Stinson Beach and will inform the designs of nature-based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

- Backshore beach grain size – wind erosion potential, proportion medium sand
- Backshore (high tide) beach width – summer, winter profile (sand erosion fetch)
- Beach orientation to dominant W winds and dry high-velocity NW winds
- Backshore beach (berm top) width variability: calm (post-storm recovery phase) and post-storm profiles
- Foredune annual wind-driven sand accretion rate (volume/shore length, and vertical accretion rate)
- Foredune plant species composition
- Foredune vegetation structure related to sand trapping and regrowth (serial dune accretion): continuity/patchiness, shoot canopy height, shoot density
- Trampling intensity (impacts on perennial foredune vegetation and regeneration, post-storm recovery).
- Presence/absence of underlying cobble berms or terraces (washovers)

5.1 Geomorphic Reference Sites

5.1.1. Historical Stinson Beach (“Baulenes” or Bolinas Spit)

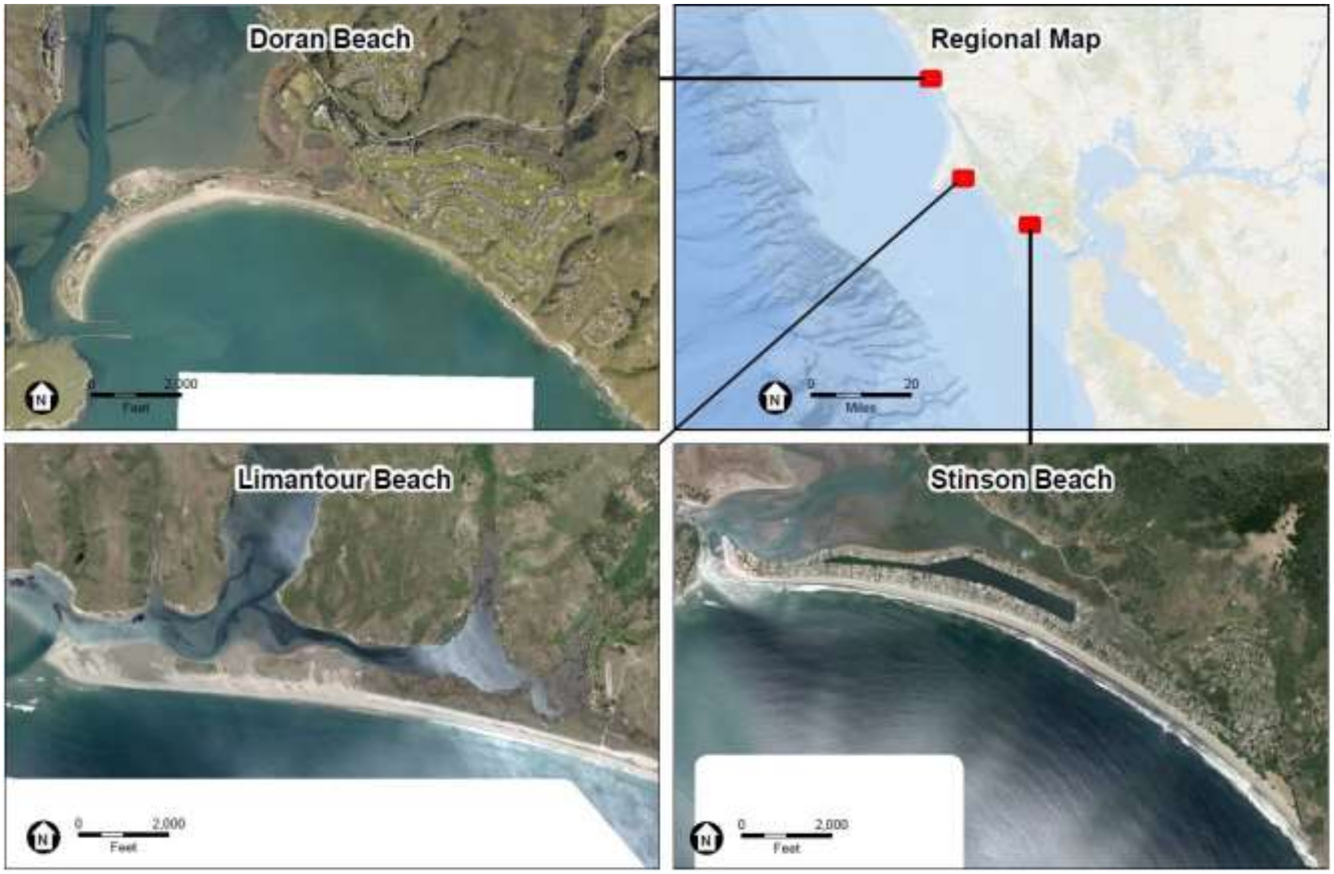
The original Stinson Beach foredune conditions are a dynamic (non-equilibrium) historical reference condition that needs further evaluation. The 1854 “snapshot” of the eastern Stinson barrier beach topography and crude vegetation types are illustrated in the U.S. Coast Survey sheet T-452 south (excerpt shown below). The remainder of the barrier beach is not represented in the corresponding north sheet of T-452. This provides a partial representation of at least one state of the spit before intensive modification. Aboriginal (Coast Miwok) modification of the sand spit was likely low in impact, since dunes have low food resource values and burning of salt-spray influenced (hygroscopic) native foredune vegetation is extremely difficult to fuel.



Detail excerpt of 1897 Tamalpais U.S. Coast Survey T-sheet, showing Stinson-Seadrift sand spit, showing narrow dunes with no significant topographic relief (Label A), narrow fringing backbarrier tidal marsh (Label B), and fringing non-tidal backbarrier freshwater wet meadow/scrub wetland with pond at the east end bordering all fed by canyon drainages (Label C). The distribution of freshwater wetlands roughly corresponds with modern willow scrub swamp behind the GGNRA parking lots today.

5.1.2. South-facing Embayed Sand Barrier Spits (refracted swell)

Bolinas Lagoon and Stinson Beach are embayments formed by co-seismic subsidence of the San Andreas Fault that underlies them. The closest comparable analogs of this barrier beach and lagoon setting are Bodega Harbor/Doran Beach and Limantour to the north (Figure 12).



SOURCE: Marin County, Sonoma County, ESRI

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Figure 12
Geomorphic Reference Sites for Stinson Beach

Doran Beach is another south-facing barrier beach sheltered from direct exposure to Pacific swell. It is smaller in length (approximately 8,850 ft) than Stinson Beach, but similar in width of unfilled or excavated barrier beach (approximately 430-450 ft). Doran Beach exhibits a more concave seaward plan form than Stinson Beach (leading to more swell dispersion into the bay and lower wave action). The jetty at Doran beach's tidal inlet is dissimilar to Stinson Beach, but it exhibits little evidence of net beach accretion at the jetty, consistent with near-equilibrium with incoming wave energy. The high tide dry beach is dissipative, gently sloping, and medium-grained. The backshore of Doran Beach is also medium sand, with a typically wide, flat berm profile in non-storm conditions. The Doran Beach berm profile appears to be distinctly wider than Stinson, possibly because storm-driven erosional retreat of the foredunes has been able to accommodate recovery space for the full berm profile, while the developed, filled Stinson shoreline restricts retreat of the equilibrium berm/foredune profile. The Doran Beach dune field exhibits minimal topographic relief, gently sloping landward (north) with undulating topography, indicating little wave-driven dune blowout activity during its formation. This is consistent with the offshore orientation of the beach and dune field to dominant, dry, high-velocity NW winds. The dune field is now dominated by marram and iceplant, but there is little evidence of strong morphological influence of the modern vegetation on the original dune topography. Marram typically builds steep, hummocky dune fields where onshore wind sand transport rates are high, or where blowout activity is high. The eastern end of the spit has a narrow berm and lacks embryo foredunes, and maintains a retreating scarp in older dune deposits (indicated by brownish organic-stained, weathered old dune soil horizons and some charcoal fragments). The central beach has a wider backshore with disorganized, trampled low-relief embryo foredunes, and low foredunes with small blowouts associated with disturbed, trampled, de-vegetated pedestrian paths. The maximum height of foredunes, despite marram dominance, is 2-3 m above adjacent slightly deflated backshore beach elevations.

Limantour Spit is the other geomorphically similar south-facing barrier beach north of Bolinas Bay and is nearly the same length (close to 16,000 ft) as Stinson Beach. The width of Limantour Beach varies with older spit reformations and washovers which increase towards the west, but proximal (east) end barrier widths of the apparent dune field range between about 120-600 ft. The foredune topography at the landward end of the spit is a nearly continuous, steep, periodically scarped foredune ridge (marram-dominated) with moderate to low-relief backdune topography. The wide backshore beach includes a dynamic embryo foredune zone that forms from storm-deposited tidal litter, and develops moderate height (mostly less than 1 m) between storms. The low embryo foredunes develop under the influence of mixed native and non-native (marram, iceplant, sea-rocket) beach and dune vegetation.

A common feature of these two reference barrier beaches and Stinson Beach is exposure to southwesterly winds, but sheltering from stronger, drier NW winds. This offshore orientation contrasts with the onshore orientation of NW winds for typical Central Coast foredunes. An important difference between the two reference barrier beaches and Stinson is the backshore beach width gradient. Doran and Limantour beaches have wide, dry backshore berms at least intermittently, which provide wide dry sand fetch to SW winds that can transport sand to the foredune zone. The narrow backshore beach and general wind climate at Stinson may constrain onshore wind sand transport, especially during high tides, to the embryo foredune zone. Wind climate at Stinson is discussed in Section 6. This aspect of reference and study site beach conditions may be valuable to monitor during brief, episodic onshore wind events during dry weather and wet weather, to estimate variability in onshore wind sand transport rates.


Wide backshore beach (Berm top) at Doran Beach, view to E, provides a long sand deflation fetch for SW winds. Marram dominates the Doran Beach foredune ridge, which ranges between about 1-2 m high (locally lower or higher). The steep seaward slope is a reformed foredune scarp (post-storm profile recovery by vegetation regrowth and sand trapping). (P. Baye July 2009)

Drift-line and embryo foredune development occurs episodically, and to limited extent, between major storm events at central Doran Beach. The slow vertical accretion of embryo foredunes despite the wide backshore deflation sand source, and exposure to SW winds, is instructive for estimating rates of natural foredune building at Stinson Beach. (P. Baye July 2015 left, July 2009 right)

Limantour Beach foredunes include small areas of native beach wildrye foredune vegetation (A) which form gentle slopes and spread widely. Most of the foredunes at the proximal end of the spit (most similar to Stinson Beach) are narrow, continuous foredune ridges 2-4 m high dominated by marram, with wide, irregular zones of embryo foredunes in varying stages of development in post-storm recovery of the beach/foredune profile, during gradual net shoreline retreat. (P. Baye)

5.2 Native foredune vegetation reference sites

These reference sites are recommended based on (a) geographic range compatibility with native plant species composition of Stinson Beach; (b) utility of models for dune-building next to residential areas with high foot traffic. These exclude sites with dominant marram, a European beachgrass, or iceplant. Local (near Bolinas Lagoon) and Regional (Marin-Sonoma coast) foredune reference sites are described below along with two other Central California reference sites.

5.2.1. Local – Landward (eastern) End Stinson Beach GGNRA

The eastern end of Stinson Beach (GGNRA overflow parking lot, normally closed) is the closest (on site) reference site for Stinson foredune design. It formed by a mix of artificial and natural sand deposition, and plant colonization. GGNRA maintenance crews years ago scraped wind-blown sand from the parking lot and pushed it in windrows along the seaward edge. These piles of mixed dirt and sand formed nuclei of embryo foredunes. The foredunes include mostly native vegetation. Foredune height has grown in the range of 2-3 m (above adjacent backshore beach) over about 15 years.

GGNRA Stinson Beach foredunes vegetation extends from the edge of the willow swamp foredunes (Vancouver wildrye) east to the cliffs, where assemblages also include pink sand-verbena, yellow sand-verbena, beach-bur. (P. Baye)

5.2.2. Local – West Kent Island foredune terrace

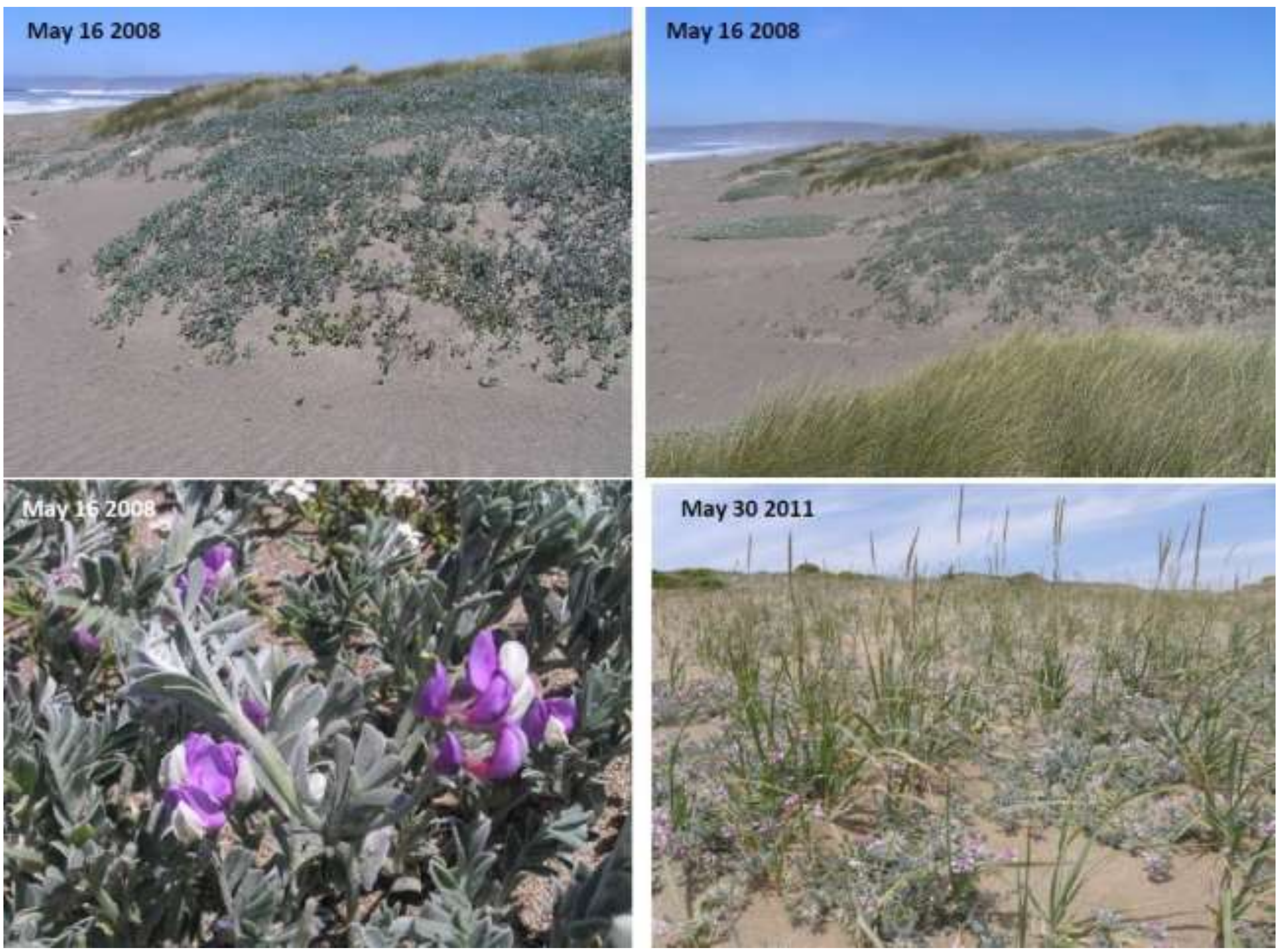
The west end of Kent Island is a dynamic sheltered beach in the tidal inlet (aggraded supratidal flood tidal delta). It cycles through erosion and accretion phases driven by the adjacent shallow tidal channel and sandy flood tidal shoals. During growth phases, it develops a wide, low foredune terrace dominated by Vancouver wildrye, which also occurs at both Limantour and east Stinson (GGNRA) beaches. This is a natural hybrid of native dune and seasonal wetland wildrye species. It is associated with other species shared at Doran, Stinson, and Limantour, including north coast sand verbena, and saltgrass. This site is in effect a low-energy extension of the sand spit foredune vegetation of Stinson Beach.

West Kent Island (Bolinas Lagoon) foredune terrace rapidly developed Vancouver wildrye foredunes, during a beach growth phase between 2012-2017. (P. Baye).

5.2.3. Regional – Restored Abbott's Lagoon Foredunes

GGNRA has removed marram and released native dune vegetation from its inhibitory influence for over 10 years. Though the west-facing beach is exposed to strong, dominant onshore NW winds, the relatively coarse beach sand has a higher threshold for onshore wind transport and thus limits dune accretion potential. Excellent examples of local native foredune vegetation stands, including single-species dominants and mixed assemblages, occur here. Major stands of silvery beach-pea occur here as single-species and mixed stands with beach wildrye, providing both a model and potential propagule source for these valuable dune-building species with complementary growth-forms.

Beach wildrye foredunes at north Abbott's Lagoon, Point Reyes, develop gentle seaward slopes. Driftwood is incorporated in the fabric of these foredunes. (P. Baye, April 2017).



The ornamental native silvery beach-pea occurs in single-species creeping (clonal) stands and forms gently sloping foredunes at Abbott's Lagoon. It also forms mixed stands with beach wildrye here, providing a potential model for Stinson Beach. (P. Baye)

5.2.4. Regional – Doran Beach.

Doran Beach embryo foredunes near the central segment of the beach (near parking lots and restrooms) have maintained a diverse assemblage of native foredune and beach plants, including the uncommon North Coast (intermediate) pink sand-verbena that also occurs at Stinson Beach. Associated native species include beach-bur, yellow sand-verbena, whiteleaf beach saltbush, saltgrass and beach wildrye.

North Coast (intermediate) pink sand-verbena at Doran Beach. (P. Baye)

Embryo foredune vegetation at central Doran Beach, dominated by native beach wildrye and non-native sea-rocket. Sand accretion rates are very slow here between storm erosion intervals; little vertical dune building occurs during beach growth phases. Note low foredune ridge dominated by the efficient sand-trapping marram vegetation landward of the embryo foredunes. (P. Baye)

5.2.5. Regional – Muir Beach

Muir Beach (GGNRA) is a pocket (headland-bound) barrier beach in a river valley south of Bolinas Lagoon. The north end of the beach has a cobble-gravel terrace formed from washovers that rework stream gravel and cobble deposits over which the beach retreats. A thin, low foredune terrace dominated by beach wildrye, Vancouver wildrye, and beach-bur forms over the coarse washover fan and stream delta.

The north end of Muir Beach is a reference site for low foredunes over a cobble beach terrace (washover) dominated by beach wildrye, Vancouver wildrye, and beach-bur vegetation. (P. Baye)

Muir Beach (north end) foredune terrace vegetation is similar to that of Kent Island's west end, but on a cobble washover terrace. (P. Baye)

5.2.6. San Mateo County – Pacifica State Beach (foredune and cobble terrace)

Pacifica State Beach at Linda Mar, Pacifica is a west-facing, coarser barrier beach with a drained and filled developed backbarrier lagoon wetland in its valley. The central foredunes were planted with beach wildrye, which formed a continuous, self-maintaining gently sloping foredune ridge up to about 3 meters above backshore berm top elevations, over a 10-year period, despite relatively high recreational use. Foot traffic is managed by symbolic fencing and brush placement over closed foot trails. Other segments of the foredunes are dominated by prostrate native dune vegetation, such as beach morning-glory, which scarcely builds foredunes above beach level. The seawall-lined parking lot is fronted by a restored beach (imported sandy fill) that spontaneously developed native foredune mounds of beach-bur despite location in a heavily trampled recreational beach area. These are all elements with potential application to Stinson Beach.

Linda Mar, Pacifica State Beach, has a wide, coarse berm and a low foredune zone. (P. Baye 2009)

Foredune vegetation in areas of high recreational use includes beach-bur (mounds) and beach wildrye (low, gently sloping ridge). (P. Baye)

Wide backshore sand deflation fetch at Pacifica State Beach provides wind-driven sand accretion source for low, hummocky foredune zones north of the beach wildrye foredune ridge. (P. Baye)

Brush mats close foot trails that may initiate dune blowouts on the lee (landward) slope of the foredunes at Pacifica State Beach. Seaward slopes of foredunes are "self-healing" under low rates of trampling, where creeping beach wildrye recolonizes gaps before blowouts develop. Symbolic fencing deters excessive trampling. (P. Baye)

Beach morning-glory has a prostrate growth habit that provides diversity but little dune accretion. (P. Baye)

The restored cobble-boulder beach (washover) terrace at the south end of Pacifica State Beach has a thin dune veneer supporting beach-bur and whiteleaf beach saltbush. (P. Baye)

5.2.7. Santa Cruz County – Wadell Creek (embryo foredune and cobble beach terrace)

Waddell Creek Beach, Santa Cruz, is a state park sandy barrier beach at the mouth of a river valley, formed over a cobble-gravel stream delta foundation, like Muir Beach. Part of the cobble beach terrace is exposed south of the creek mouth, where Marram removal has released native embryo foredune vegetation formed around nuclei of driftwood. The foredune vegetation assemblage includes most of the elements found at Doran, Stinson, and Limantour Beach, including beach wildrye, pink and yellow sand-verbena, whiteleaf beach saltbush, and beach-bur. The vegetation undergoes little trampling pressure. The beach has medium sand and a wide low tide terrace exposed to deflation from strong, dry northwest winds. Foredune accretion rates at the south end of the beach are likely to be higher than Stinson Beach, for a given vegetation stand type.

Waddell Creek sandy barrier beach and cobble-gravel, foredunes. (P. Baye)

6. Shore Dynamics Characterization

The geomorphic setting at Stinson Beach provides important context for both traditional and nature-based hazard mitigation projects. Shore dynamics at Stinson Beach are a function of tides and storm surge, waves and wind climate. The characterization summarized in this section will directly inform design criteria for backshore 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.

The environmental data gathered for the characterization includes observed offshore and modeled nearshore wave conditions from the Coastal Data Information Program (CDIP), wind and tide data from National Oceanic and Atmospheric Association (NOAA) and wind data from National Data Buoy Center (NDBC). Historic shorelines were derived from available digital elevation models produced by the U.S. Geological Survey (USGS), U.S. Army Corps of Engineers (USACE), NOAA as well as the ESA survey conducted in October, 2019. Figure 13 below shows the various environmental data stations that were accessed in order to characterize shore dynamics at Stinson Beach. Several Appendices were developed to illustrate shoreline dynamics at Stinson Beach:

Appendix E includes shoreline data collected for the study showing Mean High Water lines from specific dates between 1929 through 2019 to illustrate the seasonality of beach width at Stinson Beach.

Appendix F contain maps of existing FEMA flood hazard zones along the study area that indicate the existing exposure to a 100-year coastal storm event.

Appendix G contain maps of coastal flooding and wave run-up extents for existing sea-level for comparison to FEMA results. The hazard maps were obtained from Our Coast Our Future (OCOF), an online mapping tool hosted by Point Blue Conservation Science and produced by USGS CoSMoS (2.0). Note that the OCOF flood zone represents areas that are flooded for at least 2 minutes, while wave run-up points show the maximum landward extent of wave run-up. In contrast, FEMA distinguishes wave run-up areas with high velocity potential (VE zones) from lower velocity propagating waves (AO).

Appendix H describes the longshore sediment transport analysis performed for this study, which provides estimates of annual net sediment transport potential based on current shore conditions and SWAN modeling of wave data spanning 2007-2017.

SOURCE: NOAA, NDBC, CDIP, ESA

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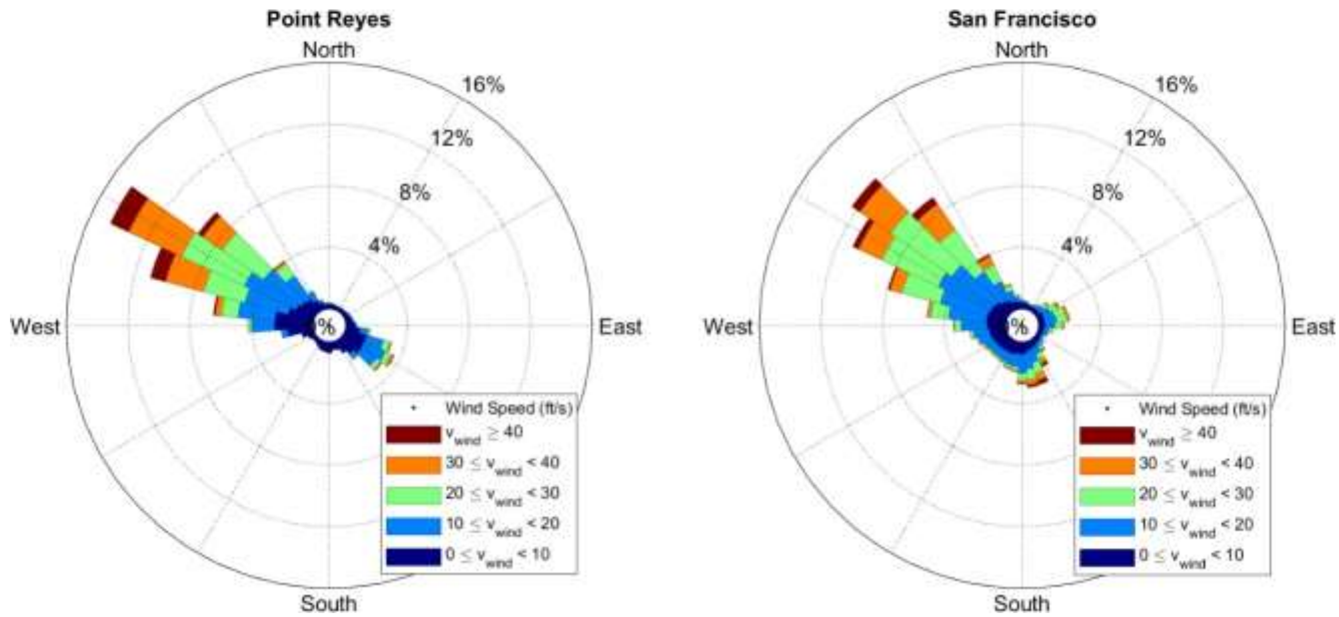
Figure 13
Environmental Data Stations

6.1 Wind

The feasibility of naturally maintaining and growing vegetated foredunes at Stinson Beach depends in part on wind-driven sand transport of the dry beach sediment. Figure 14 summarizes wind patterns at the two closest wind gauges to the study area: Point Reyes (NOAA tide gauge 9415020) and San Francisco (NDBC wave buoy 46026). The locations of these stations are shown on the location inset map in Figure 13 above. Both stations record hourly wind data; Point Reyes's data record spans from 1982-2018 while San Francisco's record spans from 2009-2018. Wind Roses based on these two datasets show that the predominant wind direction at both Point Reyes and San Francisco is from Northwest (Figure 14). At Point Reyes the secondary direction is from Southeast, while at San Francisco secondary directions include the South and Northeast. The data from each station confirm the observations made in the ecological characterization: there are limited onshore wind events (southwest) at Stinson Beach that would transport sand from the dry beach up into foredunes constructed for natural infrastructure.



SOURCE: NOAA, NDBC, ESA

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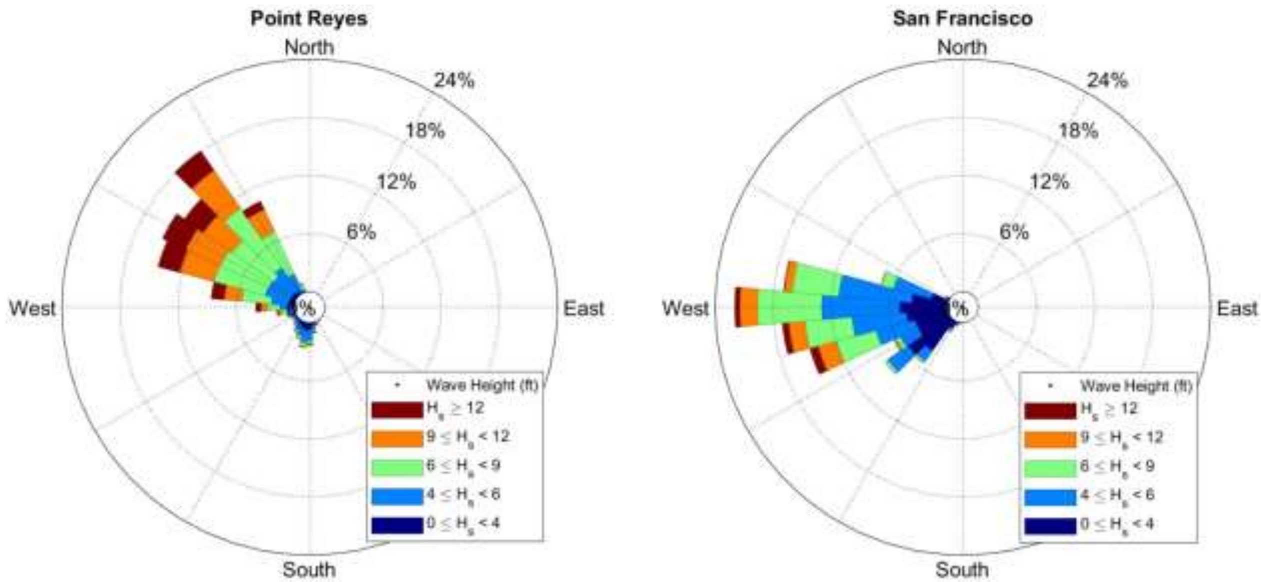
Figure 14
Wind Roses for Two Nearby Recording Stations

6.2 Waves

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. This section discusses the wave climate at Stinson Beach, based on observed data, regional wave modeling and new modeling conducted by ESA for this study.

6.2.1 Offshore Wave Buoy Data

Offshore (unsheltered, open ocean) wave conditions were characterized based on nearby buoy records and nearshore wave modeling results from the Coastal Data Information Program (CDIP). Offshore wave records were obtained from two CDIP deep water buoys: Point Reyes (CDIP 029) and San Francisco (CDIP 142). Buoy locations are shown in Figure 13. Wave roses depicted in Figure 15 show that the predominant wave directions are from the Northwest at Point Reyes and from the West at San Francisco. The significant wave heights can reach over 12 ft. The San Francisco wave gauge is located landward of the Cordell Bank and Farallone Islands and is affected by wave refraction effects in the vicinity (Battalio & Trivedi 1996; Battalio 2014), and hence is not representative of offshore waves incident to Stinson.



SOURCE: NOAA, NDBC, ESA

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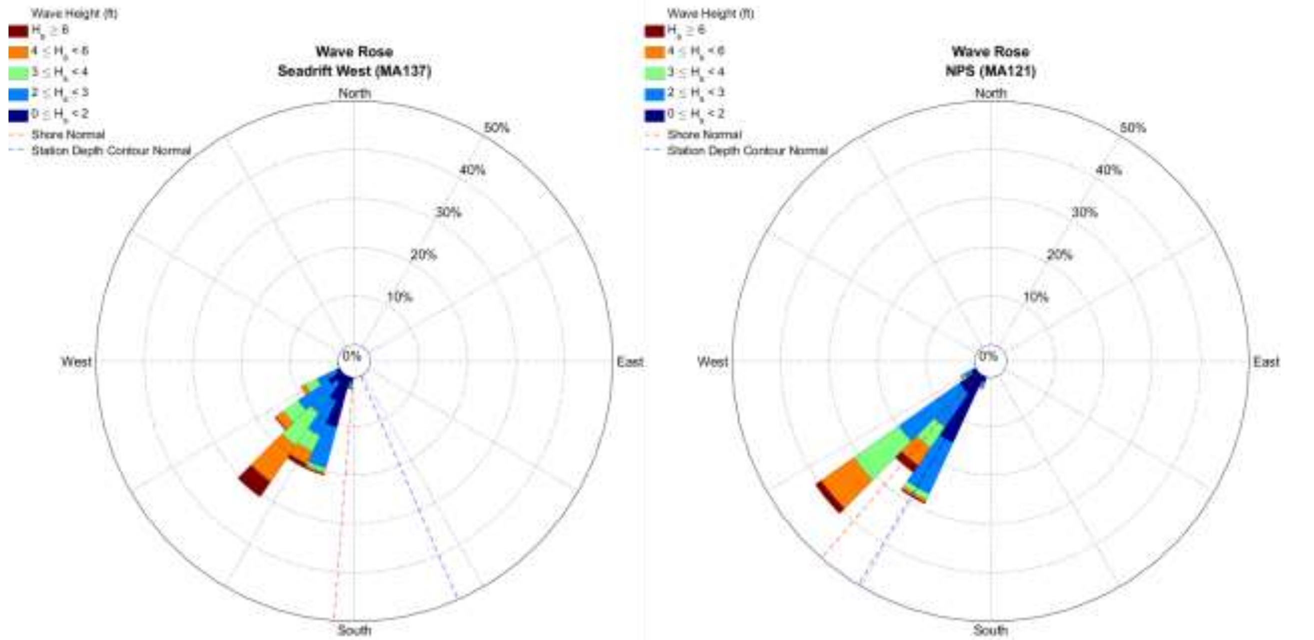
Figure 15
Offshore Wave Roses for Two Nearby Buoy Locations

6.2.2 CDIP Nearshore Wave Data

Nearshore wave conditions along Stinson Beach were first characterized from available nearshore wave data produced by the Coastal Data Information Program (CDIP). Five CDIP modeling output point (MOP) stations were selected near each of the five study shore profiles (Figure 13). Upon review, the MOP data were found to misrepresent the nearshore wave direction and height for the western profiles. Due to their location (located offshore at about -30 feet NAVD), the CDIP MOP results do not accurately represent the wave shadowing effects of the Duxbury reef, which results in wave diffraction for the western study reaches in particular, nor the wave spreading (wave refraction) that occurs as wave propagate farther into Bolinas Bay. Wave distribution roses depicted in Figure 16 show the unrealistically large relative wave angle for Seadrift West compared to NPS. ESA developed a wave transformation model in order to improve our understanding of the wave climate at Stinson Beach, discussed in the following section.



SOURCE: NOAA, CDIP, ESA

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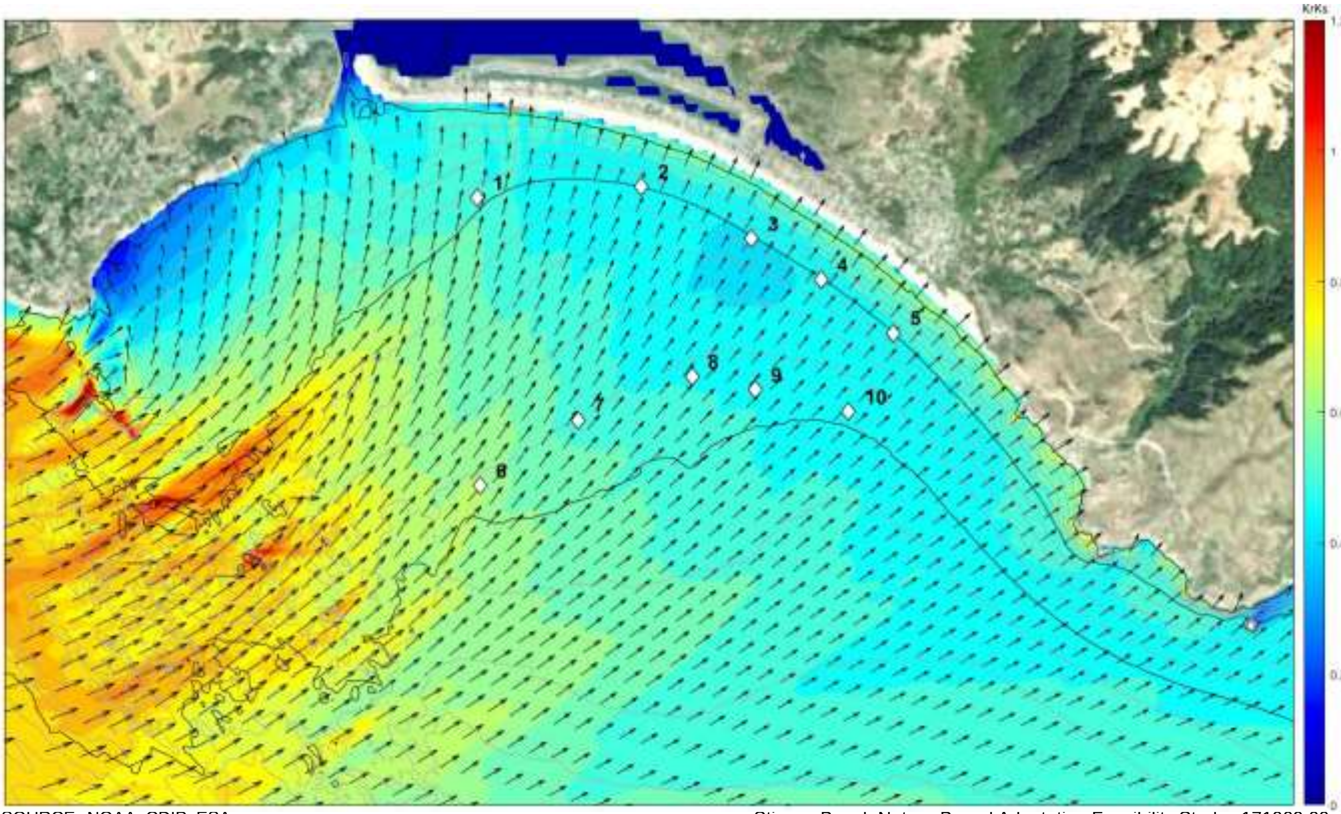
Figure 16
Nearshore Wave Roses for CDIP MOP Locations at West Seadrift and NPS Profile Locations with Normal Angle at Shoreline and Wave Model Point

6.2.3 Modeled Nearshore Wave Conditions at Stinson Beach

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. The CDIP modeled nearshore wave results were found to over-represent the swell height and relative angle of approach to the shoreline for the Seadrift reach in particular, as illustrated in Figure 16. 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 tide data from Point Reyes NOAA Station and wave data from available observation buoys and model output points near the site. The transformed nearshore wave conditions along the study area were used to compute a historic record of total water levels and detailed wave run-up for extreme events (described below) as well as refine estimates of longshore sediment transport (Section 6.3).

The following two figures summarize the importance of the SWAN modeling and results. Figure 17 below shows an example case from the SWAN model, which illustrates the shadowing effect of Duxbury Reef. Points 1 to 5 are SWAN nearshore output locations used to characterize wave climate for the study profiles, points 6 to 10 are the CDIP MOP locations investigated initially. Note the difference in wave size resulting from additional refraction between point 8 (CDIP MOP for Seadrift West profile) and point 1 (SWAN output for Seadrift West). The CDIP wave roses in Figure 16 for Seadrift West (CDIP point 6) and NPS (CDIP point 10) are quite different from those computed with SWAN which are respectively, points 1 and 5 (Figure 18). The newly modeled nearshore waves from SWAN were used to calculate a historic record and extreme event total water levels at the study area (described in Section 6.2.4) and estimate longshore sediment transport potential.

The SWAN wave transformations are considered adequate for this project. However, it is noted a more detailed modeling effort could improve results. Areas where improvement could be employed are wave diffraction, wave approach angles, wave breaking over Duxbury Reef and direct modeling of directional wave spectra for particular events.



SOURCE: NOAA, CDIP, ESA

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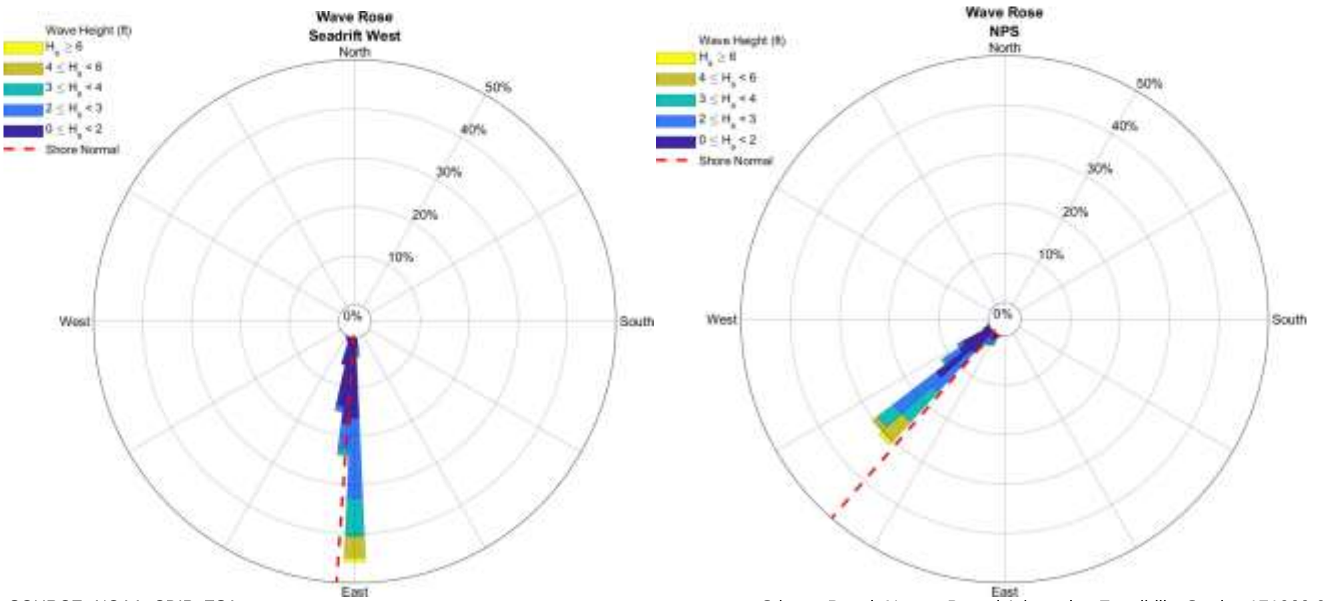
Figure 17
SWAN Model Extraction Locations and Example Wave Case
270 Degrees Direction, Tp = 20 sec, MHHW



SOURCE: NOAA, CDIP, ESA

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Figure 18
Nearshore Wave Roses for SWAN output points at West Seadrift and NPS Profile Locations with Normal Angle at Shoreline

6.2.4 Extreme Coastal Storm Wave Events at Stinson Beach

Extreme coastal storm waves were characterized based on existing reports, FEMA data and results of ESA wave transformation (described above) and run-up modeling developed for this study. A number of notable coastal storms have impacted Stinson Beach over the last few decades. Ecker and Wheelan (1984) estimated the highest breaking wave from 1951 to 1984 to be 18.6 feet at Stinson Beach Park and 12.3 feet at Seadrift (December 28, 1965) with corresponding wave run-up at high tide estimated to be 16 feet and 15 feet NAVD respectively. The following sections summarize extreme wave run-up computed for FEMA flood mapping along the study area and ESA-modeled wave run-up computed for each study profile using transformed nearshore wave data spanning 1983-2019.

FEMA Base Flood Elevations for Wave Run-up along Study Area

The Federal Emergency Management Agency (FEMA) published Flood Insurance Study for Stinson Beach (2017) estimates wave run-up elevations from 16 feet at NPS reach to 22 feet NAVD at the Seadrift Reach (details for each FEMA analysis transect are presented in Table 3). The most severe storms to hit the Stinson shoreline occurred in 1978, 1983 and 1997 (FEMA 2017). FEMA Digital Flood Insurance Rate (DFIRM) maps for the study area are provided in **Appendix F**.

Note that the wave run-up elevations in Table 3 are higher for the Seadrift reach than for the NPS reach, even though the wave exposure is the opposite (lower at Seadrift, higher at NPS): this is because the shore is steeper and the beach narrower due to armoring at the Seadrift while the NPS beach is flatter and wider, providing space for dissipation of wave run-up. Table 3 also shows that the run-up values computed for this study compare well with the FEMA values (compare the FEMA values to the values in the 1% column): This is partly because FEMA used similar methods and likely the same run-up equation, called the Stockdon equation (Stockdon 2006; FEMA

2005). This equation is often used for natural beaches without steep backshores, and is also favored for its ease of use.

TABLE 3
FEMA PACIFIC COAST STUDY TRANSECTS AND TOTAL WATER LEVELS AT STINSON BEACH

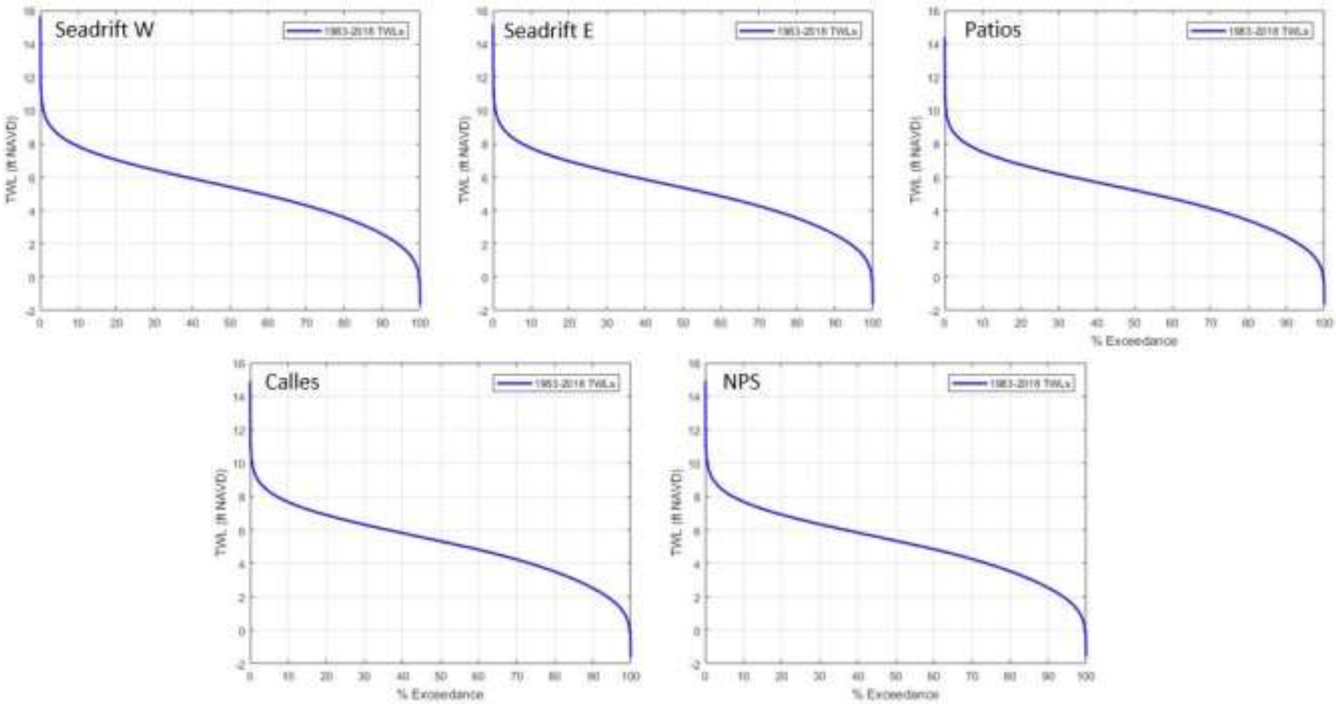
Profile	Stinson Study Reach	Description	Total Water Level (feet NAVD88)				BFE
			10% 10-yr	2% 50-yr	1% 100-yr	0.2% 500-yr	100-yr
P54	Seadrift	From the shoreline north to 322 Seadrift Road, Stinson Beach	18.2	20.9	21.9	24.4	22
P55	Seadrift	From the shoreline north to 234 Seadrift Road, Stinson Beach	16.7	18.6	19.4	20.8	19
P56	Seadrift	From the shoreline north-northeast to 142 Seadrift Road, Stinson Beach	18.8	21.3	22.2	24.2	22
P57	Patios	From the shoreline northeast to 9 Rafael Patio, Stinson Beach	15.1	18.9	21.0	27.5	21
P58	Calles	From the shoreline northeast along Calle Del Onda, Stinson Beach	13.8	15.1	15.6	16.7	16
P59	NPS	From the shoreline northeast to the Stinson Beach Parking Lot, Stinson Beach	13.9	15.4	16.0	17.4	16

Notes: Total water levels (combined tide, storm surge and wave run-up) are provided for various % annual chance of occurrence. A 1% chance annual occurrence corresponds to a 100-year storm, etc. Base flood elevations (BFE) are the FEMA designated flooding elevation for flood insurance purposes.

ESA Wave Run-up Calculations for Stinson Shore Profiles

To further understand wave run-up at Stinson Beach for this study, ESA conducted new modeling to characterize wave run-up at each study profile location. The modeling provides a reach-specific baseline understanding of wave run-up and establishes the tools to evaluate adaptation alternatives with respect to long term and storm event erosion from waves with sea-level rise.

ESA used the SWAN wave transformation modeling described above to convert offshore wave data to the nearshore along Stinson Beach. Offshore wave data from multiple sources were combined to produce a continuous record of offshore waves that were then transformed to nearshore to estimate long shore sediment transport potential (Section 6.3.2) as well as refine wave run-up estimates for each reach. Total water level (TWL) was first computed for each profile using the time series of waves and water levels and the Stockdon (2006) method, which is specific to wide beaches such as the eastern Study area. Figure 19 shows the total water level exceedance along the study area based on the transformed waves and foreshore slopes at each study profile. The highest predicted total water levels spanning 1983 to 2017 range from 14 to 16 feet.



SOURCE: ESA

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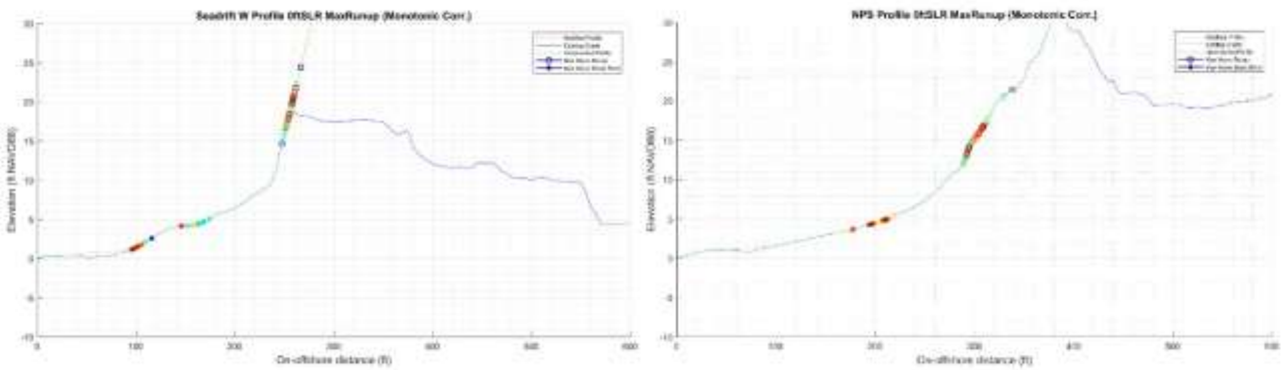
Figure 19
Computed total water level exceedance at study profiles using Stockdon wave run-up

Annual maximum events from 1983 to 2017 were identified from the computed time series of total water levels. The annual maxima were used to perform additional wave run-up calculations and extreme value analysis to estimate the 20-year and 100-year storm conditions at each study profile. The additional wave run-up calculations were performed using a composite slope method considered appropriate for steep backshores (FEMA 2005). This method requires more detailed calculations than the Stockdon method, but provides additional information about wave run-up specific to the shore profile.

