SAN FRANCISCO WATERFRONT COASTAL FLOOD STUDY, CA

DRAFT APPENDIX I ENGINEERING WITH NATURE

JANUARY 2024

USACE TULSA DISTRICT | THE PORT OF SAN FRANCISCO

US Army Corps of Engineers

PORT OF SAN FRANCISCO

Table of Contents

List of Tables

List of Figures

Sub-Appendices

I.1: Engineering with Nature Framework

I.2: Engineering with Nature Working Group members and meeting details

Acronyms and Abbreviations

Acronym	Definition
AEP	Annual Exceedance Probability
Bay	San Francisco Bay
CA	California
City	City and County of San Francisco
CFRM	Coastal Flood Risk Management
EPA	U.S. Environmental Protection Agency
EQ	Environmental Quality
EWN	Engineering with Nature
EWNWG	Engineering with Nature Working Group
FEMA	Federal Emergency Management Agency
FRM	flood risk management
GSI	green stormwater infrastructure
LEED	Leadership in Energy and Environmental Design
LF	linear foot (feet)
m/s	meter(s) per second
MLLW	mean lower low water
mph	mile(s) per hour
MSL	mean sea level
NAVD88	North American Vertical Datum of 1988
NED	National Economic Development
NNBF	natural and nature-based features
NOAA	National Oceanic and Atmospheric Administration

O&M	operations and maintenance
OSE	Other Social Effects
PDT	Project Development Team
PED	Preconstruction, Engineering, and Design
Port	Port of San Francisco
RED	Regional Economic Development
RSP	rock slope protection
RWQCB	Regional Water Quality Control Board
SAV	submerged aquatic vegetation
SF	San Francisco
SFEI	San Francisco Estuary Institute
SFPUC	San Francisco Public Utilities Commission
SFWCS	San Francisco Waterfront Coastal Study
SLR	sea level rise
STEM	science, technology, engineering, and mathematics
TWL	total water elevation
U.S.	United States
UK	United Kingdom
USACE	U.S. Army Corps of Engineers
WRP	Waterfront Resilience Program

1. Introduction

The U.S. Army Corps of Engineers (USACE) in partnership with the Port of San Francisco (Port), are leading the San Francisco Waterfront Coastal Flood Study (SFWCS) to evaluate existing and future coastal flood hazards and develop a range of feasible alternatives to reduce flood risks along the 7.5 miles of the City and County of San Francisco (City) shoreline on the bayside of the city (Appendix A. Plan Formulation). Under existing conditions, the shoreline is highly urbanized, comprised almost entirely of shoreline protection structures, such as seawalls, bulkhead wharves, and armored revetments, with small pockets of natural shorelines such as Crane Cove Park, Warm Water Cove, Pier 94 wetlands, and Heron's Head Park. The Port is an active steward of these natural shorelines, partnering with the Audubon Society, California Coastal Conservancy, and other agencies and volunteer organizations to maintain and enhance these valuable natural resources. Through the SFWCS, the Port and the City have an interest in increasing natural and nature-based solutions, where feasible, along the shoreline.

USACE is also interested in using natural and nature-based features (NNBF) within coastal resilience and coastal storm risk management projects. The USACE Engineering with Nature (EWN) program provides guidance supporting the intentional alignment of natural and engineering processes to address flooding hazards while also delivering economic, environmental, and social benefits (Bridges et al., 2015; T.S. Bridges et al., 2021; King et al., 2021). To date, USACE has published two atlases that compile successful applications of engineering with nature within the U.S. and internationally (Bridges et al., 2018; T. S. Bridges et al., 2021). USACE also promotes nature-based solution guidance developed by partner agencies (Cheng et al., 2016; Gallet, 2011; Naylor et al., 2017).

Although opportunities for expansive NNBFs are limited, the Port and USACE collaborated with local, regional, and national experts to develop a range of feasible solutions appropriate for San Francisco's shoreline. The Port also initiated a living seawall pilot study to test different seawall surface textures and concrete mixes that would allow the Port to identify that most likely approaches for creating habitat for native biota along otherwise barren seawalls.

1.1 Natural and Nature-Based Feature Selection Approach

Selecting appropriate NNBFs for each Future with Project (FWP) alternative evaluated (Appendix A: *Plan Formulation*) used the following approach:

- Asses historical shorelines and habitat types present along San Francisco's shoreline.
- Review intertidal and subtidal habitat goals Bay-wide
- Develop a feasible range of NNBFs appropriate for San Francisco's shoreline.

  - NNBFs that address wave hazards by dissipating wave energy and reducing the potential for wave runup and wave overtopping are prioritized.
  - In most locations, recommended NNBFs are combined with traditional gray infrastructure (e.g., seawalls, floodwalls, berms) and proposed as hybrid green-gray measures.
  - Other NNBFs were retained for potential mitigation purposes.
- Coordinate with the planners and engineers to identify locations within each alternative to place NNBFs while considering maritime constraints.
- Ensure that each retained NNBF identified for San Francisco's shoreline is represented within at least one FWP alternative (Alternatives C thru G, Appendix A. *Plan Formulation*).

This approach allowed for the evaluation of the full range of candidate NNBFs across the alternatives. However, the tentatively selected plan (TSP) was not optimized during this feasibility stage relative to NNBFs. For example, Alternative E is the only alternative that contains living seawalls along the northern Embarcadero waterfront. Alternative E was not selected as the TSP for Reaches 2 or 3 (the northern Embarcadero reaches). The optimization of NNBFs within the tentatively selected plan will occur in a later phase, identifying the most promising and effective NNBFs from across the alternatives for inclusion in the final Recommended Plan within the Chief's Report. The engineering and design of these features, including green-gray hybrid measures, will occur in the Preconstruction Engineering and Design (PED) phase. Both the Port and USACE are committed to including the most viable and beneficial NNBFs within the Recommended Plan.

1.2 Background

In San Francisco Bay (Bay) and along the Port's shoreline, the primary coastal hazards of interest are 1) elevated Bay water levels due to storm surge and other processes, and 2) wave hazards that result in wave runup and wave overtopping along the shoreline. Both coastal hazards will increase in severity in response to climate change (Barnard et al., 2019, 2017, 2015; Vitousek et al., 2017). *Appendix B1.1 Coastal Extreme Water Levels and High Tide Flooding* provide a thorough review of Bay coastal processes and the hazards of interest within the study area.

All FWP alternatives include a feasible range of NNBFs selected specifically to address wave hazards by dissipating wave energy and reducing the potential for wave runup and wave overtopping along the shoreline. Along highly urbanized shoreline sections, recommended NNBFs are combined with traditional gray infrastructure (e.g., seawalls, floodwalls, berms) and proposed as hybrid green-gray measures. Hybrid measures offer advantages over gray structures beyond risk reduction, including prolonging structure lifespans, increasing habitat area and connectivity, providing habitat for endangered species, improving community wellbeing, and enhancing future adaptability (Albert et al., 2021; Anderson et al., 2022; Beyer and Anderson, 2020; Nakamura, 2022; Sutton-Grier et al., 2015; USACE, 2021a, 2020a).

In the Bay, there is considerable experience in wetland and ecological restoration by USACE and other partners (Hamilton Wetlands, Sonoma Baylands, Sears Point, South Bay Salt Ponds etc.). There is also region-specific guidance for incorporating NNBFs along a wide range of shoreline types (Goals Project, 2015; SFEI and SPUR, 2019). To capitalize on this experience, the Port established an Engineering with Nature Working Group (EWNWG) comprised of international, national, regional, and local experts to identify a range of NNBFs for consideration. The EWNWG considered where NNBFs are feasible and assessed how NNBFs can contribute to coastal risk reduction, with an emphasis on wave hazard reduction, while also supporting regional habitat goals.

In select locations where topography and geographic space allow, NNBFs are proposed as the primary flood risk reduction structures. However, many common NNBFs require more space than is available along San Francisco's developed shoreline. The adjacent deep Bay waters that accommodate deep-draft large vessel- traffic and berthing for maritime uses, including the cruise ship and port industries, commercial and recreational fishing, and disaster response functions, such as the Maritime Administration's National Defense Reserve Fleet, create constraints for accommodating large-scale NNBFs. The NNBFs selected and recommended are generally small in nature and targeted toward wave hazard reduction, as opposed to surge reduction which can require more expansive features.

All FWP measures, whether green, gray, or hybrid, are described in the alternatives at a high level, with a limited level of design detail. The Project Delivery Team (PDT) members chose not to model the wave runup reduction potential of all green, gray, or hybrid measures as part of the feasibility study, as this would require a level of detail design more appropriate for the PED phase. Instead of performing detailed wave modeling, the PDT chose to use a 2-foot wave proxy. The intent of the proxy is to inform the basis of design and cost estimates, under the assumption that the future detailed design of the measure(s) can achieve sufficient wave energy dissipation to limit the wave runup elevation to 2-feet above the 1% annual exceedance probability (AEP) stillwater elevation. Based on a review of the wave heights along the shoreline (*Appendix B1.1 Coastal Extreme Water Levels and High Tide Flooding*), the wave runup elevations on the existing Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs) (FEMA, 2021), and the scientific literature, a 2-foot wave proxy was considered reasonable. Including NNBF measures to reduce the potential for wave runup reduces the design elevation of coastal flood defenses, reducing project costs while providing a range of other benefits.

The public have expressed strong preference for NNBFs where appropriate (Appendix H Public Involvement). The Bay is an area of ecological importance and a designated National Estuarine Research Reserve (NERR) by the National Oceanographic and Atmospheric Administration (NOAA) providing habitat for many species, including Endangered Species Act listed species, along with an active, engaged community that wants an accessible shoreline, and regulatory agencies that demand it. The long-term health of Bay ecosystems would benefit from the incorporation of NNBFs, including hybrid features, to the maximum extent possible and practicable. This Appendix documents the range of NNBF features evaluated along the shoreline, and the NNBF features selected for incorporation within the alternatives to provide coastal flood risk management benefits through wave hazard reduction. NNBFs that solely provide habitat or other Environmental Quality (EQ) benefits are not included in the alternatives but are described as tentatively retained for mitigation purposes.

1.3 Organization

This appendix includes the following sections to support the inclusion of NNBFs within the SFWCS:

- **I-2**. USACE Policy Guidance for Engineering with Nature
- **I-3**. Coastal Storm Risk Reduction
- **I-4**. Screening of Natural and Nature Based Features
- **I-5**. Benefits and Performance of Retained Features
- **I-6**. Retained Features in the Future with Project Alternatives
- **I-7**. Environmental Quality Benefits
- **I-8**. References

This appendix also includes two sub appendices that provide additional information on the formulation and selection of NNBFs for the San Francisco shoreline, and the Engineering with Nature Working Group (EWNWG) that supported this process.

- **Sub-Appendix I.1** Engineering with Nature Framework
- **Sub-Appendix I.2** Engineering with Nature Working Group members and meeting details

2. USACE Policy Guidance for Engineering with Nature

This section describes the major assumptions that guided the plan formation, selection of measures, and integration of NNBF measures into the SFWCS alternatives.

EWN is the intentional alignment of natural and engineering processes to deliver economic, environmental, and social benefits efficiently and sustainably through collaboration. NNBFs refer to the use of landscape features to achieve flood risk management (FRM) benefits. NNBFs may also provide other economic, environmental, and social benefits often referred to as NNBF co-benefits. These landscape features may be natural (created by natural processes), or nature based (created by a combination of natural processes and human engineering), and include features such as beaches, dunes, wetlands, reefs, and islands. Landscape features can be used alone, in combination with each other, and in combination with conventional engineering measures, such as levees, floodwalls, and other structures (USACE, 2021a).

While the SFWCS is a single-purpose coastal flood risk management study, Section 1184 of the Water Resources Development Act of 2016 (USACE, 2017) requires consideration of NNBFs in addition to nonstructural and structural measures:

> “when studying feasibility of projects for flood risk management. Furthermore, the Policy Directive, Comprehensive Documentation of Benefits in Decision Document, requires USACE decision framework to consider “in a comprehensive manner, the total benefits of project alternatives, including equal consideration of economic, environmental, and social categories” (USACE, 2021b).

NNBFs achieve a comprehensive benefits approach, which includes some coastal flood risk management benefits, as well as the ability to maximize benefits across other accounts, particularly environmental quality (EQ) and other social effects (OSE).

The USACE San Francisco District is the first West Coast EWN proving ground. This designation is applied to USACE districts committed to the broad implementation of EWN principles and practices. While this project is led by the Southwestern Division, the local values, interest, and priorities of stakeholders and the public are committed to integrating EWN into all projects across the San Francisco District’s area of responsibility.

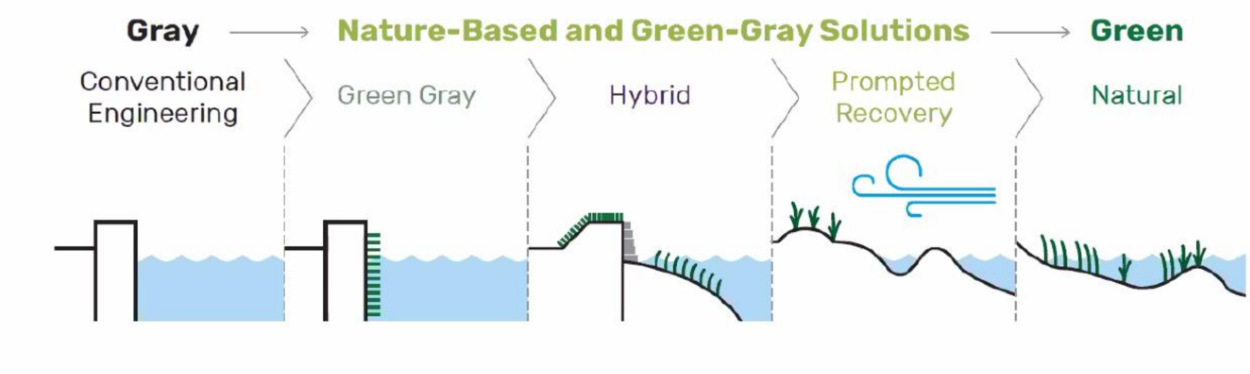
Due to the highly constrained and urbanized nature of the San Francisco shoreline, the process of integrating NNBFs into the project alternatives has been greatly informed by ongoing engagement and consultation with an EWNWG of local, national, and international leaders, practitioners, and experts in Bay geography, history, ecology, as well as living shorelines, and EWN in urban environments. The EWNWG input was refined by the Port’s consultant team and workshopped with the SFWCS PDT.

More than six EWNWG workshops were held between May 2022 and January 2023, and the EWNWG helped identify a range of potential NNBFs and opportunities, provided scientifically grounded criteria to help guide the incorporation of NNBFs, and identified knowledge gaps and potential pilot projects. Outputs from the EWN workshops were then integrated into the five future-with-project alternatives (Alternatives C–G) at two implementation phases (2040 and 2090). The two phases represent approximate timeframes for the project’s initial implementation phase and future adaptation phase. Implementation timing will vary based on the rate of observed future sea level rise.

2.1 Assumptions for Siting Natural and Nature-Based Features

This effort considered a hybrid approach to EWN that falls along a gray-green spectrum in the highly urbanized context of the study area (**Figure I-1**). In each case, the proposed measures reflect an analysis of the sited risks, opportunities, considerations, and constraints. This effort also acknowledges that the natural shoreline has been significantly modified over time through diking, ditching, draining, dredging, filling, development, and other changes. Today’s shoreline needs regular maintenance to keep people safe from flooding, does not always integrate well with the Bay’s natural habitats, and is not designed to accommodate rapid sea level rise (SLR).

There are significant opportunities to incorporate NNBFs that may help address these shortcomings and provide both flood risk reduction and ecological benefits as sea levels rise. In many cases these combinations will be hybrid, including NNBFs together with conventional engineered measures (SFEI and SPUR, 2019).



Source: USACE International Guidelines on Natural and Nature-Based Features for Flood Risk Management

Figure I-1: Continuum of Nature-Based Techniques Used in Practice

2.2 A Degree of Uncertainty and Level of Design

The NNBFs were not developed to a detailed level of design, consistent with the gray measures included within the alternatives. Due to the uncertainty in the design process, the following considerations apply:

The measures proposed are part of the alternatives and do not represent design proposals.

- The cost estimating conducted at this stage in the planning process will include a range of +100 to - 50%. This reflects the high degree of uncertainty inherent to costing adaptation strategies and the various unknowns and assumptions associated.
- *“Sources of uncertainty are largely similar to those of structural measures, although natural variability of NNBF may be greater than that of structural measures”* (USACE, 2021a).
- More examples are documented of traditional gray measures than NNBFs due to the relative novelty of EWN practices and construction, lending less certainty in the form of precedent to the design.
- “*Uncertainty is inherent in the evaluation of alternatives. A range of environmental conditions within the system, including storm and flood events and drought, may affect natural and nature-based features. The dynamic nature of natural and nature-based features introduces risks that must be considered in the*

evaluation, design, and operation of systems that include these features" (USACE, 2017).

2.3 Employing Measures in Combination

Traditional approaches provide coastal flood risk management benefits through a single measure located along a shoreline. By contrast, NNBFs can be combined across a terrestrial to aquatic transect to provide multiple integrated benefits in one location.

The USACE guideline defines the multiple lines of defense strategy as:

> "A systems approach to shoreline protection (Lopez 2009; Guannel et al. 2016; Arkema et al. 2017). The idea is that multiple habitat types from offshore to onshore, perhaps combined with some elements of conventional engineering, can be used as a buffer against storms and chronic-erosion events, making the community as a whole more resilient to storm events…A strategy of multiple natural features for storm protection (e.g., coral reefs, SAV, and mangroves) is more effective than any single habitat alone (Guannel et al. 2016)" (USACE, 2021a).

For example, while a traditional gray measure might call for a levee in each location, EWN might combine mudflats, wetlands, and an ecotone levee in the same location to provide integrated-coastal flood risk management and other benefits.

2.4 Adaptation and Performance

The NNBFs proposed are capable of being adapted as sea levels rise, as follows:

- NNBF performance objectives are "to provide functions relevant to flood risk management (FRM) while also producing economic, environmental, and social co-benefits" (USACE, 2021a).
- The objectives and performance of each NNBF will be determined by design decisions made in alignment with the alternative's overall intent (including higher or lower rates of SLR, and the location of the line of protection):

"NNBF performance may deteriorate over time, requiring routine maintenance to sustain performance over the course of an entire project lifetime. However, unlike structural measures, many NNBFs can adapt to future conditions and performance may even improve over time (e.g., wetlands migration in response to sea-level rise)" (USACE, 2021a).

NNBFs will, as with all measures, require operations and maintenance (O&M).

"Performance of NNBF over a project life cycle requires periodic assessment at a frequency commensurate with the natural dynamism of the NNBF and the location." Given the dynamic nature of NNBF, USACE recommends adaptive management plans to optimize risk management and reduce uncertainties over time" (USACE, 2021a).

Performance varies from measure to measure. This variation is reflected in the organization of individual measure performance narratives.

All NNBFs were selected to provide localized wave hazard reduction benefits, with most NNBFs selected to pair with the traditional engineered solutions within each alternative. However, in many cases, the NNBFs selected also provide EQ and OSE benefits, but these co-benefits were not a determining factor in selecting NNBFs.

2.5 Managing Risk Beyond Current Study Parameters

The current analysis targets coastal flood risk management, including elevated Bay water levels and wave hazards. However, the measures to address coastal flood risk management should not exacerbate existing stormwater and groundwater hazards within the existing coastal line of protection.

Other considerations include:

- Sea level change is expected to cause a rise in the coastal groundwater table; which, in turn, will exacerbate inland flooding over time due to reduced storage capacity in soils, tributaries, and drainage channels, and infiltrated sewers and wastewater treatment systems (Pathways and SFEI, 2022).
- Elevating the shoreline will prevent stormwater runoff from draining to the Bay and necessitate solutions to manage inland flooding, such as storage, pumping, and green infrastructure. Higher groundwater tables from SLR may reduce the effectiveness of infiltration solutions. Increasing precipitation due to climate change will also increase stormwater runoff and further raise the groundwater table (Patricola et al., 2022), and should be considered along with SLR.

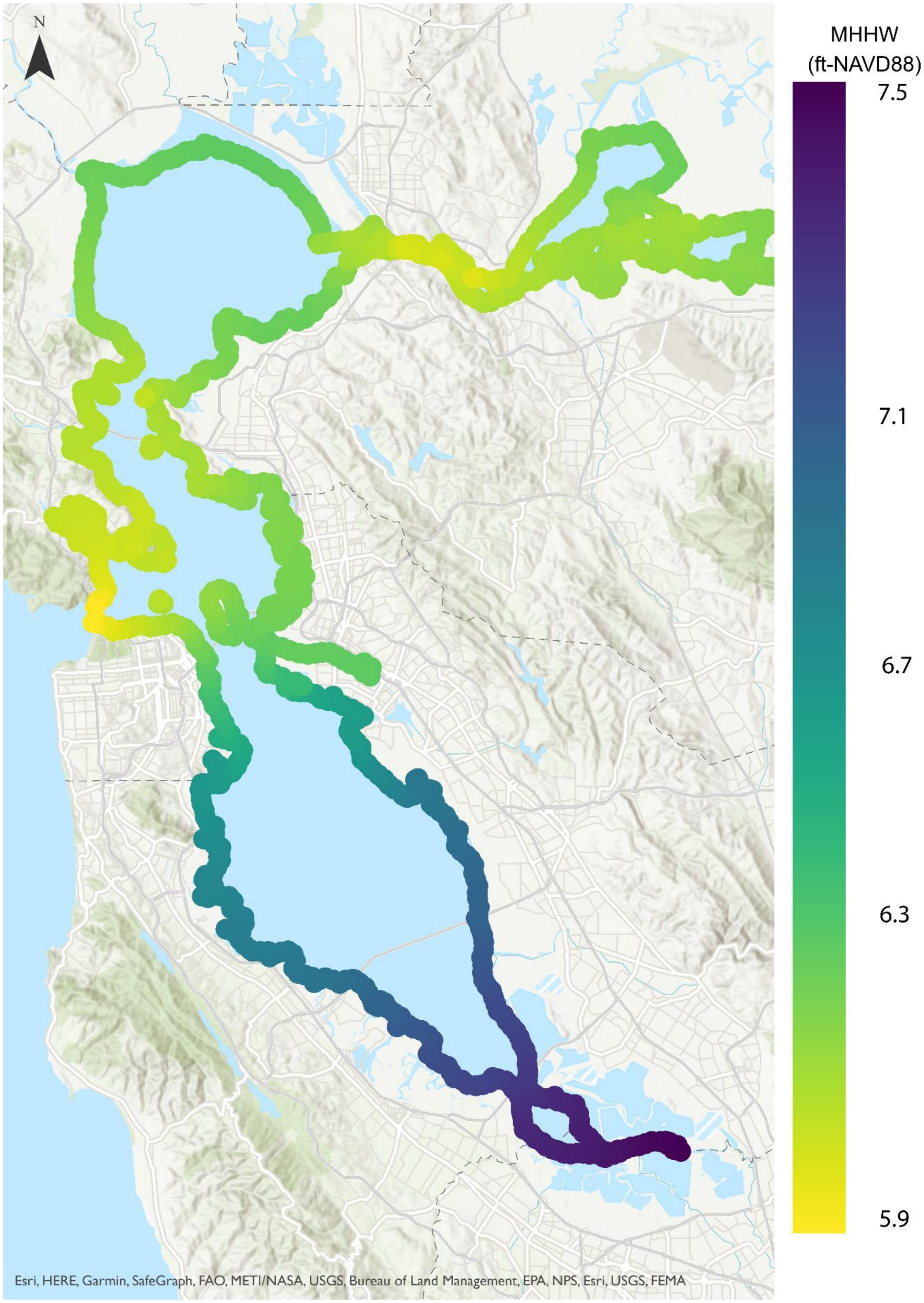
3. Coastal Storm Risk Reduction

San Francisco Bay is the largest estuary in the western U.S., with a contributing watershed that includes nearly 40% of California with substantial freshwater flows entering through the Sacramento River. The 300-foot-deep Golden Gate inlet connects the Bay with the Pacific Ocean, and the tides, ocean-driven swells, and extreme ocean water levels all enter the Bay through this single inlet. The large expanse of the Bay and the complex topography surrounding the Bay can transform storm-driven winds in a multitude of directions depending on the primary driver of the onshore or offshore winds or the track of the large storm system descending on the Bay Area. The water levels and wave heights of the Bay exhibit a high degree of variability driven by many factors, including the bathymetry, astronomical and oceanic cycles, windspeeds and direction, and atmospheric events. In the Bay, no single storm event produces the highest water level and highest wave hazard along the entire shoreline. *Appendix B1.1 (Coastal Extreme Water Levels and High Tide Flooding*) provides additional details relative to Bay hydrodynamics, wave dynamics, and storm climatology.

3.1 Bay Water Level and Wave Conditions

Figure I-2 presents the variation in MHHW along the Bay shoreline, and **Figure I-3** presents the variation in MHHW along the bayside of San Francisco. Tidal amplification of about 0.8 feet occurs from the north to the south along the city shoreline. This variation is also evident in the 1% AEP water levels along the city shoreline (**Figure I-4)**. The 1% AEP water levels are approximately 3.5 feet above MHHW, driven by multiple tidal and oceanic processes including El Niño and surge. NNBFs are not proposed to reduce the 1% AEP Bay water levels. NNBFs are proposed to reduce flood risks associated with wave-driven processes.

Understanding local wave conditions is a crucial part of coastal flood risk management, both with respect to infrastructure design (including coastal defense structures) and understanding residual risk. Along San Francisco's shoreline, NNBFs can meaningfully reduce wave hazards by dissipating wave energy and reducing wave run up elevations on natural and built shorelines, reducing the likelihood of shoreline overtopping. Waves that travel towards and perpendicular to the shoreline can runup shoreline structures including flood defenses (e.g., seawalls and levees), and, if the elevation of the wave runup exceeds the shoreline elevation, wave overtopping can occur (**Figure I-5**). In the absence of wave dissipation features, the wave runup elevation may exceed the wave crest elevation along the shorelines. The height of the wave runup depends on many factors, including the Bay water level depth and height, shoreline slope, and shoreline roughness. Wave runup elevations generally increase along steeper shorelines.

