



**PORT of
SAN DIEGO**
Waterfront of Opportunity

SAN DIEGO BAY SUSTAINABLE SHORELINES ATLAS

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A data-driven planning tool that identifies and ranks suitable multi-benefit nature-based shoreline strategies across San Diego Bay.



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This project was inspired by the San Diego Bay Integrated Natural Resources Management Plan and similar work by the San Francisco Estuary Institute and San Francisco Bay Area Planning and Urban Research Association that resulted in the development of the San Francisco Bay Shoreline Adaptation Atlas (adaptationatlas.sfei.org).

We also appreciate the discussions and feedback that improved our approach, which were generated at meetings held September 12, 2024, and February 20, 2025, by representatives from the City of Imperial Beach, City of San Diego, City of National City, San Diego Working Waterfront, San Diego Regional Climate Collaborative, California Coastal Commission, California Department of Fish and Wildlife, California State Lands Commission, National Marine Fisheries Service, Regional Water Quality Control Board, San Diego National Wildlife Refuge, U.S. Army Corps of Engineers, and U.S. Fish and Wildlife Service.



San Diego Bay

A sunlit aerial view of the Coronado Bridge stretching across San Diego Bay, with boats dotting the water and traffic flowing above.



Downtown San Diego

Aerial image of downtown San Diego, where the skyline meets the water's edge.

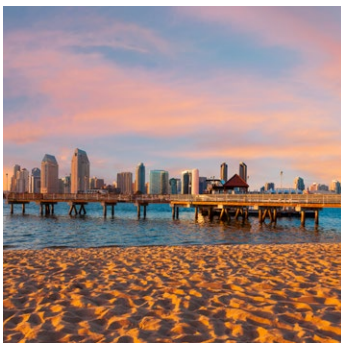
Glossary

Annual event: A typical winter storm (100% chance of occurring in any given year), driving gradual and seasonal shoreline changes (e.g., mudflat erosion, marsh accretion, beach width).

Coastal squeeze: When rising water pushes intertidal and shoreline habitats landward but existing development or hard infrastructure blocks that migration, shrinking habitat area and degrading function.

Horizontal:Vertical (H:V): Slope ratio that compares horizontal distance to vertical rise. H:V ratios are unitless, but feet-scale ratios describe engineered slopes, while mile-scale ratios describe geomorphic gradients. For example, a 100:1 mudflat slope means the ground rises very gradually, about 1 foot over roughly 100 feet.

Nature-based strategies: An umbrella concept that incorporates living shorelines, green infrastructure, building with nature, ecological restoration, etc. (Louarn et al. 2025) and involves using natural processes to reduce the vulnerability of communities to rising tides and coastal hazards while also perpetuating or restoring ecosystem services and benefits that most traditional hard armoring solutions lack, such as wildlife habitat, water quality improvement, carbon sequestration, and recreational opportunities. Nature-based strategies can take many forms along the shoreline, such as eelgrass, barrier islands, marshes, beaches, and/or ecotone levees, and are often implemented in concert with more traditional gray engineering (e.g., sills and groins) as hybrid solutions.



Runup: The maximum vertical elevation that waves reach on a beach, dune, revetment, or other shoreline structure above the still water level. For design, engineers estimate a representative runup elevation (e.g., elevation reached by 2% of waves during a storm) and add this to the design still water level, along with freeboard (an additional safety margin) to reduce the risk that shoreline structures are overtopping during storms.

Shoreline Management Unit (SMU): Contiguous geographic areas defined by unique combinations of landscape and environmental variables that influence the suitability of nature-based strategies. They encompass areas vulnerable to sea level rise and storm events where nature-based strategies can be applied.

Tidal elevations: There are two unequal high tides and two low unequal tides almost every day. Habitats are arranged by depth with respect to the tides.



Tidal Elevations

Datum	Abbreviation	Description	Elevation (feet MLLW)
MHWS	Mean High Water, Spring	19-year average height of high water occurring on spring tides	+7.8
MHHW	Mean Higher High Water	19-year average higher high tides	+5.7
MSL	Mean Sea Level	19-year average of hourly water elevation	+2.9
MLLW	Mean Lower Low Water	19-year average of lower low tides	+0.0
MLWS	Mean Low Water, Spring	19-year average height of low water occurring on spring tides	-2.2

Source: U.S. Navy et al. 2013.



Tidal Elevation Reference Table

Wave attenuation: The reduction in wave height and energy as waves travel across shallow, relatively flat areas, such as mudflats, marshes, or other shoreline features. Wave energy is dissipated through depth-limited breaking, bottom friction, and resistance from vegetation. Numerous studies have shown that nature-based shorelines can significantly attenuate wave energy and height (Narayan et al. 2016). The degree of wave attenuation depends on the water level, wave height, and width of the natural feature. In San Diego Bay, where most waves are small, short-period wind waves occurring at mid-tides, nature-based strategies can provide meaningful wave attenuation. During infrequent extreme events when large waves coincide with high water levels, much wider features are required to achieve comparable attenuation (BCDC 2013).





Bird's-Eye View of San Diego Bay

Highlighting opportunities to build on ongoing innovation and offering a roadmap to weave nature-based strategies into the fabric of the bay's working waterfront.

Executive Summary

As San Diego Bay's (Bay) shoreline infrastructure continues to change through adaptation and redevelopment, natural resources managers have an opportunity to implement nature-based strategies that offer benefits beyond shoreline protection, such as habitat enhancement, water quality improvement, carbon sequestration, and sea level rise resilience. The San Diego Bay Sustainable Shorelines Atlas (Atlas) is a dynamic tool that can be used to identify where nature-based strategies are suitable around the Bay. The objective of the Atlas is to serve as a resource to provide a list of potential multi-benefit shoreline solutions for future projects to consider. Future projects may be informed by the Atlas prior to completing their own independent vulnerability assessments, site-specific feasibility studies and

engineering design, community engagement, plan consistency analysis, and agency coordination to evaluate and refine appropriate nature-based solutions and strategies.

SECTION 1, ABOUT THIS TOOL, explains the purpose of the Atlas and its role in coastal resilience planning.

SECTION 2, SAN DIEGO BAY SHORELINES, describes the past, present, and potential future conditions of Bay shorelines. This spatial data builds the data-driven foundation for evaluating nature-based strategies.

SECTION 3, NATURE-BASED STRATEGIES, presents 10 nature-based strategies suitable in an applied context within the Bay, including a discussion of benefits and constraints of each strategy.

SECTION 4, SHORELINE MANAGEMENT UNITS, divides the Bay into 14 Shoreline Management Units, each with distinct physical and ecological conditions. Using suitability criteria, a semi-quantitative method ranks nature-based strategies as having limited, moderate, or high suitability at the Shoreline Management Unit scale. Because strategies that leverage natural processes are more likely to succeed over time, the Atlas highlights which options are most suitable within each Shoreline Management Unit, showing how multiple strategies can work together.

SECTION 5, CONCLUSION, summarizes the main findings and next steps to advance the implementation of nature-based strategies.

We hope this work can further local and regional discussions around multi-benefit shorelines strategies and provide baseline analysis for future projects within the Bay. The Atlas presents nature-based strategies purely as options, not mandatory measures. The online tool shows multiple strategies may be suitable for the same shoreline segment. Synthesis of strategy-level benefits and constraints can assist in prioritizing nature-based strategies for site-specific analysis. Building on and supporting the many innovative projects already underway, the Atlas provides guidance on how to proactively integrate nature-based strategies into existing shorelines.



CLICK HERE TO LAUNCH THE
SAN DIEGO BAY SUSTAINABLE SHORELINES ATLAS

Use online map to Zoom into areas of interest and see baywide data on existing conditions and suitable nature-based strategies

1

About This Tool

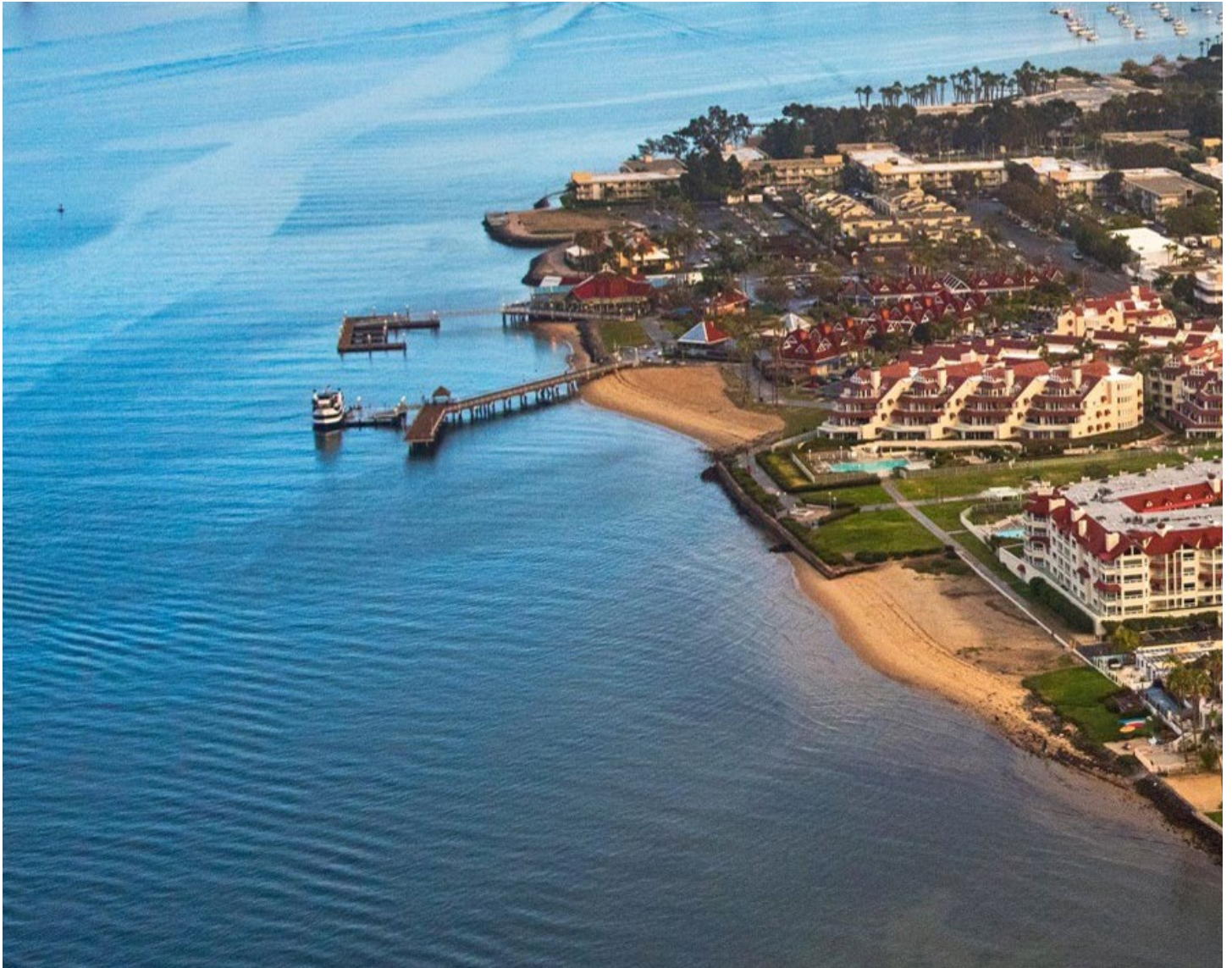
The shoreline of San Diego Bay (Bay) has been significantly modified over time through river diversion and dams, dredging, filling, urbanization, and infrastructure development. Today's shoreline is mostly hardened by revetments, seawalls, bulkheads, and wharves that prioritize structural integrity over ecological value. These armored shorelines have been constructed with varying assumptions and at different times, many of which around World War II, and were not designed to account for future sea level rise and coastal hazards. As shoreline armoring is maintained and waterfront areas are redeveloped, there may be opportunities to implement nature-based strategies.





Existing Conditions

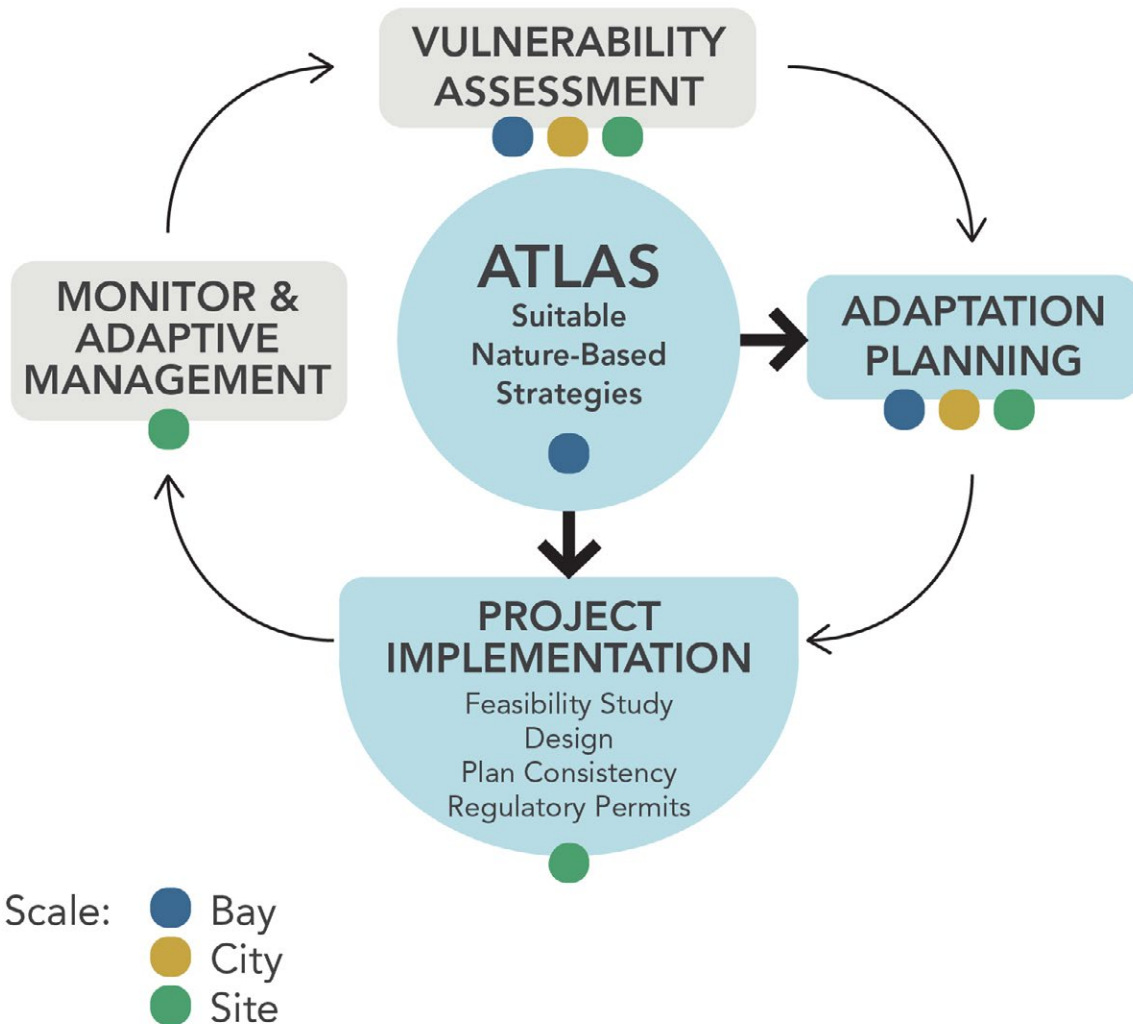
Schematic of existing conditions along San Diego Bay.



Coronado Ferry Landing Shoreline

Aerial view of the Coronado Ferry Landing shoreline along San Diego Bay.

The San Diego Bay Sustainable Shorelines Atlas (Atlas) is a dynamic tool to identify opportunities to implement nature-based strategies aligned with the Integrated Natural Resources Management Plan vision for multi-benefit shorelines that support the missions of both the U.S. Navy (Navy) and the Port of San Diego (Port) (U.S. Navy et al. 2013). Nature-based strategies enhance existing shoreline habitats and soften hard shorelines, where feasible. These approaches leverage natural processes, such as sediment deposition and vegetation growth, offering greater long-term resilience than traditional shoreline infrastructure by building elevation and dissipating wave energy as conditions change. As a result, these strategies can provide multiple benefits, including reducing shoreline erosion and flooding, improving ecological function and recreation, and sequestering carbon. The Atlas does not prescribe a particular nature-based strategy at any one location but presents an overview of potential shoreline opportunities across the Bay.



Many jurisdictions in the Bay have completed or are in the process completing, assessments of their vulnerability to sea level rise and coastal hazards. The next steps to address these vulnerabilities are adaptation planning and project implementation. The Atlas informs these phases by identifying suitable nature-based strategies and providing a starting point for further site-specific evaluation. Coastal planners, scientists, engineers, and interested parties can use the Atlas as a palette from which to draw, combine, and customize nature-based strategies based on site-specific environmental conditions, economic objectives, community priorities, and regulatory requirements. In this way, the Atlas supports decision-making by describing potential benefits and constraints of nature-based strategies while leaving applicability and implementation details—such as design and scale, consistency with long-term planning initiatives, timing, and permitting—entirely to the user.



Atlas within the Coastal Resilience Planning Process

The Atlas serves as a resource at multiple stages of the planning process, informing both adaptation planning and project implementation.



Historic Freshwater and Sediment Inputs

Historically, estimated annual sediment transport to the Bay was between 1,000,000 and 1,400,000 cubic yards. Today, because of diversions and dams, estimated annual sediment transport to the Bay is between 180,000 and 250,000 cubic yards. This is a reduction of over 80% of the natural supply of sediment available to sustain shoreline habitats.



5 Miles



San Diego River

Sweetwater River

Otay River



2

San Diego Bay Shorelines

The Bay is a natural, nearly enclosed embayment whose warm, sheltered waters serve as essential breeding, nursery, and resting ground for both terrestrial and marine species. This section describes how the Bay has changed over time and how it may evolve with sea level rise.

Historical Conditions

Prior to the 1900s, the Bay was a shallow bay fringed by extensive intertidal areas (U.S. Navy et al. 2013). Freshwater and sediment inputs from the San Diego, Sweetwater, and Otay Rivers supported mudflats, tidal marshes, and river deltas that naturally buffered the shoreline and created diverse habitats that shifted with seasonal floods and tidal cycles. Prior to the Zuniga Jetty, littoral drift contributed some sand to the bay entrance and outer shoals, but the long-term sediment budget of the Bay was overwhelmingly controlled by fluvial inputs from the San Diego, Sweetwater, and Otay Rivers. That natural system was progressively altered beginning in the late 1800s, when the San Diego River was diverted north



into Mission Bay, cutting off a major source of freshwater and sediment to the Bay. Dams on the Sweetwater and Otay Rivers further reduced sediment delivery, limiting the ability of shoreline habitats to sustain themselves.