Figure 20 shows detailed wave run-up computed for the annual maximum events using the composite slope method at the Seadrift West and NPS profiles for comparison. Compared to the Stockdon method, which uses a single shoreface slope (MLLW to MHHW) to estimate wave run-up elevation, the composite slope method (FEMA 2005) accounts for the overall shape of the beach profile and produces more accurate assessments especially for steep shores. The top 3 TWL events on each profile occurred in January 1983, February 1999 and January 2010. Because the largest TWL events generally occur in the winter, composite slope wave run-up was computed using typical winter profile conditions. Winter shore profiles were extracted from January 2018 County LiDAR for the composite slope wave run-up modeling. Of the historic annual maximum events modeled, a majority overtop the Seadrift West revetment. Maximum potential run-up for the 1983 event was modeled to be nearly 25 feet at Seadrift West, compared to 22 feet at NPS.



SOURCE: ESA

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Figure 20
Wave run-up of annual maximum events using composite slope method

Extreme value analysis was performed on the annual maximum events computed for the two wave run-up methods to estimate storm conditions at each study profile. Resulting extreme values for the 20-year and 100-year storm event based on Stockdon and composite slope run-up are shown in Table 4. The more detailed composite-slope extreme total water levels will be used to estimate the potential storm erosion along the study area and will inform the design and performance of nature-based adaptation alternatives in subsequent tasks of the project.

TABLE 4
EXTREME TOTAL WATER LEVELS AT STINSON PROFILE LOCATIONS BASED ON STOCKDON AND COMPOSITE SLOPE WAVE RUN-UP CALCULATIONS

Profile	Reach	Stockdon 5% 20-year	Stockdon 1% 100-year	Composite Slope 5% 20-year	Composite Slope 1% 100-year
1.1	Seadrift West	14.8	16.4	23.4	26.4
1.2	Seadrift East	14.3	15.9	23.6	27.7
2	Patios	13.6	15.0	24.7	28.6
3	Calles	14.1	15.6	19.9	22.8
4	NPS	14.1	15.6	19.8	22.7

Notes: Values based on Gumbell Least Squares fitted distribution.

6.3 Sediment Transport and Shoreline Evolution

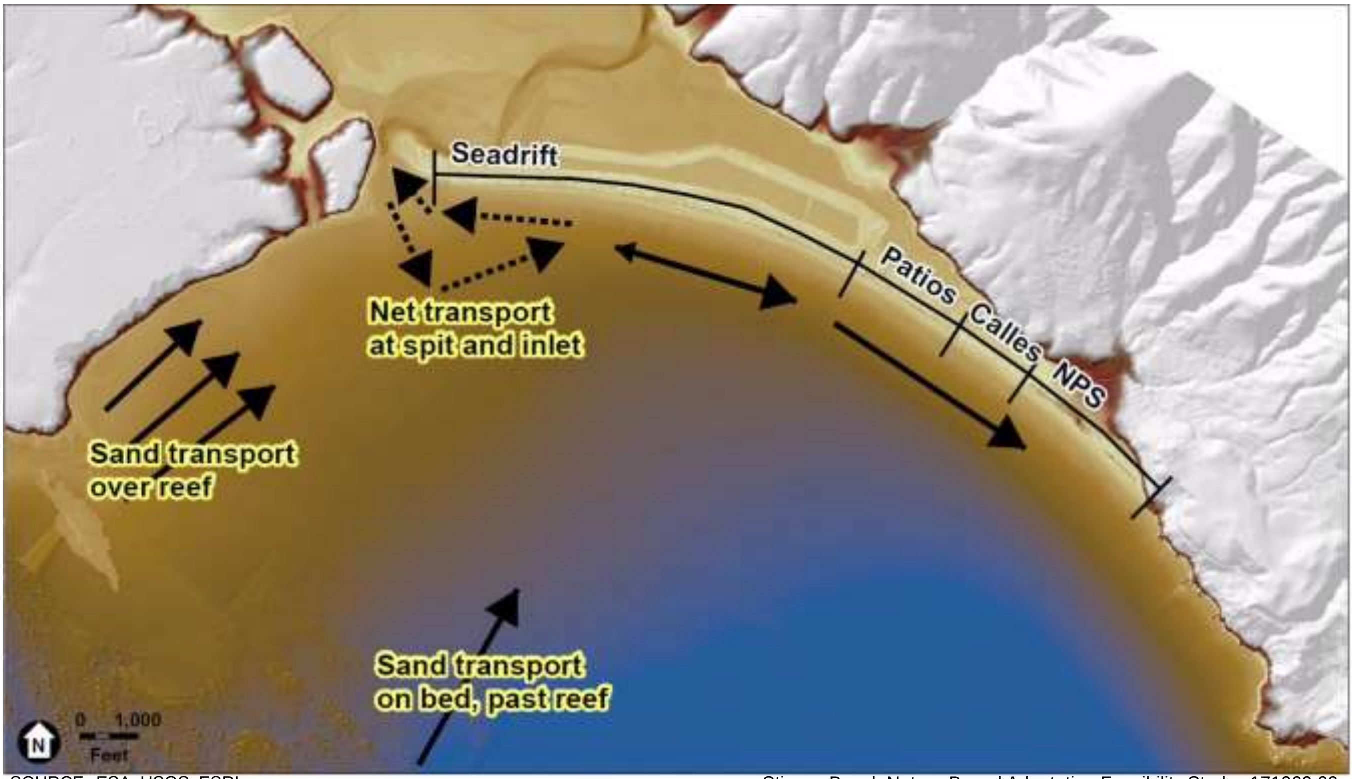
Shoreline (and beach, dune) evolution depends on long term and seasonal patterns in wave climate and shore geometry. To understand the ongoing dynamics along Stinson Beach, longshore sediment transport potential and shoreline evolution (long term and seasonal changes) were analyzed using existing data and new modeling. The longshore sediment transport potential and shoreline change characteristics presented here will be used to evaluate the feasibility of preferred nature-based adaptation approaches such as dune nourishment.

Conceptually, a given shore location undergoes seasonal changes in the beach profile such that the beach is eroded during stormier winter conditions and subsequently recovers during calmer summer seasons. This process is known as cross-shore (perpendicular to shore) sediment transport that can be regular and stable for a given location over time. If a winter is exceptionally stormy, the beach and upland can experience increased erosion that impacts dunes and or development, as occurred during the 1983-84 El Nino and others along the study shore. Longshore sediment transport occurs laterally along the shore and may fluctuate in magnitude and direction with the wave climate throughout the year. The combination of cross-shore and longshore sediment transport processes at Stinson Beach influence the overall shoreline evolution and have direct implications to the design and performance of nature-based adaptation alternatives. The following sections present the analyses of longshore sediment transport and shoreline evolution along Stinson Beach as well as geomorphic interpretation of Stinson study profiles for the purpose of estimating sea-level rise impacts to the shoreline in subsequent tasks.

6.3.1 Conceptual Description of Sediment Transport along the Stinson Shoreline

A simplified conceptual explanation of sand transport in Bolinas Bay focused on sand transport “throughput” is described below and shown in Figure 21.

- Bolinas Bay is a hook-shaped (logarithmic spiral) bay that is generally in equilibrium with waves and sand throughput. The shore fluctuates under storm / swell, seasonal, and possibly climatic (ENSO, PDO) cycles but is generally “dynamically stable” except for the effect of sea-level rise and the effect of development. Predominate wave driven sediment transport is from west-to-east and north-to-south. Duxbury Reef dissipates waves and is the upstream headland of the Bay; sand bypasses over it and in deeper water around it. Locally, near the lagoon inlet, along shore transport is toward the inlet.
- The Bolinas lagoon has a tidal inlet with sand exchange with the beach littoral sediments as well as sediment discharge of inland sources. Overall, the sand moves “through” and “past” the mouth after a somewhat circuitous “subcell” affected by tidal currents and inlet morphology. Hence, locally the net sand transport is at times westward from Stinson into the inlet, returning back out to the ocean with the ebb tide and then eastward under approaching waves. These flow paths are likely partly affected by the bathymetry and currents, which also affect the incident waves, at different tides with transport into the mouth at flood tides (especially after lower tides) and transport out at ebb tides and eastward mostly after higher tides.
- The net transport is more strongly eastward as you get to the Calles and the NPS reaches.
- There are various local sand sources and local spatial and temporal pathways
- Recent changes to sediment transport processes along Stinson Beach:
    - The armoring of the Seadrift spit has changed the mouth and spit dynamics, reducing sand supply to Seadrift via mouth migration, reduced sand overwash and spit building.
    - The reduction of tidal prism within Bolinas Lagoon may have resulted in a net deposition of sand from the ocean and or reduced discharge of sand from terrestrial sources. Higher sea-levels could increase the tidal prism of the lagoon along with the tide-driven sediment transport potential in and out of the lagoon mouth.
    - The armoring of the Seadrift shore has increased wave reflection and reduced beach elevations and could lead to nearshore trough growth and increased longshore transport rates.



SOURCE: ESA, USGS, ESRI

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Figure 21
Conceptual Diagram of Sediment Transport In Bolinas Bay

6.3.2 Longshore Sediment Transport Calculations

Longshore sediment transport (LST) potential at Stinson Beach was further studied to inform the overall feasibility of nature-based adaptation measures. LST influences shoreline erosion rates and can be used as an indicator of the potential longevity of natural infrastructure on the Pacific shore at Stinson and the potential impacts that natural features may have on adjacent coastal areas. For example, one concern may be that sand placed to widen the beach at Seadrift could lead to increased sedimentation at the lagoon mouth, potentially affecting navigation and other services.

ESA performed a preliminary assessment of Longshore Sediment Transport (LST) rates for Stinson Beach (see **Appendix H** for details). The analysis includes the use of the nearshore waves estimated for this study described in Section 6.2 and accepted methodologies and formulas to estimate the LST potential. Shore characteristics used to calculate LST potential are summarized in Table 5 below. The shore normal angle for each reach was estimated using the shoreline change analysis tool from USGS (USGS, 2020). The beach slope was measured from the MLLW water elevation to the MHHW water elevation for each beach profile for winter conditions when most LST occurs. The sediment size D50 used is the average D50 for all the samples for each profile location (sediment samples are discussed in Section 7). D50 refers to the sand grain diameter for which 50% of the sediment sample is smaller. D50, also known as median grain size, is one simplified measure of grain size.

TABLE 5
SEDIMENT AND SHORE CHARACTERISTICS USED IN LST ANALYSIS

Profile Location	D50[1] (mm)	Shore Normal[2] (degrees)	Slope[2]
Seadrift West	0.5	184	2.4%
Seadrift East	0.4	198	2.5%
Patios	0.3	211	2.4%
Calles	0.3	214	2.5%
NPS	0.4	221	2.4%

[1] *averaged for each profile location, average grain sizes per sample are reported in Table 8*
[2] *angle and winter profile slope between MLLW (-0.02 ft NAVD) and MHHW (5.74 ft NAVD)*

The LST potential along the Stinson shoreline was estimated as the average annual rate (cubic yards per year) determined from 11 years of spectral wave data (2007 to 2017). Potential LST rates along the study shoreline calculated from multiple equations are listed in Table 6. The reported accuracy of the industry-standard CERC equation is +/ 50% (USACE 1984; 2002), although there are indications that the calculated transport is biased high (over-prediction) of at least 25 % (Battalio 1985) and by a factor of 2 to 5 (van Rijn 2002). Consequently, several newer equations were applied, named after their lead developers (Kamphius 1991; van Rijn 2002). Results (Table 6) indicate that the potential net LST rate under current conditions is 230k cy/year northwest at Seadrift West and 120k to 350k cy/year southeast for all the other reaches.

The calculated rates represent the potential transport capacity of the waves (i.e., the actual transport rate will be lower if sediment supply is a limiting factor). While the sediment grain size and beach slope are comparable among reaches, the difference between the estimated potential LST is primarily due to the variation of shoreline orientation, which is consistent with findings in the literatures of LST studies. Our interpretation is that more accurate wave transformation modeling would result in smaller wave approach angles and lower net transport rates. Longshore transport calculations are very sensitive to the computed angle of incidence, especially near the zero angle (wave crests parallel to the shore) which is typical at hooked bay shores, especially given the high wave power along the California coast (Battalio 1985). The Van Rijn values are likely closer to the actual net magnitudes. The directions generally correspond to the conceptual diagram in Figure 21. Missing from these localized potential longshore transport calculations is transport during ebb flows from Bolinas lagoon, and wave driven transport across the Bolinas Bay floor beyond the surfzone. Combining the Van Rijn potential rates and the conceptual diagram, we posit that about 50,000 to 200,000 cubic yards per year enter Bolinas Lagoon from the west, passing over and around Duxbury Reef, and eventually mostly leaves Bolinas Bay to the east except for the sand that deposits in Bolinas Lagoon (about 30,000 cubic yards per year, PWA 2006). Some of the sand entering Bolinas Bay moves along the Bolinas shore to the lagoon mouth, and some moves across the bay floor to the surfzone in the vicinity of Seadrift East – Patios-Calles Reaches: We do not know the relative magnitudes of the transport along these alternative paths. Most sand then continues southeast and out of the Bay, but some sand moves north into Bolinas Lagoon and recirculates out during ebb tides, and then likely back toward the project area and east out of the Bay.

Note that the transport rates used here are called “average annual net”. Average annual means that the values vary by year and during the year. Net means the difference between transport in one direction and the other direction, meaning sand actually moves in either direction depending on the particular wave conditions, such that the total sand movement (called the “gross”) is greater than the net. Often the gross transport rate is a useful concept, for example providing a better indicator of the “loss rate” of sand placed to widen a beach, which perturbs the shore such that waves spread the sand away from the placement location over time, typically in both longshore directions.

The implications of this analysis are:

- The results are logical within practice-standard method and data uncertainty, and the analysis results are adequate for use in this study, for wave run-up, erosion and sand transport.
- Wave exposure is powerful enough to quickly move large amounts of sand, especially if the sand forms a perturbation from the shoreline planform which is in dynamic equilibrium.
- Beach nourishment may quickly be dispersed and some may move toward the Bolinas Lagoon mouth. Hence, widening the beach is riskier than adding sand to the back shore where it would only be mobilized after the shore has eroded, and the sand would help restore the equilibrium shore more than move away from the placement reach.
- With sea-level rise, the risks associated with beach nourishment will abate, and therefore beach nourishment is a future adaptation measure that should be considered. This finding may seem abstract at this point in the study but can be elaborated upon later.

TABLE 6
POTENTIAL LONGSHORE SEDIMENT TRANSPORT RATES ALONG STINSON BEACH

	Potential LST (CY/year) by Method (- is northwest, + is southeast)				
Profile Location	**CERC**	**Kamp**	**Kamp2**	**Van Rijn**	**AVERAGE**
Seadrift West	-227,300	-325,300	-237,100	-128,000	-229,400
Seadrift East	115,100	178,100	131,100	47,300	117,900
Patios	133,400	248,600	209,600	42,800	158,600
Calles	360,200	457,800	376,600	193,500	347,000
NPS	259,500	352,600	282,900	110,000	251,300

6.3.3 Shoreline Evolution Analysis

The long-term (100 years) shoreline position along the study area has been stable and has recently accreted 1-2 feet per year with the exception of Seadrift, which has eroded over the long term and has recently stabilized in its current location. The shoreline trends in the eastern reaches bodes well for natural infrastructure feasibility in terms of the available beach space and stability for average conditions. However, the exposure of Stinson Beach to storm wave impacts may pose a challenge to natural infrastructure. This section presents an analysis of long term shoreline change as well as potential impacts from extreme coastal storms at Stinson Beach.

Historic shoreline positions (mean high water, MHW=5.1 feet NAVD) were compiled from available sources and processed with the USGS Digital Shoreline Analysis Software (DSAS) to calculate long-term and seasonal shoreline changes along Stinson Beach. Historic shorelines collected for this study are shown in **Appendix E**. The oldest shoreline was derived from 1920s T-Sheets by the USGS, while the most recent shoreline was taken from Marin County LiDAR flown in January 2018. LiDAR flights conducted before and after El Nino winters provide great insight to extreme winter impacts. Table 7 below summarizes long term and seasonal shoreline evolution for each study reach. Shoreline change values correspond to the Linear Regression Rate (LRR) computed with DSAS in feet per year while seasonal fluctuations (winter/spring to summer/fall) are provided in feet.

TABLE 7
HISTORIC SHORELINE EVOLUTION SUMMARY BY STUDY REACH

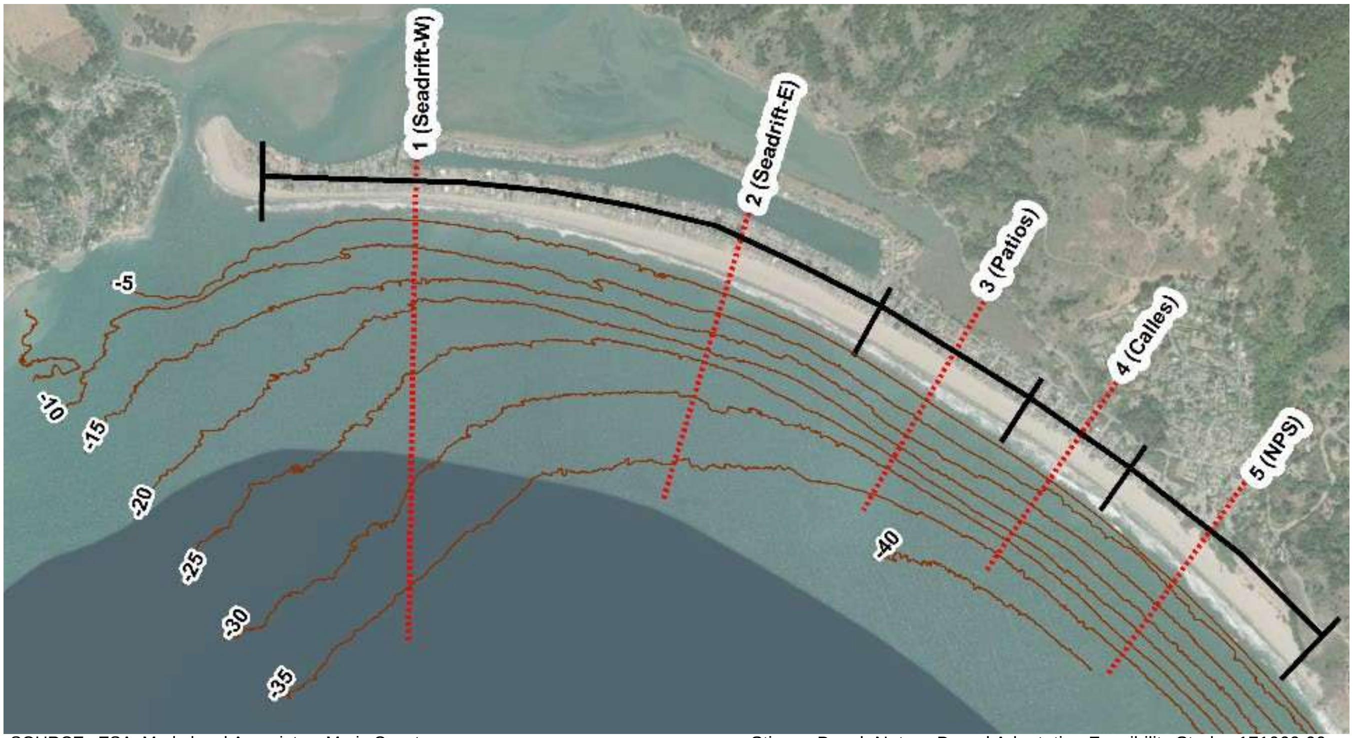
Reach	October 2019 Average Beach Width (feet)	Recent (post 1990s) shoreline change (feet/year)	Long-term (post 1920s) average shoreline change (feet/year)	Extreme winter shoreline change (feet)	
				1998 El Nino	2016 El Nino
Seadrift	156	0.2	-0.9	89	104
Patios	250	1.0	-0.1	94	151
Calles	235	1.8	0.2	47	158
NPS	264	1.4	0.1	31	136

Note: Values are averages for each reach based on transects spaced ~160 feet alongshore

Over the past century, the overall shoreline position has been relatively stable along the eastern study reaches (erosion or accretion of just inches per year) general while the Seadrift Reach has eroded steadily (0.9 feet/year on average). Positive short-term accretion rates suggest the shoreline and beach have undergone steady recovery since the 1990s. Over a similar timeframe, significant erosion events along the Stinson backshore have impacted development, wasted dunes and led to the construction of the Seadrift rock revetment (after the 1983 El Nino). These storm-driven erosion events are distinct from the average shoreline accretion taking place at Stinson and present a challenge for nature-based infrastructure solutions. To quantify the potential impacts of extreme winters at Stinson beach, MHW shorelines were extracted from available LiDAR DEMs for two recent extreme winters. Airborne LiDAR was collected before and after both El Nino winters of 1998 and 2016 by the USGS for the west coast. The recent 2016 El Nino resulted in 100 to 160 feet of shoreline erosion along the Stinson shoreline while the 1998 El Nino resulted in 30 to 100 feet of shoreline erosion. While the shoreline mostly recovered after these events, these extreme winters provide an indication of the potential impacts to natural infrastructure that is constructed on the current available beach footprint along Stinson.

6.3.4 Shore Profiles and Geomorphic Interpretation

The ESA-Merkel surveyed profile elevations were plotted with other recent elevation data for comparison and geomorphic interpretation each shore profile. Shore profile locations are shown in Figure 22 along with 5-foot depth contours developed from ESA ground survey and Merkel Sidescan Sonar.



SOURCE: ESA, Merkel and Associates, Marin County

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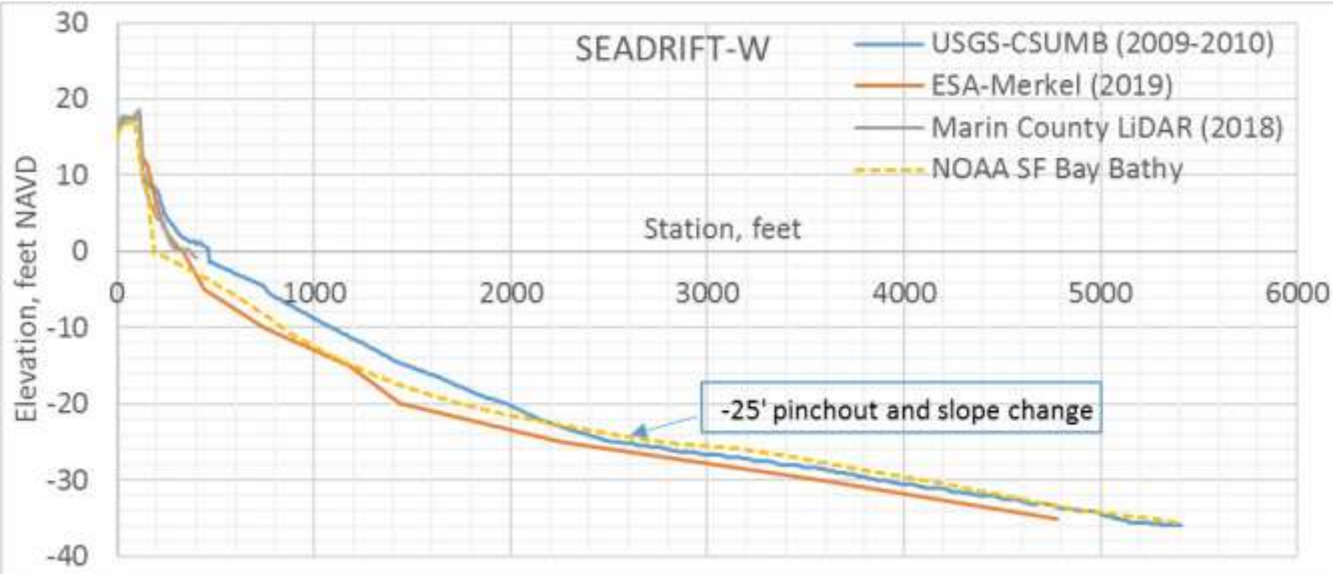
Figure 22
Study Profiles and Nearshore Depth Contours

Figure 23 to Figure 27 below show the surveyed shore profiles at each of the study reaches compared with other available data sources. The profiles are annotated with the approximate limit of the shore face, the location on the shore profile above which wave-driven transport is most active (labelled as pinchout). Note that negative elevations shown on the ESA-Merkel profiles are not official survey bathymetry but are derived from the offshore ecology sonar survey by Merkel and are included for reference. As shown on the profiles in Figure 23, the lower elevations along Seadrift West profile intercept the ebb shoal at the Bolinas Lagoon mouth, making the active shore face ambiguous. The active shore face for sea-level rise response could be shallower in this location, perhaps around –20 feet NAVD, indicating a steeper shore face slope and less recession with sea-level rise. Profiles to the east shown in Figure 24 to Figure 27 exhibit a more defined shore face indicated by smaller variation between profile data sources at each location.



SOURCE: ESA

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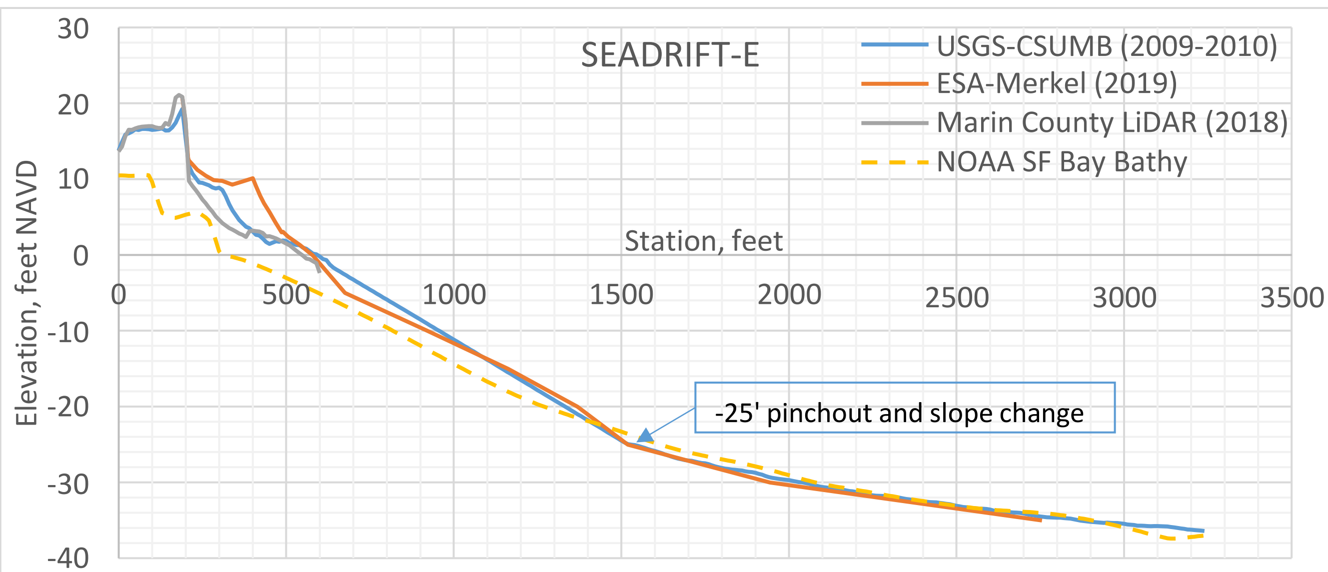
Figure 23
Seadrift West shore profile interpretation



SOURCE: ESA

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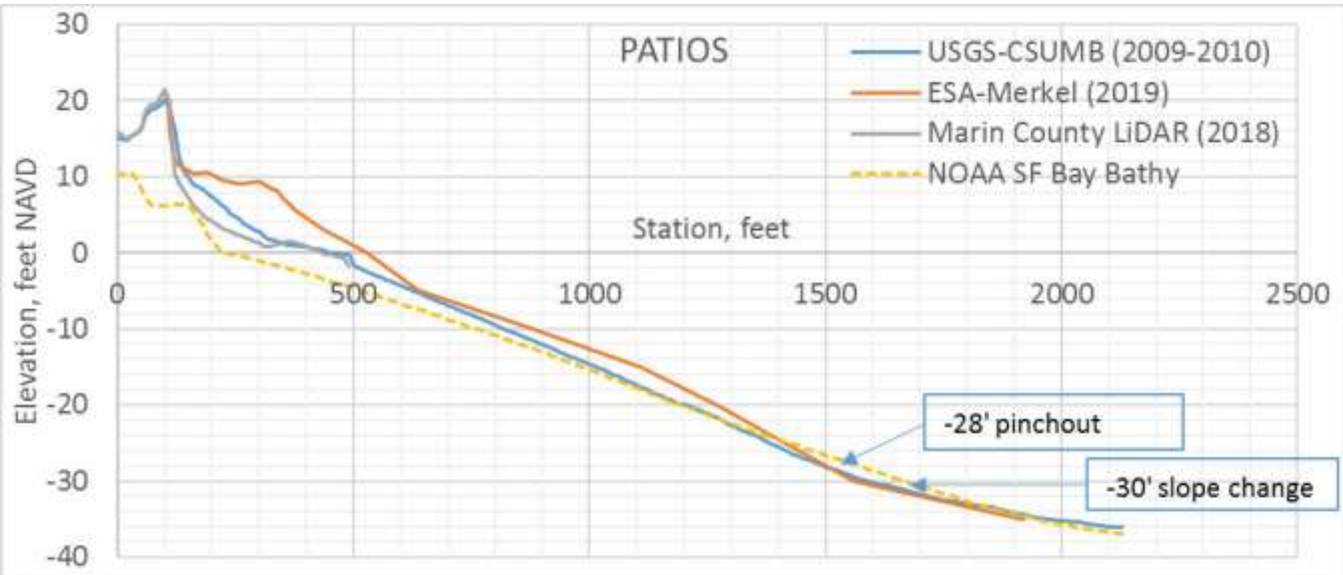
Figure 24
Seadrift East shore profile interpretation



SOURCE: ESA

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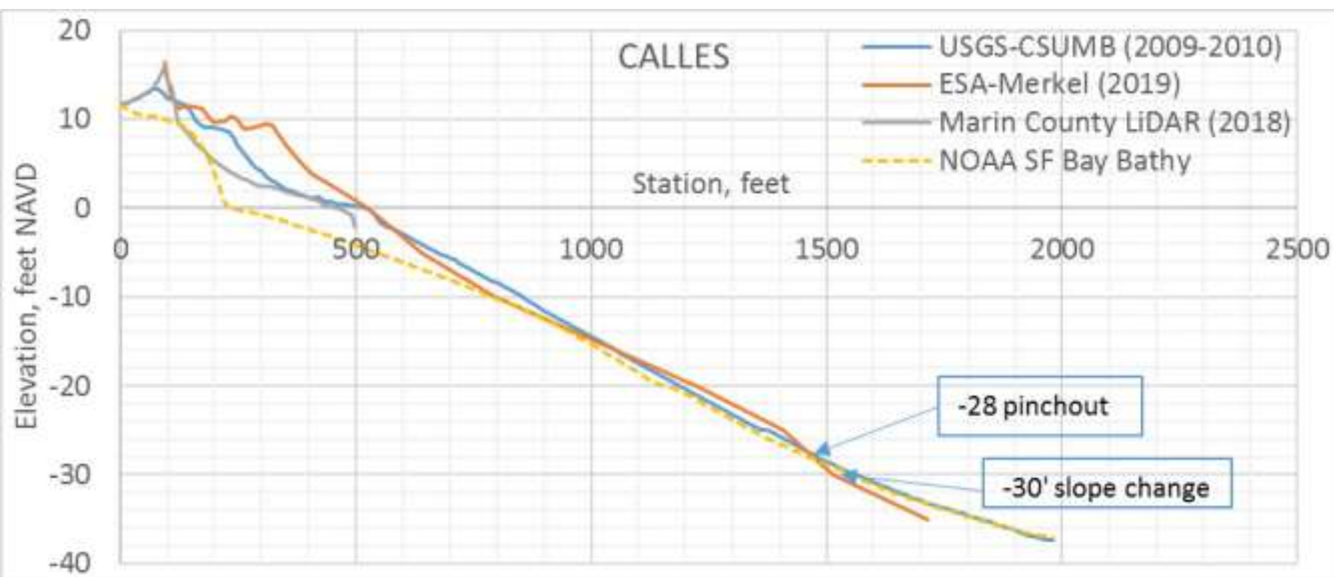
Figure 25
Patios shore profile interpretation



SOURCE: ESA

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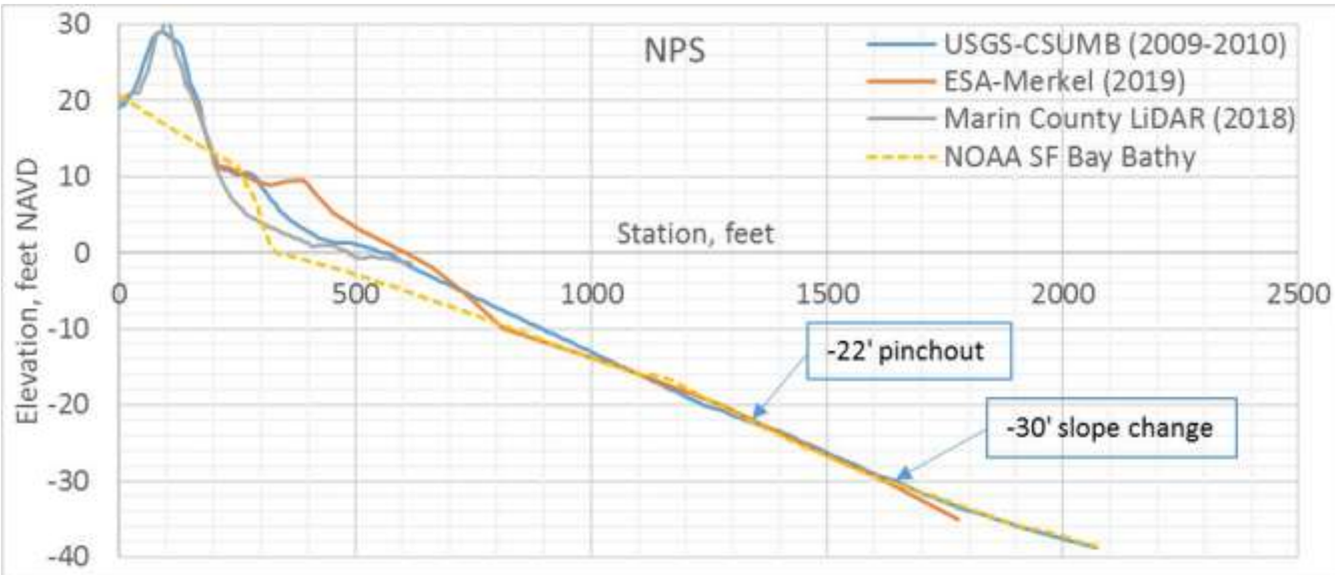
Figure 26
Calles shore profile interpretation



SOURCE: ESA

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Figure 27
NPS shore profile interpretation

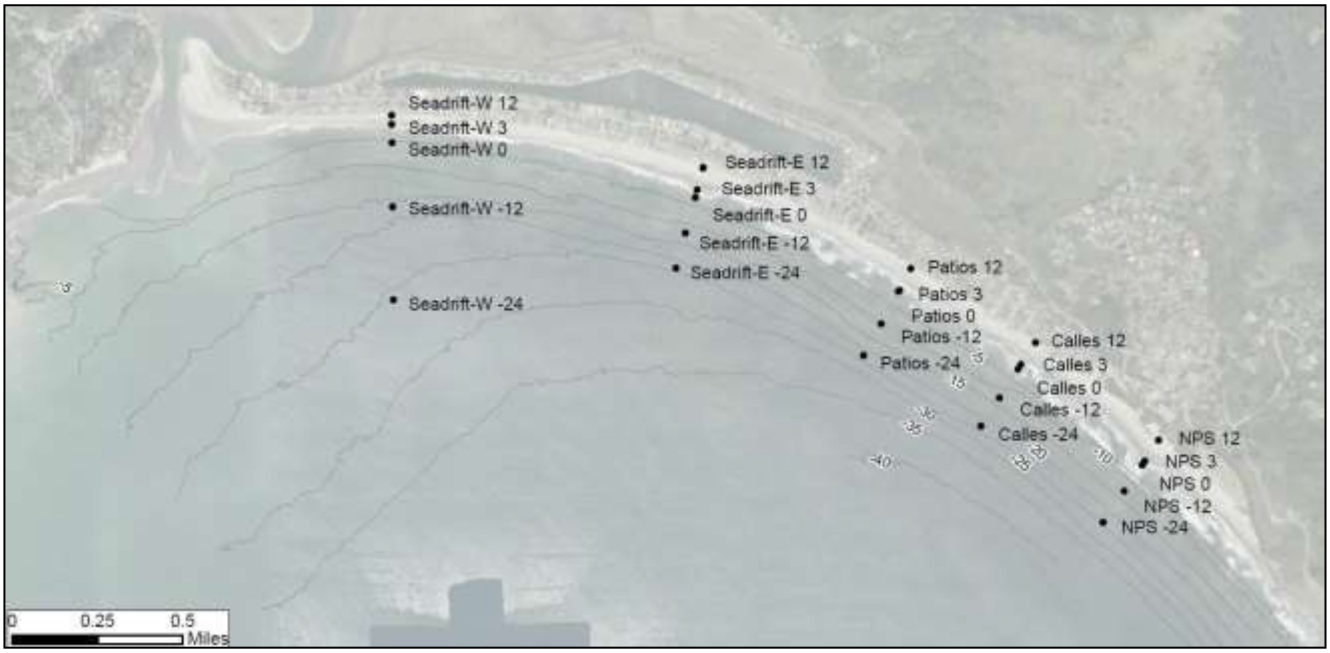
7. Sediment Characterization

7.1 Stinson Beach Sediment Sampling and Analysis

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. Sediment at Stinson Beach was characterized to provide baseline conditions for which sources can be compared for compatibility. In general, compatible sources of sediment similar to the sand at Stinson Beach in terms of size, mineralogy, roughness and appearance. From a regulatory perspective, imported beach sediment should have at least 80% sand (less than 20% fines) and be free of contaminates and organics. Dune sediment is frequently finer than beach sediment and accumulates fines including organics, and hence requirements for the sand dunes may differ.

Sediment grab samples were collected from the upper beach through the surf zone to the depth of closure (offshore limit of the active shore profile, approximately -30 feet NAVD for Stinson Beach) at the five study shore profiles shown in Figure 13. From these collections, samples were field characterized as to the nature of the sediment. The field characterization indicated that material offshore in the study area is predominantly clean sands. Only in deeper waters of the study area was silt a major component of the material. For interest purposes, a sample was collected well outside of the study area at approximately ·60 feet. This sample was similarly classified as predominantly sand, albeit silty sand.

From the collected samples, 25 samples were selected to be further analyzed for sediment grain size to characterize the surface sediments of the beach and nearshore subtidal environment. These samples were well distributed across the beach and elevation range from approximately +12 to ·24 feet NAVD (Figure 28). Samples were analyzed by Eurofins Calscience (see **Appendix D** for details). Post collection analyses of sampling location and bathymetry from survey data resulted in correction of some sampling elevations that did not fully match intended sample elevations and sampling IDs at the time of collection. For this reason, elevation has been reported in Table 8 along with sample results. Table 8 presents simplified information from the laboratory analysis as the mean grain size and total percent sand for each analyzed location while grain size envelopes were created for each profile (Figure 29) by combining the grain size distributions for each sample taken along the profile. Surface Sediments ranged from coarse to medium sand with a generally remarkably high sand fraction and low silt content across all analyzed samples.



SOURCE: ESA, Merkel & Associates, ESRI

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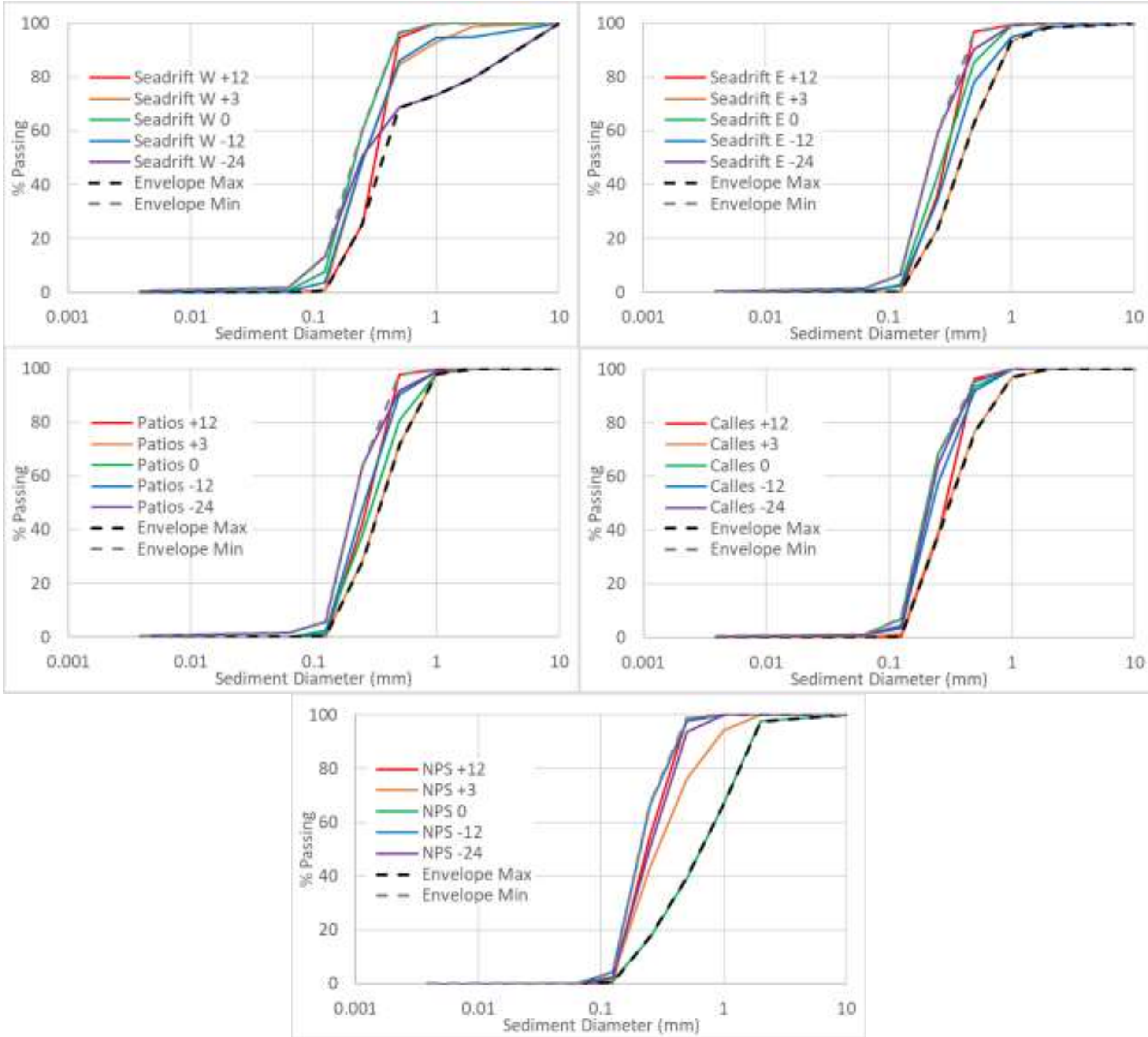
Figure 28
Locations of Sediment Grab Samples Analyzed for Grain Size

TABLE 8
STINSON BEACH SEDIMENT GRAB SAMPLE SUMMARY

Sample	Elevation (ft NAVD)	Mean Grain Size (mm)	% Sand
Seadrift W 12	12	0.317	100
Seadrift W 3	3	0.398	98.9
Seadrift W 0	-5	0.248	99.4
Seadrift W -12	-16	0.445	94.6
Seadrift W -24	-25	0.965	78.0
Seadrift E 12	12	0.299	100
Seadrift E 3	3	0.481	100
Seadrift E 0	0	0.327	100
Seadrift E -12	-12	0.428	97.9
Seadrift E -24	-24	0.278	98.7
Patios 12	12	0.283	100
Patios 3	3	0.41	100
Patios 0	0	0.356	100
Patios -12	-12	0.304	100
Patios -24	-22	0.268	99.4

Sample	Elevation (ft NAVD)	Mean Grain Size (mm)	% Sand
Calles 12	12	0.292	100
Calles 3	3	0.382	100
Calles 0	0	0.248	99.0
Calles -12	-13	0.274	99.1
Calles -24	-24	0.249	98.9
NPS 12	12	0.25	100
NPS 3	3	0.395	100
NPS 0	0	0.849	97.5
NPS -12	-12	0.236	100
NPS -24	-24	0.278	100



SOURCE: ESA, Eurofins Calscience

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Figure 29
Sediment Grain Size Distributions and Envelopes at Study Profiles

7.2 Potential Sediment Sources

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. 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 (Section 7.1). 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. This section summarizes sediment characteristics for each source as determined from existing reports and personal communications with agency staff. Based on this initial assessment, 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. Table 9 below summarizes the sediment sources identified as potentially suitable and available for use at Stinson Beach. Additional information is provided for each source below. Note Table 9 focuses on opportunistic sources and does not include commercially mined sources (e.g. Angel Island/Presidio Shoal), as these would require purchase and may be cost prohibitive, and the future of this source is subject to future permitting by resource agencies.

[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.

TABLE 9
SUMMARY OF POTENTIAL SEDIMENT SOURCES FOR NATURE-BASED ADAPTATION AT STINSON BEACH

Source Type	Location	Potential Volumes*	Sediment Type	Notes	Suitability
Maintenance Dredging	Bodega Harbor Entrance Channel	25k to 50k cy	>80% sand	Dredged every 10-12 years. Next episode expected in 2028.	High
	Pinole Shoal Channel	~180k cy per year	>80% sand and gravel	Dredged annually	High
	Phillips 66 Marine Terminal	4,238 — 16,720 cy	Predominantly sand in Dredging Areas 1 and 3	Dredged annually	Med
	Saint Francis Yacht Club	3,500 — 41,000 cy	> 94% sand in all but 1 of 10 dredging areas	Dredged annually	High
	San Francisco Main Ship Channel	200K to 488K cy per year	90% to 99% sand	Dredged annually	High
Offshore	Bolinas Graben				High
	Bolinas Lagoon Mouth	n/a	sand		
	Russian River	n/a	n/a		
Local Watershed	Easkoot Creek	600-700 cy/year	Cobble, gravel and fines.	No longer extensively dredged, but limited sediment removal at bridge crossings. Future projects to address creek flooding could provide additional sediment.	High
	Other nearby creeks	n/a	n/a		
	Upland stockpiles	n/a	n/a		

cy = cubic yards

** Includes material that is suitable for beneficial reuse and not material that is only suitable for Unconfined Aquatic Disposal*

7.2.1 Maintenance Dredging sites

Bodega Harbor Entrance Channel

Bodega Harbor is one of the three sediment sinks identified on the Marin/Sonoma County Coastline in the Greater Farallones National Marine Sanctuary's (GFNMS) 2017 Coastal Resilience Sediment Plan, accumulating at a rate of approximately 6,300 tons/year. This Plan recommends identifying potential sites to receive clean dredged material from Bodega Harbor, seeking opportunities for designing nearby restoration projects, and investigating ways to maximize beneficial reuse of clean dredged material within the system (Kordesch et al 2019).

Historically, Bodega Bay Harbor has been dredged every 10-12 years by private sector companies under contract to the US Army Corps of Engineers (USACE, 2019). The last dredging occurred in 2017 with a total volume of 70,216 cy dredged. Of the total volume, 47,915 was disposed of at SF-DODS and the remaining 22,301 (the sand) went to SF-8 for beneficial reuse (Ross 2020). In 2004 a total of 153,300 cy was dredged, with 48,300 cy of sand going to SF-8 (beneficial reuse) and the rest (fines) going to SF-DOS (Ross 2020).

Five dredging episodes occurred beginning in early 1960s. The amount of material dredged has ranged from 69,000 to 383,000 cubic yards per episode. Historically, when Bodega Harbor has been dredged, the material was placed on the beach at the local upland site near the base of the Doran Spit, however that hasn't occurred for many years. The next maintenance dredging would be tentatively planned for 2028, based on historical dredging (Kordesch et al 2019).

The most recent Sediment Sampling and Analysis Report available for Bodega Harbor is from 2016. The report documented that two of the five samples were composed of greater than 80% sand, and therefore not analyzed for chemistry. Sandy material was found in sampling areas BB1, BB2, BB3-1, and BB3-2 (where projected 2017 dredging volume was between 22,000 and 38,000 cy) and was determined to be suitable for beneficial reuse by placement in the easternmost area of SF-8. Results of physical and chemical analyses are listed on page 17 of the 2016 SAR (ECM 2017). Testing results should be reviewed further for suitability for use at Stinson Beach as part of a nature-based coastal resilience approach.

Reports are available at: https://www.spn.usace.army.mil/Missions/Projects-and-Programs/Projects-by-Category/Projects-for-Navigable-Waterways/Bodega-Bay/

Pinole Shoal Channel

Pinole Shoal Channel is located within the boundaries of Contra Costa County in the southern portion of San Pablo Bay. The federal channel, approximately 11 miles long, has an authorized width of 600 feet. The channel is dredged by USACE under its O&M program. Since 2008 it has been dredged annually, with the exception of 2018. The average annual volume during that period was about 180,000 cy (USACE 2019). According to the most recent Sediment Sampling and Analysis Report (SAR) (2017), sediment from Pinole Shoal Channel was primarily composed of fine to medium grain size sand. Total sand and gravel was above 80 percent in all three sampling location composite areas, and chemical and metal concentrations were low. The 2017 SAR concluded that based on test results, all sediment is suitable for upland placement (ADHE 2017).

The last dredging occurred in Summer 2019. The volume dredged was 199,232 cy and 100% of the material went to in-Bay disposal at the SF-10 disposal site (Ross 2020). Since this site is typically dredged annually, the next maintenance dredging is anticipated in Summer 2020 or no later than Summer 2021. Based on the results of the 2019 Tier 1 Analysis the Army Corps determined that all material (estimated at 300,000 cy) is suitable for upland/beneficial reuse as wetland cover material. The most recent sediment analysis results (2017) are summarized beginning on page 5 of the 2019 Tier 1 Evaluation, while **Appendix C** includes results for previous sediment analysis for Pinole Shoal conducted since 2009 (USACE 2019). Analysis results for three sample locations indicate sediment in some areas may be compatible with use at Stinson (>90% sand) while fines content in other areas is too high for use on the beach (though area-based volumes were not provided). Testing results should be reviewed further for suitability for use at Stinson Beach as part of a nature-based coastal resilience approach.