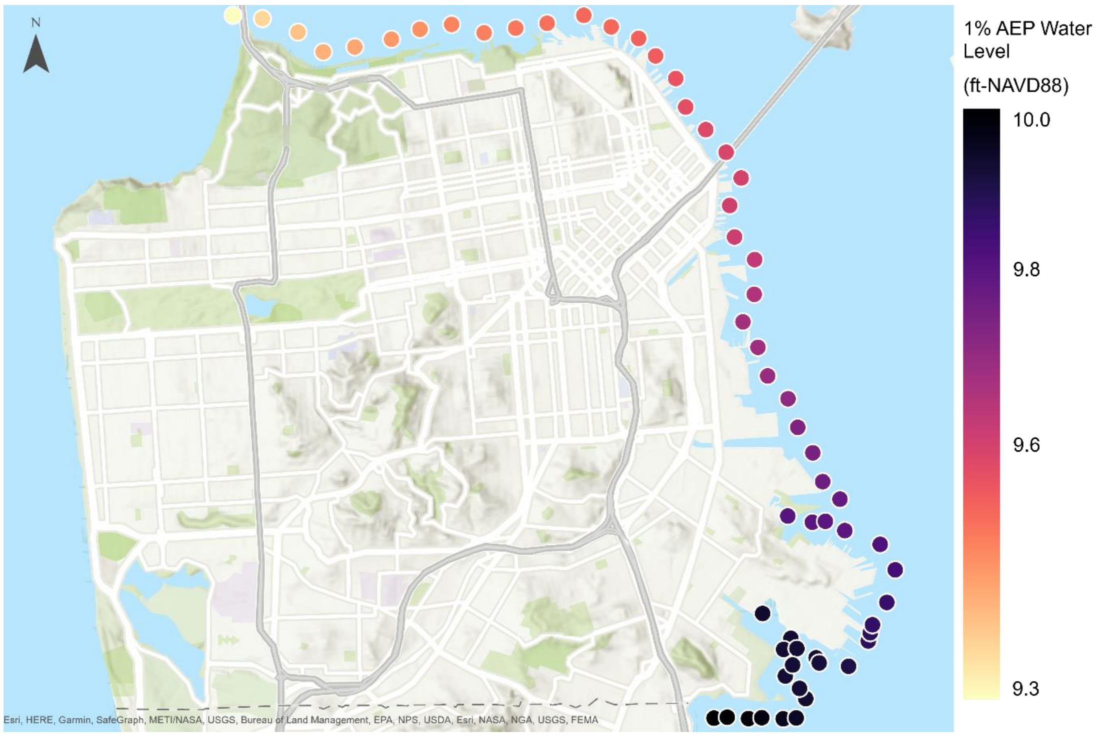


Source: *DHI 2011; 2013; May et al. 2016, Appendix B1.1 Coastal Extreme Water Levels and High Tide Flooding Report*

Figure I-2: Baywide Variation in Mean Higher High Water (relative to 2008)

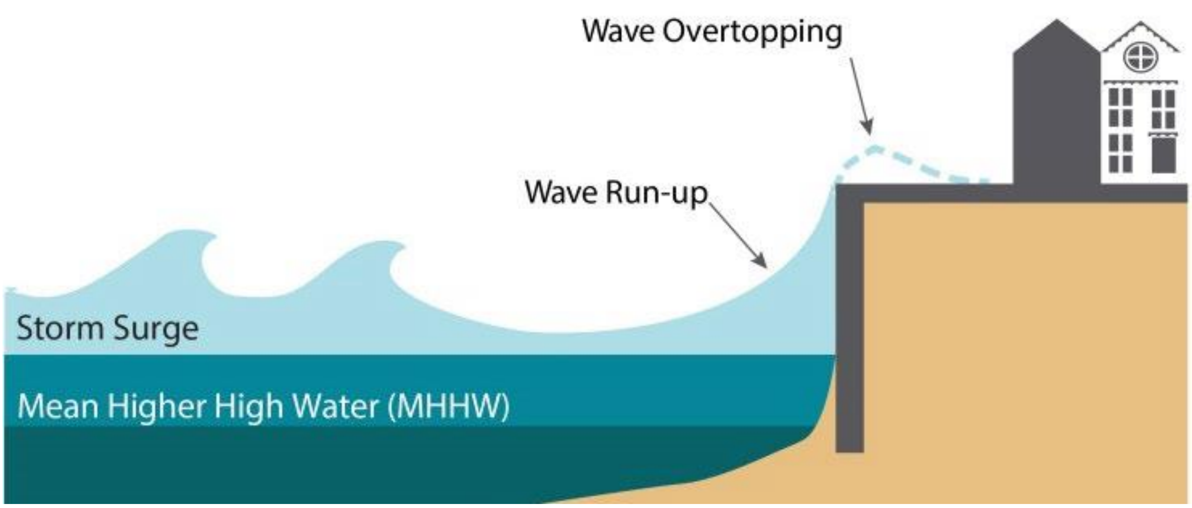
Source: DHI 2011; May et al. 2016, *Appendix B1.1 Coastal Extreme Water Levels and High Tide Flooding Report*

Figure I-3: San Francisco Shoreline Variation in Mean Higher High Water (relative to 2008)



Source: DHI 2011; May et al. 2016, Appendix B1.1 Coastal Extreme Water Levels and High Tide Flooding Report

Figure I-4: San Francisco Shoreline Variation in 1% AEP Water Level (relative to 2008)

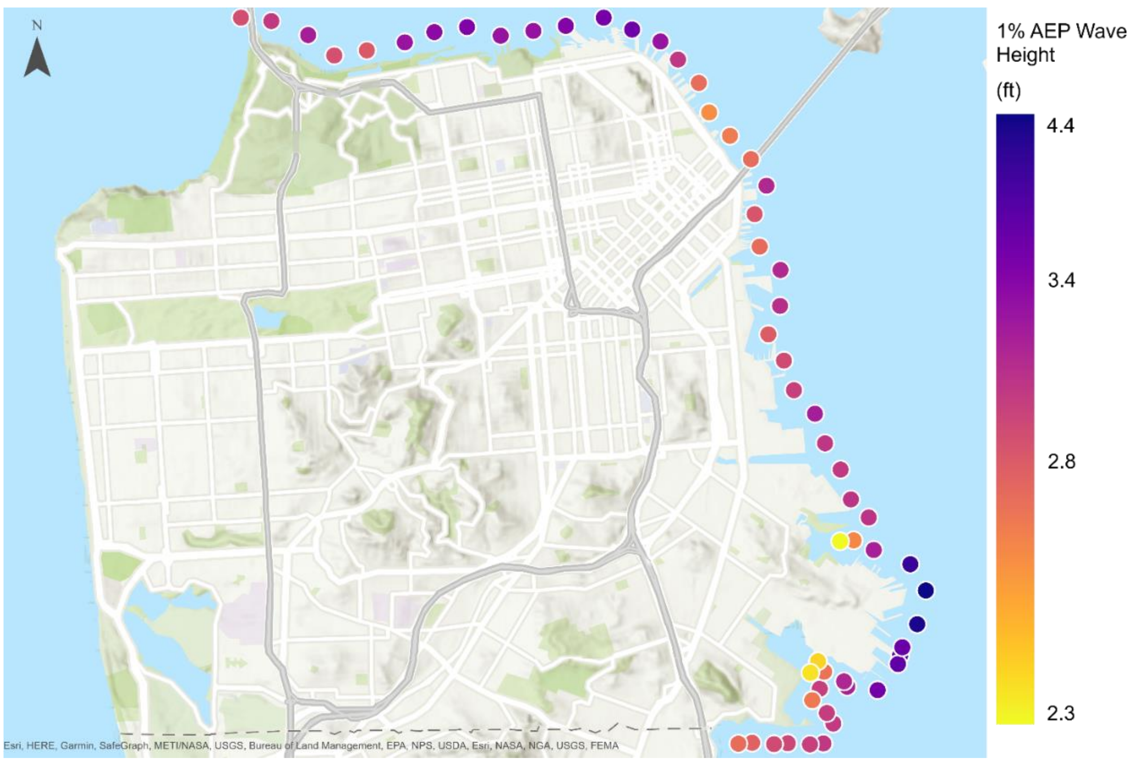


Source: *CPC 2020*

Figure I-5: Wave Runup and Overtopping along the Shoreline

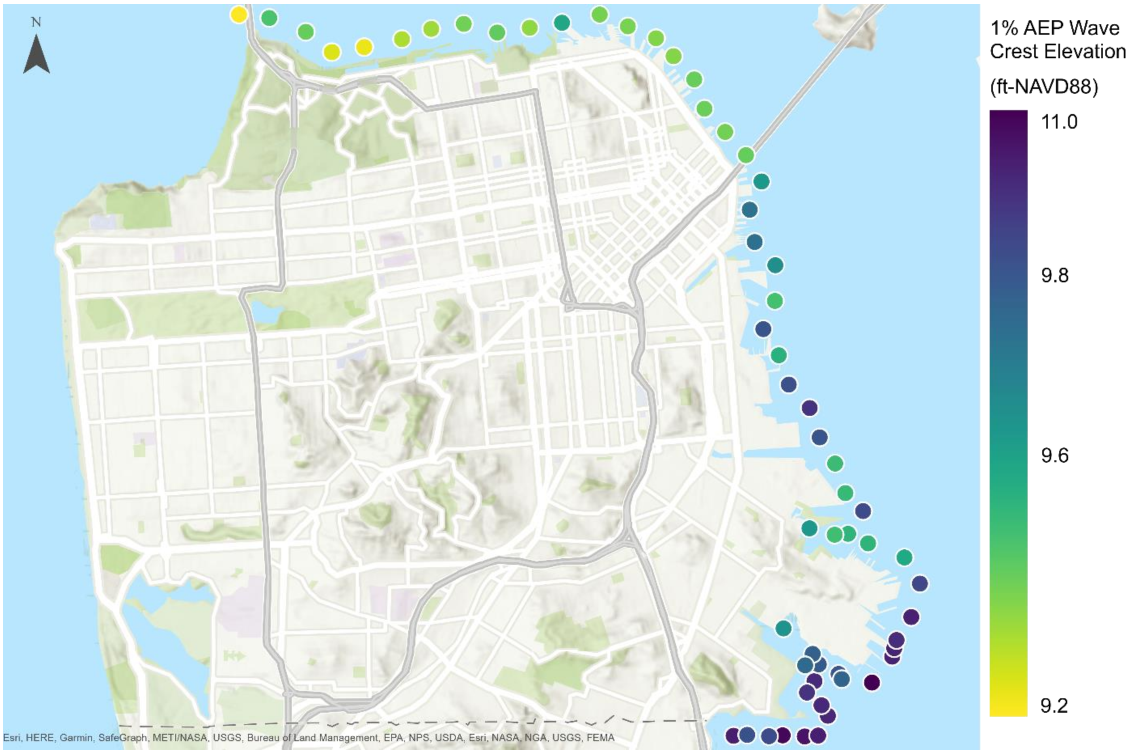
In the Bay, wind-driven waves are the dominant wave hazard along the shoreline, and the varied wind conditions generate waves with 1% AEP wave heights of two feet to four+ feet along the shoreline (**Appendix B1.1**, **Figure I-6**.). The 1% AEP wave height does not occur concurrently with the 1% AEP stillwater elevation. The 1% wave crest elevation along the shoreline is presented in **Figure I-7.**

As an approximation, if the 1% AEP stillwater elevation is 10 feet NAVD88, the addition of the 2-foot wave proxy would lead to an existing design elevation for coastal flood defenses of 12 feet NAVD88. The San Francisco FEMA FIRMs suggest a maximum existing wave runup elevation of 15 feet NAVD88, with most of the shoreline having an existing wave runup elevation of 13 feet NAVD88 or less (FEMA, 2021). Green, gray, or hybrid shoreline flood risk reduction measures should be designed to reduce wave runup elevations by about 3 feet in high wave energy areas (e.g., 15 feet NABD88 – 3 feet = 12 feet NAVD88), with wave runup reduction of 1 to 2 feet required for most of the shoreline to satisfy the 2-foot wave proxy design assumption (**Figure I-8**).



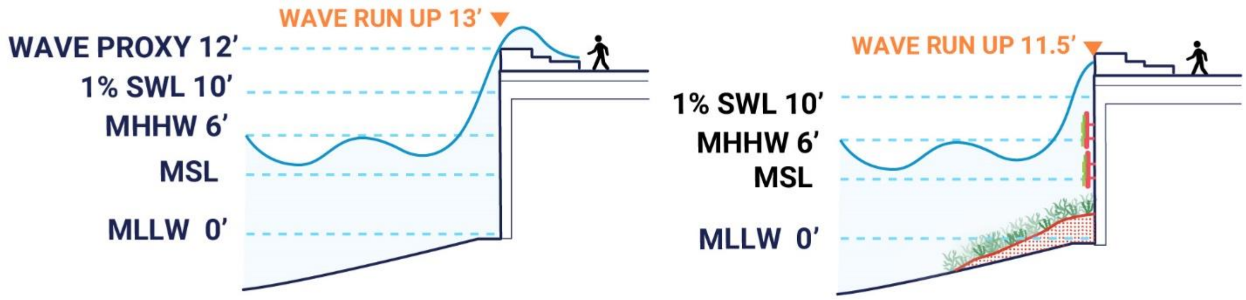
Source: DHI 2011, Appendix B1.1 Extreme Water Levels and High Tide Flooding Report

Figure I-6: Variations in 1% AEP Wind-Driven Wave Height



Source: DHI 2011, Appendix B1.1 Coastal Extreme Water Levels and High Tide Flooding Report

Figure I-7: Variations in 1% AEP Wind-Driven Wave Crest Elevation



Caption: On the left, the wall height exceeds the 1% AEP stillwater elevation (10 feet NAVD88), but the 1% AEP wave run up elevation is 13 feet NAVD88, exceeding the 2-foot wave proxy by 1 foot and overtopping the wall. On the right, hybrid structures in the lower intertidal area coupled with surface texturing on the upper intertidal area that attract native biota help dissipate wave energy, resulting a 1% AEP wave runup elevation of 1.5 feet and therefore not overtopping the wall (11.5 feet NAVD88).

Figure I-8: Wave Runup Reduction with Hybrid Green-Gray Measures

3.2 Approximate Wave Runup Elevations (Wave Proxy)

The SFWCFS study area is divided into four reaches and 15 subareas, from Reach 1 (Aquatic Park) in the north to Reach 4 (Islais Creek/Bayview) in the south (**Figure I-9**). Along the shoreline, a 2-foot wave runup proxy above the 1% AEP stillwater elevation was incorporated into the design elevation of the coastal flood defenses for all alternatives. For example, with a 1% AEP stillwater elevation of 10 feet NAVD88, the design elevations of the coastal structures are:

- 10 feet NAVD88 + 2-foot wave proxy + 1.5 feet SLR = 13.5 feet NAVD88
- 10 feet NAVD88 + 2-foot wave proxy + 3.5 feet SLR = 15.5 feet NAVD88
- 10 feet NAVD88 + 2-foot wave proxy + 7.0 feet SLR = 19.0 feet NAVD88

These values are approximate and reasonable for planning and conceptual design at the feasibility study phase. The 2-foot wave runup proxy addresses the potential for wave runup and overtopping based on existing sea levels and Bay wave dynamics. During detailed design, the measures (green, gray, or hybrid) can be designed to reduce wave runup elevations through the addition of roughness elements, changes in slope, or other features, if required.

Table I-1 presents approximate wave runup amounts with 1.5, 3.5 and 7 feet of SLR by reach and subareas, using the plan formulation SLR building blocks of 1.5, 3.5, and 7 feet of SLR (Appendix A: *Plan Formulation*). The wave runup values in 0 represent the approximate 1% AEP wave runup elevation minus the 1% AEP stillwater elevation, assuming the largest potential wave runup condition on a smooth vertical wall, and assuming a small non-linear response to sea level rise (FEMA, 2016). If the value in 0 exceeds 2 feet, wave dissipation measures may be required at that location. 0 is for preliminary evaluation purposes only and is not intended to support detailed design. 0 is only intended to identify shoreline areas where wave dissipation measures, either green, gray, or hybrid, may be suitable and perform a wave runup reduction function. Additional analysis of wave runup along the San Francisco shoreline, including estimates of wave runup reduction due to vegetation, is presented in Appendix B1.3 Wave Overtopping Sensitivity Analysis.

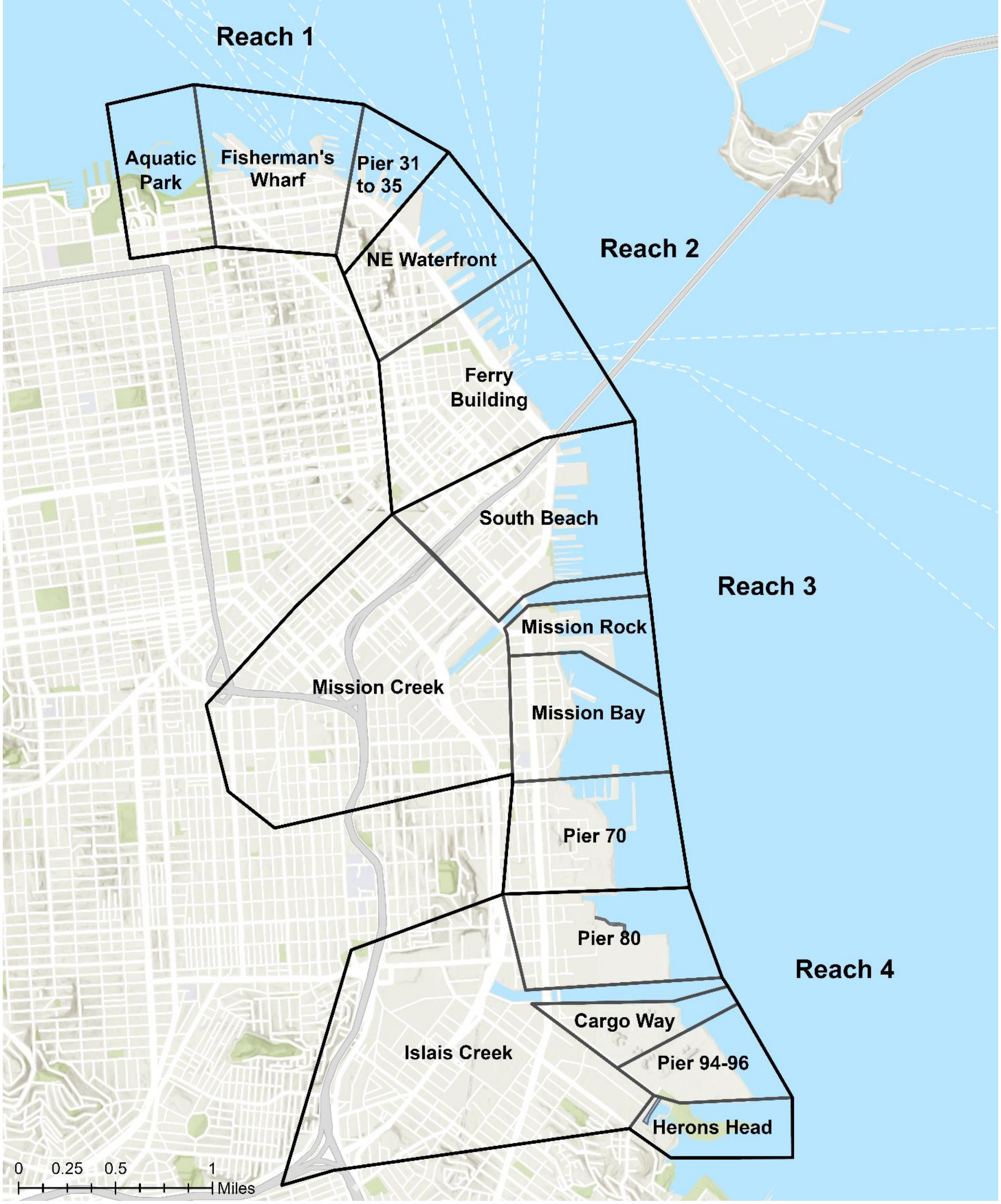


Figure I-9: Flood Study Reaches

Table I-1: Approximate Wave Runup (~1% AEP Wave Runup Elevation minus 1% AEP Stillwater Elevation)

Reach	Subarea	Wave Runup w/ 1.5 feet SLR	Wave Runup w/ 3.5 feet SLR	Wave Runup w/ 7 feet SLR
1	Aquatic Park [a]	0.0	0.0	0.0
	Fisherman's Wharf	3.5	3.9	4.2
	Pier 31 to 35	3.5	3.9	4.2
2	Northeastern Waterfront	3.2	3.5	3.8
	Ferry Building	2.9	3.2	3.4
3	South Beach	3.7	4.1	4.5
	Mission Creek [b]	0.5	0.5	0.5
	Mission Rock	4.2	4.8	5.3
	Mission Bay	3.8	4.2	4.7
	Pier 70	3.8	4.3	4.8
4	Pier 80	4.3	4.9	5.4
	Islais Creek [b]	0.5	0.5	0.5
	Cargo Way	3.3	3.6	3.9
	Pier 94-96	3.5	3.9	4.3
	Heron's Head	3.1	3.3	3.6

[a] Aquatic Park is protected by the National Park Service Municipal Pier breakwater, although this structure is currently in poor condition and has exceeded its useful life.

[b] Mission Creek and Islais Creek shoreline do not have direct wave exposure, although water levels can be elevated by 0.5 to 1 foot due to wave setup.

3.3 Reach 1

Reach 1 includes Aquatic Park, Fisherman's Wharf, and Piers 31-35. Aquatic Park is currently protected by the National Park Service Municipal Pier, a red-tagged breakwater that has exceeded its useful life. Outside of the breakwater, wind-wave driven heights greater than 4 feet and ocean-driven swell greater than 3 feet can occur. The marinas in the Fisherman's Wharf and Pier 31 to 35 areas are protected by breakwaters, but areas not protected by the breakwater could experience wave runup elevations that exceed the 2-foot wave proxy by approximately 1.5 feet or more as sea levels rise.

3.4 Reach 2

Reach 2 includes the northeast Embarcadero waterfront and the Ferry Building. The wave runup elevations could exceed the 2-foot wave proxy by 0.9 to 1.8 feet. Low-lying areas along the shoreline are overtopped by waves under existing conditions.

3.5 Reach 3

Reach 3 includes Mission Creek and the surrounding areas. Mission Creek is an area of limited wave activity, although creek water levels can be elevated by 0.5 feet or more due to wind setup. The Bay shoreline areas within this reach could experience wave runup that exceeds the 2-foot wave proxy by 1.7 to 3.3 feet.

Within the South Beach subareas, areas not protected by breakwaters have suffered wave damage under existing conditions, with South Beach Harbor (built in 1986) losing the unprotected North Dock during storms in 2018. The Port's Living Seawall Pilot Study also suffered wave damage during the March 2023 bomb cyclone and associated high wave hazards (Port, 2023).

3.6 Reach 4

Reach 4 has the highest excess wave runup, with the potential for 3.4 feet of wave runup more than the 2-foot wave proxy at Pier 80. Like Mission Creek, Islais Creek does not experience direct wave hazards, although wind setup of 0.5 feet or more can occur during high wind conditions. This reach also includes the only natural wetlands currently providing wave hazard reduction along the Port's shoreline, including the Pier 94 wetlands and Heron's Head Park.

4. Screening of Natural and Nature Based Features

The measures in **Table I-2**, **Table I-3,** and **Table I-4** were identified using the EWN Framework (**Appendix I.1**) in collaboration with the EWNWG (**Appendix I.2**). The measures were screened using the following criteria:

- For inclusion in the FWP alternatives, the NNBFs must
    - provide coastal flood risk management wave energy dissipation benefits;
    - support native vegetation and species;
    - support an enhanced aesthetic and community wellbeing (among other EQ and OSE benefits);
    - have broad public support and be in line with local and regional priorities and policies;
    - have precedents in San Francisco Bay or have precedents in similar environments and be part of an established pilot study in the Bay evaluating local benefits (e.g., the Port of San Francisco's Living Seawall Pilot Study).
- For inclusion as potential mitigation opportunities, the NNBFs
    - provide potential, but unproven coastal flood risk management wave energy dissipation benefits (e.g., lack of precedent in the Bay Area or other similar geography);
    - do not provide coastal flood risk management benefits, but may provide other flood risk management benefits (e.g., inland stormwater risk management potential);
    - provide all other benefits noted above.
- NNBFs that are screened out include:
    - features that are unsuitable due to geographic constraints of the San Francisco study area;
    - features that are considered too complex and costly for a densely urbanized area.

Table I-2 lists NNBFs that provide coastal flood risk management wave hazard reduction benefits. These NNBFs were retained and included within one or more alternatives. Two NNBFs that provide Flood Risk Management benefits (but not direct coastal flood risk management benefits) that are required to support the success of the coastal flood risk management measures were also retained in **Table I-2** and included within the alternatives. Section 5 provides a more detailed overview of the NNBFs retained.

Table I-3 lists NNBFs that were tentatively retained for mitigation opportunities. These NNBFs either had insufficient evidence of providing coastal flood risk management wave hazard reduction benefits, or they only provided habitat, environmental quality (EQ), and/or Other Social Effects (OSE) benefits. **Table I-4** lists NNBFs that were screened out and considered either unsuitable for the study area due to geographic constraints or considered too complex and costly for a densely urbanized area.

Table I-2: Natural and Nature-Based Features Retained within Alternatives

Measure	Definition and Description	Benefits	Notes
Enhancement of Existing Wetlands	Restoration or enhancement of existing coastal tidal wetlands, including establishment of inland migration corridor to maintain wetland area as sea levels rise.	☑ coastal flood risk management ☑ OSE ☑ EQ	• Enhanced coastal flood risk management benefits, increasing wave energy dissipation potential of coastal flood defense. • Likely efficient due to low relative cost relative to long-term benefits; areas for wetland enhancement along the shoreline are limited, although the number of species benefiting are numerous. • Acceptable and in line with local priorities and policies.
Wetland Creation	Establishment of a new coastal tidal wetland. This feature is primarily located along Port lands in areas of retreat, requiring depaving and infrastructure removal.	☑ coastal flood risk management ☑ OSE ☑ EQ	• Enhanced coastal flood risk management benefits, increasing wave energy dissipation potential of coastal flood defense, and relocation of at-risk structures out of the coastal floodplain. • Efficient at reducing long-term flood risk, although depaving and removal of structures and infrastructure can be costly. • Acceptable and in line with local priorities and policies; however, relocation and land use changes for areas with active urban use may not have broad public support.
Ecotone Levee	Gently sloped habitat gradient that connect flood risk management levees to tidal marsh. They can provide transition zone habitat, which is important for high-water refuge and habitat connectivity, and attenuate waves to reduce levee erosion	☑ coastal flood risk management ☑ OSE ☑ EQ	• Enhanced coastal flood risk management-benefits, increasing wave energy dissipation potential of coastal flood defense. • Acceptable and in line with local priorities and policies. • Limited locations where ecotone levees can be established along the shoreline.
Coarse Beach	Coarse sediment (cobble, gravel, larger rock size) beach acting as a submerged breakwater and wave energy dissipation	☑ coastal flood risk	• Enhanced coastal flood risk management benefits, increasing wave energy dissipation potential of coastal flood defense.

Measure	Definition and Description	Benefits	Notes
	feature. Includes both establishment and nourishment of coarse beach, located on the landward side of a sill or submerged dike parallel to the shore. Location adjacent to the store would not create a navigation hazard.	management ☑ OSE ☑ EQ	• Efficiency depends largely on technical cost considerations. • Acceptable and in line with local priorities and policies, particularly for recreation benefits and shoreline access. • Limited locations where a coarse beach can be established along the shoreline.
Living Seawall and Vertical Enhancements	Structural elements either integrated into seawalls or attached to seawalls (as panels) that create relief and varied microhabitat conditions. Living seawall elements can include a variety of structural elements that create shallow water habitat. This includes habitat benches or staircased shorelines, which are often found at the base of seawalls.	☑ coastal flood risk management ☑ OSE ☑ EQ	• Enhances coastal flood risk management benefits by providing additional wave energy dissipation potential. • Provides habitat value and may provide enhanced endangered species foraging habitat. • Public engagement by the Port has drawn broad public and agency support for this feature. • Acceptable and in line with local priorities and policies.
Naturalized or Embankment Shoreline	Naturalized shorelines or embankment shorelines can be planted with native vegetation to increase wave energy dissipation potential, reduce erosion risks, and provide tidal habitats and upland refugia	☑ coastal flood risk management ☑ OSE ☑ EQ	• Provide similar coastal flood risk management benefits to traditional earthen berms. • Reduces O&M needs by reducing erosion potential, particularly during smaller more frequent storm events. However, may require managing invasive species. • Provide additional habitat, improved aesthetic, and community co-benefits.

Measure	Definition and Description	Benefits	Notes
Ecological Armoring	Armoring units or materials that either replace traditional riprap (ecological and green riprap), integrate vegetation, or include enhancing features (such as tidepool units).	☑ coastal flood risk management ☑ OSE ☑ EQ	• Provide similar coastal flood risk management benefits to traditional gray armoring measures (riprap). • Provides additional habitat, improved aesthetic, and community co-benefits.
Creek Enhancements	Improvements to the existing creek banks (beyond raising the shoreline elevation to provide coastal flood risk management benefits). Can range in scale and include habitat shelves, planted edges, live crib walls, and other measures that increase surface complexity.	☑ FRM ☑ OSE ☑ EQ	• Required NNBF for the success of other flood risk reduction measures. • Enhancements would provide erosion control and stabilization tidal creek banks. • Creek bank improvements may improve water quality, although these benefits are uncertain. • Habitat and community benefits depend on the feature selected for implementation.
Green Stormwater Infrastructure (GSI)	Features that address urban stormwater by slowing, capturing, and infiltrating runoff. Includes green streets, tree trenches, bioswales, green roofs, and other features.	☑ FRM ☑ OSE ☑ EQ	• Required NNBF for the success of other flood risk reduction measures. • Sea level rise and elevated Bay water levels will increase inland stormwater flood risks due to insufficient stormwater drainage capacity. • Raised shoreline structures associated with the alternatives will disrupt direct inland runoff to the Bay and increase inland stormwater flood risks. • GSI features that reduce stormwater runoff can provide habitat value, minimize heat islands, and provide other benefits.

Table I-3: Natural and Nature Based Features Tentatively Retained for Potential Mitigation Purposes

Measure	Definition and Description	Benefits	Notes
Mudflat Augmentation	Consolidated fine-grained sediment deposits.	☑ OSE ☑ EQ	• Tentatively retained as part of a combination measure. Included as a supplemental component of wetland restoration and establishment.
Pier and Piling Habitat Improvement	Replacing creosote piles, paneling, and texturing of piles (e.g., pile wraps), as well as substrate improvements.	☑ coastal flood risk management ☑ OSE ☑ EQ	• May provide wave energy dissipation underneath piers; insufficient information available to assess coastal flood risk management potential. • Provides similar habitat benefits as the living seawall feature; greater benefits could result if pier and piling habitat improvements are coupled with adjacent living seawall features.
Subtidal Habitat Improvements	Establishment of beds of underwater flowering plants/Submerged Aquatic Vegetation (SAV). Creation of shellfish and oyster beds along the shallow Bay floor. Creation of artificial / constructed reef structures constructed from a variety of materials, ranging from rock to oyster shells, from concrete structures to prefabricated modules and products.	☑ coastal flood risk management ☑ OSE ☑ EQ	• Not included as an independent measure; where these features are appropriate, they require other adjacent features for wave attenuation benefits (oyster reefs paired with eelgrass beds). • Tentatively retained as part of a combination measure. Included as a supplemental component of wetland restoration and establishment (e.g., constructed oyster reefs can help reduce marsh edge erosion). • Could be integrated into Naturalized/embankment shoreline designs to provide toe protection along nearshore environment.
Living Breakwater (New or Enhanced)	Offshore vertical breakwater structure parallel to the shore with a variety of ecosystem-enhancing features.	☑ coastal flood risk management ☑ OSE ☑ EQ	• Breakwaters and breakwaters improvements were not considered as part of the alternatives, but they can provide coastal flood risk management benefits. • Ecosystem enhancements could be added to existing breakwaters to provide habitat benefits. • A new offshore vertical breakwater can support

Measure	Definition and Description	Benefits	Notes
			ecosystem-enhancing features while reducing wave energy, reducing the height of the coastal flood defenses. • A traditional rock breakwater is likely infeasible given the deepwater along the San Francisco shoreline. • This feature was retained for additional study given potential coastal flood risk management benefits and applicability to study area.
Afforestation and Urban Corridors	Extensive tree planting focusing on areas with extensive nonpermeable surfaces and stormwater runoff.	☑ FRM ☑ OSE ☑ EQ	• This feature does not address the primary study authority of addressing coastal flood risk management benefits. • May provide inland stormwater drainage benefits and reduce inland stormwater flood risk. • Supports other benefits, including reducing heat islands and improving community wellbeing.