Major dredging and filling of the Bay occurred from the 1930s through the 1960s to support naval expansion and harbor development, including Spanish Bight infill and the creation of Harbor and Shelter Islands and portions of the Chula Vista Bayfront. These projects converted the Bay's shorelines into developable land, replacing natural habitats with artificial peninsulas, hardened edges, and deep-draft piers and berths. Large-scale dredging and filling permanently reshaped the natural shoreline and required armoring, such as seawalls, bulkheads, and quay walls, to hold up over-steepened banks and keep adjacent water deep. By the 1970s, the combination of dredging, filling, and watershed modifications fundamentally transformed the Bay from a dynamic estuarine system into a highly engineered harbor heavily influenced by Navy and Port operations, and urban development within the Port's member jurisdictions (City of Coronado, City of San Diego, City of National City, City of Chula Vista, and the City of Imperial Beach). Although the shoreline has



been significantly altered over time, historical conditions provide insight into the geomorphic and hydrologic processes that shaped the landscape and can inform where and how nature-based strategies may function effectively today.

Existing Conditions

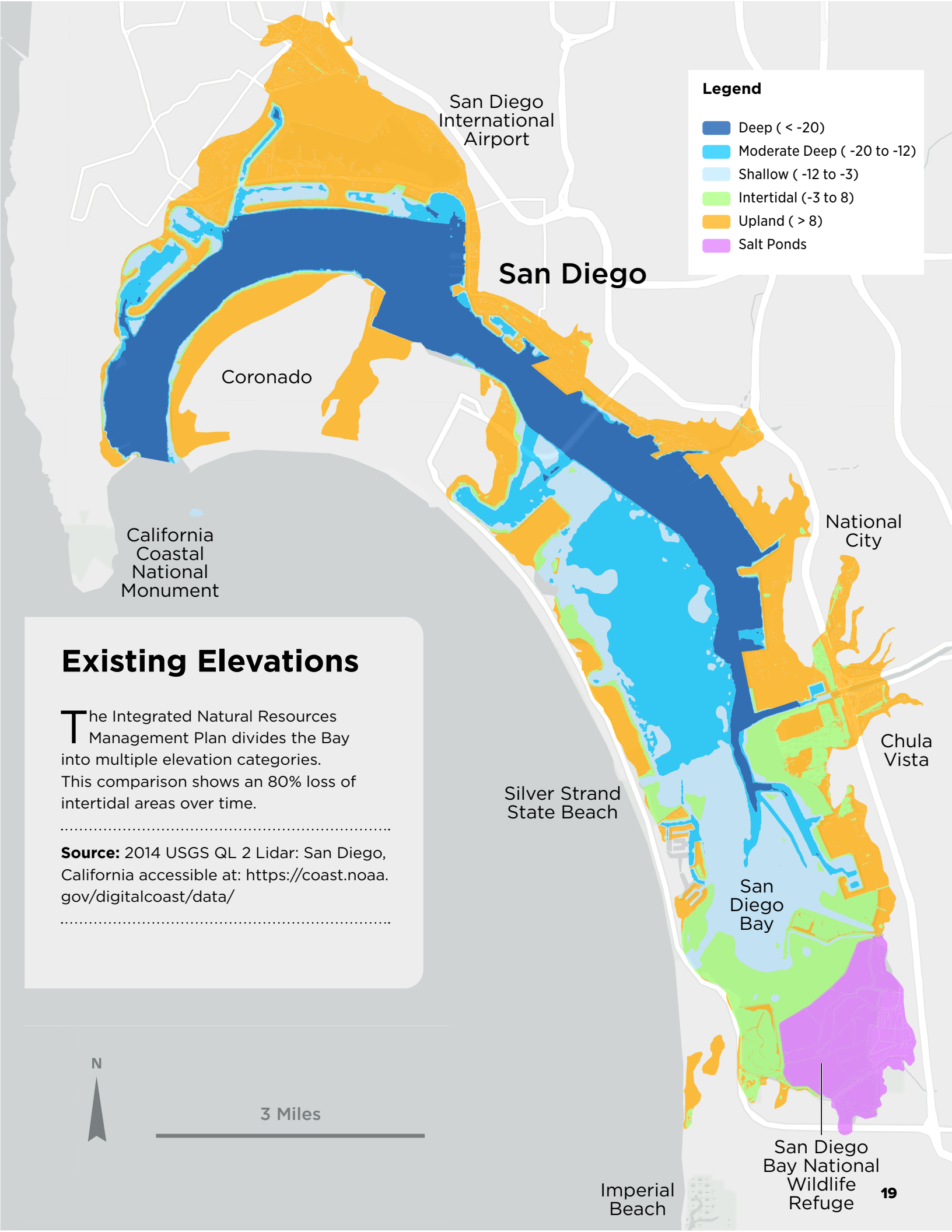
The Bay is now a large, permanently open, highly engineered, marine-dominated embayment. Freshwater inflow is limited to surface runoff from urban areas and near river mouths after storms. This means estuarine circulation and sediment transport occur only seasonally and locally. This severely reduced sediment transport to the Bay is evident by the low volume of maintenance dredging necessary to maintain safe and reliable navigation (U.S. Navy 2024). The lack of natural sediment supply contributes to baywide erosion, and the need to protect developed areas has led to reliance on shoreline armoring. **Appendix 1** characterizes the existing shoreline and establishes the foundation for nature-based strategy suitability analysis presented in **Section 4**.



Engineered Embayment

Once shaped by natural sediment flows, the Bay is now a marine-dominated, engineered embayment where reduced sediment supply contributes to erosion along developed shorelines.





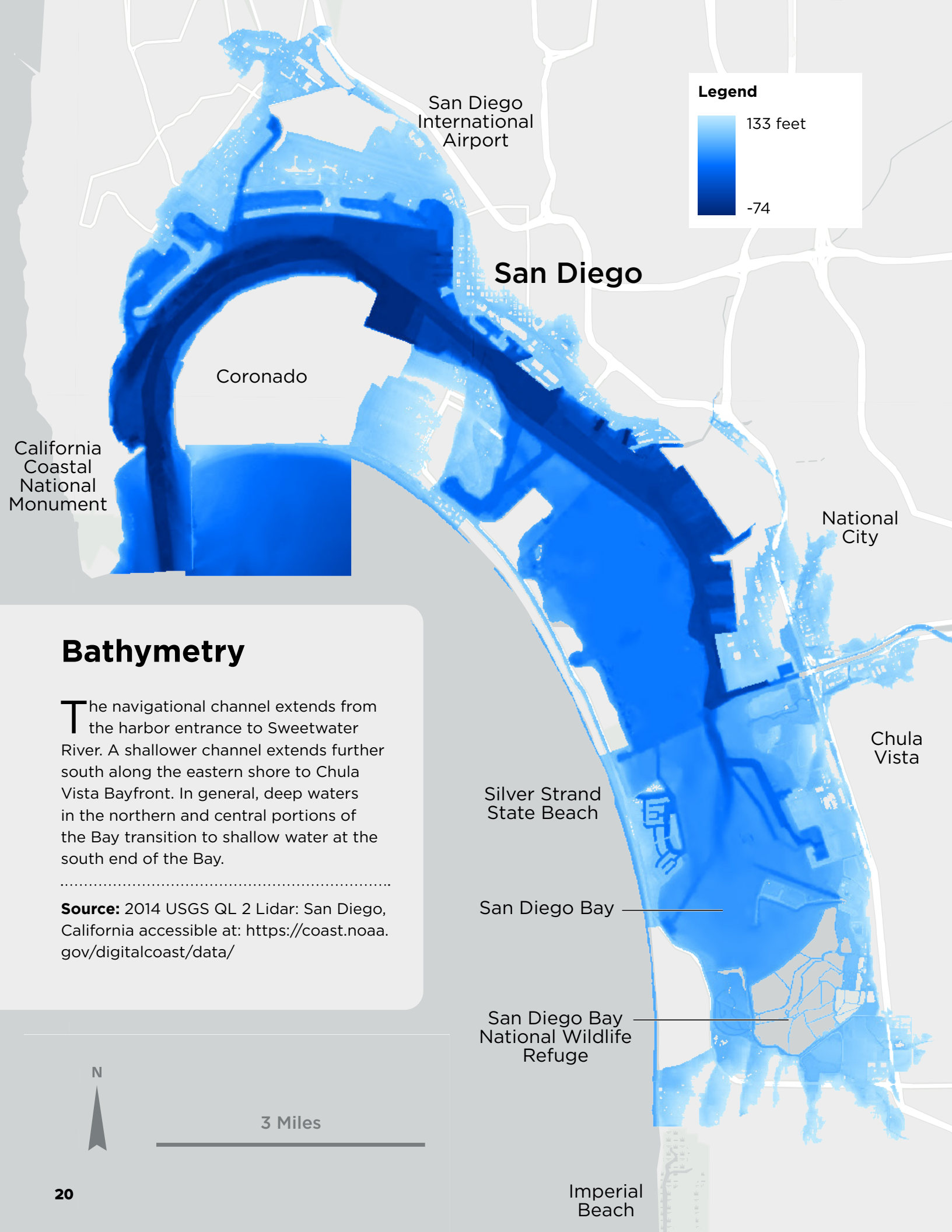
Legend

- Deep (< -20)
- Moderate Deep (-20 to -12)
- Shallow (-12 to -3)
- Intertidal (-3 to 8)
- Upland (> 8)
- Salt Ponds

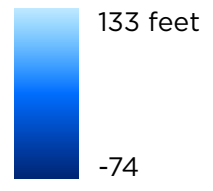
Existing Elevations

The Integrated Natural Resources Management Plan divides the Bay into multiple elevation categories. This comparison shows an 80% loss of intertidal areas over time.

Source: 2014 USGS QL 2 Lidar: San Diego, California accessible at: <https://coast.noaa.gov/digitalcoast/data/>



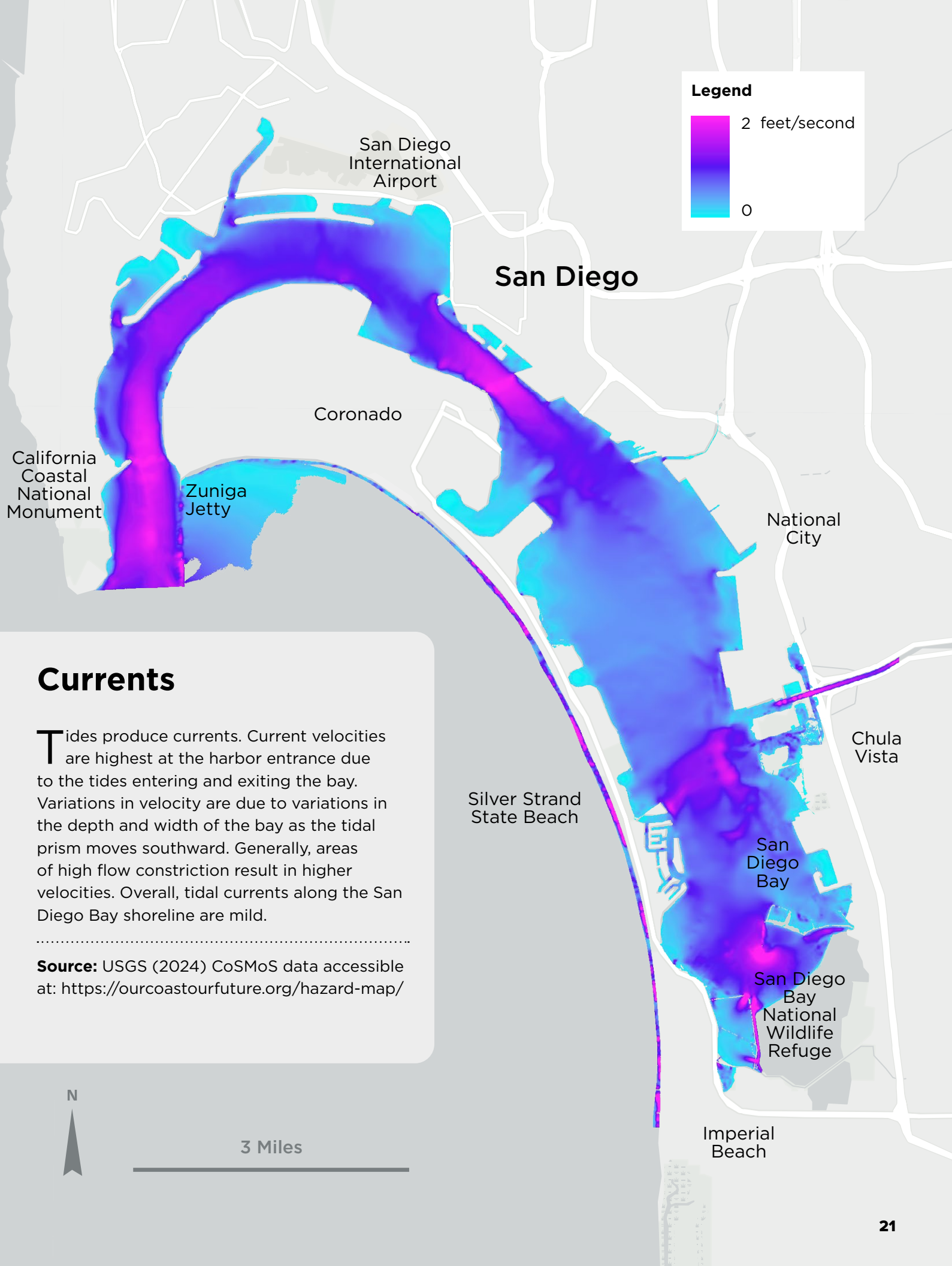
Legend



Bathymetry

The navigational channel extends from the harbor entrance to Sweetwater River. A shallower channel extends further south along the eastern shore to Chula Vista Bayfront. In general, deep waters in the northern and central portions of the Bay transition to shallow water at the south end of the Bay.

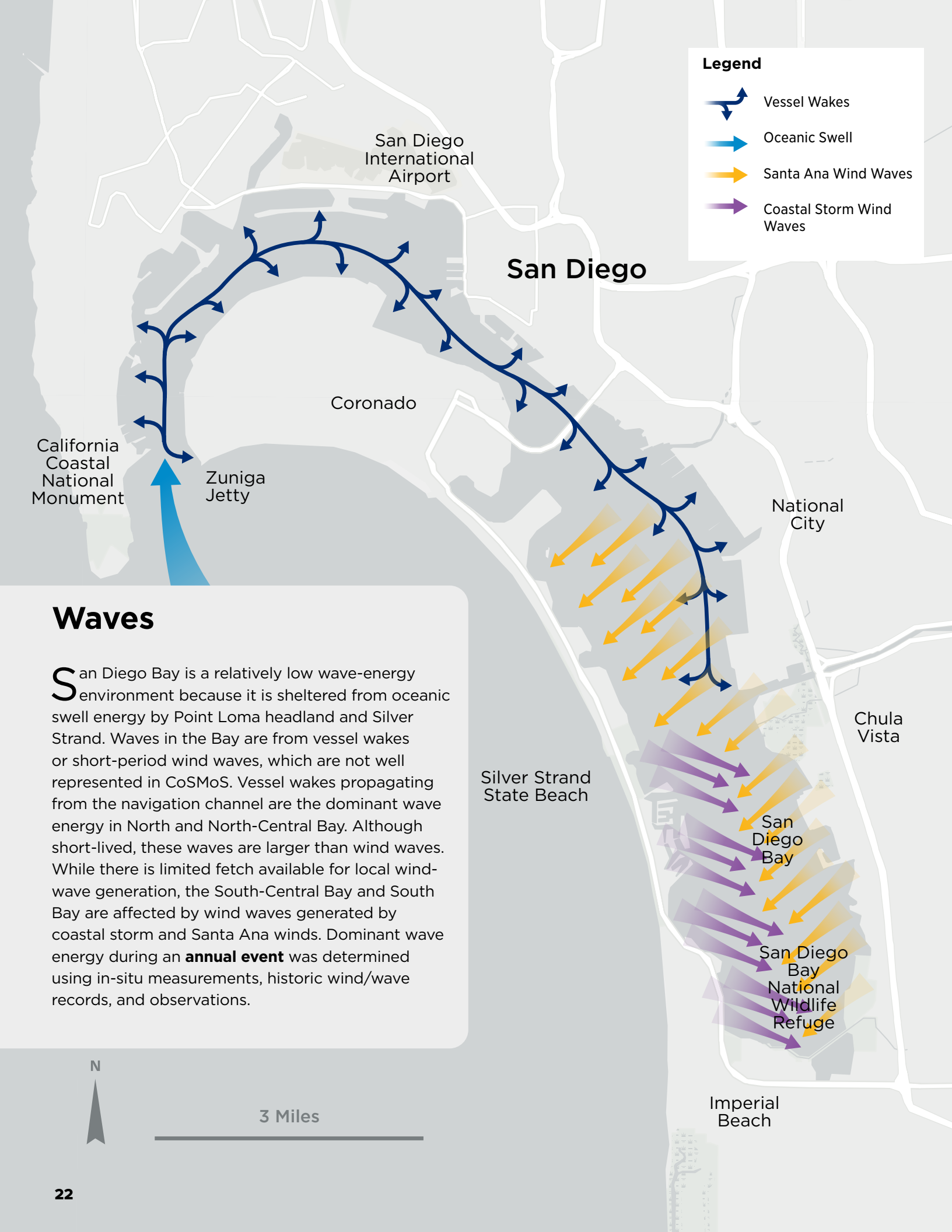
Source: 2014 USGS QL 2 Lidar: San Diego, California accessible at: <https://coast.noaa.gov/digitalcoast/data/>



Currents

Tides produce currents. Current velocities are highest at the harbor entrance due to the tides entering and exiting the bay. Variations in velocity are due to variations in the depth and width of the bay as the tidal prism moves southward. Generally, areas of high flow constriction result in higher velocities. Overall, tidal currents along the San Diego Bay shoreline are mild.