Reports available online: https://www.dmmosfbay.org/site/alias_8959/171100/default.aspx

Phillips 66 Marine Terminal

Phillips 66 San Francisco Refinery (SFR) Marine Terminal is located southwest of the Carquinez Strait in Contra Costa County, between the cities of Rodeo and Crockett, CA. Dredging, of various volumes, has occurred annually since 2006 at this location. The most recent dredging (Dredging Episode 5) was completed in late 2019, with a total sediment volume of 15,400 cy. Of this material, 6,000 cy went to SF-8 for beneficial reuse and the remaining went to the Montezuma Wetlands Restoration Project (MWRP) (Ross 2020). Dredging episode 4 resulted in 8,145 cy being dredged in 2018, with disposal at SF-9. Disposal for past dredging episodes has included placement at SF-9 as well as beneficial reuse (except for 2013 and 2018). The volume of beneficial reuse placement varied between 4,238 cy and 16,720 cy (Pacific EcoRisk 2019).

Testing performed in 2007, 2011, and 2016 (the most recent testing date) indicated that the maintenance material was Suitable for Unconfined Aquatic Disposal at SF-8 or SF-9 and for placement at upland beneficial reuse sites at the Cullinan Ranch Restoration Project (CRRP), or MWRP because some material had too much fines. The dredging footprint for Phillips 66 includes up to 5 areas, though all 5 are not dredged during each episode. For example, for Episode 5, dredging is being proposed in Areas 1, 2, and 3 but not in 4 and 5. Areas 1 and 3 have historically been comprised of primarily sand (Pacific EcoRisk 2019). Testing results should be reviewed further for suitability for use at Stinson Beach as part of a nature-based coastal resilience approach.

Reports available online: https://www.dmmosfbay.org/site/alias__9032/172567/default.aspx

Saint Francis Yacht Club

SFYC is dredged annually at least since 2009. Dredge volume varied between 3,509 (I-Dock 2017) and 41,000 (Entrance Channel-Outer Basin, 2010) cubic yards. The summary of dredging episodes and suitability determinations for 2009-2018 are in a table on page 3 of the 2020 Tier 1 request memo. City of San Francisco Recreation and Park Department (RPD) is currently (2020) proposing to dredge 20,000 cy from the Entrance Channel. In 2019 dredging occurred in a small area surrounding the dock as well as the Entrance Channel for a total volume of 11,186 cy, with disposal at SF-8. In the past, disposal of dredged material has been at SF-8 or beneficial reuse for wetland restoration or other purposes (e.g. transfer to San Rafael Rock Quarry) (Boudreau 2020).

Sediment varies depending on areas being sampled, but most dredging areas are predominantly sand. Tier 1 memo from Boudreau Associates (June 2019) states “Grain size analysis results have consistently exhibited high sand content, although some samples have shown less than 80 percent sand and proportionally higher fines. The most recent sand percentage from a composite sample collected in 2016 was 95.4. Generally, the Entrance Channel material is predominantly sand (with less fines content) toward its northeastern (or bayward) end, with higher concentrations of fine material toward the western, or Marina·ward, portion of the area” (Boudreau 2020). While the entrance channel is predominantly sand, the April 2019 Sediment Analysis Report concludes that composite sediment sample that was tested from the small area surrounding the boat slip dock to be dredged, was mostly silt (64%) and clay (29%) (AWHE 2017).

Reports available online: https://www.dmmosfbay.org/site/alias__8975/171420/default.aspx

San Francisco Main Ship Channel

The SF Main Ship Channel provides deep draft entry for commercial vessels en route to the San Francisco Bay; the eastern end of the channel is approximately 4.5 miles from the Golden Gate Bridge. SF Main Ship Channel (i.e. SF Bar Channel), as congressionally authorized, is 2,000 feet wide and 26,200 feet long. The channel is dredged annually by the Army Corps under its Operations and Maintenance (O&M) program. Volumes of material dredged from the SF Main Ship Channel over the past 11 years have ranged from 200,312 to 488,464 cy. The Tier 1 Evaluation (2019) states that dredging was proposed for June 2019 of 567,562 cy to be placed at Ocean Beach Demonstration Site (OBDS) for beneficial reuse. Prior to that, 466,583 cy was dredged in 2018 and placed at OBDS. The dredging and placement history is shown in table on page 4 of the 2019 document.

Historically dredging has been completed either by the Army Corps or contractor and material is placed at OBDS and at SF-8 (USACE 2019).

The last grain size sampling event was in 2018, and the next sampling event is scheduled for 2026. Grain size analysis of shoaled sediment in the SF Main Ship Channel has historically and predictably been shown to be comprised of greater than 90% sand. The 2010 sampling event indicated the percentage of sand at over 97%. The most recent sampling event from 2018 showed 96% (USACE 2019).

Reports available online: https://www.dmmosfbay.org/site/alias_8956/171040/default.aspx

Angel Island / Presidio Shoal

Angel Island and Presidio Shoal are part of commercial sand mining leases and are not dredged for navigational purposes. Thus the sand would need to be purchased and would probably be cost prohibitive. However, these sources are included in this report as possible alternatives to purchase sand if opportunistic sources are not available.

7.2.2. Offshore sources

The following offshore sand sources require further investigation. An important consideration for these sources is the fact that they are within national marine sanctuaries.

Bolinas Graben

Grabens are depressed blocks of the Earth's crust that are bordered by parallel faults. Two grabens exist where the San Gregorio Fault intersects the San Andreas Fault, north of Bolinas Lagoon. These depressions between the two faults occur offshore (Bolinas Graben) and onshore (Bolinas Lagoon, discussed below). The GFNMS 2020 Coastal Resilience and Sediment Plan (CRSP) (Kordesch et al 2019) includes a strategy to further characterize the sediment at this source and assess feasibility for use in beach nourishment for restoration purposes. Bolinas Graben is located within the Greater Farallones National Marine Sanctuary (GFNMS), and any dredging or extraction of sediment would require a Sanctuary permit since it is prohibited pursuant to the following GFNMS Regulation: "Constructing any structure other than a navigation aid on or in the submerged lands of the Sanctuary; placing or abandoning any structure on or in the submerged lands of the Sanctuary; or drilling into, dredging, or otherwise altering the submerged lands of the Sanctuary in any way." GFNMS can consider a proposal to dredge sand from Bolinas Graben or Lagoon only if it is used for habitat restoration or shoreline resilience projects that enhance ecosystem functions. Since GFNMS has strict permitting criteria it would be very important to work with sanctuary staff early on. The permit application review process would include a NEPA analysis of by staff of potential impacts to the submerged lands (DeLaney 2020)

Bolinas Lagoon Mouth

Bolinas Lagoon was characterized as a sediment sink in the 2018 Marin-Sonoma Coastal Regional Sediment Management Report (CRSMR) with 5,180 tons/year accumulating (USACE 2019). This sediment sink was also identified in the GFNMS' CRSP (2019) as a potential source of sand for beneficial reuse projects that could provide ecosystem benefits. The accumulated sediment at the Bolinas Lagoon mouth may serve as a potential opportunistic sediment source resulting from any future dredging of the lagoon mouth, no though no such activities have been proposed or planned. This location is within the boundaries of GFNMS, and is therefore subject to the permitting considerations described above. Sources of sediment to Bolinas Lagoon include Easkoot Creek, Pine Gulch Creek and the Bolinas cliffs.

Offshore of Russian River

Russian River, which discharges into the Pacific 45 miles northwest of Stinson Beach, has an estimated sediment source of 900,000 tons/year (George et al. 2018; Milliman and Farnsworkth, 2011) that accumulates offshore and can be considered as a potential offshore dredging source of sediment for Stinson Beach adaptation.

7.2.3. Local Watershed Sources

Easkoot Creek

Easkoot Creek is a tributary to Bolinas Lagoon, draining 1.59 square miles of watershed through Stinson Beach and finally draining into Bolinas Lagoon. Due to a lack of channel capacity it frequently overflows its banks in the area between Arenal Ave. and Calle de Arroyo. The creek runs adjacent to the Stinson Beach Parking lot and causes flooding in the lot during heavy rainfall events. Flooding issues are exacerbated by sedimentation in the creek that reduces channel capacity. Historically Easkoot Creek was dredged regularly and extensively, with the last large dredging episode in 1987, however recently dredging has been significantly reduce and limited to sites where the creek crosses roads. The reason for severe reductions in dredging of the creek in recent years is the presence of federally listed steelhead and unsustainable cost. In the past, several studies have been completed, looking at measures that could be taken to address persistent flooding issues at Easkoot Creek. Engineering studies in 1971 and 1984 investigated diverting high flows directly to the ocean. More recently, in 2008, an interagency working group developed the Bolinas Lagoon Ecosystem Restoration Project, which includes the following recommendations related to Easkoot Creek: 1) investigate using a portion of the GGNRA parking lot as a seasonal floodplain, 2) assess sediment sources and identify approaches that address problem areas, and 3) improving floodplain access and removing deltas along the Eastern shore of Bolinas Lagoon (Love 2009). Current sediment removal is focused excavation of "glory holes" near bridge crossings. This includes sediment removal about every two years near Parkside Café where the creek makes a bend. The material excavated from this location is primarily cobble and gravel with some fines as well, however no grain size analysis has been completed for sediments in the creek. Sediment volumes from dredging in the past few years have been between 600-700 cy. Marin County performs all dredging of the creek under permit and easement from National Park Service. Historically it was done by Marin County Roads but is now performed by private contractors (Epke, pers. comm.).

Coarse sand and gravels from Easkoot Creek could be used as dune anchors or mixed with cobbles for a buried cobble berm in the nature-based adaptation concepts developed for this study. Mean annual sedimentation for the period of 1979-2011 was estimated to be about 122-160 CY/yr in lower Easkoot Creek (OEI 2014). The sampled sediment size showed a median sediment diameter (D50) ranging from about 20 to 50 mm for surface sediment. Five bulk samples of the bed, gravel bar, and other deposits were also collected and analyzed, showing a D50 from about 6 mm to 16 mm, representing higher bed load sediment supply. Based on analysis of the two bulk samples from deposition gravel bars near Calle del Pradero and Calle del Pinos, an upper limit on the diameter of sediment typically transported through Easkoot creek to Bolinas Lagoon is about 20 mm.

Other nearby creeks

Coarse sand and gravels excavated for nearby creek sediment management activities could be beneficially reused at Stinson Beach (e.g. Lewis, Williams, Garden Club Canyon).

Other Potential Sources

Other sources of sand/sediment could include sand already dredged and stockpiled in upland “ponds” at places like Noyo Harbor where the cost of disposing of it in order to reclaim capacity is otherwise prohibitive; or dredged sand that will be transported a fairly long distance anyway that could be diverted to Stinson for a relatively small incremental cost, such as Pinole Shoal or Phillips 66. Purchasing sand already harvested by sand miners might be a last resort possibility. (Brian Ross, Pers. Comm.)

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Chapter 3
Climate Scenarios and Adaptation Criteria

This chapter presents climate scenarios and discusses adaptation criteria and thresholds that are used in the development and evaluation of nature-based adaptation alternatives at Stinson Beach. Climate scenarios represent near to mid-term sea level rise with and without potential coastal storm impacts. Adaptation thresholds provide the foundation for developing location specific design parameters and action thresholds for natural infrastructure at Stinson Beach. The chapter is divided with the following headings:.

1. Climate Scenarios
2. Adaptation Evaluation Criteria and Thresholds
3. Summary
4. References

1. Climate Scenarios

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 scenario (e.g. no storm, 20-year or 100-year storm). 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. The feasibility of adaptation alternatives are evaluated based on performance within these scenarios.

This study's assessment of long-term sea-level rise is based on the State of California Sea Level Rise Guidance 2018 Update (published by the California Natural Resources Agency and Ocean Protection Council). This latest state guidance was released after Marin CDA completed the C-SMART Vulnerability Assessment (2016) and Adaptation Plan (2018). Table 1 summarizes the scenarios selected for C-SMART. These scenarios are referenced to the hazard mapping *Our Coast Our Future* (Point Blue Conservation Science) developed using Coastal Storm Modeling Software (CoSMoS) modeling by the US Geological Survey, which includes sea-level rise from 0 to 2 meters in 0.25-meter (~10 inch) increments with options of four storm scenarios: average conditions (no storm), annual storm, 20-year storm and 100-year storm. Marin CDA is currently planning to update the C-SMART Vulnerability Assessment to include at least two scenarios for average conditions, which show long-term inundation from sea level rise without flooding from storm impacts. ESA is coordinating with CDA as this update progresses so that this study will include the updated scenarios.

TABLE 1
SEA-LEVEL RISE SCENARIOS USED IN C-SMART*

Sea-level Rise Scenario		Term
1	0.8 feet + annual storm	Near
2	0.8 feet + 20-year storm	Near
3	1.6 feet + 20-year storm	Medium
4	3.3 feet + 100-year storm	Long
5	6.6 feet + 100-year storm	Long

** C-SMART reports are accessible at https://www.marincounty.org/depts/cd/divisions/planning/csmart-sea-level-rise/csmart-publications-csmart-infospot*

The 2018 state guidance on sea-level rise now provides future sea-level rise projections for varying levels of risk aversion from the updated 2018 State guidance (see Table 2 below). Risk aversion can be considered the inverse of risk tolerance.

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). For comparison, decisions made for an unpaved coastal trail could have a low risk aversion while decisions regarding a coastal power plant or wastewater facility would exercise extreme risk aversion. Further descriptions of sea-level rise scenarios and discussion of risk aversion can be found in the State guidance.

TABLE 2
SEA-LEVEL RISE PROJECTIONS FOR SAN FRANCISCO IN FEET (CALNRA & OPC 2018)

Year	Low Risk Aversion (16% probability of exceedance)	Medium-High Risk Aversion (0.5% probability of exceedance)	Extreme Risk Aversion (no probability calculated)
2030	0.5	**0.8**	1
2040	0.8	**1.3**	1.8
2050	1.1	**1.9**	2.7
2060	1.5	**2.6**	3.9
2070	1.9	**3.5**	5.2
2080	2.4	**4.5**	6.6
2090	2.9	**5.6**	8.3
2100	3.4	**6.9**	10.2

Probabilistic Projections (based on Kopp et al. 2014) are associated with high emissions scenario.

Note that the underlined Medium-High Risk Aversion values from the updated 2018 state guidance in Table 2 are similar to the C-SMART values for 2030 (0.8 feet), 2050 (1.9 feet = ~1.6 feet), 2070 (3.5 feet = ~3.3 feet) and 2100 (6.9 feet = ~ 6.6 feet). The similarity of the most recent California sea-level rise projections in Table 2 and C-SMART Vulnerability Assessment scenarios in Table 1 allow this project to be compatible with both. The proposed scenarios for this study are listed in Table 3.

Note that State guidance does not include the episodic increases in water levels associated with El Niños, King Tides or other storm surges and waves. State guidance does recommend consideration of extreme events. Extreme storm events, although infrequent are very important for Stinson; the community may appear safe and stable to a visitor today given its wide beaches but the risks that extreme storm events pose to the community are significant. Therefore, climate scenarios were chosen so that adaptation alternatives can be evaluated over time considering the long term progression of tides and shoreline erosion as well as extreme storm events. Table 3 lists the proposed climate scenarios for this study including the approximate timing of sea-level rise associated with the low and med-high risk aversion projections as defined by the Ocean Protection Council (OPC). The scenarios represent the average conditions (no storm) and 20-year storm conditions at existing and two future sea levels (1.6 and 3.3 feet sea-level rise).

TABLE 3
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)*

We note that many planning studies identify the 100-year storm as the "benchmark" event for evaluation. C-SMART included the 100-year for longer term planning (that is, with higher sea-levels), as shown in Table 1. For this study, we propose to focus on the near- to mid-term for design criteria and consider a 20-year coastal storm in addition to average conditions. Potential impacts from a 100-year coastal storm event are described in subsequent analysis task, 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 (pending further analysis). Longer term vulnerabilities to sea-level rise and storms are addressed in terms of future potential adaptation pathways that may stem from the preferred alternative(s) analyzed in this study. Existing 100-year exposure is indicated by the FEMA flood hazards maps. The 1983 El Nino conditions provide another indication of a severe event and is often used as surrogate for events on the order of 100-year recurrence, although Ecker and Whelan (1984) estimated the 1982-83 El Nino to be a 10- to 12-year recurrence event at Stinson. Griggs and others (2005) report that severe damages occurred to homes and infrastructure in 1977-78, 1982-83 and 1997-98 El Nino winters. The USGS CoSMoS modeling also selected "storm" conditions for hazard mapping, which was considered in C-SMART. ESA will select a severe storm condition for analysis after consultation with the County and a review of these candidate sources.

2. Adaptation Evaluation Criteria and Thresholds

This section describes the various criteria that are used to evaluate adaptation alternatives, establishes a basis for adaptation thresholds relevant to nature-based adaptation at Stinson Beach based on existing guidance and reference sites, and proposes site-specific adaptation thresholds for each Stinson study reach. The adaptation thresholds are further refined during modeling of the adaptation alternatives in the next project task.

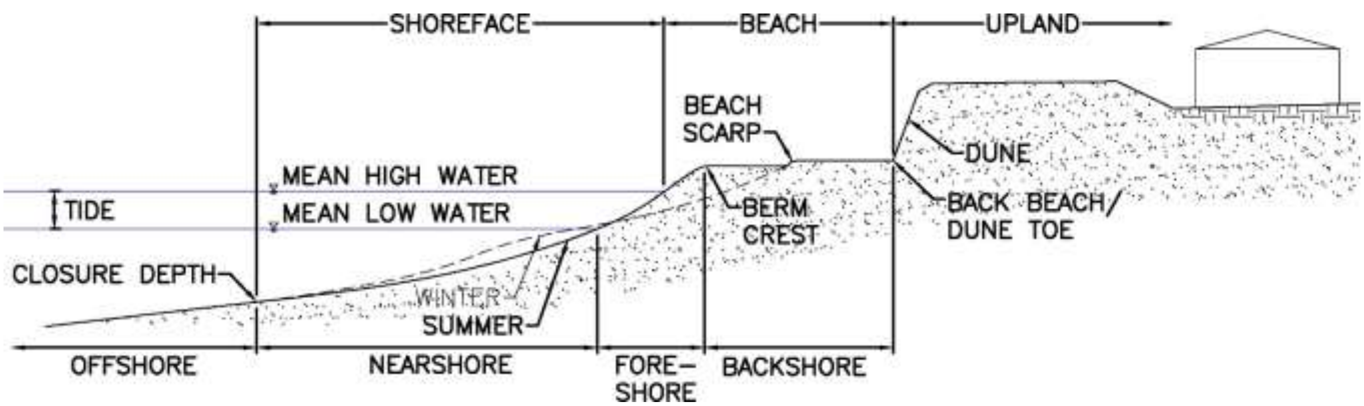
Section 2.1 develops a framework for establishing evaluation criteria and adaptation thresholds for Stinson Beach, using background on beach morphology and relevant adaptation guidance recently published by California, and prior work from the C-SMART program. Section 2.2 summarizes the information derived from other coastal locations with natural features, called reference sites. Section 2.3 summarizes existing shore geometry and geomorphic parameters pertinent to natural infrastructure. In Section 2.4, evaluation criteria are described along with preliminary reach-specific adaptation thresholds to be used in this Feasibility Study.

2.1 Framework

Adaptation by definition is a process of change. In the context of coastal hazards and sea-level rise, the thresholds that trigger adaptation actions are based on the progression of coastal flooding, inundation and erosion hazards in relation to shoreline assets (e.g. development). Evaluation criteria are the specific parameters (e.g. beach width, wave run-up elevation) used to analyze the adaptation alternatives in this project. The evaluation criteria were selected to articulate the specific shore morphology at Stinson Beach and enable a thorough analysis of the potential impacts from sea-level rise and storms. Thresholds were established for certain criteria to time the maintenance needs for each alternative and evaluate its overall feasibility. A range of adaptation measures and other concepts such as thresholds are discussed in the C-SMART Adaptation Report and Appendix B (ESA 2016).

2.1.1 Beach Morphology

A typical beach profile is shown in Figure 1, labeled with features that define a beach and determine its morphologic responses (i.e. erosion, migration) to physical forces (e.g. high ocean levels, sand supply, storms, sea-level rise). The profile is labeled for the typical summer/fall condition when the beach is widest, showing a beach scarp from a typical prior winter shoreline configuration (dashed line). The profile is similar to existing conditions in the Patios Reach where there are foredunes between the development and beach. As described in the Existing Conditions memo, the backshore along Stinson Beach study area is a mix of foredunes, shore armor and back beach/upland development. The pre-development shore was sparsely vegetated low dunes except at the western end (now Seadrift) which was likely an over-washed and dynamic sand spit. The concept of beach morphology illustrated in Figure 1 was applied to determine existing and future beach widths and the potential locations of dunes and cobble berms considered in this project.



SOURCE: ESA

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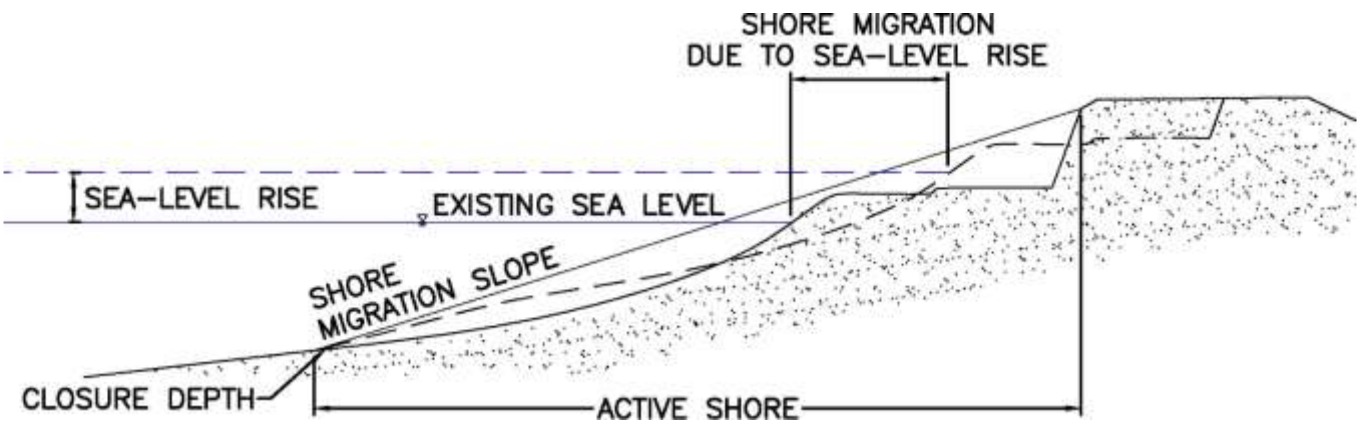
Figure 1
Typical Beach Profiles and Morphologic Features

Reach-specific evaluation criteria used to evaluate adaptation alternatives in this study are based on physical shore parameters shown in Figure 1 (e.g. beach and dune width, foreshore and overall profile slope) as well as physical forcing from the ocean (sea-level rise, storm surge and wave run-up). Sea-level rise and will have a long-term effect on the shore profile, determined for this study by the slope of the active shore. As shown in Figure 2 below, the active shore extends from the closure depth to the backshore-upland transition. In the case of Figure 2 (similar to Patios and NPS reaches), this includes the existing foredunes that can supply sand to the migrating beach. For existing conditions at Seadrift and Calles reaches, the active shore ends at the back of the beach where rock revetment (Seadrift) and beach-top development (Calles) are non-erodible. In these locations, the shore migration slope is flatter in comparison to the reaches with erodible dunes. The flatter migration slope as well as non-erodible armoring will lead to faster beach loss with sea-level rise. By implementing natural infrastructure such as foredunes the effective shore migration slope can be steepened, thereby reducing the lateral movement of the shore due to sea-level rise. Coastal storm impacts will also be evaluated based on the profile slopes as described in Section 2.4.



SOURCE: ESA

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Figure 2
Erodible Dune-Beach Profile Migration with Sea-Level Rise

The criteria used to evaluate adaptation alternatives are described in the context of existing conditions at Stinson Beach. Adaptation thresholds are established for some of these criteria to determine the timing of maintenance actions and potential future adaptation pathways.

2.1.2 Relevant Studies

The adaptation criteria and thresholds established for Stinson Beach build on local planning and regional guidance documents. This section summarizes relevant information from the Marin County Sea-level Rise Adaptation Report and State guidance on natural infrastructure. Selected adaptation criteria and proposed thresholds for Stinson Beach are discussed in Section 2.4.

C-SMART Sea-Level Rise Vulnerability and Adaptation Studies

This section summarizes key findings and recommendations from the C-SMART Sea-level Rise Vulnerability Assessment and Adaptation Plan as they pertain to Stinson Beach. The overall vulnerability of the Stinson community to sea-level rise is important to this feasibility study because the timing of other adaptation measures (e.g. to address flooding from Bolinas Lagoon and Easkoot Creek) may influence feasibility of natural infrastructure on the beach. ESA reviewed the coastal hazard maps developed for C-SMART Sea-level Rise Vulnerability Assessment (2016) with respect to each study reach so that nature-based adaptation along the

Pacific shoreline can understood in the context of overall community vulnerabilities to climate change and sea-level rise. This will enable a more informed feasibility assessment and identification of potential adaptation pathways for the Stinson community.

The amount of sea-level rise that leads to exposure in each study reach is summarized in for three types coastal hazards: coastal storm event flooding, long term erosion and long term tidal inundation. The sea-level rise exposures correspond to a baseline condition where no intervention is taken and do not consider existing coastal armoring in order to fully understand the potential vulnerabilities. Similarly, FEMA flood hazard maps for this area conservatively assume a failed condition of the revetment at Seadrift. The sea-level thresholds correspond to when action must be taken to mitigate hazard impacts. Note that nature-based infrastructure along the Pacific coastline does not address tidal inundation and storm flooding impacts from Bolinas Lagoon and Easkoot Creek, these flood sources are described in the context of future adaptation pathways but not explicitly analyzed in this study.

TABLE 4 COASTAL HAZARD EXPOSURES WITH SEA-LEVEL RISE FOR STUDY REACHES

Reach	Coastal Storm Flooding, source	Long-Term Coastal Erosion	Tidal Inundation
Seadrift	0 to 1.6 ft (0 to 50 cm), wave run-up/lagoon	1.6 to 6.6 ft (50 to 200 cm)	4.1 ft (125 cm)
Patios	10 in (25 cm), lagoon	3.3 to 6.6 ft (100 to 200 cm)	1.6 ft (50 cm)
Calles	0 in, wave run-up	3.3 ft (100 cm)	1.6 ft (50 cm)
NPS	10 in (25 cm), wave run-up/overtopping	6.6 ft (200 cm)	> 6.6 ft (>200 cm)

Sea-level rise exposure determined from C-SMART coastal hazard zones for inundation and flooding (USGS/OCOF) and erosion (ESA)

Due to the low-lying nature of the sand spit that comprises the study area, at some point 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.

Building on the Vulnerability Assessment, the Marin Open Coast Sea-Level Rise Adaptation Report (C-SMART 2018) establishes an adaptation framework for coastal adaptation in Marin County and describes various adaptation strategies that could be implemented at Stinson Beach. Given the beach's natural and recreational values to local residents and visitors, a preferable adaptation approach for Stinson Beach includes measures to preserve the beach. This feasibility study takes the County and Stinson community one step closer to smart sea-level rise adaptation by analyzing nature based adaptation. Specific adaptation thresholds were developed for beaches in the Stinson community in general. Relevant thresholds are summarized in Section 2.4 along with proposed thresholds for this study that account for the various shore conditions in each reach. The following beach width adaptation thresholds were identified in C-SMART (ESA 2016) and provide a general basis for this study:

- **Maintenance threshold, plan for action**: Fall season beach width of 80 feet or less; and,
- **Adaptation threshold, take action**: Fall season width less than 25 feet.

The fall season was selected because this is when the beaches are typically their widest with less variation year-to-year than in the winter months when conditions can change markedly within a day. While most people use the beach during the summer, a fall beach width is the appropriate reference condition for the purpose of implementing natural infrastructure. Natural infrastructure features would likely be constructed in the fall, outside of summer peak recreation season but at a time of year when beaches are widest for constructability (pending any environmental restrictions). Conceptually, a fall beach width of 80 feet is manageable relative to the average seasonal change of 40 to 120 feet at Stinson computed for this study, and may therefore be adequate for a winter season and storm induced erosion for moderate winters. However, a fall beach width of 25 feet will likely result in a near "zero" beach width by Spring and potential upland erosion and damages to development, hence spurring adaptation actions such as dune construction. Actual seasonal and event-induced beach width changes are quite variable and respond to multiple forcing parameters.

A planning level geomorphic analysis for C-SMART developed the following risk-based beach width thresholds based on a coastal storm erosion event that could occur every two to five years (see Table 5). If a beach width narrows to the point where coastal storm erosion exceeds the beach width, backshore development may be damaged. The beach width thresholds in Table 5 do not explicitly consider ecological function or recreation, which are important considerations in this feasibility study.

TABLE 5. RISK LEVELS FOR VARYING BEACH WIDTH.

Excess Beach Width W (feet)	Risk Level
W > 50	Low
50 > W > 33	Medium
33 > W	High

Stinson Beach width adaptation thresholds based on C-SMART can be interpreted here as:

- Target beach width minimum is 130 feet, measured in the Fall season;
- Maintenance triggered when fall beach width less 80 feet; and,
- Immediate action needed when beach width is less than 50 feet.

Along with natural infrastructure guidelines developed for the state and reference site geometry, these adaptation thresholds form a basis for site-specific thresholds described in Section 2.4.

Note that this feasibility study does not propose beach nourishment (widening) via placement of sand below the MHW line because the existing beaches are fairly wide along most of the study area, allowing adaptation measures to be taken along the backshore and upland. For this project, dune erosion will provide sand supply to reduce the extent of shore recession, and subsequent sand placement could be on the dry beach to rebuild the eroded dune, thereby avoiding sand placement in the Marine Sanctuary. Also, a cobble berm could be used to limit erosion while facilitating subsequent beach recovery. Additionally, sand placement to widen the beach beyond its existing width may increase the transport of sand to the Bolinas Lagoon inlet, may potentially have adverse effects and generally may be less effective than backshore adaptation. Finally, placement of sand in the ocean (generally below high tide) requires additional regulatory approvals and in particular is generally prohibited in the Marine Sanctuary offshore. However, alternatives could include beach nourishment that places sand on the back shore (above and landward of the beach face) to limit impacts to the nearshore. This study will address beach widening (sand placement, beach nourishment) as a longer-term adaptation action, consistent with future projections of very narrow beaches in response to sea-level rise.

Natural Infrastructure Guidance for California

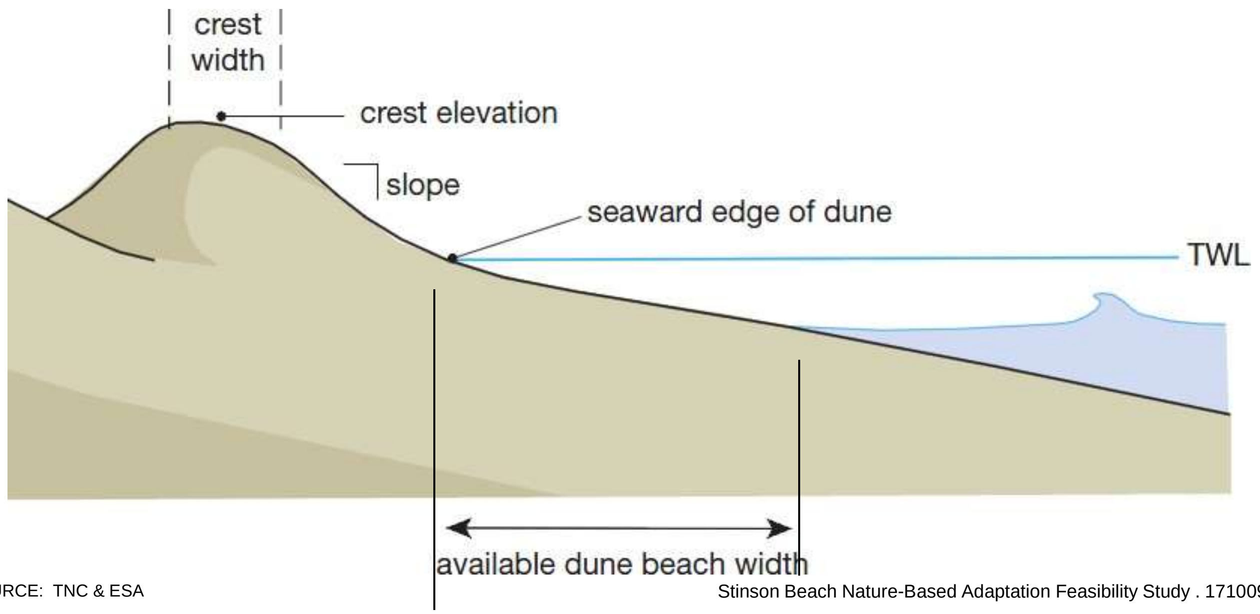
The State of California recently funded development of guidelines for use of natural infrastructure, including cobble berms and dunes, to mitigate coastal erosion and flood hazards (TNC and others 2018; ESA and others 2018). The resulting documents provide good starting points for developing adaptation thresholds. Adaptation thresholds can also be related to dimensions measured at reference sites with desired morphology. Dimensions can be tested using analysis of erosion and wave run-up hazards to assess the ability of the feature(s) to protect upland assets against sea-level rise and storms.

The following schematics developed by ESA for managing shoreline change in California show the characteristic dimensions for two natural shoreline infrastructure types that are assessed for this study: vegetated sand dunes and cobble berms. Natural vegetated sand dunes are located landward of the typical wave run-up zone, where the plants have time to establish and grow (Figure 3, Figure 4). Cobble berms (Figure 5) are typically farther seaward and in the zone of wave run-up during periods of elevated waves and water levels (i.e. storms). Note that the cobble berm in Figure 5 is shown covered by a sandy beach and shore, which is representative of a mild wave climate consistent with the summer-fall seasons. On sandy shores, natural cobble berms are typically covered by sand in the summer and fall when waves are smaller and may be exposed in the winter when larger waves move the sand offshore to form sand bars (as illustrated in Figure 1). During extreme conditions, wave run-up may overtop the crest and reach uplands and/or development. Engineered versions of dunes and cobble berms may locate these features farther seaward to limit erosion and preserve the landward beach and dune space. An example is the use of sand to bury rock armor at Seadrift; a similar approach with a cobble berm buried with sand could be employed with the understanding that extreme conditions will erode the dunes. Hence, when using natural shore infrastructure, it is helpful to understand the natural geometry and processes (aka geomorphology) and the degree to which development constrains the geomorphology and thus degrades the performance of natural infrastructure (reduced functional life, increased maintenance requirements, increased disturbance and reduced ecology and access benefits). The Natural Infrastructure Guidance report documents standard minimum design criteria for effective natural infrastructure implementation on open and sheltered coasts. Open coast dunes and cobble berm minimum design dimensions are shown in Figure 4 and Figure 5 and described in Section 2.4 along with specific recommended adaptation thresholds for each study reach.

The desired minimum beach width fronting dunes is on the order of 100 feet according to the concept-level parameters outlined in the Natural Infrastructure Guidelines (TNC and others 2018). This width was selected for dune sustainability, in terms of limiting wave-induced erosion while maintaining a dry beach for wind-blown sand supply (dunes naturally grow with help of onshore winds that blow sand off the dry beach which settles within vegetated areas). While this current study’s Existing Conditions assessment (ESA 2020) has found that natural dune accretion is limited at Stinson Beach, the utility of maintaining wide dunes to reduce storm erosion and wave run-up reduction remains important.

The Natural Infrastructure Guidelines indicate the following geometries for dunes and cobble berms, and associated beach widths that may be sustainable at Stinson Beach:

- Sand dune footprint width of at least 50 feet;
- Dune-fronting beach widths of at least 100 feet recommended; and,
- Cobble berms of at least 50 feet (top width).



SOURCE: TNC & ESA

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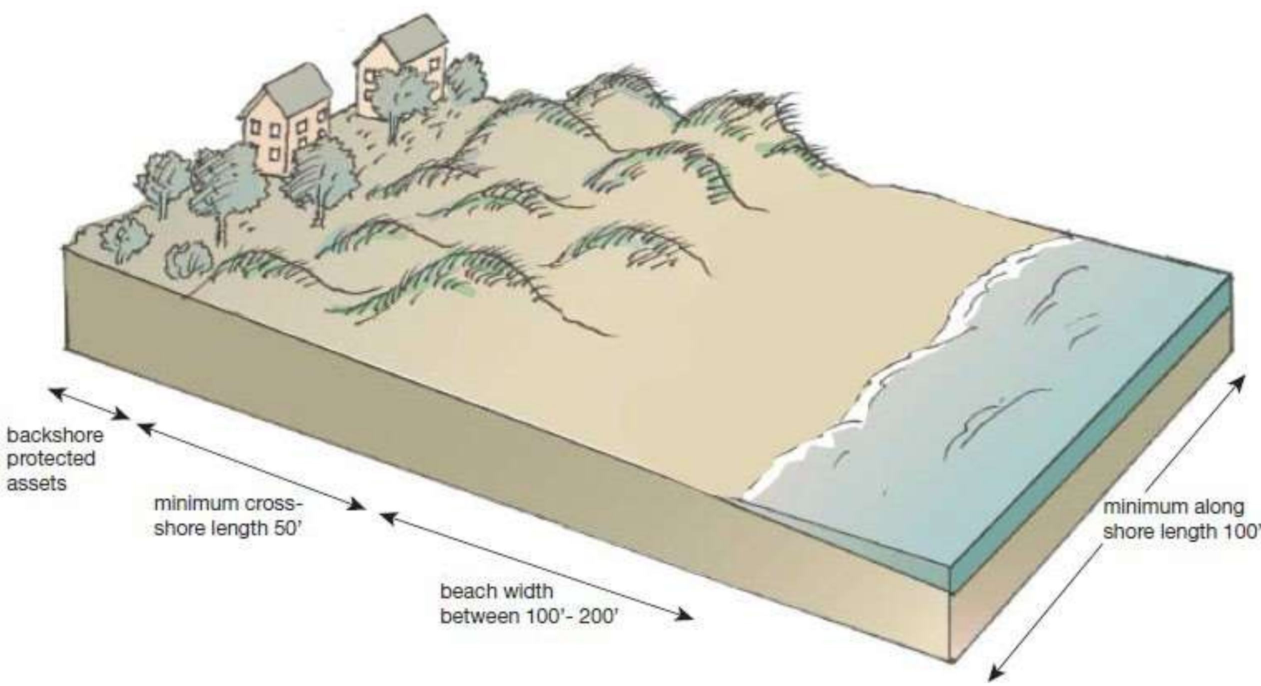
Figure 3
Conceptual dune cross section.
TWL refers to total water level which is the elevation of wave run-up that is seaward of stable dunes under typical conditions



SOURCE: TNC & ESA

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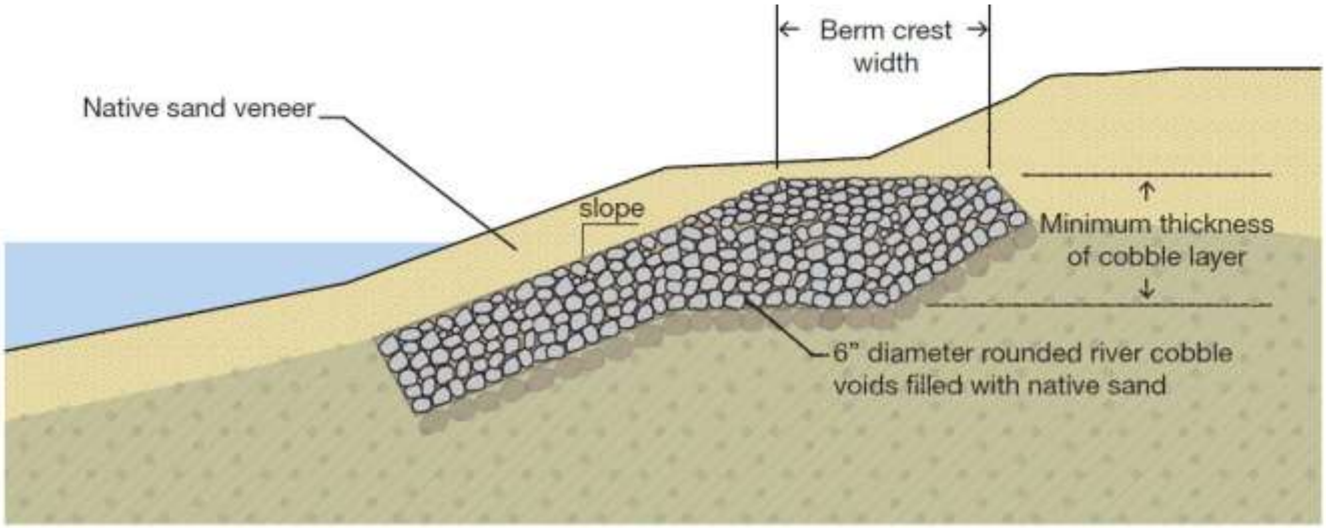
Figure 4
Oblique conceptual dune schematic showing the preferred location of development landward of beach-dune natural infrastructure that allows adequate space to support natural geomorphology that provides access and ecology benefits



SOURCE: TNC & ESA

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Figure 5
Conceptual cross section of a cobble berm located relative to ocean water levels and shore during typical conditions

2.2 Characteristic Dimensions of Natural Features at Reference Sites

As described in this study's Existing Conditions assessment (ESA 2020), reference sites provide important context for adaptation criteria and thresholds. Table 6 below lists typical shore dimensions at the four closest reference sites to the study area. Dunes at the Stinson NPS parking area, Limantour Beach and Doran Beach each indicate a stable dune form of approximately 100 feet wide and 10 to 15 feet above the fronting beach. Steep Ravine, located southeast of the Stinson Boulders, is a small cove with a cobble beach berm that is covered intermittently by a sandy beach. This local example indicates that wave action naturally builds up the cobble in this location to approximately 15 feet NAVD, based on available LiDAR data. This example cobble berm represents an upper limit of the design criteria for this study since this location is more exposed to wave action than the rest of Stinson Beach.

TABLE 6
REFERENCE SITE CHARACTERISTIC DIMENSIONS

Reference Site	Backshore Feature	Fronting Beach Elevation (feet NAVD)	Fronting Beach Width (feet)	Feature Width (feet)	Feature Elevation (feet NAVD)
Stinson NPS	Dune	10 to 12	250 to 260	80 to 100	20 to 25
Limantour	Dune	10 to 13	180 to 200	100 to 150	22 to 27
Doran	Dune	8 to 10	170 to 190	100 to 200	18 to 19
Steep Ravine	Cobble Berm	n/a	n/a	40	15 to 16 (crest)

Characteristic dimensions were determined from 1997, 1998, 2015, 2016 and 2018 LiDAR data.

In summary, reference sites indicate potential geometries for dunes and cobble berms, and associated sandy beach widths:

- Sand dune footprints of 80 to 120 feet with crest elevations of 18 to 27 feet;
- Beach widths fronting the dunes between 170 and 260 feet; and,
- Cobble berm top widths of about 40 feet.

2.3 Existing Beach Characteristics at Stinson Beach

Existing conditions and historic trends at Stinson Beach establish the baseline from which adaptation alternatives can be modeled and evaluated for feasibility (see Study Memorandum 1, ESA 2020). Beach dimensions indicate the amount of space that is available today to construct natural infrastructure. Observed shoreline changes, beach elevations and slopes can be used to estimate future beach widths and space available for natural infrastructure.

Table 7 summarizes beach characteristics from a beach profile selected to represent each of the five study reaches at Stinson Beach. The Reach characteristics were developed from historical data, field measurements taken in the October 2019 (presented in the Study Memorandum 1: Existing Conditions, ESA 2020), and a calculation of the beach migration due to sea-level rise based on the shoreface geometry (explained below). These characteristics help us to define the adaptation thresholds as described in Section 2.4. Figure 6 below shows the study reaches and analysis profile locations for reference.

SOURCE: ESA, Marin County 2018 Imagery, ESRI

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Figure 6
Stinson Beach Study Reaches and Analysis Profiles

TABLE 7
BEACH CHARACTERISTICS AT ANALYSIS PROFILE LOCATIONS

Profile Location	Distance from Beach to Development (feet)	October 2019 Beach Width (feet)	Average seasonal shoreline change envelope (feet)	Extreme winter shoreline change envelope (feet)	Winter beach width, minimum to average (feet)	Shore Face Slope (from depth of closure to backshore / dune crest)	Shoreline Recession Potential (feet recession per foot sea-level rise)	Beach sea-level rise capacity (winter beach width – shore recession potential) (feet sea-level rise)
Seadrift W	0 (60) [1]	103	76	85	18 to 27	0.016 to 0.3 [2]	32 to 64 [2]	0 to 1
Seadrift E	0 (100) [1]	214	118	140	74 to 96	0.029	35	2 to 3
Patios	90	250	71	151	99 to 179	0.035	29	3 to 6
Calles	0	235	51	158	77 to 184	0.032	31	2.5 to 6
NPS	250 [3]	264	43	136	128 to 221	0.036	27	4.5 to 8

[1] Distance to homes reported in parentheses; distance from beach to rock revetment is zero feet at both Seadrift profiles.
[2] Seadrift west shore profile intercepts the Bolinas lagoon ebb shoal.
[3] Distance to parking lot; distances from back of beach to NPS buildings are 50 to 80 feet

Distance from Beach to Development – The typical distance from the 2019 surveyed back of beach to landward development (shore armoring, homes/buildings, parking lot, or road). Distances reported in Table 6 are at the specific profile location; distances vary within each reach. This distance in combination with beach width provides the available space for natural infrastructure.

October 2019 Beach Width – The beach was surveyed in the fall when beaches are expected to be their widest at Stinson Beach. The October 2019 beach width was wider than typically observed based on a review of aerial photographs and shoreline data, and hence indicates an optimistic assessment of available space. Constructing natural infrastructure such as dunes and cobble berms requires space, and this requirement must be balanced by the need to maintain adequate beach widths to support recreation and ecology, as well as allowing sufficient beach width to dissipate waves and wave run-up. These existing beach widths inform our study by establishing the baseline from which to project and analyze the adaptation alternatives.

Trends in shore position change – Trends in shore change are typically computed as the average change in position over many years. Because the shore line position changes continuously in response to a range of variable drivers (tides, waves, sand supply), the average shore position change is an approximate calculation dependent on the time period over which the average is computed. As summarized in Table 7, the average changes computed were less than a foot per year since the 1920s while beach accretion (seaward movement of the shore) was computed since 1990. The overall shore change trend in the project area is considered to be small (between -0.1 to +0.2 feet per year) relative to natural variability and calculation uncertainty, and for practical purposes a zero long-term change rate is selected as a baseline for evaluation.

Average seasonal shoreline change envelope – Aside from long term trends in erosion or accretion, shoreline location fluctuates between its seaward-most position in the late summer/fall to its landward-most position in the late winter/spring. The average seasonal shoreline change envelope was computed from available shorelines collected for this study, for each reach at Stinson.

Extreme winter shoreline change envelope – Stinson Beach has experienced its share of extreme winters in the last few decades. The available shoreline data provide examples of the extreme shoreline change that occurred over the 1998-1999 and 2015-2016 El Nino winters. These shoreline erosion distances provide an indication of the potential cumulative effects of an extreme winter on the shoreline positions along Stinson Beach. Similar to the values in Table 6, extreme winter shoreline erosion of most of the dry beach occurred in the 1977-78 and 1982-83 El Nino winters, followed by construction of rock revetment shore protection along Seadrift (Ecker and Whelan 1984; Griggs and others 2005).

Winter Beach Width – The range of beach widths for existing conditions was calculated by subtracting the extreme and average beach widths from the October 2019 beach width. As noted above, the October 2019 beach is considered abnormally wide and hence the computed winter beach width is also considered abnormally wide. The result is a range of beach widths that can be expected in the winter-spring seasons, by Reach, each likely a maximum width. This beach width is an indication of exposure to backshore flooding and erosion damages: A wider winter beach provides greater protection to the back shore from waves, while a narrower beach is an indication of damage risk. This winter beach width is used to compute the sea-level rise capacity, discussed below.

Shore Face Slope – The Shore Face is defined schematically in Figures 1 and 2, and the overall slope of this zone of active wave-driven sand transport is used to estimate the shore response to sea-level rise. This slope characterizes the active shore profile that experiences the forces of the ocean. The shore face extends from the backshore/upland transition (edge of dune or development) out to the (depth beyond which the shore profile does not change appreciably year-to-year (closure depth)). The shore face slope is used in coastal engineering to estimate the landward shoreline recession potential due to sea-level rise (Bruun 1964), discussed below. Field data collected for this project and existing bathymetric (seafloor elevation) data were used in estimating the shoreface slope (see Study Memorandum 1: Existing Conditions, ESA 2020). Note that Seadrift West shore is adjacent to the ebb tidal shoal (sand bar formed by falling tides) of the Bolinas Lagoon mouth, resulting in a flatter profile slope relative to the other shore profiles. For the purposes of this study, a shore face slope of 30:1 (horizontal:vertical) is selected, indicating that the shore can be expected to migrate about 30 feet landward for each foot of sea-level rise, and rise vertically with sea-level rise. This shore migration calculation is approximate, is predicated upon assumed adequate sand supply and sufficient wave energy to keep up with sea-level rise, assumes that wave exposure and sand transport are steady, and neglects seawalls.

Shoreline Recession Potential (with sea-level rise) – An important factor in the feasibility of nature-based adaptation at Stinson Beach is the amount of sea level rise that the design infrastructure can cope with. Nature-based solutions require space to be effective, and sea level rise can have a significant impact on the shoreline location and beach width. As indicated in Table 7, as little as 2 feet of sea level rise could all but eliminate beaches at Seadrift West while beaches at other reaches may persist longer.

Beach Sea-level Rise Capacity – The approximate amount of sea-level rise that can be accommodated while still having a beach at Seadrift and Stinson is provided in the last column in Table 7. The amount of sea-level rise that will result in complete loss of the winter beach is computed by dividing the winter beach width by the shoreline recession potential. The Seadrift reach is the least sustainable with a capacity of between 0 and 3 feet of sea-level rise. The Patios and Calles reaches have a capacity of 2.5 to 6 feet, and the NPS reach has a capacity of 4.5 to 8 feet. Note that backshore damages by waves can occur well before the beaches completely disappear, and the capacity to accommodate sea-level rise is used here in the context of available space for natural. The existing dunes at the Patios and NPS reaches are neglected even though the additional sand supply would be expected to reduce the shore migration.

Prior C-SMART analysis indicated the Seadrift beach widths would be lost with about 3.3 feet of sea-level rise (1 meter) and the remainder of the Stinson beaches would be lost with about 6.6 feet of sea-level rise (2 meters), based on the OCOF scenarios (ESA 2015). The results presented in Table 7 are more detailed and rigorous but generally consistent with the prior beach vulnerability assessment.

2.4 Stinson Beach Nature-Based Adaptation Evaluation Criteria and Adaptation Thresholds

The nature-based adaptation alternatives are developed using criteria linked to beach morphology and the proximity of the developed backshore, for each study reach. Evaluation criteria for beach width, dune width, cobble berm width and wave run-up intensity are described below. When conditions violate the criteria, e.g. the beach width is less than the criterion value, the feasibility of the natural infrastructure type becomes uncertain. When future conditions result in a violation of criteria, a threshold for adaptive action is reached. Here, we develop criteria by reach for existing and future conditions in order to support formulation of alternatives, and to serve as a foundation for feasibility analysis of alternatives.