Table I-4: Natural and Nature Based Features Screened Out and Not Included

Measure	Definition and Description	Result	Notes
Submerged Breakwater	Offshore structures parallel to the shore; can be constructed of varied materials, from rock, oyster shell, to artificial reef structures. The highest elevation of the structure is intended to be submerged for some or all the tidal cycle.	Screened	• This feature could pose a navigation hazard within the study area. • The Bay's large tidal range limits the effectiveness of submerged features for reducing wave energy.
Sandy Beaches (Establishment and Nourishment)	Fine-sediment (sandy) beach acting as a submerged breakwater and flood protection. Includes creation of a sandy beach on the landward side of a sill or submerged dike parallel to the shore.	Screened	• Sandy beaches are not efficient in this highly constrained and diversified shoreline. • Erosion concerns for sandy sediments • O&M costs are likely cost prohibitive, making this feature inefficient at providing coastal flood risk management benefits
Polder Creation	Low-lying area enclosed by dikes and disconnected from surrounding hydrology.	Screened	• Insufficient area to create polders along the San Francisco shoreline. • Existing restoration efforts in San Francisco are focused on restoring tidal action to polders to create tidal wetlands. Creation of new polders would be in opposition of this restoration goal.

Measure	Definition and Description	Result	Notes
Islands	Constructed or restored barrier, deltaic or in-Bay islands.	Screened	• Not appropriate for the deep water setting along much of San Francisco's shoreline. Additional challenges include: – Permitting – Local acceptability – Cost – Feasibility
Creek Daylighting	Restoration of waterways that have been covered, piped, or canalized to a naturalized, above ground condition. Creek daylighting could include restoration of adjacent floodplains with embankments to contain creek flows during high flow events.	Screened	• This feature does not address the primary study authority of addressing coastal flood risk management benefits. • This feature could potentially be part of a GSI plan to address inland stormwater issues. • This feature may be cost prohibitive in the densely urbanized watersheds of San Francisco.
Watershed and Creek to Baylands Reconnection	Restoration of Bay hydrological system across the transect using dam removal, upstream creek restoration, and creek mouth delta restoration.	Screened	• Similar to creek daylighting, although larger in scale; could require restoration of historic creek mouth / deltas. • Restoration of this scale in a densely urbanized city would be cost prohibitive. • Restoration of this scale would require substantial retreat, including relocation of homes, businesses, and transportation corridors.
Wharf Enhancements (Light Penetration)	Penetrations and wells in wharf structures to allow light to penetrate the water columns under the wharf.	Screened	• Light penetrating features along Seattle's seawall provide enhanced photosynthesis opportunities for species; the water in the vicinity of the seawall is relatively clear. • The Bay water adjacent to San Francisco's seawall

Measure	Definition and Description	Result	Notes
			is extremely turbid, blocking light penetration of any significant depth below the water surface; this feature is unlikely to provide much benefit within the study area.

5. Benefits and Performance of Retained Features

This section describes the NNBFs considered and retained in the alternatives for their ability to provide coastal flood risk management benefits (i.e., wave energy dissipation to reduce wave runup and overtopping) along the San Francisco shoreline. For each NNBF measure, the following information is provided:

- Overview and examples of the measures
- Benefits provided across the four accounts:
  - National Economic Development (NED)
  - Regional Economic Development (RED)
  - Environmental Quality (EQ)
  - Other Social Effects (OSE)
- Performance of the measure and operations and maintenance requirements or considerations

5.1 Enhancement of Existing Wetlands

5.1.1 Overview

This measure includes restoration and enhancement of existing coastal wetland, tidal wetland, and mudflats. Coastal wetlands include tidal wetlands, brackish wetlands, and tidal freshwater wetlands. Example actions may include using terracing to reduce erosion and attenuate waves (USACE, 2021a). This measure may be combined with engineered structures (e.g., levees, berms, revetments) or other NNBFs (e.g., ecotone levees). **Figure I-10** shows existing wetland at Heron's Head Park.

5.1.2 Benefits

Coastal flood risk management benefits:

- Wave hazard reduction: Reduce or dissipate wave energy and/or reduce the potential for inland wave propagation (USACE, 2021a). This measure is not proposed for surge hazard reduction, which would require more expansive wetland areas. Wetlands and intertidal habitats with more limited widths can provide wave energy reduction (Ding et al., 2019; Manousakas et al., 2022).
- Erosion protection: Wetlands can reduce erosion and inland migration of the shoreline (Alongi, 2008; USACE, 2021a).

Photo Credit: Port of San Francisco

Figure I-10: Heron's Head Park, San Francisco highlighting wetland enhancement, and a coarse beach created to slow marsh edge erosion

EQ benefits:

- Supports fish population and habitat, "providing essential habitat for a wide range of marine and estuarine organisms," supporting the local fishing community and enhancing fisheries production (USACE, 2021a).
- Prevents future wetland loss: 94% of all wetland areas have been lost in the Bay area (Goals Project, 2015). Specifically, 79% of tidal wetland and 42% of tidal flat habitats were lost by 1998 (Goals Project, 2015). While restoration projects from the late 1980s to today have recovered some ecological functions, existing wetlands face a classic case of coastal squeeze (Goals Project, 2015; U.S. Fish & Wildlife Service, 2013) between rising Bay waters and the existing edge of development. Enhancing the existing wetlands can prevent further loss of critical habitat over the long-term by providing adaptive capacity and supporting vertical accretion or upland migration of wetland ecological functions with SLR.
- Improves connectivity of critical regional habitat by enhancing patch size and reducing distances between patches.

> "Landscape connectivity is the extent to which movement of individual organisms is facilitated or hindered by the landscape. A highly connected landscape is one where an animal can easily disperse between habitat patches, which promotes healthy and persistent populations of wildlife. Loss of habitat generally drives fragmentation and isolation; habitats that were once more contiguous are broken up into smaller patches that become separated by greater distances" (SFEI, 2021).

- Improves water quality: wetlands can filter pollutants from upland runoff (USACE, 2021a) and support water quality by trapping suspended sediments.
- Sequesters carbon through restored plant mass and soil and prevents loss of previously sequestered carbon through conservation. "Carbon sequestration in existing tidal wetlands averaged about 80 g C/m^2/yr. (grams of carbon per square meter per year) over the last century" in the Bay (Goals Project, 2015).
- Promotes biodiversity along a highly urbanized shoreline.

OSE benefits:

- Expands access: Existing wetland sites are predominantly on the southern waterfront. Wetland enhancements provide opportunities to expand open space and access in environmental justice communities with limited open spaces and waterfront access.
- Improves social connectedness, leisure, and recreation by providing a public resource (Hemmerling et al., 2023; Ye and Qiu, 2021):
    - Enhances opportunities for waterfront access to the Bay and includes open space and recreational spaces.
    - Provides opportunities for Bay Trail recreational connections.
    - Reduces stress and anxiety factors with open space and activities.
    - Provides educational opportunities to enhance community identity.
- Provides numerous public health and safety benefits by lowering pollution and risk for asthma and cardiovascular disease (Finlayson et al., 2005; Finlayson and Horwitz, 2015).
- Promotes economic vitality (Kumar et al., 2023; Mazzotta et al., 2019):
    - Providing a more livable and desirable area
    - Boosting the local economy, especially fishing and eco-tourism industries

5.1.3 Performance

Wetland NNBFs include the conservation of existing wetlands, restoration of degraded and degrading wetlands, and construction of new wetlands (see Section 5.2). They may be combined with structural measures, such as ecotone levees (see Section 5.3), as well as other NNBFs, such as upland habitat, coarse beaches, mudflats, and subtidal habitat features. The coastal flood risk management performance of wetland NNBFs to reduce flood and erosion risks, particularly by reducing wave heights, is well documented (USACE, 2021a):

- Can prevent erosion of the toe of landward structural features within 1 to 10s of meters (measured between the wetland edge and upland).

  > *"Small wetlands on the order of tens of meters (measured from the wetland edge to upland) can still provide erosion-reduction co-benefits, protecting shorelines and assets close to shore from erosion that occurs during lower-intensity waves caused by wind and boat wakes"* (Currin et al., 2010).

- Can attenuate waves within 10s of meters (approximate scale of Pier 94 and Heron's Head Park wetlands), potentially resulting in reduced height of structural measures. Wave reduction performance is dependent on topography, vegetation characteristics, and water level and wave characteristics (Baker et al., 2022; Ding et al., 2019; Manousakas et al., 2022).

  > *"A synthesis of more than 69 studies shows that salt marshes are particularly effective at wave attenuation, reducing incoming wave heights by nearly 70% on average across all observations."* (Currin et al., 2010)

Wetlands can provide coastal flood risk management, EQ, and OSE benefits independently of other measures (for example, ecotone levee); but benefits are amplified when wetland NNBFs are integrated with structural measures and other NNBFs. For example, a wetland-fringing coarse beach, mudflat augmentation, or breakwater may trap sediment on the landward side of a wetland, allowing sediment to accrete and raise surface elevations. Likewise, an ecotone levee landward of existing wetlands may provide inland migration space that preserves flood risk management, environmental, social, and economic functions as sea levels rise. These integrated measures sustain the wetland resource and perpetuate its associated benefits in the long-term (Fleming et al., 2018; Levin et al., 2021).

Much of the Bay's wetlands have been lost, largely due to historical development. Looking forward, SLR is projected to drown many remaining wetlands, including Pier 94 Wetlands and Heron's Head Park Wetland. Given the substantial evidence of flood risk benefits and ecosystem services, wetlands are critical to maintain, enhance, and establish as sea levels rise.

The Bay Area has a particularly long history of tidal wetland restoration dating back to the 1960s, which provides a wealth of rigorously studied and monitored cases, including by USACE. Locally, many relevant efforts are completed or underway to preserve and enhance existing wetlands:

- Heron’s Head Park Shoreline Resilience Project, San Francisco, CA (Port). Phase 1 complete (authorized 2020), and Phase 2 in progress (authorized 2022)
- Pier 94 Wetlands Restoration, San Francisco, CA (Port). Complete. Restoration began 2002.
- Bel Marin Keys – Wetland Restoration, Marin County, CA (USACE). Restoration beginning 2024)
- Hamilton Wetlands, Novato, CA (USACE). Restoration began 2014. Ongoing monitoring until 2027.
- Pinole Creek – Wetland and Living Shoreline, Contra Costa County, CA
- Eden Landing Wetland Restoration, Hayward, CA. Restoration began in 2004 and is ongoing as a phased restoration project.
- Skaggs Island –Wetland Restoration, San Pablo Bay, CA. Restoration began 2010.
- Sonoma Baylands, North Bay, CA (USACE). Restoration completed 1996, ongoing monitoring continues.
- South San Francisco Bay Shoreline Study, South Bay, CA (USACE). Construction began 2021.
- South Bay Salt Pond Restoration Program, South Bay, CA. Restoration began in 2009 and is ongoing as a phased restoration project.

Coastal flood risk management, EQ, and OSE benefits are positively correlated with wetland size. Existing wetlands in the study area include Pier 94 and Heron’s Head Park wetlands, which are 10s of meters in width. In both instances, their scale and potential for expansion or migration are constrained by topography, bathymetry, and development. To preserve these critical resources, they must either accrete in elevation or migrate and expand inland. Preservation may require additional structural measures, achieving a hybrid green-gray measure.

Preservation and enhancement of these existing wetlands may be constrained by:

- Spatial availability: Limited space is available for inland migration and may amplify costs, given existing development and potential real estate acquisition expenses.
- Complexity of regulatory compliance.
- Geotechnical feasibility: Constructability on soft Bay mud.

- Sediment supply: The Bay's diminishing sediment supply poses a challenge for wetland restoration and establishment as sea levels rise. Bay wetlands are keeping pace with current rates of SLR; however, under higher rates of rise, sediment delivery and augmentation may be required to sustain wetlands in the long-term (SFEI and SPUR, 2019). Many local efforts are underway to address projected Baylands sediment needs, including beneficial reuse of dredge material and construction by-products, reconnecting sediment pathways from tributaries to the Bay, collection of sediment trapped behind dams, and others (Goals Project, 2015).
- Wave attenuation and erosion protection benefits may reduce maintenance costs and increase the lifespan of protected structures by reducing day-to-day and acute damage caused by waves (USACE, 2021a). Maintenance existing wetland may include the following activities (USACE, 2021a):
- Routine monitoring
- Maintenance of vegetation and invasive species management
- Monitoring and repair after with storm damage
- Sediment renourishment. Tidal wetlands / marshes and coarse beaches may require sediment placement with every 12 to 18 inches of sea level rise (to allow them to keep pace with sea level rise). For the 100-year period of analysis from 2040 to 2100, the approximate number of augmentations needed are shown below, assuming implementation in 2040.
    - Low curve = no augmentations
    - Intermediate curve = 1 to 2 augmentations
    - High curve = 5 augmentations

5.2 Wetland Creation

This section describes wetland creation, which may include transforming developed areas to create areas suitable for wetland establishment (**Figure I-11**). No FWP alternatives include Bay fill for wetland creation (Appendix A: *Plan Formulation*), although Bay fill may be included for other project elements.

Figure I-11: Schematic of Wetland Creation

5.2.1 Overview

This measure includes the establishment of new wetlands at locations that historically did not include wetlands. This is distinguished from restoring or enhancing wetlands where it exists today (as described in Section 5.1). “Depaving” refers to a process of removing infrastructure, structures, and paving materials or artificial fill (such as concrete and asphalt); establishing appropriate substrates and topography to support tidal wetland habitat; and introducing tidal action to the site.

Wetland creation measures may require using terracing or other structures to reduce erosion and increase the wave energy dissipation potential (USACE, 2021a). **Figure I-12** shows a Bay area example of Hamilton Wetland restoration, a USACE project which restored a former airfield to tidal wetland habitat using dredge material spoils from the Port of Oakland’s 50-foot deepening dredging project.

Photo Credit: USACE

Figure I-12: Hamilton Wetlands (formerly Hamilton Army Airfield), Novato.

5.2.2 Benefits

Coastal flood risk management benefits:

- New wetlands provide and augment the same coastal flood risk management benefits as existing wetlands (Section 5.1).

EQ benefits:

- New wetlands provide and augment the same environmental benefits as existing wetlands (Section 5.1).

OSE benefits:

- New wetlands provide and augment the same social co-benefits as existing wetlands (Section 5.1).

5.2.3 Performance

The performance of created wetlands is similar to existing wetlands once established, including continued maintenance to maintain sediment supply with higher rates of SLR (Section 5.1.3). They are likewise integrated in combination with other structural measures or NNBFs, and are subject to similar constraints of space, regulatory complexity, and geotechnical feasibility.

By adding to the overall wetland area, they augment associated benefits. For example, upland areas that have been converted to intertidal areas can store flood waters during coastal and stormwater flood events, redistributing the flood volume and reducing flood damages. The flood storage potential is correlated to the size of the created wetland area, with larger wetlands providing more flood storage potential (USACE, 2021a).

Compared to the existing wetland NNBF, the performance of newly established wetlands may also vary in order of magnitude due to differences in dynamic processes of sediment transport and geomorphology, vegetation establishment and growth, and others.

Site preparation must consider the comprehensive physical, socioeconomic, and governance systems influencing a given location (USACE 2021). For alternatives in which the line of defense is located inland of the existing shoreline, depaving would be required to convert developed areas to wetlands.

Given the challenges and uncertainties of wetland establishment and the constrained urban context of the Bay, few examples of this measure are implemented and documented in literature. In general, a relative lack of data on the performance of newly established wetlands may undermine confidence in this measure. However, in the long-term, the benefits and performance of a mature wetland NNBF are well supported by both literature and precedent.

In the Bay, wetlands have been established as follows:

- Hamilton Army Airfield Wetland Restoration (Novato, California [CA]) (0): A multiphase, decade-long ongoing USACE project on San Pablo Bay, which has restored 648 acres of wetland to date. The project provides flood risk reduction for Novato and decreased the height of the inland levee due to the wave runup reduction benefits of the wetlands. This project included the beneficial use of dredge material, public access, and trails (USACE, 2014).
- Sonoma Baylands project recreated tidal wetlands using 2.0 million cubic meters of dredged material. The Baylands project used dredged material in far lower quantities than previous projects to assure that the fill served as a template for the development of a wetland with an extensive tidal slough system. The project design also included a series of peninsulas to break up wind-driven waves and increase sedimentation rates. The target species for the project were the endangered California clapper rail and the salt marsh harvest mouse. The use of dredged material reduced the time needed for habitat development by several decades (USACE, 1994).
- South San Francisco Shoreline study is currently in Phase 2. The project includes coastal and tidal flooding risk reduction, wetland restoration, and public access and recreation (USACE, 2023).

5.3 Ecotone Levee

This section describes ecotone levees, which may include depaving developed areas to create sufficient space for these measures. No FWP alternatives include Bay fill for ecotone levee implementation (Appendix A: *Plan Formulation*), although Bay fill may be included for other project elements. Ecotone levees are also known as a horizontal or laid-back levee (0).

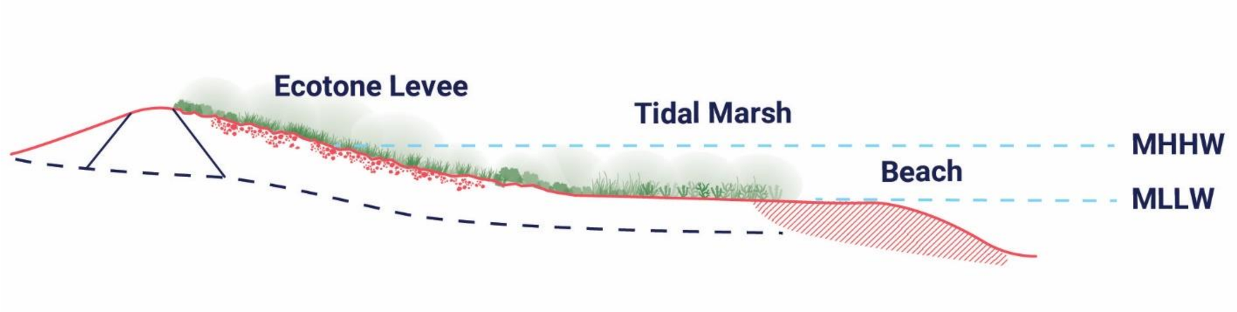


Figure I-13: Schematic of Ecotone Levee

5.3.1 Overview

An ecotone levee provides gentle naturalized slopes landward of the tidal zone and can provide transition zone habitat from terrestrial to tidal wetland ecosystems. USACE has defined ecotone levees as consisting of "a traditional levee material core with a shallow ecotone slope atop the side slopes" (Bridges et al. 2015; Piercy et al. 2020). Ecotone levees are implemented together with existing or proposed tidal wetlands, brackish wetlands, tidal mudflats, beaches, or other shoreline measures. These wide and vegetated levees are typically built at a slope ranging between 30:1 to 10:1 (Horizontal:Vertical). **Figure I-14** shows a Bay Area example at Sears Point.

Photo Credit: Julian Meisler, Sonoma Land Trust

Figure I-14: Sears Point Restoration Project, Sonoma

5.3.2 Benefits

Coastal flood risk management benefits:

- Wave hazard reduction (soft shoreline): Reduce or dissipate wave energy and reduce the potential for inland wave propagation.
- Wave hazard reduction (hard shoreline): Reduce or dissipate wave energy, reduce wave runup elevation, and reduce shoreline overtopping. This can also provide an additional benefit of reducing the design height of the structure (including levee, floodwall) needed (SFEI, 2021).
- Erosion protection (soft shoreline): Reduce erosion and inland migration of the shoreline.
- Erosion protection (hard shoreline): Reduce erosion at the toe of structure.

EQ benefits:

- Creates ecological connections and improves wildlife habitat by connecting upland and wetland habitats that are often disconnected with the use of traditional gray measures (levees):

  - Connection and upland improvements can provide high-tide refuge, nesting, and foraging habitat.
  - Enhanced connectivity along the waterfront can support the regional flyway.
- Prevents loss of critical habitat by supporting upland migration of wetland ecological functions with SLR:
- “The protection and recovery of these [threatened and endangered] species requires a holistic approach that goes beyond enhancing landscape connectivity alone. Supporting viable populations will require **maintaining and increasing the amount of suitable habitat,** enhancing local-scale connections where isolated populations exist, and **improving the quality of existing habitat”** (emphasis added) (SFEI and SPUR, 2019)
- Restores naturalized coastal connections and processes between upland and intertidal conditions (hydrological, sediment, and vegetative):
  - Restoring erosion and sediment regimes
  - Enhancing water quality
- Promotes biodiversity along a highly urbanized shoreline:
- Increases carbon sequestration through more plant biomass and soils (upland and tidal wetlands).

OSE benefits:

- Proposed ecotone levee sites are predominantly in the southern waterfront and addresses opportunities to expand open space and access in environmental justice communities with limited open spaces and waterfront access.
- Improves social connectedness, leisure, and recreation by providing a public resource (Hemmerling et al., 2023; Ye and Qiu, 2021):
  - Enhances opportunities for waterfront access to the Bay and provides open space and recreational spaces.
  - Provides opportunity for Bay trail recreational connections.
  - Reduces stress and anxiety factors with open space and activities.
  - Provides educational opportunities to enhance community identity.
- Promotes economic vitality (Kumar et al., 2023; Mazzotta et al., 2019):
  - Providing a more livable and desirable area
- Provides numerous public health and safety benefits by lowering pollution and risk for asthma and cardiovascular disease (Finlayson et al., 2005; Finlayson and Horwitz, 2015).

5.3.3 Performance

An ecotone levee is a structural measure (levee) used in combination with a gently sloped structure that incorporates upland habitat and wetlands and is subject to many of the same performance considerations as the wetland NNBFs (Section 5.1 and Section 5.2). Ecotone levees have been increasingly deployed and tested to supplement gray levee infrastructure. In the Bay, a number have been designed, implemented, or piloted:

- South San Francisco Bay Shoreline Project (USACE, 2023) (Basis of Design for Ecotones at Reaches 1, 4, and 5)
- Sears Point, North Bay (constructed)
- City of Palo Alto’s Regional Water Quality Control Plant, Horizontal Levee Pilot Project (in design)
- Oro Loma full-scale pilot (constructed)

Several of these local examples are paired with freshwater discharge points from nearby wastewater treatment facilities to mimic the freshwater input regimes of endemic wetlands in the Bay (USACE, 2021a).

Nationally, USACE has studied ecotone levees at a conceptual design level in its *Sabine Pass to Galveston Bay Report* (USACE, 2019a). Given the ongoing study and relative novelty of this measure compared to traditional levees, few examples are established and tidally connected at scale. However, these early efforts in the Bay show promise for coastal flood risk management performance and other co-benefits.

By attenuating waves and reducing wave height, ecotone levees may reduce the overall coastal flood elevation. This can lower the targeted design elevation for coastal flood defense structures, potentially resulting in cost and material savings and simpler construction. For example, the Palo Alto pilot project anticipates that an ecotone levee can reduce the levee height by up to 2 feet compared to traditional levees (City of Palo Alto, SFEP, 2020). This benefit may be instrumental at sites where wave runup exceeds 2 feet. Like tidal wetlands, coastal flood risk management benefits of ecotone levees scale with size: the larger the distance between the toe and crest, the greater the benefit (USACE, 2021a).

The benefits of ecotone levees are dependent on the performance of other bayward measures, including tidal wetland (existing or proposed), coarse beaches, and mudflats. For instance, a wetland-fringing coarse beach may break waves ahead of the tidal wetland behind it, promoting sediment accretion and vegetation growth by protecting the wetland from erosion, and supporting the upland migration of the wetland along the ecotone slope at pace with SLR. The beach and sustained wetland create roughness that, in turn, provides wave attenuation and erosion protection for the structural levee core. The integrated benefits of ecotone levees and other intertidal measures call for their consideration as a system, rather than independent measures.

This integrated system has a significant spatial requirement that is incompatible with constrained sites. Bayward, the ecotone levee may impact existing intertidal and subtidal habitats and raise complex policy and geotechnical feasibility challenges with the addition of Bay fill. Landward size may be constrained by existing development or expense of real estate acquisition (USACE, 2021a).

Once implemented, the erosion control benefits of an ecotone levee can reduce O&M costs compared to traditional gray infrastructure. A vegetated or hybrid shoreline can reduce operation and maintenance costs (less than $100 per linear foot (LF)) compared to hardened shorelines ($100 to 500+ per LF), according to estimates from the Texas General Land Office (2019).

Similar to the wetland NNBFs, ecotone levee maintenance may include the following activities (USACE, 2021a):

- Routine monitoring
- Maintenance of vegetation and invasive species management
- Structural maintenance
- Monitoring and repair associated with storm damages
- Sediment renourishment

5.4 Coarse Beach

5.4.1 Overview

Coarse beaches are also known by the following names:

- Intertidal beach
- Cobble beach
- Gravel beach
- Shingle beach
- Perched beach
- Beach nourishment
- Silled beach
- Pocket beach
- Fringing beach (when combined with wetlands)

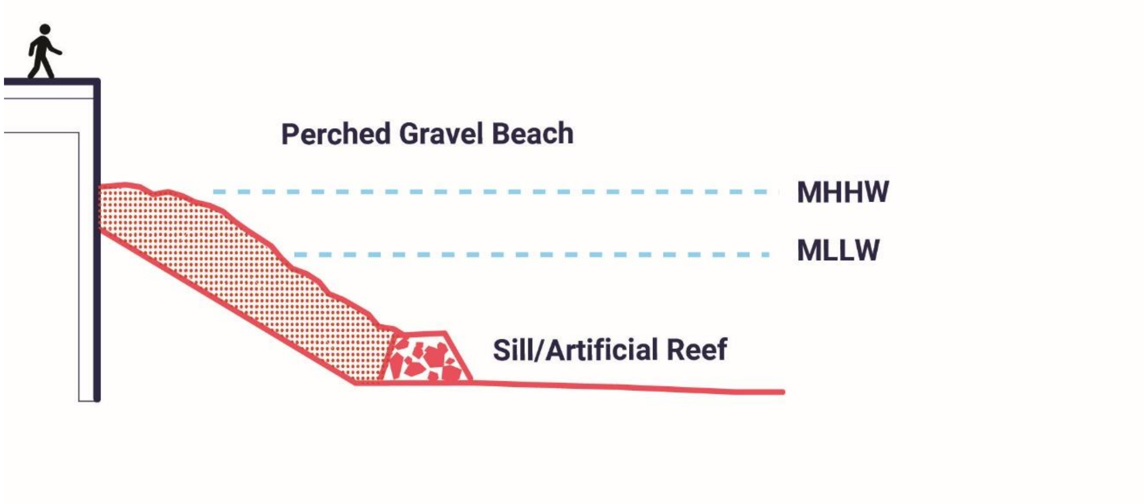


Figure I-15: Schematic of Coarse Beach

In coastal engineering, a coarse beach acts as a submerged breakwater, raising shoreline elevations, absorbing wave energy, and reducing runup (Bujak et al., 2023; Li et al., 2022). While a range of sediment types can be used to create a perched beach (such as sand), coarse sediment (such as gravel, boulders, or cobble) provides added ecological benefits by mimicking rocky habitat and reduces loss due to sediment transfer. Coarse beaches typically have a profile with steep slopes and discrete berms and ridges (USACE, 2021a).

The measure includes both the establishment of new coarse beaches and the renourishment and enhancement of existing coarse beaches. Newly established coarse beaches are typically perched with sediment deposited on the landward side of a sill or submerged dike parallel to the shore. They can also be perched on a shore platform, often composed of finer-grained sediment or sand.

Establishing new coarse beaches in this study area is only proposed in areas of shallow Bay water to minimize the amount of sediment required to reach the designed crest elevation. Coarse beaches in the study area would be considered Bayhead or pocket beaches. These small-scale beaches are defined by their siting, which creates conditions that often lead to diminished longshore erosive conditions. Existing coarse beaches also act as submerged breakwaters. Within the site area, existing coarse beaches (such as at Heron's Head Park, Pier 94 Wetlands) are subject to erosion and threatened by SLR. Artificial sediment nourishment can help preserve the flood, ecological, and social benefits of these beaches.