Source: USGS (2024) CoSMoS data accessible at: <https://ourcoastourfuture.org/hazard-map/>



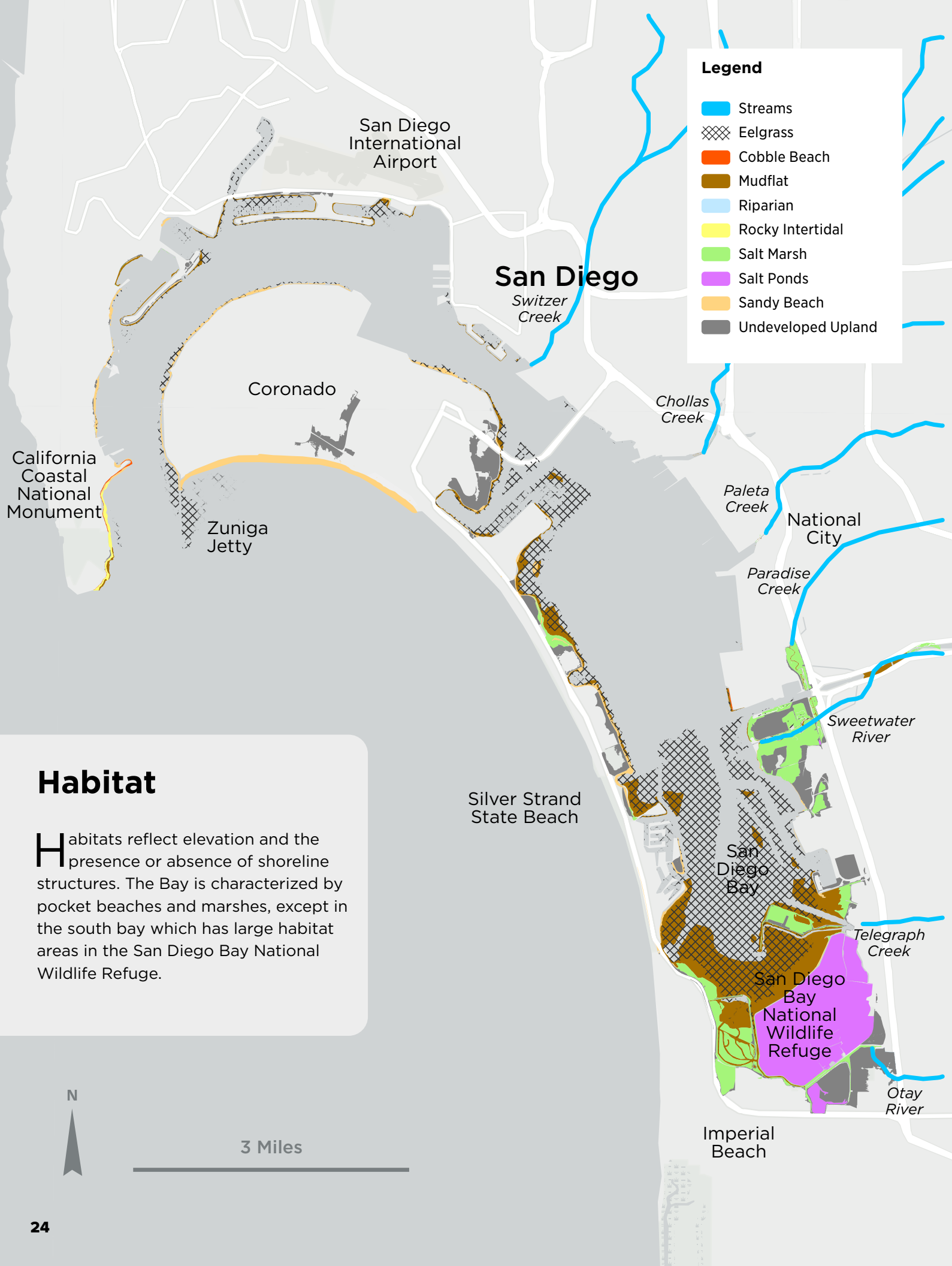
Legend

-  Vessel Wakes
-  Oceanic Swell
-  Santa Ana Wind Waves
-  Coastal Storm Wind Waves

Waves

San Diego Bay is a relatively low wave-energy environment because it is sheltered from oceanic swell energy by Point Loma headland and Silver Strand. Waves in the Bay are from vessel wakes or short-period wind waves, which are not well represented in CoSMoS. Vessel wakes propagating from the navigation channel are the dominant wave energy in North and North-Central Bay. Although short-lived, these waves are larger than wind waves. While there is limited fetch available for local wind-wave generation, the South-Central Bay and South Bay are affected by wind waves generated by coastal storm and Santa Ana winds. Dominant wave energy during an **annual event** was determined using in-situ measurements, historic wind/wave records, and observations.



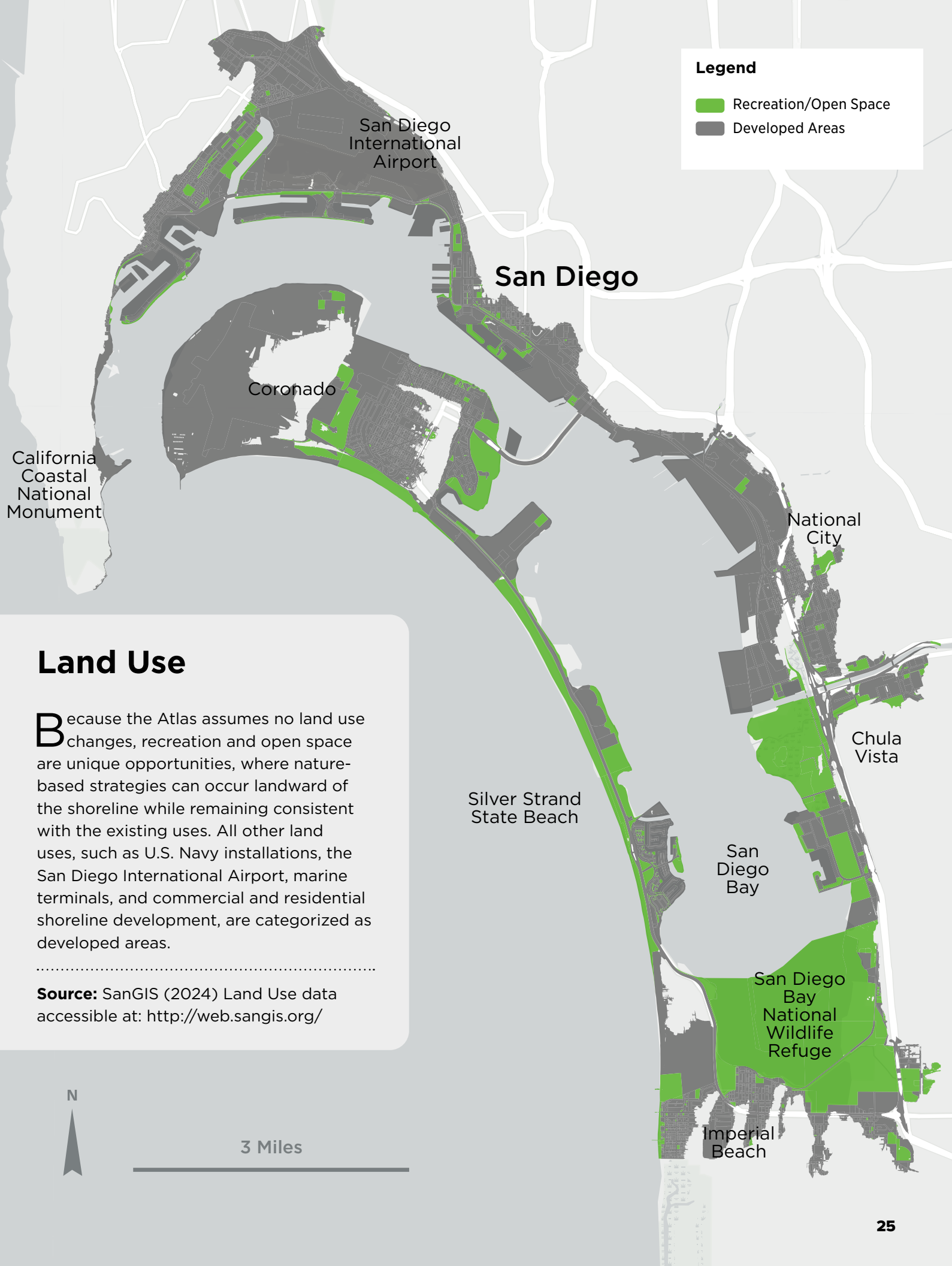


Legend

- Streams
- Eelgrass
- Cobble Beach
- Mudflat
- Riparian
- Rocky Intertidal
- Salt Marsh
- Salt Ponds
- Sandy Beach
- Undeveloped Upland

Habitat

Habitats reflect elevation and the presence or absence of shoreline structures. The Bay is characterized by pocket beaches and marshes, except in the south bay which has large habitat areas in the San Diego Bay National Wildlife Refuge.



Legend

- Recreation/Open Space
- Developed Areas

Land Use

Because the Atlas assumes no land use changes, recreation and open space are unique opportunities, where nature-based strategies can occur landward of the shoreline while remaining consistent with the existing uses. All other land uses, such as U.S. Navy installations, the San Diego International Airport, marine terminals, and commercial and residential shoreline development, are categorized as developed areas.

Source: SanGIS (2024) Land Use data accessible at: <http://web.sangis.org/>

Future Conditions

Sea level rise and coastal storms threaten existing development and shoreline habitats. Based on sea level rise scenarios for San Diego (OPC 2024), 1.6 feet and 3.3 feet of sea level rise for 2060 and 2080 to 2090 are appropriate intermediate-high risk aversion projections to consider (Appendix 1). Boat launches, piers, and parks are vulnerable to storm impacts with 1.6 feet of sea level rise and to daily inundation with 3.3 feet of sea level rise. Approximately 3.3 feet of sea level rise will cause most Port assets, including critical infrastructure, to be vulnerable to storm impacts. To avoid these consequences, nature-based strategies are recommended in the Atlas to modify existing shorelines and create additional habitat.

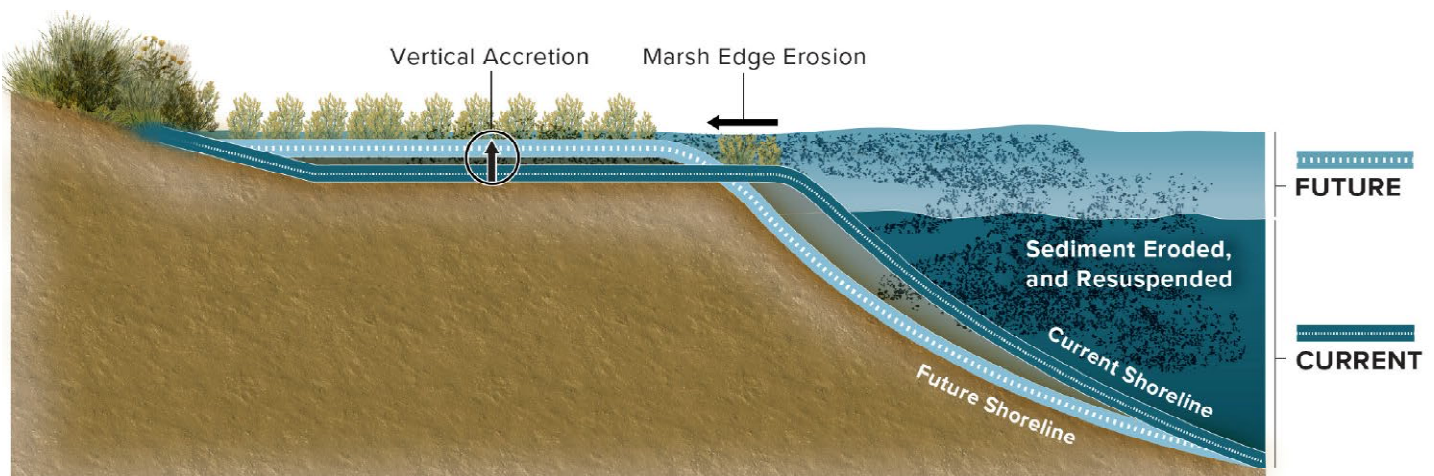
Nature-based projects are considered most effective in the near term under lower sea level rise scenarios. The design life of nature-based strategies is approximately 50 years post-construction. Given that planning, funding, and permitting require time before construction can begin (typically 2 to 4 years), projects should consider sea level rise scenarios of 1.6 feet and 3.3 feet (corresponding to 2060 and 2080 to 2090) to ensure nature-based projects remain resilient over their intended design life.

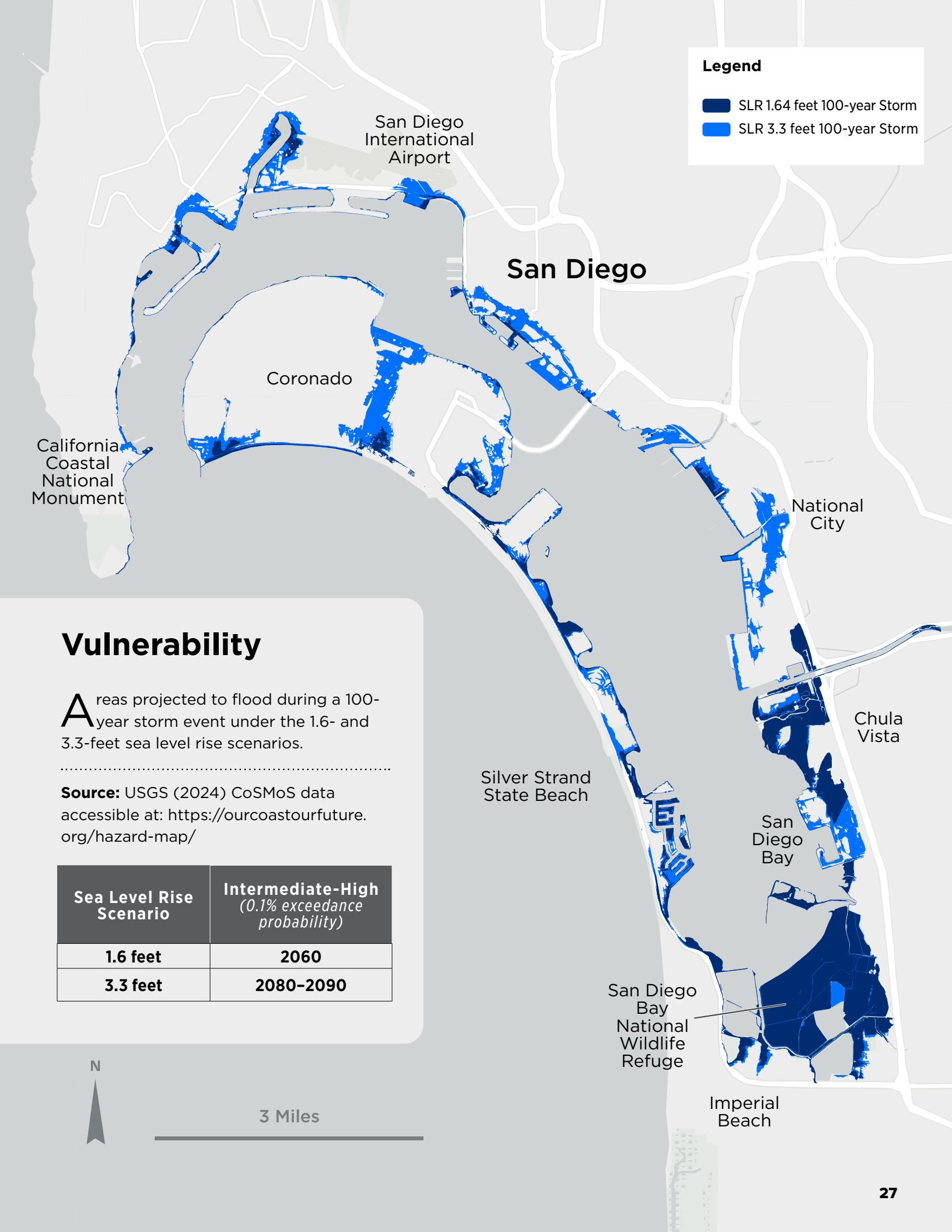
Shoreline habitats only exist at certain elevation ranges, and due to higher water levels and more frequent inundation, they face the risk of increased erosion and drowning. It is critical to understand if and how habitats can gain elevation fast enough to maintain their positions in the tidal frame and keep pace with sea level rise. Mudflats and marshes are able to adapt to rising sea levels if they have sufficient sediment to build up their elevation and access to upland areas to migrate landward. However, with decreased sediment supply and no upland transition zone, sea level rise can outpace vertical accretion, and these habitats would be squeezed between a rising Bay and existing development, gradually downshifting from marsh to mudflat and then mudflat to shallow subtidal.



Schematic of Marsh Evolution

With sufficient sediment supply and migration space, marshes can build upward and landward rather than drown under rising seas.





Legend

- SLR 1.64 feet 100-year Storm
- SLR 3.3 feet 100-year Storm

Vulnerability

Areas projected to flood during a 100-year storm event under the 1.6- and 3.3-foot sea level rise scenarios.

Source: USGS (2024) CoSMoS data accessible at: <https://ourcoastourfuture.org/hazard-map/>

Sea Level Rise Scenario	Intermediate-High (0.1% exceedance probability)
1.6 feet	2060
3.3 feet	2080-2090

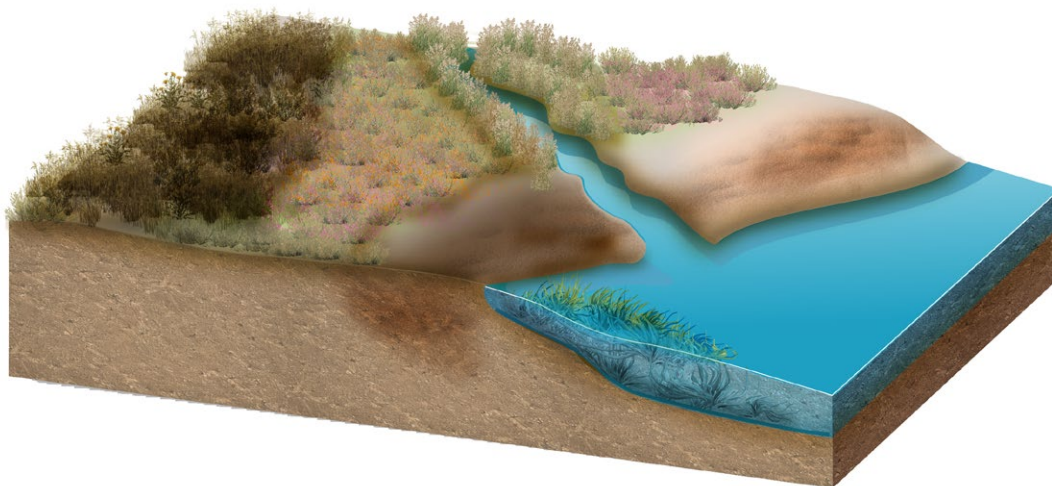
3

Nature-Based Strategies

This section describes 10 nature-based strategies suitable for a given shoreline context within the Bay. Although nature-based strategies are described individually in this section, they are rarely implemented individually. Unlike traditional gray engineering, which tends to focus on a single shoreline solution, nature-based strategies are commonly combined as a continuum of habitats and features, from subtidal to upland, that work together to reduce waves and flooding while enhancing ecological functions. For example, a mudflat or coarse beach in front of a marsh can help break waves before they reach the marsh, protecting it from erosion and helping preserve the many benefits the marsh provides. Similarly, a marsh can help protect an ecotone levee by breaking waves and trapping sediment, reducing erosion and flooding of the levee while adding ecological benefits. Thus, when layered along the shallow subtidal to intertidal zone, nature-based strategies can work synergistically, creating integrated benefits that surpass what any single strategy could provide on its own (USACE 2024).