Criteria and thresholds proposed in this section are based on relevant guidance, reference sites, and the shore dynamics at Stinson Beach, as well as the sea-level rise scenarios presented above.

At this stage of the project, these criteria are focused on the sustainability of the natural infrastructure types under consideration, in order to formulate alternatives for subsequent analysis. The criteria presented here may be refined and additional design criteria and adaptive thresholds may be developed based on analysis of the alternatives and public engagement.

2.4.1 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 (see Section 1). The results of this feasibility study will include updated, site-specific sea-level rise thresholds for future adaptation at Stinson Beach based on the evaluation of criteria described below. 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 are needed to address flood impacts from Easkoot Creek and Bolinas Lagoon with sea-level rise (see community-wide sea-level rise thresholds summarized in Section 2.1).

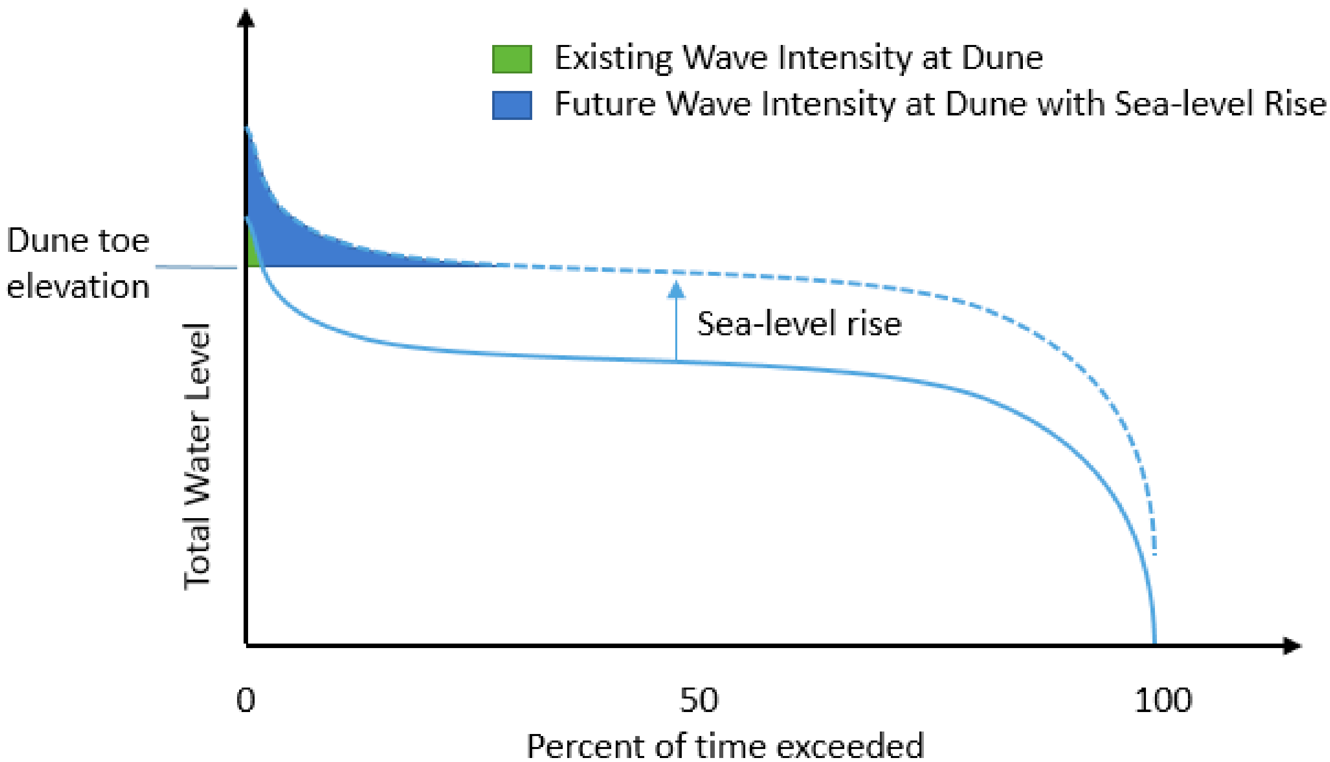
2.4.2 Wave Run-up Intensity

Wave run-up intensity are used to evaluate the performance of dune and cobble adaptation measures at Stinson Beach and establish thresholds for maintenance and further adaptation actions. While wave run-up and associated onshore sand transport are constructive processes that formed the Stinson shore, extreme wave run-up is the driver of flooding and erosion risk to backshore development that will increase with sea-level rise.

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 the backshore. For the adaptation alternatives evaluation, wave run-up elevation and extent that is exceeded several times per year are used as an indicator of the seaward limit of the feature, and wave run-up intensity for the 20-year storm are used to assess dune erosion potential and protection of the backshore. Potential wave run-up intensity for the 100-year storm is analyzed but it will not inform the maintenance scheduling of nature-based adaptation alternatives in this study.

One way to evaluate the intensity of wave run-up is to identify the extent and frequency of wave run-up reaching a particular location such as a dune or development. The intensity of wave run-up can then be quantified as the extent that it crosses a point defined relative to the sea in horizontal distance and elevation. This concept was developed for the California Coastal Resilience projects as conceptually depicted in Figure 7 to predict erosion of dunes, bluffs and beyond coastal structures, as well as to predict run-up overtopping of natural and man-made barriers and associated inland flooding. The cumulative distribution of total water level (TWL = ocean level plus wave run-up) at a particular shore location is computed, showing the percent time that the TWL exceeds an elevation on the shore (e.g. dune toe elevation). The area of the cumulative TWL curve above the elevation is defined as the intensity of wave run-up at the selected location. This intensity can be converted to volume of water overtopping the barrier, momentum-force loadings on structures, as well as an indicator of backshore dune erosion.

Based on published guidelines (TNC and others 2018), the future location and elevation of the back beach (at the toe of the dunes) can be preliminarily projected based on total water levels that are exceeded only about 10 to 20 days per year, or exceeded about 4% of the time (conceptual diagram shown in Figure 7). Cobble berm crests are overtopped more frequently while also lowering wave run-up due to greater dissipation, and their crest elevations for active cobble-gravel berms (storm berms are higher) can be preliminary projected at an elevation of about 80% of that for a dune toe (TNC and others 2018). In order to check these general guidelines, we computed wave run-up at Stinson Beach and compared the run-up elevations to the existing dune toe elevations at the NPS Reach. Computed wave run-up at Stinson (see Study Memorandum 1: Existing Conditions, ESA 2020) for estimated winter conditions indicates the 4% exceedance is a reasonable approximation, yielding elevations ranging from 11.4 feet NAVD at NPS to 13.9 feet NAVD at Seadrift West and comparing favorably to the existing dune toe elevations at the NPS Reach (~11 feet NAVD in winter 2018, 12.4 feet NAVD in fall 2019). A preliminary estimate for cobble berm crest elevation corresponding to 80% TWL exceedance is around 6-8 feet NAVD along the study area. Pending selection of alternatives by reach and more detailed analysis of the alternatives, the Implementation Criteria and Adaptive Thresholds for dune and cobble-gravel berms are summarized in Table 8.



SOURCE: ESA

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Figure 7
Concept of wave run-up intensity at a dune as cumulative distribution of total water level

TABLE 8
PROPOSED DUNE TOE, DUNE CREST AND COBBLE-GRAVEL BERM CREST ELEVATIONS / THRESHOLDS FOR STINSON BEACH NATURE-BASED ADAPTATION

	Selected for Implementation (feet)			Threshold for Adaptive Action (feet)		
Study Reach	**Dune Toe Elev.**	**Dune Crest Elev.** [1]	**Cobble-Gravel Berm Crest** [2]	**Dune Toe Elev.**	**Dune Crest Elev.** [3]	**Cobble-Gravel Berm Crest** [2]
Seadrift E	10	15 to 20	8 to 10	13	n/a	7
Patios	10	15 to 20	8 to 10	12	n/a	7
Calles	10	15 to 20	8 to 10	12	n/a	6
NPS	10	15 to 20	8 to 10	11	n/a	6

1. Dune crest elevation range for fore dunes (lower elevations) and barrier dunes (higher elevation)
2. Cobble-gravel berm crest elevation can range between these approximate values.
3. Dune crest elevation threshold to be determined

2.4.3 Beach Thresholds

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, dune toe 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 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 hydrodynamic loading on coastal armoring structures. Wider beaches also provide increased recreational and ecological values. More generally, beaches are an important component of the coastal morphology at Stinson Beach.

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 is 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). As indicated in Table 7 above, average 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.

Existing reports and observations provide a basis for design dimensions for beaches at Stinson:

- C-SMART risk analysis described in Section 2.1 indicates a **target minimum fall beach width of 130 feet,** computed by adding the maintenance threshold width (80 feet) *plus* an excess beach width to result in low risk from severe events (50 feet).
- The California natural infrastructure guidelines suggest a minimum fronting beach width of 100 feet for nature-based adaptation measures such as dunes and cobble berms.
- Reference Sites at Stinson (NPS Reach), Limantour and Doran beaches have beaches ranging from 170 to 260 feet wide.
- Observations from the 1998 and 2016 El Ninos indicate potential shoreline storm erosion up to 220 feet.

Criteria for beach widths in each study reach are provided in Table 9 below and based on typical seasonal and extreme El Nino winter shoreline changes. The beach width considers two distances: the average seasonal shoreline change envelope plus 50 feet OR the observed extreme El Nino winter shoreline change. Beach width is modeled according to the climate scenarios described in Section 1 to determine maintenance needs and feasibility of each adaptation alternative. The proposed criteria in are used to formulate alternatives and may be refined during subsequent evaluation of alternatives.

TABLE 9
BEACH WIDTH CRITERIA / THRESHOLDS FOR STINSON BEACH NATURE-BASED ADAPTATION ANALYSIS

Study Reach	Minimum Beach Width for Implementation (feet)	Beach Width Threshold for Action, (feet)
Seadrift E	130	170
Patios	130	160
Calles	130	150
NPS	130	140

2.4.4 Dune Thresholds

Dunes provide a natural buffer to flooding and erosion landward of beaches. Dunes naturally erode 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 reconstruction. In any case, the dune width would be 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. To maximize protection of backshore development against coastal erosion and wave run-up, maintenance or reconstruction is needed once the dune erodes past the design storm erosion distance. Additional protection could be provided by increasing the height of the dunes or implementing other adaptation measures such as a cobble berm core or other traditional armoring at the landward side of the dunes.

Prior studies and observed conditions at reference sites provide examples of design dimensions for dune features:

- C-SMART adaptation analysis considered a linear dune 13 feet tall (above the beach) and 50 feet wide.
- The California Natural Infrastructure Guidelines suggests a minimum footprint width for dunes to be on the order of 50 feet.
- Reference Sites at Stinson (NPS Reach), Limantour and Doran beaches have dunes ranging from 80 to 150 feet wide.
- Observations from the 1977-78 winter indicate up to 90 feet of dune erosion occurred along Seadrift (Griggs et al. 2005)

Adaptation threshold distances for dunes in each study reach are provided in Table 10 below. The thresholds are based on the potential erosion distance associated with the 20-year storm. Constructed dune dimensions are determined for each Stinson Beach reach based on available space, type of dune, and wave run-up intensity and extents. These minimum thresholds are used to determine timing of additional maintenance of constructed dunes and may be refined during the alternatives evaluation analysis.

TABLE 10
DUNE WIDTH THRESHOLDS FOR STINSON BEACH NATURE-BASED ADAPTATION ANALYSIS

Study Reach	Dune Width Minimum Desired for Implementation (feet)	Dune Width Threshold for Action (feet)
Seadrift E	100	50
Patios	100	55
Calles	100	60
NPS	100	65

2.4.5 Cobble Berm Thresholds

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. This threshold berm width may correspond to the potential erosion of a design storm event (e.g. 100-year wave event). For adaptation alternatives in which a cobble berm is buried and or behind vegetated dunes, this threshold would only be met once the fronting beach and dunes erode. The following berm widths are summarized from existing studies and data from a reference site adjacent to Stinson:

- C-SMART analysis selected a cobble berm with a width of 50 feet seaward of dunes.
- The California Natural Infrastructure Guidelines suggests a minimum top width of 50 feet with a crest elevation based on wave run-up that is close to but lower than that for sandy beaches without cobble, and a base width of at least 80 feet.
- An assessment of Steep Ravine indicates a dynamic cobble berm top width of about 40 feet has persisted in this cove adjacent to Stinson Beach.

These dimensions are used to assess whether there is adequate space for cobble based on existing conditions, and minimums are used for maintenance triggers or potential failure, and are hence thresholds for adaptive action. The design cobble berm geometry is determined based on available space and wave run-up exposure.

Preliminary adaptation threshold distances for dunes in each study reach are provided in Table 11 below. Constructed cobble berm dimensions are determined for each Stinson Beach reach based on available space, type of dune, and wave run-up extents, with these minimum thresholds used as triggers for adaptation on such constructed dunes.

TABLE 11
COBBLE BERM WIDTH THRESHOLDS FOR STINSON BEACH NATURE-BASED ADAPTATION ANALYSIS

Study Reach	Cobble Berm Width Minimum Desired for Implementation (feet)	Cobble Berm Width Threshold for Action (feet)
All Reaches	50 top, 80 base	30

3. Summary

Climate Scenarios used in this study (Table 3) are selected based on the prior C-SMART study and the most recent sea-level rise guidance from the State of California.

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 to marginal beach space available.

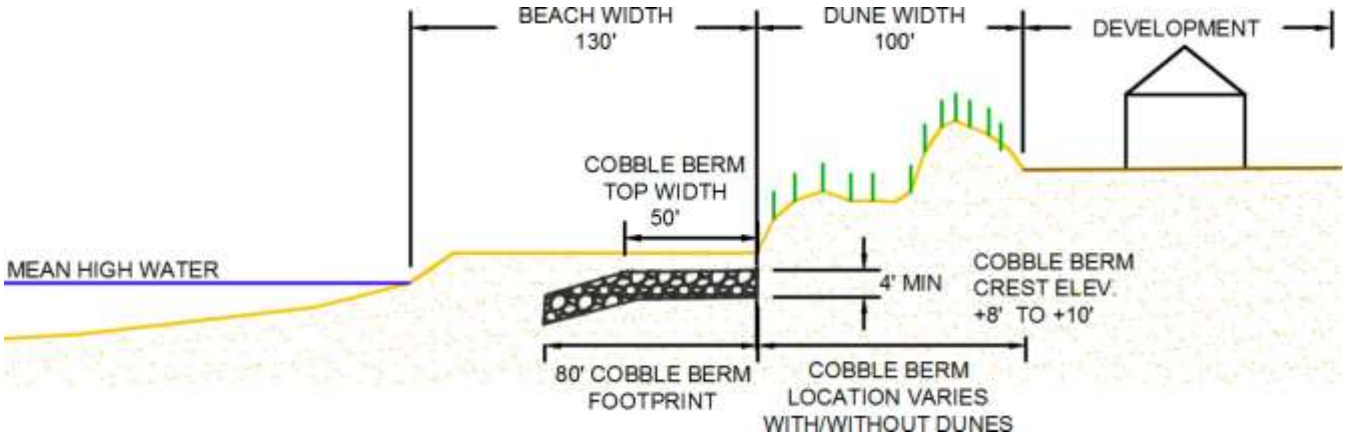
The October 2019 beach widths vary from about 100 feet to 260 feet, with development located between 0 and 250 feet landward of the back of the beach. In general, Seadrift West has the least beach width and distance to development, the Calles reach is next in terms of development setback distance, followed by the Patios reach. The NPS reach has the greatest development setback distance.

Beach widths in Seadrift are expected to narrow to essentially zero with less than 3 feet of sea level rise, with Seadrift West particularly vulnerable owing to the existing narrow beach. The Patios and Calles beaches are wide enough to persist longer, and accommodate 3 to 6 feet of sea-level rise. The NPS reach is the widest and is expected have some beach remaining with sea-levels 4.5 to 8 feet higher than now. These values are updated using recently-collected data but are similar to values reported in C-SMART (Section 2.1). In order to maintain beaches and natural infrastructure for the purpose of recreation, ecological function and hazard reduction, thresholds are established in Table 12 below.

TABLE 12
SUMMARY OF PROPOSED THRESHOLDS FOR STINSON BEACH NATURE-BASED ADAPTATION

Study Reach	Beach Width Threshold for Adaptation Action (including other natural infrastructure feet)	Dune Width Threshold for Action (feet)	Cobble Berm Width Threshold for Action (feet)
Seadrift E	170	50	30
Patios	160	55	30
Calles	150	60	30
NPS	140	65	30

The minimum desired dimensions for implementation of natural infrastructure types are provided schematically in Figure 8. These dimensions are used to select alternatives by reach.



SOURCE: ESA 2020

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

Study Memorandum 3 details the design and maintenance scheduling of natural infrastructure alternatives for each Stinson Beach study reach. The alternatives are informed by consideration of desired space (based on guidelines, reference sites and informed by Stinson shore dynamics summarized above) and the available distance between development and the shore. The alternatives are evaluated with respect to potential erosion and wave run-up for existing and future conditions with sea-level rise. Wave run-up and total water level (TWL) are computed with future sea-level rise and used to assess the function of natural infrastructure alternatives. Ultimately, benefits and relative costs of each nature-based alternative are evaluated relative to a traditional armoring approach.

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Chapter 4
Adaptation Alternatives

This chapter describes the development and evaluation of adaptation alternatives for the Stinson Beach Nature-Based Adaptation Feasibility Study (study). The alternatives development builds upon prior work describing existing conditions, climate scenarios and adaptation thresholds. The process for developing and selecting adaptation alternatives is documented, followed by a description of evaluation methods and results.. This chapter is divided into the following sections:.

1. Introduction
2. Description of Nature-Based Infrastructure Types
3. Suitability of Nature-based Infrastructure at Stinson Beach
4. Adaptation Alternatives Development
5. Adaptation Alternatives Cross Section and Planview Detail
6. Adaptation Alternatives Evaluation
7. Long-term Adaptation Pathways for Stinson Beach
8. References

1. Introduction

The nature-based adaptation alternatives proposed for Stinson Beach build upon the adaptation strategies presented in the C-SMART Adaptation Report (Marin County 2018). A range of near-term adaptation alternatives were developed in this study based on existing conditions along the shoreline, seasonal shoreline changes and potential storm impacts (see Chapter 3 and Study Memorandum 1, ESA 2020a). Long-term adaptation pathways consistent with the near-term alternatives analyzed in this study are also discussed to facilitate integrated adaptation planning for the greater Stinson-Seadrift community. The following nature-based infrastructure types were considered for application:

1. **Foredunes** – natural Pacific Coast sand dune geometry with native perennial vegetation and low-relief hummocks, typically found on the landward side of a beach, and sometimes fronting larger mature dunes.
2. **Foredunes and cobble-gravel berm** – foredunes with buried cobble-gravel berm for erosion protection.
3. **Dune embankment** – linear sand embankment that is landscaped to form a protective barrier to wave run-up and erosion during extreme events. A dune embankment is a compressed (narrower footprint) version of mature dunes that are often in the form a wide “dune field”. Dune embankments are taller and narrower than foredunes and can be widened or combined with foredunes, if space allows.
4. **Dune with cobble-gravel berm** – a dune embankment with a buried cobble-gravel berm for increased erosion protection.
5. **Cobble-gravel berm** – buried cobble-gravel (c-g) berm without dune cover. The c-g berm is a mass of rounded rock in a layer placed in the upper tide range just below dry beach elevations, seasonally buried by sand and exposed during high surf conditions. The c-g berm is also called a “dynamic revetment” because it provides flood and erosion protection to landward areas, but is more malleable than traditionally engineered rock revetments during elevated wave breaking and runup. 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. This variant applies to all the nature-based

infrastructure types that include a cobble-gravel berm, but is included primarily to accommodate drainages from inland, such as Easkoot Creek flood flows at the Stinson Beach National Park facility.

Two adaptation alternatives are proposed for analysis for four of the five reaches – Seadrift East, Patios, Calles, and NPS. Based on the existing narrow beaches and existing armoring along the western Seadrift Reach and proximity to the Bolinas Lagoon mouth, only one alternative was analyzed (cobble berm). See Figure 22 and Figure 23 that show plan view schematics of nature-based adaptation alternatives 1 and 2.

The five nature-based infrastructure types are described in Chapter 2. Chapter 3 describes which nature-based infrastructure types are suitable by reach, based on the existing conditions. The full range of natural infrastructure types are screened and the adaptation alternatives selected in Chapter 4. Chapter 5 presents diagrams of the adaptation alternatives by reach. Chapter 6 documents the evaluation of adaptation alternatives. Long-term potential adaptation pathways comprised of additional adaptation strategies are described in general terms in Chapter 7: these strategies include sand placement to widen beaches (beach nourishment), shore armoring, raising buildings on piles, and other actions that accommodate or retreat landward/upward. Chapter 8 presents our salient conclusions of the evaluation and next steps toward implementing natural infrastructure at Stinson Beach.

2. Description of Nature-Based Infrastructure Types

Nature-based shore infrastructure for adaptation -- sometimes referred to as natural infrastructure, natural adaptation measures, and living shorelines -- refers to using natural physical features to mitigate coastal hazards. The following definition was recently developed as part of California's Fourth Climate Assessment (Newkirk and others 2018) which also includes descriptions of various nature-based shore infrastructure projects:

"For the purposes of this study, 'natural shoreline infrastructure for adaptation' means using natural ecological systems or processes to reduce vulnerability to climate change related hazards while increasing the long-term adaptive capacity of coastal areas by perpetuating or restoring ecosystem services."

Examples of nature-based shore infrastructure are provided in terms of Case Studies in a related report (Judge and others 2018), and descriptions of nature-based and other adaptation measures are provided in the C-SMART Adaptation Report (Marin County 2018), including Appendix B (ESA 2016). Shore infrastructure types applicable to this study are summarized below along with natural and built examples in California.

2.1. Foredunes

Foredunes are low-relief landforms resulting from the interaction of onshore wind-blown sand transport and native plants. The dunes are not barriers but rather dissipate wave run-up gradually, while being resilient. Figure 1 shows the restored foredunes at Surfers Point, Ventura CA. An example of a more natural dune system that also provides flood and erosion protection can be found at Pacifica State Beach in the Linda Mar District of Pacifica (Figure 2). It consists of a young dune field and foredunes, seaward of road embankment and ditch where space is limited by Highway One. Figure 3 is a photograph of a naturally formed foredune providing significant flood protection, where European beachgrass was removed, and the dune was revegetated with native Northern California dune plants, located between the ocean and Humboldt Bay, California (Judge and others 2017). Figure 4 shows foredunes established at the NPS reach. These types of dunes can be established within a few years following minor earthwork and native plantings, and vegetation maintenance. The dune field dissipates wave run-up via roughness and porosity over the relatively flat zone with limited scour. Sand deposition can occur with wave run-up as well as wind-blown transport.

SOURCE: Louis White

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Figure 1
Foredunes at Surfers Point, Ventura, CA (Judge and others 2017)

SOURCE: City of Pacifica (top); Peter Baye (bottom)

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Figure 2
Dunes at Pacifica State Beach, Linda Mar, Pacifica, CA.

SOURCE: Andrea Pickart

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Figure 3
Seaward edge of restored and revegetated young foredunes, Humboldt Dunes (Judge and others 2017)

SOURCE: Peter Baye Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 4
Foredunes at NPS Stinson Beach

2.2. Dune Embankment

A dune embankment is an engineered version of a natural mature dune, compressed into a contiguous linear embankment, acting as an erodible levee or dike. Dune embankments are sometimes referred to as linear dunes and sand embankments. An example is found at Ocean Beach, San Francisco (Figure 5) and at the NPS reach of Stinson Beach (Figure 6). Note that the vegetation and dune geometry of dune embankments are typically not native to this area, but provide a pleasant natural appearance. However, native plants could be incorporated into dune embankment designs. Twentieth century dune stabilization along the entire Pacific Coast was based on the planting and subsequent natural spread (invasion) of the European marram or beachgrass, which has sand-trapping and binding capacity that far exceeds all native Pacific Coast dune plant species. Marram's stiff, erect, dense, tall broom-like vegetation builds steep, high foredunes where rates of onshore wind transport of sand are sufficient. In comparison, native dune grasses such as beach wildrye build gentler foredune slopes because of their inherently more open, spreading growth habit.

The dune embankment is a barrier to wave run-up and overtopping when intact. During extreme conditions, waves erode the dune and the eroded sand migrates to the beach and surf zone, conceptually dissipating the wave power and reducing the landward extent of the erosion event. Reconstruction is required after erosion. Planting is required to maintain the dune shape and limit wind-blown transport landward. Controlled access across the dune is recommended to maintain vegetation where the embankment crosses heavily used lateral access points (Calles, NPS reaches).

Where there isn't much beach width available to implement natural infrastructure, dune embankments are sometimes placed within the available space on a shore such as on exposed cobble berms or over rock revetments. A local example of a smaller sand embankment is Seadrift (Figure 7) where a rock revetment was constructed and then buried with beach sand in the 1980s. Some of the rock revetment is still buried under vegetated foredunes in the center of the Seadrift reach (which is the widest beach in Seadrift reach), while other areas are exposed but protect the remaining foredunes landward of the structure. Another example is at South Ocean Beach, San Francisco where a sand embankment is placed every 1 to 3 years to mitigate bluff and beach erosion in critical areas (Figure 8). These "dunes" are temporary and presumed to have little ecological value. Where space is available, dune embankments may be combined with foredunes to more closely resemble a natural dune field.

SOURCE: : SPUR 2012

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 5
Dune Embankment at Ocean Beach, San Francisco, CA

SOURCE: Bob Battalio Aug 2018

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 6
Dunes at National Park Service Beach
Stinson Beach, CA

SOURCE: James Jackson 2019 Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 7
Seadrift dune embankment covering rock revetment (left) and eroded with rock exposed (right) Seadrift, CA

SOURCE: Louis White Dec 2016 Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 8
Sacrificial sand embankment, South Ocean Beach, San Francisco, CA

2.3. Foredunes and Dune Embankments with Cobble-Gravel Berms

Dunes behind cobble-gravel berms are typically found near river mouths and other sources of coarse sediment in California. In a nature-based infrastructure context, constructed cobble-gravel berms can be combined with foredunes and dune embankments to provide a more resilient, erosion-resistant shore form. The cobble-gravel berm may be buried by the dune feature for most of the year, but exposed seasonally following large wave events.

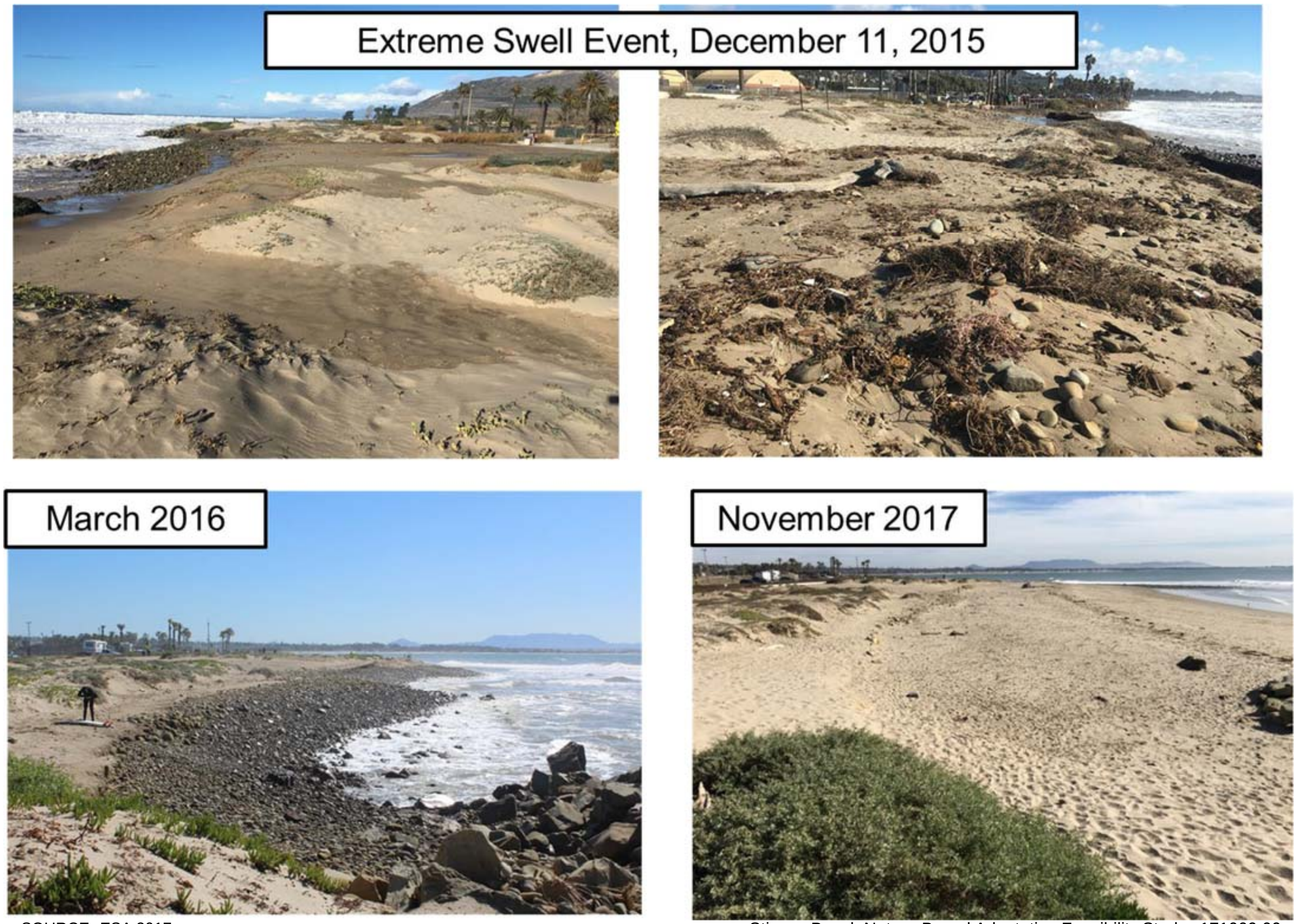
Natural cobble-gravel berms are typically below a sandy beach with sufficient dry sand to feed dune growth via wind, augmented by vegetation trapping and growth. Where there is adequate sand supply, the cobble is typically covered by sand, but exposed during extreme high wave events in the winter season. Where the shore is eroding, the cobble may be exposed at all times. The cobble and gravel tend to be moved onshore by waves and hence the exposed cobble-gravel berms slow but do not stop shore migration. The outcome of this process of migrating shore is depicted in Figure 9 at Emma Wood State Beach in Ventura, CA, near the Ventura River Mouth.

SOURCE: Bob Battalio early 2000s

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 9
Emma Wood State Park. Migrating cobble berm backed by vegetation and fronted by sand. The trees on the beach were behind the cobble berm and beach prior to the shore migrating landward.

Figure 10 shows the extent of wave run-up at the Surfers Point dunes during an extreme swell event that caused damages in other parts of Ventura but did not damage the dunes or adjacent backshore. The cobble and dunes dissipated the large wave run-up. The sand beach was eroded, exposing the cobble berm. The sand beach recovered the following summer. Note that the dunes are located landward of the cobble berm face, and are protected by the cobble berm. As shown in Figure 10, the foredunes were flooded slightly but remained intact over the extreme 2015-2016 El Nino.



SOURCE: ESA 2017

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Figure 10
Post event performance and recovery of cobble and dune shore in Ventura, CA

2.4. Cobble-Gravel Berm

Cobble-gravel berms refer to coastal sediment deposits that are coarser (larger particle diameter) than sand, and can include sizes ranging from gravel to boulder. Cobble berms are most prevalent at river and creek mouths but also form at the base of cliffs, whether as lag deposits buried under sandy beaches (only exposed seasonally and/or during storms) or as higher, well developed berms that extend to higher levels of wave run-up. Cobble-gravel berms and lag deposits are essentially natural rock revetments, sometimes referred to as "dynamic revetments" in the coastal engineering literature because the rocks move in response to waves and wave run-up. Rock movement results from the smaller, more rounded rocks, as compared to the rocks used in traditionally designed rock revetment shore armoring, which consist of larger, "rough, angular" stone generated at rock quarries which tend to "lock together" with a small foot print if placed carefully. The cobble-gravel berms tend to have flatter slopes and a larger footprint than traditional rock revetments, which increases dissipation of waves and wave run-up with less wave reflection and scour. These characteristics facilitate sandy beach recovery. The cobble-gravel deposits are also easier to traverse and likely provide better ecology than traditional shore armor.

These coarser sediments tend to move onshore if mobilized by waves due to the asymmetric power of waves coming to shore versus receding back to sea. Coarse sediment movement on the shore is greatest when waves accelerate onshore during run-up; coarse sediment movement is lower when waves recede (down-rush) via infiltration of run-up water into the porous sediment mass and steep angle of repose of the larger particles (stability of the piled berm) (Everts and others 2002). In other words, the waves expend most energy as they run-up on the shore and move large sediments, some of the water seeps into the berm while the rest flows back to sea, leaving most of the coarse sediment in place as a berm. The crest of the cobble-gravel berm is, like sandy beaches, related to wave run-up elevations (Lorang 2002).

If the coarse sediment supply is not sufficient to form a large enough mass or is too large for the waves to move inland and upslope, the sediment will accumulate in a lower, thinner deposit called a "lag deposit". Cobble-boulder-gravel lag deposits are typically found at the base of coastal bluffs where coarse material accumulates on wave-cut shore platforms and is buried by sand much of the time, but exposed during extreme winters. A local example cobble berm exists east of Stinson in the cove below Steep Ravine. Examples of cobble-gravel berms and lag deposits elsewhere in California are shown in Figure 11 and Figure 12.

(right)
Cobble Berm, Goleta, Santa Barbara County, CA. March 8, 2017. Note deposition of wrack on berm crest, indicating extent of wave runup and physical process supporting ecological function. Source: Surfrider Foundation.

(left)
Cobble berm at Prisoner's Harbor, Santa Cruz Island, CA. Photograph by Jenny Dugan.

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Figure 11
Cobble-Gravel berms in California

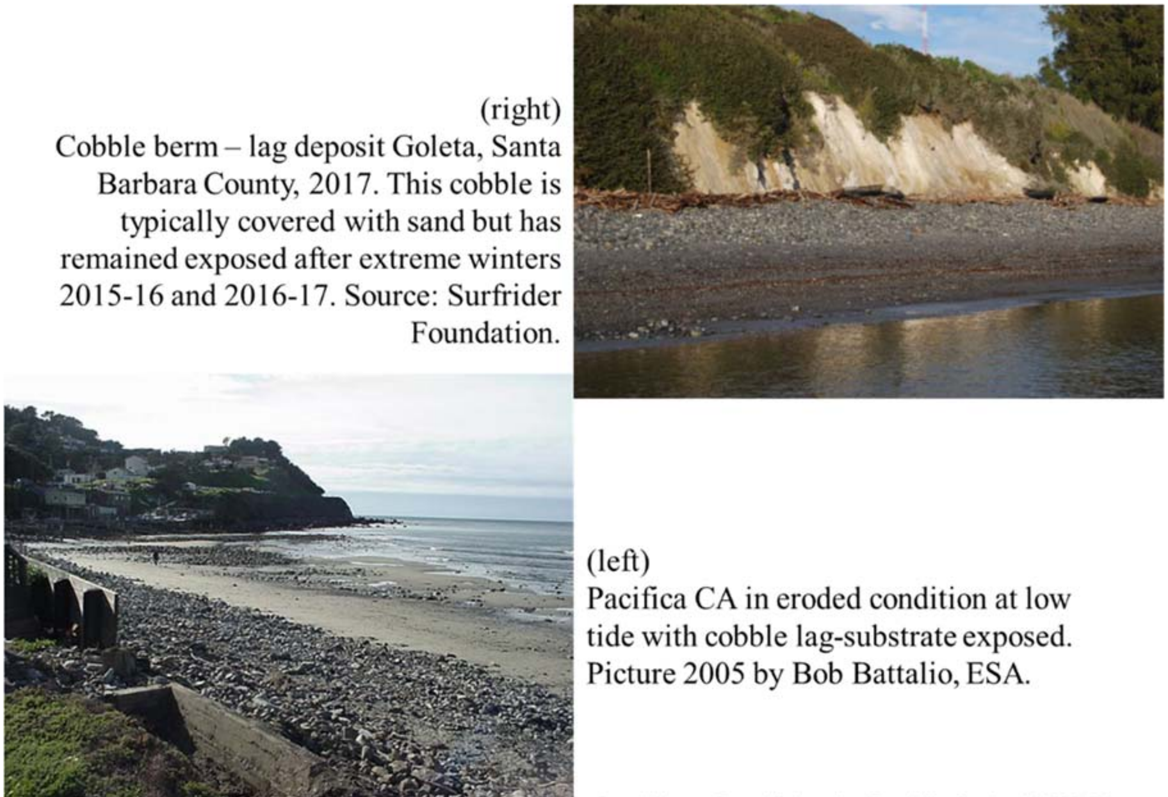

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Figure 12
Cobble / gravel / boulder lag deposits

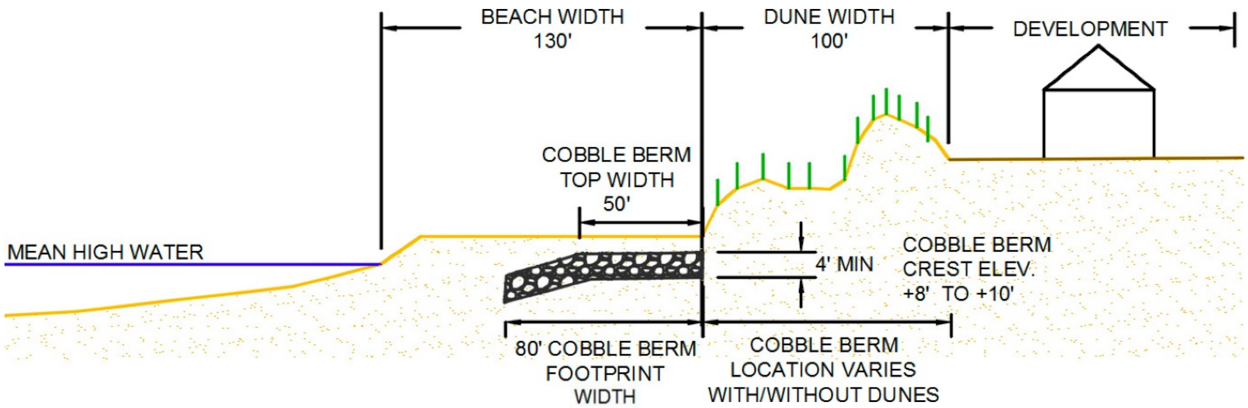
3. Suitability of Nature-based Infrastructure at Stinson Beach

ESA developed an initial range of nature-based infrastructure types that could be implemented at each study reach. General suitability of different types is based on a comparison of desired space for natural infrastructure function and the available space along Stinson Beach defined as the distance seaward of existing development to the shoreline. The desired and available space metric is generically called “shore width” that includes beaches and existing dunes where present. The shore widths available by reach (Section 3.2) are based on historic and existing conditions described in Study Memorandum 1 (ESA 2020a) and the minimum desired shore widths for nature-based infrastructure types are summarized in Section 3.1 and further described in Study Memorandum 2 (ESA 2020b). Section 3.3 discusses the suitability of different natural infrastructure types in each reach.

3.1. Minimum Natural Infrastructure Width Requirements

The desired cross-shore width dimensions for beaches, dunes and cobble-gravel berms were previously developed based on a review of site conditions, reference sites and natural infrastructure guidelines (Study Memorandum 1, ESA 2020a). These dimensions are shown schematically in Figure 13. These dimensions are desired minimums to result in morphologic and ecologic functions, and are provided for screening of alternatives as well as providing an indication of the benefit of development setbacks to increase available space and performance of nature-based approaches.

Given the limited space available in the study area, minimum dimensions somewhat less than the desired dimensions are considered for this study. The minimum space requirements for each nature-based infrastructure type were determined from the C-SMART analysis and Natural Infrastructure Guidelines (TNC and others 2018) and compared to the existing space available along the shoreline (see Existing Conditions, ESA 2020a). The minimum dune width is 50 feet (foredune and dune embankment features). The minimum top width for cobble berm is 50 feet, while the minimum overall cobble berm footprint is 80 feet including the seaward sloping face. The minimum beach width is 100 feet from either the 50 feet of dunes or the 50 feet of cobble-gravel berm top width.



SOURCE: ESA 2020

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Figure 13
Conceptual Desired Dimensions for Natural Infrastructure Elements at Stinson Beach

3.2. Available Shore Width by Reach

Minimum feature widths for dunes, cobble-gravel berms and optimum fronting beach widths are superimposed on aerial photographs of the study area in Figure 14 and Figure 15. Minimum feature widths are measured from the "back of beach" red line, which represents the current transition of the beach to upland features or structures such as dune toe (back of dune), coastal armor or homes. The blue lines represent the location of the mean high water (MHW) shoreline surveyed in October 2019 (light blue) and the same shoreline extracted from January 2019 County LiDAR. The area between the "back of beach" and the MHW shoreline is considered the space available for nature-based infrastructure. A "development line" is added where built assets are landward of the "back of beach" line used to locate the alternatives. Development includes the Seadrift rock revetment (some of which is buried behind foredunes), homes in the Patios and Calles reaches, and buildings/parking lots in the NPS reach. These lines are approximate and schematic but adequate for the purposes of this alternatives screening analysis. Note that the October 2019 beach was abnormally wide compared to recent aerial imagery and shoreline data, and represents the maximum available space under existing conditions. The January 2019 beach is representative of a recent minimum for the study area based on collected shorelines.

Available beach width by reach based on recent survey data and LiDAR

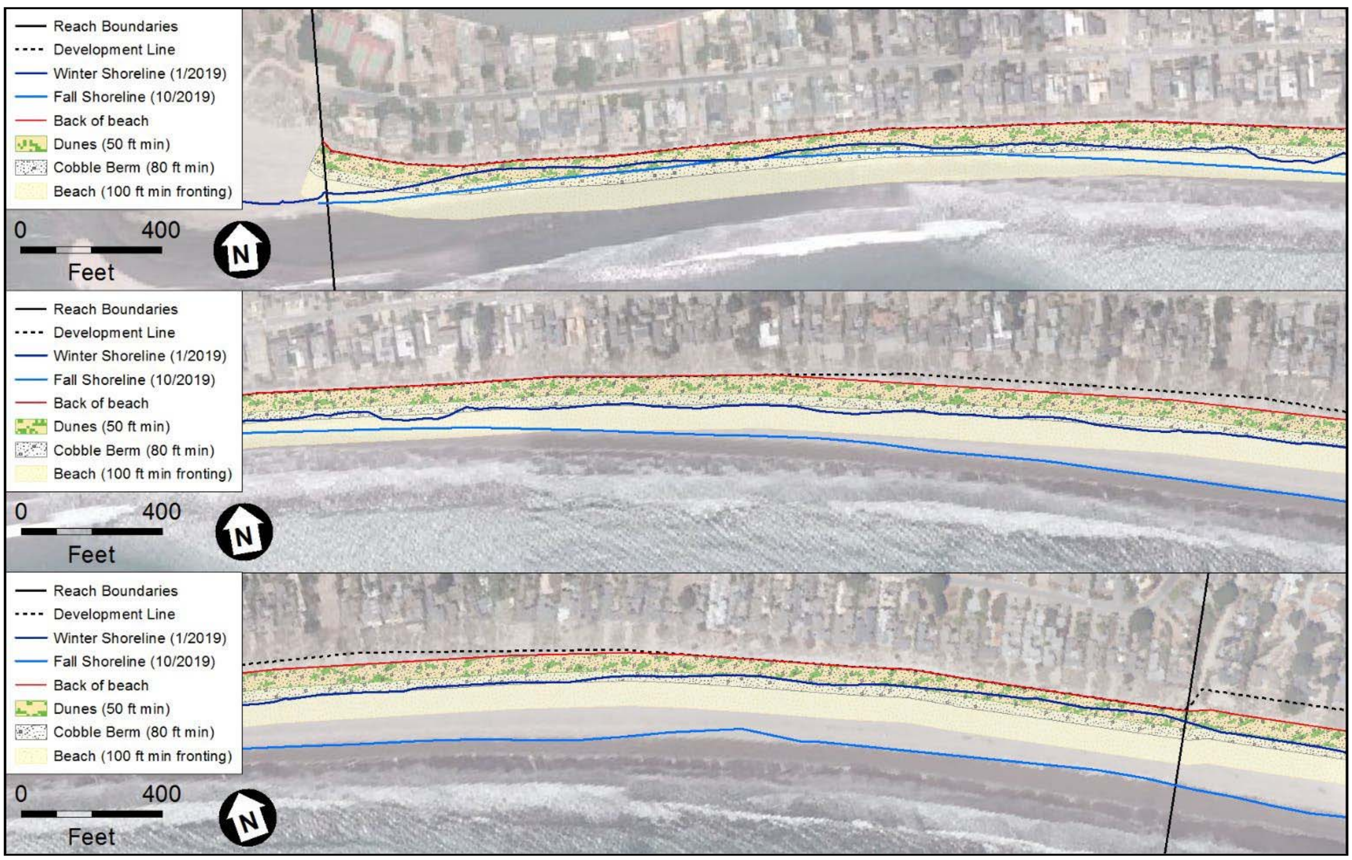
- Seadrift (Figure 14) is discussed as two reaches due to the varying beach width alongshore. Western Seadrift does not have adequate space for nature-based infrastructure given the relatively narrow beach and the existing shore armor (rock revetment) which is covered by vegetated sand in some locations.

Seadrift East has a wider beach adequate to meet the minimum dimensions of nature-based infrastructure. Note that the back of beach is located at the exposed rock revetment along most of Seadrift except in the center of the reach where the revetment is buried by foredunes.

- The Patios reach (Figure 15 top) has 50 to 100 feet of unarmored dunes fronting the development, which can be considered as available dune space when evaluating alternatives.

- The Calles reach (Figure 15 middle) has small dunes intermixed with development along the shoreward edge. A straight line connecting the most seaward development is used as the back of beach in order to determine available space. Small pockets exist between the most seaward homes that provide additional space for natural infrastructure. By removing the seaward-most homes, wider continuous natural infrastructure could be built.

- The NPS reach (Figure 15 bottom) has larger dunes present and the back of beach here is located at the dune toe (the dune face is bare and looks like beach sand in the aerial imagery).



SOURCE: ESA, Marin County 2018 Imagery

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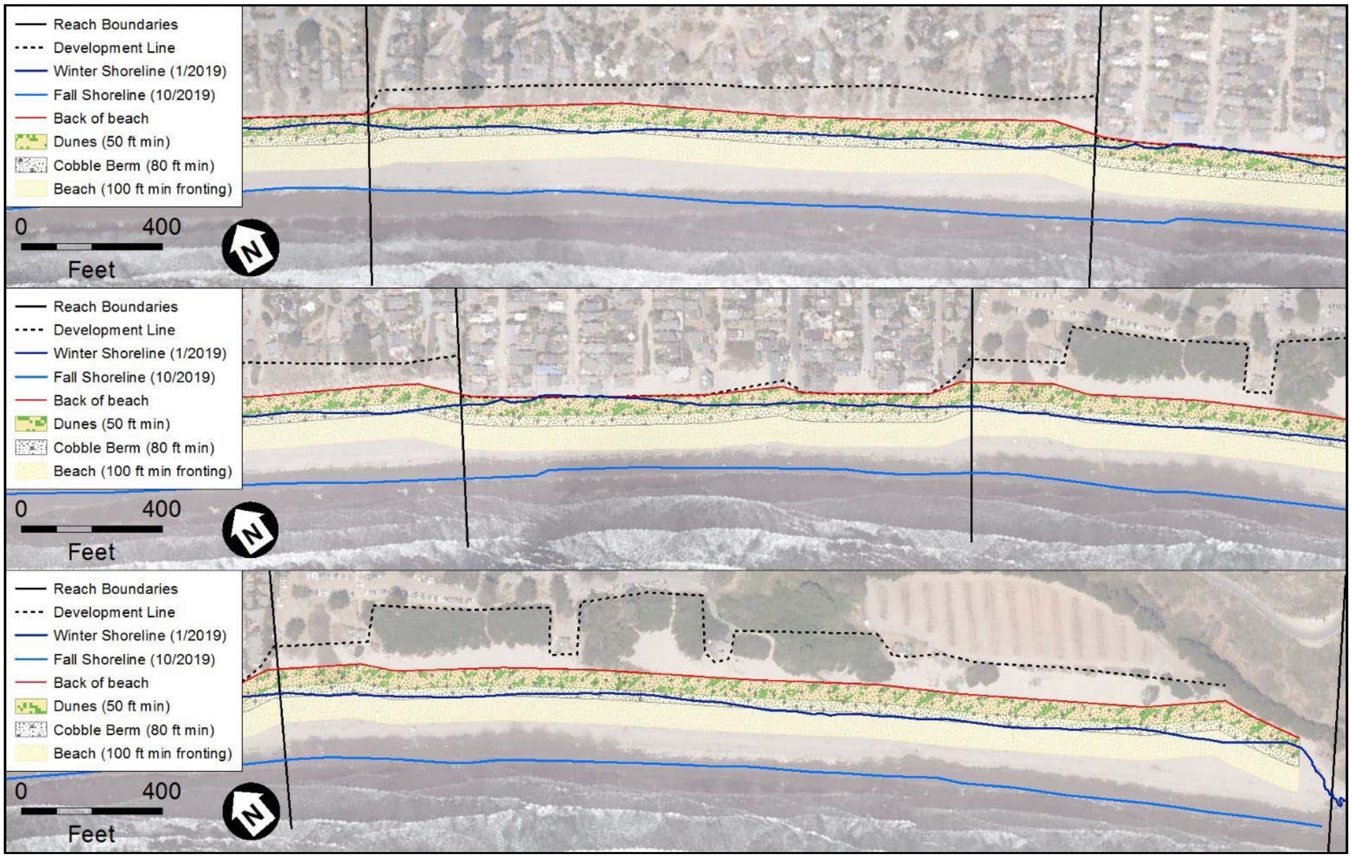
Figure 14
Available Space for Natural Infrastructure along Seadrift Reach: West (top), Center (middle) and East (bottom)



SOURCE: ESA, Marin County 2018 Imagery

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Figure 15
Available Space for Natural Infrastructure along Patios (top), Calles (middle) and NPS (bottom) Reaches

3.3. Suitability of Nature-Based Infrastructure by Reach

Table 1 provides a comparison of minimum desired infrastructure width and actual beach width available based on the existing beach widths surveyed in October 2019. The fall beach condition is used to determine suitability because the natural infrastructure would be ideally constructed in late summer/fall. Note that the beach widths measured in October 2019 are wider than typical beach widths, and therefore natural infrastructure types that require smaller footprints were emphasized. Several nature-based infrastructure types are selected as potentially suitable for each reach, as marked by “Y” in Table 1, effectively screening the types and identifying those suitable for each reach.