Coarse beaches can be built with a crest that reaches the designed flood elevation or be combined with other landward structural measures. Naturalized coarse beach profiles allow for greater benefits in reducing erosion and can be designed in combination with other NNBFs, including tidal wetlands. When combined with other measures, their primary coastal flood risk management benefit is to reduce wave runup, extending the lifespan and operation and maintenance costs of inland gray infrastructure.

Figure I-16 shows examples of coarse beaches as part of wetland restoration in San Francisco at Pier 94.

Photo Credit: SFEI

Figure I-16: Pier 94 Coarse Beach Restoration. San Francisco

5.4.2 Benefits

Coastal flood risk management benefits:

- Wave hazard reduction: Reduce or dissipate wave energy and/or reduce the potential for inland wave propagation (Bujak et al., 2023; Li et al., 2022).
- Erosion protection: Reduce erosion and inland migration of the shoreline (Lorang, 1991).

EQ benefits:

- This would represent an expansion of a historically important habitat type, with very limited existing instances in the Bay.
- Creates habitat, as submerged and intertidal rock can provide habitat for algae and animals, as well as invertebrates and fishes, such as herring, rockfish, and others.
- Prevents or reduces loss of critical habitat by protecting landward wetland areas.
- Promotes biodiversity along a highly urbanized shoreline.

OSE benefits:

- Proposed sites for coarse beaches are predominantly on the southern waterfront and address opportunities to expand open space and access in environmental justice communities with limited open spaces and waterfront access.
- Promotes economic vitality by:
  - Providing a more livable and desirable area
- Improves social connectedness, leisure, and recreation by providing a public resource:
  - Enhances opportunities for waterfront access to the Bay and provides open space and recreational spaces
  - Enhances opportunity for Bay Trail recreational connections
  - Reduces stress and anxiety factors with open space and activities

5.4.3 Performance

This section includes both the establishment of new coarse beaches and the nourishment and enhancement of existing coarse beaches. The focus on coarse beaches (predominantly gravel and boulder surface material) in this study is informed by the well-documented historical presence of sandy and rocky intertidal beaches within the study area. These small pocket beaches played an important ecological role and responded to local patterns of erosion, abundance, and composition of sediment; tidal extent; wave dynamics; and other site conditions (Goals Project, 2015). While this study does not propose the restoration of these historical shorelines (impossible, given the intervening changes), the prevalence of coarse beaches does help clarify the appropriateness of the measure within the study area geography.

While the establishment of new coarse beaches and the nourishment and enhancement of existing coarse beaches present some differences in the feasibility of their implementation, they pull from a shared set of documented cases that support their performance and benefits, and inform their design, construction, and operation and maintenance considerations (Lorang, 2000, 1997; SFEI, 2020; Simpson et al., 2007). Both established and enhanced coarse beaches benefit from the restoration of natural sediment transport processes. They both also demonstrate improved performance when coupled with other landward NNBFs, such as tidal wetlands.

Perched coarse beaches established with a shore platform or silled toe have been carried out in a variety of contexts nationally and internationally. Nationally, cases such as Olympic Sculpture Park present a well-documented case of the feasibility of perched coarse beach implementation (USACE, 2021a).

Coarse beach nourishment and enhancement, on the other hand, is supported by extensive case evidence in the Bay, with a range of benefits documented. Cases with implemented coarse beaches include:

- Heron’s Head Shoreline Resilience Project (*within the study area*)

- Pier 94 Wetlands (*within the study area*)
- Point Pinole Cobble Wetland
- Aramburu Island Beach, Richardson Bay
- Greenwood Beach, Richardson Bay

In addition to these local examples, there is extensive literature documenting the wave runup benefits provided by coarse beaches. Peer-reviewed studies have shown coarse beaches capable of “dissipating in excess of 90% of all incident wave energy” (Watt and Moses, 2005). This same study demonstrated the capacity for coarse beaches to dissipate waves from a large variety of wave conditions.

USACE has documented the establishment of a shingle (coarse) barrier beach from Cley to Salthouse along the North Norfolk Coast in the United Kingdom (UK), as a part of a larger restoration effort. This case, carried out over more than 15 years, has demonstrated benefits to flood and coastal erosion protection, providing “protection against the 2013 tidal surge event and improving the resilience of the shoreline to subsequent storms” (Bridges et al. 2018).

Coarse beaches can provide a critical habitat for the Bay Area. The ecological benefits of coarse beaches have been demonstrated in implemented cases nationally. Monitoring in Seattle, for example, has shown that the perched beach at Olympic Sculpture Park has seen the “rapid development of aquatic and terrestrial biota” (Toft et al., 2010). Heron’s Head Park and Pier 94 (as documented in Section 4) are also important wildlife habitat nodes.

Coarse beaches have been designed, implemented, and piloted both in combination with gray infrastructural measures, such as seawalls, and with other NNBFs, such as wetlands (often referred to as beach-fringed wetlands). Coarse beaches implemented with inland NNBFs enhance the performance of those measures by buffering them from wave energy and reducing over wash. Coarse beaches Bayward of gray measures, including seawalls and riprap, on the other hand, have been shown to have “less sediment cover at higher intertidal elevations due to truncation of the upper profiles” (USACE, 2021a), reducing their capacity to provide long-term flood mitigation benefits.

The amount of sediment required for establishing a coarse beach is important when considering the feasibility of implementation. In deep waters, coarse beaches require large supplies of both small and large sediment material. In this study area, coarse beaches are only identified in areas with more suitable shallow waters. The small scale of pocket beaches and their sediment transfer characteristics will also inform the material demands for this measure.

While sediment material sources are a consideration, an evolving regulatory environment means there are opportunities for the strategic beneficial reuse of dredge and other industrial by-products. Opportunities to reuse either dredged material (for example, Port of Oakland) or nearby industrial by-products and uses (such as from Hanson Aggregates, a concrete aggregate supplier adjacent to Pier 94) should be explored. USACE has extensive documented cases of beneficial use of dredged material for EWN purposes across the country.

As with all beaches, coarse beaches are subject to erosion, especially when faced with storms that bring a combination of high-water levels and surges. Dependent on local wave and wind conditions, erosion can reduce the beach crest. Erosion can reduce the performance of the beach and can lead to failure.

Established coarse beaches have not eroded more rapidly than other beaches. At Olympic Sculpture Park, sediment loss was relatively stable, with seasonal surface shifts over the first three years (Toft et al., 2010). Minor annual sediment losses have occurred, and without natural mechanisms for sediment deposition, the site will eventually require renourishment. To date, the coarse pocket beach at Olympic Sculpture Park has not suffered major sediment loss. However, shifting and mixing of surface and subsurface sediment has resulted in the exposure of smaller sediments, which could be more vulnerable to movement in future storms. The proposed coarse beaches of the Olympic Park study are bayhead and pocket beaches.

While the erosive nature of bayhead and pocket beaches is still an area of active research, in the Bay Area they are suggested to have “a limited ability to transport sediment due to the presence of their headlands” (SFEI, 2020), potentially reducing concerns that they are more likely to suffer from rapid sediment losses with the need for more frequent renourishment compared with other beach types.

5.5 Living Seawall and Vertical Enhancements

5.5.1 Overview

Living seawalls consist of structural elements combined with traditional seawalls that create varied microhabitat conditions through surface relief and material composition (**Figure I-17**). Elements can be added (that is, bolt-on rock pools or tiles), or built into the design (that is, precast concrete). The introduction of surface complexity (for example, surface texture, grooves, crevices, and nooks) to traditionally smooth surfaces promote vegetation growth, provides foraging habitat, and creates shelter from predation. The surface complexity may also promote wave energy dissipation (Dong et al., 2020; O’Sullivan et al., 2020).

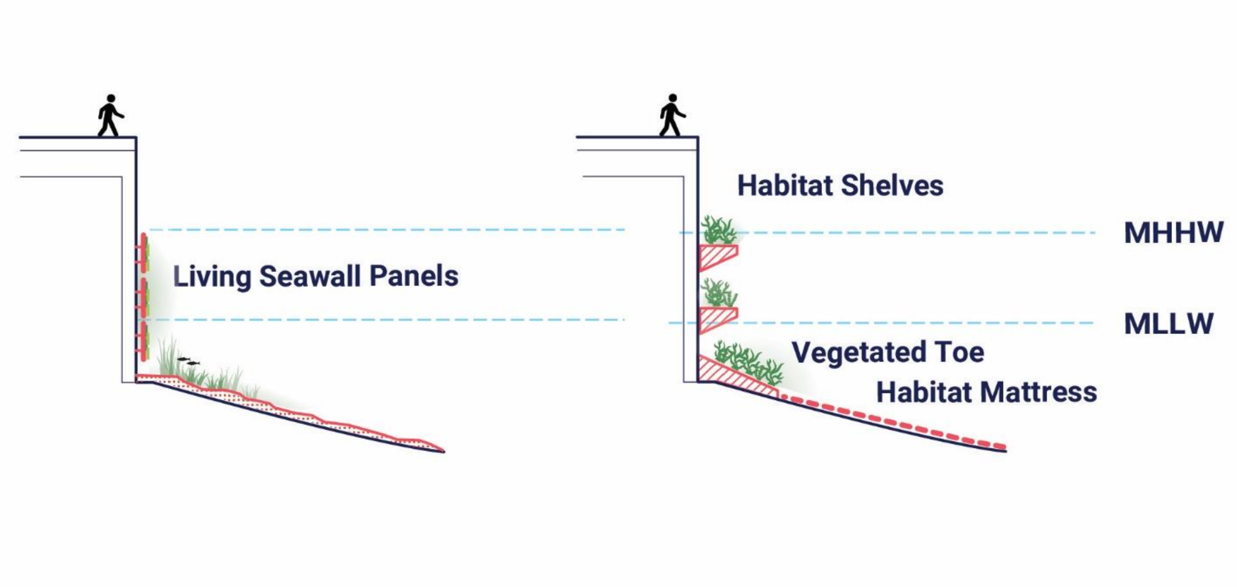


Figure I-17: Schematic of Living Seawall Enhancements

Eco-engineered structural elements may include concave or stepped seawall profiles, attached panels, integrated, and attached shelves, or a raised Bay floor created by a habitat bench or marine mattress. These elements, their surface textures, and material composition may be designed to promote recruitment by targeted organisms.

Like seawalls, pilings can be enhanced with attached or integrated features that increase complexity through surface relief, texture, and material composition. These features can either be integrated with the piling structure and used to replace old pilings or applied as a wrapped surface treatment to existing pilings. **Figure I-18** shows an example from the Seattle Seawall project, and **Figure I-19** shows the scientists monitoring the biota established on the Port’s Living Seawall Pilot Study.

Photo Credit: Waterfront Seattle

Figure I-18: Elliot Bay Seawall. Seattle, Washington

5.5.2 Benefits

Coastal flood risk management benefits:

- Wave energy reduction: Additional friction created by surface complexity may provide dissipation of wave energy, depending on design (O'Sullivan et al., 2020; Salauddin et al., 2021).
- Enhanced pilings may create additional friction against waves in the nearshore environment, indirectly dissipating wave energy. Reductions in wave energy may reduce wave runup at the shoreline and reduce erosion of the line of defense.
- Recruitment of oysters and bivalves can dissipate wave energy and reduce erosion of the structure (Morris et al., 2017; Vozzo et al., 2021).

Photo Credit: Abby Mohan

Figure I-19: Monitoring for the Port of San Francisco's Living Seawall Pilot Study

EQ benefits:

- Enhances and provides habitat diversity along seawalls and hardened structures where little habitat exists currently.
- Improves ecological connectivity by providing steppingstones to adjacent habitat patches.
- Recreates historical habitat types, such as rocky subtidal habitat.
- Improves water quality through recruitment of bivalves (Vozzo et al., 2021).
- Supports recreational and commercial fishing by enhancing fish habitat as follows:
    - Rock and attached vegetation are used by Pacific herring, other fish, and some invertebrates for spawning (SFEI, 2020)

- Remediate for creosote pilings: Creosote pilings are prevalent throughout the San Francisco waterfront, posing risks to local fish populations (namely, Pacific herring) that lay their eggs on these structures. Removal or treatment of these pilings will improve water quality and nearshore habitat for forage fish.

OSE benefits:

- Provides educational opportunities about Bay ecosystems and coastal resilience.
- Promotes economic vitality by boosting the local economy, especially the fishing industry.

5.5.3 Performance

Living seawalls modify and supplement traditional gray seawalls. The texture is used to create the seawall face itself (as precast concrete) or placed on the face of the seawall (textured tiles). Use of precast concrete components may speed construction and reduce project costs. Living seawalls can provide coastal flood risk management benefits by adding sufficient texture to dissipate wave energy while also providing additional habitat benefits (Vozzo et al., 2021).

Multiple studies show that living seawalls can reduce wave energy (Dong et al., 2020; Salauddin et al., 2021). Living seawalls provide benefits to benthic invertebrate, algae, and fish species (Morris et al., 2017; O'Shaughnessy et al., 2020). These structures can also use special concrete mixes to enhance durability and reduce erosion (Salauddin et al., 2021).

Biodiversity enhancements should not degrade the structure or reduce access for maintenance or repairs, and this consideration should be integral to project design. The planning and design of the living seawall must consider both SLR and potential increased storm intensity due to climate change. Inspections should occur after large events, and routine monitoring of species diversity and invasive species management should occur as part of operations and maintenance.

There are local, national, and international examples of living seawalls:

Local

- Port of San Francisco Living Seawall Pilot study (ongoing) will quantitatively evaluate species recruitment and diversity on textured tiles at three locations along the seawall. Monitoring began in 2023, with the results expected in 2026.

National

- The Seattle Seawall used precast concrete to provide risk reduction for liquefaction, coastal and wave hazards, and SLR, while simultaneously providing habitat targeted to important species (Guenther et al., 2016). Completed in 2017, this project improved nearshore habitat and is expected to extend the design life of the seawall to more than 75 years (Guenther et al., 2016).

International

- Sydney Harbor living seawall using modular tiles attached to the seawall and showed 20% greater recruitment of species than on unmodified seawalls (Strain et al., 2018).

5.6 Naturalized or Embankment Shorelines

5.6.1 Overview

Naturalized shorelines or embankment shorelines are ways to sculpt the land surface to provide wave runup reduction, reduce flood risk, as well as provide ecological benefits. Two different NNBF naturally sloped shorelines are proposed, dependent on the existing conditions and predicted future conditions at each site: naturalized and embankment shorelines. Naturalized shorelines include gentle slopes and shallow water, with a range of upland plantings, habitat shelves, tidal wetlands, beaches, submerged sills, and rock mounds. Alternatively, an embankment shoreline is used along a creek, where space is more constrained, and typically has a steeper slope leading to deeper water just offshore and includes upland planting and ecological (vegetated) riprap. The schematics shown in **Figure I-20** and **Figure I-21** are example cross sections and are not intended to represent a recommended design feature.

Figure I-20: Schematic of Naturalized Shoreline

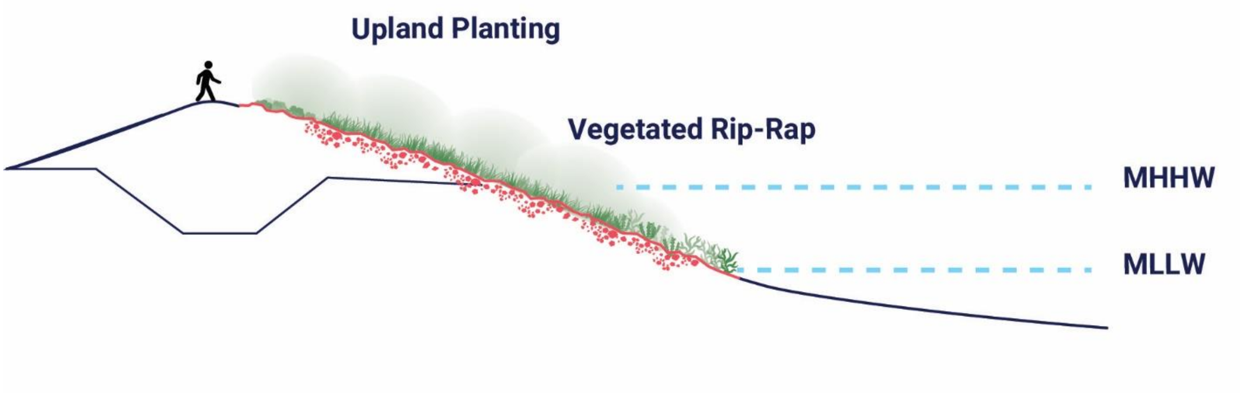


Figure I-21: Schematic of Embankment Shoreline

The shoreline enhancements for streambank erosion control can include the use of bioengineering measures, which USACE defines as “the combination of biological, mechanical, and ecological concepts to control erosion and stabilize soil through the use of vegetation or a combination of it and construction materials” (Allen and Leech 1997).

Embankment shorelines can also include integrated habitat shelves to reinforce and vegetate urban creek edges. These features can create crenulations and pockets with a variety of physical environments. Embankment shoreline edges can also be enhanced with the following materials:

- Planted vegetation
- Live crib walls
- Armoring rock and cobble of various sizes
- Other natural materials, such as logs

Like ecological armoring or living seawalls, substrates may further consist of materials and textures that support recruitment of targeted species. These layered enhancements offer many possible combinations and approaches that can be refined to suit site and design needs.

5.6.2 Benefits

Coastal flood risk management benefits:

- Naturalized or shoreline embankments provide similar coastal flood risk management benefits as ecotone levees (Section 5.3), but in a reduced footprint.

Wave hazard reduction: Vegetation or ecological armoring on the naturalized or shoreline embankments reduces or dissipates wave energy, reduces wave runup elevation, and reduces shoreline overtopping (USACE, 2020b).

EQ benefits:

- Creates ecological connections/corridors and improves wildlife habitats that are often disconnected with the use of traditional gray measures (levees):
- Connection and upland improvements can provide high-tide refuge, nesting, and foraging habitat.
- Improves habitat diversity along highly urbanized shorelines.

OSE benefits:

- Improves social connectedness, leisure, and recreation by providing a public resource:
    - Provides opportunities to educate about Bay ecosystems and coastal resilience, as well as foster stewardship through enhanced visibility and experience of the nearshore environment, especially for recreational boaters.
    - Supports recreational and commercial fishing through provision of aquatic habitat.
    - Reduces stress and anxiety factors with open space and activities.

5.6.3 Performance

Naturalized or shoreline embankments are similar to ecotone levees but feature steeper slopes (less than 10:1 (Horizontal:Vertical) and thus a smaller spatial requirement, allowing for use at more constrained sites. Since the proposed NNBF naturalized or shoreline embankments are vegetated, they are subject to many of the same performance considerations as the wetland and ecotone levee NNBFs (Section 5.1 and 5.3). Naturalized or shoreline embankments are commonly used to manage runoff, as they can be effective for flow attenuation by slowing down flow.

A vegetated gently sloping naturalized or shoreline embankments or shaped shoreline can dissipate wave energy at a lower cost than hard armor wave protections since, unlike inert material, vegetation that has been damaged can often reestablish itself. Vegetated shoreline stabilization is considered a “soft” approach that is often less expensive to install and maintain than hard armor protection. The slope of the naturalized or shoreline embankments in shallow depths used in vegetated protection also reduces the amount of wave energy that is transferred to the shore. As the water becomes shallow, the wave steepens. The maximum wave height is approximately three-fourths of the water depth. At this point, the wave becomes unstable, breaks, and then reforms at a lower height (NRCS, 2014). Vegetation on naturalized or shoreline embankments can provide habitat for both terrestrial and aquatic organisms, nutrient cycling functions for water quality improvement, and sediment deposition enhancement.

Naturalized or shoreline embankments have been used for many small Natural Resources Conservation Service (NRCS) projects, or to protect shorelines, but given the relative novelty of this measure compared to traditional unvegetated berms, few examples have been established and studied at scale. A sample vegetated naturalized embankments was studied as a potential climate resilient flood barrier design in Boston (Boston Public Works, 2018).

Naturalized shorelines would follow the performance of ecotone levees more closely than embankment shorelines but would include other measures to address wave energy such as a submerged sill. Embankment shorelines are generally steeper sloped, and typically include vegetated riprap, the performance of which is described for ecological armoring (Section 5.7).

Naturalized or shoreline embankments, similar to ecotone levee maintenance, may include the following:

- Routine monitoring
- Maintenance of vegetation and invasive species management
- Structural maintenance
- Monitoring and repair associated with storm damages
- Sediment renourishment

5.7 Ecological Armoring

This section describes ecological armoring, which includes ecological and green riprap and tidepool features.

5.7.1 Overview

Ecological armoring measures aim to replicate the natural processes and functions of rocky, intertidal habitat, providing erosion, wave energy protection, and ecological benefits along the shoreline. Ecological armoring is a direct replacement for traditional riprap. Interlocking layered armored protection units or differently shaped riprap, sometimes with integrated tide pools, are designed to mimic natural intertidal conditions and create microhabitats, including vegetation establishment, while still providing the protection and benefits of traditional gray structures. Units can be stone (riprap), concrete, or other precast material (including eco-concrete) (Perkol-Finkel and Sella, 2015, 2014).

In suitable wave environments, the armor units may be vegetated by filling voids in the rock with soil and planting upland, intertidal, and subtidal species (Summers, 2010). Design elements include material composition, and micro- (rock and unit and void size) and macro- (feature shape and orientation) configuration to reduce wave energy, limit erosion, and target desired species complexity (SFEI, 2020). **Figure I-22** provides an example use of eco-concrete armoring along a revetment.

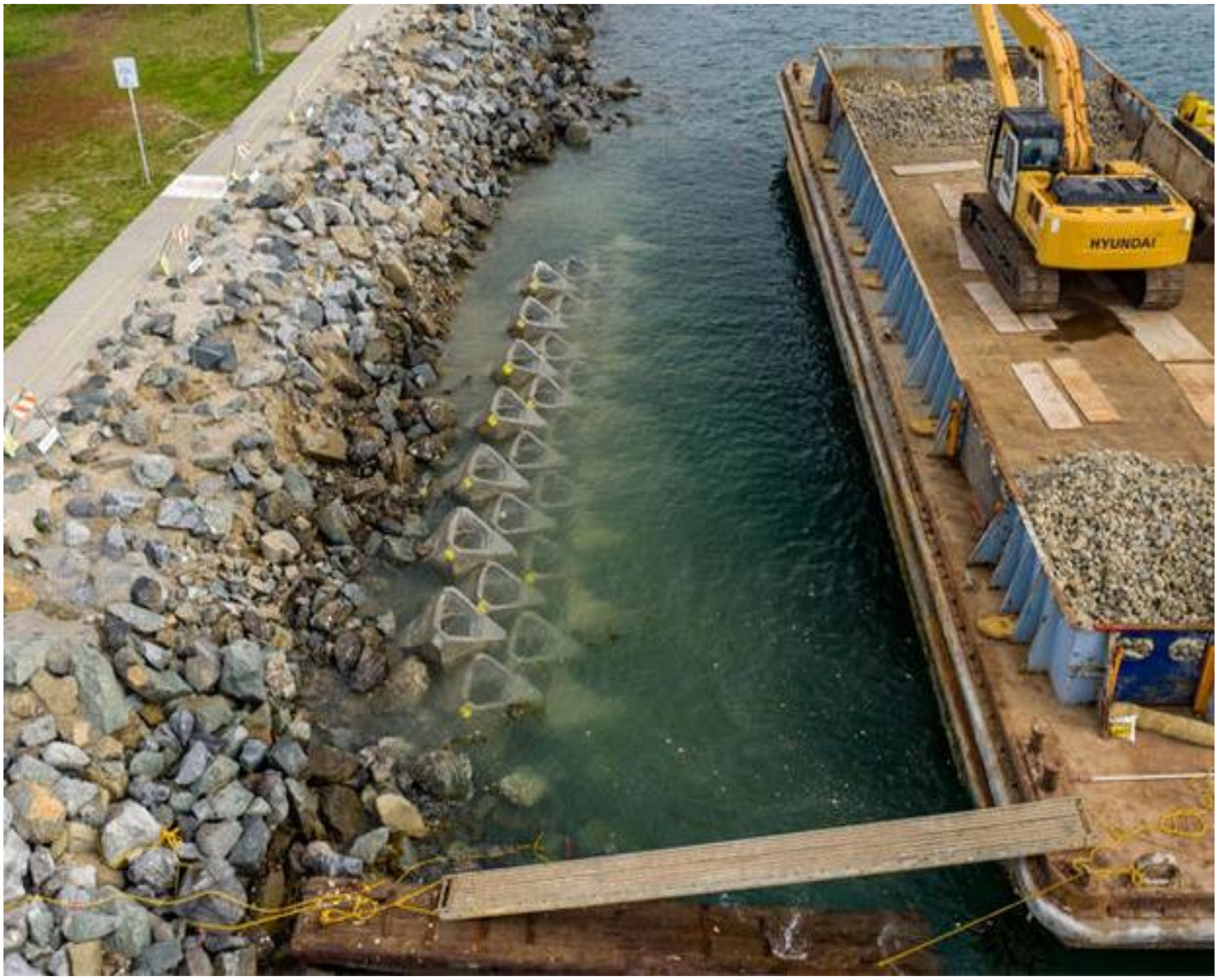


Photo Credit: Port of San Diego

Figure I-22: Eco-concrete Coast lock Blue Economy Pilot Project San Diego

5.7.2 Benefits

Coastal flood risk management benefits:

- Wave hazard reduction: Reduces or dissipates wave energy, reduces wave runup elevation, and reduces shoreline overtopping. Can reduce the design height of the structure needed (e.g., levee, floodwall) (USACE, 2020b).
- Erosion protection: reduce erosion at the toe of structure.

EQ benefits:

- Creates habitat through colonization of subtidal and intertidal armor units. This can expand an historically important habitat type (rocky intertidal) with limited existence in the Bay. Subtidal and intertidal rock can provide habitat for algae and animals, as well as invertebrates and fishes, such as herring, rockfish, and others (Morris et al., 2017).
- Improves habitat diversity along highly urbanized shorelines.

OSE benefits:

- Promotes economic vitality by:
    - Providing a more livable and desirable area
    - Increasing natural capital
    - Boosting the local economy, especially fishing and eco-tourism industries
- Improves social connectedness, leisure, and recreation by providing a public resource:
    - Provides opportunities to educate about Bay ecosystems and coastal resilience, as well as foster stewardship through enhanced visibility and experience of the nearshore environment, especially for recreational boaters.
    - Supports recreational and commercial fishing through provision of aquatic habitat.
    - Reduces stress and anxiety factors with open space and activities.
- Supports the local fishing community.

5.7.3 Performance

Rocky, intertidal armoring measures replace or integrate with gray, armored shorelines or naturalized or embankment shorelines and supplement their wave attenuation and erosion protection benefits, while also providing ecological benefits. Units may replace armoring entirely, while other features (such as vegetation, tide pools, or reef units) may integrate with traditional riprap. The surface complexity is enhanced through vegetation, geometry, or design. Because these measures can occupy the same footprint as their comparable gray measure, they are most suitable for shorelines that are spatially constrained by upland development or topography and Bayward bathymetry or maritime uses.

Ecological armoring can provide erosion protection that will reduce O&M potential, resulting in long-term cost savings and extended lifespan of other structural measures. However, vegetation establishment needs correct hydrological conditions.

Few built examples are documented with long-term studies that quantify coastal flood risk management benefits. However, many recent installations and pilot projects are assessing coastal flood risk management potential. At the Port of San Diego, interlocking rocky intertidal units were used to armor the shoreline. These units were made of an ecological concrete mixture that has a different pH value than regular marine concrete. This concrete can promote the growth of marine species. These units were shaped with textures and grooves and integrated tide pools. The installation was placed alongside traditional riprap and the ecological armor units are expected to provide the same degree of wave and erosion protection (Kowal, 2022).

There are local and national examples of subtidal habitat improvement projects:

Local

- Crane Cove Park, San Francisco
- McCovey Cove, San Francisco (planned)

National

- Eco-concrete Coast Lock Blue Economy Pilot Project, Port of San Diego (Kowal, 2022)
- New York’s East Rockaway Inlet to Rockaway Inlet and Jamaica Bay Reformulation Project (USACE, 2019b)

5.8 Creek Enhancements

5.8.1 Overview

Creek and lagoon enhancements include a variety of improvements to creek banks. For the SFWCS, these features are limited to the lower creek banks along Islais and Mission Creeks, which are tidal water ways. Creek enhancements include measures such as bioengineering for streambank erosion control, which USACE defines as “the combination of biological, mechanical, and ecological concepts to control erosion and stabilize soil through the use of vegetation or a combination of it and construction materials.” (Philadelphia Water, 2016).

Enhancements may be considered at macro-, mega-, and micro-scales. Habitat shelves (such as benches, terraces, or sills) are features that can be integrated with embankments to reinforce and vegetate urban creek edges. These features can create crenulations and pockets with a variety of physical environments along the corridor at a macro-scale. At a mega-scale, to increase surface complexity, a creek or lagoon edge could be enhanced with the following materials:

- Planted vegetation
- Live crib walls
- Armoring rock and cobble of various sizes
- Other natural materials, such as logs

Like living seawalls (Section 5.5) and ecological armoring (Section 5.6), substrates may include materials and textures at a micro-scale that support recruitment of targeted species. These layered enhancements offer many possible combinations and approaches that can be refined to suit site and design needs (**Figure I-23)**.