Schematic of Combined Strategies

A suitability analysis first screens for feasible nature-based strategies based on physical and ecological conditions. Viable options are then assessed for benefits and constraints, guiding site-specific design and implementation.

Guiding Principles

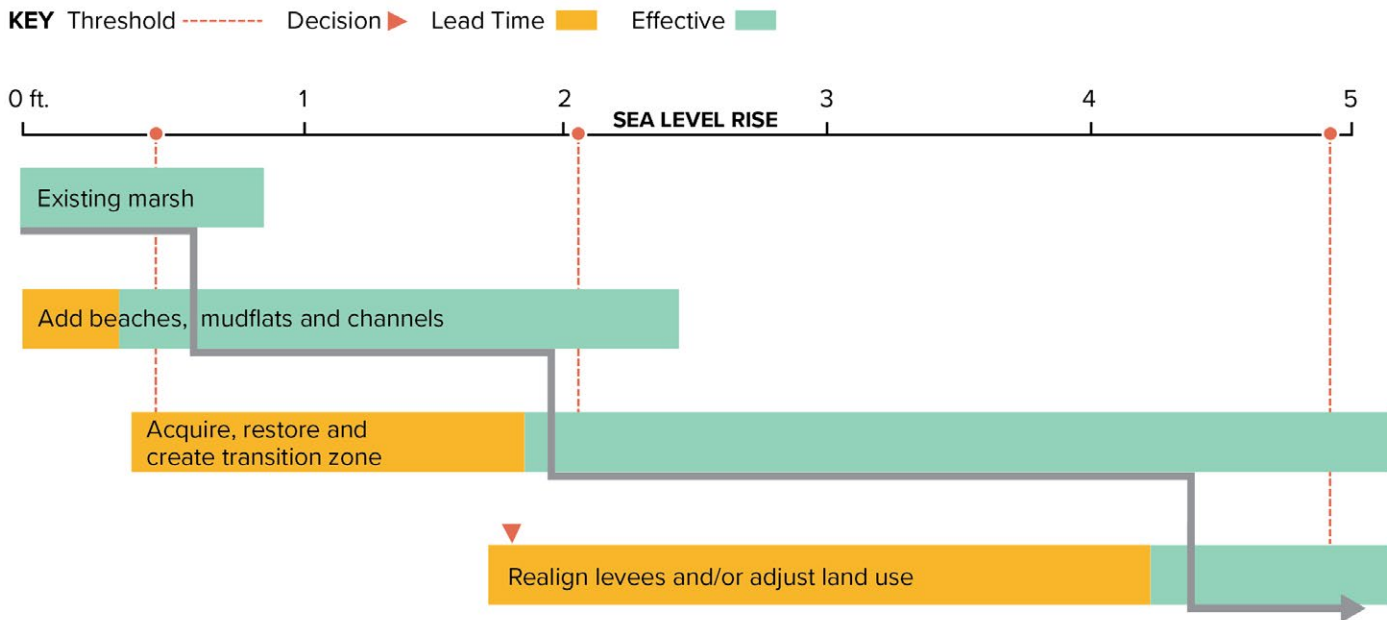
Project development begins with a suitability analysis to identify which nature-based strategies are appropriate based on physical and ecological conditions. This eliminates infeasible strategies early; the result is a short list of potential solutions, not a preferred alternative. Strategies that pass this initial screen are then evaluated based on their relative benefits and constraints. This differentiates suitable strategies, i.e., what do we gain and what does it take? Together, this information informs site-specific analysis, project concepts, and implementation decisions.

Because much of the Bay's shoreline is highly developed, and the Atlas assumes no changes in land use, the suitability of a strategy in large part depends on how much space is available (Louarn et al. 2025). Existing upland development and land uses are retained, except in areas designated for recreation or open space, where nature-based strategies can occur landward of the shoreline. In these locations, such strategies enhance recreational and open space values while remaining consistent with the existing uses.

As a result, the space available to implement nature-based strategies is often located bayward of the existing shoreline. However, the placement of fill for habitat is a regulatory constraint that can result in a short- or long-term reduction of aquatic resources and may trigger compensatory mitigation, even for restoration efforts. The resulting financial burden can limit feasibility and, in some cases, lead to otherwise viable projects being abandoned due to insufficient funding. The Atlas acknowledges the inherent tension between “holding the line” and “minimizing fill.” In constrained settings, limited and strategic placement of fill bayward of existing development may be necessary to combat drowning and coastal squeeze under sea level rise and create or sustain shallow subtidal and intertidal habitats, such as graded marsh benches or terraced shoreline slopes.

In most locations, nature-based strategies require more space and more intact natural processes (e.g., sediment transport) than are currently available. As such, these strategies will likely be implemented in combination with traditional gray engineering as hybrid approaches. These strategies can serve as a first line of defense, protecting shoreline habitats, infrastructure, and communities while considering longer-term planning for adaptation in the future.

Conceptual Adaptation Pathway



Adaptation Pathways

Nature-based strategies often represent near-term actions, and as sea level rises, adaptive management and implementation of additional strategies may be needed to raise the function of a strategy to a higher level (e.g., a marsh functions within a narrow tidal range and thus may initially need strategies to reduce erosion and increase the sediment supply, then need a transition zone to migrate to higher elevations, etc.). Adaptation pathways illustrate this approach of implementing strategies over time (“what to do and when”). Adaptive management decisions are typically triggered when certain monitoring thresholds are reached. In this way, strategies are phased as new conditions and information emerge.

Because many of the strategies have fairly long lead times for planning, permitting, and construction, decisions about how and when to implement them must be made well in advance of when they are needed in order to be effective. Although it may not be necessary to develop adaptation strategies today for the longest-term sea level projections, it is important to understand how near-term strategies will enable—or limit—future actions for a particular area. As project concepts are further developed and refined through technical studies, an adaptive pathways approach can assist with long-term decision-making processes. Additional technical studies, community outreach, and design refinement are required to develop a detailed adaptation pathways approach for a specific location.



Conceptual Adaptation Pathways

Phasing nature-based strategies over time, guided by monitoring triggers and long-term sea level projections.

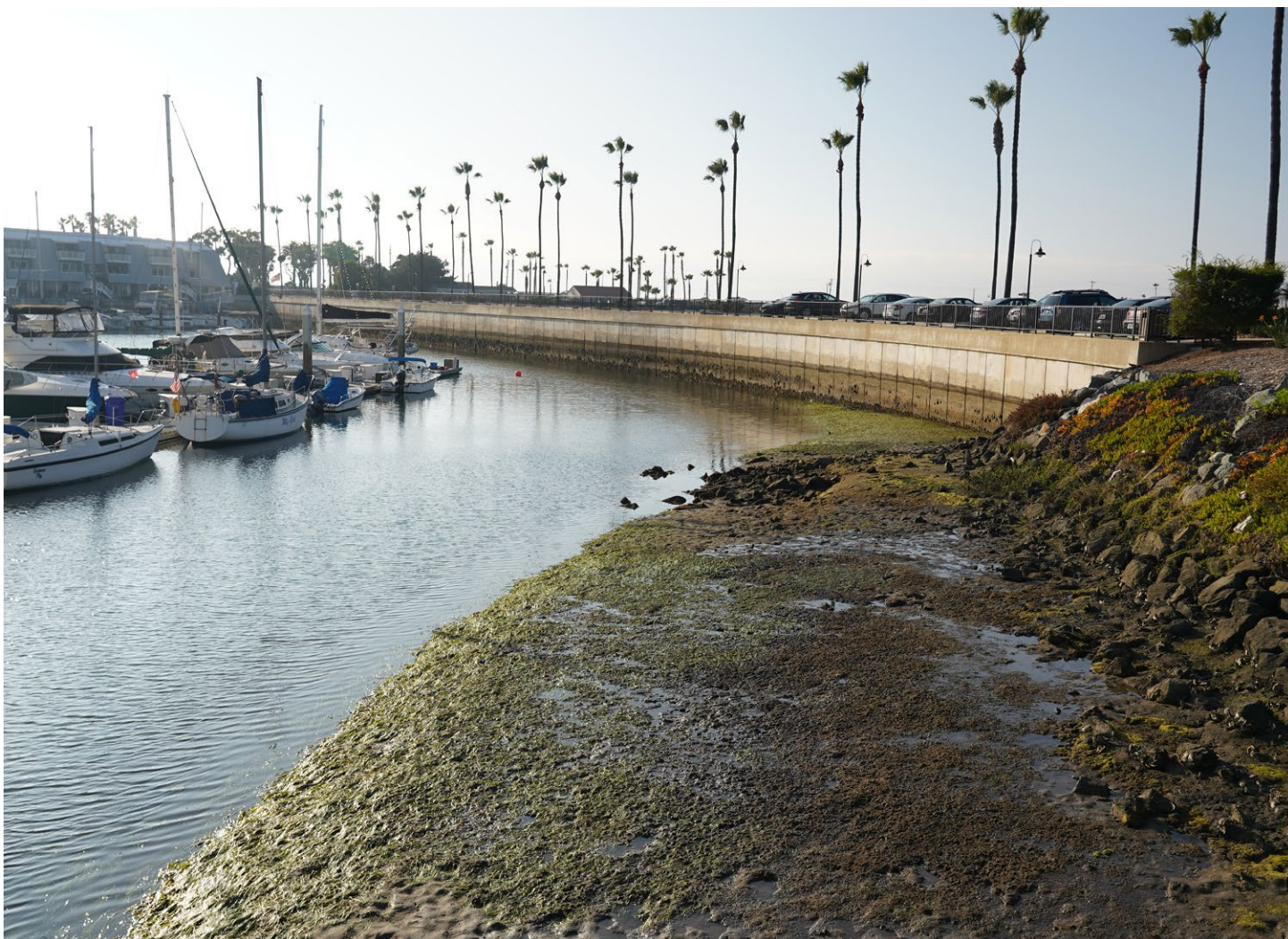
Summaries

There is a general description of each of the 10 nature-based strategies, including a discussion of benefits and constraints. Qualitative rankings—limited (L), moderate (M), and high (H)—allow for high-level differentiation of the strategies. Importantly, the rankings do not describe benefits compared to existing conditions, as this would require site-specific information. Additionally, it is important to note that shorelines have intrinsic limitations, such as bathymetry and width, and so for a given location, comparing specific strategies may not be appropriate. For example, ecological armoring may be the only suitable improvement for a riprap shoreline that is adjacent to deep water, exposed to high wave energy and currents, and backed by maritime development. In this case, some of the “limited” benefits associated with ecological armoring are the highest benefits feasible given the physical conditions of the site. Finally, and especially when considering cost, note that comparisons are considered on a project basis, not a unit area basis, because the scale of the 10 nature-based strategies is different (e.g., eelgrass tends to cover larger areas than ecological armoring).



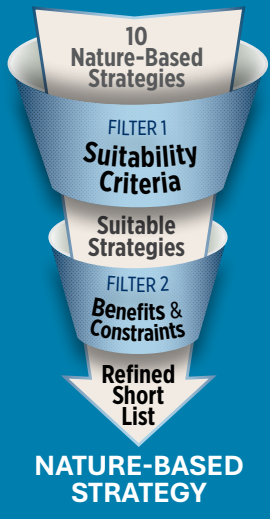
King Tide Retreat

San Diego Bay's lowest king tide waters recede along the Silver Strand, January 11, 2022.



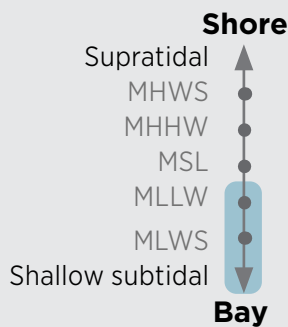
Benefits And Constraints

Rankings: **L** Limited, **M** Moderate, **H** High

 10 Nature-Based Strategies FILTER 1 Suitability Criteria Suitable Strategies FILTER 2 Benefits & Constraints Refined Short List NATURE-BASED STRATEGY	BENEFITS					CONSTRAINTS	
	 Habitat Enhancement	 Water Quality Improvement	 Carbon Sequestration	 Flood Risk Management	 Public Access	 Cost	 Permitting
	- Creates habitat - Increases connectivity - Improves ecological function	- Filters pollutants - Traps contaminants	Stores carbon	- Attenuates waves at high tide - Raises flood protection	Provides recreation and educational opportunities	- Not compatible with existing infrastructure - Difficult construction - Does not minimize fill	- Inconsistent with existing land use - Lack of precedent
 Eelgrass	H	M-H	M-H	L	L	\$\$-\$	L-M
 Barrier Islands	M-H	M	L-M	H	L	\$\$\$	M-H
 Nearshore Reefs	M	L-M	L	L-H	L	\$\$-\$-\$	L-H
 Mudflats	M	L	M	L-H	M	\$\$	M-H
 Tidal Marshes	H	M-H	M-H	M	L-M	\$\$-\$-\$-\$	M-H
 Beaches	L-M	L	L	M	H	\$\$	M
 Ecotone / Embankment Slopes	M-H	L	L-M	M-H	M-H	\$\$\$	M-H
 Ecological Armoring	L-M	L	L	M	M	\$\$-\$	L-M
 Living Seawalls	L	L	L	M	L	\$\$-\$	L
 Creek-to-marsh Reconnection	H	M-H	M-H	L-H	L-H	\$\$-\$-\$-\$	M-H



Location Within The Tidal Transect:

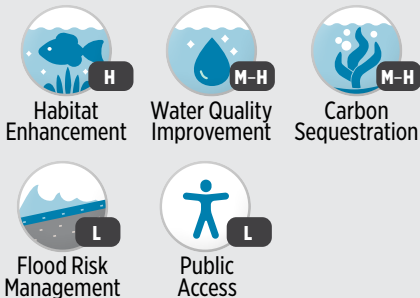


Examples:

- San Diego Bay Eelgrass Habitat Expansion Program

Benefits:

L Limited, **M** Moderate **H** High



Constraints:

\$ Limited, **\$\$** Moderate, **\$\$\$** High

L Limited, **M** Moderate, **H** High



Suitability:

Protected, low-energy environments with shallow depths (-10 feet to 0 feet MLLW); gentle slopes minimize fill and create stable beds; avoid areas with deeper-draft vessel navigation.

Eelgrass

Eelgrass is a type of seagrass recognized as an important and productive habitat in the Bay. Eelgrass in the Bay consists of two species: common eelgrass (*Zostera marina*) and Pacific eelgrass (*Z. pacifica*). Of the two, common eelgrass is much more prevalent, particularly along the shoreline margins and within the southern and southwestern portions of the Bay. Pacific eelgrass is an open coastal species and is only found in the Outer Bay waters in areas of clean sands and well-flushed environments.

Eelgrass establishment occurs naturally through the expansion of existing beds into adjacent areas with suitable substrate, either by lateral rhizome growth or by seeds and flowering shoots dispersed by currents. Eelgrass beds spread via a horizontal network of rhizomes beneath the sediment surface. While rhizomes stabilize bottom sediments, the blades both dampen wave energy and slow currents, reducing suspended sediment and turbidity. This promotes sediment deposition and gradual increases in bottom elevation, which improve light penetration to the eelgrass canopy, thereby reinforcing a self-sustaining cycle of eelgrass growth.

Eelgrass beds in the Bay are believed to have suffered substantial losses due to past dredge and fill projects as well as past municipal stormwater and industrial discharges. Over the last several decades, discharges have been curtailed and water quality has improved, and now eelgrass occupies the Bay wherever there are suitable environmental conditions. Establishing new eelgrass beds would require altering the environment by raising or lowering an area's elevation, altering its slope, or changing its energy environment or circulation parameters to create suitable habitat. Planners and scientists have begun identifying and planning opportunistic sites in the Bay for the reuse of suitable dredged material from navigational maintenance and capital improvement dredging projects to expand eelgrass habitat areas.

Benefits

Eelgrass forms marine meadows that provide multiple benefits, including habitat structuring, sediment stabilization, wave dampening, nutrient uptake, and carbon sequestration. Eelgrass meadows provide multilevel foraging opportunities in addition



to spawning and nursery areas for fish and invertebrates in nearshore environments. When eelgrass extends all the way to the water's surface, wave attenuation benefits are maximized; thus, eelgrass beds are most effective at dissipating wave energy and slowing tidal currents at low tides. Furthermore, eelgrass helps improve water quality by absorbing pollutants, generating oxygen, and promoting particulate deposition. Eelgrass also cycles atmospheric carbon and promotes carbon sequestration within sediment (blue carbon), while absorbing dissolved carbon in the water column, buffering against ocean acidification. Due to the generally subtidal nature of the Bay's eelgrass habitat, suitable shorelines are largely not in conflict with surface water uses of shallow Bay waters (Merkel & Associates 2021).



Constraints

Establishing new eelgrass beds would require modifications to bathymetry, raising regulatory constraints related to the placement of fill (Section 3.1). Although there is a good track record of approved eelgrass projects, it may take several years to implement a project (U.S. Navy 2024). Existing eelgrass guidelines, including the California Eelgrass Mitigation Policy and Implementing Guidelines (NMFS 2014), must be well understood before a site can be adopted and any proposed project must undergo review by relevant resource agencies, such as the U.S. Army Corps of Engineers, California Coastal Commission, California Department of Fish and Wildlife, and Regional Water Quality Control Board.

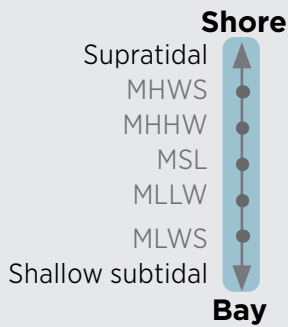


Eelgrass beds are not recommended as a primary mechanism for flood protection because they offer little protection during storms at high tide. Additionally, sea level rise threatens to reverse the current trend of eelgrass expansion because deeper water may not allow for adequate light penetration for eelgrass to persist in deeper beds. There is some capacity for eelgrass to transition to higher elevations as sea level rises—by raising the Bay bottom with suitable dredged materials, the shallower water depths can create a suitable light environment to support eelgrass growth. Upslope areas should be factored into future designs to provide an opportunity for eelgrass beds to migrate to higher elevations over time.