Table 1. Suitability of natural infrastructure type by reach, screened by available beach width

	Beach width (feet)[1]	Foredunes	Foredunes with Cobble-Gravel Berm	Dune Embankment	Dune Embankment with Cobble-Gravel Berm	Cobble-Gravel Berm	Notes
Desired Natural Infrastructure Width (feet)		230	130	100	100	80	
Seadrift West	103			Marginal	Marginal	Y	See text regarding potential use of a dune embankment, with or without Cobble-Gravel berm
Seadrift East	214		Y	Y	Y	Y	
Patios	250	Y	Y	Y	Y	Y	
Calles	235	Y	Y	Y	Y	Y	
NPS	264	Y	Y	Y	Y	Y	See text regarding Cobble-Gravel lag geometry option

[1] Measured Oct 2019, wider than typical beach width.
Y= feasible alternative based on space considerations.

For the Seadrift West Reach, it seems possible based on the average October 2019 beach width of about 100 feet that a dune embankment with or without a cobble-gravel berm could be employed along some of this reach. However, this area is known to have narrow beaches with wave run-up reaching the rock revetment on the back of the beach during winters (see Study Memorandum 1). For the more typical narrow beach conditions, dunes would be subject to frequent wave action resulting in a vertical scarp that is generally not desirable from an access perspective (see Figure 16). Similarly, a cobble-gravel berm located seaward of the dunes would be exposed much of the time, resulting in a rocky instead of sandy shore. Therefore, it is our judgment that dunes with or without cobble are not likely to perform well at Seadrift West reach.

At the NPS Reach, an option for a cobble-gravel lag instead of the cobble-gravel berm is noted. This option is provided in recognition of gravel stream sediments that exist in the area due to the proximity of Easkoot Creek. Historically, during flood flows, Easkoot overtops its banks and flows across the NPS reach to the ocean. Placement of a cobble-gravel mass in the form of a low apron, or lag, could facilitate these flood flows across the dunes with less erosion, however dune repairs would be expected after significant Easkoot overflows.


e
SOURCE: Bob Battalio, early 2000s

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Figure 16
Scarp at eroded dune embankment, Ocean Beach, San Francisco

4. Adaptation Alternatives Development

The nature-based adaptation alternatives proposed for Stinson Beach build upon the adaptation strategies presented in the C-SMART Adaptation Report (Marin County 2018) and suitably natural infrastructure types described above. A range of near-term adaptation alternatives were selected for this study (Section 4.1) that combine one or more natural infrastructure types. The potential natural infrastructure combinations were then prioritized using qualitative selection criteria. Two adaptation alternatives were developed for the study area by combining the appropriate natural infrastructure types for each reach (Section 4.2). The nature-based alternatives were evaluated along with an armoring baseline (Chapters 6, 7). Long-term adaptation pathways consistent with the near-term alternatives analyzed in this study are also discussed to facilitate integrated adaptation planning for the greater Stinson-Seadrift community (see Chapter 8).

4.1. Priority Rating of Nature-Based Infrastructure Combinations

Adaptation Alternatives for Stinson Beach were selected from applicable nature-based infrastructure combinations using a priority rating scheme. Priority ratings of high, medium or low were developed by qualitatively applying several criteria. The overall rating was assigned based on the average of the ratings of the selection criteria, as shown in Table 2. The selection criteria used to form the overall ranking (Table 2) of adaptation alternatives are described below. Alternative evaluation criteria described in Chapter 6 are derived from these selection criteria.

- **Natural Context:** A nature-based infrastructure type is more desirable if it is consistent with the natural setting. A review of reference sites indicates that foredunes are the most natural shore typologies under consideration (Baye 2019). Linear dune embankments and cobble-gravel berms are not native to the Stinson Beach area, with the exception of cobble-gravel deposits associated with Easkoot Creek, which occasionally overflows across the NPS reach to the ocean. Native dune vegetation is likely to be more compatible with backshore beach habitat quality suitable for western snowy plovers, compared with European beachgrass. Native beach wildrye and associated broadleaf perennial dune plants tends to form gentler, wider foredune slopes and more open, sparse vegetation cover at the seaward edge of the foredune.

- **Ecology Benefits:** The more natural foredunes support native plants and associated fauna and therefore provide the highest ecology outputs. In addition, because foredunes promote the natural cycling of sediment and accommodate rather than reflect wave energy, they tend to increase beach width which is beneficial for shorebirds. In central and California shorebird abundance is greater on beaches with wider, flatter swash zones and wider upper beach areas (Neuman et al. 2004, Neuman et al. 2008). Wide upper beaches are especially important for plover species that forage and roost at or above the high tide drift line and are strongly associated with beach cast wrack deposits (Dugan et el. 2003, Nielsen et al. 2013), including the federally protected western snowy plover occurs in the area. Dune embankments, depending on their persistence and types of plants can provide ecology benefits as well by increasing beach width relative to beaches backed by hard armor, but may not be the correct shape to retain the beach cast wrack that is beneficial to shorebirds. Cobble-gravel berms are believed to have some ecological value similar to but less than a sandy beach and increased shoreline habitat diversity may increase the diversity of shorebird species using the area (Point Blue unpubl. data). The cobble helps limit beach erosion and promotes wider beaches which is beneficial for shorebirds. However, if the cobbles become mobile in the swash zone, they may crush invertebrates and negatively impact beach ecology when exposed for long periods.

- **Effectiveness of Protective Services:** The goal of this application of natural shore infrastructure is to provide protection to development from coastal erosion and flooding hazards with sea-level rise. Where there is adequate space, the foredunes provide this benefit most efficiently. Dune embankments may appear to be more effective owing to their higher relief, but they also tend to erode and scarp more than foredunes. Cobble-gravel berms and lag can restrict erosion but are naturally overtopped by wave run-up during extreme events: Hence cobble-gravel berms function best in combination with dunes that dissipate overtopping wave run-up. The effectiveness of protective services for alternatives are quantified in Chapter 6, which include estimation of maintenance requirements (and thus costs) with future sea-level rise. Native foredune vegetation, including widely creeping perennials, is more likely to facilitate rapid post-storm recovery of storm wave-eroded foredunes. Native foredune vegetation is also less likely to form foredune morphology with high, steep, narrow seaward slopes that form reflective wall-like erosional scarp profiles after major winter storms, compared with foredunes built by European beachgrass.

- **Access and Aesthetics:** Foredunes provide the least barrier to shore access and views, and are generally considered aesthetically pleasant because they naturally form as gradual transitions from the beach to uplands. The high relief (steep) geometry of dune embankments could impede coastal recreation access and views of the ocean to a greater extent. The dune embankment height or face steepness can make it difficult to traverse without access improvements such as stairs. On the other hand, dune embankments may also be favored, especially for the visual sense of protection resulting from the higher dune crest elevations. Cobble-gravel berms are accessible but not as comfortable to walk on when exposed, especially on the sloping face, and have a different appearance than the native beach strand. However, cobble-gravel berms are more natural and traversable compared to other engineered armoring structures.

- **Relative Cost:** nature-based infrastructure types with a lower cost of construction and lower maintenance requirements are given a higher ranking. Foredunes are the lowest initial cost type if adequate space is available, and low maintenance once the desired vegetation is established. Dune embankments require greater amounts of sand and grading, and may require irrigation for planting and access structures to traverse grade changes, resulting in greater costs. Additionally, dune embankments are more subject to wave run-up erosion impacts due to their exposed steep face. Cobble-gravel berms require import of the sediments and hence have the highest initial cost. However, the maintenance requirements of Cobble-gravel berms can be low. All features will need increased maintenance (and costs) with higher sea levels (see Chapter 6).

TABLE 2. NATURAL INFRASTRUCTURE SELECTION CRITERIA RANKING

Selection Criteria	Foredunes	Foredunes with Cobble-Gravel Berm	Dune Embankment	Dune Embankment with Cobble-Gravel Berm	Cobble-Gravel Berm
Natural Context[1]	High	Medium	Medium	Low	Lowest
Ecological Benefits	High	Medium	Medium	Medium	Low
Effectiveness for Protective Services (provided space available)	High	Highest	Medium	Medium-high	Medium
Access / Aesthetics	High	Medium	Medium-low	Medium-low	Low
Relatively lower Cost / Maintenance Needs[2]	High	Medium	Low	Med-low	Medium
OVERALL RATING / PRIORITY	**HIGH**	**MEDIUM**	**MEDIUM-LOW**	**MEDIUM-LOW**	**LOW**

[1] For reaches except NPS, which ranks relatively higher for Cobble-Gravel berm because it has a natural source of cobble and gravel from Easkoot Creek.
[2] High ranking assigned to low cost.

4.2. Alternatives Selected by Reach

Alternatives were selected for each reach from the various nature-based infrastructure alternatives in Table 2. Additional considerations that informed the selection of alternatives include existing development location/type and beach conditions in each reach. The selection process is described below by reach with details pertinent to alternative suitability. Additional information can be found in Study Memorandum 1 (ESA 2020a).

Seadrift: Seadrift West already has a shore armor device and has limited space available for dunes (Table 1). Given the existing rock and limited space, a cobble-gravel berm was selected as potentially beneficial to limit the extents of erosion and wave run-up and facilitating beach recovery. The beach is progressively wider with distance eastward, and Seadrift East has sufficient space for a dune embankment.

Patios: development in the Patios Reach is set back farther, and the more desirable foredunes are potentially feasible with or without a cobble berm. A dune embankment with or without a cobble-gravel berm, or a cobble-gravel berm alone could be suitable, but are considered less ecologically beneficial options.

Calles: The development in the Calles Reach includes a range of setbacks from the ocean, and both dunes and cobble-gravel berm were selected. Either foredunes or a dune embankment alternatives are selected.

NPS: The NPS reach has the greatest available space: it has a wide beach today and relatively high accommodation space for beach and dune migration with sea-level rise. The reach has dunes of varied height along the back beach today. Foredunes alone and with a cobble-gravel berm are selected for this reach. The cobble gravel berm would include a lag deposit at the west end of the reach to facilitate Easkoot Creek discharge during high flood flows (Figure 17), and consistent with coarse creek sediments (Figure 18). The lag deposit would be lower in elevation, and slope toward the shore forming an apron for the creek discharge. This treatment would likely be localized where the creek flows are directed based on park renovation or NPS guidance. In summary, foredunes and dune embankments (with or without cobble berm) are suitable for all but Seadrift West reaches while the cobble-gravel berm is suitable for all reaches. The selected nature-based adaptation alternatives for feasibility analysis are listed in Table 3.

The nature-based adaptation alternatives are depicted in cross section and plan view schematics in Chapter 5. Following review with the project TAC and County in June 2020, these selected alternatives were evaluated for effectiveness in mitigating sea-level rise and storm impacts based on coastal engineering assessment (Chapter 6). The evaluation includes a baseline condition to compare and quantify the relative benefits of nature-based features. The armoring baseline (referred to as Alternative 0 in this evaluation) assumes that development is armored using a traditional rock revetment. The evaluation also identifies if and when additional adaptation actions may be required such as armoring or structural modifications to development.

TABLE 3. SELECTED NATURE-BASED ADAPTATION ALTERNATIVES BY STUDY REACH

Reach	Adaptation Alternative	Notes
Seadrift West	1. Cobble-Gravel Berm	Marginal space, existing shore armor
Seadrift East	1. Dune Embankment 2. Cobble-Gravel Berm	Limited but increasing space, existing shore armor
Patios	1. Foredunes 2. Foredunes + Cobble-Gravel Berm	Development set back, some existing foredune infrastructure
Calles	1. Foredunes + Cobble-Gravel Berm 2. Dune Embankment + Cobble-Gravel Berm	Irregular development line creates pockets of additional space for natural infrastructure
NPS	1. Foredunes 2. Foredunes + Cobble-Gravel Berm	Cobble-Gravel berm with cobble-gravel lag geometry added as third option

SOURCE: NPS May 2018

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Figure 17
Easkoot Creek scour at NPS reach. Blue line shows channelized Easkoot Creek. Dashed red line shows flood flow avulsion through parking lots and dunes to beach

SOURCE: : Louis White 2019

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Figure 18
Easkoot Creek sediment basin (left) and scour repair using creek sediments, covered by beach sand (right), NPS reach

4.3. Integration of Reach-based Alternatives

The reach analysis using typical profiles has resulted in the selection of two alternative natural shore infrastructure types for each reach. While it is possible that a project for one or more reaches proceeds separately, it is also reasonable to consider a multi-reach project. Hence, it makes sense to consider similar natural shore infrastructure alternatives for all reaches: this could be considered a potential project that would be constructed at one time, for example. Following this concept integrating all reaches, it may make sense to consider alternatives as a function of time: That is, as sea levels rises and the shore narrows, the entire shore treatment may be modified within the context of a project adaptation. For example, the initial project may consist of dunes where there is adequate space and cobble-gravel berms where there is not. Given a future sea-level above a threshold, cobble-gravel berms could be added to the remaining reaches. Conversely, it is possible that reaches may act separately, similar to the way the Seadrift community has armored its shore, and the Park Service is unlikely to construct shore protection owing to their national guidelines to limit interference with natural coastal processes.

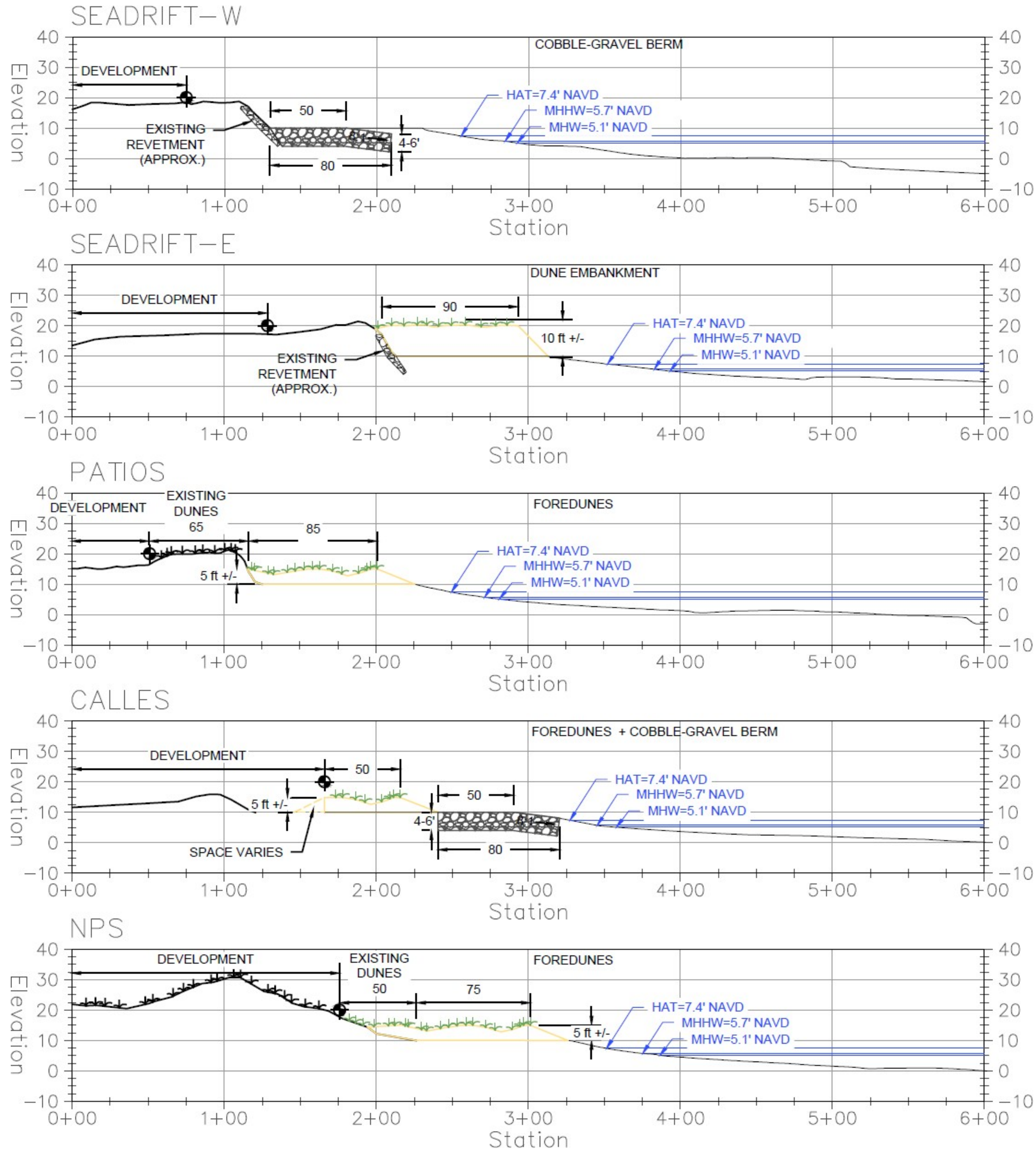
5. Adaptation Alternatives Cross Section and Plan View Detail

The nature-based infrastructure adaptation alternatives evaluated for feasibility are depicted in cross section (Figure 19 and Figure 20) and plan view (Figure 22 and Figure 23). Alternative 1 presents the “more natural” of nature-based infrastructure types, consisting of foredunes where there is sufficient space and dune embankments where space is limited. Alternative 2 presents 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. See Section 6.1 for details on typical cross section development for the alternatives.

Figure 21 shows a cross section for the west end of NPS reach to illustrate the cobble lag deposit that could be implemented as part of a cobble berm alternative to facilitate drainage of Easkoot Creek overflows and prevent impacts to adjacent property. This lag feature is important to consider for natural infrastructure at NPS given recent flooding impacts, but the lag deposit was not evaluated for performance in this study.

Typical water levels are shown in the cross section figures for reference to illustrate that alternatives are constructed at the back of the dry beach and above the tide range. Note that development in NPS reach is limited to a few buildings amidst dunes. The representative location of development is annotated on each cross section with a marker placed arbitrarily at elevation 20 feet for illustrative purposes. The baseline adaptation alternative (Alternative 0, not shown in figures) assumes rock revetment is constructed to protect development and maintained with sea-level rise. The armoring would be located along homes in Patios reach (beneath/behind existing dunes), along homes in Calles reach, and in front of the three buildings in the NPS reach (not the entire reach length).

Note that cobble berms are shown near the surface in the following figures; the cobble berms would be buried just below beach elevations when constructed.



SOURCE: ESA

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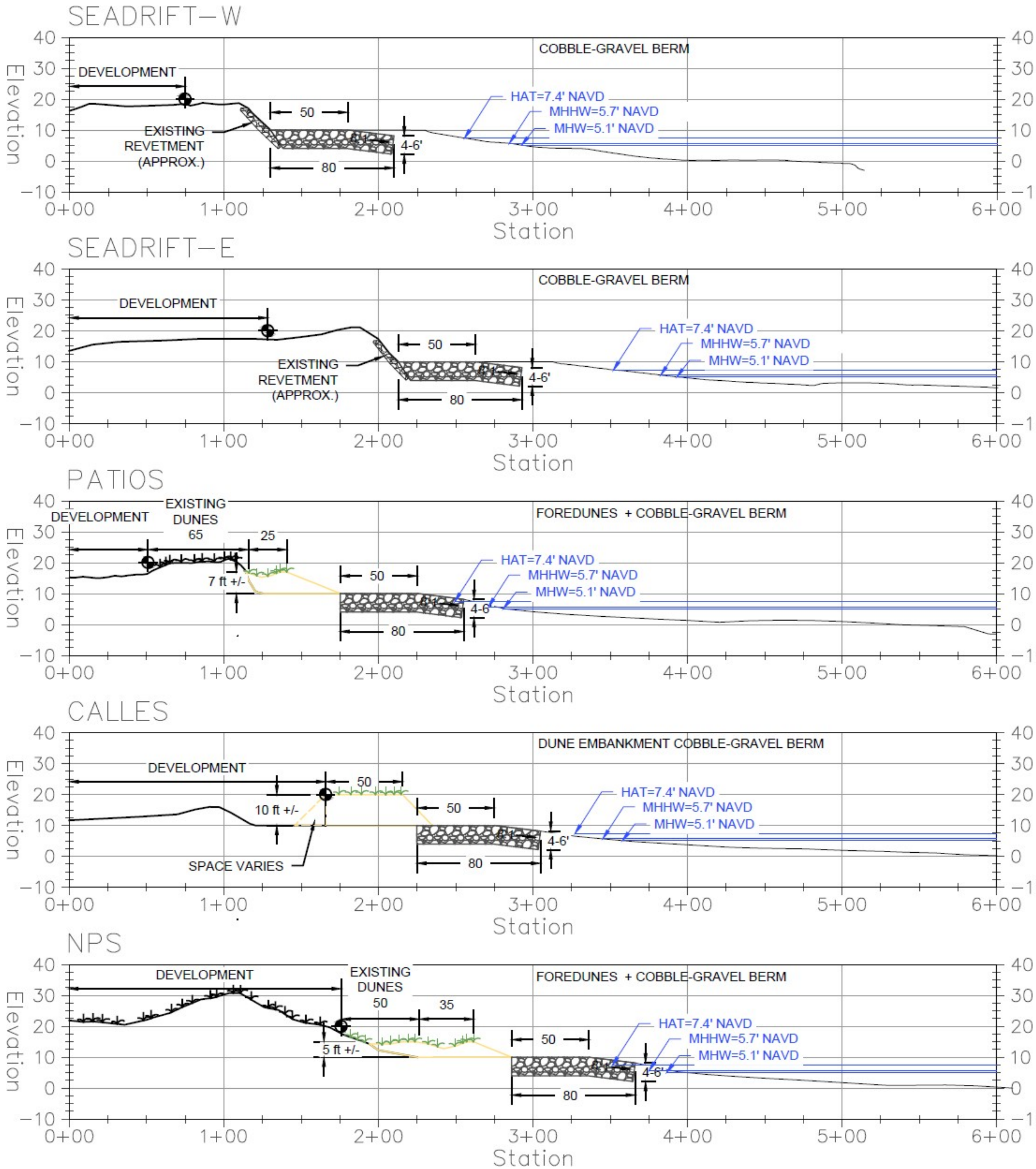
NOTE: 2X Vertical Exaggeration, axes in feet

Figure 19
Alternative 1 Cross Sections



SOURCE: ESA

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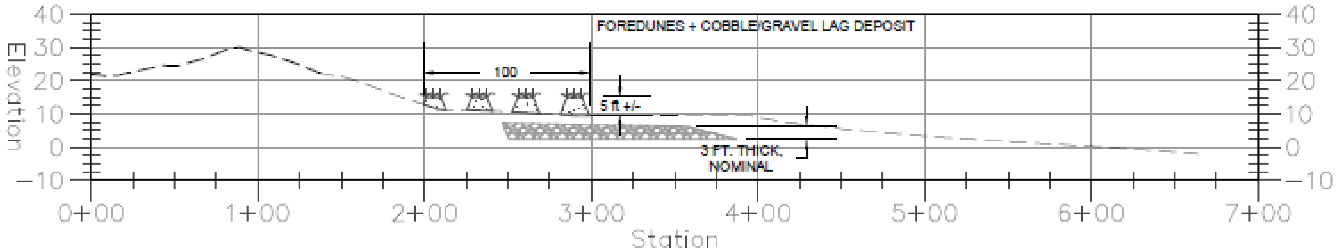
NOTE: 2X Vertical Exaggeration, axes in feet

Figure 20
Alternative 2 Cross Sections



SOURCE: ESA

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NOTE: 2X Vertical Exaggeration, axes in feet

Figure 21
NPS Cross Section illustrating cobble lag deposit at west end (not evaluated)

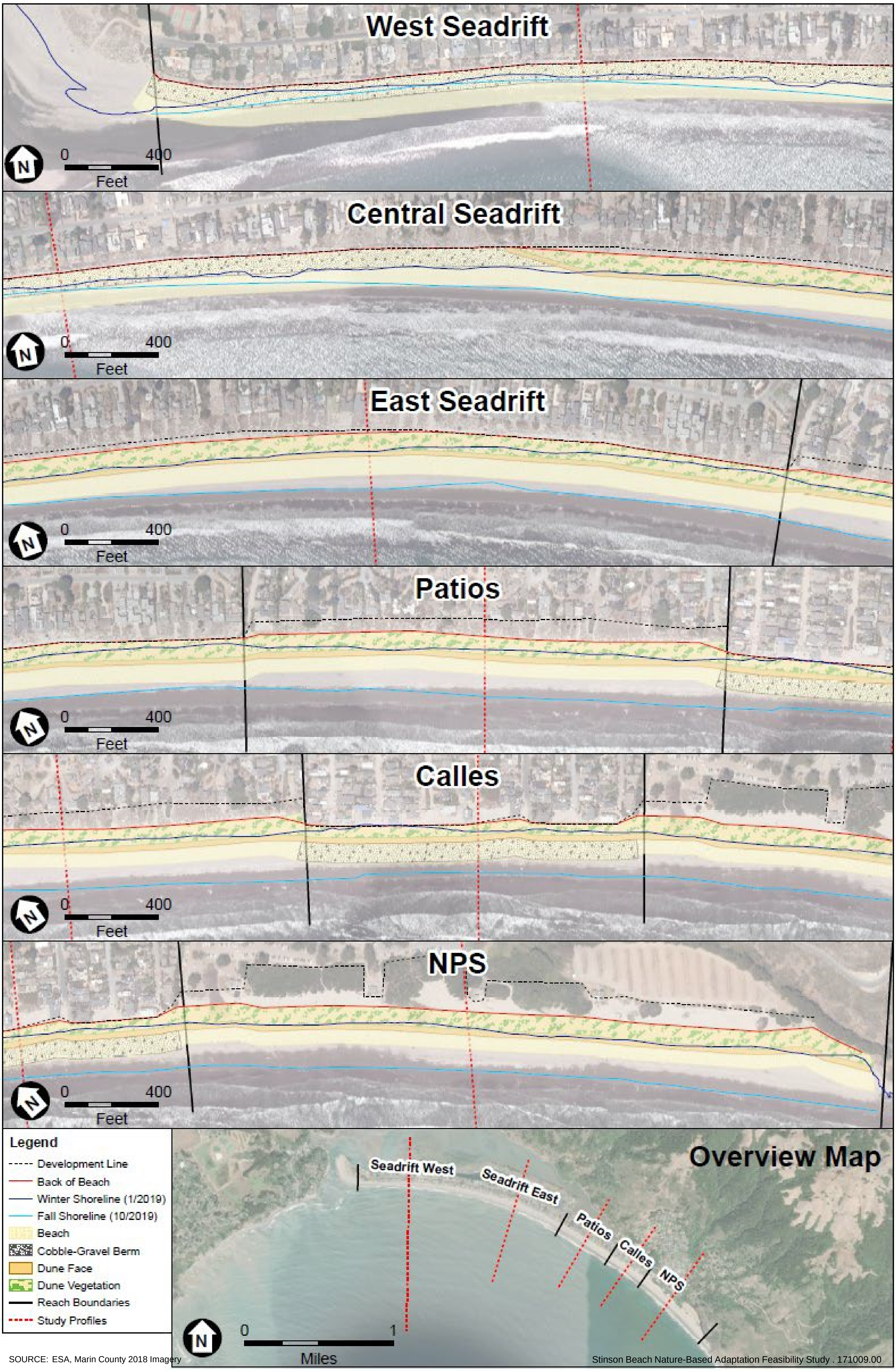
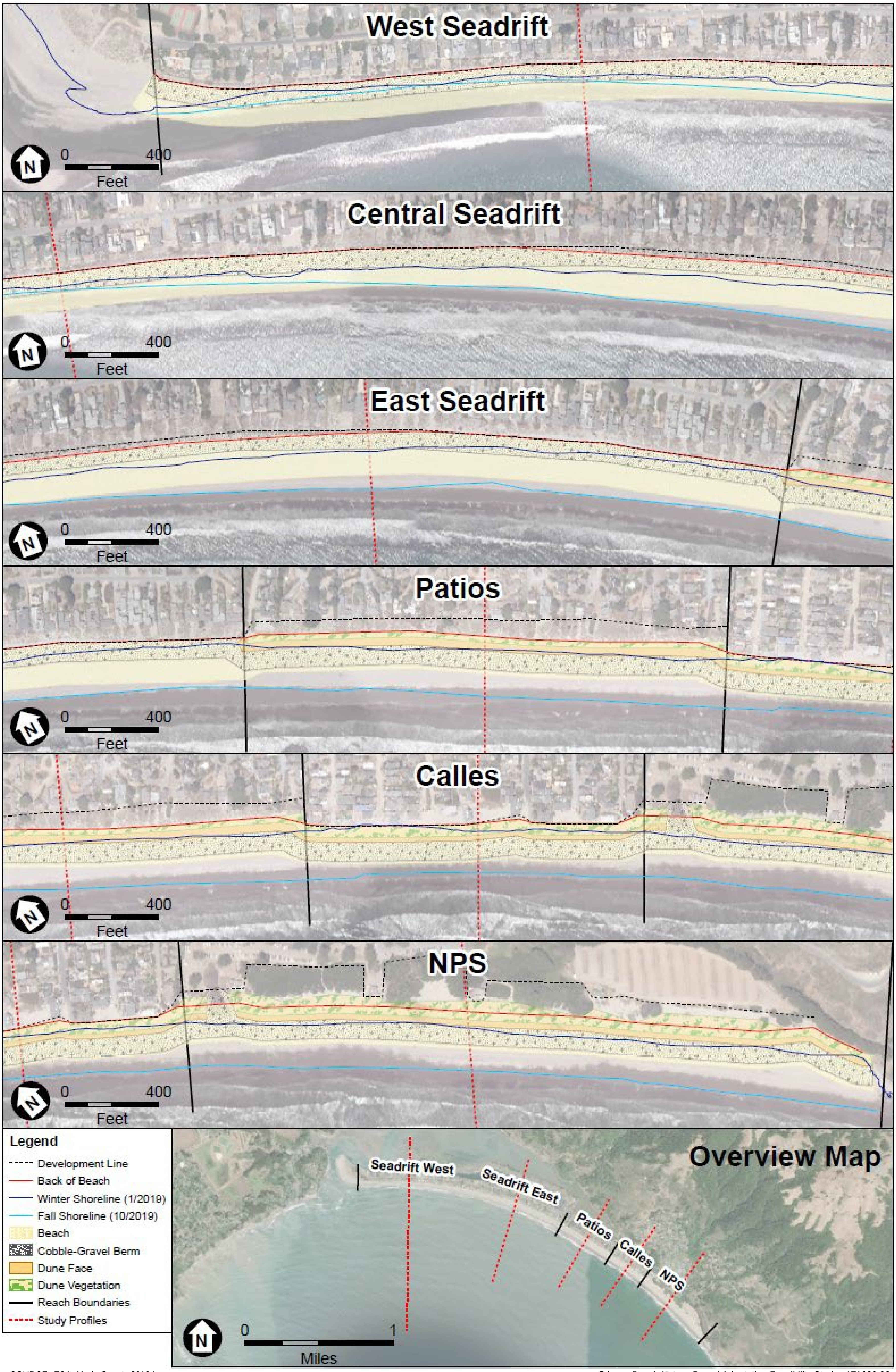


Figure 22
Alternative 1 Plan View



SOURCE: ESA, Marin County 2018 Imagery

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Figure 23
Alternative 2 Plan View

6. Adaptation Alternatives Evaluation

The nature-based adaptation alternatives evaluated for this study are intended to provide sea-level rise protection for vulnerable development along the Pacific shore and maintain the ecological and recreational values of the beach and dunes at Stinson Beach. The adaptation alternatives are based on the community values identified through the C-SMART process, stakeholder engagement for this study as well as a detailed understanding of existing conditions and coastal processes along the study area. Adaptation alternative performance was determined with two technical analyses: modeling shoreline evolution with sea-level rise and modeling of wave run-up for initial and future conditions with sea-level rise. The nature-based alternatives are evaluated along with a traditional shoreline armoring baseline to illustrate the relative persistence of beach (and dune) widths and associated benefits with and without the use of natural infrastructure. This Chapter describes the evaluation process and results.

The outputs of the shoreline evolution modeling directly inform the design life analysis and storm protection benefits. The cross-shore widths of the beaches and dunes over time are used as indicators of both ecological and recreation values (coastal resources benefits), as well as storm and sea-level rise hazard reduction benefits to backshore development (protective services benefits).

Section 6.1 describes the starting conditions for shore profiles used to size and locate natural infrastructure along the shoreline as well as model their evolution with sea-level rise. The following sections describe the methods and results of the evaluation criteria listed below.

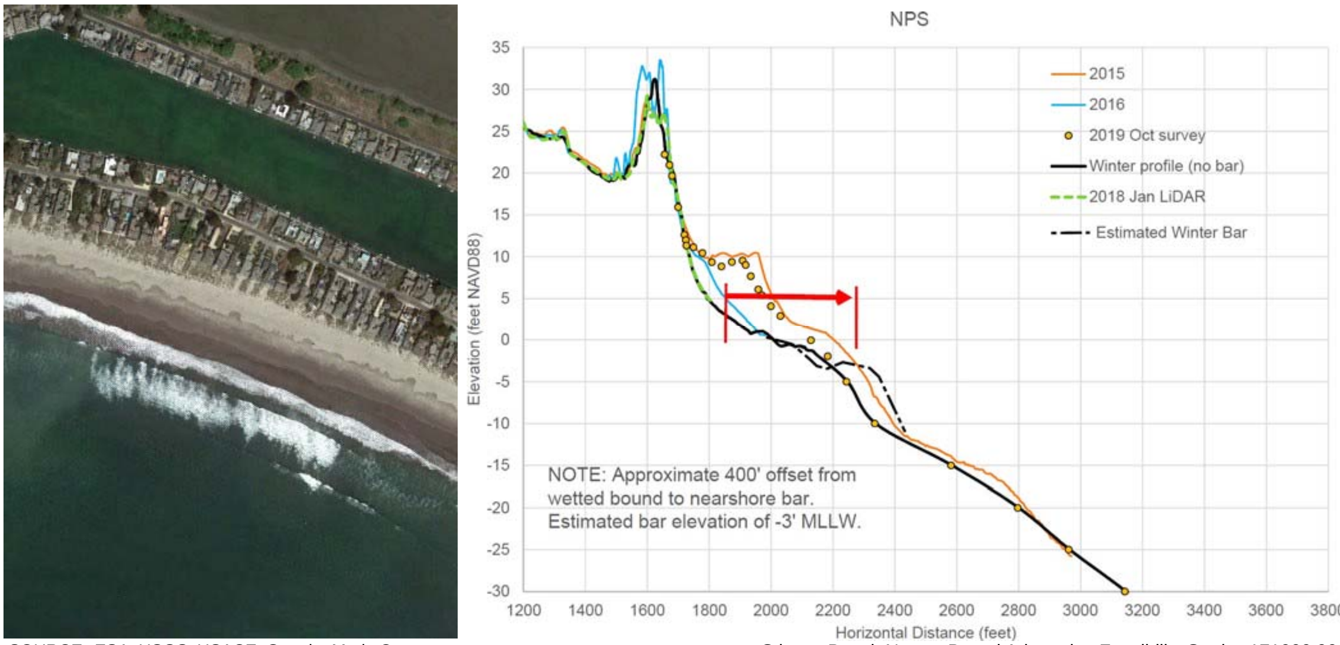
- Design Life Analysis (Section 6.2)
- Storm Protection Benefits (Section 6.3)
- Geomorphic and Habitat Benefits (Section 6.4)
- Constructability (Section 6.5)
- Environmental Impacts and Regulatory Considerations (Section 6.6)
- Public Access (Section 6.7)

An adaptation alternatives evaluation summary matrix that includes relative scoring for each of these categories is presented in Chapter 7.

6.1. Initial Conditions Shore Profiles for Alternatives Evaluation

Initial conditions shore profiles were developed for each reach to evaluate the adaptation alternatives. This section describes the considerations that went into the initial conditions for the armoring baseline and nature-based alternatives. The armoring baseline alternative assumes backshore armoring is constructed and/or maintained when needed to protect backshore development. Winter conditions, when coastal storms occur and beach widths are narrow, were used to evaluate alternatives' functional design life and performance reducing wave run up. Summer conditions, when beaches are wide, were used to consider seasonally influenced factors such as recreational access and beach ecology.

Initial conditions shore profiles were developed starting with 2019 winter LiDAR elevations onshore (above water only) and 2019 fall bathymetry survey data for offshore elevations. The limited bathymetric survey data are not representative of winter conditions in the surf zone, requiring the creation of representative profiles for our analysis. Typical coastal practice entails estimating a winter profile (sometimes called "the Most Likely Winter Profile – MLWP; FEMA 2005). A shore-parallel sand bar was added to the profiles to better represent typical winter conditions that affect wave run-up: Aerial photographs with breaking waves were used to locate the nearshore bar crest and estimate its depth. Figure 24 shows a plan and cross section view of the estimated nearshore sand bar feature. While this is an estimate, it is our experience that winter sand bars typically occur and limit wave run-up on the beach by forcing waves to break farther offshore: Hence, omitting a nearshore bar in the calculations will likely result in an over-estimate of wave runup.

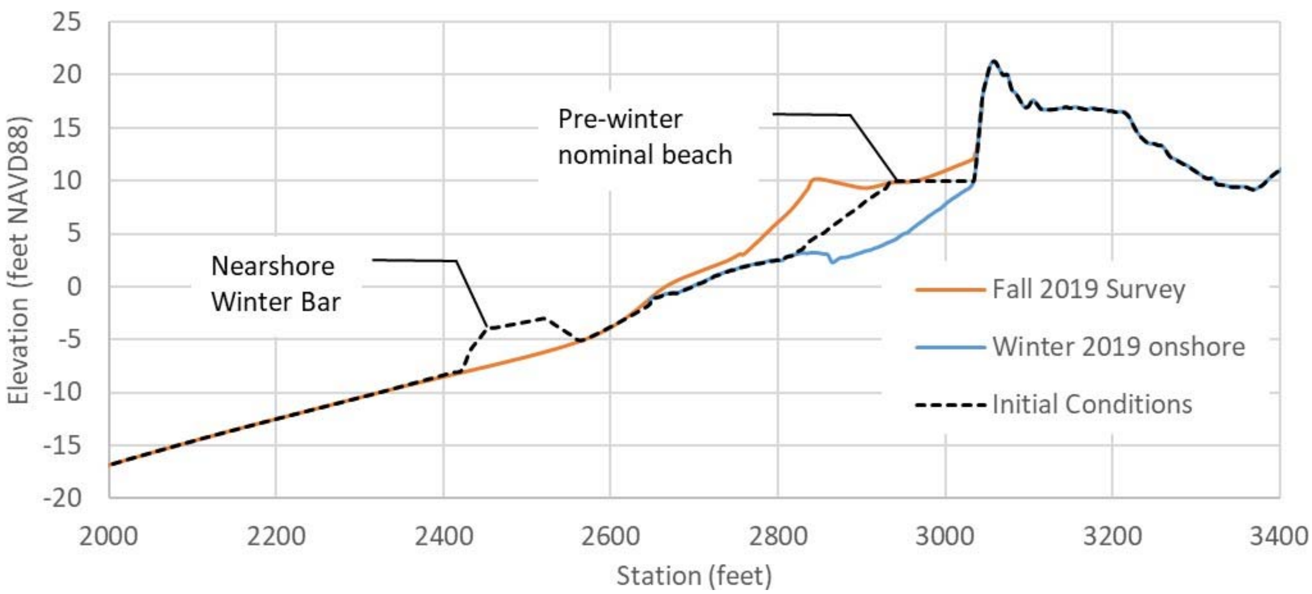


SOURCE: ESA, USGS, USACE, Google, Marin County

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 24
Nearshore bar estimation

Since we expect the natural infrastructure to be constructed prior to winter, the profiles extracted from mid-winter LiDAR data were modified to represent a wider beach berm; a 100-foot nominal beach berm at elevation 10 feet NAVD was added to each profile except for the Seadrift West profile where a 50 foot top width was added to represent narrow beach conditions. For each profile, the resulting widened beach berm was connected to the lower profile using representative beach slopes. An example of the resulting initial conditions profile for Seadrift East is plotted in Figure 25, showing mid-winter 2019 conditions onshore, fall 2019 beach and nearshore conditions, and the added nearshore bar and nominal pre-winter beach width. Adaptation alternative components (cobble berm, foredunes / embankment) were sized accordingly to fit onto the initial conditions profiles to provide protection against a stormy winter (e.g. a 2015-2016 El Nino winter).



SOURCE: ESA

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 25
Initial conditions profile development with nearshore bar and nominal beach berm that can accommodate natural infrastructure

6.2. 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. These shoreline morphology concepts are applied to evaluate the nature based adaptation alternatives over time. This section describes the geomorphic methods and results of the design life analysis including relative engineering costs to construct and maintain alternatives with up to 1 meter (3.3 feet) of sea-level rise. The beach, dune and cobble width outputs from the design life analysis are then used to evaluate the storm protection, recreational, and ecological benefits provided over a traditional shore armoring baseline (Sections 6.3 to 6.5). Beach width is defined as the distance from the backshore (dune or armoring toe) to the MHW shoreline. Dune width is defined from the toe of the dune to the first line of development. Existing dunes are included in the evaluation of Patios and NPS reaches.

6.2.1. Modeling long term shoreline evolution with sea-level rise

The effective life of each adaptation alternative depends in part on long term sea-level rise. Beach, dune and cobble shore evolution were estimated using geomorphic models of the response of the shore to long term sea-level rise. The models evaluate the longevity of both constructed and existing natural infrastructure along the study area and indicate the need for reconstruction or other adaptation actions once erosion surpasses a minimum natural infrastructure width. Dune and cobble erosion methodologies are described in the subsections below followed by the results for the baseline and alternatives. Coastal storm event impacts are discussed below in relation to long term shoreline evolution.

Beach and dune erosion with sea-level rise is modeled for the baseline and nature-based adaptation alternatives for each reach. Erosion of the shoreline, dunes and cobble berms is calculated based on beach width (BW). In general, erosion of dunes and cobble increases from wide beach (no backshore erosion) to narrow beach (greatest erosion), as described in the following subsections.

Dune Erosion

A wide beach provides a buffer against wave run-up at the backshore and can limit dune erosion and damages to development under normal (non-storm) conditions over time. As the beach narrows, waves begin to impact the backshore and erode dunes (if present) at an increasing rate. Once the beach width shrinks to the stable minimum width, the shoreline and dune erode at the same rate, this minimum beach width is maintained by the sand eroded from the dunes, once the dunes erode completely, the beach width diminishes and may disappear especially during stormy winters.

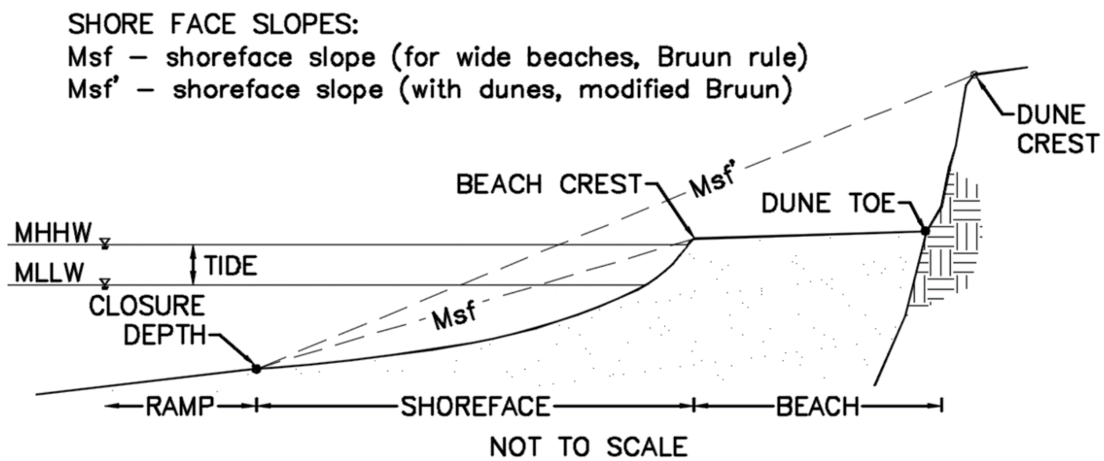
Dune erosion (without cobble berm) is based on the Bruun rule (1962) which assumes the equilibrium shore face slope of wide beaches is maintained with sea-level rise. The shore face is the active portion of a beach profile that is affected by waves, the shore face extends from the beach crest to the closure depth (offshore location on a shore profile beyond which the profile does not change over time). Dune (and shoreline) erosion was modeled in three stages depending on beach width, described below.

(1) **Beach Width > Average Winter Width** – A wide beach provides a buffer limiting dune erosion. The shoreline shifts landward on the equilibrium shore face slope extending from the beach berm crest out to the depth of closure (i.e. standard Bruun slope for wide beaches, shown as Msf in Figure 26).

(2) **Average Winter Width > Beach Width > Minimum Stable Width** – In this transitional condition, the dune begins to gradually erode as the beach approaches the minimum stable width. The shoreline shifts landward on a shore face slope that transitions linearly between the standard Bruun slope and a modified Bruun slope that accounts for the height of dunes behind the beach that contribute sand to the beach during erosion events (shown as Msf’ in Figure 26).

(3) **Beach Width < Minimum Stable Width** – The shoreline and backshore erode on modified Bruun profile slope (from backshore toe/crest to depth of closure).

Figure 26 shows the standard Bruun slope (**Msf**) and the modified Bruun slope (**Msf’**) that accounts for sand in the dunes that is mobilized to the lower profile during erosion events. The minimum stable beach width is observed to be approximately 60 feet on average along Stinson Beach. The average winter beach width ranges from 90 feet at Seadrift West to 140 feet at NPS based on observed winter shorelines obtained for this study.



SOURCE: ESA

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 26
Schematic shore profile with shore face slopes used for geometric erosion model

Cobble Berm Erosion

The cobble berm is included in some adaptation alternatives to provide a greater level of protection against wave run-up and erosion. The cobble berm is placed in front of existing backshore or constructed dunes, just beneath the beach elevation (10 feet NAVD88 for the purpose of this study). With sea-level rise, any beach fronting the cobble berm is assumed to erode according to the standard Bruun slope until the cobble is exposed. The cobble berm then gradually becomes part of the shifting beach profile as the shoreline meets the cobble berm. The shore face slope steepens as more cobble is exposed, slowing the rate of shoreline erosion until the cobble berm is overwhelmed. When the cobble berm fails, the backshore begins to erode at the same rate as the shoreline.

(1) **<u>Beach Width</u> > Cobble Berm Width** – a wide beach acts as a buffer that limits backshore erosion; the shoreline erodes on standard Bruun profile slope (from the beach berm to depth of closure).

(2) **Cobble Berm Width > <u>Beach Width</u> > Minimum Stable Cobble Width** – The transitional condition in which the cobble berm begins to erode. The shoreline and cobble berm erode on a slope that gradually steepens due to the increasing fraction of cobble berm exposed (height) relative to the overall sand shore face height (from depth of closure to cobble berm crest elevation). The transgression slope ranges from the standard Bruun (when the shoreline meets cobble) to a cobble recession slope of 6H:1V. The initial constructed cobble berm width is 80 feet, while the cobble berm failure threshold width is 30 feet (i.e. **Minimum Stable Cobble Width**). At 30 feet width, the cobble berm needs to be reconstructed. The cobble is mobilized by rising sea-levels as follows:

- Wave run-up builds the berm landward and upward at a distance equal to SLR
- Scour of sand in front of the berm drops the seaward end of the berm downward at a distance equal to SLR
- Increased breaking waves flatten the cobble slope
- The cobble berm width is monitored until it is reduced to 30 feet

(3) **<u>Beach Width</u> < Minimum Stable Cobble Width** – cobble berm fails and dune erosion begins, shoreline and backshore erode on modified Bruun profile slope (from backshore dune crest to depth of closure).

A cobble-gravel berm can act as a barrier to the sand stored in the upper profile (dry beach and dunes), preventing its transport to the lower profile (foreshore, intertidal zone) by waves over time. While a cobble barrier reduces overall cross-shore sediment transport, the longshore sediment transport rates along Bolinas Bay are assumed to be sufficient to supply sands to the surfzone seaward of the cobble berm face. This assumption is considered to be less valid for larger amounts of sea-level rise, conceptually over ~3 feet, which will result in a demand for sand that exceeds the supply by longshore transport.

Seasonal Erosion

Seasonal changes in ocean conditions result in narrowing of the beaches in the winter through spring and widening of the beaches through the summer, typically reaching maximum widths in the fall. When the winter shore approaches the natural infrastructure features (dunes and c-g berms), we expect some degradation of the features before the following summer recovery of the beach.   Dune and cobble-gravel berm erosion were computed based on the extent the features encroached into the winter beach. Reach-average seasonal shoreline fluctuations were taken from Study Memorandum 1.

The “seasonal erosion” can be tracked along with erosion due to sea-level rise, and the cumulative erosion used to determine when reconstruction thresholds are reached. Alternatively, maintenance can be applied to mitigate seasonal impacts. In practice, renovation for natural and traditional infrastructure is typically addressed after the cumulative effects of seasonal and extreme event(s) reach a threshold of reduced performance considered a “trigger” for maintenance.

Erosion Thresholds for Action

Erosion thresholds for dune and cobble berm width are documented in Study Memorandum 2. The cobble berm failure threshold width is 30 feet as described above. Dune threshold widths were determined based on observed erosion that occurred during the 2015-2016 El Nino; dunes eroded by 45 to 65 feet in some locations. These thresholds were applied to determine the maintenance needed to sustain natural infrastructure features with 3.3 feet sea-level rise. Corresponding volumes and associated costs of sand and cobble needed to maintain protective natural infrastructure features are described in Section 6.4.

6.2.2. Model Outputs of Natural Infrastructure Widths

Natural infrastructure widths are computed from the erosion at each sea-level rise increment. Beach width is defined as the distance from the backshore (dune or armoring toe) to the MHW shoreline. Dune width is defined from the toe of the dune to the first line of development, including existing dunes located at the patios and NPS reaches.

The location, type and density of development vary along the study area. The NPS development is of low density and is primarily parking lot and visitor serving amenities For other reaches, development spans the entire reach and is situated at the back of beach (see development line in Figure 22 and Figure 23). The Seadrift reach has a rock revetment that is treated as the non-erodible backshore for calculating infrastructure widths. Built residences along Seadrift are set back at varying distances from the revetment. The Calles reach has homes situated at the back of beach with the seaward-most developments location used as the reference for infrastructure widths.

The shore response modeling described in Section 6.2.1 are applied for both sea-level rise and seasonal fluctuations. Fall beach widths were used to an indicator of ecology and recreation benefits, with greater benefits associated with wider fall beaches. Existing shore (dune and beach) widths are reported in Table 4 along with future widths for the eroded shore resulting from 3.3 feet (1 meter) of sea-level rise. The desired additional space after 3.3 feet of sea-level rise is included in the right-most column of Table 4, and computed as the difference between the initial constructed natural infrastructure width and the future remaining summer shore width available for constructing natural infrastructure. The results in Table 4 are discussed below.