Photo Credit: Thames Estuary Partnership

Figure I-23: Thames Estuary Edges. London, UK

5.8.2 Benefits

Coastal flood risk management benefits:

- Wave hazard reduction: Reduces or dissipates wave energy and reduces the potential for inland wave propagation.
- Erosion protection: Reduces erosion and inland migration of the shoreline.

EQ benefits:

- Water quality improvements: (Allen and Leech, 1997) Captures and filters stormwater runoff; traps sediment; and protects water quality of creeks, lagoons, and the Bay.

- Promotes biodiversity along a highly urbanized shoreline, especially intertidal and upland habitat. “Planted vegetation controls erosion and serves as good wildlife and fisheries habitat in riparian systems.” (Allen and Leech, 1997)
- Helps restore connections between terrestrial and aquatic habitats. The black-crowned night-heron, for example, requires both large trees for nesting and aquatic habitats for foraging (Audubon, n.d.). Enhancing connectivity between these habitats will support this sensitive population, recently seen to return to Mission Creek (INaturalist, n.d.).
- Helps sequester carbon in plant biomass and soils.
- Supports fish populations with habitat and streamside shade.

OSE benefits:

- Enhances opportunities for waterfront access to the Bay and includes open space and recreational spaces:
    - Waterfront open space can benefit neighboring communities as well as visitors.
    - Opportunity for Bay Trail and Bay Water Trail recreational connections
    - Improves aesthetics.
- Promotes economic vitality by:
    - Providing a more livable and desirable area
    - Boosting the local economy, especially fishing and eco-tourism industries
- Improves social connectedness, leisure, and recreation by providing a public resource.
- Reduces stress and anxiety factors with open space and activities (Vujcic et al., 2017).
- Provides educational opportunities to enhance community identity.

5.8.3 Performance

Creek enhancements are intended to stabilize the creek banks and reduce erosion and to prevent bank failure and potential contamination of adjacent waterways.

Bioengineering and vegetation techniques can stabilize waterway (Allen and Leech, 1997):

- The root system holds soil particles together, improving the soil’s binding network structure and reinforcing bank stability.

- The water flow dissipates energy against plant material rather than the soil, reducing flow velocities.
- Vegetation buffers against erosion caused by transported materials.
- Vegetation encourages sediment deposition by slowing the flow of water.

Selecting the appropriate suite of bioengineering measures for the varied site conditions is essential to the successful performance of creek and lagoon enhancements. These measures can be combined, or different measures can be applied as constraints and conditions allow. Features include:

- Habitat shelves, benches, terraces, sills
- Revegetation (plantings, live staking, brush layering, hydroseeding)
- Vegetated walls (live crib walls, gabion baskets)
- Toe stabilization (rock, gravel, logs)
- Vertical surface texturing and roughness (for example, paneling)

San Francisquito Creek Bank Stabilization and Revegetation Master Plan (SFCJPA, 2021) (a USACE project) presents a useful example of varied measures that can provide bank stabilization benefits.

Nationally, USACE has implemented a variety of urban stream restoration projects that use bioengineering techniques for bank stabilization and erosion control along sites facing dynamics like those in the study area. In Connecticut, USACE's Mill River Restoration project includes naturalization, restoration of riparian habitat and wetlands, and the reduction of sedimentation into the river. Bioengineering methods employed include "stone-reinforced toes, coir fascines, live stakes, and erosion control fabric" (USACE, 2004). Mill River provides an excellent example of bank stabilization and floodplain restoration being "achieved primarily through the planting of native vegetation, including trees, shrubs, and herbaceous riparian and wetland species" (USACE, 2004).

In another example, USACE's Horner Park Restoration Project in Chicago regraded and vegetated the riverbanks and introduced cobble bars to address erosion hazards (Bridges et al. 2018). The erosion protection documented for projects like Horner Park can potentially extend the lifespan of structural berms. Adding roughness, which helps reduce erosion and add ecological complexity to engineered edges, can also be achieved using natural elements, like wood logs, as demonstrated at Hamakami Strawberry Farm in Washington, even along the banks of a high-energy river (FEMA, 2023).

To achieve coastal flood risk management performance, precautions must be made "to prevent both undercutting the stream bank toe and erosion of the upper and lower ends (flanking) of the treated project reach" (Allen and Leech, 1997) through a hard toe and flanking protection. Bank toes, however, can be hardened with natural elements, such as a row of logs with the root wads attached, as has been done along the Snohomish River (FEMA, 2023).

NNBFs must comply with USACE planting guidelines for structural berms where specified for the line of defense. Vegetation is subject to several uncertainties, which may undermine the measures' coastal flood risk management benefits:

- It may fail to grow or be undermined.
- It may be uprooted by wind and water.
- Wildlife may depredate it (Allen and Leech, 1997)

Several techniques allow for the integration of planting into structural slopes, terraces, and walls. Live crib walls, for example, can provide stabilization of steep banks and protect slopes from undercutting (Norwegian Geotechnical Institute, 2016). On less-steep banks, live staking can provide similar benefits while requiring less integrated structural support.

Creek and lagoon enhancement measures provide an important co-benefit by mitigating or improving water quality. Runoff mechanisms transport and concentrate urban pollutants in waterways. In particular, the creation of lagoons behind tide gates at the creek mouths (Alternative F) will exacerbate this problem by impeding tidal flushing over time. Water quality is a significant concern for local regulatory authorities, particularly the Regional Water Quality Control Board (RWQCB) and will likely require mitigation measures to address impacts.

Vegetation measures can slow runoff, which helps filter sediment and reduce erosion. Although performance depends on a range of factors, the U.S. Environmental Protection Agency (EPA) has found that a 50-foot vegetated buffer for construction projects has a sediment removal efficiency of approximately 25 to 90% (EPA, 2021).

In a constructed lagoon (Alternative F), vegetated embankments can also help remove stormwater pollutants, including:

- Nutrients
- Organics
- Metal
- Bacteria
- Oil and grease

Although some specific pollutants may require pretreatment (SFPUC, 2016).

Along the Thames River, the Estuary Edges program has piloted various strategies of vegetated intertidal terracing in multiple sites to recover intertidal habitat lost to the encroachment of development on the river. The Greenwich Peninsula Northeast Terrace has shown initial success in tidal wetland development (Port of London Authority, 2023a). The Thames River has also used river wall panels to create a range of habitats along vertical riparian edges in constrained sites that lack space to widen the riparian corridor, demonstrating the adaptability of this measure to varied conditions. River wall panels, similar to living seawall panels, are often prefabricated units that can be designed to optimize micro-habitat in line with local ecological needs.

In Islais Creek and Mission Creek, creek enhancements are principally constrained by spatial availability between upland development and existing habitat or deep water in creek channels. Complex geotechnical conditions and local regulations around Bay fill and habitat may complicate creekside construction. Terracing may be useful to bridge elevation differences in this context. Given the available space, these measures may be adaptable to higher design elevations by adding terraces or extending embankments upland.

Creek and lagoon enhancements may have the following O&M requirements (Port of London Authority, 2023b):

- Routine monitoring of habitat development (sediment accretion, plant establishment)
- Litter removal
- Invasive species removal

5.9 Green Stormwater Infrastructure

5.9.1 Overview

Combined stormwater and groundwater may result in inland flooding that will be trapped behind an elevated shoreline. Green stormwater systems (GSI) take advantage of the natural processes of soils and plants to slow down and filter stormwater and keep it from overwhelming sewer systems, thereby mitigating inland flooding (SFEI and SPUR, 2019). These measures can be small (street or parcel) or large (neighborhood) scale. Examples include:

- Rain gardens
- Permeable paving
- Green bulb-outs
- Stormwater drainage wells

5.9.2 Benefits

Coastal flood risk management benefits:

- Mitigates inland stormwater flooding behind the line of defense.

EQ benefits:

- Improves water quality from reduction in pollutants reaching Bay waters.

OSE benefits:

- Provides numerous public health and safety benefits by lowering pollution and risk for asthma and cardiovascular disease (Bowen and Lynch, 2017; EPA, 2017; Kumar et al., 2019).
- Promotes economic vitality by providing a more livable and desirable area (FEMA, 2022).

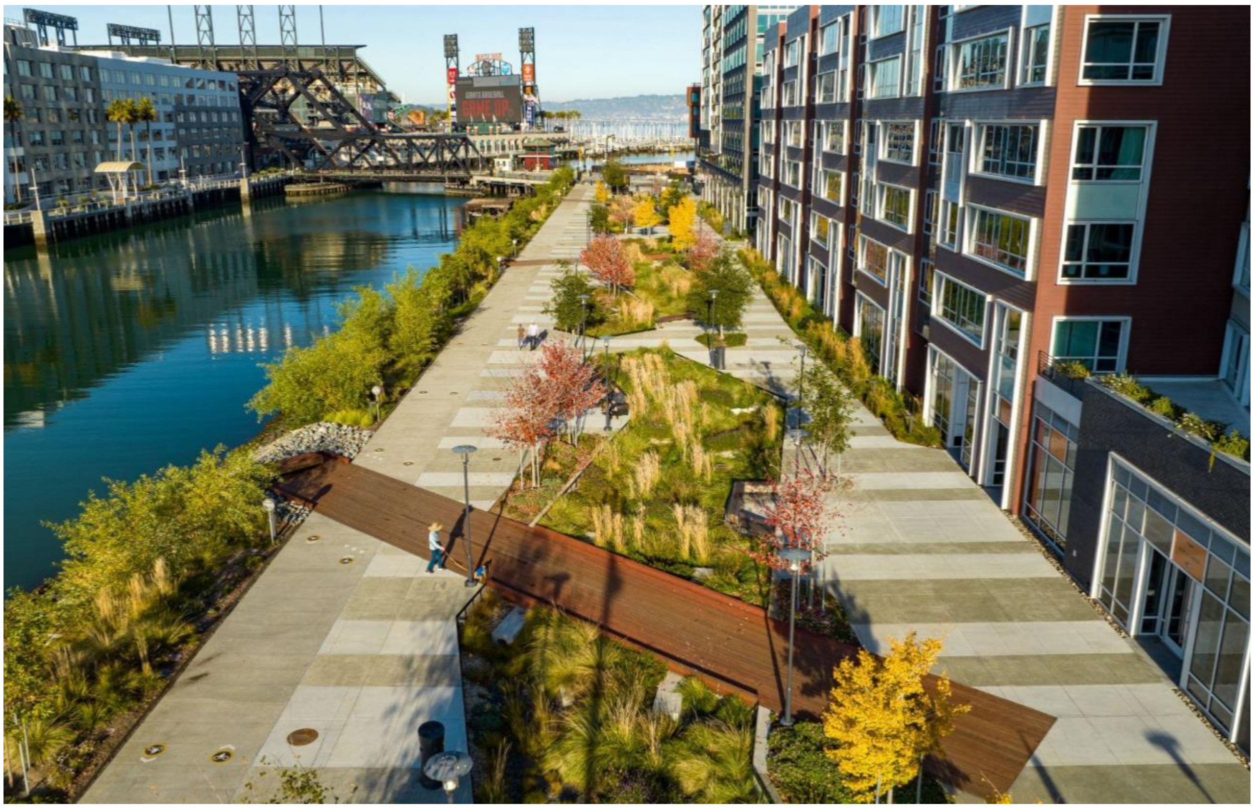


Photo Credit: CMG Landscape Architecture

Figure I-24: Mission Creek Park, San Francisco

- Improves social connectedness, leisure, and recreation by providing a public resource (Shakya and Ahiablame, 2021; Ying et al., 2022):
  - Recreation and community hub improvements if integrated with larger flood storage measures (for example, urban detention basin transformed into recreation space)
  - Enhanced opportunities for waterfront access to the Bay and inclusion of open space and recreational spaces
  - Improvements to the aesthetic quality of existing open spaces
  - Reduction in stress and anxiety factors with new open space and activities

  - Provision of educational opportunities to enhance community identity

5.9.3 Performance

GSI is separate from gray coastal infrastructure but can help gray infrastructure performance and capacity by reducing stormwater flooding and impacts. GSI can also help gray infrastructure adapt in capacity, resulting in cost savings in deferred upgrades or replacement.

GSI construction and operations can be expensive due to the degree of surface changes and diverse use of spaces needed to accommodate storm benefits. However, co-benefits to the environment and community members can show value (SFEP, 2022). Operation and maintenance can be challenging for plants within urban environments due to temperature extremes, trash, weeds, and pollutants (Philadelphia Water, 2016). Routine, reactive, and during storm event maintenance is needed so that the GSI functions as intended and provides the necessary benefits.

There are local and national examples of GSI projects:

Local:

- Wiggle Neighborhood Green Corridor, San Francisco
- Upper Yosemite Creek Daylighting, San Francisco
- Chinatown Spofford Living Alley, San Francisco
- Baker Beach Green Streets, San Francisco
- Holloway Green Street, San Francisco
- Mission & Valencia Green Gateway, San Francisco
- San Francisco State University Infiltration Basin, Bioswale, San Francisco
- Sunset Circle vegetated swales and infiltration basins, San Francisco
- San Pablo Avenue Green Stormwater Spine, Alameda County
- Serramonte Main Branch Library Stormwater Treatment Gardens, Daly City

National

Green City, Cleaner Waters, Philadelphia, Pennsylvania

6. Retained Features in the Future with Project Alternatives

The FWP Alternatives include the retained NNBFs identified in Section 4 and described in Section 5. NNBFs build on the characteristics of the existing landscape and seek to maximize opportunities within proposed alternatives, while considering maritime constraints. Each retained NNBF is included within at least one FWP alternative

(Alternatives C thru G, Appendix A. *Plan Formulation*). This approach allowed for the evaluation of the full range of candidate NNBFs across the alternatives.

However, the tentatively selected plan was not optimized relative to NNBFs during this feasibility stage. The optimization of NNBFs will occur in a later phase, identifying the most promising and effective NNBFs from across the alternatives for inclusion in the final Recommended Plan within the Chief’s Report. The engineering and design of these features, including green-gray hybrid measures, will occur in the PED phase. Both the Port and USACE are committed to including the most viable and beneficial NNBFs within the Recommended Plan.

6.1 Alternative A – No Action

Alternative A is the “No Action”, meaning no action is taken to reduce flood risks beyond projects that are already approved along the San Francisco waterfront. Alternative A represents a baseline for comparison to evaluate the costs and benefits of all other alternatives. NNBFs were not identified or evaluated for Alternative A.

6.2 Alternative B – Nonstructural

Alternative B is the non-structural option, which moves people and assets away from the flood risk, uses nonstructural measures (such as floodproofing) to reduce risks, and allows water to disperse naturally rather than constructing traditional structural solutions. NNBFs were not identified or evaluated for Alternative B.

6.3 Alternative C – Defend, Scaled for Lower Risk

Alternative C is designed to adapt the shoreline to withstand 1.5 feet of SLR over the 100-year evaluation period using a combination of structural and nonstructural measures (**Figure I-25**). This alternative uses ecological armoring and living shoreline measures that aim to replicate the natural processes and functions of rocky, intertidal habitat, providing erosion, wave energy protection, and ecological benefits along the shoreline.

Alternative C includes the following NNBFs:

- Naturalized/embankment shorelines (Section **Error! Reference source not found.**) with ecological armoring (Section 5.7)
- Creek enhancements (Section 5.7.3)

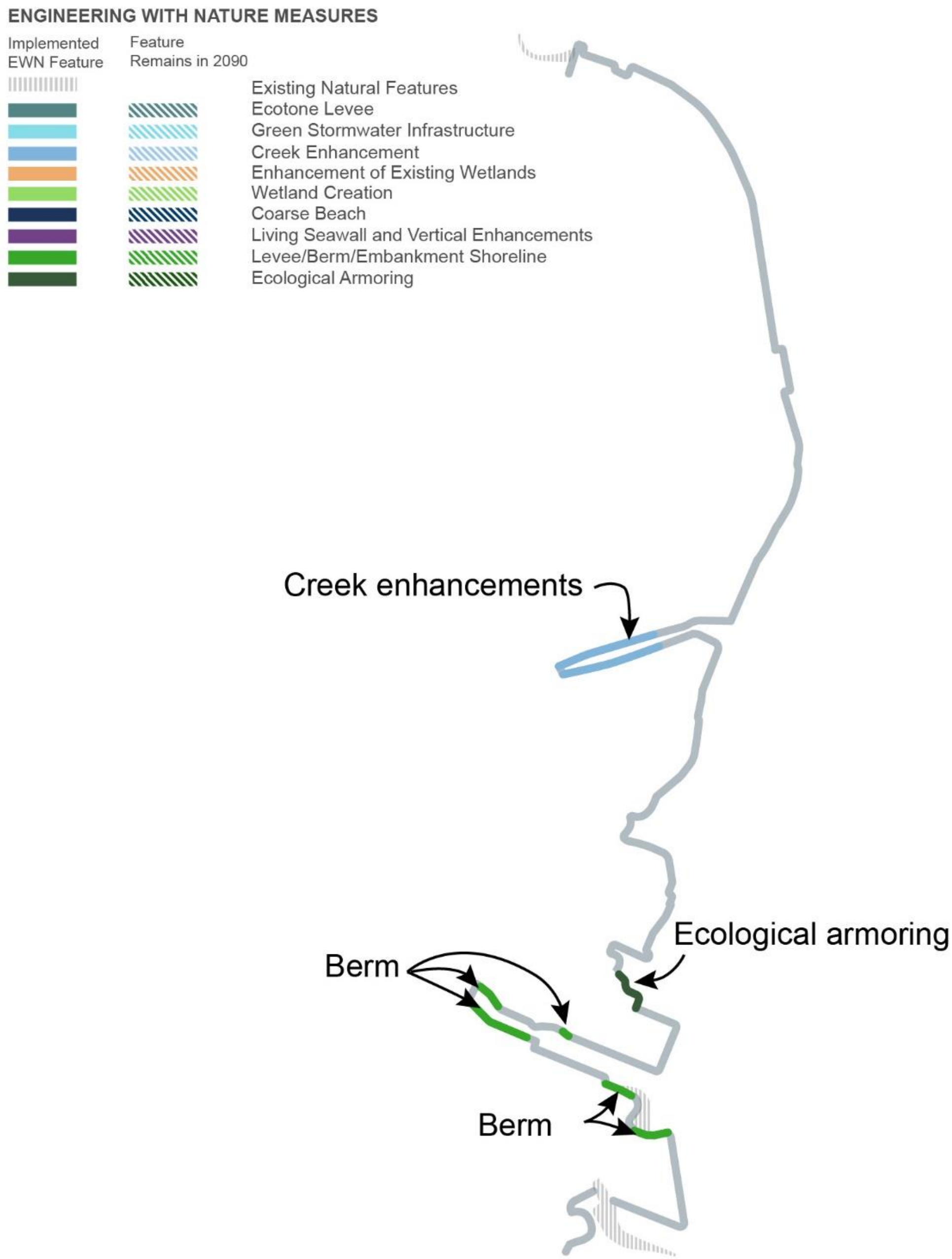


Figure I-25: Natural and Nature-Based Features in Alternative C

6.4 Alternative D – Defend, Scaled for Low-Moderate Risk

Alternative D is designed to adapt the shoreline to 1.5 feet of SLR in 2040 (**Figure I-26**), with the possibility of adapting to up to 3.5 feet of SLR in 2090 (**Figure I-27**) depending on the future SLR trajectory.

Alternative includes the following NNBFs:

- Wetland enhancement (Section 5.1)
- Ecotone levees (Section 5.3)
- Naturalized/embankment shoreline (Section **Error! Reference source not found.**)
- Ecological armoring (Section 5.7)

In 2040, ecotone levees are proposed at Crane Cove Park, Piers 94 and 96, and Heron's Head Park. The ecotone levees would have approximately a 30H:1V slope (where H is horizontal, and V is vertical). The intent is to transition across different habitat types along the various elevations to attenuate waves for flood risk reduction while elevating ecological performance by incorporating productive habitats and high-water refuge.

Ecological armoring is proposed at Warm Water Cove. The existing embankment naturally transitions from a steep slope to a gentler, flat inland slope. Ecological armoring will reduce erosive and wave forces and provide additional habitat value.

In 2090, if additional sea level rise adaptation is required, an ecotone levee with ecological armoring is proposed for Warm Water Cove.

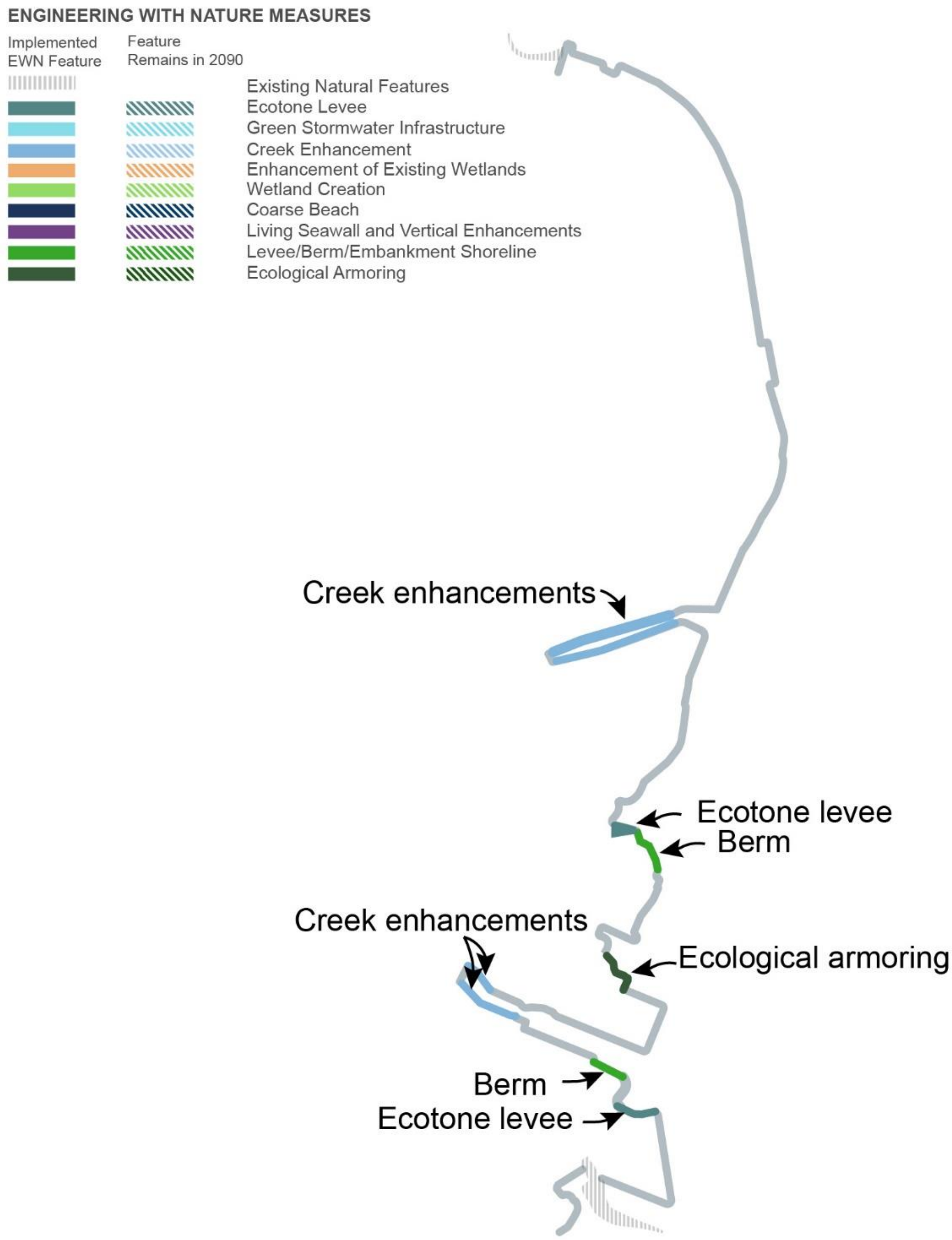


Figure I-26: Natural and Nature-Based Features in Alternative D (2040)

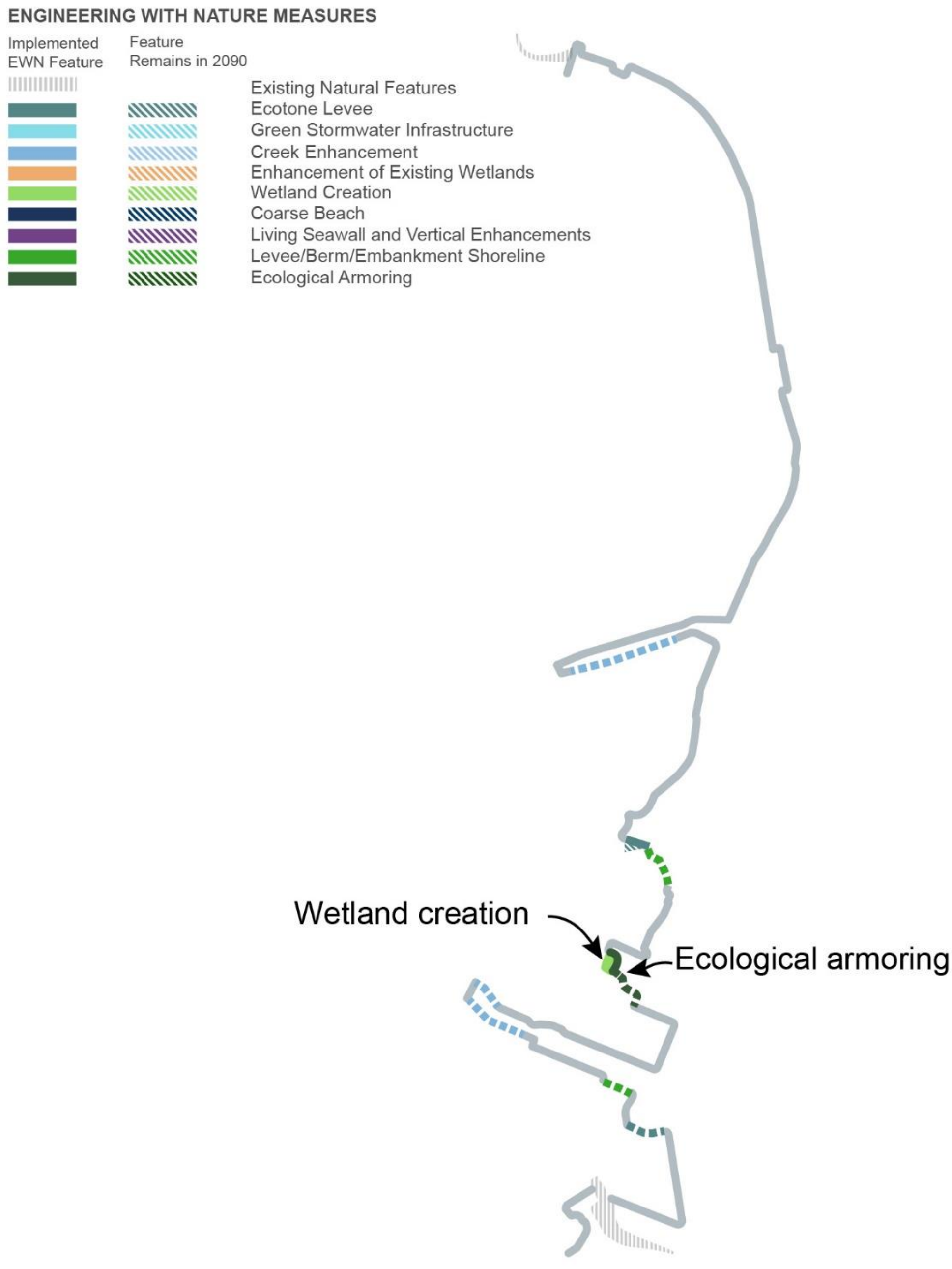


Figure I-27: Natural and Nature-Based Features in Alternative D (2090)

6.5 Alternative E – Defend Existing Shoreline, Scaled for Higher Risk

Alternative E was designed to “hold the line” by preserving a waterfront that looks and functions much as it does today by adapting the shoreline. Alternative E addresses 3.5 feet of SLR in 2040 (**Figure I-28**), with adaptation to address up to 7 feet in 2090 (**Figure I-29**) depending on the future SLR trajectory.

Alternative E includes the following NNBFs:

- Ecotone levees (Section 5.3)
- Living seawall and vertical enhancements (Section 5.5
- Naturalized/embankment shorelines (Section **Error! Reference source not found.**)
- Creek Enhancements (Section 5.8)

In 2040, creek enhancements are included along Islais and Mission Creeks, and embankment shorelines are included along the Mission Bay and Pier 70 shorelines. A naturalized shoreline with space for inland wetland migration as sea levels rise is proposed for the Pier 94 Wetlands.

The urbanized northern waterfront is anticipated to include primarily vertical seawalls. Alternative E includes deeply textured surfaces that create varied micro-habitat conditions along 100 percent of the vertical seawalls to maximize ecological habitat value. These features are only included in Alternative E, although living seawalls can be included within any alternative that includes vertical shorelines. The introduction of surface complexity (e.g., surface texture, grooves, crevices, and nooks) promotes vegetation growth, provides foraging habitat, and creates shelter from predation.