Location Within The Tidal Transect:

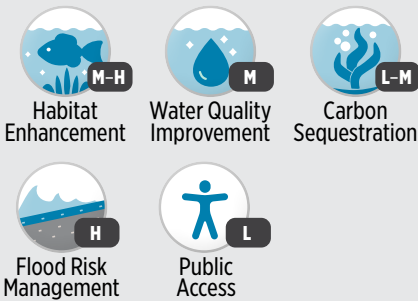


Examples:

- Homeport Island
- Chula Vista Wildlife Reserve (CVWR)

Benefits:

L Limited, **M** Moderate **H** High



Constraints:

\$ Limited, **\$\$** Moderate, **\$\$\$** High

L Limited, **M** Moderate, **H** High



Suitability:

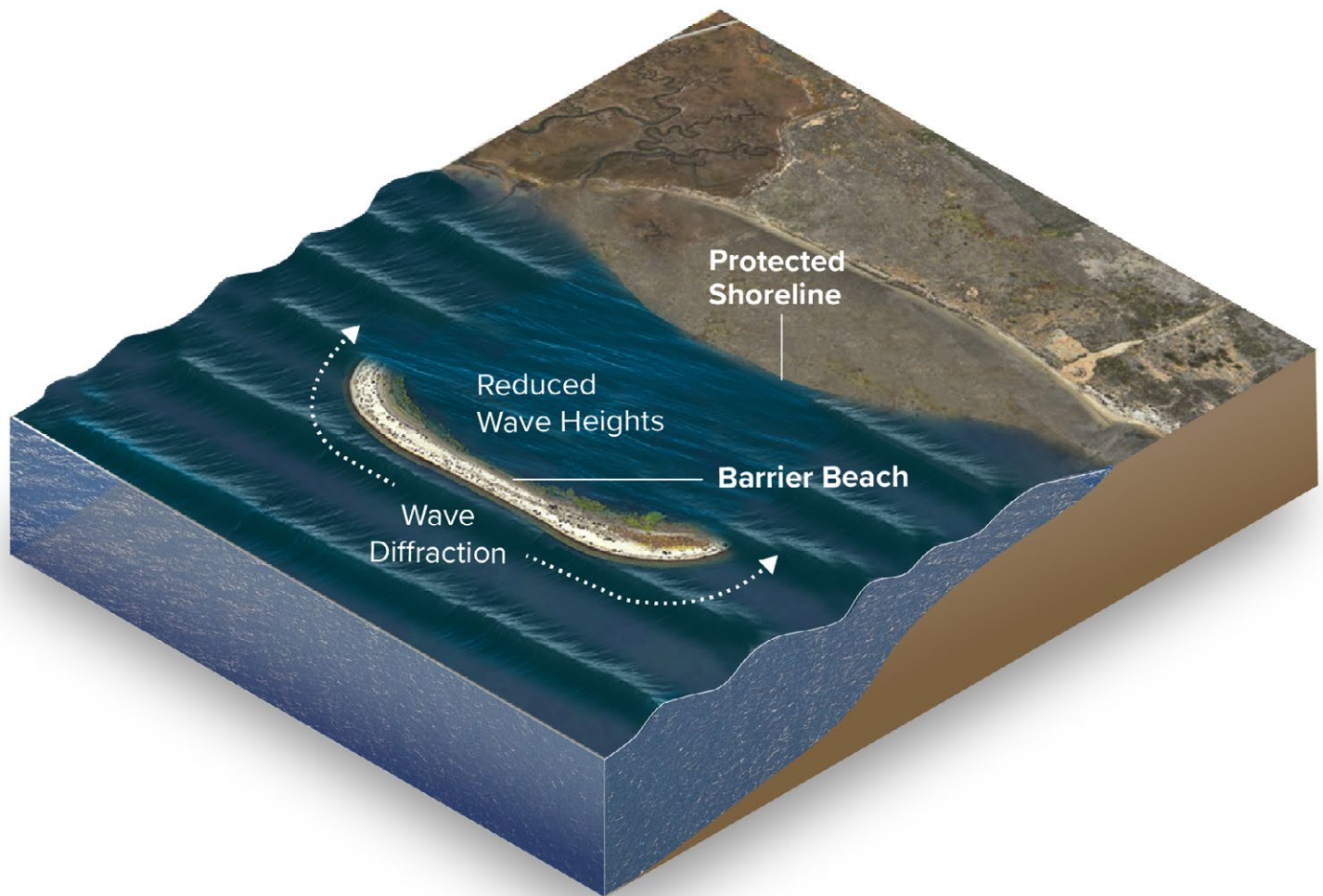
Shallow water and slopes (e.g., shoals) and concave shoreline geometries minimize fill, maximize stability, and promote sediment deposition and retention.

Barrier Islands

Barrier islands serve as a natural breakwater and may include many habitat features, depending on island size and hydrodynamic conditions. They are constructed parallel to the shoreline and typically involve placing sediment within a subtidal area to raise the elevation high enough above the tides and waves to provide flood risk management. As the first line of defense, barrier islands reduce the energy and height of incoming waves. By breaking waves offshore, a low-energy, depositional environment is created on the leeward side of the island, making the shoreline more suitable for other nature-based design alternatives. Concave shorelines extend these benefits over relatively larger areas compared to parallel shorelines. The crux of a feasible barrier island is material—sediment and anchoring materials should be stable against current and wave energy.

Dredging and barrier island creation often go hand in hand because suitable sediments are needed to build islands. In the Bay, the Navy's Homeport Island and the Port's CVWR are two examples of barrier islands constructed through beneficial reuse of dredge material. The rock jetties flanking Homeport Island were meant to form two sides of the island, connected by a gentle slope with heights increasing from east to west and with the high point where the current island sits. The Navy pumped sand dredged from the Naval Base Coronado aircraft carrier basin to the site and used the submerged jetties to contain the slurry placement. However, suitable material was limited during construction, and the island was constructed to approximately one-third of its original design size. Without fine-grained sediment to provide cohesion, the island became an overwash shoal. Homeport Island has been slowly decreasing in size due to erosion and may eventually convert to subtidal habitat.

The CVWR is an approximately 80-acre habitat mitigation site constructed from dredged material generated during development of the Chula Vista Harbor in the late 1970s and early 1980s. The island was built on and expanded from a previously constructed berm that separated the cooling water intake and discharge channels of the now-demolished South Bay Power Plant. In 1983, portions of the constructed perimeter dikes were intentionally breached to restore tidal exchange and promote



marsh development. Since its creation, CVWR has evolved into a functioning marsh, home to several important species such as a protected California least tern (*Sternula antillarum browni*) nesting colony. Given its engineered origin, bayward location, and ongoing shoreline erosion challenges, CVWR presents a unique opportunity to evaluate nature-based shoreline strategies and pilot demonstration projects. Perimeter dikes/levees in the CVWR and South San Diego Bay Unit can be strengthened and transformed into barrier islands to address wave erosion and accelerate marsh development.

Benefits

Barrier islands provide multiple benefits, including habitat enhancement, dredged material management, and wave attenuation. Inherently, they can be designed to incorporate multiple nature-based strategies. Eelgrass, oyster reefs, mudflats, tidal marshes, beaches, and ecotone levees can be incorporated in the design of an island or in the space behind it. Islands can provide predator-free habitat for nesting birds, while the leeward side of an island provides protected nursery habitats for young fish,



Barrier Island

Schematic illustrating the coastal protection function of a barrier island, demonstrating wave diffraction around the barrier, reduced wave heights in the lee of the island, and the resulting protected shoreline landward of the structure.



Creation of Homeport Island

Aerial view of Home Port Island in San Diego Bay, an example of barrier island creation.

invertebrates, and other aquatic life to grow and develop. By attenuating wave energy and stabilizing bottom sediments, barrier islands can reduce turbidity and limit the resuspension of sediment-bound contaminants, resulting in moderate, localized water-quality improvements.

Constraints

Barrier islands typically require the placement of fill, making regulatory constraints related to fill a key feasibility consideration (Section 3.1). The lack of suitable materials and adequate space are also often limiting factors in creating or enhancing barrier islands. These constraints are particularly pronounced in the Bay, where extensive eelgrass beds are present and, under sea level rise, potential tradeoffs between preserving existing eelgrass habitat and creating barrier island features raise complex habitat-conversion and permitting considerations regarding long-term ecosystem benefits.

Furthermore, because barrier islands are constructed offshore in relatively higher-energy environments, uncertainties associated with construction are typically greater than those associated with other nature-based strategies. Two of the primary construction uncertainties for barrier islands are the consolidation of fine-grained sediments, which can cause subsidence and loss of elevation, and the erosion of sandy sediments, which can rapidly reduce island volume and longevity (Bridges et al. 2021). In addition, upfront



capital costs can be significant because in-water work and handling large volumes of sediment for shallow-water placement is generally expensive.

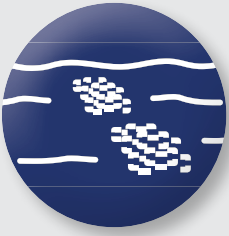
Barrier islands are at an increased risk from sea level rise and storms because they experience coastal hazards on all sides. Whether barrier islands can survive sea level rise depends on their ability to migrate landward and move sediment onto and behind the barrier, either via overwash or through flood-tidal delta deposition. Given the Bay's relatively low sediment supply, barrier islands may not be able to migrate fast enough and could drown. Thus, renourishment of barrier islands will likely be needed for them to continue to protect the shoreline behind them and support wildlife.



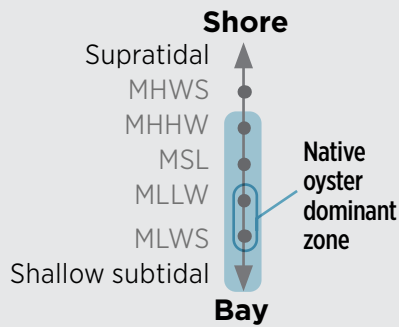
West Ski Island

A man-made barrier island located in Mission Bay, San Diego. Photo by Jacob Swing.





Location Within The Tidal Transect:

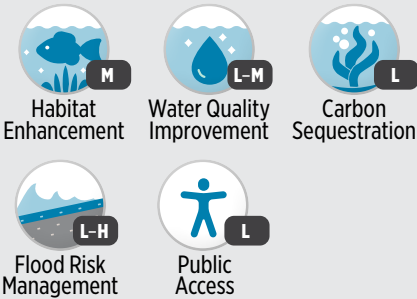


Examples:

- CVWR
- Upper Newport Bay
Living Shorelines Project

Benefits:

L Limited, **M** Moderate **H** High



Constraints:

\$ Limited, **\$\$** Moderate, **\$\$\$** High

L Limited, **M** Moderate, **H** High



Suitability:

Moderate wave energy and current between -5 feet and 2 feet MLLW for oyster reefs and up to MHHW for non-oyster rock reefs; gentle slopes stabilize artificial reef substrate; shell bags may be placed in boating areas, while reef balls require protected areas with limited boating to avoid collision.

Nearshore Reefs

Artificial nearshore reefs are constructed from hard materials for the purpose of creating a structural barrier to attenuate wave energy while simultaneously providing foraging and/or nursery habitat for native marine species. Reef design and placement may be augmented to target specific species, such as kelp, fish, or oysters. Outside the Bay, in deeper waters with larger wave energy, artificial reefs may be constructed using rock piles to restore or enhance giant kelp beds. Numerous low-relief rock piles placed at varied depths, with varying rock and crevice sizes, can also increase the diversity of fish that may use the reefs for reproduction and shelter. Within the Bay, artificial nearshore reefs prioritize oyster recruitment and can be constructed from various materials (baycrete, recycled oyster shell, limestone, etc.) in the intertidal zone for the purpose of providing hard substrate suitable for settlement by the native Olympia oysters (*Ostrea lurida*) known to occur throughout the Bay. The highest densities tend to occur south of Glorietta Bay and adjacent to the CVWR (Tronske et al. 2018). Restored oyster beds establish in shallower depths compared to kelp/rocky reefs and therefore may be situated closer to the shoreline. This proximal added structure may provide stability to upshore beach sand and increase beach retention (i.e., perching structure). Oyster reefs are a priority artificial reef type in the context of the Atlas, as their increased suitability in low-energy subtidal environments are more widely applicable within the Bay.

There are numerous design approaches to oyster reefs. Based on project goals and site context, strategic placement of hard substrate within the appropriate tidal elevation range and environmental conditions can encourage existing larvae to settle and expand the spawning population of oysters in the Bay. Hard substrate can range from recycled oyster shells held within biodegradable netting to the use of proprietary baycrete or concrete reef unit products. Deployment of fabricated reef structures, while often less cost-effective, may provide the added benefits of reef durability, greater oyster recruitment, and potentially higher wave attenuation due to their higher relief within the water column. Native Olympia oysters and non-native Pacific oysters (*Magallana gigas*) in the Bay have been shown to co-exist between 1.5 feet and 2.2 feet MLLW; native dominance



occurs between 0.4 feet and 1.5 feet MLLW, and native exclusivity occurs below 0.4 feet MLLW. Therefore, any method of reef creation must occur on low-sloping substrate, with some portion of its vertical relief occurring below 1.5 feet MLLW to target the maximum zone of Olympia oyster occupation and the minimum zone of dominance by non-native Pacific oyster occupation. Low-relief shell bags are generally constrained to a narrow elevation range due to silt infill of the shell at lower energy levels lower on the shore, whereas reef balls may be placed at a wider elevation range because their increased height ensures some portion of hard substrate will be present within this species settlement zone. The steeper surfaces of reef balls shed sediment more effectively than do low-gradient, highly porous shell bags. Any method of reef creation should also occur parallel to the shore in sheltered waters with low sediment deposition rates, low to moderate wave action (from wind waves and boat wakes), and good circulation to allow plankton transport. Reefs placed near freshwater sources are not expected to be at risk of excessively low salinity because of low rainfall in the region.



Nearshore Reefs Beach Retention

Nearshore reef inside the semi-protected Coos Bay, showing the effects of the reef on beach retention.



Nearshore Reefs CVWR Reef Ball

Reef balls installed within the intertidal zone at the CVWR, serving as nearshore reef structures to enhance habitat and provide coastal protection.

Benefits

Artificial nearshore reefs supply biogenic habitat for marine invertebrates and fish, subsequently increasing local use by birds and larger marine species by providing foraging opportunities. Reef growth and persistence also modify abiotic conditions by dissipating wave energy and slowing tidal currents at low and mean tides, which subsequently enhances sediment deposition and shoreline stabilization. Complete wave attenuation is generally not possible unless reefs are built well above elevations typically required by kelp or native oysters. Additionally, nearshore reefs can enhance water quality and clarity through various mechanisms depending on the targeted reef species. Kelp removes excess nutrients and carbon dioxide from water and reduces suspended sediment. Oysters filter particles from the water column, transferring nutrients to benthic organisms and contributing to organic matter burial, with some potential for carbon sequestration.



Constraints

It is necessary to carefully select restoration sites that carry the lowest likelihood of reef disturbance and oyster mortality to buffer against potential low-recruitment years. The San Diego Bay Native Oyster Living Shoreline Project, completed in 2021 along the northern shoreline of CVWR, has provided biological and physical data to inform future efforts within the Bay. There are additional known areas of established high density oyster reef elsewhere in the Bay that provide larvae stock that could naturally support future nearshore oyster reef efforts. Utilizing concrete reef balls (as opposed to bagged shell) provides a higher level of stability and durability that will allow greater persistence during low-recruitment years; however, this method is more costly and requires the introduction of permanent hard substrate, which may lead to additional regulatory challenges. Successful reef placement also requires sediment with sufficient strength to support the unit.

Sea level rise may prevent oyster reef persistence. As the sea level rises, oysters will continue to settle and survive within a relatively narrow elevation range that is influenced by desiccation stress, wave energy, sedimentation, and likely predation. Oyster beds can self-maintain through landward migration as sea level rises. If reefs are constructed using bagged shell, this could potentially occur naturally, but sediment loading of the shell bags will be a significant concern in most areas of the Bay. If reef balls are used, additional reef balls may need to be deployed at higher tidal elevations to provide migration substrate.



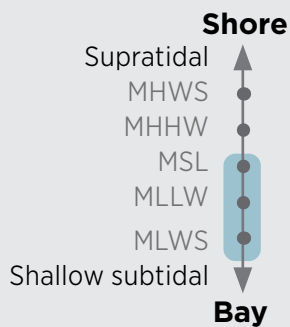
Shell Bags

Photograph of nearshore reef shell bags immediately post-construction (left). Shell bags approximately 6-12 months post-restoration (right).





Location Within The Tidal Transect:

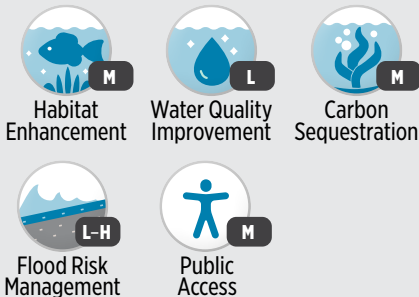


Examples:

- Eden Landing San Francisco Bay Shallow Water Strategic Placement Pilot Project

Benefits:

L Limited, **M** Moderate **H** High



Constraints:

\$ Limited, **\$\$** Moderate, **\$\$\$** High

L Limited, **M** Moderate, **H** High



Suitability:

At or near existing mudflats (southern Bay); mudflats with eelgrass beds would be negatively impacted by shallow-water placement of sediment (e.g., turbidity and burial).