TABLE 4. WINTER AND SUMMER SHORE WIDTH RESULTS FROM ADAPTATION ALTERNATIVES EVALUATION

Reach	Alternative	Initial (Post-construction) Conditions Widths with no SLR (feet)						Future Conditions Widths with 3.3 feet SLR (feet)						*Additional shore width needed for NI with 3.3 feet SLR*[2]
		Winter Beach Width	Winter Dune Width	**Winter Shore Width**	Summer Beach Width	Summer Dune Width	**Summer Shore Width**	Winter Beach Width	Winter Dune Width	**Winter Shore Width**	Summer Beach Width	Summer Dune Width	**Summer Shore Width**	
Seadrift West	0. Armored at Development	92	n/a	**92**	172	n/a	**172**	0	n/a	**0**	76	n/a	**76**	*54*
	1. Cobble-Gravel Berm	92	n/a	**92**	172	n/a	**172**	59	n/a	**59**	80	n/a	**80**	*50*
Seadrift East	0. Armored at Development	102	n/a	**102**	182	n/a	**182**	6	n/a	**6**	86	n/a	**86**	*94*
	1. Dune Embankment	30	73	**103**	98	100	**198**	20	0	**20**	100	0	**100**	*80*
	2. Cobble-Gravel Berm	102	n/a	**102**	182	n/a	**182**	65	n/a	**65**	80	n/a	**80**	*100*
Patios	0. Armored at Development	127	70	**197**	207	70	**277**	54	44	**98**	134	44	**178**	*52*
	1. Foredunes	30	159	**189**	109	175	**284**	30	73	**103**	110	73	**183**	*47*
	2. Foredunes + Cobble-Gravel Berm	73	125	**198**	158	125	**283**	47	125	**172**	80	125	**205**	*25*
Calles	0. Armored at Development	134	n/a	**134**	214	n/a	**214**	41	n/a	**41**	121	n/a	**121**	*69*
	1. Foredunes + Cobble-Gravel Berm	61	75	**136**	156	75	**231**	49	75	**124**	80	75	**155**	*35*
	2. Dune Embankment + Cobble-Gravel Berm	69	70	**139**	157	70	**227**	50	70	**120**	80	70	**150**	*40*
NPS[1]	0. Armored at Development	138	55	**193**	218	55	**273**	76	25	**101**	156	25	**181**	*34*
	1. Foredunes	42	146	**189**	122	155	**277**	42	86	**128**	122	86	**208**	*7*
	2. Foredunes + Cobble-Gravel Berm	83	110	**193**	163	110	**273**	49	110	**159**	80	110	**190**	*25*

[1] NPS results represent conditions for the few areas with development; most of the reach has existing dunes with the capacity to retreat landward over time and maintain beach width.
[2] Desired additional width needed to maintain functional natural infrastructure (beach, cobble, dunes) along study shore.

Shore width results interpretation

The following paragraphs interpret the shore width results presented in Table 4. The interpretation focuses on width of the shore (beach and dunes) at winter minimum dimensions with some discussion of the results pertaining to protective services (erosion and wave run-up reduction). The subsequent report sections build on these shore width results in terms of Storm Protection Benefits (Section 6.3), Geomorphic and Ecological Benefits (Section 6.4), Environmental Impacts (Section 6.6) and Public Access (Section 6.7). In general, wider shore widths provide greater benefits to storm protection, ecology and public access.

Seadrift reach is divided in two for the purposes of this study, as beaches along the western half are considerably more eroded than the eastern half. Implementing a cobble gravel berm can sustain shore width with sea-level rise (winter shore width of 60-65 feet and summer width of 80 feet with 3.3 feet SLR), providing protective services, access and ecological functions beyond that of the armoring baseline (winter beach width disappears with 3.3 feet SLR). Beach width may be able to recover along the eastern reach with 3.3 feet SLR, but the more exposed western reach will experience limited summer beach recovery. Implementing a dune embankment along the eastern half of the reach can help to maintain a small winter beach width (20 feet) with 3.3 feet SLR.

Note that the winter beach widths in front of the existing rock revetments are forecast to decrease substantially with 3.3 feet of sea-level rise: from about 90-100 feet now to 6 feet or less. The narrow forecast beach width means that waves will directly impact the rock revetments during the winters, increasing the risk of backshore damages. While natural infrastructure alternatives are forecast to provide a wider winter beach, the incremental increase may not be realized during strong events that may destabilize the cobble mass modeled at Seadrift East. Hence, the Seadrift area appears to require additional adaptation measures, such as flood proofing and raising the homes on piles, etc. Further discussion on wave run-up is in Section 6.3.

Patios reach has more sea-level rise capacity owing to the existing dunes present and more landward development. Implementing foredunes provides additional protective services in the near term but only a marginal increase in beach widths with sea-level rise. A dune embankment may be worth considering in this location in order to maximize sand volume and mitigate wave run-up, especially within the context of adaptation at the adjacent reaches. Adding a cobble berm is predicted to increase protective services substantially for future conditions with SLR of 3.3 feet, due to a much wider winter shore (74 feet wider compared to baseline).

Calles reach does not have notable existing dunes and thus a cobble gravel berm is included with each natural infrastructure alternative. The natural alternatives perform similarly over the armoring baseline: beach width is reduced initially by constructing the natural infrastructure but results in an overall greater shore width with sea-level rise (approximately 30 feet wider in the summer and 80 feet wider in the winter than baseline with 3.3 feet SLR).

NPS reach contains a few developed areas near the back of beach, whereas the rest of the reach has limited backshore development and thus can accommodate dune and beach transgression from sea-level rise. For areas with development, implementing natural infrastructure can lead to a sustained fronting winter shore width that is 30 to 60 feet greater than the armoring baseline with 3.3 feet SLR, providing greater protective services. The fore dunes in alternative 2 are forecast to result in a slightly wider shore with more dunes and less beach. Adding cobble (alternative 3) doesn’t provide much benefit except for a wider winter shore width.

Other considerations

Note that results for the baseline alternative (armoring) indicate that the winter beach for much of the shore would be mostly lost with 3.3 feet of sea-level rise without natural infrastructure. This finding is consistent with the C-SMART Vulnerability Assessment (Marin County 2016) that led to this study.

For alternatives with a cobble-gravel berm, the beach width results in Table 4 include portions of the cobble berm that are exposed above high tide. As the beaches reach their minimum width in winter, cobble and gravel will become exposed along the intertidal and upper beach face depending on the severity of winter storms and amount of sea-level rise that occurs. Thus cobble and gravel will make up portions of the winter beach width and these exposed portions of the cobble gravel berm will slowly become buried in sand over the summer.

Over time with sea-level rise, the shore will migrate toward developed areas. The landward extent of coastal flooding and erosion hazards will also migrate landward and the risk of damages to development will increase. The reduction of space between the development and migrating shore will also degrade coastal resources and reduce the space available for natural infrastructure to function. Here we review the modeling of shore change in terms of space needed for natural infrastructure function. This space needed is simply the space desired for natural infrastructure function minus the space available. This concept of "space needed" is useful toward developing design criteria for additional adaptive actions such as:

- Beach nourishment – widening the beach seaward by sand placement,
- Retreat or realignment – widening the beach and/or dunes landward by realigning development, and
- Hybrids – combining beach widening (beach nourishment and retreat) with other measures to reduce required space, such as engineered structures and raising homes on piles)

Beach width calculations for the armoring baseline assume that armor is placed to protect backshore development (homes, buildings) and the existing rock armor along Seadrift is maintained. The footprint of this new armor is not accounted for in the beach width results for Alternative 0. In reality, armoring will result in a reduced beach width due to the footprint of the armoring structure. For example, rock sloped revetments require a footprint roughly 10 to 30 feet wide or more depending on the type of structure.

6.2.3. Sensitivity of natural infrastructure widths to seasonal changes and storms

The nature-based adaptation alternatives are expected to provide benefits over the armoring baseline in terms of sustained shore width with sea-level rise. However, California natural foredune dynamics 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 growth, vegetation succession, and foredune accretion occur. This is an important consideration at Stinson Beach as foredune accretion potential is low (Study Memorandum 1) so recovery of eroded dunes depends on maintenance actions by humans.

Sensitivity analyses were performed to highlight the effects of seasonal shoreline changes and coastal storms on natural infrastructure widths. Two primary factors influence the performance of adaptation alternatives for sea-level rise protection. The first factor is that a nominal beach width was added to represent fall conditions when the alternatives would be constructed on dry beach before winter. Results in Table 4 were thus adjusted for seasonal fluctuations to illustrate the potential minimum and maximum beach widths for alternatives. Secondly, starting with the first winter after construction, seasonal shoreline fluctuations would impact the natural infrastructure to some degree. Over time, erosion of the dunes will trigger maintenance. Adjustment for these two factors reduced the performance of the baseline (Alt 0) more than the natural infrastructure alternatives (Alts 1 and 2).

Coastal storm impacts

While natural infrastructure widths in Table 4 indicate natural infrastructure could persist with up to 3.3 feet of sea-level rise under average conditions, coastal storms will continue to impact the Stinson shore as they have in recent decades (see Study Memorandum 1). Recent storm impacts to Stinson from the 2015-2016 El Nino winter include 45 to 65 feet of dune erosion in hot spots along the study area on the order of a couple hundred feet along shore. This 2015-2016 winter was considered a proxy for the 20-year event in this study.

Table 5 presents the probability of a given 20-year (5% annual chance) or 100-year (1% annual chance) coastal storm event occurring over the design life of natural infrastructure. The years for each SLR amount correspond to the Medium-High risk projection that OPC (2018) recommends for community planning. The probabilities of storm occurrence summarized in Table 5 indicate that portions of the constructed natural infrastructure (dunes and or cobble berms) will likely need to be rebuilt over time due to storm impacts before sea-level rise requires larger-scale maintenance actions for dunes and cobble berms. This study considers impacts of the 20-year event. This is a simplification; impacts for more extreme events, while less likely, can be more widespread and will need to be considered in further study.

TABLE 5. STORM EVENT PROBABILITY OF OCCURRENCE OVER TIME

SLR (m)	**SLR (ft)**	***Year****	Probability of event occurring between 2020 and ***Year***		Probable number of events occurring between 2020 and ***Year***	
			20-year event	100-year event	20-year event	100-year event
0.25	0.8	***2030***	40%	10%	0.5	0.1
0.5	1.6	***2046***	74%	23%	1.3	.3
1	3.3	***2067***	91%	38%	2.4	0.5

* timing from OPC 2018 Med-High projection

6.2.4. Engineering Costs of Adaptation Alternatives

Typical engineering unit costs were compiled from applicable sources to quantify the construction and maintenance costs of natural infrastructure features for long term sea-level rise impacts and storm event impacts. Table 6 lists engineering unit costs from comparable traditional and nature-based adaptation projects.

TABLE 6. COMPILATION OF ENGINEERING UNIT COSTS FOR SHORELINE ADAPTATION

Material	Unit[1]	Cost	Source
Beach-quality sand	CY	$45	Climate Ready Monterey Bay (ESA 2013) (inland/offshore sources)
Beach-quality sand	CY	$25	Pacifica LCP Adaptation Plan (2018) escalated from 2018. Offshore sources and 700,000 cubic yards.
Beach-quality sand	CY	$60	Pacifica BBIRP draft (GHD, 2021). 1,000,000 cubic yards.
Sand Embankment	CY	$15	Ocean Beach Sand Backpass Project. Free sand sourced within 5 miles. Unrestricted trucking of sand on roadway. Dumping and minor grading.
Cobble/Gravel Berm with sand cover	LF	$1,600	Ocean Beach Master Plan (SPUR 2012), which considered Surfers Point Phase 1 (constructed 2010)
Dune Vegetation Establishment	Ac	$9,000	Estimated for this study (see Appendix A)
Dune Vegetation Revegetation	Ac	$8,600	Humboldt Dunes removal of non-natives and invasives, planting and maintenance of desired native vegetation. Escalated from 2015.
Foredune Construction	Ac	$130,000 to $275,000	Surfers Point Phase 1 dune construction and planting with fencing. Range based on actual costs using volunteers and estimated cost with traditional construction contracting, escalated from 2012.
Dune Restoration	Ac	$116,000	Humboldt Dunes, including vegetation establishment, escalated from 2015.
Rock Revetment[2]	LF	$8,000	Pacifica Sea Level Rise Adaptation Plan (ESA 2018)
Rock Revetment	LF	$17,800	Pacifica BBIRP draft (GHD, 2021). 2,700 feet of shore.
Reinforced Concrete Seawall[2]	LF	$18,000	Pacifica Sea Level Rise Adaptation Plan (ESA 2018)

[1] CY=cubic yard; LF=linear foot; Ac=acre.

[2] Armoring baseline assumes Rock Revetment is used, Reinforced Concrete Seawall is provided for comparison

ESA estimates the following unit costs for the Stinson Beach adaptation alternatives shown in Table 7. These are preliminary estimates for alternative comparison, based on other projects with an expected uncertainty of +50% to -30%. These estimates do not include ancillary items of work that can increase actual project costs by up to 100%. Engineering, environmental review, permitting, construction administration and monitoring “soft costs” are not included.

TABLE 7. ENGINEERING UNIT COSTS SELECTED FOR STINSON ADAPTATION ALTERNATIVES EVALUATION

Material	Unit[1]	Cost
Beach-quality sand	CY	$45
Cobble/Gravel Berm with sand cover	LF	$1,600
Dune Vegetation Establishment	Ac	$9,000
Rock Revetment	LF	$8,000

[1] CY=cubic yard; LF=linear foot; Ac=acre.

Volumes to construct and maintain the alternatives for storms and 3.3 feet of sea-level rise were calculated from the constructed dimensions, shore evolution modeling described above and potential storm impacts that could occur during the timeframe for 3.3 feet sea-level rise. Table 8 presents the volumes of sand and cobble needed to build and maintain natural infrastructure at Stinson Beach for 3.3 feet of sea-level rise. These volumes may be lower or higher depending on storm impacts that occur during the project timeframe.

TABLE 8. ESTIMATED QUANTITIES TO IMPLEMENT NATURE-BASED ADAPTATION ALTERNATIVES

Materials	*Alternative 1*	*Alternative 2*
Construction		
Sand	**157,000 cubic yards**	**63,000 cubic yards**
Cobble	**95,000 cubic yards**	**255,000 cubic yards**
Dune Vegetation	**16.8 acres**	**6.3 acres**
Maintenance for storms and 3.3 feet SLR		
Sand	**326,700 cubic yards**	**118,000 cubic yards**
Cobble	**190,000 cubic yards**	**510,000 cubic yards**
Dune Vegetation	**4.1 acres**	**4.1 acres**

The probable construction and sea-level rise maintenance costs for the baseline and alternatives are summarized in Table 9. These costs only include the raw materials (sand, cobble/gravel, plantings) summarized in Table 8. Engineering design, permitting, and construction administration costs are not included but could be estimated as 30% of the engineering costs in Table 9. The adaptation baseline assumes a rock revetment is constructed along the development (e.g. existing Seadrift revetment) and is reconstructed after major storm events along 15% of the total structure (per maintenance records for the Seadrift revetment described by Noble et al 2007). The total engineering costs for a baseline that uses a reinforced concrete seawall can be 2-4 times the Baseline cost shown in Table 9. See Chapters 4 and 5 for detailed descriptions and figures of the nature-based adaptation alternatives.

TABLE 9. ENGINEERING COST ESTIMATES FOR STINSON ADAPTATION ALTERNATIVES

	Engineering costs for construction and maintenance with 3.3 feet SLR and coastal storm recovery for two events		
Reach	**Baseline**	**Alternative 1**	**Alternative 2**
Seadrift West	$39,900,000	$12,300,000	$12,300,000
Seadrift East	$39,500,000	$13,600,000	$12,200,000
Patios	$38,300,000	$4,800,000	$8,800,000
Calles	$26,900,000	$7,400,000	$7,000,000
NPS	$10,000,000	$7,500,000	$14,000,000
TOTAL	**$154,600,000**	**$45,600,000**	**$54,300,000**

Total engineering costs for the baseline assume existing armoring along Seadrift is intact, new armoring is constructed along the entire Patios and Calles reaches and only existing buildings are protected in NPS reach (other areas in NPS are allowed to erode). The cost for the baseline assumes reconstruction of all armoring at 3.3 feet sea-level rise. Costs for the alternatives include sand and cobble volumes needed to construct and sustain minimum feature widths with 3.3 feet of sea-level rise as well as sand volumes needed for coastal storm recovery maintenance. Minimum feature widths are set by storm erosion thresholds defined for each reach. Storm recovery assumes erosion impacts from a 20-year storm that occurs twice over the course of 3.3 feet of sea-level rise (i.e. year 2067, see Table 5 for storm occurrence probability versus sea-level rise).

Dune transgression with sea-level rise was calculated starting with constructed conditions shore profiles at existing sea-level. Given a lack of dune building observed (see Existing Conditions, ESA 2020a), dunes are not assumed to accrete with SLR. Additional sand volume and revegetation efforts are included in the SLR maintenance for dunes to maintain their overall height above the beach to maintain storm erosion and flooding protection. Storm erosion impacts were estimated assuming 30% of each reach is eroded during the design storm (based on Patios and NPS erosion extents measured from the pre and post 2015-2016 El Nino LiDAR data). Costs for recovery include sand volume and revegetation of eroded dune width. Dune erosion behind cobble berms was limited to 50% of erosion without cobble, owing to the dissipation of wave breaking and run-up provided by the cobble berm. Since lower-relief foredunes are naturally resilient to wave run-up and overtopping compared to artificial dune embankments (Figure 27), they may require less revegetation efforts after storms than estimated for this study.

SOURCE: ESA

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Figure 27
Wave run-up impacts on two dune types: Ocean Beach San Francisco dune embankment scarp is eroded (left) while Surfers Beach Ventura foredunes are overtopped yet resilient (right)

6.3. Storm Protection Benefits

Storm protection benefits of the alternatives were evaluated by comparing wave run-up with and without nature-based adaptation for initial constructed conditions and future conditions with sea-level rise. The extent of wave run-up was computed for two wave events representing the 20-year (March 2016) and 100-year (January 1983) coastal storms. The landward extent of the run-up was used, and a distance from the seaward edge of development was computed for comparison. Conceptually, the farther into the development the wave run-up extends, the lower the storm protection benefits. The wave run-up results for the two alternatives assume that dune and cobble features are maintained above the minimum threshold dimensions for storm erosion protection (see Section 6.2).

6.3.1. Design storm event protection

The 20-year coastal storm is used to evaluate the alternative protective services since it is the benchmark event used to size and maintain the alternatives in the Design Life Analysis (Section 6.2). Table 10 presents the 20-year coastal storm wave run-up extents relative to the location of backshore development within each reach. The results show that the presence of dunes and cobble berms can reduce wave run-up through physical obstruction as well as the increased roughness provided by dune vegetation and cobble/gravel when compared to flat bare sand fronting an armoring structure. The Seadrift revetment is overtopped by the 20-year event. Patios and NPS reaches are buffered by existing dunes but seaward-most properties in the Calles reach are exposed at existing sea level. Maintained natural infrastructure alternatives can reduce the landward extent of wave run-up and are therefore considered to provide a protective service (benefit). However, the calculations indicate that natural infrastructure alternatives may provide complete protection in some locations when adequately maintained.

TABLE 10. WAVE RUN-UP REDUCTION OF 20-YEAR STORM EVENT BY NATURE-BASED ADAPTATION ALTERNATIVES

	Inland Wave Run-up Extent, feet relative to backshore development Positive (+) is seaward, Negative (-) is landward					
	Constructed conditions at existing sea level			Future conditions with 3.3 feet sea-level rise		
Reach	**No Alt**	**Alt 1**	**Alt 2**	**No Alt**	**Alt 1**	**Alt 2**
Seadrift W	-71	-39	-39	-130	-52	-52
Seadrift E	-92	11	-80	-112	-69	-88
Patios	26	79	83	-22	22	35
Calles	-102	29	24	-150	-35	-3
NPS	0	79	79	-43	-3	2

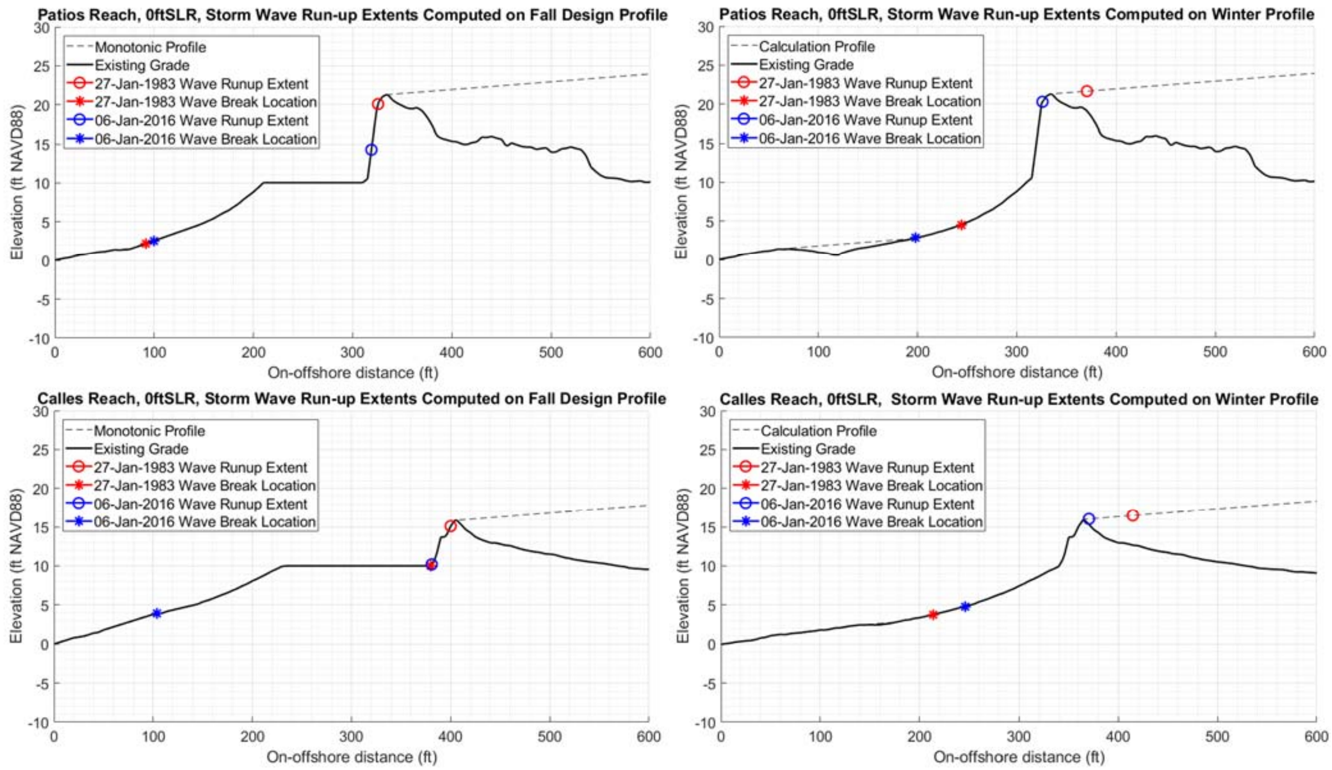
6.3.2. Sensitivity of wave run-up to seasonal changes and storms

The wave run-up results in Table 10 account for average seasonal beach width fluctuations in each reach that would occur after the alternatives are constructed on a fall beach profile. Wave run-up impacts may be different than reported in Table 10 depending on timing of wave run-up event(s), the actual reductions of natural infrastructure widths from seasonal changes, and erosion during stormy winters (El Ninos) or singular extreme events. This section discusses the sensitivity of wave run-up computed for the alternatives evaluation to these factors. Natural infrastructure constructed along Stinson Beach will be stressed by seasonal shoreline changes that can reduce the effectiveness of natural infrastructure at reducing wave run-up during storms. Wave run-up during a storm that occurs in late fall (when the beach is still wide) will not extend as far landward as a similar storm that occurs during late winter (when the beach is narrowest from cumulative effects of stormier conditions. To highlight the effect of a wide beach on run-up extents, wave run-up computed using the January 2019 winter profile are compared to the run-up extents given a 100-foot wide beach berm. The differences in run-up extents between the late fall (100-foot beach berm added to the 2019 winter profiles) and late winter profile conditions are shown in Table 11.

TABLE 11. COMPARISON OF 20-YEAR STORM WAVE RUN-UP EXTENTS FOR LATE-FALL AND LATE-WINTER BEACH CONDITIONS FOR THE ARMORING BASELINE

Inland Wave Run-up Extent, feet relative to backshore development Positive (+) is seaward of development, Negative (-) is landward			
Reach	**Late Fall**	**Late Winter**	*Difference*
Seadrift W	-7	-33	*-26*
Seadrift E	-4	-14	*-9*
Patios	66	59	*-7*
Calles	-46	-75	*-30*
NPS	39	22	*-17*

Without the nominal beach berm added, wave run-up extends 10 to 30 feet further landward assuming the same conditions landward of the beach. Calles reach shows the greatest difference in run-up extents because it has no backshore dunes and is thus lower in elevation, whereas the Patios reach shows the smallest difference in run-up given its existing dunes with a steep dune face. The 20-year results in Table 11 correspond to the 2016 wave event plotted in Figure 28. The plots depict the wave breaking location (star) and run-up extent (circle) corresponding to maximum events from 1983 (red) and 2016 (blue). Run-up was computed on the existing shore profile (black line) with calculation profile shown (dashed line). Wave run-up results in Table 10 account for average seasonal adjustments that were observed in each reach and documented in Study Memorandum 1.



SOURCE: ESA

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Figure 28
Comparison of wave run-up extents for Patios (left) and Calles (right) profiles with (top) and without (bottom) 100-foot beach berm

Wave run-up extends further landward when the beach is narrow in winter (right plots) for each wave event compared to the design fall profile (left plots) that includes a 100-foot wide beach berm. Top plots show the Patios profile with taller dunes that buffer wave run-up with and without the beach berm. Bottom plots show the Calles profile, where the lack of taller dunes leads to a greater difference in wave run-up without the beach berm. These results indicate that gravity (a barrier with higher elevation forces wave run-up upward against gravity) is the dominant factor in reducing wave run-up compared to roughness over a distance (e.g. vegetation and minor topography changes). While this may indicate a taller dune embankment is preferable, lower foredunes may prove to be more resilient during wave events (Figure 28) and provide other benefits, most notably native ecology.

Extreme storm wave run-up reduction

While the natural infrastructure alternatives are not designed to withstand wave run-up and erosion from more extreme events (e.g. 100-year storm), they can reduce the overall impacts to coastal development. This potential reduction of storm impacts is quantified in terms of inland wave run-up extents for a representative extreme coastal event modeled on the winter shore profile. Table 12presents the inland wave run-up extents computed for the January 1983 El Nino event used as the characteristic 100-year storm. Protection benefits provided by well-maintained natural infrastructure is limited with 3.3 feet of sea-level rise, but the results show that these features do reduce the overall inland wave run-up extent compared to the armoring baseline.

See Section 6.3.3 for discussion on results sensitivity to seasonal changes and storms. The results account for seasonal adjustments that would occur over the winter after construction of alternatives during late fall. Overall, the relative benefit of Alt 1 and 2 depends on the beach conditions at the time of the 100-year event. Note that the run-up results presented below do not include the beach and dune erosion that would occur during the 100-year storm and hence likely underestimate inland wave run-up extent.

TABLE 12. WAVE RUN-UP REDUCTION OF 100-YEAR STORM EVENT BY NATURE-BASED ADAPTATION ALTERNATIVES

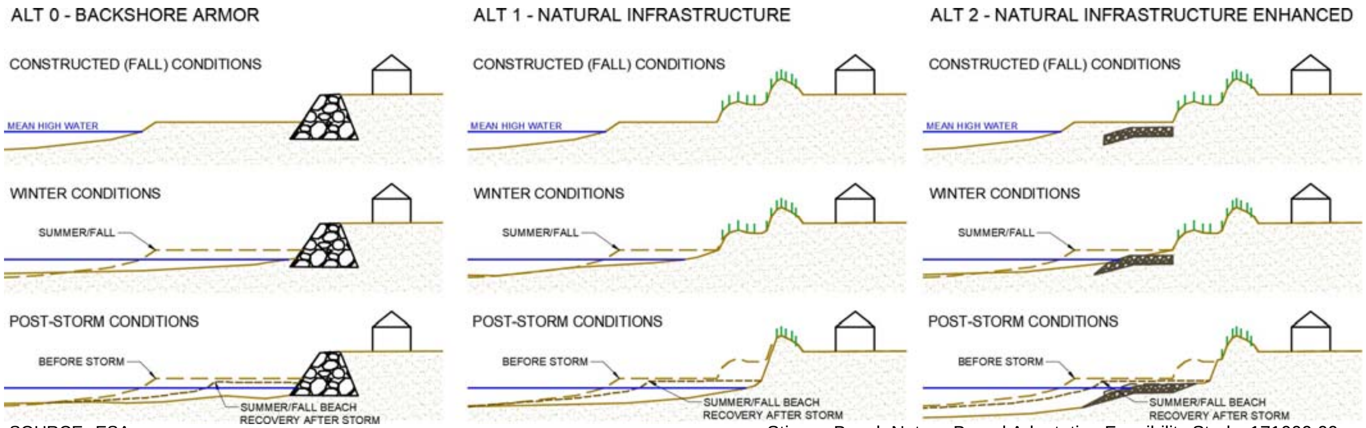
	Inland Wave Run-up Extent, feet relative to backshore development Positive (+) is seaward, Negative (-) is landward					
	Constructed conditions at existing sea level			Future conditions with 3.3 feet sea-level rise		
Reach	**Alt 0**	**Alt 1**	**Alt 2**	**Alt 0**	**Alt 1**	**Alt 2**
Seadrift W	-107	-49	-49	-213	-152	-152
Seadrift E	-118	-30	-83	-160	-100	-99
Patios	-19	38	37	-111	-18	1
Calles	-176	-35	10	-266	-186	-63
NPS	-30	1	0	-69	-34	-26

6.4. Geomorphic Changes and Ecologic Benefits

Nature-based adaptation alternatives increase the resiliency of a dune and beach system compared to traditional shoreline armoring approaches. The following sections discuss the geomorphic changes expected after the implementation of the adaptation alternatives (Section 6.4.1) and resulting benefits to shore ecology (6.4.2).

6.4.1. Geomorphic Changes from Natural Infrastructure Implementation

Nature-based approaches can change shore geomorphology in a way that provides benefits to beach ecology by harnessing the dissipative effects of natural infrastructure, as well as their ability to recover seasonally and after storms. In contrast, traditional shore protection structures tend to exacerbate beach erosion and suppress recovery, thereby degrading ecology as the shore evolves over time. Conceptual cross sections of the baseline and adaptation alternatives are shown in Figure 29 to illustrate the typical geomorphic response of each alternative to seasonal changes and coastal storm impacts. The typical conditions associated with each alternative are described below for constructed (fall) conditions when a wide beach is present, in late winter when the beach is narrowest and after an extreme coastal storm event.



SOURCE: ESA

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Figure 29
Conceptual schematics of seasonal shore morphology for adaptation alternatives

Constructed (Fall) Conditions: The top schematic for each alternative depicts typical conditions after construction in the fall when a wider beach is present. A rock revetment is shown for the armoring baseline (Alternative 0), compared to dunes (Alternative 1) and dunes with cobble berm (Alternative 2).

Winter Conditions: The middle schematics show potential conditions after winter, when the beach is narrowest. Without natural infrastructure the beach may shrink to a narrow band of wet sand or disappear in front of armoring even during an average winter. Seadrift West, which has only a narrow beach in summer months and limited wet intertidal slope in winter, provides an example of potential winter conditions that could develop in other reaches if an armoring approach is taken in other reaches. For natural infrastructure alternatives, winter erosion of the beach may impact existing or constructed dunes at the back of beach depending on how stormy a winter is and whether a cobble berm is included. Cobble berms that are buried within the beach footprint may become exposed during the winter.

Post-storm Conditions: The bottom schematics show typical conditions after an extreme coastal storm event during which the beach is eroded. The armoring alternative may lose much if not all dry beach during the storm and experience scour at the toe of the armoring structure, leaving less sand available for beach recovery. The alternatives with dunes can reduce the overall beach erosion and aid in quicker beach recovery. The dunes provide new sand volumes to release during erosion events, and enlarge the volume of sand available where dunes are present. This volume is however finite and can be overcome by consecutive storms. The dunes erode to a lesser extent when a cobble berm is placed in front of the dunes. The cobble berm will deform and migrate inland during the storm or series of storms, as described in Section 6.2.1,.

The benefits of natural infrastructure to shore ecology functions are further described below.

6.4.2. Ecological Benefits of Natural Infrastructure

Natural infrastructure alternatives proposed at Stinson Beach would provide direct benefits to ecology by increasing the longevity of a sandy beach and dunes. Pacific Coast sandy beaches are shaped by their morphodynamic state and by significant biological inputs of macroalgal wrack and associated nutrients from the adjacent nearshore marine ecosystem. Sandy beaches of the California coast are inhabited by a wide array of shorebird species that use beaches for both roosting and foraging. Most shorebird species that occur at Stinson Beach are present in winter and during spring and fall migration periods with the exception of the federally listed western snowy plover, which occasionally nests on the outer spit and uses Stinson Beach for foraging and roosting throughout the year. In the Stinson Beach region, shorebird abundance on sandy beaches is correlated with macroinvertebrate abundance, species richness, and biomass (Nielsen et al. 2013), underscoring the importance of invertebrate foraging resources for shorebirds. Sandy beaches also play an important role as alternate habitat for estuarine and intertidal-associated shorebirds, many of which are experiencing declines in global population size (Rosenberg et al. 2019). The proximity of Bolinas Lagoon to Stinson Beach likely influences both species diversity and overall abundance of shorebirds using Stinson Beach. See Study Memorandum 1 (ESA 2020a) for more information on shorebirds at Stinson Beach.

Dunes: Dunes provide protection to development while maintaining beach width longer than 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. Dunes are especially beneficial during winter when the beach is narrowest. For example, during field visits in December 2019, the beach in front of Seadrift was absent, lacking the beach berm with wrack that supports invertebrates that shorebirds feed on. Compare this condition to the Patios reach which has dunes, a beach was present, even at high tide, providing space for foraging shorebirds. While both types of dunes can increase resiliency of beaches, lower foredunes are a more natural form in areas of narrow shores and support native flora and fauna. 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.

Sand lens atop constructed cobble berms at Surfer's Beach in Ventura County (left) and Pacifica State Beach (right). Source: Bob Battalio

In summary, the utilization of natural infrastructure features for shoreline adaptation at Stinson can help sustain an overall wider shore area that includes sandy beach, vegetated dunes, and/or cobble gravel berm compared to traditional armoring. Table 13 quantifies the relative ecologic benefits provided by the natural infrastructure alternatives, calculated as the difference in winter and summer shore width between the baseline (Alternative 0) and nature-based alternatives (Alternative 1 or 2). The overall shore width includes beach and dune width (winter beach width includes some cobble), as adjusted for winter and subsequent summer widths shown in Table 4. The results show that the surplus shore width is greatest in winter when storms impact the shoreline, which indicates the greater protective services of the nature-based alternatives (see Section 6.3) as well as increased benefits to ecology (migrating shorebirds during winter season). Both nature-based alternatives provide a wider shore for nearly all reaches in summer and winter, indicating benefits to shore ecology in the form of sustained high intertidal habitat, wrack deposition and resulting macroinvertebrate populations and shorebird roosting/foraging habitat. Alternative 1 in Patios reach has less shore width surplus over the baseline owing to the existing dunes in this reach.

TABLE 13. BENEFITS OF NATURE-BASED ADAPTATION ALTERNATIVES COMPARED TO ARMORING BASELINE

	Winter Shore Width Surplus		Summer Shore Width Surplus	
Reach	**Alt 1**	**Alt 2**	**Alt 1**	**Alt 2**
Seadrift W	59	59	36	36
Seadrift E	14	59	14	0
Patios	5	74	5	47
Calles	83	79	36	36
NPS	27	59	27	40

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 vegetation 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 actions (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 will depend on external climate variables and related intensification of maintenance and repair actions. A “best-case” scenario for vegetation would entail weak storm conditions for 1-3 years after initial construction and revegetation, coinciding with average to wet well-distributed winter and spring rainfall. A “worst-case” scenario would entail either extreme heat or drought events (especially winter drought) coinciding with the first growing season after vegetation, or major storm erosion within the first 1-2 years. These circumstances are not readily predictable. Adaptive management based on contingencies for substantial supplemental revegetation or sediment replacement may be needed to offset ecological uncertainties.

If optimal or substantially successful vegetation outcomes are reached, the Stinson Beach foredune system may provide the longest foredune dominated by native vegetation on the North-Central Coast, and the largest population of North Coast pink sand-verbena, for a decade or more. Longer-term sustainability of the foredune under higher sea levels, however, would likely depend on landward transgression of the foredune zone, which is precluded by development except in the NPS reach. The NPS reach, therefore, is the most likely segment to sustain long-term ecological benefits for foredune vegetation. Additional background information on beach and foredune vegetation zones and dynamics, including conceptual planting plan and costs for Stinson Beach, are provided in Appendix A.

6.5. 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 because it is primarily “rough grading” of imported 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.

6.6. Environmental Impacts and Regulatory Considerations

Environmental impacts associated with the baseline and natural infrastructure alternatives are discussed in terms of beach (onshore) and benthic (nearshore) ecology. For this study, environmental impacts are discussed with regards to ecosystem functions that affect shorebirds, invertebrates and natural beach flora. Impacts from each alternative include construction activities, effects on long term cross-shore and longshore sediment transport, and maintenance activities. Regulatory considerations are also summarized for the various agencies with jurisdiction near the study area. Table 14 presents a qualitative ranking of adverse ecological impacts that may occur as a result of the baseline armoring and natural infrastructure adaptation alternatives.

TABLE 14. ECOLOGICAL IMPACT OF ADAPTATION ALTERNATIVES

Qualitative Ranking of Adverse Impacts (High to Low)			
Reach	**Alt 0**	**Alt 1**	**Alt 2**
Seadrift West	High	Medium	Medium
Seadrift East	High	Medium	Medium
Patios	Medium	Medium	Medium
Calles	Medium	Low	Medium
NPS	High	Low	Medium

The natural infrastructure modeling results from Table 4 were used to rank the ecological impacts in each reach. We assume that a greater beach and dune width results in more positive ecological benefits so any reduction in width from existing conditions is considered a negative impact. We also assume that all three alternatives will have impacts from either construction, maintenance or both. However, we assumed that the ecological impacts of construction and maintenance of Alternative 2 would be greater than Alternative 1 because of the introduction of non-native cobble to the system that could crush or otherwise harm invertebrates when exposed to wave action. We assume the ecological impacts from the armoring alternative are the greatest because in addition to impacts from maintenance that would be similar to the other alternatives, we assume that scour from existing and new armor could increase erosion when exposed and degrade ecological functions. We find that in general, the ecological impacts of Alternatives 1 and 2 are less than the armoring alternative. Additionally, we find that the impacts of Alternatives 1 and 2 are similar in the Seadrift East and Patios reaches. However, in the Calles and NPS reaches, we find that sufficient beach and dune width is protected in Alternative 1 so the additional ecological impacts of Alternative 2 outweigh protective ecological benefits within these reaches. Specific environmental impacts are discussed in the following subsections.

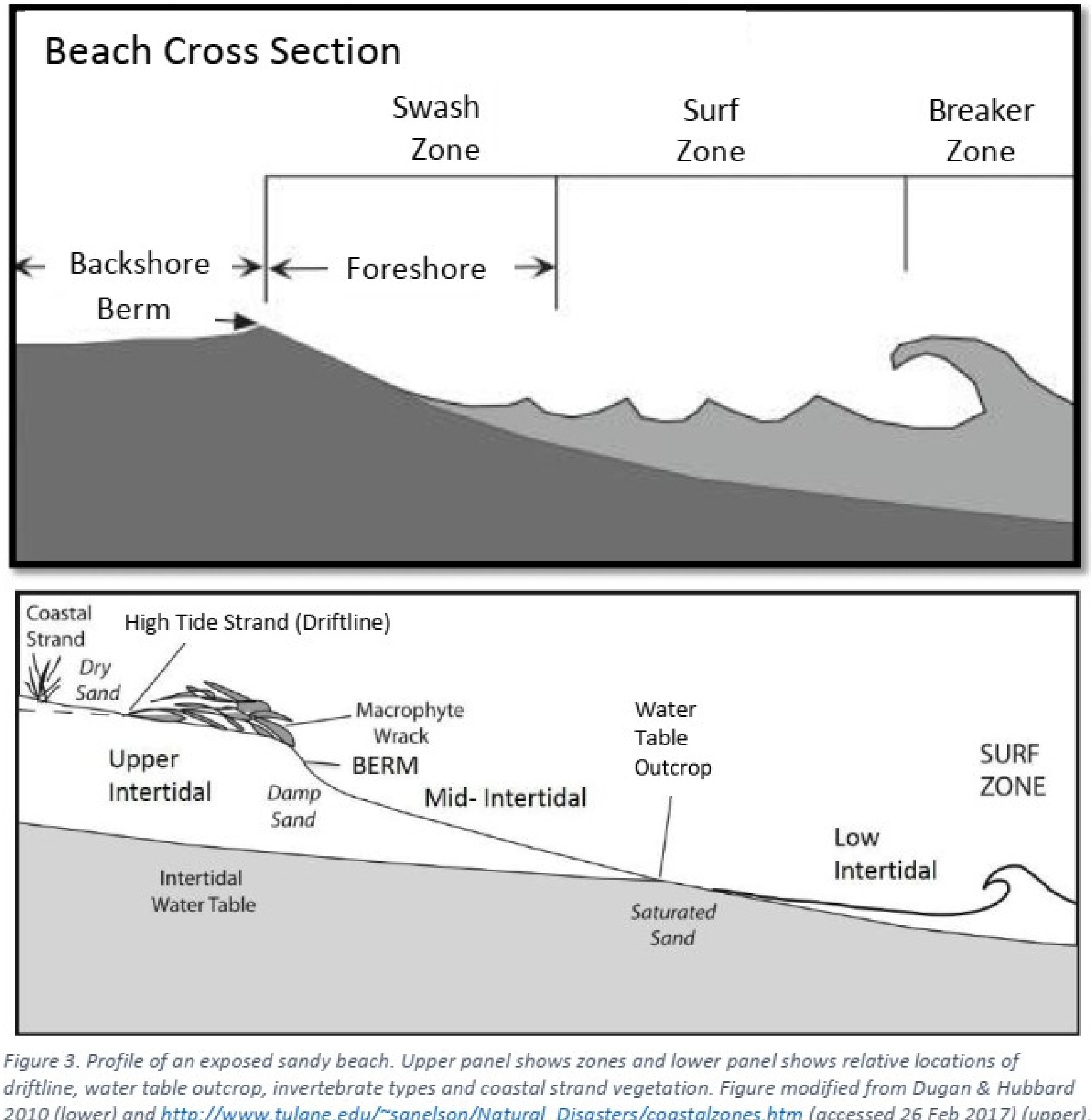
All of the alternatives, including the baseline, have adverse impacts at construction and during maintenance. In addition, the team anticipates a net degradation in ecology over time due to erosion of the beaches and foredunes with sea-level rise and the effects of existing armoring. The relevant point of comparison isn't how the alternatives compare to existing conditions, but rather how the natural infrastructure alternatives compare to the traditional armoring adaptation approach. Relative impacts were computed to illustrate the comparative performance of Alternatives 1 and 2 to the baseline. Relative scores were calculated by subtracting the Alt 0 scores from Alt 1 and Alt 2 in Table 14 above. Negative scores mean less impact than the baseline. Table 15 illustrates that nature-based alternatives can have less environmental impacts overall than traditional armoring approach to shoreline protection. See Section 6.4 for descriptions of the geomorphic and habitat benefits that natural infrastructure provides over armoring.

TABLE 15. RELATIVE ECOLOGICAL IMPACT OF NATURE-BASED ADAPTATION ALTERNATIVES COMPARED TO TRADITIONAL ARMORING

Relative Impact Score (compared to armoring baseline Alt 0)*		
Reach	**Alt 1**	**Alt 2**
Seadrift West	lower	lower
Seadrift East	lower	lower
Patios	similar	similar
Calles	lower	similar
NPS	much lower	lower

6.6.1. Potential Impacts to Beach and Benthic Ecology

Shore ecology is discussed in terms of beach (onshore, dry) and benthic (offshore, subtidal). Figure 30 shows a typical shore cross section (top) with the backshore berm (i.e. dry beach), swash, surf, and breaker zones at the top panel. Ecological features are shown on the lower panel.



SOURCE: Neilsen et al 2017

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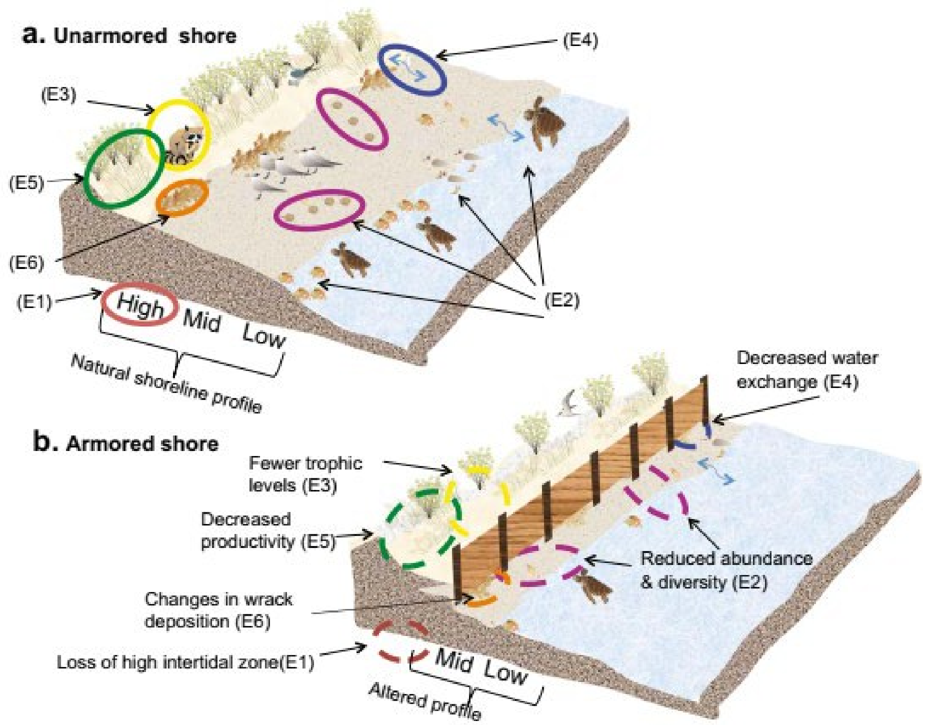
Figure 30
Beach geomorphic and ecology zones

Potential changes to beach and benthic ecology for the armoring baseline are illustrated in Figure 31 below from Dugan 2017. The graphic provided shows that armoring an eroding shoreline leads to loss of high intertidal zone and corresponding reduced species abundance and diversity, fewer trophic levels on the shore, decrease water exchange, decreased productivity and changes in wrack deposition. In contrast, natural infrastructure implementation will have temporary impacts to the shore via construction and maintenance but over time increases beach longevity and its ecological functions with sea-level rise. The potential impacts are discussed in the following sections.

Fig. 3 Comparison between unarmored (**a**) and armored (**b**) shorelines, with examples of effects for the six ecological responses evaluated in this review (E1 habitat distribution, E2 species assemblage, E3 trophic structure, E4 nutrient cycling, E5 productivity, E6 connectivity). *Broken ellipses* in panel **b** signify negative impacts and correspond to the ellipse of the *same color* in panel **a**



SOURCE: Dugan 2017

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Figure 31
Comparison of unarmored and armored shoreline and ecological responses, adapted from Dugan 2017

Onshore Beach Ecological Impacts

Construction 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. Sediment placement directly on intertidal zones of sandy beaches causes mortality of invertebrates resulting from direct burial by sediments and from crushing and mechanical disturbance from heavy machinery (Schlacher et al. 2014). Construction equipment can cause significant mortality of surface-dwelling wrack-associated invertebrates (e.g., Talitrid amphipods) and soft-bodied benthic invertebrates associated with the wet and semi-wet beach areas. Burial of kelp wrack during construction also may inhibit the re-population of affected reaches by wrack-associated invertebrates, which are dependent on the presence of wrack for dispersal and are only capable of dispersing small distances (Grantham et al. 2003). The probability of these 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. Maintenance or reconstruction of natural infrastructure (i.e., application of additional sediment or cobble, shaping of topographic features) that results from expected erosion will result in similar, repeated impacts to sandy beach invertebrate populations. Because invertebrate populations may be relatively slow to recover after significant disturbances (Schlacher et al. 2014), the time between planned maintenance events will have a large influence on the relative level of overall impact.

Installation of the natural infrastructure typologies also may result, in some cases, in a conversion of flat, sparsely vegetated beach habitat to more continuously vegetated foredune habitat, and narrowing of the existing beach. Conversion of the area above MHW to dunes, dune embankments, or cobble will result in a reduced amount of gently sloping beach above MHW and the slope of the converted area above MHW likely will increase. More steeply sloped beaches are less suitable for shorebirds that forage in the swash zone (Neuman et al. 2008) and also may negatively impact species, such as the western snowy plover, that typically occupy the gently-sloped, semi-wet to dry shoreline above MHW. Available swash zone habitat also will decrease which may limit foraging opportunities for shorebirds in the affected areas. Because surface-dwelling and sub-surface dwelling invertebrate taxa are the primary prey of shorebirds on sandy beaches, construction and maintenance of the natural infrastructure typologies may have negative impacts on shorebird use of the affected reaches, with less overall use of the altered habitats above MHW and potentially less use of the swash zone. The backshore beach is also habitat for seedling establishment (“nursery” habitat) for some rare strand plant species, like North Coast pink sand-verbena. Habitat trade-off between unvegetated or sparsely vegetated flat sand beach (invertebrate and shorebird habitat), to more terrestrial vegetated foredune (vascular plant and terrestrial insect habitat) is a direct consequence of constructing vegetated foredune features in the backshore.

Under the baseline 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). In contrast, implementing the nature-based adaptation alternatives will help maintain high intertidal zones along the shore, reducing the long term negative ecological impacts of sea-level rise at Stinson Beach.

Nearshore Benthic Ecological Impacts

The nearshore zone along the entire length of Stinson Beach is comprised of sand bottom habitat while rocky reefs are found extending off Duxbury Point (Duxbury Reef) to the northwest and Rocky Point to the south of the study area (Merkel & Associates 2019). Details on benthic habitats and features are detailed in Study Memorandum 1 (ESA 2020a). Adaptation alternatives proposed on and above the dry beach will have limited to no impacts to nearshore ecology.

The ecology of the subtidal environment within the project area is expected to reflect the dynamic nature of a wave exposed sand bottom habitat. Organisms in this environment are adapted to transitory sand movement and either adapt by vertical movement in the sediment (e.g., polychaetes and bivalves), or lateral movement up and down the beach (e.g., most arthropods, fish). In addition, sand beaches have a significant component of effectively short-lived annual species that are decimated in abundance during storm periods when the sand substrate disturbance is greatest and then recruit heavily during the spring months. This active beach community is well adapted to shifting sand conditions driven by natural seasonal cycles, and it is resilient to differences in the intensity of disturbance that occur with infrequent major storms.