In 2090, an additional naturalized shoreline is included at Warm Water Cove to provide flood protection if SLR tracks along a higher SLR trajectory.

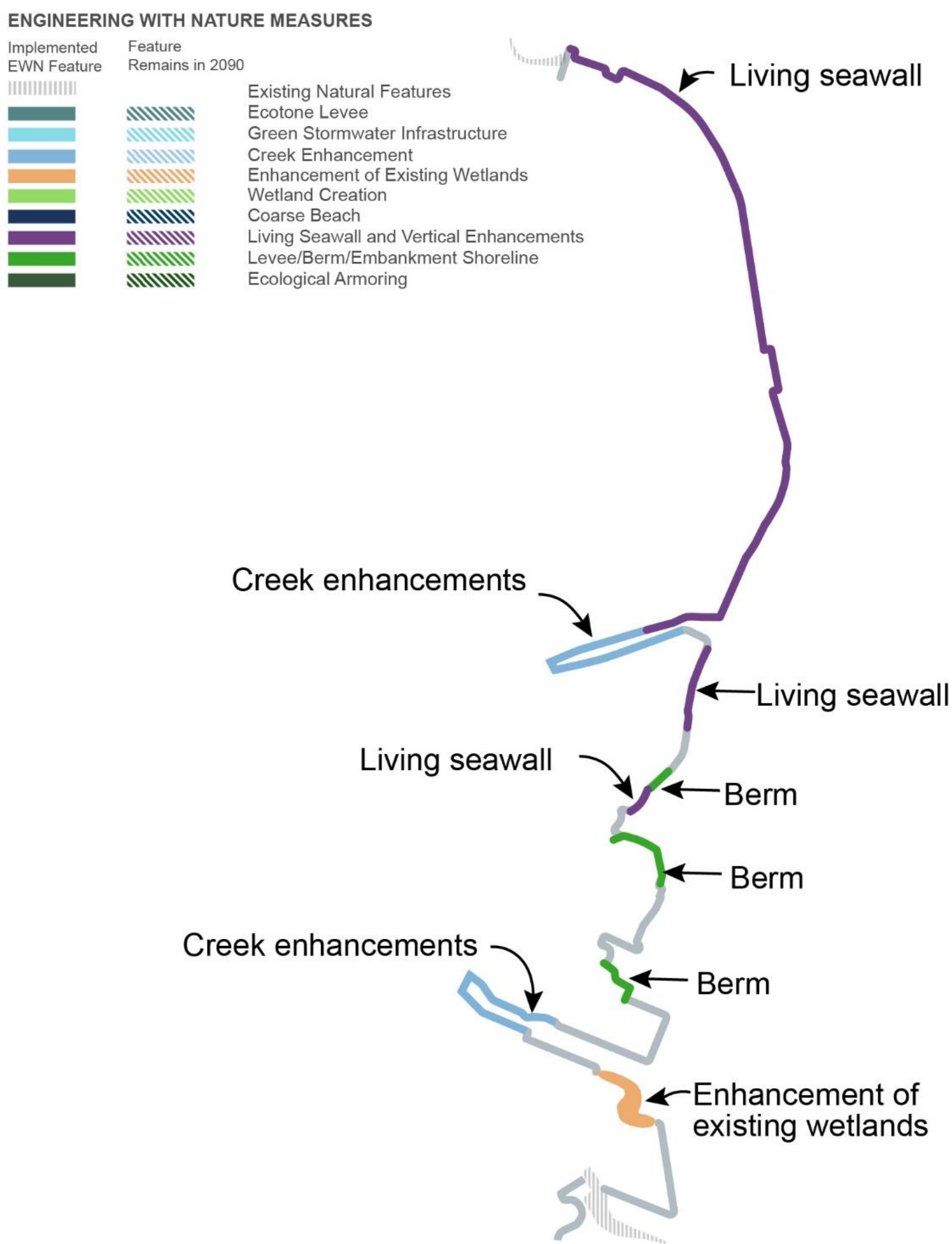


Figure I-28: Natural and Nature-Based Features in Alternative E (2040)

Figure I-29: Natural and Nature-Based Features in Alternative E (2090)

6.6 Alternative F – Manage the Water, Scaled for Higher Risk

Alternative F is intended to “manage the water” by integrating typical passive flood protection measures near the existing shoreline along a large portion of the study area, managed retreat from the existing shoreline in select locations, and water control structures near the mouths of Mission and Islais creeks to minimize the need for extensive rework of the existing inland drainage system. Alternative F addresses 3.5 feet of SLR in 2040 (**Figure I-30**), with adaptation to address up to 7 feet in 2090 (**Figure I-31**), depending on the future SLR trajectory.

Alternative F includes the following NNBFs:

- Wetland enhancement (Section 5.1)
- Ecotone levees (Section 5.3)
- Coarse Beach (Section 5.4)
- Naturalized/embankment shorelines (Section **Error! Reference source not found.**)
- Ecological armoring (Section 5.7)
- Creek enhancements (Section 5.8)
- Green stormwater infrastructure (Section 5.9)

In 2040, ecological armoring is proposed at Warm Water Cove on the Bayside of a vegetated naturalized shoreline. A naturalized shoreline with space for inland wetlands migration as sea levels rise is proposed for the Pier 94 Wetlands. Creek enhancements are included along Mission and Islais creek to stabilize the shoreline and improve water quality when the water control structures are closed to provide flood storage in advance of heavy rainfall events. The water control structures can allow the creeks to operate as largescale green stormwater infrastructure solutions.

In 2090, depending on the future rate of SLR, Alternative F proposes an additional ecotone levee with coarse beach at Crane Cove Park, wetland enhancement and ecological armoring at Warm Water Cove, and additional wetland enhancement with an embankment shoreline at Heron’s Head Park.

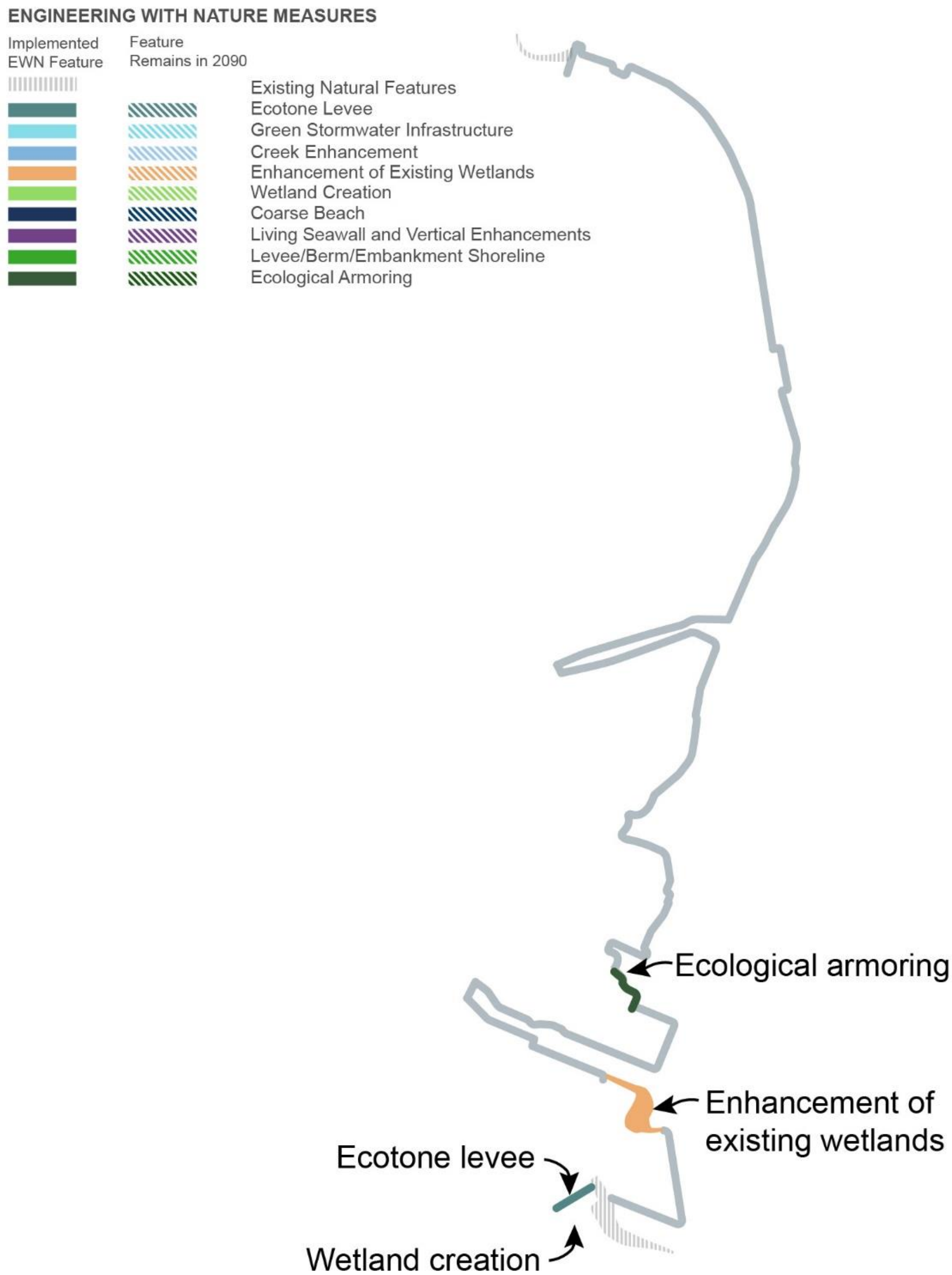


Figure I-30: Natural and Nature-Based Features in Alternative F (2040)

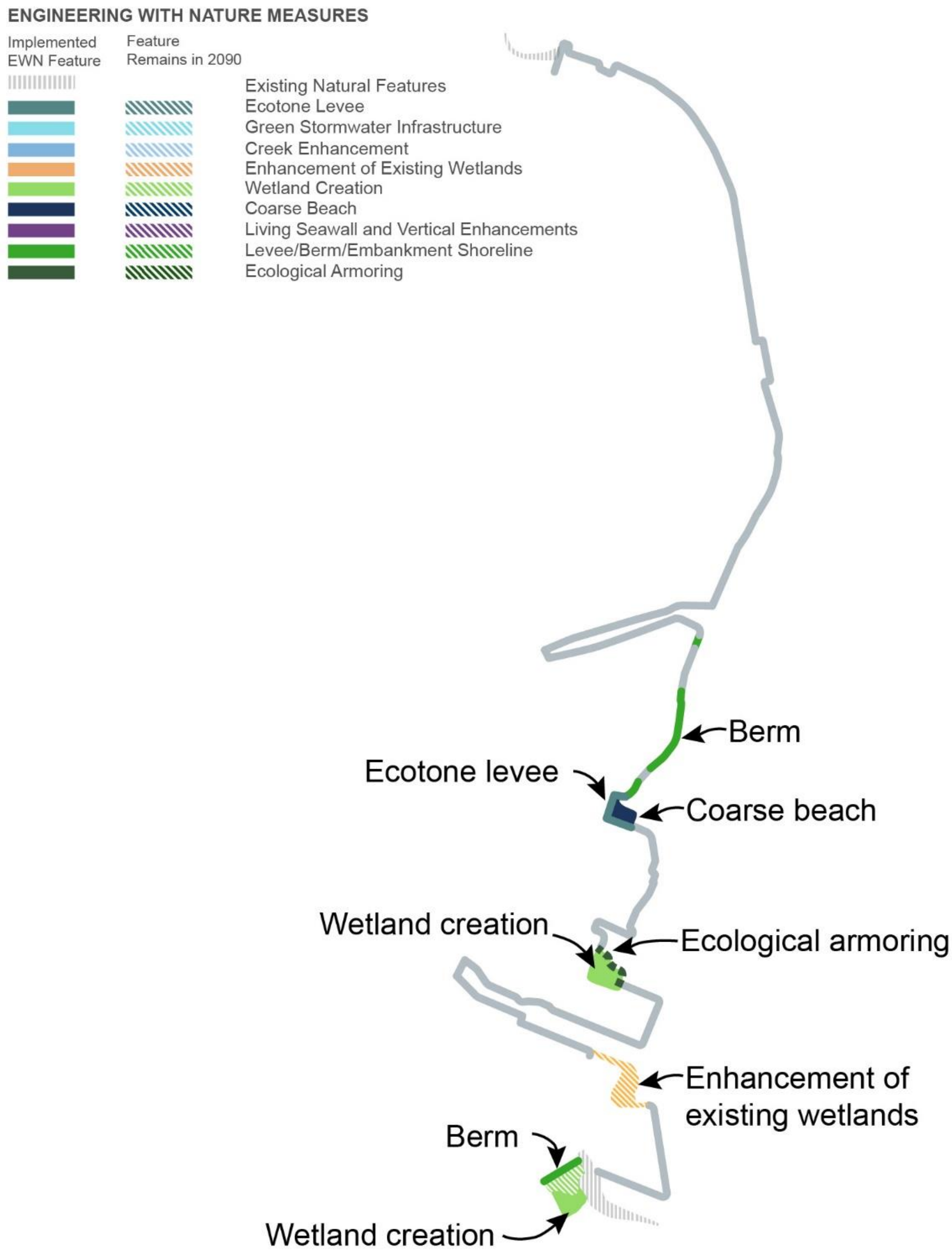


Figure I-31: Natural and Nature-Based Features in Alternative F (2090)

6.7 Alternative G – Partial Retreat, Scaled for Higher Risk

Alternative G is designed to “align with watersheds” by advancing shoreline adaptation while working with natural inland flooding patterns to floodproof some buildings and infrastructure and move others away from the highest-risk areas through partial retreat. Alternative G is designed to address 3.5 feet of SLR in 2040 (**Figure I-32**), with adaptation to address up to 7 feet in 2090 (**Figure I-33**) depending on the future SLR trajectory.

Alternative G includes the following NNBFs:

- Wetland enhancement (Section 5.1)
- Wetland creation (Section 5.2)
- Ecotone levees (Section 5.3)
- Naturalized/embankment shorelines (Section **Error! Reference source not found.**)
- Ecological armoring (Section 5.7)
- Creek enhancements (Section 5.8)
- Green stormwater infrastructure (Section 5.9)

In 2040, Alternative G includes creek enhancements along Mission and Islais Creeks, ecological armoring near Warm Water Cover, and wetland enhancements at the Pier 94 Wetlands.

In 2090, depending on the rate of future SLR, development would be retreated from the southern waterfront shoreline to allow for expansive wetland creation. Islais Creek also includes retreat, providing areas to establish a natural floodplain and areas for potential inland stormwater flood storage (i.e., green stormwater infrastructure).

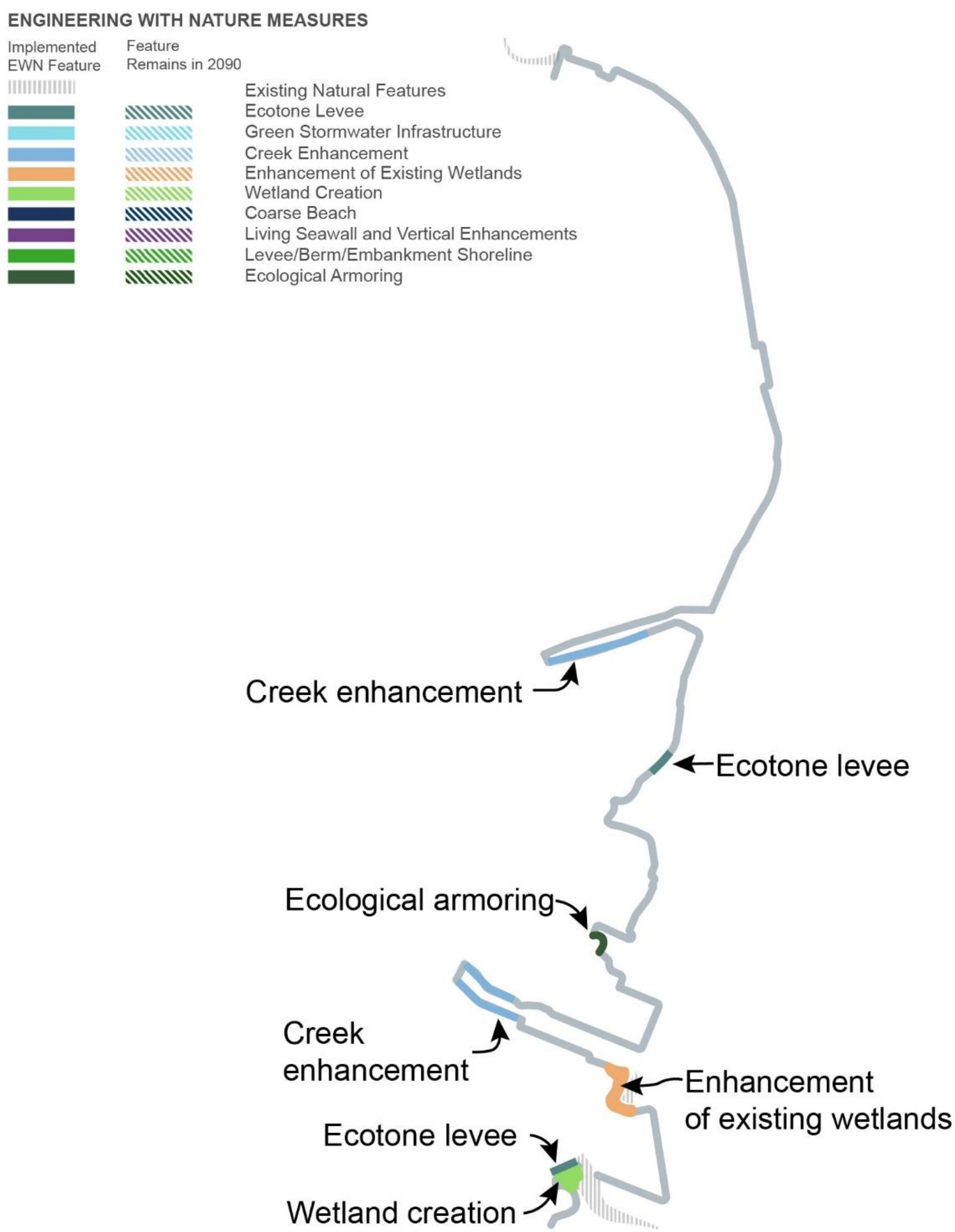


Figure I-32: Natural and Nature-Based Features in Alternative G (2040)

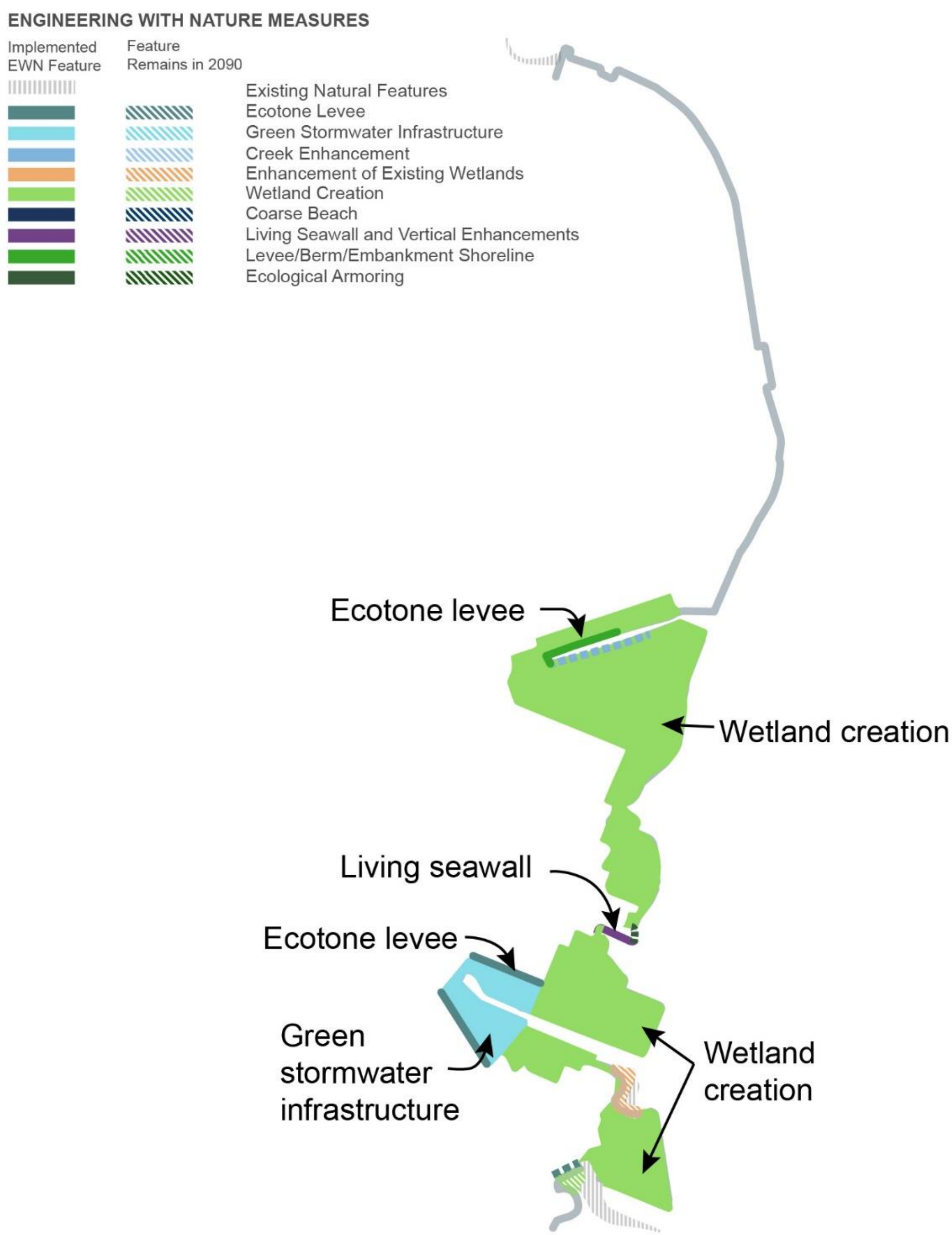


Figure I-33: Natural and Nature-Based Features in Alternative G (2090)

6.8 Phase Implementation and Augmentations

Most NNBFs may require implementation in phases (and augmentations as sea levels rise). Tidal wetlands may require sediment placement with every 12 to 18 inches of SLR, to allow them to keep pace with SLR, because the Bay is sediment limited. On the

Low SLR curve, no sediment augmentations are required post 2040. On the Intermediate curve, one to two augments are likely required post 2040. On the High curve, five augmentations or more may be required post 2040. Monitoring is required to assess the need and timing for future sediment placement.

Ecological armoring may require placement of additional armoring upslope as sea level rise. Limiting the armoring to the area needed for wave energy dissipation may provide an enhanced aesthetic while also limiting the initial cost and extent of armoring.

Ecotone levees are generally designed to accommodate inland migration as sea levels rise; therefore, future sediment augmentations may not be required.

Living seawalls, such as ecological enhancements on vertical walls, should be designed to allow habitats to migrate as sea levels rise. As sea levels rise, the lower intertidal areas will become subtidal, and previously unexposed areas on the upper seawall will become intertidal habitat. No future modifications would be required, although routine inspections and maintenance will be required.

All NNBFs will require monitoring after storm events and repair and maintenance as needed, similar to traditional gray infrastructure.

7. Environmental Quality Benefits

NNBFs provide a variety of benefits, including NED and RED benefits related to coastal flood risk management, OSE benefits for the surrounding communities, and EQ benefits. The NED, RED, and OSE benefits are presented in Appendix E: *Economic and Social Considerations*. This section provides a summary of the EQ benefits for the FWP alternatives relative to the NNBFs.

The following NNBF metrics were evaluated for the EQ account. To account for the two actions, each metric was evaluated at 2040 (for the period between 2040 and 2090), and 2090 (for the period between 2090 and 2140). The metrics were also evaluated waterfront wide (**Table I-5** thru **Table I-7**), and by reach (**Table I-8** thru **Table I-19**), to support the selection of the Total Net Benefits Plan.

- **Flood storage (acres):** the volume of flood storage provided within each alternative.
- **Wave attenuation (linear feet):** the length of NNBFs along the Bay shoreline, regardless of feature type, providing wave energy dissipation. NNBFs along the creek banks are not included.
- **Carbon sequestration (metric tons):** the amount of carbon sequestered by intertidal wetland habitats, calculated as carbon sequestered between 2040 and 2140 for the first actions, and 2090 and 2140 for the second actions.
- **Intertidal habitat (acres):** the total acreage of intertidal habitat enhanced or created across the suite of NNBFs included in each alternative.

- Connectivity (qualitative): based on habitat patch size, the number of habitat patches, and the average distance between habitat patches.

When evaluating the EQ benefits on the USACE Low SLR projection, only the metrics for 2040 in 0 thru 0 are used, as a second action is not necessary.

When evaluating the EQ benefits on the USACE Intermediate SLR projection, the metrics for 2040 and 2090 are used for Alternatives C and D, and the metrics for 2040 are used for Alternatives E, F, and G which are scaled for a higher rate of SLR.

When evaluating the EQ benefits on the USACE High SLR projection, the metrics for 2040 and 2090 are used for all alternatives.

Table I-5: Waterfront Wide EQ Benefits (2040)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	42	-
Wave Attenuation (linear feet of NNBF wave dissipation)	2,000	4,200	25,400	1,200	1,800
Carbon Sequestration (metric tons)	800	700	3,100	1,100	2,100
Intertidal Habitat (acres)	10	9	39	14	26
Connectivity (qualitative)	limited	limited	moderate	limited	moderate

Table I-6: Waterfront Wide EQ Benefits (2090)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	-	45
Wave Attenuation (linear feet of NNBF wave dissipation)	-	750	-	2,300	23,100
Carbon Sequestration (metric tons)	-	350	200	2,200	60,000
Intertidal Habitat (acres)	-	4	3	28	750
Connectivity (qualitative)	limited	limited	limited	moderate	very high

Table I-7: Total Waterfront Wide EQ Benefits (2040 + 2090)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	42	45
Wave Attenuation (linear feet of NNBF wave dissipation)	2,000	4,950	25,400	3,500	24,900
Carbon Sequestration (metric tons)	800	1,050	3,300	3,300	62,000
Intertidal Habitat (acres)	10	13	42	41	776
Connectivity (qualitative)	limited	limited	moderate	moderate	very high

Table I-8: Reach 1 EQ Benefits (2040)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	-	-
Wave Attenuation (linear feet of NNBF wave dissipation)	-	-	5,000	-	-
Carbon Sequestration (metric tons)	-	-	-	-	-
Intertidal Habitat (acres)	-	-	-	-	-
Connectivity (qualitative)	none	none	none	none	none

Table I-9: Reach 1 EQ Benefits (2090)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	-	-
Wave Attenuation (linear feet of NNBF wave dissipation)	-	-	-	-	-
Carbon Sequestration (metric tons)	-	-	-	-	-
Intertidal Habitat (acres)	-	-	-	-	-
Connectivity (qualitative)	none	none	none	none	none

Table I-10: Total Reach 1 EQ Benefits (2040 + 2090)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	-	-
Wave Attenuation (linear feet of NNBF wave dissipation)	-	-	5,000	-	-
Carbon Sequestration (metric tons)	-	-	-	-	-
Intertidal Habitat (acres)	-	-	-	-	-
Connectivity (qualitative)	none	none	none	none	none

Table I-11: Reach 2 EQ Benefits (2040)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	-	-
Wave Attenuation (linear feet of NNBF wave dissipation)	-	-	8,900	-	-
Carbon Sequestration (metric tons)	-	-	-	-	-
Intertidal Habitat (acres)	-	-	-	-	-
Connectivity (qualitative)	none	none	none	none	none

Table I-12: Reach 2 EQ Benefits (2090)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	-	-
Wave Attenuation (linear feet of NNBF wave dissipation)	-	-	-	-	-
Carbon Sequestration (metric tons)	-	-	-	-	-
Intertidal Habitat (acres)	-	-	-	-	-
Connectivity (qualitative)	none	none	none	none	none

Table I-13: Total Reach 2 EQ Benefits (2040 + 2090)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	-	-
Wave Attenuation (linear feet of NNBF wave dissipation)	-	-	8,900	-	-
Carbon Sequestration (metric tons)	-	-	-	-	-
Intertidal Habitat (acres)	-	-	-	-	-
Connectivity (qualitative)	none	none	none	none	none

Table I-14: Reach 3 EQ Benefits (2040)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	24	-
Wave Attenuation (linear feet of NNBF wave dissipation)	-	-	9,100	-	-
Carbon Sequestration (metric tons)	300	100	1,300	-	300
Intertidal Habitat (acres)	3	1	15	-	4
Connectivity (qualitative)	none	limited	moderate	none	limited

Table I-15: Reach 3 EQ Benefits (2090)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	-	-
Wave Attenuation (linear feet of NNBF wave dissipation)	-	-	-	800	5,300
Carbon Sequestration (metric tons)	-	-	200	700	40,000
Intertidal Habitat (acres)	-	-	3	9	500
Connectivity (qualitative)	none	limited	limited	moderate	very high

Table I-16: Total Reach 3 EQ Benefits (2040 + 2090)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	24	-
Wave Attenuation (linear feet of NNBF wave dissipation)	-	-	9,100	800	5,300
Carbon Sequestration (metric tons)	300	100	1,500	700	40,300
Intertidal Habitat (acres)	3	1	18	9	504
Connectivity (qualitative)	none	limited	moderate	moderate	very high

Table I-17: Reach 4 EQ Benefits (2040)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	19	-
Wave Attenuation (linear feet of NNBF wave dissipation)	2,000	4,200	2,400	1,150	1,750
Carbon Sequestration (metric tons)	500	600	1,900	1,100	1,800
Intertidal Habitat (acres)	7	7	24	14	23
Connectivity (qualitative)	limited	limited	moderate	moderate	none

Table I-18: Reach 4 EQ Benefits (2090)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	-	45
Wave Attenuation (linear feet of NNBF wave dissipation)	-	750	-	1,500	17,800
Carbon Sequestration (metric tons)	-	300	-	1,500	20,000
Intertidal Habitat (acres)	-	4	-	19	250
Connectivity (qualitative)	none	limited	limited	moderate	very high

Table I-19: Total Reach 4 EQ Benefits (2040 + 2090)

	Alt C	Alt D	Alt E	Alt F	Alt G
Flood Storage (acres)	-	-	-	19	45
Wave Attenuation (linear feet of NNBF wave dissipation)	2,000	4,950	2,400	2,650	19,550
Carbon Sequestration (metric tons)	500	900	1,900	2,600	21,800
Intertidal Habitat (acres)	7	12	24	33	273
Connectivity (qualitative)	limited	limited	moderate	moderate	very high

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SAN FRANCISCO WATERFRONT COASTAL FLOOD STUDY, CA

DRAFT SUB-APPENDIX I.1 ENGINEERING WITH NATURE FRAMEWORK

JANUARY 2024

USACE TULSA DISTRICT | THE PORT OF SAN FRANCISCO

US Army Corps of Engineers

PORT OF SAN FRANCISCO

1. Introduction

NNBFs serve as the first line of defense against coastal hazards, soften the shoreline and absorb energy instead of reflecting it back into the Bay. NNBFs also build capacity to adapt to SLR over time, either naturally or through periodic augmentations if higher rates of SLR prevail. Integration of NNBFs with the built shoreline achieves benefits for both urban and natural systems − beyond what the “traditional” approaches of “defend, accommodate, or retreat” strategies are capable of in isolation. Policy measures that encourage the incorporation of NNBFs into all strategies will increase the efficiencies and success of NNBFs if they can be fully scaled and integrated. Linking EWN projects to municipal projects can encourage private investment. Updating zoning and planning to consider EWN can also streamline the permitting of NNBFs (USACE 2020).