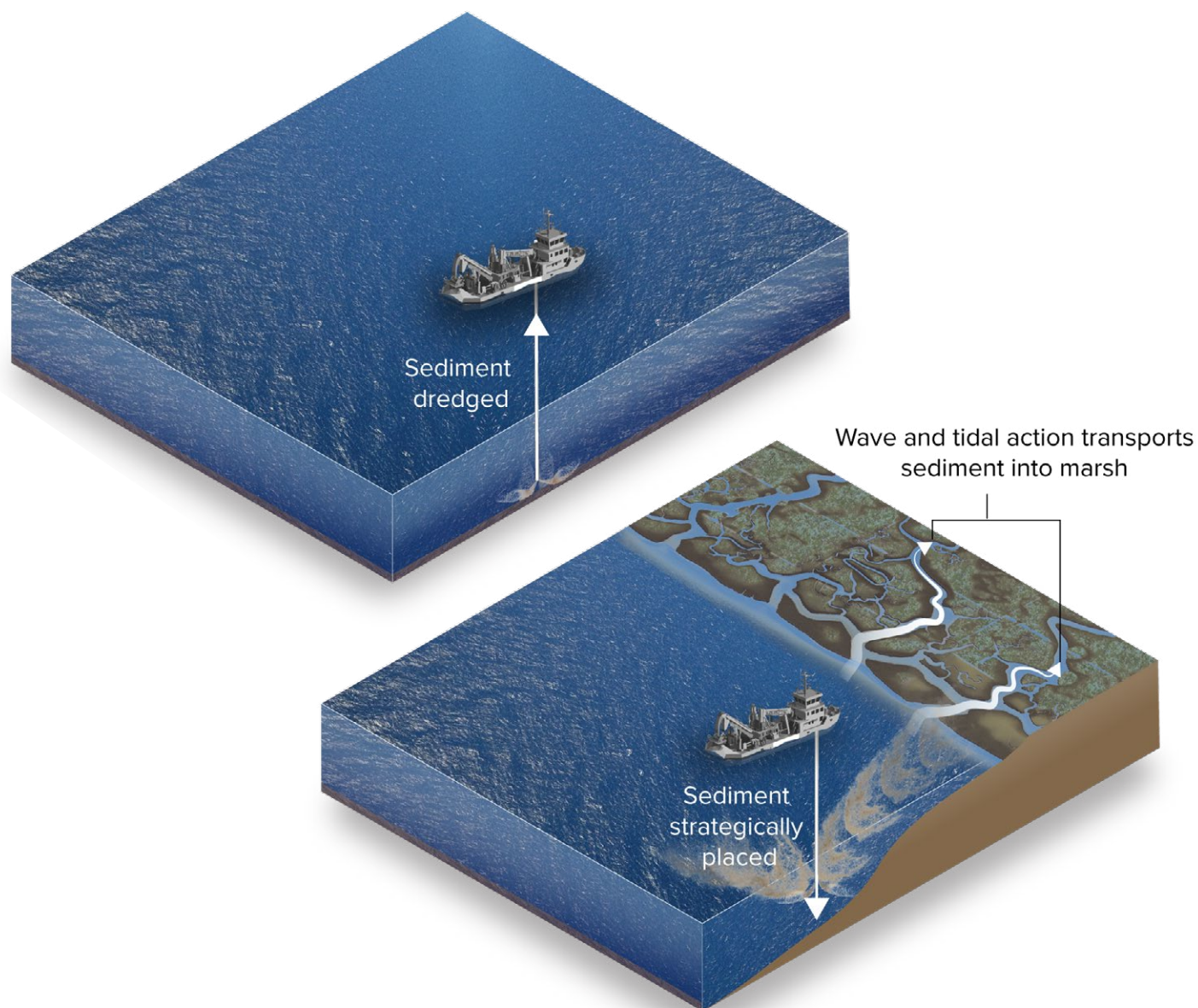
Mudflats

Mudflats are non-vegetated habitats exposed at low tide and submerged at high tide. As their name implies, they are muddy shoals made up of fine sediment (silts and clay) along very gentle slopes (100H:1V to 1,000H:1V, Horizontal:Vertical). In the Bay, mudflats occur between the highest eelgrass and lowest cordgrass (*Spartina foliosa*), approximately -2 feet to 3 feet MLLW. The most extensive mudflats occur north of the salt ponds in the South Bay.

A combination of sediment supply and wave energy determines the shape and elevation of a mudflat. At low tides, waves break on mudflats, and at mid-tide levels, waves break near the mudflat-marsh transition, against a vertical scarp, or along a gradual slope, depending on the marsh geometry. Mudflats serve as sediment reservoirs, where sediment can be resuspended into the water column by wind-wave action, transported on the marsh during flood tides, and deposited during slack waters. Thus, mudflats are intimately linked to the adjacent tidal marshes because they both limit the amount of wave energy reaching the marsh edge and supply sediment to the marsh for vertical accretion.

Preserving and enhancing existing mudflats involves direct or indirect placement of fine sediments to increase mudflat elevations. Dredged sediment can be introduced directly into the water column as a plume or indirectly by first placing the material as a mound at a shallow, subtidal location adjacent on the mudflat. In both cases, the sediment can be resuspended by waves and transported by tides and currents for deposition on existing mudflats and marshes, mimicking the natural sediment dynamics.

This unconfined aquatic placement technique is referred to as strategic shallow-water placement and is being piloted for the first time in California by the U.S. Army Corps of Engineers off Eden Landing in San Francisco Bay (USACE and SWRCB 2023). Because wind and waves do the heavy lifting, results may be unpredictable—some of the sediment will not end up in the desired location due to differential settling and dispersion within the water column. The goal of this pilot project is to determine the effectiveness of beneficially using material



dredged from navigation channels to help sustain mudflat and marsh, given sea level rise and limited sediment supply. Using containment barriers, such as large-diameter dredge pipes, to retain placed sediment allows for more rapid and effective consolidation of the sediment during low-tide periods.

Benefits

Mudflats provide critical foraging and roosting areas for shorebirds, and they reduce shoreline erosion and flooding because waves attenuate as they travel across wide mudflats (BCDC 2013). Mudflats also promote the mineral cycles of the Bay, such as carbon sequestration in fine sediments. Furthermore, mudflats provide additional natural open areas for recreation and educational opportunities (birdwatching, etc.).



Mudflats Shallow-water Placement

Schematic showing how this technique closely mimics natural processes.

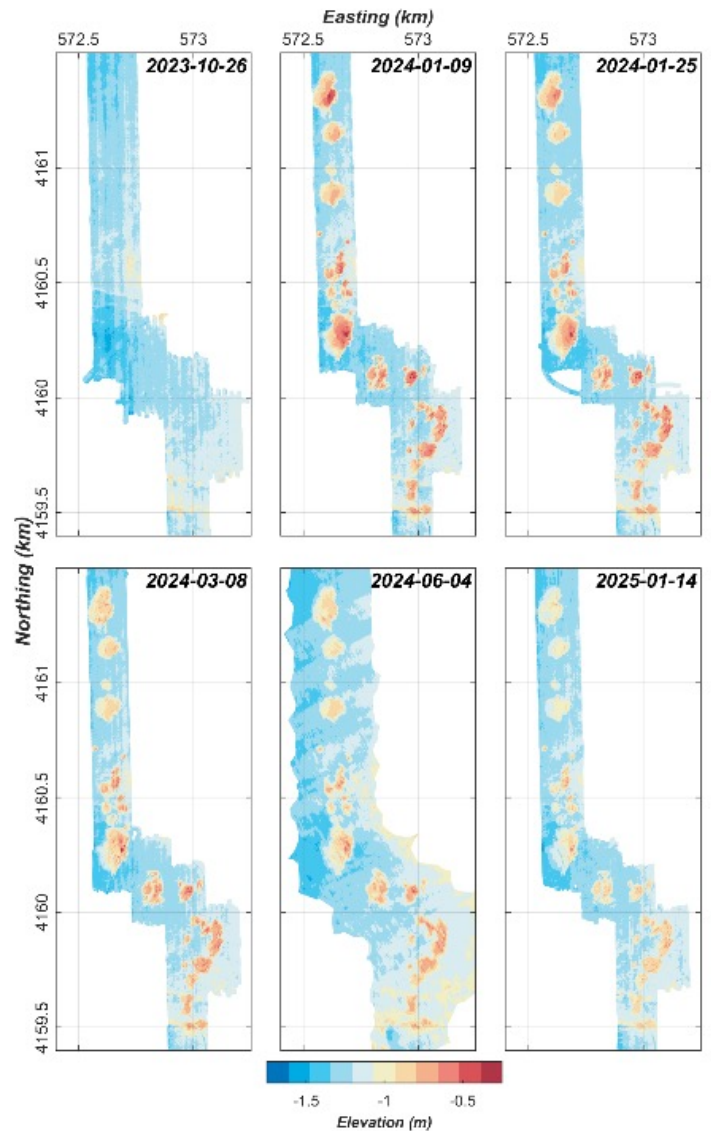
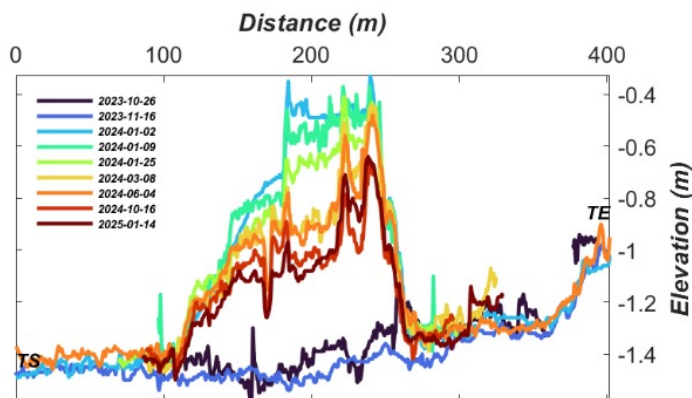
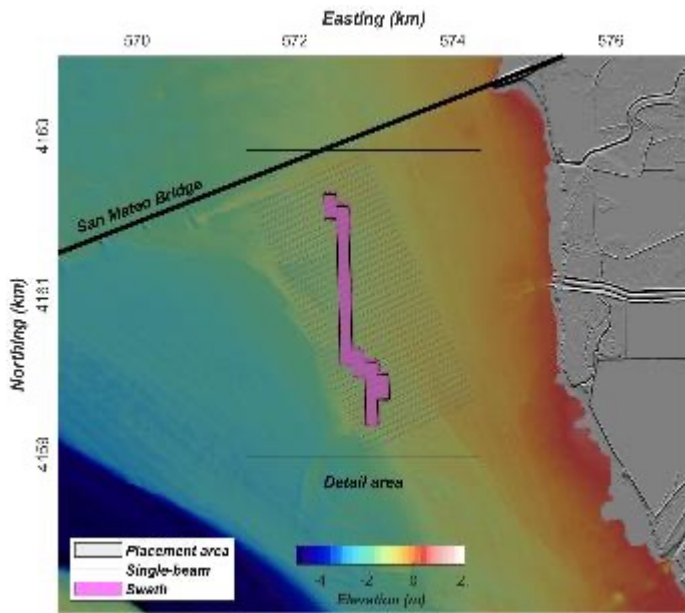


Mudflats along Bayshore Bikeway

View of intertidal mudflats along the Bayshore Bikeway, providing important coastal habitat within the San Diego Bay shoreline.

Constraints

Because the cost is a function of the distance between the dredge and placement sites, proximal sediment supply is desired for mudflat augmentation. On average, the Navy anticipates that one or two dredge projects per year might generate suitable material, with an approximate, but highly variable, annualized diversion rate of 50,000 cubic yards of sediment (U.S. Navy 2024). Because unconfined mudflat augmentation is untested in the Bay, it will likely face a more difficult permitting process with resource agencies. Placement may work best with relatively small



The Eden Landing Strategic Shallow Water Placement Pilot Project

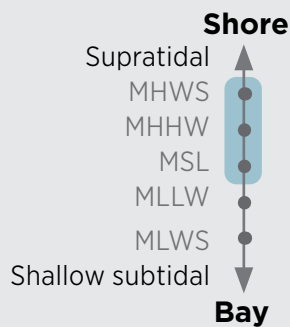
Placed about 90,000 cubic yards of dredged sediment from the Port of Redwood City federal navigation channel Dec. 6–31, 2023 in shallow subtidal area in South San Francisco Bay. Repeat bathymetric mapping show that the height and volume of the placement mounds are gradually decreasing. Images from Julie Beagle.

volumes released at frequent intervals so that efforts can be scaled to the marsh area and long-term sedimentation rate, but dredging often results in relatively large volumes at infrequent intervals.

Mudflats can adapt to changes in sea level and sediment supply over long timescales by migrating landward. Because sediment input to the Bay has been severely reduced, sea level rise may outpace sediment deposition on mudflats, such that mudflats will become submerged permanently and convert to subtidal areas. Thus, increasing the sediment available to mudflats would be an important consideration for their long-term survival.



Location Within The Tidal Transect:

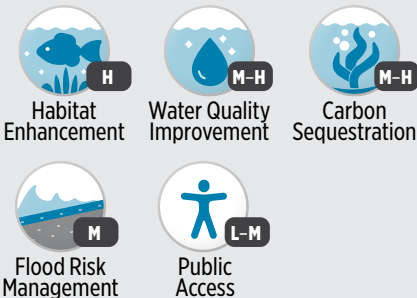


Examples:

- South Bay Wetlands Restoration and Enhancement Project

Benefits:

L Limited, **M** Moderate **H** High



Constraints:

\$ Limited, **\$\$** Moderate, **\$\$\$** High

L Limited, **M** Moderate, **H** High



Suitability:

Gradual slopes (30H:1V+) in low-energy environments (often existing marshes); pocket marshes landward of the shoreline in recreation/open space areas.

Tidal Marshes

Tidal marshes are emergent wetlands dominated by salt-tolerant vegetation, such as pickleweed (*Salicornia virginica* and *S. bigelovii*). The majority of the remaining Bay tidal marsh is in the South Bay. Sweetwater Marsh is a long-established tidal marsh. New marsh is developing at the mouth of Telegraph Creek due to changes in shoreline configurations. New marsh is also developing within the CVWR due to restoration efforts. At the former South Bay Salt Works, marshes are also being established by reintroducing tidal inundation to the series of diked open-water ponds constructed in the late nineteenth century (USFWS 2006).

Restoring degraded marshes may involve a variety of techniques based on site conditions. Adding coarse beaches or other shoreline features buffers wave energy and reduces marsh edge erosion, whereas improving tidal channels increases connectivity. Many of the Bay's marshes are sediment-limited due to historical watershed modifications, so thin-layer sediment placement can help accelerate vertical accretion, enabling marshes to keep pace with sea level rise without smothering vegetation. In addition, setting aside or grading adjacent upland areas to appropriate topographic elevations provides space for marshes to migrate landward over time. Where there is limited space, marshes may need to be terraced and/or buttressed with a sill to maintain marsh elevations.

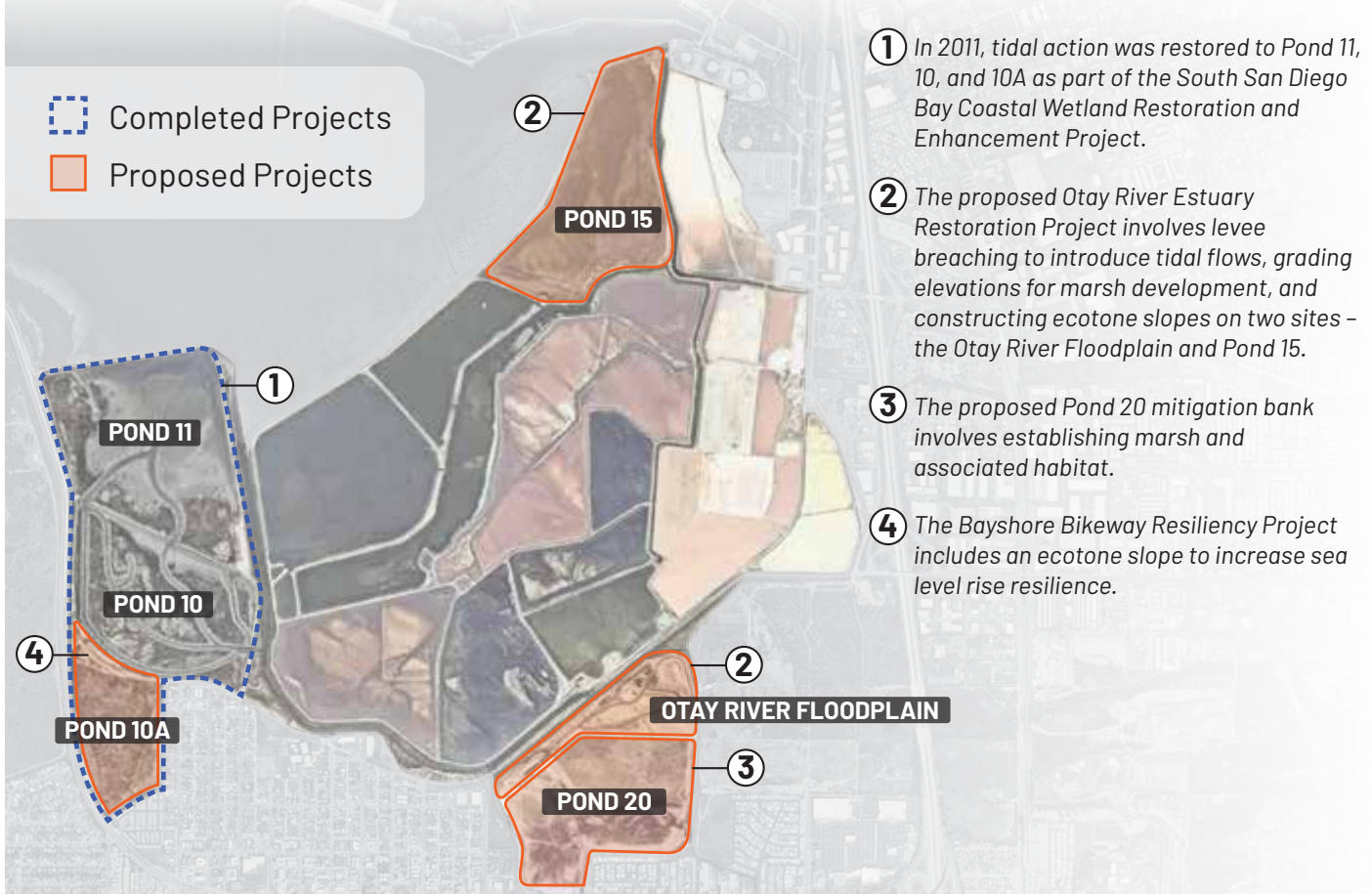
Building new marsh often involves placing sediment to raise subsided areas to achieve elevations appropriate for marsh vegetation and breaching dikes to restore tidal action. Compared to existing marshes, high performance of newly established marshes may take longer to achieve because natural processes like sediment transport, sediment chemistry development, and vegetation growth take time.

Benefits

Marsh benefits are positively correlated with marsh size. Tidal marshes include a diversity of habitat types that host an array of plant, invertebrate, fish, bird, and mammal species, many of which are listed as threatened or endangered under state and federal law. Tidal marshes also improve water



Completed and Proposed Projects in the South San Diego Bay Unit of the San Diego National Wildlife Refuge



quality by filtering sediment and pollutants, and they provide carbon sequestration due to their high rates of plant productivity and low rates of decomposition, leading to the development of highly organic soils (carbon sinks). They reduce flood risk by attenuating wave energy and height through depth-limited breaking and vegetation-induced friction. The vegetation slows the water down, which also promotes sediment deposition and helps to maintain appropriate marsh elevations for depth-limited breaking, benefiting landward development. Furthermore, tidal marshes provide additional areas for public access and recreation and create educational opportunities by providing wildlife viewing opportunities.

Constraints

The limited distribution of existing marshes and shoreline space constrains the potential for marsh restoration and creation. It will be necessary to invest in nature-based pilot programs and projects to maintain existing



South Bay Projects

Map illustrating completed and proposed coastal resilience projects within the South San Diego Bay Unit of the San Diego National Wildlife Refuge.