The adaptation alternatives evaluated in this study are restricted to actions proposed on the high beach environment and none of the alternatives are expected to have a substantial impact on the characteristics of the subtidal beach environment below the swash zone. While an argument may be made that some of the alternatives may favor expanded or reduced beach erosion and thus transport of sediment long-shore or offshore, the character of the subtidal environment would not change from baseline under any of the alternatives considered. As a result, the nearshore environment would remain a sandy soft bottom habitat with seasonal and localized dynamism due to wave climate conditions.

6.6.2. Regulatory Considerations

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.

Alternatives 1 and 2 would require close collaboration with a number of permitting and resource agencies during the project planning and regulatory compliance process. Study Memorandum 4: 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.

Additional information on regulatory issues are discussed in Study Memorandum 4. Regulatory and Policy Considerations.

6.7. Public Access

Public access across and along the shoreline is important to maintain; the beach is visited by millions of people annually including local residents. The natural adaptation alternatives provide long term benefits to public access while having some temporary impacts. Traditional armoring structures can lead to a loss of fronting beach and hindered public access as seen along the western portion of Seadrift during winter months. With sea-level rise, beaches in front of armoring structures along the rest of the study area may be lost during winter. The following sections summarize the benefits and impacts of natural adaptation to public access.

6.7.1. Benefits to public access

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, while it’s not possible to maintain existing beach widths with sea-level rise, the natural infrastructure alternatives result in wider beach widths compared to the Alternative 0 baseline.

6.7.2. Impacts to public access

Public access impacts are discussed in terms of potential impacts during construction, potential impacts during coastal storms and considerations for long term shore evolution with sea-level rise.

Construction period access

Construction of natural infrastructure for adaptation would ideally occur during late fall when beaches are wide and recreation is lower. 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.

Access during coastal storm flooding and erosion 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.

Example of reduced lateral access along Seadrift rock revetment in winter illustrates potential long term beach conditions with sea-level rise and/or post-storm conditions for the traditional armoring baseline (Peter Baye 2019)

6.8. Adaptation Alternatives Evaluation Summary

The evaluation of baseline and nature-based adaptation alternatives is summarized in Table 16 below. Scores ranging from 1 (worst) to 5 (best) were developed for the various evaluation categories. The scores are based on qualitative analysis performed to estimate construction effort and costs, shore width modeling, wave run-up calculations, and interpretations of shore widths for the purpose of ecology and recreation/public access and expert elicitations regarding ecologic impacts and regulatory considerations.

The sum of scores are, out of a maximum of 35:

- Alternative 0 – Baseline Armoring = 11
- Alternative 1 – Natural Infrastructure (dunes, some cobble berms) = 23
- Alternative 2 – Natural Infrastructure Enhanced (dunes with cobble berms) = 21

The baseline armoring scores relatively poorly because of lower scores for all criteria. Alternative 1 which focuses on sand dunes with limited cobble armor scores the highest, and adding cobble berms (Alternative 2 scores slightly lower. Different weighting of the numerical scores can represent different perspectives and judgments, and there are uncertainties associated with the scores. For example, cobble berms may be considered armoring similar to rock revetments and hence rank lower in regulatory considerations. Sand sources and cobble-gravel sources have not been identified, and there may be reduced reliability with natural features verses structures, both of which could increase the cost of the natural infrastructure and hence lower their "cost" ranking. However, the rankings for natural infrastructure (Alternatives 1 and 2) are substantially higher than armoring (Alternative 0) and therefore likely to remain so even with refined different scores and weights.

TABLE 16. ADAPTATION ALTERNATIVES EVALUATION MATRIX

Category	Design Life Analysis	Storm Protection Levels	Coastal Habitat Benefits	Environmental Impacts	Regulatory Considerations	Public Access Benefits	Constructability	Total Score (Sum)
Metric[1]	Cost	Run-up and Erosion Reduction Potential	Beach and Dune Resilience	Expert Elicitation	Expert Elicitation	Beach Width	Methods and Materials	
Alternative 0 Backshore armoring baseline for comparison	**Score: 2** **$155M to construct and maintain with 3.3 ft SLR** Armoring structures will require costly upgrades and repairs as sea-level rises and beaches erode, leading to more frequent wave overtopping potential..	**Score: 2** **Two reaches overtopped today, three reaches with 3.3 ft SLR.** Armoring structures can withstand erosion from waves but are overtopped during storm events, especially when fronting beach width and elevation is low (from sea-level rise effects and/or due to the reflective nature of armoring that increases beach erosion).	**Score: 1** **Average shore width with 3.3 feet SLR: 49 feet winter to 121 feet summer** Armoring structures create a barrier to sediment exchange between the beach and any dunes behind them, this leads to beach loss on eroding shores (Seadrift is an example). NPS reach could retain more dunes with SLR given the reduced extent of armoring needed to protect development in this reach. Otherwise beaches along the shore may disappear in front of continuous armoring structures with as little as 1 to 3 feet SLR.	**Score: 1** **Medium-High Impacts** Armoring structure construction and maintenance impacts beach ecology. Over time and during storms, scour at armoring structures increases beach erosion and degrades habitat functions including loss of high intertidal zone and corresponding reduced species abundance and diversity, fewer trophic levels on the shore, decrease water exchange, decreased productivity and changes in wrack deposition.	**Score: 1** Alternative 0 may be difficult to approve for this location due to environmental impacts and the fact that less ecologically damaging alternatives exist.	**Score: 2** **Average beach width 30 feet winter to 109 feet summer with 3.3 feet SLR** Hard armoring reflects wave energy during storms and can increase beach erosion, leading to loss of lateral beach access. Armoring structures are more difficult to traverse when exposed and require additional cross-shore access such as stairs.	**Score: 1-2** Armoring structures require more rigorous construction preparations and methods but are straightforward. Rock revetments require base prep and additional equipment and care during rock placement; reinforced concrete seawalls require base prep, rebar and forming and concrete pouring.	**Score Total: 11**
Alternative 1 Natural infrastructure (dunes, some cobble berms)	**Score: 3** **$46M to construct and maintain with 3.3 ft SLR** The sandy shore naturally responds to SLR with less intervention over time resulting in a more resilient beach. Stormy winters and extreme events may increase maintenance requirements.	**Score: 3** **One reach overtopped today, two reaches overtopped with 3.3 ft SLR.** Properly maintained natural infrastructure can reduce wave run-up and impacts to development. Dunes respond dynamically to wave run-up during storms and maintain beach width and elevation compared to armoring. However, maintenance will be needed after extreme events and stormy winters.	**Score: 3** **Average shore width with 3.3 feet SLR: 77 feet winter, 144 feet summer** Constructing and widening dunes increases the adaptive capacity of beaches for sea-level rise. Sand eroded from the dunes during winter or a given storm dissipates wave energy and nourishes beaches, thereby making the sandy beach relatively higher, wider and more persistent than without dunes. Foredunes also provide foraging opportunities and other habitat features for beach organisms.	**Score: 3** **Medium-Low Impacts** Construction and maintenance will impact beach ecology via construction activities and habitat conversion from beach to dune. However, beach erosion is reduced over time by presence of dunes, prolonging ecological functions over armoring Alternative 0.	**Score: 4** Alternative 1 would require construction activities including placement of fill. 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 and stakeholder approval.	**Score: 3** **Average beach width 40 feet winter to 108 feet summer with 3.3 feet SLR** Dunes provide sand to maintain beaches over time with SLR and after storms, preserving beach recreation area and lateral shore access. Placement of natural infrastructure reduces recreation area on beaches initially but results in a more resilient and accessible beach-dune shore form. Cross-shore access through foredunes provided by roped or fenced paths. Dune embankment requires more significant access features such as stairways	**Score: 3-4** Nature-based alternatives are highly constructible, however the availability of sand and cobble is unknown. Sand-only dunes are easiest to construct without the need for over-excavation to place cobble berm.	**Score Total: 23**
Alternative 2 Natural infrastructure enhanced (dunes with cobble berms)	**Score: 3** **$54M to construct and maintain with 3.3 ft SLR** Cobble berms increase the resilience of the shore width by reducing wave run-up on dunes and the erosion caused over time and during storms. Stormy winters and extreme events may increase maintenance requirements.	**Score: 3** **One reach overtopped today, two reaches overtopped with 3.3 ft SLR.** Introducing cobble berms adds protective benefits in the form of increased roughness that reduces wave run-up and erosion of dunes behind them that further buffer wave run-up.	**Score: 4** **Average shore width with 3.3 feet SLR: 105 feet winter, 149 feet summer** Cobble berms lengthen the functional life of dunes behind them, but can be exposed during storm events/winters. However, native invertebrates and insects can live in cobble shores, providing food for other fauna and an overall ecological benefit compared to armoring. Cobble berms also facilitate sand beach recovery and reduce wave impacts to sand dunes behind them.	**Score: 2** **Medium Impacts** Similar construction impacts as Alternative 1, with slightly more beach and dune area preserved with sea level rise. Addition of cobble-gravel berm introduces potential for invertebrate crushing or other impacts when exposed to wave action.	**Score: 3** Alternative 2 requires a more extensive construction process and placement of more cobble berm than Alternative 1. Due the potential environmental impacts of the project construction and the placement of material in these highly protected and ecologically sensitive locations, this alternative would require additional scrutiny and review by permitting agencies, presenting a relatively more challenging permitting scenario than Alternative 1.	**Score: 3** **Average beach width 56 feet winter to 100 feet summer with 3.3 feet SLR** Compared to Alt 1, Alt 2 may maintain upper beach and dunes longer with use of cobble berm, better preserving lateral shore access. Results indicate similar Cross-shore access through foredunes provided by roped or fenced paths. Dune embankment requires more significant access improvements	**Score: 2-3** Nature-based alternatives are highly constructible, however the availability of sand and cobble is unknown. Cobble berms require additional effort to over-excavate sand, place and bury the cobble berm.	**Score Total: 21**

[1]Score ranges from worst (1) to best (5).

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7. Long-term Adaptation Pathways for Stinson Beach

The distinction between near-term and long-term shore adaptation alternatives is based on projected sea-level rise. With sea-level rise, the Pacific shoreline will migrate landward. The beach will become narrower as the shore approaches the existing development. The reduction in available space between the shore and development will make nature-based infrastructure less sustainable – indeed, the beach is part of the natural shore infrastructure at Stinson Beach. The beach and other natural shore infrastructure types can be maintained by reconstruction but the frequency of damage and reconstruction will increase with rising sea levels, likely reaching practical limits. Therefore, additional adaptation measures for the study reaches are likely to be needed later in the century when sea levels rise over 3 feet.

A range of future sea-level rise adaptation measures are described in the C-SMART Adaptation Report (Marin County 2018). A supporting technical memorandum to the C-SMART Adaptation Report provides additional information on adaptation strategies, including case studies of Seadrift and Stinson Beach (ESA 2017). These adaptation case studies are compatible with the proposed nature-based adaptation alternatives and informed this study.

Reach-based example adaptation pathways are summarized below as one set of adaptation pathways for Stinson-Seadrift to guide community planning efforts by the County, local residents and other stakeholders. The adaptation pathways illustrate how future adaptation measures may follow the near-term alternatives developed for this study. For Seadrift, the existing rock revetment is presumed to be maintained and renovated for more extreme conditions forecast with sea-level rise. When wave overtopping cannot be adequately mitigated by the beach and shore armor, raising the homes above the flood levels was identified as an additional adaptation measure. An example adaptation pathway for Seadrift reach is provided in Table 17.

TABLE 17. EXAMPLE ADAPTATION PATHWAY FOR SEADRIFT REACH

Year	Adaptation Action
2020	Existing revetment is adequately maintained/upgraded
2030	Construct cobble berm along toe of revetment, rebuild/upgrade cobble berm and repair revetment after storm impacts
2040	Rebuild/upgrade cobble berm and repair revetment after storm impacts
2050	Upgrade revetment for higher sea-levels, rebuild cobble berm, elevate and/or retreat the most vulnerable homes
2070	Elevate and/or retreat homes in FEMA V-zone
anytime	*Emergency cobble/revetment repairs if extreme storm erosion occurs*

For the remainder of Stinson Beach, a wider range of adaptation strategies were considered potentially feasible. In addition to the adaptation strategies identified for Seadrift (shore armor, beach nourishment and raising buildings), natural shore infrastructure comprised of dunes with and without cobble-gravel berms were identified. Modification of Easkoot Creek was also identified as a flood risk reduction strategy. Allowing flood discharge across Stinson Beach was identified because this additional flow path, which occurred at the NPS reach in 2014 and 2016, lowers the flood levels downstream in the more developed area. Another adaptation strategy identified for the NPS reach was retreat, likely consisting of relocation of parking and facilities farther inland to accommodate shore migration without shore armoring. While the adaptation alternatives in this feasibility study focused on natural infrastructure, a hybrid approach may be taken at one or more reaches that includes a buried wall or other armoring structure at the landward side of dunes or cobble berm that could act as a backstop for higher sea-levels and or extreme winter dune erosion events. Some homes in the Calles reach are located seaward of the overall neighborhood, creating pockets where wider natural infrastructure features may be constructed. These homes could be relocated at some point to provide room for a wider natural infrastructure project for the entire reach. Example adaptation pathways for the eastern reaches are provided in the tables below.

TABLE 18. EXAMPLE ADAPTATION PATHWAY FOR PATIOS REACH

Year	Adaptation Action
2020	Construct foredunes with cobble berm at toe of foredunes
2030	Maintain dune width for storm protection as needed
2040	Maintain cobble berm and dune width for storm protection as needed
2050	Maintain cobble berm and dune width for storm protection as needed
2060	Rebuild cobble berm for higher sea levels, raise dune elevations to match sea-level rise
2080	Elevate and/or retreat homes and restore dunes
**anytime*	*Emergency dune repairs if extreme storm erosion occurs*

TABLE 19. EXAMPLE ADAPTATION PATHWAY FOR CALLES REACH

Year	Adaptation Action
2020	Construct dune embankment with cobble berm at toe of foredunes
2030	Maintain dune width for storm protection as needed
2040	Maintain cobble berm and dune width for storm protection as needed
2050	Maintain dune width for storm protection as needed
2060	Rebuild cobble berm for higher sea levels, raise dune elevations to match sea-level rise, elevate or retreat of seaward most homes.
2080	Elevate and/or retreat homes and restore dunes
**anytime*	*Emergency dune repairs if extreme storm erosion occurs*

TABLE 20. EXAMPLE ADAPTATION PATHWAY FOR NPS REACH

Year	Adaptation Action
2020	Construct cobble berm or foredunes along select buildings/development, implement cobble lag at west end of reach for Easkoot overflow drainage.
2030	Maintain dune widths for storm protection as needed in front of buildings
2040	Maintain cobble berm and dune widths for storm protection as needed
2050	Maintain dune width for storm protection as needed, begin landward retreat of seaward most buildings.
2060	Rebuild cobble berms for higher sea levels, raise dune elevations to match sea-level rise. Continue retreat planning for buildings and other development.
2080	Retreat remaining structures, restore dunes
**anytime*	*Emergency dune repairs if extreme storm erosion occurs*

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Chapter 5
Regulatory Considerations

1.1 Introduction

This Permitting Roadmap has been prepared for the County of Marin (County), to support planning efforts for the Stinson Beach Nature Based Adaptation Feasibility Study (Study). The Permitting Roadmap includes:

1) A general description of the environmental compliance process expected to be required for the project (Section 1.1);
2) The specific permits and approvals expected to be required for project implementation, as presented in **Table 1** (Section 1.2)
3) Detailed information, by agency, presented in individual 'Agency Summaries' (in Section 1.3 below; and
4) A matrix of the project's anticipated Planning, CEQA, and Permitting Requirements (Attachment A) which outlines the actions typically taken during project planning, CEQA analysis, permitting, and pre-construction through post-construction, in chronological order, and with relevant agencies and responsible parties identified.

To characterize the regulatory framework and environmental compliance process anticipated for the project alternatives described in the Study, the ESA team and County prepared this Permitting Roadmap to identify the permits and approvals expected to be required, procedural requirements for application submittal, typical data/information needed to support permit applications, and regulatory agency contact information. This document was developed following direct regulatory agency outreach and in coordination with relevant local jurisdictions to include their specific permitting requirements as they relate to potential nature-based adaptation projects at Stinson Beach. Agency contact details are included in each of the individual Agency Summaries (Section 1.3).

The information presented in this document represents the specific information provided by agency staff, during individual interviews/discussions and multi-agency meetings convened for this feasibility study. The information and recommendations in the individual agency permitting writeups has been reviewed and edited by agency staff. Staff have provided a significant amount of input on many of the known permitting considerations that would be associated with the types of projects being evaluated in this Study, including identifying the necessary permits/approvals, issues of potential concern, and the necessary studies, surveys and reports. However, staff cannot provide extensive review or definitive answers on whether such a project would be approved, until there is an actual proposed project with preliminary design plans and other required information and analyses.

Overall, the involved agencies are very much in support of nature-based coastal resilience approaches and have stressed the importance of working with agency staff during the planning process, so their feedback and concerns are addressed in the final design. In general, for these types of nature-based adaptation projects, agencies will take into account that short-term disturbances are often necessary for achieving long-term enhancement and resiliency. But if there are opportunities to avoid and minimize impacts, they will want to see that evaluated and also want a clear picture of the maximum benefits the project can achieve over the long term vs. the proposed unavoidable impacts, to get a “balanced” view of the project as a whole.

The overall regulatory compliance process consists of environmental review (pursuant to the California Environmental Quality Act, or CEQA, and - if applicable - the National Environmental Policy Act, or NEPA), followed by permitting and/or agency approvals, and it concludes with compliance review and documentation. Note: compliance review and documentation often begin prior to construction (e.g., with pre-construction surveys or the preparation of focused plans) and typically ends after a certain duration of long-term post-construction monitoring.

Environmental review consists primarily of compliance with the California Environmental Quality Act (CEQA) and, if applicable, NEPA; it also includes compliance with various other federal and state environmental laws, some of which require permits or other forms of discretionary approval. Environmental review (CEQA/NEPA) for nature-based adaptation measures is typically completed, or nearly completed, prior to embarking on the permitting process, since the information developed during the environmental review phase will be used by permitting agencies in reviewing the project and making permit decisions. However, environmental review and permitting should be viewed as an iterative process, and coordination between the permit applicant and regulatory agencies should begin early and reoccur often to ensure that the environmental review documentation will provide the information necessary to satisfy the needs of the permitting and review agencies.

Environmental review for the project will require preparation of CEQA documentation. Compliance with CEQA is required for all projects that necessitate approval or financing by the state or local government or participation by state government. NEPA compliance is required for projects that are sponsored by a federal entity; this can include projects for which a federal agency is the project proponent, projects which would occur on federal land, projects that have federal funding, and/or projects for which a federal agency takes a major federal action (such as issuing a permit). Therefore, NEPA analysis may or may not be required, based on the project specifics.

NEPA and CEQA each require preparation of different documentation. CEQA documentation for nature-based adaptation measures would typically consist of an Initial Study/Mitigated Negative Declaration (IS/MND); NEPA documentation for nature-based adaptation measures, if required, would typically consist of an Environmental Assessment (EA). Although NEPA and CEQA require different documentation, they can be conducted at the same time and frequently can be combined into a joint NEPA/CEQA document, provided the lead agencies for each process reach an agreement on the document’s necessary format and contents.

Note re. CEQA: for this project, Marin County is expected to be the responsible agency for ensuring CEQA compliance, and to serve as the CEQA ‘lead’ agency, based on the project’s location and the County’s role in issuing a discretionary approval (grading permit) for the project. The CEQA lead agency is responsible for determining the appropriate level of analysis (CEQA document type, or if it is categorically exempt), preparing the appropriate document, circulating it for review as necessary, and approving it.

Note re. federal compliance: if there is federal involvement with a project (per the examples above), a federal 'lead' agency must be established. The federal 'lead' agency is then responsible for demonstration of project compliance with all federal environmental laws, including NEPA. This often includes conducting federal inter-agency coordination during the 'permitting' phase of a project, to ensure compliance with various federal environmental laws (such as the Endangered Species Act, the National Historic Preservation Act, etc.). For this project, although it is not proposed by a federal agency and does not have federal funding, it could occur partially or wholly on federal land. As such, federal agency involvement includes both the NPS (in granting a Special Use Permit) and the U.S. Army Corps of Engineers' (USACE, in its issuance of a permit for in-water activities). The NPS and USACE would need to reach an agreement on which agency should serve as the federal 'lead' agency for this project, based on their respective levels of involvement and responsibility.

Process for Agency Input and General Permitting 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 sites, environmental sensitivity of the existing ecological habitat, and multiplicity of jurisdictions and regulations involved, the permitting process for any of the alternatives evaluated would require an extensive effort to obtain agency approvals. However, for comparison, the more traditional approach of using hard armoring would present a much larger permitting challenge and compensatory mitigation burden, and would likely not be approved due to environmental impacts and the fact that less ecologically damaging alternatives exist. As with any project involving construction on the California coast, a proposed project in Marin County would require numerous studies, surveys and reports, and an extensive public input process. However, there is much overlap between the information that is required to be submitted for each agency's permitting process. The Planning, CEQA, and Permitting Requirements Matrix (Attachment A) compiles each of these necessary actions into a matrix, along with identifying the relevant agencies, responsible parties, and status for each. The individual Agency Summaries in Section 1.3 contain more detailed agency-specific information and guidance, and Table 1 in Section 1.2 presents the overall required permits/approvals by agency.

If the collaborative work and discussions with agencies occur early and often, then the actual permit application review/approval process can be done much more efficiently. This should include review of CEQA documents, the draft Project Description, information on receiver sites and access routes, and any biological literature reviews, assessments or surveys, information on sediment compatibility and testing requirements, etc. Specific recommendations are provided below in the Agency Summaries.

1.2 Permits and Approvals Required

A summary of the expected permits and/or approvals to be required is presented in **Table 1** below. Detailed information for each Local, State, or Federal agency or jurisdiction expected to require a permit or approval is presented, by agency, in Section *1.3 Agency Summaries*, further below.

TABLE 1
STINSON BEACH NATURE BASED ADAPTATION PROJECT –
SUMMARY OF ANTICIPATED PERMIT & APPROVAL REQUIREMENTS

Agency	Requirement (Permit/Compliance)	Notes, Key Issues & Concerns, Recommendations
Federal Agencies		
U.S. Army Corps of Engineers (USACE)	PERMIT: Section 404/10 Individual Permit or Regional General Permit - *Clean Water Act* (CWA)/ *Rivers and Harbors Act* (RHA)*	• Permits are required for discharges of dredged and/or fill material into federal waters and for structures or work that could affect navigation. • The USACE could issue a one-time Section 404/10 Individual Permit for a term of their discretion and based upon project specifics, or a ‘programmatic’ Section 404/10 permit, such as a Regional General Permit (RGP), for a term of typically 5-10 years and with an efficient process for renewal. • The federal lead agency (assumed to be the USACE) leads *FESA Section 7* consultations with USFWS and NMFS (see below), and the *NHPA Section 106* review process with the SHPO (see below) as part of its permit process. • For beach fill placement, a Sampling and Analysis Plan (SAP) and Sediment Analysis Report (SAR) are required – and must also be submitted to EPA and RWQCB. • In order for USACE to issue a permit for a project, the proponent must demonstrate that the proposed project is the "least environmentally damaging practicable alternative." For either an Individual Permit or RGP, the USACE permit process includes a Public Notice, requires preparation of an Alternatives Analysis in compliance with the 404(b)(1) Guidelines, and preparation of a NEPA document (expected to be an Environmental Assessment for this project). ***Key Issues/Concerns*:** • Physical, chemical, and biological integrity of waters of the U.S., and navigation. • Compliance with all other federal environmental laws. ***Recommendations*:** • The County should work with USACE to determine if a multi-year Regional General Permit (RGP) is appropriate for the project (5-10 year term)

TABLE 1 (CONTINUED)
STINSON BEACH NATURE BASED ADAPTATION PROJECT –
SUMMARY OF ANTICIPATED PERMIT & APPROVAL REQUIREMENTS

Agency	Requirement (Permit/Compliance)	Notes, Key Issues & Concerns, Recommendations
Greater Farallones National Marine Sanctuary (GFNMS)	COORDINATION/PERMIT: Sanctuary Permit or Authorization - *National Marine Sanctuaries Act* (NMSA); *United States Code of Federal Regulations, Title 15, Part 922*	• Permits are required for activities that would discharge into the sanctuary or cause alteration of the sanctuary's submerged lands. • The GFNMS shoreward Sanctuary boundary is the Mean High Water Line (MHWL). Placement of structures or beach fill below MHWL will require a Sanctuary permit. • It is also prohibited by GFNMS regulations to discharge any material or matter outside Sanctuary boundaries if it subsequently enters the boundaries and "injures" Sanctuary resources. ***Key Issues/Concerns*:** • GFNMS concerns include any type of ecological impacts to Sanctuary resources (with a focus on biological resources and water quality), including potential indirect effects from activities occurring outside the Sanctuary boundary. ***Recommendations:*** • Collaboration with GFNMS staff should be included throughout the planning process including participation in stakeholder meetings, regular project updates and key document review, to ensure that the proposed activities won't have the potential to adversely affect sanctuary resources. A jurisdictional delineation should be conducted to precisely determine the proposed project areas in relation to the MHWL.
National Park Service; Golden Gate Recreational Area (NPS/GGNRA)	COMPLIANCE/PERMIT: Special Use Permit - *Title 36 of the Code of Federal Regulations.*	• A Special Use Permit is required from GGNRA for construction activities within NPS lands. • GGNRA will need to determine that beach nourishment at Stinson Beach is consistent with NPS Management Policies. • The National Park Service Beach Nourishment Guidance includes detailed regulatory/permitting information and guidelines for minimizing ecological impacts of projects. ***Key Issues/Concerns*:** • GGNRA concerns include potential impacts to public access and any type of ecological impacts from placement of sediment, protection of the creek and dunes, etc.
National Park Service; Golden Gate Recreational Area (NPS/GGNRA) (cont.)		***Recommendations:*** • Contact GGNRA Planning Division during project planning/design phase to determine permitting/regulatory process/requirements.

TABLE 1 (CONTINUED)
STINSON BEACH NATURE BASED ADAPTATION PROJECT –
SUMMARY OF ANTICIPATED PERMIT & APPROVAL REQUIREMENTS

Agency	**Requirement (Permit/Compliance)**	**Notes, Key Issues & Concerns, Recommendations**
U.S. Environmental Protection Agency (EPA)	COMPLIANCE: Sections 401 and 404 - *Clean Water Act* (CWA)	• EPA may review and comment on the *CWA Section 404* permit process, and reviews sediment testing and quality (SAP, SAR). • EPA disposal-related regulations are located at Title 40 CFR Part 230 (40CFR 230). • The *Inland Testing Manual* (ITM) is the key reference document concerning testing of fill material, and compliance with *CWA Section 404(b)(1) Guidelines for evaluation of potential impacts associated with fill placement activities.* ***Key Issues/Concerns*:** • Physical, chemical, and biological integrity of beach fill material, compatibility with receiver site materials. ***Recommendations:*** • Include EPA in agency outreach; consult as needed regarding sand compatibility, testing and analysis.
U.S. Fish and Wildlife Service (USFWS)	COMPLIANCE/PERMIT: Informal Consultation or Biological Opinion - *Section 7 of Federal Endangered Species Act* (FESA) COMPLIANCE: *Migratory Bird Treaty Act* (MBTA)	• Project compliance is required for projects with the potential to adversely affect federally-listed species or designated critical habitats protected by USFWS. • USACE, as the lead federal agency, is responsible for conducting *Section 7 Consultation* with USFWS (or determining 'No Effect,' if applicable) as part of their permit process. ***Key Issues/Concerns*:** • <u>*FESA Section 7*</u>: Potential impacts to federally-listed terrestrial species and/or habitat (e.g. shorebirds including western snowy plovers and listed plants and animal species • <u>MBTA</u>: Potential impacts to migratory bird species.
National Marine Fisheries Service (NMFS)	COMPLIANCE/PERMIT: Informal Consultation or Biological Opinion - *Section 7 of Federal Endangered Species Act* (FESA) COMPLIANCE: Informal Consultation - *Magnuson-Stevens Fishery Management and Conservation Act* (MSA) COMPLIANCE: Coordination/Consultation - *Marine Mammal Protection Act* (MMPA)	• Project compliance is required for projects with the potential to adversely affect federally-listed species or designated critical habitats protected by NMFS • USACE, as the lead federal agency, is responsible for conducting *Section 7* and *MSA Consultations* with NMFS (or determining 'No Effect,' if applicable) as part of their permit process. • *MMPA* compliance and/or permits are sought directly by the applicant from NMFS (if determined necessary). ***Key Issues/Concerns*:** • <u>*FESA Section 7*</u>: Potential impacts to federally-listed aquatic species and/or habitats (e.g., fish and marine mammals). • <u>*MSA*</u>*:* Potential impacts to *Essential Fish Habitat* (EFH). • <u>*MMPA*</u>*:* Potential impacts to non-listed marine mammals.

TABLE 1 (CONTINUED)
STINSON BEACH NATURE BASED ADAPTATION PROJECT –
SUMMARY OF ANTICIPATED PERMIT & APPROVAL REQUIREMENTS

Agency	Requirement (Permit/Compliance)	Notes, Key Issues & Concerns, Recommendations
State Agencies		
California Coastal Commission (CCC)	PERMIT: Coastal Development Permit (CDP) - *California Coastal Act* (CCA); *Coastal Zone Management Act* (CZMA)	• All structures in the coastal zone (including beach nourishment projects, according to the CCA) require CCC approval pursuant to *Coastal Act Section 30106.* • A Coastal Development Permit (CDP) would be required for all alternatives, based on their location within the coastal zone. • The CCC will review the CDP application to ensure consistency of the proposed project with the CCA and CZMA. ***Key Issues/Concerns*:** • The use of land and water within the coastal zone, including: views, public access, recreational opportunities, water quality, sediment compatibility, wildlife disturbance, and other CCA/CZMA concerns. • CCC is generally supportive of nature-based adaptation projects and opportunistic beach nourishment consistent with the CCA and CZMA.
State Water Resources Control Board (SWRCB)/ San Francisco Bay Regional Water Quality Control Board (RWQCB)	PERMIT: Section 401 Water Quality Certification*/Waste Discharge Requirements - *Clean Water Act/Porter-Cologne Water Quality Control Act* PERMIT: General Permit for Storm Water Discharges from Construction Activity.	• Any projects with impacts to waters or wetlands that require a USACE Section 404 CWA permit will also require Section 401 Water Quality Certification from the RWQCB. In addition, certain waters or wetlands may be jurisdictional only at the state level, and require Waste Discharge Requirements from the RWQCB (but no Sec 401 Certification). • **A storm water discharge permit is required for projects with the potential to disturb one or more acres of land. This would require the development and implementation of a *Storm Water Pollution Prevention Plan* (SWPPP) and Best Management Practices (BMPs) for construction. • RWQCB can issue a programmatic permit to be concurrent with the USACE's RGP. • RWQCB permits include a fee based on amount of fill placed/acres disturbed. Projects may qualify for a discounted fee for Ecological Restoration and Enhancement Projects. ***Key Issues/Concerns*:** • Water quality, beneficial uses (including biological and human use values). • Physical, chemical, and biological integrity of beach fill material, compatibility with receiver site.
California Department of Fish and Wildlife (CDFW)	COMPLIANCE: California Endangered Species Act (CESA) PERMIT: Incidental Take Permit, if deemed necessary by CDFW.	• If determined unavoidable, 'take' of state-listed species (such as mortality or habitat destruction) requires an Incidental Take Permit (ITP). • CDFW will review and comment on the project's CEQA document(s), to address potential take of state-listed species, and provide recommendations on avoidance and minimization measures to prevent take. • Take of state-listed species can be avoided with implementation of biological mitigation measures (such as seasonal avoidance, pre-construction surveys, selection of specific sand placement methods, and long-term monitoring and adaptive management). If the applicant determines that take of state-listed species or habitat cannot be avoided, then it is possible for CDFW to issue a *CESA Incidental Take Permit (ITP).*

TABLE 1 (CONTINUED)
STINSON BEACH NATURE BASED ADAPTATION PROJECT –
SUMMARY OF ANTICIPATED PERMIT & APPROVAL REQUIREMENTS

Agency	Requirement (Permit/Compliance)	Notes, Key Issues & Concerns, Recommendations
California Department of Fish and Wildlife (CDFW) (cont.)		• Based on the lack of streambeds or lakes at the specific project site(s), a CDFW Section 1600 LSAA is not expected to be required. ***Key Issues/Concerns*:** • *CESA:* potential impacts to California listed species (e.g. bank swallows, listed plants). ***Recommendations:*** • The County should conduct early outreach to and coordination with CDFW to discuss project details and determine whether an ITP or programmatic ITP may be required or can be avoided, review potential impacts to listed species, and allow opportunity for CDFW staff to provide input on developing any physical and biological monitoring requirements for the project.
California State Lands Commission (CSLC)	PERMIT: Lease Agreement for Utilization of Sovereign Lands - California Public Resources Code; Division 6 State Lands Act	• CSLC jurisdiction begins below MHT; any work or new structures or placement of fill below MHT would require a CSLC Lease. • If the alternative involves work or placement below MHT, then a Lease would be required.
State Historic Preservation Officer (SHPO)	COMPLIANCE/PERMIT: Consultation or Agreement – *Section 106 of National Historic Preservation Act (NHPA)*	• Project compliance is required for projects with the potential to adversely affect certain cultural resources (including historic architecture, and archaeological or paleontological resources, etc.). • USACE, as the lead federal agency, is responsible for conducting *Section 106 Consultation* with SHPO. • Marin County would be responsible for conducting a required *Cultural Resources Inventory*. ***Key Issues/Concerns:*** • potential impacts to archaeological resources, historic buildings or structures, etc.
California Department of Transportation (Caltrans)	PERMIT: Encroachment Permit	• Any project located on or affecting a Caltrans owned or maintained roadway (such as a state highway section or interchange) may require approval by Caltrans in the form of an *Encroachment Permit*. ***Key Issues/Concerns:*** • Potential impacts to traffic, safety ***Recommendations:*** • County should contact Caltrans to determine whether an Encroachment Permit would be required for traffic impacts.
Local Jurisdictions		
County of Marin	PERMITS/ APPROVALS: Potential: grading/construction permits (to be determined during Ph, 2 Permitting) CEQA: Lead Agency	• The project lies primarily within the California Coastal Commission's (CCC) jurisdiction and is, therefore, subject to a CCC Coastal Development Permit rather than a County-issued Coastal Permit. • A ministerial grading permit may be required by the County after the Coastal Development Permit is issued. • It is assumed that the County would be the CEQA lead for the projects being evaluated in this Study. The CEQA lead agency is responsible for determining the appropriate level of analysis (CEQA document type, or if it is categorically exempt), preparing the appropriate document, and approving it. • The CEQA lead agency is also responsible for tribal consultation pursuant to Public Resources Code 21080.3 (Assembly Bill 52)..

TABLE 1 (CONTINUED)
STINSON BEACH NATURE BASED ADAPTATION PROJECT –
SUMMARY OF ANTICIPATED PERMIT & APPROVAL REQUIREMENTS

Agency	Requirement (Permit/Compliance)	Notes, Key Issues & Concerns, Recommendations
Bay Area Air Quality Management District (BAAQMD)	PERMIT: BAAQMD permit	• BAAQMD permits are typically only required for stationary and operational/permanent sources of emissions (such as permanent gravel processing/screening/conveyor equipment, or permanent equipment/facilities), not construction-related transportation or temporary mobile processing, as under the proposed project. • Project activities will still need to comply with local and state air quality regulations, to be demonstrated in CEQA analysis. ***Key Issues/Concerns*:** • There may be potential for airborne dust to be carried to downwind sensitive receptors. ***Recommendations:*** • Contact BAAQMD regarding airborne dust and potential need for permit.

1.3 Agency Summaries

This section contains *Agency Summaries*, each of which provides agency contact information, an overview of the agency or jurisdiction's regulatory and permitting considerations including applicable laws and regulations, and agency-specific concerns and considerations. The *Agency Summaries* also provide project-specific guidance and recommendations on the path forward during various 'phases' of the project: project planning and CEQA documentation and review ('Phase I')), project permitting ('Phase II'), and ongoing project implementation and adaptive management ('Phase III'). The information presented in the *Agency Summaries* has been reviewed by staff from each participating agency and reflects current thinking and information at the time of the preparation of this Regulatory Roadmap(mid-2021).

Detailed information for each agency expected to require a permit or other form of approval is provided in the *Agency Summaries* below, in the following order, for applicable federal, state and local jurisdictions:

Federal:

- 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)
- Golden Gate National Recreation Area (GGNRA)

State:

- California Coastal Commission (CCC)
- California Department of Fish and Wildlife (CDFW)
- Regional Water Quality Control Board (RWQCB)
- California State Lands Commission (CSLC)

Local:

- County of Marin

U.S. Army Corps of Engineers (USACE)

Contact

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USACE Requirements for Permitting/Environmental Compliance

***Phase I**: Project Planning and CEQA Documentation and Review*

✓ Provide draft of this USACE "Permitting Roadmap" section to USACE Regulatory Division staff, for review.

☐ Provide USACE Regulatory Division staff with opportunity to review draft Project Description and CEQA/NEPA document(s). It will also be helpful to coordinate with USACE staff on the likely permitting pathway for the project to determine whether an Alternatives Analysis and NEPA documentation will be required, and if so, to aim to prepare project documentation that will meet the USACE's needs while also meeting other agency's similar needs, fi applicable.

☐ Contact USACE Planning (Tom Kendall, Chief), to discuss potential for USACE to construct projects.

☐ Seek USACE Regulatory Division staff input on developing sediment testing and compatibility protocols and physical and biological monitoring requirements for the project.

☐ Contact the Dredged Material Management Office (DMMO), hosted by the USACE and including multiple Bay Area regulatory agencies, for informal input regarding recommended sand testing and compatibility measures as well as potential sand sources.

☐ Conduct a Section 106 cultural resources inventory and site survey.

☐ Conduct site surveys to map existing vegetation communities and habitats, for use in evaluating potential project effects to sensitive biological species and/or habitats. Studies should be suitable for use in CEQA analysis and permitting.

Phase II: Permitting

- NOTE: The USACE would issue a Section 404 and 10 Permit pursuant to the Clean Water Act and Rivers and Harbors Act, respectively, for any project that would place structures or fill, or conduct work, within navigable waters of the U.S.[1]

- NOTE: The most likely permit type for the project would be a new Regional General Permit (RGP), which is considered a 'programmatic' permit type and is authorized via the Individual Permit process. This would require a detailed application including a brief Alternatives Analysis in compliance with the 404(b)(1) Guidelines, a Public Noticing process to adjacent property owners and interested parties, and a brief NEPA analysis and decision document addressing program effects (which is prepared by the USACE but often based on analyses prepared by the applicant).

- NOTE: The Section 404/10 permit process requires demonstration of avoidance and minimization of impacts to waters to the maximum extent practicable and requires demonstration of compliance with other related federal and state environmental laws, prior to permit issuance. See Table 1 above and *Key Points* below for details.

- NOTE: During Phase II, the need for mitigation should be evaluated and, if required, the specifics would be developed during the permitting process. If USACE staff determine that mitigation is required, this would require additional coordination with staff and the preparation of a Compensatory Mitigation Plan.

- ☐ Conduct pre-application consultation with USACE San Francisco District Regulatory Division, to confirm the most appropriate permit type(s), information requirements, and procedures. This could be done at an existing USACE-facilitated monthly Inter-Agency Pre-Application Meeting (which typically has many agencies in attendance) or an individual project-specific meeting organized by the permittee.

- ☐ Prepare a Jurisdictional Delineation of Aquatic Resources, to establish the geographic extent of Section 404 and/or Section 10 waters of the U.S. within all project sites, to enable an assessment of impacts.

- ☐ Prepare and submit Section 404/10 permit application.

- ☐ Prepare a Monitoring and Adaptive Management Plan for the project.

Phase III: Ongoing Project Implementation and Adaptive Management

- ☐ Complete permit reporting requirements and renew the existing permit, or apply for a new one, prior to expiration, as applicable.

- ☐ Provide USACE staff with a notification of any project maintenance, including placement of additional material, and an opportunity to review and comment on plans and documents

[1] See *Agency Background and Regulatory Overview* below for a discussion of USACE jurisdiction.

related to such maintenance or adaptive management actions (as applicable and stipulated by project permits).

- ☐ Continue to provide any relevant documents or studies as they become available, including monitoring reports, sediment testing and compatibility results, proposed updates to the project, adaptive management plans or measures, etc.

- ☐ Evaluate project efficacy and monitoring results over the short- and long-term, to implement adaptive management strategies for the project, if appropriate, as identified during Phase II permitting.

Key Points:

- The USACE is generally supportive of beach restoration/nourishment projects that would provide protection to ecological habitat from coastal hazards and/or mitigate the impacts of coastal erosion and sea level rise, if properly designed and implemented.

- The USACE follows regulatory restrictions (promulgated by the EPA) for sand (quality and compatibility).

- The USACE must demonstrate compliance with other related federal and/or state environmental laws, prior to permit issuance. These include but are not limited to:

    - Federal Endangered Species Act (FESA) Compliance

        - typically via Section 7 Consultation with USFWS and/or NMFS, as requested by the USACE, if determined necessary

    - National Historic Preservation Act (NHPA) Compliance

        - typically via Section 106 Consultation with the State Historic Preservation Officer (SHPO), as requested by the USACE

    - Coastal Zone Management Act (CZMA) Consistency

        - typically via the Coastal Development Permit process, as led by the California Coastal Commission (CCC) or local jurisdiction with permitting authority

    - State Water Quality Certification

        - In California, as promulgated by the State Water Resources Control Board and/or the Regional Water Quality Control Boards (San Francisco Bay Region, for this project)

Agency Background and Regulatory Overview:

USACE has regulatory authority over activities involving waters of the U.S. pursuant to Section 404 of the Clean Water Act (in ocean waters, up to the High Tide Line[2]) and Section 10 of the Rivers and Harbor Act (in ocean waters, up to the Mean High Water Line). This includes the regulation of any work, development or structure that may cause obstructions to navigable waters of the U.S., or the temporary or permanent placement of dredged and/or fill material within waters of the U.S.

The USACE is the chief decision-making agency for beach nourishment projects, responsible for issuing permits under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act. USACE disposal-related regulations are located at 33CFR 320-330 and 33 CFR 335-338. For more information on USACE policies, procedures and regulations, refer to the Coastal Sediment Management Workgroup's Beach Restoration Regulatory Guide (BRRG; EIC, 2006).

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2 The USACE's definition of the High Tide Line (HTL) in coastal tidal waters is subject to some discretion and best professional judgement. Generally, it is located somewhere above the Mean Higher High Water (MHHW) and below the Highest Astronomical Tide (HAT), should not include certain extremes (like King tides) or wave runup, and should include some empirical observations if possible. Because of this, the proposed approach to establishing HTL should be discussed with the USACE prior to using it for any program or design decisions.

U.S. Environmental Protection Agency (EPA)

Contact

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San Francisco, CA 94105

EPA Requirements for Permitting/Environmental Compliance

Phase I: Project Planning and CEQA Documentation and Review

- NOTE: although it is not required, EPA staff suggested they should be provided opportunities to review draft CEQA and NEPA documents and other project materials.

✓ Provide a draft of this EPA "Permitting Roadmap" section to EPA staff, for review.

☐ Seek EPA staff input on sediment testing protocol/standards (for both the project site and potential sources of sand for placement) and development of physical and biological monitoring requirements for the project.

Phase II: Permitting

- NOTE: The EPA does not issue permits for a project such as the one being evaluated for Stinson Beach. However, they oversee and may comment on CWA Section 404 permits as issued by the USACE (unless an EPA veto occurs), and they review projects seeking USACE Section 404 permits for compliance with the 404(b)(1) Guidelines. They also typically do impose specific testing and compatibility requirements for sediment placement on beaches, in coordination with USACE.

☐ The USACE permit for the project, which the EPA technically oversees, would need to outline a sediment compatibility protocol based on the approved Sampling and Analysis Plan (SAP) prepared for the project. EPA staff can assist with the development of these protocols during Phase I and Phase II.

☐ Prior to seeking other agency permits, provide EPA staff an opportunity to review sediment testing protocol/standards for in-water dredged and upland excavated sediment.

☐ Prior to seeking other agency permits, provide EPA staff with opportunity to review the preliminary draft Project Description (PD), including information on any proposed receiver sites and an explanation of how the sediment would be handled (e.g., specifics of sand testing and processing/placement). The PD also needs to state that the purpose of the placement of sediment is beneficial reuse, not disposal. EPA would review and comment on proposed locations for placement and how the actual placement project will occur (methods used).

- ☐ Continue to provide updates and additional project information to EPA as it becomes available. Provide opportunity to comment on any environmental review aspects of project development including sediment testing, monitoring, and compatibility requirements, BMPs, mitigation measures, etc.

***Phase III*: Ongoing Project Implementation and Adaptive Management**

- ☐ Continue to provide to EPA any relevant documents or studies as they become available, including monitoring reports, sediment testing and compatibility results, proposed updates to the project, adaptive management plans or measures, etc.

- ☐ Provide EPA staff with a notification of any project maintenance, including placement of additional material, and an opportunity to review and comment on plans and documents related to such maintenance or adaptive management actions (as applicable and stipulated by project permits or approvals).

Key Points:

- EPA is very supportive of this type of opportunistic beach nourishment/shoreline resiliency project for Marin County, if properly planned and implemented.

- Although no permit would be issued by EPA, they should be involved as key participants in certain aspects of project planning and implementation. While EPA comments on CWA Section 404 permits are generally advisory in nature (unless an EPA veto occurs), they can impose specific testing requirements for sediment placement.

- EPA staff prefers earlier involvement during development of compatibility standards and testing protocols for source sediment. This involvement will be at the advisory level, but will ultimately be required for and incorporated into related permits (such as the USACE Section 404/10 and RWQCB Section 401 permits).

- EPA staff encourage the project's sediment compatibility criteria to be designed with flexibility in mind, to better enable project implementation using a variety of possible sand sources, both at initial construction and during any additional placement activities that may occur during adaptive management.

- EPA staff have identified potential concerns with placement of inland material with high organics or sandstone formation-like materials too high on the upper/dry beach. One of the SCOUP[3] projects in the San Diego region (Fletcher's Cove or Loma Santa Fe Grade Separation) experienced major issues, since placement was high up in the 'dry' and the material compressed and became hardened like cement — it took 3 years for waves to break it up. This should be a consideration when looking at sediment compatibility for certain upland source material.

[3] SCOUP – Sand Compatibility and Opportunistic Use Program, a component of the California Coastal Sediment Master Plan, as developed by the San Diego Association of Governments with funding from the California Department of Boating and Waterways.

- If a project involves water that runs off the site (decant water), such as is the case for many dredging/nourishment projects involving wet sediment, then any decant water could be covered under a USACE Nationwide Permit (NWP) 16 (still under CWA Section 404) and through the CWA Section 401 process with the Regional Water Quality Board. This process could then be embodied in the overall permitting for the project.

- EPA does not officially review CEQA/NEPA documents – so don't expect them to automatically receive the document(s) and provide input. Instead, EPA is interested and willing to informally review relevant materials such as the Project Description (including receiver site descriptions and sediment compatibility protocol) or other relevant studies or CEQA/NEPA document(s) sections, which should be provided to EPA if their input is considered beneficial or critical to project success.

Agency Background and Regulatory Overview:

EPA and USACE are the two main agencies involved in regulating discharges of fill and dredged material in federal waters and/or wetlands. The EPA and USACE use a guidance document called the Inland Testing Manual (ITM) for sediment testing and compatibility determinations. EPA has authority under the CWA Section 404 33 U.S.C 1344, and their disposal-related regulations under the Marine Protection, Research, and Sanctuaries Act are located at Title 40 CFR Parts 220-230 (40CFR 220-230). EPA is responsible for developing and interpreting environmental criteria used to evaluate permit applications, identifying activities and/or aquatic resources that are exempt from permitting, reviewing/commenting on individual permit applications, and enforcing Clean Water Act Section 404 provisions. EPA also has authority to veto USACE permit decisions.

U.S. Fish and Wildlife Service (USFWS):

Contact

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USFWS Requirements for Permitting/Environmental Compliance

Phase I: Project Planning and CEQA Documentation and Review

- NOTE: although USFWS typically does not become involved in project review until the USACE approaches them for Section 7 Endangered Species Act (FESA) consultation as a part of the USACE's Section 404/10 permit process, earlier coordination with USFWS should occur, to ensure their input is considered during project development.

✓ Provide a draft of this USFWS "Permitting Roadmap" section to USFWS staff, for review.

☐ Seek USFWS staff input on sand compatibility protocols and placement methods, biological monitoring and adaptive management recommendations, and specific avoidance and minimization measures for western snowy plover and other sensitive species known or expected to be present.

☐ Coordinate with USFWS staff during the planning process to identify and address any potential impacts to federally listed species and/or sensitive habitats by modifying the project design.

Phase II: Permitting

- NOTE: the required FESA Section 7 consultation with USFWS will be the responsibility of the USACE to conduct, as part of their permitting process.

- NOTE: Section 7 FESA consultation pathways may include: 1) a conclusion of no anticipated adverse effects to USFWS-listed species and therefore no requirement for USFWS input/approval; 2) a conclusion of some potential for adverse effects to USFWS-listed species, the development of avoidance and minimization measures, and USFWS concurrence with a determination of 'not likely to adversely affect,' with implementation of the measures; or 3) a conclusion of potential for unavoidable adverse effects to USFWS-listed species, USFWS issuance of a Biological Opinion including provisions for some 'take' of listed species and/or protected habitats, and associated requirements for avoidance, minimization, and mitigation measures.

- ☐ Continue to provide updates and additional project information as it becomes available. Provide USFWS staff the opportunity to comment on any environmental review aspects of program development including biological monitoring, sediment testing and compatibility requirements, BMPs, mitigation measures, etc.

<u>Phase III</u>: Ongoing Project Implementation and Adaptive Management

- ☐ Continue to provide any relevant documents or studies as they become available, including monitoring reports, sediment testing and compatibility results, proposed updates to the project, adaptive management measures, etc.

- ☐ Provide USFWS staff with relevant documents or surveys regarding the known listed species or habitats as they become available.

- ☐ Evaluate project efficacy and monitoring results with respect to sensitive species and their habitats over the short- and long-term, to implement adaptive management strategies for the project, if appropriate, as identified during Phase II permitting.

- ☐ Provide USFWS staff with a notification of any project maintenance, including placement of additional material, and an opportunity to review and comment on plans and documents related to such maintenance or adaptive management actions (as applicable and stipulated by project permits).

- ☐ Complete permit reporting requirements and renew the existing permit, or apply for a new one, prior to expiration, as applicable.

Key Points:

- USFWS is generally supportive of beach restoration/nourishment projects that would provide protection to ecological habitat from coastal hazards and/or mitigate the impacts of coastal erosion and sea level rise, if properly designed and implemented to protect biological resources. Oftentimes, adverse effects to biological resources (species and/or their habitats) occur during project construction/implementation, but are followed by long-term benefits to these same species/habitats. Therefore, construction/implementation methods must be carefully considered.

- Key USFWS-protected species of concern for the Project at Stinson Beach include: western snowy plover, two-fork clover, and California clapper rail (also known as California Ridgway’s rail):

    - Western snowy plovers (*Charadrius alexandrinus nivosus*), Pacific coast population, 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 their 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.