Numerous frameworks and guidelines for incorporating NNBFs already exist, including many focused specifically on Bay habitats (Bridges et al. 2015; Bridges et al. 2021; SFEI and SPUR 2019). This document does not seek to replace these existing frameworks. In addition, the Bay’s ecosystems and subtidal habitats have scientifically based long-term restoration and conservation goals that this framework draws from (CSCCC and OPC 2010; Goals Project 2015).

2. Engineering With Nature Principles

The following principles represent the foundation of EWN as applied to this study:

- **Wherever feasible**, incorporate natural, ecological, recreational, and habitat elements and processes into project components and opportunities. Innovative EWN solutions integrated into structural and nonstructural waterfront strategies will increase the resilience of both flood protection elements and ecosystem services. Constraints include:
    - Maritime use
    - Navigation and berthing
    - Maintenance considerations
    - Disaster response needs
- **Maximize habitat interconnectivity** to maximize ecosystem services and benefits and watershed connections. Consider the full tidal profile, from subtidal to intertidal to future intertidal areas (considering SLR). This aligns with the Regional Habitat Goals call for progression from static to adaptive planning to solve vulnerabilities created by climate change. Innovative strategies for SF include (CSCCC and OPC 2010):
    - Living seawalls and vertical enhancements of hardscapes
    - Linked pocket habitats.
    - Wetland creation and restoration

- **Build NNBF capacity among City agency staff, and foster collaboration among agencies to develop and implement NNBF strategies**. Cultivate relationship building with regulatory agencies to understand the tradeoffs between short-term impacts and long-term benefits and adaptability with NNBF strategies. A successful NNBF project will require the expertise and financial support of many different agencies and staff. These stakeholders should be engaged from the initial development process, through implementation and ongoing maintenance and monitoring of pilot studies and final projects. This can include the following:
    - Community -driven building capacity within agency and City staff, regulatory communities, community-based organizations, and others
    - Opportunities to help us learn how to fund, permit, implement, monitor, and adapt.
- Be **bold and creative** – pilot studies are important to success. EWN should be designed to provide the same or additional flood risk reduction as traditional flood protection strategies and achieve additional co-benefits. The EWNWG convened by the Port will identify pilot studies and projects that can inform these strategies.
- Identify opportunities to **preserve natural areas for ecological functions,** as well as recreation and shoreline access, and identify new areas to restore. Ecological elements integrated into structural measures can reduce the substantive size of structural measures through natural attenuation of coastal hazards, which is advantageous along densely urbanized shorelines (for example, rocky, subtidal habitat that provides toe protection for seawalls). Ecosystem benefits (for example, restoration of native eelgrass and oyster beds) and community benefits can also be achieved together with refinement of structural measures.
- **Connect watersheds to the shoreline** wherever possible to promote green stormwater infrastructure (GSI) and urban biodiversity.
- Understand the regional **historical and natural context** to identify areas where natural processes can be restored or improved.
- Directly link EWN solutions to address **coastal risks** and city-wide climate action and carbon sequestration goals (but stay high level on mitigation).
- Seek **policy and institutional** measures to amplify EWN impact.

3. San Francisco Historical Shoreline

While the shoreline has been significantly filled and modified, it is critical to understand underlying geologic and geomorphic features to help understand landscape function. The city's Bay shoreline was filled with materials of varying quality by the mid-1800s (**Figure I.1-1**). Historically, the SF shoreline supported rocky intertidal habitats, subtidal habitats, and tidal wetlands, particularly near the mouths of Islais Creek and Mission Creek (SFEI 1998).

Source: SFEI 1998

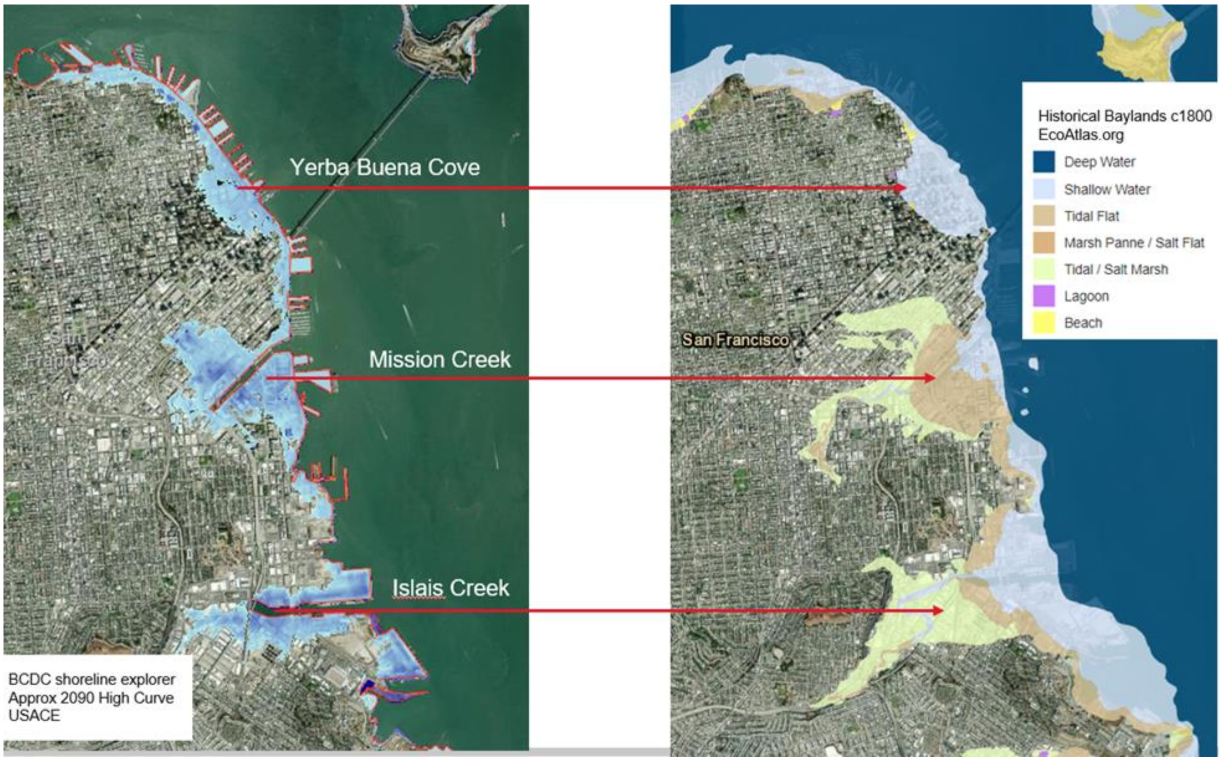
Figure I.1-1: San Francisco Historical Shoreline

Today, very little quality habitat exists along the shoreline. However, Heron's Head Park and the Pier 94 Wetlands are both constructed habitats teeming with life that provide homes or respite to an array of threatened and endangered species (for example, Bryant's savannah sparrows, or term Endangered Species Act [ESA]-listed California clapper rails among others) and important recreation opportunities for underserved communities. These small but vital areas provide hope that the creation of additional habitats will support ecological function and resilience.

The San Francisco Estuary Institute (SFEI) has documented the historical ecology or the scientific study of past landscapes of the San Francisco Peninsula from around 1800 (**Figure I.1-2**) (SFEI and SPUR 2019). A closer examination of the historical ecology along the shoreline, combined with an understanding of present conditions, can help identify compatible nature-based approaches for adapting to the future environment **0**).

Although historical shorelines cannot be recreated, the crenulated character of the future developed shoreline could host a variety of rocky, intertidal, and subtidal habitats that thrived here over 150 years ago. These habitats, though smaller in footprint, are most resilient when they are interconnected across subtidal, intertidal, and upland gradients, and include restoration of physical processes, such as sediment delivery across the watersheds (SFEI and SPUR 2019).

Many EWN projects are proven and tested, while others remain pilot projects due to the limited opportunities to test innovative approaches. The San Francisco shoreline will require a mix of both. The Port's Living Seawall Pilot Project is an example of this, as it is designed to test approaches for attracting a variety of species to establish homes on a textured and complex seawall.



Source: Vandever et al. 2017; SFEI and SPUR 2019

Figure I.1-2: San Francisco Sea Level Rise and San Francisco Historical Baylands

4. Complimentary Projects

Several projects are completed or underway around the Bay Area, along the San Francisco shoreline, and across the world that incorporate EWN principles. These projects can help inform potential future adaptation strategies and best practices.

4.1 Living Seawall Pilot Project, San Francisco

The Living Seawall Pilot Project is the first of its kind on the Bay. The project is a collaboration between the Port and Smithsonian Environmental Research Center to help define best practices for embedding natural elements within and along engineered structures to inform the WRP and support adaptation for other Bay Area coastal communities.

The Living Seawall Pilot Project is designed to better understand how the Port can create viable vertical habitats along the waterfront that provide benefits to the larger Bay ecosystem. The pilot project includes attaching a series of concrete panels made with materials developed to benefit the ecosystem, promote the establishment and success of native species to the seawall or breakwaters (**Figure I.1-3**). The panels are installed at four locations with variable wave energy.

The panels include flat and textured designs to assess surface texture's effect on promoting beneficial marine growth. The pilot project will also assess (1) the number of species established and the quality of the habitat provided across the full tidal range, from the high intertidal zone to the subtidal zone, along with differences in wave exposure and salinity gradients; and (2) the ability to scale the project up to larger expanses of the seawall to provide greater benefits for native species.

Photo Credit: Port of San Francisco

Figure I.1-3: Port of San Francisco Living Seawall Pilot Study

4.2 Heron's Head Park, San Francisco

Heron's Head Park is a 21-acre park originally constructed as part of a never-completed cargo terminal, Pier 98, and officially zoned as an industrial area. The park is now home to native plants, more than 100 bird species, and one of the few wetlands on the San Francisco shoreline (**Figure I.1-4**). Heron's Head Park provides wave protection for the adjacent Pier 96.

The EcoCenter at Heron's Head Park is the first Leadership in Energy and Environmental Design (LEED) Platinum, Zero Net Energy Building in SF, using sustainable onsite power and wastewater systems. The educational community center at the EcoCenter and the park walking paths, bird watching, and ecosystem restoration activities are part of a commitment to create a sustainable and accessible waterfront for generations to come.

However, SLR, wave hazards, and erosion threaten the habitat and recreational value of the park. In response, the Port developed and is implementing plans for the Heron's Head Park Living Shoreline project to achieve the following objectives[1]:

- Stabilize the southern shoreline and protect it from continued erosion and subsidence.
- Restore native plant vegetation to enhance biodiversity and ecological function.
- Create a resilient shoreline that can adapt to a moderate amount of SLR through 2050.
- Create youth employment and community engagement opportunities through hands-on involvement in park restoration activities.

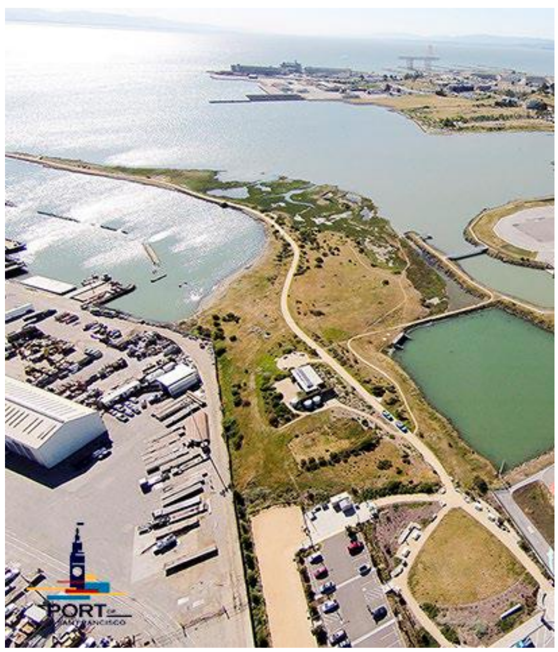


Photo Credit: Port of San Francisco

Figure I.1-4: Heron's Head Park

4.3 Pier 94 Wetlands, San Francisco

The Pier 94 Wetlands formed along the Bay shoreline at the end of Pier 94 after a portion of the pier's fill material subsided and became inundated by the Bay tides.

[1] https://opc.ca.gov/2021/09/prop-68-climate-resilience-miniseries-episode-5-herons-head-shoreline-resilience-project

Although small, these wetlands are now home to over 168 species of birds, including migratory birds, and provide a rare and valuable tidal wetland habitat for a variety of plant and animal species (**Figure I.1-5**).

The Port, in collaboration with the Golden Gate Audubon Society, improved the physical, hydrologic, and aesthetic features of the wetland to strengthen its ecosystem[2]. The Audubon Society also removed invasive species and added a transition zone that increased the size and habitat value of the wetland and is pursuing funding for a living shoreline project that would provide oyster habitat while protecting the wetland from erosion.

Photo Credit: Chris Benson

Figure I.1-5: Pier 94 Wetlands

4.4 Crane Cove Park, San Francisco

Crane Cove Park is a new open space along a formerly inaccessible stretch of industrial shoreline established in 2020[3]. The design of the park accommodates coastal flooding and SLR. It includes native landscaping and tidepool features to provide potential urban habitat. The tidepools were incorporated into the riprap surrounding the shoreline. The tidepools were created using “eco-concrete”, concrete with a proprietary bio-enhancing admixture with features beneficial to marine organisms developed by ECOncrete[4] (**Figure I.1-6**).

However, the park is surrounded by urban uses; thus, no bird nesting or roosting locations occur within the site, and no substantive aquatic habitats are known to have developed as of spring 2023.

[2] https://goldengateaudubon.org/conservation/wetlands/pier-94/
[3] https://sfport.com/projects-programs/crane-cove-park
[4] https://econcretetech.com/

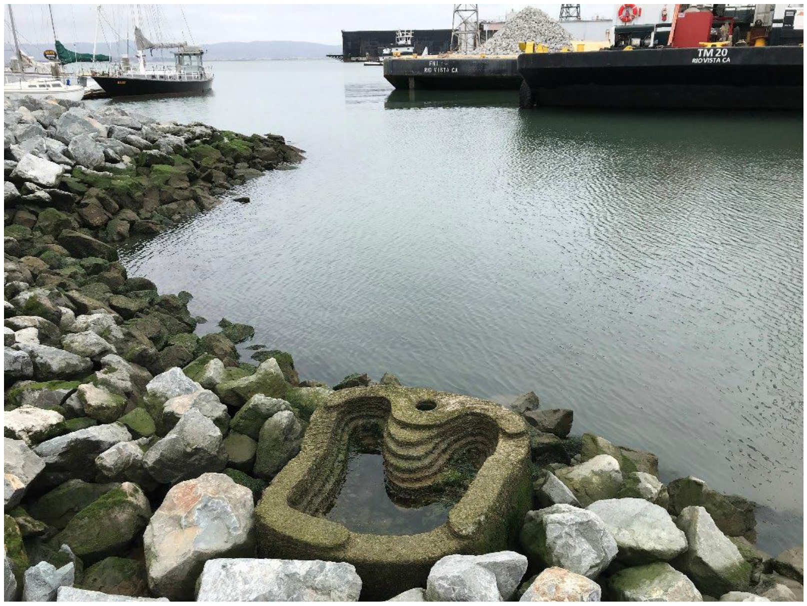


Photo Credit: Carol Bach, Port of San Francisco

Figure I.1-6: ECOncrete Tide Pools, Crane Cove Park San Francisco

4.5 Elliot Bay Living Seawall Project, Seattle, Washington

The Elliott Bay Seawall protects Seattle's downtown waterfront from waves and the erosive forces of Puget Sound and Elliott Bay. It serves to protect the core waterfront commercial and tourist district, the Alaskan Way arterial corridor, major regional utilities, and access to the busy Colman Dock Ferry Terminal. Originally constructed in the early 1900s, the seawall required replacement due to its deteriorating condition and seismic vulnerability (Guenther et al. 2016).

The new seawall was designed to withstand the design earthquake and be durable enough to last a minimum of 75 years. The structure is supported on a jet grout-improved cellular soil mass to mitigate soil liquefaction effects during an earthquake. Concrete mixes and reinforcing schemes were selected to enhance durability. The design also incorporated allowances for projected SLR and potential tsunami waves.

The new structure makes extensive use of modular precast concrete components to speed construction, provide enhanced durability, reduce project costs, and minimize impacts to adjacent properties. Precast elements used on the project include custom-designed precast face panels, precast zee-shaped superstructure segments, and light penetrating sidewalk panels.

Another primary goal of the project was to enhance shallow-water aquatic habitat along the face of the wall. This was accomplished, in part, by creating a 15-foot-long cantilevered sidewalk with a light-penetrating surface that serves to create improved fish habitat along the wall's 3,700-foot length. Habitat-friendly concrete surface finishes and fill materials were also used.

The project work also required development of a complex construction sequence to facilitate the construction process within a confined and congested site with active adjacent properties. This project was primarily geared toward fish habitat improvement (Guenther et al. 2016).

4.6 Sydney Harbor Living Seawall Project, Sydney, Australia

The living seawall idea began in Sydney Harbor, Australia and now has locations on three continents and in several countries, including Singapore, Wales, and Gibraltar[5]. The Sydney Marine Institute of Sciences created habitat panels featuring complex surface designs that mimic the natural environment, from mangrove roots to rocky shorelines. The panels are designed to mimic a wide variety of environments with different patterns and can be mounted on existing hard infrastructure. The introduction of surface complexity (for example, surface texture, grooves, crevices, and nooks) to traditionally smooth surfaces promotes vegetation growth, provides foraging habitat, and creates shelter from predation. The surface complexity may reduce wave height and wave energy (O'Sullivan et al. 2020; Dong et al. 2020; Salauddin et al. 2021).

The institute has been experimenting with these panels for 20 years with a variety of different textures to provide an ecological value and promote biodiversity within artificial structures in the marine environment. The benefit extends beyond just invertebrates and seaweed because fish can shelter in the provided habitat or benefit from additional food sources promoted by the panels. The increased oysters, mussels, and other bivalves can improve water clarity and quality, which can then enhance the water quality around the urban environment and provide more benefits to the local fishing community (Vozzo et al. 2021; Strain et al. 2018).

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SAN FRANCISCO WATERFRONT COASTAL FLOOD STUDY, CA

DRAFT SUB-APPENDIX I.2 ENGINEERING WITH NATURE WORKING GROUP

JANUARY 2024

USACE TULSA DISTRICT | THE PORT OF SAN FRANCISCO

1. Engineering with Nature Working Group

This section provides background information and details about the EWNWG.

1.1 Background on Working Group

The EWNWG was created to complete the following tasks:

- Identify what types of NNBFs should be considered along the 7.5 miles of San Francisco's waterfront within the Port's jurisdiction.
- Determine where nature-based features are feasible.
- Determine how NNBFs can contribute to regional habitat goals.
- Determine how to maximize EWN and ecological enhancements in all project Alternatives.
- Identify what data gaps may exist.
- Make recommendations for future studies, including scientific research and pilot studies that will better support incorporating NNBFs along an urbanized shoreline.

This group provided spatially explicit guidance to the Port Waterfront Resilience Program (WRP) and USACE project teams to incorporate into alternatives development. This section provides high-level summaries of the multiple meetings throughout Phase A.

1.1.1 Working Group Members

Table I.2-1 lists the EWNWG members and their affiliations.

Table I.2-1: Engineering with Nature Working Group Members and Affiliations

Name	Affiliation	Expertise
Burton Suedel	USACE	EWN Subject Matter Expert
Julie Beagle	USACE	EWN Subject Matter Expert
Chela Zabin, PhD	Smithsonian Environmental Research Center	Ecologist, Living Seawall Project
Andrew Chang, PhD	Smithsonian Environmental Research Center	Ecologist, Living Seawall Project
Jeremey Lowe, PhD	SFEI	Coastal Geomorphologist

Name	Affiliation	Expertise
Evan Jones	Architectural Ecologies Lab at California College of the Arts	Architect
Peter Baye	Independent Ecologist	Ecologist
Marilyn Latta	CA State Coastal Conservancy	Restoration Ecologist
Jason Toft	University of Washington	Seattle seawall project
Stuart Munsch	NOAA (expertise Seattle)	Seattle seawall project
Pippa Brashear	SCAPE	Landscape Architect (expertise New York Harbor)
Erica Spotswood	Second Nature	Urban Biodiversity
Sarah Minnick	SFPUC	Utility Planning Manager (stormwater)
Willis Logdon	SFPUC	Watershed Planner
Nigel Pontee, PhD	Jacobs	EWN Subject Matter Expert (global EWN experience)

SCAPE = SCAPE Landscape Architects

SFPUC = San Francisco Public Utilities Commission

2. Methods

The EWN planning team used a variety of tools to gather and integrate EWN into every alternative. The meetings were initially structured with charettes presented to the working group contextualizing the unique characteristics of different waterfront reaches and the work that has been done for the waterfront flood study.

A separate outreach effort was conducted to engage the local fishing community. This outreach was done in multiple languages (English, Spanish, Mandarin, and Cantonese) along all municipal piers and de facto fishing locations within the study area. The outreach was conducted to better understand both the species that were fished but also what the value of the fishing access brought to the community across a variety of areas. The results of this outreach were presented to the working group in meeting 2.

Three large group meetings were conducted with breakout rooms for focused discussion in each meeting. Small group meetings for deeper discussion on topics were conducted with targeted expertise several times during the process. Finally, there was a series of integration with traditional infrastructure-based alternatives in coordination with USACE engineers and planners.

3. Meeting 1: May 25, 2022

This section provides Meeting 1 details.

3.1 Objectives

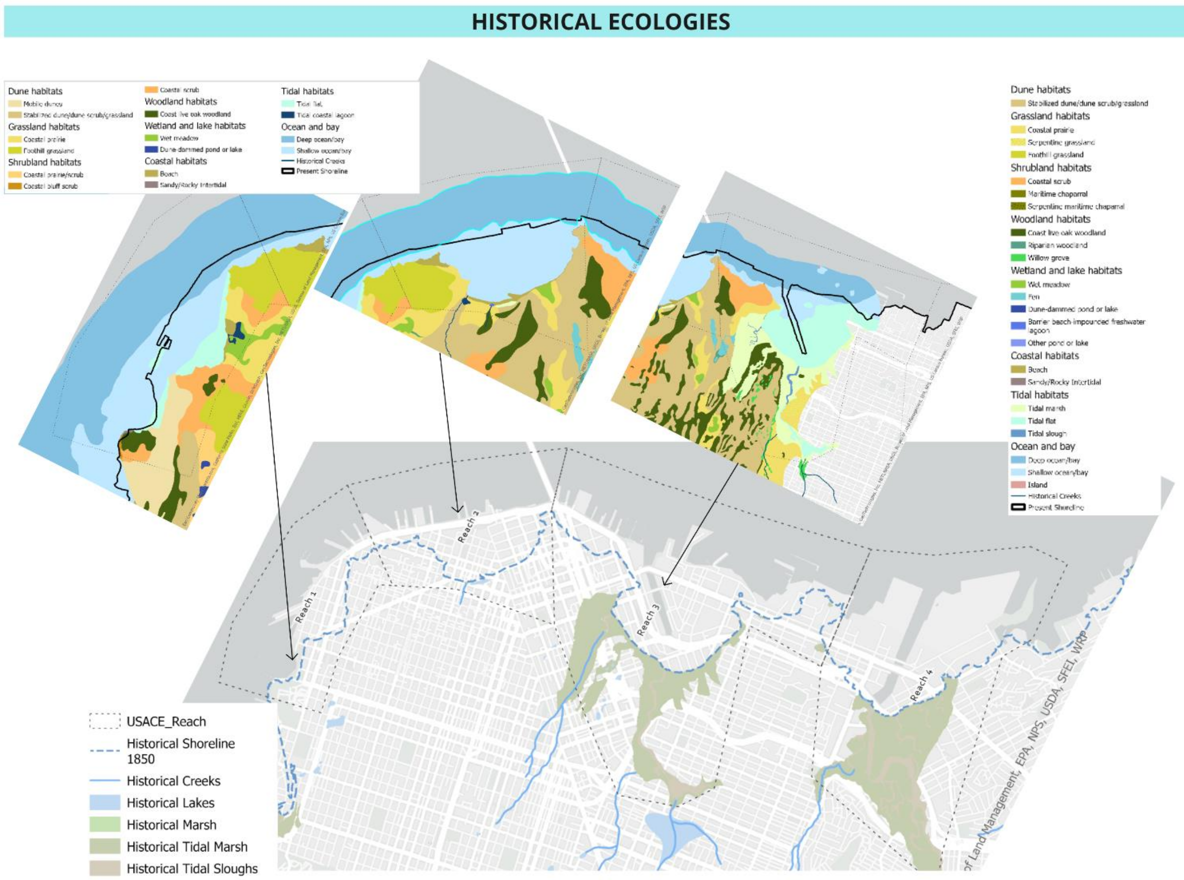
Objectives of Meeting 1 were as follows:

- Introductions
- Historical Shoreline Ecology presentation from SFEI
- Ecological Context Today
- Innovative Urban Ecology Precedents: Members presented pop-up presentations of innovative urban ecology precedents or of work they have done to orient the group to work done around the Bay and the world and to learn about each other's areas of expertise.
- Miro Activity: Exercise to flesh out what nature-based solutions people would like to apply in specific geographies (northern waterfront, Mission Creek, and Bay, and Islais Creek and Bayview); which habitats people seek to create and where; and which precedents people find inspiring or applicable there.

3.2 Agenda and Discussion Summary

Attendees reviewed the program work to date and existing conditions. The consultant team shared program framing and goals for the working group.

Sean Baumgartner from SFEI shared a presentation on the historical ecology of SF within the project boundaries. Pre-Gold Rush, the city shoreline had sand dune, coastal bluff and scrub area, and tidal flats and sloughs. During the building of the city, much of the shoreline was filled in using Bay mud. The tidal wetlands were drained, changing the ecology around Mission and Islais creeks and extending the present-day shoreline into the Bay (**Figure I.2-1**).