Pond 15 Breach

Pond 15 was breached in February 2025 after more than a decade of work on the Otay River Estuary Restoration Project (Sally Brown - U.S. Fish and Wildlife Service).

tidal marshes as sea levels rise. For example, developing a regional sediment management plan that emphasizes the beneficial reuse of all suitable dredged material from the Bay, flood-control channels, and other watershed sources would help increase sediment available to marshes and develop best practices for adaptive management (e.g., determining the location, volume, and frequency of sediment placement and thin-layer placement that do not cause unacceptable impacts to biological resources). The permitting timeline for tidal marsh restoration can be lengthy, requiring careful analysis of trade-offs between short-term impacts and long-term benefits. Supporting efforts to develop programmatic permits to streamline the regulatory process can help address this constraint (see Appendix 4).



Tidal marshes are particularly vulnerable to sea level rise because marsh vegetation is adapted to a specific tidal-inundation regime. Marsh elevation is maintained through the accumulation of mineral sediment on the surface of the marsh and through the input of organic matter from local plant production. As the sea level rises, the depth, duration, and frequency of marsh inundation will increase, stressing marsh vegetation. Stressed marsh vegetation will lead to decreased accretion and a loss in marsh elevation, which in turn will lead to more inundation and further plant stress. With this negative feedback loop, tidal marshes might “drown” and convert to mudflat. With sea level rise, planners can prioritize areas that have both proximal sediment supply to promote sediment deposition and migration space at the back of marshes to allow marshes to naturally retreat.

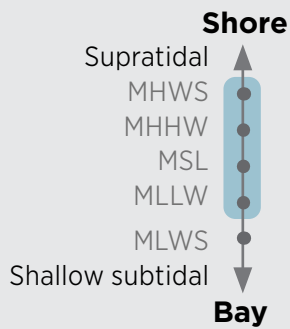


Sweetwater Marsh

South of the D Street fill, Sweetwater Marsh preserves a remnant of the historic tidal wetlands that once bordered much of southern San Diego Bay prior to twentieth-century harbor deepening and navigation improvements.



Location Within The Tidal Transect:



Examples:

- Aramburu Island, Marin County
- Heron's Head Park Shoreline Resilience Project, San Francisco

Benefits:

L Limited, **M** Moderate **H** High



Habitat Enhancement



Water Quality Improvement



Carbon Sequestration



Flood Risk Management



Public Access

Constraints:

\$ Limited, **\$\$** Moderate, **\$\$\$** High

L Limited, **M** Moderate, **H** High



Cost



Permitting Complexity

Suitability:

Moderate wave energy and sediment supply (mostly existing beaches along the North Bay, Coronado Island, and Silver Strand); pocket beaches landward of the shoreline in recreation/open space areas; coarser beaches in front of eroding marshes and structural shorelines.

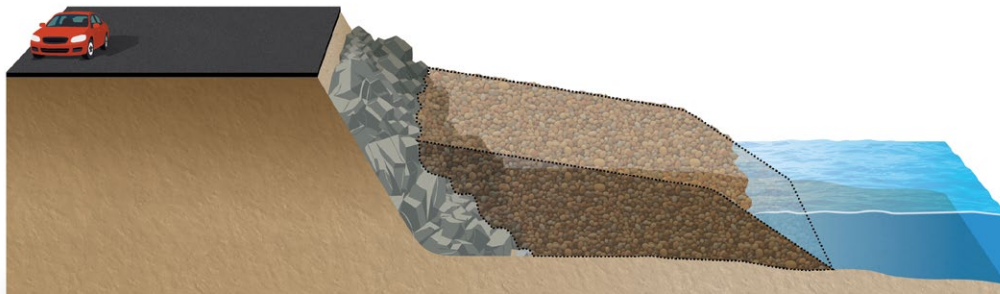
Beaches

Beaches are dynamic features that consist of sand, gravel, and cobble, either from natural sources (e.g., sand spit) or through engineered nourishment. Beach sediment grain size varies in the Bay. Most sandy beaches were built and are actively maintained for recreational use, such as Spanish Landing and Coronado Tidelands. Kellogg/La Playa Beach was a historically natural pocket beach but is currently nourished to address erosion. Crown Cove and other pocket beaches along the Bay side of the Silver Strand are part of a naturally occurring sand spit. On Ballast Point and to the south of Ballast Point, there are natural cobble bluff-backed beaches along Point Loma. Outside the Bay due to the larger sand supply and wave energy of the open coast, there is space to expand vegetated dunes south of Zuniga Jetty from Breaker's Beach to Hotel Del Coronado. As part of a natural sand spit, this area historically supported dunes, and the Zuniga Jetty reinforces local sand accumulation along the shoreline. Along Central Beach, routine grooming and heavy foot traffic currently suppress dune formation. Reducing grooming efforts, retaining wrack, adding fencing for access control, and planting native foredune species are standard measures to let dunes establish naturally.

During normal tides, waves break and dissipate energy over the beach face. During storms, waves reach the supratidal berm, and gravel and cobble tend to move upslope, such that backshores accumulate coarser sediment. Coarser beaches have slopes as steep as 4H:1V, whereas sandy beaches have slopes ranging from 8H:1 to 15H:1. Within their reduced footprint, coarse beaches dissipate wave energy over shorter distances and can therefore help stabilize the shoreline in locations that are eroding or subject to increasing wave action. Precedent fringing coarse beaches have been implemented and proposed along eroding marsh edges in numerous locations in San Francisco Bay. The dynamics of the bayward edge of the marsh is extremely important because marsh retreat is thought to be the chief mechanism by which marshes worldwide are being lost (SFEI ASC 2015). In urbanized estuaries, perched coarse beaches bayward of hardened shoreline, such as riprap and seawalls, have also been shown to enhance the performance of those measures by buffering them from wave energy while increasing habitat where little existed before (USACE 2024). Coarse beaches are generally less erodible than sandy beaches.

**A**

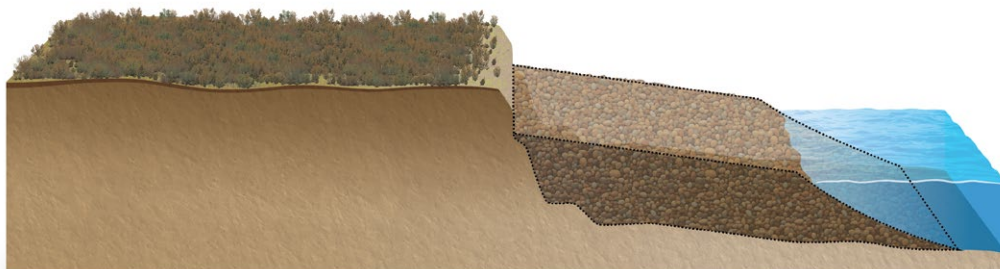
Replacement for or addition to riprap

**Coarse Beach Placement Concepts**

Conceptualized profiles of a coarse beach can serve multiple purposes. Other placements and locations are possible and should be piloted, monitored, and evaluated for effectiveness.

B

Protection for an eroding marsh scarp



Benefits

Sandy beaches serve as important habitat for foraging, resting, roosting, and nesting bird species, including the endangered California least tern and threatened snowy plover (*Charadrius nivosus*). Coarse beaches create interstitial refugia and wrack-rich foraging zones that support invertebrates. There is extensive literature documenting the wave attenuation benefits of beaches (Bridges et al. 2021). The wider the beach, the more the beach prevents waves from reaching the backshore, thereby reducing maintenance costs and extending the lifespan of inland assets. Community well-being is benefited by the recreational and educational opportunities that beaches provide.

Constraints

Siting beaches in shallow locations that minimize the need for fill is an important feasibility consideration. Erosion can reduce beach performance, and sediment retention structures, such as groins, may be required to limit sediment losses from the system and maintain beach function over time.



Beach Elegant Terns

Terns in flight and resting along the shoreline, highlighting the importance of beach habitat for nesting and foraging activities.

Beaches can respond to changes in tidal extent, wave dynamics, sediment variability, and other site conditions if they have sufficient sediment and space. However, given the Bay's reduced sediment supply and predominantly developed shoreline, beaches would likely decrease in width over time. As the sea level rises, the frequency of required nourishment is likely to increase. Opportunities to beneficially reuse dredged material to nourish beaches and acquire backbeach land to enable landward migration of the beach would increase sea level rise resilience.

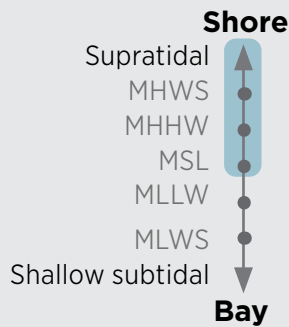


Crenulate Shoreline

Pocket beaches within Oakland Middle Harbor, demonstrating how cove and headland formations shape crenulate shorelines along the coast.



Location Within The Tidal Transect:

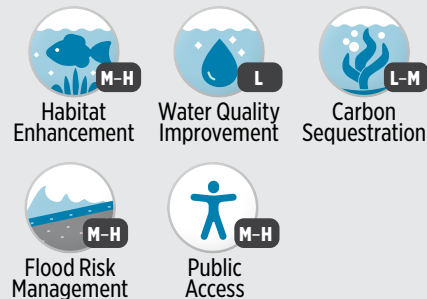


Examples:

- Sears Point Restoration Project, Sonoma County
- Palo Alto Horizontal Levee Pilot Project

Benefits:

L Limited, **M** Moderate **H** High



Constraints:

\$ Limited, **\$\$** Moderate, **\$\$\$** High

L Limited, **M** Moderate, **H** High



Suitability:

Adjacent to marshes and/or in recreation/open space areas where there is sufficient space landward of the shoreline for gently sloping levee; may be incorporated into flood-risk management projects.

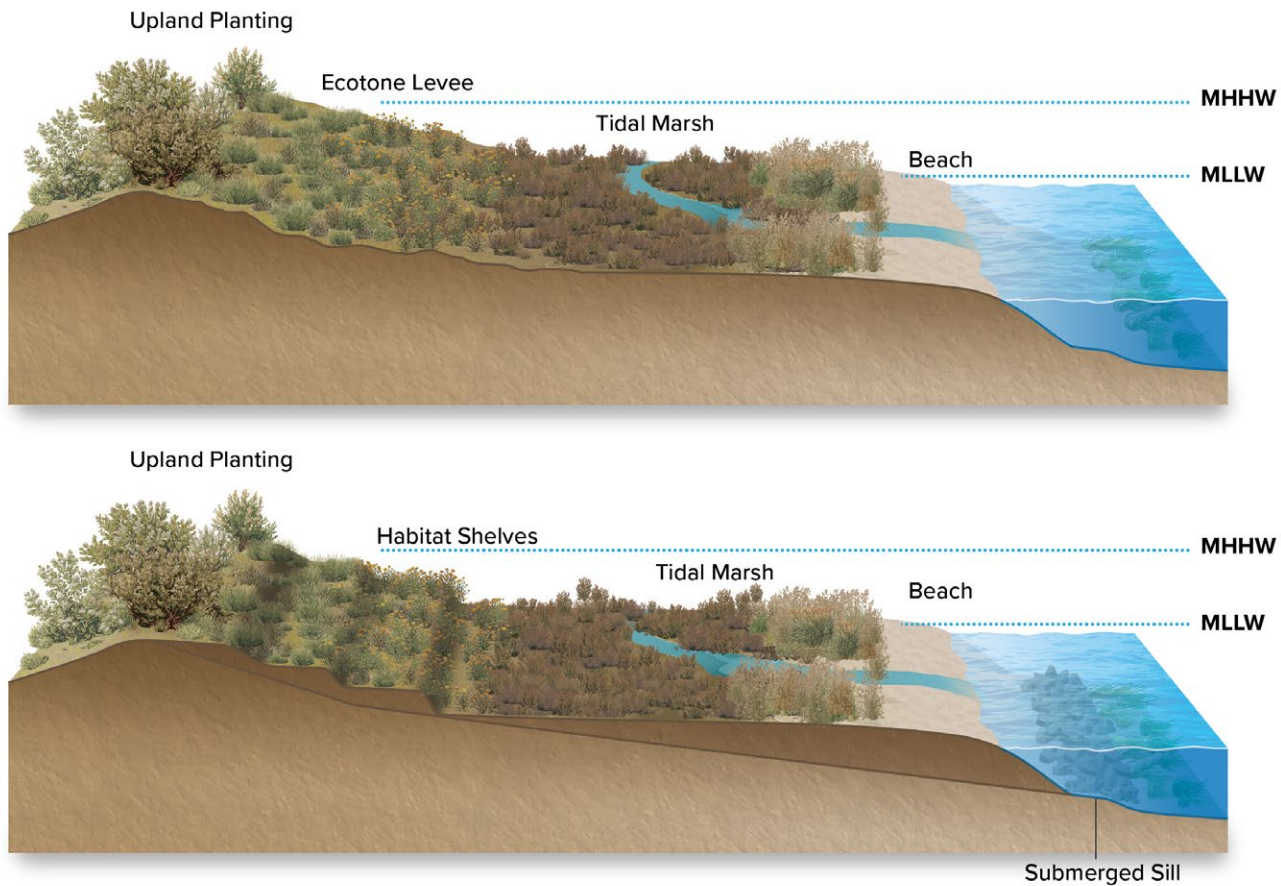
Ecotone Levees and Embankment Slopes

Ecotone levees refer to the modification of a traditional flood risk management levee to vegetated shallow slopes (also referred to as “horizontal levees”). The slope of an ecotone levee is much gentler than a normal flood risk management levee (2H:1V to 4H:1V), more akin to the slope of natural transition zones in broad alluvial valleys. Ecotone levees connect the upper intertidal zone (high marsh around MHHW) to the elevation of the flood risk management levee crest. Embankment slopes are similar to ecotone levees but feature steeper slopes, allowing for use at more constrained sites. Embankment slopes can include submerged sills and terraced slopes to reach suitable elevations along a relatively narrow shoreline.

Enhancing transition zones requires space and sediment. Ecotone levees and embankment slopes range from 30H:1V to 7H:1V, respectively. Ecotone levees are particularly compatible in the South Bay because there is room for transition zones and landward migration, and urban development requiring flood protection is adjacent to tidal marsh/salt pond habitat. Ecotone levees and embankment slopes are less appropriate along steep, hardened shorelines in the Central Bay. To reduce the initial amount of fill required, it might be possible to construct the transition zone in stages that are phased based on the observed rate of sea level rise, the availability of dredged material, and financial resources. An initial, smaller berm could be built at the outboard edge of the transition zone, with fill placed behind it over time. Establishment of transition zones will involve topsoil preparation and active revegetation using techniques to increase target-native vegetation and inhibit weed invasion.

Benefits

Ecotone levee and embankment slope benefits are positively correlated with size: the larger the distance between the toe and crest, the greater the benefit. These gentle slopes



provide high tide refugia and habitat connectivity as well as space for transition zone function and marsh landward migration. In addition, ecotone levees and embankment slopes dissipate wave energy and reduce wave runup, thereby reducing the traditional levee crest height required to provide the same level of protection. Furthermore, the tops of ecotone levees and embankment slopes are great locations for trails, which expand recreational and educational opportunities. Ecotone levees and embankment slopes also recreate and increase gradual, undeveloped slopes to allow intertidal habitats to migrate landward as sea level rises.

Constraints

Shallow slopes require space and considerable volumes of sediment to construct and incur associated costs. This significant spatial requirement makes them incompatible with many shorelines that are squeezed between the Bay and urban development. For example, the Bayshore Bikeway Resiliency Project



Ecotone Levee and Embankment Slope Schematic

Schematic illustrating the conceptual design of an ecotone levee (upper) and embankment slope (lower), depicting the transition of habitat zones across the different profiles.



Ecotone Levees and Embankment Slopes



La Playa Cove

Before: South La Playa Cove's failing shoreline. **After:** A cobble berm buttresses the shore, raising a marsh bench and stabilizing the coastline.



determined an ecotone levee design crest height of 12.5 feet (GHD 2023)¹. Assuming a minimum slope of 7H:1V, the ecotone slope would need to be 30 feet wide. This space may be easier to accommodate when restoring salt ponds to tidal marsh. Within existing marshes, there may be difficult trade-offs between preserving marsh now and planning for marsh in the future in light of sea level rise (converting existing marsh to upland). Resource agencies can consider adaptive management and the possibility of placing fill along the upper edges of the transition in small areas annually (or in years when fill is available), allowing for limited, temporary habitat impacts. Unsorted dredge or upland material would be suitable fill. However, the material would need to be coarse enough to allow for infiltration, and most maintenance dredging results in relatively fine-grained sediment. Clean-capping soils, up to a thickness of 3 feet, would be required to accommodate the rooting zone of the terrestrial native species. Ecotone levees are largely untested, so monitoring the establishment of natural terrestrial plant communities in the near term and the transgression of these communities over the longer term would be necessary.



Otay River Floodplain

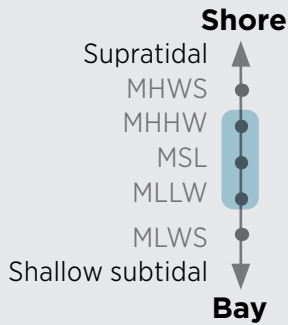
An ecotone slope is being constructed along the Otay River floodplain to transition gradually from the levee crest down toward the channel, creating a gently sloping elevation gradient that supports upland-to-tidal habitat connectivity and improves resilience to sea level rise.

Photo by Dr. Laurie Koteen.

¹ Max tide + SLR + Freeboard = 7.8 feet + 3.5 feet + 1.2 feet = 12.5 feet (NAVD88).



Location Within The Tidal Transect:

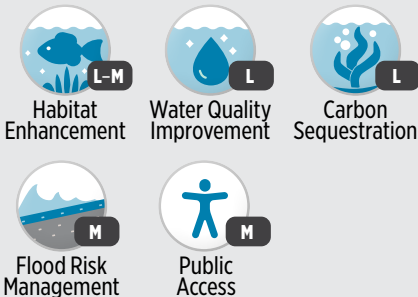


Examples:

- EConcrete COASTALOCK Blue Economy Pilot Project, Harbor Island, San Diego Bay
- Rocky Intertidal Albany Bulb Shoreline, San Francisco Bay

Benefits:

L Limited, **M** Moderate **H** High



Constraints:

\$ Limited, **\$\$** Moderate, **\$\$\$** High

L Limited, **M** Moderate, **H** High



Suitability:

Similar to riprap, 2:1 to 4:1 slopes exposed to moderate wave energy and currents (little room between the Bay and upland development).