- At least 6 Western snowy plovers were observed at the Stinson Beach study area, during a December 2019 biological survey, foraging and resting along the lower beachface, and resting in human footprint depressions along the upper foreshore, near but below the narrow dry backshore. Western snowy plovers are unlikely to breed at highly populated Stinson Beach, but their presence as wintering groups indicates a need to incorporate project measures to monitor their distribution and movements and avoid disturbance or adverse habitat modification during any project implementation phases.

- California clapper (Ridgway's) rail (*Rallus obsoletus*) has occurrences noted in the California Natural Diversity Database (CNDDB) on Stinson Beach.

- The two-fork clover has possible occurrences listed by CNDDB on the southern part of Stinson Beach, but this population is possibly extirpated according to the database. Surveys would help to determine the existence and then location of remaining populations, if present. If found, conservation measures should be added to protect the remaining populations in the area.

Agency Background and Regulatory Overview:

The U.S. Fish and Wildlife Service (USFWS) plays a consultative role under Sections 7 and 10 of the Endangered Species Act (FESA). Pursuant to FESA, the lead federal agency responsible for environmental review of a proposed project is required to determine whether or not any species listed as either threatened or endangered under the FESA are present in the study area and to determine whether the project will cause any potentially significant impacts on that species. While these determinations must be made by the federal lead agency, they are typically informed by analyses and recommendations prepared for and provided to the federal lead agency by biological resource specialists (i.e., consultants to the project proponent). As noted above, for this project, the required consultation with USFWS will be the responsibility of the USACE to conduct, as part of their federal permitting process.

The USFWS (and NMFS, see below) both are guided by the same set of regulations under the FESA; however, each agency is exclusively responsible for different listed species. USFWS generally has jurisdiction over terrestrial plants and animals (including sea otters, and including certain fish such as smelt), while NMFS is generally responsible, under FESA, for most listed fish and under the MMPA, marine animals as well as non-listed marine mammals (such as harbor seals, sea lions, elephant seals, etc.).

Greater Farallones National Marine Sanctuary (GFNMS)

Contact

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Website: https://farallones.noaa.gov

GFNMS Requirements for Permitting/Environmental Compliance

***Phase I**: Project Planning and CEQA Documentation and Review*

- NOTE: GFNMS will require an assessment of the potential effects of the placement of sediment on the Bolinas Lagoon ecosystem (for example: will it impact the ecological system, benthic system, and/or the more regional movement of sediment?). GFNMS will need to understand long term impacts of the project on Bolinas Lagoon and Stinson Beach before making a permit decision.

✓ Provide draft of this GFNMS "Permitting Roadmap" section about the Sanctuary to GFNMS staff, for review.

☐ Provide GFNMS staff with opportunity to review draft Project Description and CEQA/NEPA documents.

☐ Seek GFNMS staff input on developing physical and biological monitoring requirements for the project.

☐ Hold discussions with GFNMS staff to solicit input on any potential biological impacts of concern, including those to the subtidal and intertidal species/habitats, and coordinate with GFNMS staff to address any issues throughout the project design process.

☐ If a constructed reef is being proposed, discuss design and material considerations (such as using 'natural' vs. man-made materials, and oyster shells) and the implications for permitting and potential assignment of habitat 'credits' for ecological restoration. Note: GFNMS clarified that use of non-native oysters for coastal resiliency purposes cannot be permitted outside of an approved aquaculture lease boundary.

***Phase II**: Permitting*

☐ NOTE: The project proposes some material placement within the Sanctuary boundaries. If material is proposed for placement below the Mean High Water Line (MHWL) within Sanctuary boundaries, then a GFNMS permit is required. Any habitat restoration/coastal resilience project involving 1) deposition of material below MHWL, 2) placement of any structure on submerged lands of the GFNMS, or 3) discharge of material or matter from beyond the boundary that has the potential to subsequently enter the Sanctuary and injure a Sanctuary resource or quality, requires GFNMS review and approval (i.e. GFNMS permit). Currently, there are only two permit categories that the project could potentially qualify for: 1) further research or monitoring related to Sanctuary resources and qualities; or 2) projects which assist in managing the Sanctuary. NOTE: beach scraping with construction machinery below the MHWL could not be permitted by GFNMS[4].

- NOTE: GFNMS has specific permit procedures and issuance criteria (§922.83 National Marine Sanctuaries Act) whereby the Director must consider a number of factors in reviewing permit applications. For example, whether: "*The proposed activity will be conducted in a manner compatible with the primary objective of protection of Sanctuary resources and qualities, considering the extent to which the conduct of the activity may diminish or enhance Sanctuary resources and qualities, any potential indirect, secondary or cumulative effects of the activity, and the duration of such effects*". A full list of these factors can be found on this page of the Electronic Code of Federal Regulations website.

☐ Continue to provide updates and additional project information as it becomes available. Provide GFNMS staff the opportunity to comment on any environmental review aspects of project development including sediment placement and testing, compatibility requirements, physical and biological monitoring, BMPs, mitigation measures, etc.

☐ Prepare and submit a permit application and other required materials, if directed to do so by GFNMS staff. Permit applications and instructions are available on the GFNMS Website: https://farallones.noaa.gov/eco/permits/.

Phase III: Ongoing Project Implementation and Adaptive Management

☐ Continue to provide to GFNMS with any relevant documents or studies as they become available, including monitoring reports, sediment testing and compatibility results, proposed updates to the project, adaptive management measures, etc.

☐ Provide GFNMS staff with a notification of any project maintenance, including placement of additional material, and an opportunity to review and comment on plans and documents related to such maintenance or adaptive management actions (as applicable and stipulated by project permits).

☐ Complete permit reporting requirements and renew the existing permit, or apply for a new one, prior to expiration, as applicable.

4 Maria Brown, personal communication, 11/04/20 West MAG zoom meeting.

Key Points:

- GFNMS is generally supportive of habitat restoration/nourishment projects that would restore and provide protection to ecological habitat from coastal hazards and/or mitigate the impacts of coastal erosion and sea level rise to natural resources, if properly designed and implemented. However, a permit can only be issued if the ecosystem restoration benefits outweigh the negative environmental impacts of a project.

- Collaboration with GFNMS staff should be included throughout the planning process including participation in stakeholder meetings, regular project updates and key document review, to ensure that the proposed activities won't directly or indirectly adversely affect sanctuary resources.

Agency Background and Regulatory Overview:

The Office of National Marine Sanctuaries, a division of NOAA, administers the 14 national marine sanctuaries. A National Marine Sanctuary is a federally designated area within United States waters that protects areas of the marine environment with special conservation, recreational, ecological, historical, cultural, archeological, scientific, educational, or aesthetic qualities.

GFNMS was designated in 1981 in accordance with the National Marine Sanctuaries Act (NMSA) and is managed under the authority of the Act. Under the NMSA, GFNMS has the ability to grant permits for prohibited activities and enforce regulations, provided that the activities meet certain criteria such as having, at most, short-term and negligible adverse effects on sanctuary resources and qualities (15 CFR Part 922, Subpart H). The mission of the sanctuaries, which is to understand and protect the ecosystem and cultural resources of coastal California, is carried out through resource protection, research, education, and public use. As such, the Sanctuaries address a wide range of resource protection issues within their boundaries, and reduce or prevent detrimental human impacts on sanctuary resources through collaborative partnering efforts, regulations and permits, emergency response, enforcement and education.

The Farallones sanctuary implements and enforces seventeen federal regulatory prohibitions within the GFNMS area designed to preserve and protect the natural and cultural resources and qualities of the ocean and estuarine areas within the boundaries of the sanctuaries. For a beach restoration project at Stinson Beach, there are several of these prohibitions that could pertain, and thus trigger the need for GFNMS review and permitting. These are summarized below:

1) *Discharging or depositing, from within or into the Sanctuary, any material or other matter (with the exception of certain activities, such as fish parts from lawful fishing activities, treated vessel sewage, clean deck wash down, etc.)*
2) *Discharging or depositing, from beyond the boundary of the Sanctuary, any material or other matter that subsequently enters the Sanctuary and injures a Sanctuary resource or quality (with the exception of several activities unlikely to be applicable to the activities considered in this Study).*

3) *Drilling into, dredging or otherwise altering the submerged lands of the Sanctuary; or constructing, placing, or abandoning any structure, material, or other matter on or in the submerged lands of the Sanctuary (with the exception of several activities, such as boat anchoring, lawful fishing, certain types of aquaculture activities, and harbor maintenance projects).*

4) *Taking or possessing (disturbing or injuring) any marine mammal, sea turtle, or bird within or above the Sanctuary, except as authorized by the Marine Mammal Protection Act, Endangered Species Act, or Migratory Bird Treaty Act (regardless of intent).*

5) *Introducing or otherwise releasing from within or into the Sanctuary an introduced species (with the exception of striped bass and some shellfish species approved for aquaculture).*

6) *Disturbing marine mammals or seabirds by flying motorized aircraft at less than 1,000 feet over the waters within any of the seven designated Special Wildlife Protection Zones. Failure to maintain a minimum altitude of 1,000 feet above ground level over such waters is presumed to disturb marine mammals or seabirds. (Stinson Beach and the surrounding area is in one of these seven zones. Motorized aircraft include flying Unmanned Aerial Systems/drones.)*

National Marine Fisheries Service (NMFS)

Contact

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NMFS Requirements for Permitting/Environmental Compliance

Phase I: Project Planning and CEQA Documentation and Review

☐ NOTE: although NMFS typically does not become involved in project review until the USACE approaches them for Section 7 Endangered Species Act (FESA) consultation as a part of the USACE's Section 404/10 permit process, earlier coordination with NMFS should occur, to ensure their input is considered during project development.

✓ Provide a draft of this NMFS "Permitting Roadmap" section to NMFS staff, for review.

☐ Seek NMFS staff input on sand compatibility protocols and placement methods, as well as developing physical and biological monitoring requirements for the project, and adaptive management recommendations, as well as specific avoidance and minimization measures for sensitive species known or expected to be present.

☐ Coordinate with NMFS staff during the planning process to identify and address any potential impacts to federally listed species and/or sensitive habitats by modifying the project design.

Phase II: Permitting

- NOTE: the required FESA Section 7 consultation with NMFS will be the responsibility of the USACE to conduct, as part of their permitting process. In contrast, if non-listed marine mammals could be adversely affected, the project proponent would request a permit (IHA or LOA) pursuant to the MMPA directly from NMFS Protected Resources Division.

- NOTE: Section 7 FESA consultation pathways may include: 1) a conclusion of no anticipated adverse effects to NMFS -listed species and therefore no requirement for USFWS input/approval; 2) a conclusion of some potential for adverse effects to NMFS-listed species, the development of avoidance and minimization measures, and NMFS concurrence with a determination of ‘not likely to adversely affect,’ with implementation of the measures; or 3) a conclusion of potential for unavoidable adverse effects to NMFS -listed species, NMFS issuance of a Biological Opinion including provisions for some ‘take’ of listed species and/or protected habitats, and associated requirements for avoidance, minimization, and mitigation measures.

- ☐ Continue to provide updates and additional project information as it becomes available. Provide NMFS staff the opportunity to comment on any environmental review aspects of project development including biological monitoring, sediment testing and compatibility requirements, BMPs, mitigation measures, etc.

***Phase III**: Ongoing Project Implementation and Adaptive Management*

- ☐ Continue to provide any relevant documents or studies as they become available, including monitoring reports, sediment testing and compatibility results, proposed updates to the project, adaptive management measures, etc.

- ☐ Evaluate project efficacy and monitoring results with respect to sensitive species and their habitats over the short- and long-term, to implement adaptive management strategies for the project, if appropriate, as identified during Phase II permitting.

- ☐ Provide NMFS staff with a notification of any project maintenance, including placement of additional material, and an opportunity to review and comment on plans and documents related to such maintenance or adaptive management actions (as applicable and stipulated by project permits).

- ☐ Complete permit reporting requirements and renew the existing permit, or apply for a new one, prior to expiration, as applicable.

Key Points:

- We will want to confirm whether beach haul-outs for marine mammals occur at any of the project sites or in the project construction areas (if so, an Incidental Harassment Authorization, or IHA, may be required).

- The project will need to analyze potential effects to listed species and Essential Fish Habitat (in a Biological Assessment document) for the federal lead agency’s review and use in Section 7 FESA and/or MSA consultations, if appropriate.

Agency Background and Regulatory Overview:

Similar to USFWS (above), NMFS is the federal agency responsible for managing, protecting, and conserving living marine resources and their habitats throughout the Exclusive Economic Zone (typically, waters between 3 and 200 miles offshore).

NMFS becomes involved with projects by the way of providing consultation pursuant to Sections 7 and 10 of the Endangered Species Act (FESA), which governs potential impacts of various activities to species and habitats that are either federally listed or proposed for listing. NMFS also reviews project proposals for their potential impacts to essential fish habitat (EFH) under the Magnuson-Stevens Fishery and Management Conservation Act (MSA).

Pursuant to FESA, the lead federal agency responsible for environmental review of a proposed project is required to determine whether or not any species listed as either threatened or endangered under the FESA are present in the study area and to determine whether the project will cause any potentially significant impacts on that species. While these determinations must be made by the federal lead agency, they are typically informed by analyses and recommendations prepared for and provided to the federal lead agency by biological resource specialists (i.e., consultants to the project proponent). As noted above, for this project, the required consultation with NMFS will be the responsibility of the USACE to conduct, as part of their federal permitting process.

NMFS (and USFWS, see above) both are guided by the same set of regulations under the FESA; however, each agency is exclusively responsible for different listed species. NMFS is generally responsible for most listed fish and marine animals. USFWS generally has jurisdiction over terrestrial plants and animals.

Finally, pursuant to the Marine Mammal Protection Act (MMPA), NMFS is responsible for protection of most non-FESA-listed marine mammal species found in the region (such as seals, sea lions, elephant seals, etc.). Consultation and/or permitting under the MMPA is conducted through NMFS Protected Resources Division in Silver Spring, MD, and is done directly between the applicant and NMFS.

Golden Gate National Recreation Area (GGNRA)

Contact

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GGNRA Requirements for Permitting/Environmental Compliance

***Phase I*: Project Planning and CEQA Documentation and Review**

- NOTE: Access to and along the beach will be a key issue for GGNRA that must be addressed during project planning. Currently, public access down to the beach can be challenging in areas where a sacrificial sand berm is constructed to provide protection from winter storms. Depending upon the project design, a temporary staircase, boardwalk or other accessway may be required to facilitate access. This access issue should be discussed with NPS staff early in the planning/design process.

✓ Provide draft "Permitting Roadmap" section about GGNRA, to NPS staff for review.

☐ Provide GGNRA staff with opportunity to review draft project description and CEQA documents.

☐ Review National Park Service Beach Nourishment Guidance[5] and ensure that the project design and proposed monitoring program is consistent with the guidelines in that document.

☐ Seek GGNRA staff input on developing physical and biological monitoring requirements for the project.

☐ County and GGNRA staff should meet to discuss GGNRA's potential role in planning/implementation for Stinson Beach projects, including coordination mechanisms and roles and responsibilities for each jurisdiction. These discussions would occur as distinct meetings, not as part of the West Marin Advisory Group (WMAG) meetings that the County and GGNRA also will participate in.

☐ County should contact GGNRA Planning staff to discuss the project design and environmental review/permitting process.

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5 Dallas, K. L., J. Eshleman, and R. Beavers. 2012. National Park Service beach nourishment guidance. Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2012/581. National Park Service, Fort Collins, Colorado.

***Phase II*: Permitting**

- NOTE: Any proposed nature-based adaptation project within NPS jurisdiction will require a Special Use Permit from GGNRA. County should continue to engage with GGNRA Planning division to establish requirements for the permitting/environmental review process.

- NOTE: GGNRA concerns include protection of the creek and dunes; potential impacts to public access; and any type of ecological impacts from placement of sediment, protection of the creek and dunes, etc.

- ☐ At the onset of the permitting process, coordinate with GGNRA staff to schedule a project presentation/discussion at a GGNRA Project Review Meeting, where representatives from various divisions within the NPS can provide feedback on the project design and permitting process.

- ☐ Invite GGNRA Planning/Permitting staff to participate in a multi-agency pre-application permitting meeting/site visit, to discuss the proposed project and identify potential issues of concern.

- ☐ Continue to provide updates and additional project information as it becomes available. Provide GGNRA staff the opportunity to comment on any environmental review aspects of project development including sediment testing, monitoring, and compatibility requirements, BMPs, mitigation measures, etc.

***Phase III*: Ongoing Project Implementation and Adaptive Management**

- ☐ Continue to provide GGNRA staff with any relevant documents or studies as they become available, including monitoring reports, sediment testing and compatibility results, proposed updates to the project, adaptive management measures, etc.

- ☐ Provide GGNRA staff with a notification of any project maintenance, including placement of additional material, and an opportunity to review and comment on plans and documents related to such maintenance or adaptive management actions (as applicable and stipulated by project permits).

- ☐ Complete permit reporting requirements and renew the existing permit, or apply for a new one, prior to expiration, as applicable.

Key Points:

- GGNRA doesn’t have an official stance on nature-based adaptation projects, however there is precedent for ongoing large opportunistic beach nourishment projects being implemented on GGNRA land at Ocean Beach in San Francisco. GGNRA’s Restoration and Management Priorities include: 1. Stop habitat loss, 2. preserve local biodiversity, and 3. engage visitors with the great outdoors.

- The 2006 NPS Management Policies (NPS 2006) provide important considerations for evaluating when beach nourishment should, or should not, take place in a park unit. GGNRA will need to determine that beach nourishment at Stinson Beach is consistent with NPS management policies.

- The National Park Service Beach Nourishment Guidance (Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2012/581) addresses NPS policy considerations, sediment compatibility considerations, project design considerations aimed at minimizing impacts, monitoring requirements, and permits and regulations.

- Western snowy plovers, while found in some of the other Stinson Beach reaches, are not found within the areas where NPS has jurisdiction.

Agency Background and Regulatory Overview:

There are a number of Federal and State laws and regulations that protect National Park sites including Golden Gate National Recreation Area (GGNRA). In addition to the general NPS regulations in Title 36 of the Code of Federal Regulations each national park site has specific local regulations established under the Superintendent's discretionary authority under Title 36 CFR. These regulations are compiled annually and available on the GGNRA park website and in print at park headquarters. The June 17, 2020 edition of the Superintendent's Compendium, which includes these site-specific rules and regulations, is currently being enforced.

The GGNRA's mission is to preserve and enhance the natural, historic and scenic resources of the lands north and south of the Golden Gate for the education, recreation and inspiration of people today and in the future. GGNRA was established by Congress in 1972 to offer a national park experience to a diverse urban population, while preserving and interpreting the park's outstanding natural, historic, scenic, and recreational values.

One of the largest urban parks in the world, GGNRA welcomes over 17 million visitors a year. The park is as diverse as it is expansive; it contains attractions such as Alcatraz Island, Crissy Field, the Marin Headlands and Rancho Corral de Tierra. GGNRA also includes significant historical and natural resources and houses the largest museum collection in the NPS. Over half of North American avian species and nearly one third of California's plant species are found in the park. GGNRA includes 83,000 acres throughout 91 miles of shoreline.

California Coastal Commission (CCC)

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CCC Requirements for Permitting/Environmental Compliance

***Phase I*: Project Planning and CEQA Documentation and Review**

- NOTE: CCC staff will review all CEQA documents and should also be given an opportunity to provide input and review of project documents including the project description, project purpose, project design, project plans, biological assessments, coastal hazard assessment, survey results, etc. It is also helpful to coordinate with CCC staff on alternatives to be examined through the CEQA process, prior to the process moving forward.

✓ Provide draft "Regulatory Roadmap" section about the Coastal Commission, to CCC staff for review.

☐ Through the initial conceptual development of the project, allow opportunity for CCC staff to provide input on the following: project description, project design, project purpose, project plans, project alternatives, identification of biological impacts and potential mitigation requirements, development of any restoration plans associated with the project, developing physical and biological monitoring requirements for the project, and developing monitoring, maintenance, and adaptive management plans for the project.

☐ Work with CCC and County staff to determine coastal development permit (CDP) jurisdictional boundaries in the proposed project area and explore the potential option for a *consolidated* CDP (see below for more details on this permit type).

☐ If it is likely that a consolidated CDP would be pursued, there should be adequate stakeholder outreach and input gathered at the local level prior to finalizing the design and submission of a CDP to the Commission.

***Phase II*: Permitting**

- NOTE: If the work would occur within areas of both the County and CCC CDP jurisdictional areas, the Applicant could pursue a consolidated CDP through the CCC if all parties agree to such a process. This will allow for a more efficient and effective CDP process. However, during the permitting phase this will require close coordination between the CCC, County and any other involved parties. A multi-year permit can have a term of at least 5 (and up to 20) years, depending on the nature of the project.

- NOTE: Federal park projects in the Coastal Zone are not subject to County-issued coastal permits. LCP policies regarding recreational uses within Point Reyes National Seashore and Golden Gate National Recreation Area simply provide guidance to both the NPS and CCC, which typically review federal projects under what is known as the Federal Consistency Review Authority. However, all non-federal development that occurs on federal lands is subject to CDP review by the CCC.

- ☐ Pre-application discussions and project development should occur in advance of submitting the permit application. This includes cooperation between County and CCC staff throughout the environmental review process as discussed above. If the collaborative work and discussions occur early and often, then the actual permit application review/approval process can be done much more efficiently. This should include review of CEQA documents, the draft Project Description, information on receiver sites and access routes, and any biological literature reviews, assessments or surveys, information on sediment compatibility and testing requirements, etc.

- ☐ During the pre-application process, determine specifics of information submittal requirements.

- ☐ Prepare and submit permit application. Applications are available on the CCC website: https://documents.coastal.ca.gov/assets/cdp/CDP_Application_Form_ncc.pdf

- ☐ Once the permit is processed and approved, the County and any other co-applicants will then adopt the CDP through an agreement letter, a resolution or other agreed-upon legal mechanism. Any agreement should stipulate who will handle the required CDP conditions.

***Phase III*: Ongoing Project Implementation and Adaptive Management**

- ☐ Continue to provide CCC staff with any documents or studies required by any approved CDP conditions,(e.g., monitoring reports, sediment testing and compatibility results, proposed updates to the project, adaptive management measures, etc.)

- ☐ Provide CCC staff with a notification of any project maintenance, including placement of additional material, and an opportunity to review and comment on plans and documents related to such maintenance or adaptive management actions (as applicable and stipulated by project permits).

- ☐ Complete permit reporting requirements and renew the existing permit, or apply for a new one, prior to CDP expiration, as applicable.

Key Points

- CCC Staff are generally very supportive of these types of opportunistic beach restoration projects; however, there are concerns that they would need to see addressed. If the purpose of the project is in part to serve as shoreline protection for existing development (as opposed to a restoration project primarily for restoration purposes), then it will need to be evaluated similar to other shoreline protection under the Coastal Act and must meet the following tests: (1) the shoreline protection is proposed to protect an "existing structure" (i.e., structures built prior to January 1, 1977 and have not been redeveloped since) or public beach or to serve a coastal-dependent use; (2) the existing structure or coastal dependent use is in danger from erosion; (3) shoreline-altering construction is required to protect the existing threatened structure or coastal dependent use (in other words, is the least environmentally feasible alternative); and (4) the required protection is designed to eliminate or mitigate its adverse impacts on shoreline sand supply and impacts to public access and recreation. Thus, information regarding the historical development (and redevelopment) and permitted status of development behind the living shoreline may be needed as part of the CDP application materials. Biological concerns may also include habitat conversions, how/where the sand is placed, the allowable volumes of sediment at each project site, and the quality/compatibility of the sediment.

- Protecting public access, both vertical and lateral, is one of the primary mandates of the CCC and therefore, any proposed project must address potential impacts to public access and recreation in the project area and mitigate for potential impacts through the development of in-kind public access areas and facilities or through an in-lieu fee. California Coastal Act (Section 300001.5) states that one of the basic goals is to "*maximize public access to and along the coast and maximize public recreational opportunities in the coastal zone consistent with sound resources conservation principles and constitutionally protected rights of private property owners*."

- Non native invasive species are another concern of the CCC. In Stinson Beach there is a lot of European beachgrass (*Ammophila*) on the existing dunes. A proposed project would need to mitigate for that and provide a strategy to keep it from invading the new dune. In certain cases where nonnative sand material is moved to a beach, CCC staff have advocated removing native sand and using it as a topper for nonnative sand.

- The CCC permitting process will require public involvement. If there is opposition or public controversy surrounding the proposed project, then that can delay the permitting process. <u>CCC staff recommend hosting public workshops during the early stages of project development so feedback can be incorporated into the project prior to the permit application phase</u>.

- The permit process also requires significant stakeholder notification. For example, the applicants will need to identify and notify all property owners within 100 feet of any project site, at a minimum, as well as all known and interested parties. Once permit applications have been submitted, public notices must be placed in visible locations at/near the project site. There are similar permitting requirements for other agencies as well.

- Since the applicant(s) will be a local government entity, there are no anticipated CCC permit fees.

Agency Background and Regulatory Overview

The California Coastal Commission (CCC) was established by voter initiative in 1972 (Proposition 20) and later made permanent by the Legislature through adoption of the California Coastal Act of 1976.

In partnership with coastal cities and counties, the CCC plans and regulates the use of land and water in the coastal zone. Development activities, which are broadly defined by the Coastal Act to include (among others) construction of buildings, divisions of land, and activities that change the intensity of use of land or public access to coastal waters, generally require a coastal permit from either the CCC or the local government.

The Coastal Act includes specific policies (see Division 20 of the Public Resources Code) that address issues such as shoreline public access and recreation, lower cost visitor accommodations, terrestrial and marine habitat protection, visual resources, landform alteration, agricultural lands, commercial fisheries, industrial uses, water quality, offshore oil and gas development, transportation, development design, power plants, ports, and public works. The policies of the Coastal Act constitute the statutory standards applied to planning and regulatory decisions made by the CCC and by local governments, pursuant to the Coastal Act.

One of the most significant provisions of the federal CZMA gives state coastal management agencies regulatory control (federal consistency review authority) over all federal activities and federally licensed, permitted or assisted activities, wherever they may occur (i.e., landward or seaward of the respective coastal zone boundaries fixed under state law) if the activity affects coastal resources.

California's coastal management program is carried out through a partnership between state and local governments. Implementation of Coastal Act policies is accomplished primarily through the preparation of Local Coastal Programs (LCPs) that are required to be completed by each of the 15 counties and 61 cities located in whole or in part in the coastal zone. Completed LCPs must be submitted to the CCC for review and approval. An LCP includes a land use plan (LUP) which may be the relevant portion of the local general plan, including any maps necessary to administer it, and the zoning ordinances, zoning district maps, and other legal instruments necessary to implement the land use plan. Coastal Act policies are the standards by which the CCC evaluates the adequacy of LCPs.

Development within the coastal zone may not commence until a CDP has been issued by either the CCC or a local government that has a Commission-certified LCP. After certification of an

LCP, coastal development permit authority is delegated to the appropriate local government, but the CCC retains original permit jurisdiction over certain specified lands (such as tidelands and public trust lands). The CCC also has appellate authority over development approved by local governments in specified geographic areas as well as certain other developments.

California Department of Fish and Wildlife (CDFW)

Contact:

For Marine Region (any potential impacts below Mean High Water [MHW]):

Arn Aarreberg – Environmental Scientist
(707) 791-4195; Arn.Aarreberg@wildlife.ca.gov

California Department of Fish and Wildlife, Marine Region
3637 Westwind Blvd., Santa Rosa, CA 95403

For Bay-Delta Region (Terrestrial and above MHW):

Amanda (Mandy) Culpepper – Environmental Scientist
(707) 428-2075; Amanda.Culpepper@wildlife.ca.gov

California Department of Fish and Wildlife, Bay-Delta Region
2825 Cordelia Rd. #100
Fairfield, CA 94534

CDFW CEQA/CESA Resources:

Website: https://www.wildlife.ca.gov/Conservation/Environmental-Review

CDFW Native Plant Resources:

Website: https://www.wildlife.ca.gov/Conservation/Plants

Note: the updated survey protocol link can be found on this page, under Information on Rare, Threatened and Endangered Plants and Natural Communities.

Survey and Monitoring Protocols can also be found here:
Website: https://www.wildlife.ca.gov/Conservation/Survey-Protocols#377281280-plants

CDFW Requirements for Permitting/Environmental Compliance:

<u>Phase I</u>: Project Planning and CEQA Documentation and Review

- <u>NOTE</u>: CDFW will review all CEQA documents but should also be given an opportunity to provide early input and review of the Project Description (PD), biological assessments, etc. prior to the release of draft CEQA documents. For example, provide CDFW staff with opportunities to review the preliminary draft Project Description, information on project sites and access routes, sediment analysis results, and any biological literature reviews, assessments or surveys.

- <u>NOTE</u>: Because there is no existing jurisdiction (i.e., streambeds or lake resources) pursuant to CDFG Code Section 1600 within the proposed project site(s), a CDFW Section 1600 Lake and Streambed Alteration Agreement (LSAA) is not expected to be required.

✓ Provide draft of this CDFW “Regulatory Roadmap” section to CDFW staff for review.

☐ Provide PD and other materials described above to CDFW staff for opportunity to review.

- ☐ Coordinate with CDFW staff during the planning and design process to identify and address any ecological issues of concern and determine what surveys will be required.

<u>Phase II</u>: Permitting

- ▪ <u>NOTE</u>: The project should be designed to avoid any 'take' of listed species or habitat. However, if take of state-listed species or habitat cannot be avoided, it will be necessary for CDFW to issue a *CESA Incidental Take Permit (ITP).* The ITP process is complicated and could take a long time to complete, including negotiating often-costly compensatory mitigation, etc. Therefore, the preferred strategy is to avoid and/or mitigate adverse impacts so that no ITP is needed.

- ☐ Conduct early outreach to CDFW to determine whether an ITP may be needed or can be avoided. If avoidance of 'take' is not possible, coordinate with CDFW to determine whether a standard ITP, or possibly a programmatic ITP, is required.

- ☐ Provide CDFW information related to terrestrial project activities and potential impacts to state-protected wildlife resources. This will allow CDFW staff to coordinate review of potential impacts to listed species.

- ☐ Allow opportunity for CDFW staff to provide input on developing any physical and biological monitoring requirements for the project.

- ☐ Coordinate with CDFW staff to ensure thorough baseline surveys are conducted during project development and before finalizing design plans. This is important because distribution of species (especially plants) can change significantly over time. Note: In addition to the baseline surveys, additional surveys will be required as individual projects are implemented.

<u>Phase III</u>: Ongoing Project Implementation and Adaptive Management

- ▪ <u>NOTE</u>: in addition to the baseline surveys likely to be required during Phase II, surveys would likely be required just prior to project construction and each subsequent placement/maintenance activity, to address natural variations in species populations, distribution, etc. Reference sites for similar species may be used to indicate ideal survey timing, esp. for listed plants.

- ☐ Continue to provide CDFW staff with any relevant documents or studies as they become available, including monitoring reports, sediment testing and compatibility results, proposed updates to the project, adaptive management measures, etc.

- ☐ Provide CDFW staff with a notification of any project maintenance, including placement of additional material, and an opportunity to review and comment on plans and documents related to such maintenance or adaptive management actions (as applicable and stipulated by project permits).

- ☐ Complete permit reporting requirements and renew the existing permit, or apply for a new one, prior to expiration, as applicable.

Key Points:

- Completing good initial biological surveys is highly encouraged by CDFW staff. They also view impact avoidance and minimization as the preferred approach rather than issuing an ITP. Coordination with CDFW throughout project development and CEQA will help ensure the project is designed to avoid or mitigate potential impacts that would otherwise require an ITP.

- CDFW staff point out that early consultation is extremely valuable so that planning doesn't get too far along without knowing the red flags for CDFW. Providing an early opportunity for document review is also encouraged by CDFW staff. This would allow potential issues of concern to be identified and addressed early on in the process to avoid later delays.

- The CDFW website has good resources and species lists: www.wildlife.ca.gov/Conservation

- There are no state Marine Protected Areas (MPAs) in the vicinity of the project area.

- CDFW concerns include terrestrial impacts to listed species in sensitive dune habitats. Also of concern would be incompatible grain size, indirect impacts to adjacent habitat (from migration of sediment/materials after placement), smothering of rocky nearshore habitat, and, if pumping of sediment is necessary then entrainment/impingement impacts to species that reside in the water column or sand could be a concern.

Agency Background and Regulatory Overview:

The California Department of Fish and Wildlife (CDFW; formerly the California Department of Fish and Game or CDFG) maintains the California list of threatened and endangered species. Under the California Endangered Species Act (CESA) it is illegal to 'take' any species that are listed under CESA as endangered and threatened. 'Take' is defined roughly as any activity resulting in direct mortality, permanent or temporary loss of occupied habitat that would result in mortality or disruption in reproduction to one or more individuals of the species. CDFW may evaluate a proposed project's potential to negatively affect species listed as either endangered or threatened in the state. In certain cases, an *Incidental Take Permit* (ITP) may be required (see info above). CDFW often becomes involved in proposed projects through reviewing and commenting on CEQA/NEPA documents (Environmental Impact Reports or Environmental Impact Statements).

CDFW also protects the state's fish and wildlife resources associated with lakes and streams pursuant to CDFG Code Section 1600, by issuing Lake and Streambed Alteration Agreements (LSAAs) for projects which propose to divert flows from or otherwise substantially alter these lake and stream resources. Note: as mentioned previously, as there are no streambeds or lake resources within the proposed project site(s), a CDFW LSAA is not expected to be required.

For more information on CDFW refer to the Beach Restoration Regulatory Guide (BRRG; EIC, 2006) and the CDFW website: www.wildlife.ca.gov.

Regional Water Quality Control Board (RWQCB)

Contact

Nicole Fairley
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Additional Contacts:

Liz Morrison
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San Francisco Bay Regional Water Quality Control Board
1515 Clay Street, Suite 1400
Oakland, CA 94612

Website: https://www.waterboards.ca.gov/sanfranciscobay

401 Certification
Website: https://www.waterboards.ca.gov/sanfranciscobay/certs.html

RWQCB Requirements for Permitting/Environmental Compliance

Phase I: Project Planning and CEQA Documentation and Review

✓ Provide this draft "Regulatory Roadmap" RWQCB section to RWQCB staff for review.

☐ Provide RWQCB staff with opportunity to review the preliminary draft Project Description, including information on receiver sites and an explanation of how the sediment would be handled (e.g., specifics of sand testing for compatibility and processing/placement).

☐ During the planning and design process, ensure that the Basis of Design (BOD) has been documented and provided to RWQCB staff for review. This includes documentation of any alternatives that were considered, and the process for narrowing down the alternatives to the proposed project. Throughout the project design process, the County needs to clearly document any decisions made for the design updates and the technical reasoning that informed it. RWQCB would like to have a chance to review the BOD after any key changes or additions before permit applications are submitted to ensure that all potential alternatives and avoidance/minimization measures are evaluated. This information is used to demonstrate to the RWQCB what impacts are unavoidable and any subsequent mitigation needs, and will potentially be used to prepare an 'Alternatives Analysis' which may be required as part of a permit application to the RWQCB.

☐ Allow opportunity for RWQCB staff to provide input on developing physical and biological monitoring requirements and sediment testing protocol/standards for in-water dredged and upland excavated sediment.

- ☐ Provide all CEQA documents to RWQCB for review.

- ☐ Continue to provide updates and additional project information as it becomes available. Provide opportunity to comment on any environmental review aspects of project development including sediment testing, monitoring, adaptive management/maintenance approach, and compatibility requirements, BMPs, mitigation measures, etc.

Phase II: Permitting

- NOTE: The project applicant(s) will need to apply for a *Section 401 Water Quality Certification* for any project that requires and receives a USACE Section 404 CWA permit (see also USACE Roadmap section). Generally, this includes sand placement activities below the High Tide Line (HTL). RWQCB will also need to review the project for its potential effects on *Beneficial Uses, as designated for each regulated water body.*

- NOTE: For these types of nature based adaptation projects, RWQCB will take into account that short term disturbances are often necessary for achieving long-term enhancement and resiliency. But if there are opportunities to avoid and minimize impacts, they will want to see that evaluated and also want a clear picture of the maximum benefits the project can achieve over the long term vs. the proposed unavoidable impacts, to get a “balanced” view of the project as a whole.

- NOTE: RWQCB can issue a multi-year *401 Certification*, consistent with the terms of the USACE Section 404 CWA permit.

- NOTE: During the permitting phase, the need for mitigation would be evaluated after adequately demonstrating that avoidance of potential impacts has been maximized; if unavoidable impacts are identified and RWQCB staff determine that mitigation is required, the specifics would be developed in coordination between the County and RWQCB staff. For some nature-based solutions (like this project), they may be determined ‘self-mitigating’ based on the project’s benefits and not require separate mitigation actions.

- NOTE: The RWQCB, USACE, and EPA will collaborate regarding specific testing requirements for sediment placement on beaches.

- ☐ A “pre-filing meeting” with the RWQCB must be officially requested at least 30 days prior to submitting the 401 Application, and may be held subject to the RWQCB’s discretion. In general, multiple pre-application meetings are encouraged to facilitate the permitting process, and USACE staff should be copied on all official meeting requests and application submittals to the RWQCB; specific instructions can be found in the 401 Certification links above.

- ☐ RWQCB also recommends a ‘kickoff’ permitting meeting with all agencies present, at the beginning of the permitting phase. This could be done at an existing USACE-facilitated monthly Inter-Agency Pre-Application Meeting or an individual project-specific meeting organized by the permittee.

- ☐ Determine the potential fee requirements for one-time and multi-year permits (the Dredge and Fill Fee Calculator can be found in the 401 Certification website provided above, and RWQCB staff can assist in utilizing the Fee Calculator). Discuss with RWQCB staff whether the project qualifies for the discounted Ecological Restoration project fee.

- ☐ Coordinate with RWQCB staff and in collaboration with EPA staff, to determine requirements for sediment testing and compatibility (e.g. chemical/pollutant requirements) for source sand and any specific monitoring requirements.

- ☐ If project impacts would exceed one acre of uplands, pursue Construction Stormwater Discharge permit requirements. These would typically require the development and implementation of a *Storm Water Pollution Prevention Plan* (SWPPP) and Best Management Practices (BMPs) for construction.

- ☐ Prepare and submit permit application. Applications are available on the RWQCB website: https://www.waterboards.ca.gov/sanfranciscobay/certs.html. Do not submit permit application until project details and permitting requirements/process has been worked out and reviewed by RWQCB staff; RWQCB staff encourage submittal of draft application materials for their review and feedback, to assist in ensuring completeness of the final submittal.

- ☐ Ensure that the maintenance/adaptive management measures and specific triggers are worked out in coordination with RWQCB staff and incorporated into the 401 Certification.

Phase III: Ongoing Project Implementation and Adaptive Management

- ☐ Continue to complete permit reporting requirements and provide any relevant documents or studies to RWQCB staff as they become available, including monitoring reports, sediment testing and compatibility results, etc.

- ☐ Provide RWQCB staff with a notification of any project maintenance, including placement of additional material, and an opportunity to review and comment on plans and documents related to such maintenance or adaptive management actions (as applicable and stipulated by project permits).

- ☐ Complete permit reporting requirements and renew the existing permit, or apply for a new one, prior to expiration, as applicable.

Key Points

- The RWQCB supports nature-based projects because they leverage and build upon natural processes.

- The RWQCB’s jurisdiction is the High Tide Line (HTL), which is the maximum high tide that’s not impacted by storm events. To determine their jurisdictional boundary, staff recommends using the 17-year epoch and referring to May, June or July conditions when there are not many storm events, during highest tides. Any materials (sand or cobble) placed below the HTL would require a permit.

- If there are ‘permanent impacts’ related to the project, RWQCB may require compensatory mitigation. However, RWQCB staff understands that the ultimate goal of the project is to create/restore habitats and adapt to rising sea level, so they would take a ‘balanced’ view when evaluating mitigation needs (and may be able to consider such a project ‘self-mitigating,’ depending on the specifics).

- RWQCB staff will be concerned with project effects to water quality; designated Beneficial Uses (including biological and human use values); physical, chemical, and biological integrity of beach nourishment material; and compatibility with receiver site materials.

- RWQCB staff may have more detailed concerns regarding sediment compatibility. Material may need to be tested for contaminants/pollutants. The specifics of this testing will be determined during Phase I and Phase II above, as well as per guidelines implemented by the EPA.

- RWQCB permits often require long-term monitoring; for this project type, monitoring requirements are likely to include both biological resources as well as physical aspects such as monitoring of placed material (e.g. beach profile changes). Monitoring is often also required for mitigation activities.

Agency Background and Regulatory Overview

It is the responsibility of the Regional Water Quality Control Boards (RWQCB) to preserve and enhance the quality of the State's waters through the development of *Water Quality Control Plans* (Basin Plans) and the issuance of *Waste Discharge Requirements* (WDRs), which are required by the *California Water Code*. WDRs issued by the Regional Water Boards are subject to review by the State Water Board, but do not need the State Water Board's approval before becoming effective.

In addition, any projects requiring a Section 404 CWA permit from the USACE will require *Section 401 Water Quality Certification* by the Regional Water Boards. Therefore, beach nourishment projects require the project sponsor to obtain a Water Quality Certification from the corresponding RWQCB in order to be issued a valid 404 CWA permit by the USACE.

Finally, the RWQCB requires all construction projects with the potential to disturb one or more acres of land to obtain a *General Permit for Storm Water Discharges from Construction Activity*. The Storm Water Permit requires the development and implementation of a *Storm Water Pollution Prevention Plan* (SWPPP). The SWPPP identifies Best Management Practices (BMPs) for reducing or eliminating pollutants in runoff that discharges into waterways and storm drains.

California State Lands Commission (CSLC)

Contact

Christopher Huitt, Senior Environmental Scientist
(916) 574-2080; christopher.huitt@slc.ca.gov

Eric Gillies, Assistant Chief of the Environmental Planning & Management Division
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California State Lands Commission
100 Howe Ave, Suite 100
South, Sacramento, CA, 95825

Website: https://www.slc.ca.gov/

CSLC Requirements for Permitting/Environmental Compliance

<u>Phase I</u>: Project Planning and CEQA Documentation and Review

- ☐ Provide CSLC staff with opportunity to review the preliminary draft project description, including information on receiver sites and an explanation of how the sediment would be handled (e.g., specifics of sand testing for compatibility and processing/placement).

- ✓ Provide draft “Permitting Roadmap” section about CSLC, to staff for review.

- ☐ Allow opportunity for CSLC staff to provide input on developing physical and biological monitoring requirements and sediment testing protocol/standards for in-water dredged and upland excavated sediment.

- ☐ CSLC (Christopher Huitt) can provide expertise and input for determining appropriate size and scale of restoration projects to maximize project benefits, during the design phase.

- ☐ Provide all CEQA documents to CSLC for review.

- ☐ Continue to provide updates and additional project information as it becomes available. Provide opportunity to comment on any environmental review aspects of project development including sediment testing, monitoring, and compatibility requirements, BMPs, mitigation measures, etc.

<u>Phase II</u>: Permitting

- <u>NOTE</u>: A CSLC Lease (or Amendment to an existing CSLC Lease) is required for any project activity or placement of materials on ‘sovereign land.’ ‘Sovereign land’ includes the majority of the ‘ungranted tidelands and submerged lands’ of the state. If needed, the project applicant applies for a Government Agency Lease (rent free). There is a fee for CSLC staff time in processing the Lease application and review of project.

- NOTE: A boundary determination will need to be conducted, if one hasn't been recently done, to identify possible CLSC jurisdictional boundaries within the project site(s). CSLC may be able to complete a records review of jurisdiction in the proposed project site(s). If no recent surveys have been completed at the site(s), a CSLC crew can conduct the surveys, when they have availability. A CSLC Lease (or Amendment to an existing Lease) is only required if CSLC jurisdiction exists at the project site(s), as determined by the records review or boundary survey.

- NOTE: CSLC can issue a lease for a term of up to 25 years, depending on the activity and proposed actions. This term will be determined after CSLC staff conducts a detailed project review.

- ☐ CSLC should be invited to a permitting 'Kickoff' meeting with all agencies present at the beginning of the permitting phase. This could be done at an existing USACE-facilitated monthly Inter-Agency Pre-Application Meeting or an individual project-specific meeting organized by the permittee.

- ☐ If the CSLC will serve as CEQA lead and the habitat restoration area is less than 5 acres, then a Categorical Exemption could be used. If the total project footprint is determined to be less than 5 acres, then the exemption should be discussed with CSLC staff.

***Phase III*: Ongoing Project Implementation and Adaptive Maintenance**

- ☐ Provide updates and notifications to CSLC staff for any proposed or potential action that would result in updates to project development, design or maintenance (e.g. future renourishment of constructed beach/foredunes).

- ☐ Provide CSLC staff with a notification of any project maintenance, including placement of additional material, and an opportunity to review and comment on plans and documents related to such maintenance or adaptive management actions (as applicable and stipulated by project permits).

- ☐ Complete permit reporting requirements and renew the existing permit, or apply for a new one, prior to expiration, as applicable.

Key Points

- CSLC will require that the project's potential impacts be evaluated with sea level rise and climate change in mind. An Environmental Justice (EJ) review shall be conducted concurrently with the sea level rise and climate change evaluation, to identify any at-risk or disadvantaged communities within the immediate area or ½ mile of each project location. This review is consistent with the CSLC's EJ policy. (https://www.slc.ca.gov/envirojustice/).

- Regarding mitigation, CSLC would rely on the CEQA lead agency's approved mitigation program to reduce potential impacts and understands that the ultimate goal of the project is to create/restore habitats and adapt to rising sea level. Therefore, CSLC would take a 'balanced' view when evaluating mitigation needs.

- CSLC will rely on the expertise of other state and federal regulatory agencies and their jurisdictional authorities.

Agency Background and Regulatory Overview

The CSLC derives its authority from both the Public Resource Code and the California Code of Regulations. Public Resources Code section 6301 grants exclusive jurisdiction to the CSLC over all ungranted tidelands and submerged lands including the beds of navigable rivers, streams, lakes and bays. The CSLC administers this authority, including the leasing of sovereign lands for marinas, docks, and moorings pursuant to Title 2, Division 3, Chapter 1, of the California Code of Regulations. The CSLC also has certain residual and review authority for tidelands and submerged lands legislatively granted in trust to local jurisdictions (PRC §6301 and §6306). All tidelands and submerged lands, granted or ungranted, including navigable lakes and waterways, are subject to the protections of the Common Law Public Trust.

As general background, the State of California acquired sovereign ownership of all tidelands and submerged lands and beds of navigable lakes and waterways upon its admission to the United States in 1850. The State holds these lands for the benefit of all people of the State for statewide Public Trust purposes, which include but are not limited to waterborne commerce, navigation, fisheries, water-related recreation, habitat preservation, and open space. On tidal waterways, the State's sovereign fee ownership extends landward to the mean high tide line, except for areas of fill or artificial accretion or where the boundary has been fixed by agreement or a court. On navigable non-tidal waterways, including lakes, the State holds fee ownership of the bed of the waterway landward to the ordinary low water mark and a Public Trust easement landward to the ordinary high-water mark, except where the boundary has been fixed by agreement or a court. Such boundaries may not be readily apparent from present day site inspections.

County of Marin (the Project Proponent/Applicant):

Contact

Leslie Lacko, Senior Planner
(415) 473-4333; llacko@marincounty.org

County of Marin, Community Development Agency
Planning Division
3501 Civic Center Drive, Suite 308
San Rafael, CA 94903

County of Marin Involvement in Environmental Compliance

NOTE: The County of Marin is the project proponent, and applicant for permits. The County is also anticipated to serve as the CEQA lead agency, although this role is subject to other factors and therefore will be decided in the future.

***Phase I*: Project Planning and CEQA Documentation and Review**

- ☐ County should coordinate with regulatory agencies to discuss project and identify and address constraints, early in the design process.

- ☐ Collaborate with landowners to seek necessary approvals, and possibly form alliances to further project objectives and increase the likelihood of success. Initiate discussions about potential options for project proponents, such as creating a 'Special District' (which could consist of a Geological Hazard Abatement District [GHAD] or a Joint Powers Authority [JPA]). Discuss governance structure and implementation strategies and identify roles and responsibilities of various project beneficiaries throughout planning/environmental review/permitting process.

- ☐ The CCC, as the lead agency under the California Coastal Act, would also be responsible for complying with CEQA. The CCC's permit process is CEQA-equivalent under the law, which means that through the permit process the CCC will cover the elements required under CEQA in its staff report and make appropriate findings for CEQA compliance. The County, as the expected CEQA lead agency for the project, should coordinate with CCC to ensure the CEQA document satisfies both agencies' requirements under CEQA. See also the Agency Summary for the CCC (above).

***Phase II*: Permitting**

- ☐ The project proponent (County CDA) will need permission from County Parks, which owns the section of beach at the Calles and Patios.

- ☐ For each alternative dune scenario, the work would take place primarily within the California Coastal Commission's (CCC) jurisdiction. Therefore, a Coastal Development Permit (CDP) will be required through the CCC. This CDP should be consistent with Marin County's Local

Coastal Program, the California Coastal Act, and, should GGNRA pursue the project in partnership with the County, the federal Coastal Zone Management Act (CZMA).

***Phase III*: Ongoing Project Implementation and Adaptive Management**

- ☐ Conduct all permit-required surveys, studies, and/or monitoring and report preparation.
- ☐ Ensure coordination with all permitting agencies to provide staff with any relevant documents or studies as they become available, including notifications of project maintenance, planned placement of additional material, monitoring reports, sediment testing and compatibility results, proposed updates to the project, adaptive management measures, etc.
- ☐ Complete permit reporting requirements and renew the existing permit, or apply for a new one, prior to expiration, as applicable.

Key Points

- The County may have the role of assisting in the development of a ‘Special District’ (which could consist of a Joint Powers Authority [JPA], or a Geologic Hazard Abatement District [GHAD] formed by the property owners) whereby the County would not be solely responsible for managing, constructing, or maintaining the project. In such a case, a Coastal Development Permit would be applied for by the legal entity as the project proponent.
- A County Building Permit would not be needed for the project since nothing is being “built.”
- A County Grading Permit would be required; grading permits are typically pursued after the CCC releases a Notice of Determination to issue its permit but before the finalized CDP is issued.
- Other than a County Grading Permit, no other applicable ordinances have been identified at this time, that would require other permits or approvals from the County of Marin. When additional project information becomes available, such as permitting level design plans, the County should evaluate whether and additional municipal stormwater permits (MS4s), or tree or creek ordinances might apply.

Chapter 6
Conclusion and Next Steps

1. Conclusions and Next Steps

This chapter presents salient conclusions of the study and recommended next steps for nature-based adaptation at Stinson Beach.

1.1 Conclusions

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 anenhanced 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 armoringapproaches 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 naturalsystem.

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 thoughtof 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 ofnatural 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 quickerbeach 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 thirdthe 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 ofwinters 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 structuresif 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 bermand 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 adaptationneed to commit to ongoing maintenance program and ready to respond to coastal storm impacts. The managementimplications 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 atthe 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 ofcobble 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.

2 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 canfacilitate 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 preliminarydesign 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 withfuture 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 stormchanges (coordinate with ongoing surveys reach by GGNRA staff)