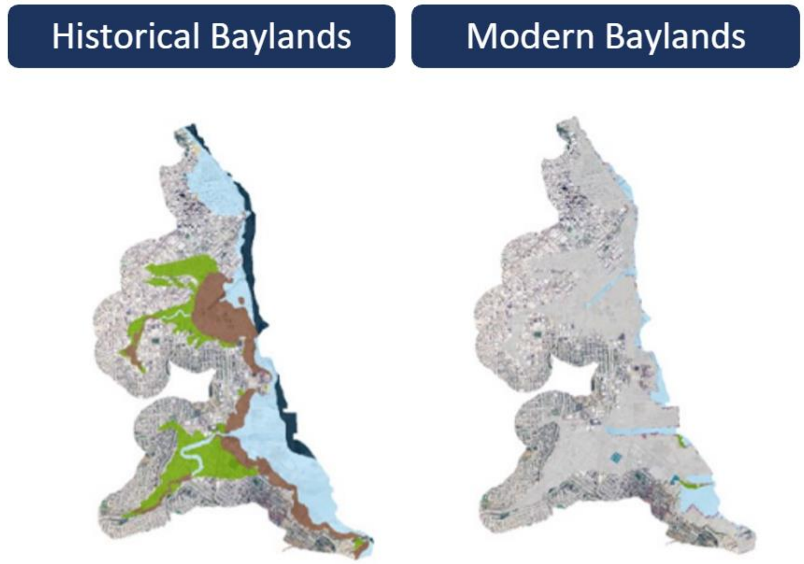


Source: Sean Baumgartner, San Francisco Estuary Institute

Figure I.2-1: Historical Ecologies and Shoreline by Reach

This presentation set up the working group by improving understanding the historical ecology, and then talking about the changes that have occurred. Much of the SF shoreline has been filled in, the wetlands, coves, mudflats, and shallow subtidal habitat have all been filled out to the edge of the deep-water channel shown in dark blue in the left-most graphic (**Figure I.2-2**). To understand what alternatives can work within this project area, the working group needed to combine understanding of underlying geomorphology and geology with the vast changes that have occurred on the landscape.

When analyzing the typologies of the land and water interface in the Bay, most of the project shoreline falls into “Narrow Baylands, urban waterfronts, with deep water and very little space” (SFEI and SPUR, 2019). There are some areas around the southern part of the study area where pocket Baylands, pocket beaches, and some shallow water habitat remains. Because of this landscape setting, and patterns of development and fill, the areas of the shoreline projected to be inundated due to SLR largely align with the historical Baylands (0).



Source: Adaptation Atlas, SFEI

Figure I.2-2: Historical and Modern Baylands

The overview continued with some background on the work done around the region in nature-based solutions and the regional goals. The subtidal and Baylands goals had more than 200 scientists around the Bay collaborating on how to maintain and adapt critical Baylands and subtidal habitat. The SFEI Adaptation Atlas suggested suitability for alternatives and grounding the process in NNBF guidelines from USACE (including the rocky, intertidal chapter authored by Burton Suedel, who was in attendance).

Two additional elements were highlighted to consider, first connecting GSI and urban biodiversity corridors to the shoreline. Secondly, the wetland habitat that exists on the shoreline is only present in two places, and there is a need to protect and prevent this valuable habitat from disappearing.

Following this background on the study, the project area, and the work to date, the attendees introduced themselves with short pop-up presentations of innovative urban precedents employing EWN that were both local and international. After this, there was a breakout room Miro board exercise to flesh out what nature-based solutions people would like to apply in specific geographies (northern waterfront, Mission Creek and Bay, and Islais Creek and Bayview); which habitats people seek to create and where; and which precedents people find inspiring or applicable there.

The breakout room discussions took a blue-sky approach. The working group members were asked to brainstorm what could be possible in each geography.

For the northern waterfront, pilot studies on habitat creation around pilings were identified as being beneficial to understanding what habitat could be created and what species would be best to attract.

Mission Creek and Mission Bay breakout group discussed the following topics:

- GSI and stormwater management

- Increasing flood storage
- Widening the creek
- Looking into land use improvements, such as integrating flood plains and repurposing parking lots

This group also discussed creating pocket beaches, reorienting riprap, and enhancing vertical concrete (**Figure I.2-3** is an example Miro Board).

Figure I.2-3: Mission Creek and Mission Bay Geography Breakout Miro Board

The final breakout room focused on Islais Creek. This group envisioned eco-friendly riprap incorporated with coarse material beaches. This group also focused on preserving the areas with wetland habitat currently and pilot studies in the future to better understand ecological armoring and uses of oyster bags.

3.3 Takeaways

Important takeaways from Meeting 1 include:

- The shoreline is highly modified, and different strategies will be needed for each geography.
- Pilot studies will be needed to plan the best strategies.
- It is important to consider subtidal to inland connections when designing alternatives.

4. Meeting 2: July 20, 2022

This section provides Meeting 2 details.

4.1 Objectives

Objectives of Meeting 2 were as follows:

- Present initial waterfront flood hazards and initial suite of adaptation alternatives.
- Review EWN goals and strategies from first meeting (May 25, 2022).
- Discuss how EWN strategies can support and enhance the City's initial adaptation strategy alternatives.

4.2 Agenda and Discussion Summary

At the start of the meeting, the EWN project team provided an overview of the goals of the working group and set the stage for the subsequent discussion. This included:

- A summary of discussions since the first EWN meeting
- An overview of the findings from the fishers' walking tour
- Quick presentation from Pippa Brashear, who discussed the living breakwater in Staten Island, and Nigel Pontee from Jacobs, who provided an overview of their work in other regions; both shared lessons learned and best practices that could be transferred to alternative development.

The EWN project team then provided an overview of the adaptation strategy alternatives E, F, and G developed to date. This was the first time the EWNWG had been presented the alternatives by the different geographic reaches:

- Northern waterfront
- Mission Creek and Mission Bay
- Islais Creek and Bayview

These presentations supplemented the read-ahead 2-pagers that were sent out in advance of the working group meeting. Participants had the opportunity for questions and discussion after each reach's strategies were presented.

There are municipal fishing piers in every geography along the SF waterfront. These piers are frequented by members of different communities and have different shoreline conditions. To better understand the fisher's perspective on fish habitat types and needs, as well as to build support for the fisher community, a walking tour with Spanish, Mandarin, Cantonese, and English speakers was conducted.

These informal conversations with the community brought several findings that were presented to the working group to help them understand the local community dynamics. Main findings included:

- Fishers select docks based on proximity to public transit and convenience relative to their home.
- Most people fish for recreation and to experience nature, not for subsistence.
- Fishers prefer places with a municipal fishing pier designation.
- Some long-term fishers have seen a decline in fish when shorelines are cleaned up and made less complex. They noted that loss of habitat (such as broken pilings) has led to loss of species.

Adaptation alternatives are developed to address combined flood risks (coastal, stormwater, and groundwater inundation). USACE's goal is to integrate and embed NNBFs with flood risk reduction measures (City planning horizon considers 2150 hazards). A more detailed description was provided in the read-ahead materials provided to the group in advance of the meeting.

Workshop participants were then separated into three breakout rooms divided by the three geographic reaches to discuss how NNBFs could support or enhance the City's initial adaptation strategy alternatives:

- Alternative E would defend the city by raising the existing shoreline, prioritizing keeping coastal water out and keeping people, buildings, and infrastructure where they are to the extent possible:
    - Preserve a waterfront that looks and functions much as it does today, despite the expense and challenges.
- Alternative F would defend the city mostly at the existing shoreline but would start to create coastal defenses partially inland at Islais and Mission creeks:
    - Create a comprehensive flood protection system, designed, and operated to limit the impacts of both coastal and inland flooding.
- Alternative G would defend the city mostly at the existing shoreline but would reimagine the shorelines around Islais and Mission creeks and create inland coastal flood defenses at the Port's cargo facilities:
    - Transform the city's infrastructure to align with its natural watersheds, supporting a more passive and resilient approach to flood risk.

The attendees participated in a breakout room Miro board exercise reviewing alternatives E and F for each of the three geographies (there was not enough time to discuss strategy G). This included suggestions and feedback on the already present

NNBFs and ideas for additional improved measures. The discussion followed from the guiding principles:

- Reduce flood risk from SLR and wave overtopping.
- Improve ecological value by integrating NNBFs into adaptation alternatives.

Following breakout sessions, workshop participants reconvened and provided summaries of breakout room discussions. The meeting closed with a broader discussion on next steps and questions to address.

Conversation in the Northern waterfront breakout room focused on the area between the Bay Bridge and Ferry Building as an area suitable for habitat creation due to its shallow water. Considerations included:

- There is good potential for habitat with public access (for example, tide pools accessible to the public, or to add a fishing pier or enhance fishing piers in that area).
- Focus on making habitat that will benefit fish.
- Based on recent intertidal work, participants noted that Hyde Street Pier had a nice bed of eelgrass, which is important for fish and other species. There could be more opportunities for those pocket sandy areas that could support eelgrass.
- South Beach area has development opportunities at Piers 30 and 32 and Piers 38 and 40. There is potential to extend the South Beach breakwater to offer habitat protection (see living breakwater precedent from Pippa and NYC (NYS, 2023; SCAPE, 2023)) and ensure that the breakwater provides wave attenuation, while also attracting native species. One participant provided a list of species from this area to potentially target habitat creation.
- The group discussed floating breakwaters, but some participants provided reasons for why they are not viable. Most notably, they potentially attract invasive species. Additionally, there is no analog in natural systems for floating breakwaters. Native species are not adapted to that type of structure; however, non-native species are excellent at colonizing this type of structure. Given local concern with native species and volume of invasive species present, a floating breakwater may not be a good idea in the Bay. Moreover, something that floats may be less solid than something structural; therefore, it might have limited wave attenuation benefits. Additionally, the cost of maintenance and magnitude of waves makes them less effective. Floating breakwaters work better in environments with lower wave energy than the San Francisco shoreline.

Outstanding questions from the group:

- Are toe structures or sills being evaluated so that perched beaches and wetlands, or mixed shore habitat types, can be fit to steep profiles that otherwise prohibit them?
- Gravel beaches and sills can go together. Examine examples and lessons learned to bring into planning.

Participants in the Mission Creek and Mission Bay group focused on Alternative F because this was the most “Bayward” and had the most opportunities to reimagine a future shoreline edge. However, all strategies could work across the three options. **Figure I.2-4** shows the Miro board.

- The alternatives identified here could be applied and mixed and matched across alternatives (for example, the tide pool with public access could be in several alternatives).
- In Alternative E, we don’t have the tide gates there will still be freshwater outfalls in these areas, so this is not a good location for eelgrass near the mouth, so it was moved further south.
- The nutrient loads are of more concern than freshwater for eelgrass. Oysters are harmed by freshwater. Short cycles of water turnover would be better (that is, if outfalls should be used infrequently and of short duration). Need to consider habitat conditions based on water quality. Oyster bags recommended to be moved down south from the mouth.
- Coarse beaches and shelves submerged as sill structure could be suitable across all three strategies. But Alternative E, especially, which is focused on edges, could give us more of a bench to work with than just augmenting a seawall.
- Emphasis was placed on thinking about phasing and not pre-empting long-term strategies with mid-term actions that could have future impacts. Make sure we anticipate long-term changes to tidal hydrology. If designing alternatives with two phases, make sure that you don’t do something in the first stage that will be impacted in the second stage.
- With phased adaptive alternatives, need to factor both habitat and regulatory strategy. Need to have permitting and physical structures aligned; some permitting protocols are for physical structures, and some are for habitat.
- Concern was raised about vegetation with deep roots that require space as roots grow. Some areas might not be appropriate for trees but better for shallow-rooted vegetation. Historically, there were not a lot of trees in this area; those that were here were dwarf trees. Need to consider future higher temperatures. However, it is important to balance this with the fact that trees provide cooling and shading features as well.

On fill, should consider all geotechnical considerations if using lightweight concrete for elevation.

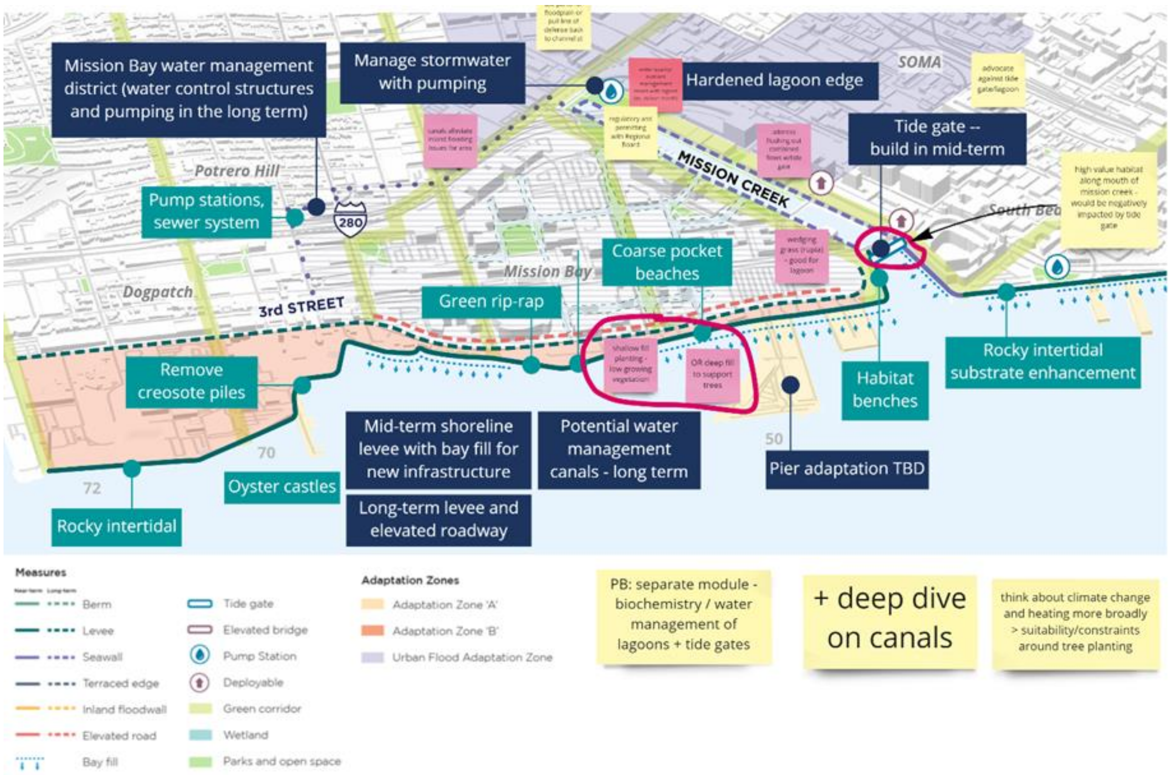


Figure I.2-4: Mission Creek and Mission Bay Geography Breakout Miro Board

- The riprap that exists along that creek area and comes out to the Bay is beautiful habitat right now and has the highest diversity of seaweeds in the Bay. If a lagoon with bad water quality periodically washed out into that area, it could have big impacts.
- Water quality and biogeochemical studies for tidal and nontidal lagoons have been done. There are regional precedents for water management (South Bay salt ponds and Suisun Wetland). Before we put a tide gate on, should look at long-term management, as these are biogeochemical engines that behave predictably and can transform ecosystems; for example:
    - If we are facing 5-15 feet of SLR, we will need to address these tradeoffs. We may need a gate, but it will come with substantial consequences, and we will need to analyze those tradeoffs.
    - Will be looking at water management aspect of that facility, and O&M will need to be investigated and rough cost estimates determined before moving forward with this option. These comments were similar from Regional Water Quality Control Board. Concern was expressed that there could be a heavy management cost with a, perhaps, limited lifespan.

- Long-term implementation of GSI in the upper watershed through capital investments and programmatic work is expected to reduce the stormwater volume at outfalls.

The group had a limited conversation regarding Alternative G. This included these comments:

- Perched sill beaches could extend this alternative.
- Could think about open space on Mission Creek and how to use that as floodable space as opposed to tide gates.
- Extremely interested in the opportunities and the feasibility of the canals. These types of strategies can have lower maintenance and more habitat opportunities long-term but are the hardest to convince people of their benefits.

The Islais Creek breakout room overall discussion focused on the contrast of shoreline typology within this area with both hard edges and natural spaces. This is the area with the most contrast in development types. The group reflected that the starting point for picking and choosing the measures would be good to use the current state of the shoreline as an initial guide (that is, where we have hardened shoreline, expect structural features that lend themselves to an enhancement of ecological considerations).

- Where we have a softer shoreline, we are looking at NNBFs that are greener and that still have some flood protection functions. From the perspective of USACE, the areas with soft shoreline now include Heron’s Head and Pier 94 and 95. In these areas:
    - Need to consider tenants and term of leases when planning the areas for setback and stages of retreat or adaptation.
    - Natural alternatives should be targeted to a specific issue and should be clear about what ecosystem services or what habitat enhancements provide in terms of resiliency in general.
    - As the future starts to happen, we can focus on more localized opportunities. Piers 94 and 95 could be targets for setback. They already have a wetland, and we know they need to move back to continue to exist. Whoever owns these piers would need to consider:
    - Whether we need additional sediment supply in the future. The current source might be cut off, so may need thin-layer placement to allow it to remain vertical and persist.
    - This area is particularly difficult to manage sediment, as it is dredged for Port activities. Perhaps Heron’s Head Park is where you can better place sediment. You have natural and hard areas next to each other. Islais Creek is really a shipping channel.
    - This could include open space that has a berm with some capacity to defend, but also some open space that will have capacity to store storm or

flood protection. This would yield a multi-purpose, multi-benefit type of feature.

  - Heron's Head Park currently is this type of space, with primary habitat and community access. The focus should be to sustain these into the future.

- There is both an initial opportunity, as well as future adaptation opportunities in areas where there is retreat to make room for habitat migration. How can we use NNBFs to help with that falling back transition?
- Identified this as an area we could have a potential offshore breakwater reef but questioned whether that will interfere with shipping? This is the area with the deepest water berths, so could do limited breakwater outside of Heron's Head Park. Breakwater could also help with sediment accretion to help wetlands maintain and persist.
- Bringing forward from Workshop 1, GSI actions from upstream (tree planting, bioswales) could help with flood reduction. Could explore opportunities to better manage rainwater.
- Conversation around tide gate for storm events and floating Wetlands brought up more questions than answers:
  - Could we use floating Wetlands?
  - Would they be in the way of shipping? They could be in the way of area and could have regulations. There may be an opportunity around Heron's Head Park or inside the tide gate.
  - What benefits are these providing within the tide gate area if not wave dissipation?
  - There is a prototype in Port of Oakland of a floating Wetland in place now, and Bay Conservation and Development Commission is allowing for more experimental options.

Questions and considerations the group had:

1. When thinking about beaches for the shoreline, design setting around the beach and consider surrounding conditions. It could make sense to have toe structure or sill reef in area for beach.

4.3 Takeaways

Important takeaways from Meeting 2 include:

- In areas where shoreline is soft, maintain that shoreline type.
- There are a lot of options (coarse beaches, perched beaches, widening channels, ecologically enhanced riprap), but pilot studies will inform best practices.

- TIDE GATES HAVE A LOT OF WATER QUALITY AND HABITAT IMPLICATIONS AND WILL NEED TO BE PLANNED AND MANAGED EFFECTIVELY.

5. Focus Group: Steep Shorelines and Subtidal Habitat (August 30, 2022)

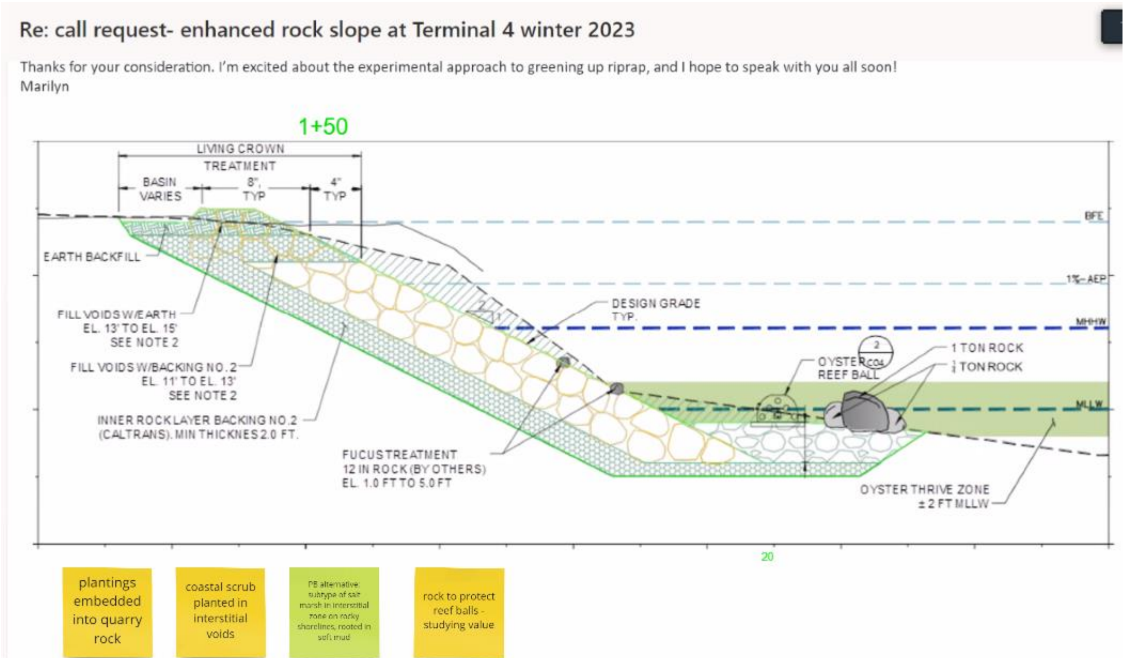
This was a working group member led focus group with no formal presentations or agenda. Instead, it was a time for the members to gather and discuss EWN strategies specifically related to the steep shorelines and subtidal habitat, primarily found in the northern waterfront geography. This was attended by about half of the EWNWG members.

The focus group was led by Jeremey Lowe of SFEI, and the meeting started with asking what benefits to the species and habitats would the measures that are proposed bring? Some considerations that came out of the discussion were:

- Consider a stepped profile, staircased terrace like riverine banks:
  - Intertidal areas and deeper pools
  - Rocky reefs
  - Perched wetlands
  - Vegetation from upland to intertidal to subtidal
  - Enhance sloped bulkheads
  - Enhance rock armoring
- Consider overwater piers and decks that, during rebuilding, can be designed to bring light into the subtidal habitat areas:
  - New eelgrass surprisingly present and expanding at toe of riprap at Treasure Island.
  - Consider waterlogged decay-resistant logs to act as fill and raised platforms (potentially readily available Eucalyptus).
- Consider auto-compacted load-bearing filled areas, natural substrate, or fill with historic shipwreck when considering areas to add habitat (so, to consider type of substrate, not just depth and location).
- A recommendation to protect natural Bay floor substrate wherever possible.
- A recommendation to consider a stepped profile staircased terrace like riverine banks.
- Flat vertical walls next to unstructured deep-water habitat is not high value; plan for better transitions from shore to Bay and connections over gradients.
- Be clear about gradient across intertidal and subtidal environments:

- Eelgrass and native Olympia oyster habitat, mussels, seaweeds, other habitat forming species spanning across both intertidal and subtidal; avoid making artificial bin designations lumping all into "subtidal."
- Avoid generalizing all aquatic reefs as "Oyster reefs"- oysters are a focal habitat, but nearshore reefs in San Rafael (SCC constructed 2012, monitored 2012-17) have been documented to support more than 100 plant and animal species, including fish, crabs, mussels, and seaweeds.
- Avoid generalizing all vegetation as "tidal wetland" or "eelgrass"- plan for range of vegetation types across gradient upland; coastal scrub; riparian; high, mid, and low wetland; seaweeds; and eelgrass.
- Be specific and include a diversity of habitat types - similar to diverse portfolio in stock market - each species will perform differently in different SLR scenarios and climate change impacts.
- Avoid binary choices of habitat methods (that is, one type over another), and plan for combinations of green and green-grey treatments based on slope, substrate, opportunities to modify existing materials and structures. Remove or reuse existing materials and structures. Consider breakwaters, green riprap, stepped pools, subtidal oyster elements, plantings within areas, and in adjacent inland and nearshore.
- Avoid assuming depth limits of species - unknown for oysters and eelgrass - anecdotal evidence of oysters on pilings 50 to 60 feet; potential best oyster habitat at -1 foot MLLW and higher, but lack of surveys and pilot projects in -1 to -15 foot MLLW zone, potential competition and impacts from sponges and other species -1 to -? feet MLLW.

- Design criteria and provide group with clear parameters and boundary conditions to develop ideas, starting with preset list of methods and random placement on maps.
- Consider designs such as enhanced rock slope design Marilyn shared for Terminal 4 wharf removal site in Richmond (**Figure I.2-5**):
    - Add green elements to riprap and quarry rock - crown plantings, seaweed cobbles, oyster elements at toe; other similar greening methods embedded into traditional Caltrans rock slope protection (RSP) designs.
    - Entire face of RSP can include vegetation, cobble, and wetlands.



Source: EWNWG Member Marilyn Latta (SCC)

Figure I.2-5: Steep Shorelines Project Example of Enhanced Rock Slope

6. Focus Group: Watershed and Upland Connections (September 1, 2022)

This was a working group led focus group with no formal presentations or agenda. Instead, it was a time for the members to gather and discuss NNBFs specifically related to the watershed and upland habitat connection, primarily found in the Southern waterfront geography. This was attended by about half of the EWNWG members.

The focus group was led by Jeremey Lowe of SFEI, and the meeting started with a review of the existing conditions opportunities and bathymetry (Mission Creek example is shown on **Figure I.2-6**).

Figure I.2-6: Watershed and Upland Connection Miro Board

The group discussed Alternative E and the opportunities for widening and other big changes in Islais Creek. Some considerations that came out of the discussion were:

- The importance of creating upland pockets of habitat; for example, through connecting bioswales and plantings along the shoreline and east to west across the city that would improve habitat and range for important or at-risk species. Other ideas include:
    - Distributed tree planting
    - Incentivized programs for green roofs
    - Parking lots that have trees added to them for more shade cover
    - Softening hard edges
    - Working with existing features to make them as good as they could be, rather than fighting urbanization.
- Opportunities for stormwater reuse rather than just discharges, as there is a lot of upstream management, and we need to rethink how we rebuild things so water can move through. Create bigger-scale connectivity hydraulically, but also from a place making perspective and ecologically.
- This area has the opportunity for big moves and changes. The SFPUC project stops at a point adjacent to the Islais Creek inland footprint of this project, so creating a connection and synergy between projects and efforts could be a benefit. A recommendation from the group for further study is a full discussion and understanding of how this area could be understood hydraulically.

7. Meeting 3: September 7, 2022

This section provides Meeting 3 details.

7.1 Objectives

This section provides Meeting 3 objectives:

- Review the focus group discussions and gather feedback from working group members not at one or the other of the meetings.
- Begin the conversation on evaluation criteria.
- Finalize the Miro board with alternative ideas for the team to build off and bring to the USACE engineers.

7.2 Agenda and Summary

Attendees reviewed the discussions from the two focus groups and continued those discussions. After hearing the report from the two focus groups, the group turned their attention to the Miro board. The Miro board was organized with the ideas from the first working group (the blue sky, all possibilities are brainstormed), the second meeting (responding to EWN strategies in the adaptation strategies), and the ideas gathered during the two focus groups. The group responded to some of the “big” ideas that have been discussed to help evaluate the different tradeoffs of these ideas. Criteria that were important for evaluation of the measures were discussed, and future pilot studies were identified.

7.3 Takeaways

Important takeaways from Meeting 3 included:

- Data will be critical to identifying, preserving, and improving important habitats and species. There are known data gaps that will need to be closed prior to plan implementation.
- In addition to design (textured seawall, reef ball), material composition is important to consider.
- When considering tide gates, assume Mission Creek and Islais Creek seawalls are about 8-10 feet NAVD88. The gate needs to be closed before the water level exceeds 9 feet NAVD88 to prevent overtopping:
    - As SLRs, the gate will close more often.
    - Today, such a gate would close perhaps once every 100 years. With 6 inches of SLR, which we might expect by 2030, the barrier would close about every 10 years; by 2050 and 12 inches of rise, closure might happen every 2 years.
    - In the latter half of the century, if sea levels rise 24 to 36 inches, then closure would occur every month or week. By 36 inches, the gate is closing every 2 days.

Discussion points for evaluation criteria that were discussed included:

- Ecological connectivity: Do the measures connect across habitats and create an ecological corridor? Or are they isolated patches that, when combined, won’t produce the desired benefits?

- Protecting habitat that currently exists is a high priority.
- The group acknowledged that we are working within a highly altered environment that is challenging. They recommended being very careful in creating a methodology that identifies target species and approaches need to consider the relative risk. Start with engaging the local groups with knowledge now (such as Audubon) that can identify what is there now, and what the recent changes in species composition have been. Then you can engage with naturalists and practitioners who can help identify habitat enhancements that would be most beneficial for target species.

Pilot studies that were identified include:

- Suite of surveys to identify existing habitats and species distributions (supratidal to subtidal). Fish, drone, and elevation surveys.
- Small-scale experiments:
    - Modified pier pilings for surface treatments
    - Testing of different sustainable materials
    - Seeding seawalls with target species
    - Water-retaining features (tidepools)
    - Oyster bags
- Make pilot projects look across multiple habitats and consider the entire seascape.

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