Ecological Armoring

Ecological armoring is a nature-based alternative to traditional riprap, designed to mimic natural characteristics, such as rocky intertidal habitat, and provide heterogeneity to shoreline margins while providing shoreline protection from wave erosion. Ecological armoring can take different forms, such as interlocking armor units, varied riprap size and shape, variable substrate integration, and dramatic elevation differences. Materials can be stone, shell material, precast concrete units, or other materials with surface topology and textures that promote desirable organism colonization that can be sustainably sourced and used in the construction of ecological armoring solutions. Design focuses on material composition, microscale relief, and macroscale configurations to reduce wave energy, limit erosion, retain substrate elements, and support habitat complexity. By breaking and dissipating wave energy across complicated surfaces, ecological armoring can create natural characteristics such as tidepools that retain perched water, quiescent water protected from open Bay wave energies, and roosting areas above most of the tidal range.

Ecological armoring is ideal when there is not enough space to deploy other nature-based strategies such as eelgrass, mudflats, tidal marshes, ecotone levees, and beaches. Ecological armoring may be more suitable in the North Bay than the South Bay due to the dominant existing shoreline type, higher wave energy, and relatively lower sediment supply, which limits smothering of organisms on rocky shorelines. Ecological armoring may extend below the tidal zone to attenuate wave energy distributed below the water line. Ecological armoring can be integral to shoreline protection or applied as a surficial enhancement to promote physical and biological functions such as wave energy dissipation, runoff reduction, increased biodiversity, and focused resource enhancement (e.g., native oyster or shellfish).



Benefits

The benefits of ecological armoring primarily come from enhancing biodiversity along hardened shorelines and reducing wave runup in areas where space is at a premium and there remains a desire to increase habitat function. While the per-unit-area functional lift of ecological armoring tends to be lower than some of the more natural habitat options, it may be the best available shoreline solution for highly restricted shorelines. The benefits of ecological armoring may be greater when dealing with severely reduced habitat function in extensively urbanized environments. Permitting may be a shorter process with fewer requirements because work is within an existing developed footprint and the habitat enhancement represents an ecological uplift compared to the existing condition. Replacing traditional riprap



Revetment Shoreline

Revetment shoreline with low intertidal rocky habitat barrier and reduced-energy flat of crushed oyster shell and sand to enhance shellfish recruitment and provide a variable foraging area for shorebirds and wading birds (Albany Bulb, San Francisco Bay).



Pocket Gravel Beach

Pocket gravel beach formed by riprap peninsulas and islands to create containment for gravel fill. The peninsulas and islands are designed to provide enough elevation to be seen at all tides and to provide roosting habitat and a full intertidal zone for habitat development. Varied rock size and slope adds to the heterogeneity and increases diversity within the feature (Albany Bulb, San Francisco Bay).

with ecological armoring could provide increased longevity to a structural shoreline while creating additional habitat. Wave reflection off a revetment can scour the toe and displace armor stones, undermining the structure and causing progressive failure. In contrast, ecological armoring can be designed with more heterogeneity, which provides more effective wave attenuation and better preserves the structural integrity of the shoreline.

Constraints

Low-energy environments may deposit sediment on ecological armoring. Some of the ecological armoring solutions may extend protrusions into the Bay or lay back slopes to broader widths. As a result, the design would need to consider navigation concerns and subtidal slopes to ensure the sites can accommodate shoreline modifications. Ecological armoring cannot migrate landward, so designs must provide future accommodation space for intertidal species to reduce the risks associated with coastal squeeze.



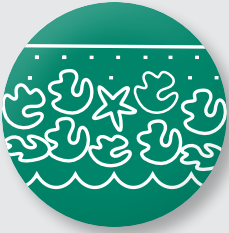
ECONcrete COASTALOCK

Interlocking tide pool units pilot project installed along the existing armored shoreline of Harbor Island, San Diego Bay. Installed in 2021, this was the first installation of these units in the world, and its performance has informed and catalyzed similar projects around the globe. Post-construction monitoring has indicated establishment of a high-functioning ecosystem while providing structural integrity equal to or greater than the existing rock revetment.

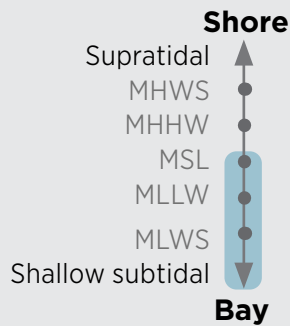


Mixed-Rubble Shoreline

As compared to steeper, large-rock revetment, a relaxed, mixed-rubble shoreline provides a wider intertidal zone and greater moisture retention, favoring a mix of algae and invertebrates. Wave runup can be reduced by integrating a greater diversity of rock sizing and variable shoreline angles (Albany Beach Shoreline, San Francisco).



Location Within The Tidal Transect:



Examples:

- Port of San Francisco Living Seawall Pilot Study

Benefits:

L Limited, **M** Moderate **H** High



Habitat Enhancement



Water Quality Improvement



Carbon Sequestration



Flood Risk Management



Public Access

Constraints:

\$ Limited, **\$\$** Moderate, **\$\$\$** High

L Limited, **M** Moderate, **H** High



Cost



Permitting Complexity

Suitability:

Existing vertical, hard shorelines (seawalls, bulkheads, quay walls) exposed to high wave energy; living seawalls add ecological features but do not replace the hard shoreline and deep-water infrastructure.

Living Seawalls

In locations with existing armoring and deep water, there is not space for large-scale nature-based strategies that may extend into the Bay. Living seawalls are vertical enhancements (e.g., textured panels) designed to be integrated with or attached to traditional seawalls. They can provide surface complexity through textures, grooves, crevices, and nooks along hardened structures where little habitat previously existed (USACE 2024). Materials and textures can be specifically designed to promote the recruitment of targeted organisms, such as algae, invertebrates, bivalves, and small fish on otherwise barren seawalls. Living seawalls are installed above the sediment line at subtidal and intertidal elevations. Living seawalls are a space-constrained option used where a vertical shoreline is nonnegotiable.

Benefits

Living seawalls provide modular, removable habitat on existing structures. They can recreate rocky habitat and improve connectivity by serving as stepping stones to adjacent habitat patches without encroaching into navigation channels or requiring operational changes. The recruitment of bivalves can improve water quality and clarity through filtration.

Constraints

Living seawalls are best treated as an ecological upgrade to necessary hard infrastructure. However, habitat gains are likely microscale and species selective. Siting living seawalls in and around a working waterfront or naval facility requires careful consideration of operations, security, and maintenance (e.g., seawalls must be kept outside of berthing and fender envelopes and avoid obstruction to intakes/outfalls).

Living seawalls are fixed features and do not have adaptivity capacity to keep pace with sea level rise because seawalls are designed to limit overtopping for a particular condition (extreme water level and wave runoff). The level of protection that seawalls provide will decrease with sea level rise. Increasing water levels reduce freeboard, result in larger waves reaching the wall, and jeopardize the foundation. Given this context, the useful life of existing seawalls is limited, and living seawalls provide near-term habitat benefits until longer-term, more comprehensive strategies are developed and implemented.



Living Seawalls

Port of San Francisco Living Seawall Pilot Project.

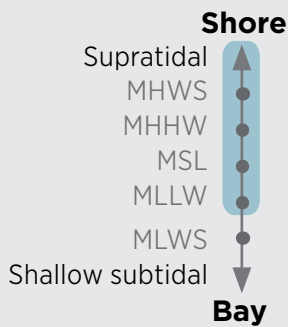


Habitat Panels

Sydney Harbor Living Seawall Project.



Location Within The Tidal Transect:

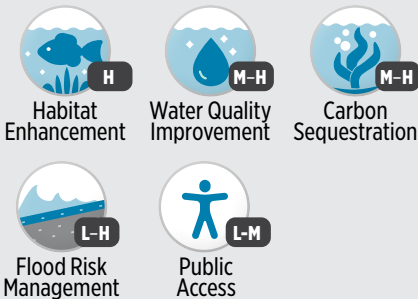


Examples:

- Calabazas and San Tomas Aquino Creeks into Pond A8, Santa Clara Valley, San Francisco Bay
- Otay River Estuary Restoration Project

Benefits:

L Limited, **M** Moderate **H** High



Constraints:

\$ Limited, **\$\$** Moderate, **\$\$\$** High

L Limited, **M** Moderate, **H** High



Suitability:

Limited because there are few channels adjacent to open space in the tidal reach (e.g., Telegraph Creek); Palomar Drain and Otay River depend on the salt production operations and restoration efforts.

Creek-to-Marsh Reconnection

Creek-to-marsh reconnection seeks to reestablish the historical connection between creeks and shoreline habitats (SFEI 2023). Historically, the Bay received freshwater and sediment during the rainy months, with flows becoming intermittent during the dry season, lining the shoreline with deltas, marshes, and mudflats. Historical maps from the mid-1800s show that the Otay River mouth consisted of a series of three or four shifting channels that flowed across a gentle sloping alluvial fan, through the marsh, and into the Bay (Grossinger et al. 2011). During storms, this watershed-derived sediment helped intertidal habitats to adjust their elevations and maintain their positions in the tidal frame. Dams constructed on the Otay and Sweetwater Rivers, as well as the now diverted San Diego River, have radically curtailed freshwater and sediment delivery to the Bay, permanently altering the complex habitat mosaics and high biodiversity that once existed around these river mouths.

Otay R 1916 Flood - Aerial photograph taken in the aftermath of the January 1916 deluge shows Otay River and Tijuana River floodwaters flowing into South San Diego Bay. Source: Raymund Morris, courtesy Water Resources Collections and Archives, University of California Riverside.

Reconnecting creeks to their adjacent marshes through levee breaching and channel realignment is an approach to improve sediment delivery to marshes and is being pursued by the Otay River Estuary Restoration Project (USFWS 2018). This directly addresses the challenge of marshes not having enough sediment to gain elevation at a pace with sea level rise.

Benefits

Creek-to-marsh reconnection is a sustainable and cost-effective way to direct creek flows onto marshes, delivering vital sediment for vertical accretion and sea level rise adaptation. It also establishes salinity gradients, the exchange of nutrients and food resources, and movement corridors between the channel and the marsh. In addition,



marsh-to-creek reconnection can provide a more expansive area for floodwater inundation and potential flood stage reduction.

Constraints

The biggest constraint for marsh-to-creek reconnection is the limited open space adjacent to creeks. To avoid a scenario where flooding the marsh increases flood risk for landward development, it is also important to complete site-specific modeling and other analyses to assess how marsh-to-creek reconnection affects upstream water surface elevations. Reconnecting creeks to marshes can deliver whatever sediment still moves through the watershed; however, the Sweetwater and Otay Rivers are sediment-starved due to regulation, rerouting, and channelization. This means the volume and size of sediment reaching marshes are constrained, and other watershed strategies are needed to more holistically restore sediment transport from creeks to marshes, such as sediment bypass/sluicing, floodplain setbacks, etc. Reconnection projects should also be paired with upstream trash capture, debris interception features, and long-term maintenance



Otay River 1916 Flood

Aerial photograph taken in the aftermath of the January 1916 deluge shows Otay River and Tijuana River floodwaters flowing into South San Diego Bay. Source: Raymund Morris, courtesy Water Resources Collections and Archives, University of California Riverside.



Creek-to-Marsh Reconnection

commitments to reduce the potential for trash and other contaminants flowing into the Bay.

As sea level rises, the tides will extend farther upstream, possibly causing new flooding risks associated with backwater effects and excess sediment deposition as fluvial flood waters meet higher tidal waters. Berms may need to be raised and extended upstream, or development moved back, to make room for riverine and tidal flows. This is an opportunity to realign channels and prioritize sediment delivery for shoreline elevation gain.



Telegraph Creek Marsh

A relatively recent marsh in the bay that was borne by the construction of the J Street Peninsula and rock jetty defining the north side of the South Bay Power Plant Intake Channel. These protective structures have protected the creek delta from wind erosion and allowed sediment to deposit and marsh to develop, demonstrating what's possible when creeks are connected to intertidal areas.





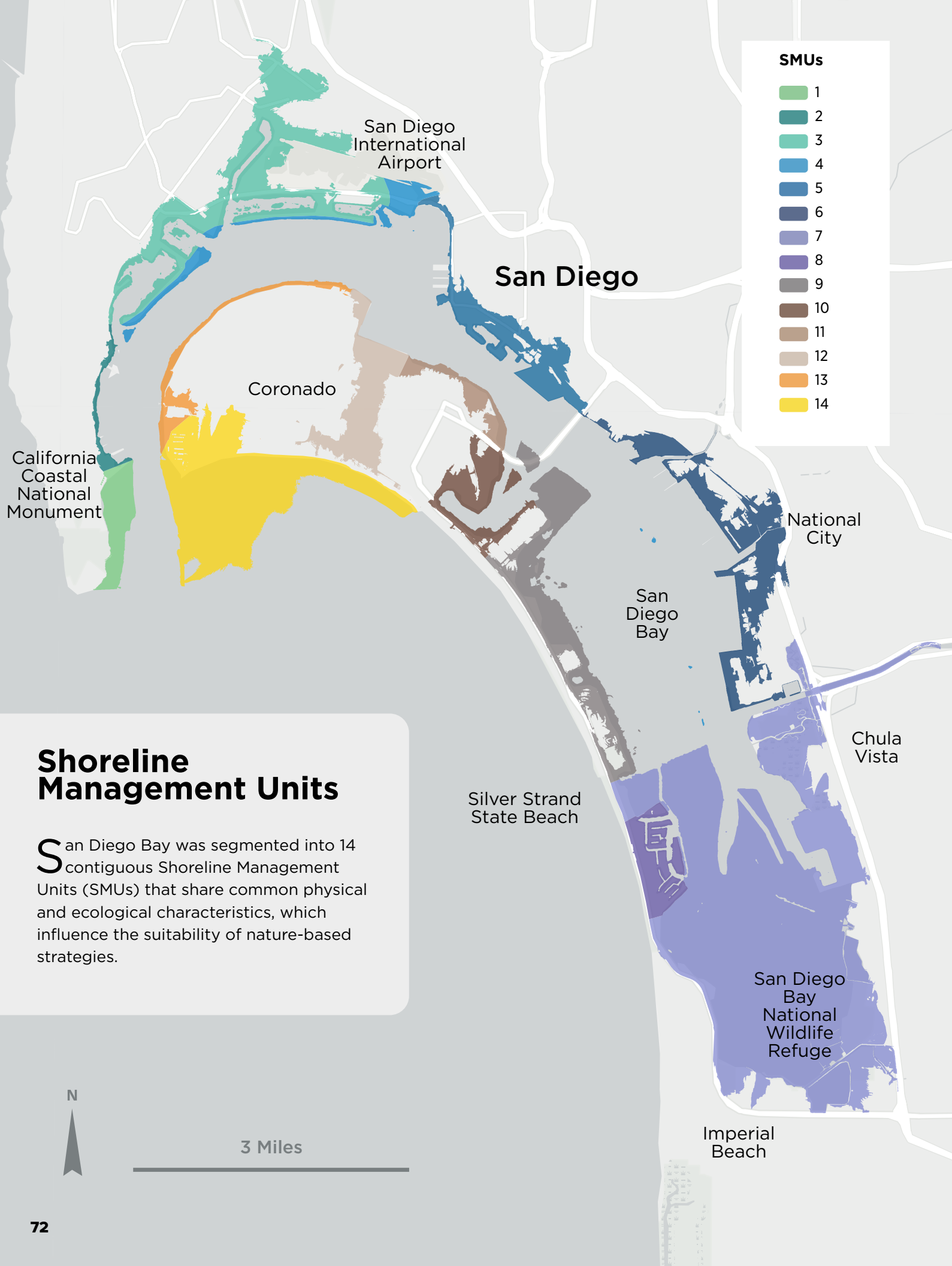
4

Shoreline Management Units

This section divides the Bay into 14 Shoreline Management Units (SMUs) that share similar physical and ecological conditions. Using suitability criteria, a semi-quantitative method ranks nature-based strategies as having limited, moderate, or high suitability at the SMU scale. While SMU-scale rankings do not constitute a site-specific alternatives analysis, they indicate which strategies are generally most suitable given the natural processes operating in different parts of the Bay (Newkirk et al. 2018). Implementation of any strategies will require more detailed and site-specific study, planning, design, and engineering.







Nature's Boundaries

SMUs are contiguous geographic areas defined by unique combinations of environmental variables that influence the suitability of nature-based strategies. They encompass areas vulnerable to sea level rise and storm events where nature-based strategies can be applied. Appendix 2 describes the methods used to delineate SMU boundaries on the bayward, upland, and lateral sides.



View from Cabrillo National Monument on Point Loma

Aerial view of SMU 2 featuring the USNS Waters in San Diego Bay. This shoreline is largely hardened by military and navigational infrastructure, including Naval Base Point Loma Annex, limiting opportunities for nature-based strategies except along select segments such as Smuggler's Cove.

Strategy Suitability Criteria

Rankings: **L** Limited, **M** Moderate, **H** High

NATURE-BASED STRATEGY	WAVE ENERGY	CURRENTS	BATHYMETRY	WIDTH OF SHALLOW SUBTIDAL AND INTERTIDAL ZONE	SOFT SHORELINE	OPEN/ RECREATIONAL SPACE
	Criteria					
	<i>From local wind waves and vessel wakes</i>	<i>Retains sediment in suspension and scours the bottom</i>	<i>Datum MLLW</i>	<i>Interacts with waves and buffers the shoreline</i>	<i>Mudflat, marsh, beach, or open space</i>	<i>Natural areas and parks</i>
 Eelgrass	M	M	-10 to 0	H		
 Barrier Islands	M	M	-10 to 8	M		
 Nearshore Reefs	M	M	-5 to 6	M		
 Mudflats	L	L	-2 to 3	H	H	
 Tidal Marshes	L	L	+3 to 8	H	H	H
 Beaches	M	M	0 to 8	M	L	H
 Ecotone / Embankment Slopes	L	L	3 to 8+	H	M	H
 Ecological Armoring	H	H	-2 to 5	L	L	
 Living Seawalls	H	H	-5 to 3	L	L	
 Creek-to-marsh Reconnection	L	L	0 to 8	H	L	H

Strategy Suitability Rankings

Suitability was determined based on our assessment of the historical, existing, and probable future shoreline conditions; collaboration with government agencies; and best professional judgment. The table below summarizes the required landscape conditions for each strategy to be suitable. For example, eelgrass is suitable in areas with moderate wave energy, moderate currents, bathymetry of -10 to 0 MLLW, and a wide shallow subtidal and intertidal zone. Suitability is based on a threshold approach; strategies are omitted from shoreline areas that do not meet suitability criteria. In other words, eelgrass is also suitable in areas with low wave energy and low currents, but not high wave energy and currents. Not all six criteria apply to the suitability of every strategy. For instance, shoreline type does not apply to eelgrass and is represented as a blank in the Strategy Suitability Criteria table.

To calculate overall suitability for each nature-based strategy by SMU, these six suitability criteria were evaluated using a semi-quantitative method as having limited, moderate, or high suitability based on SMU conditions. The six criteria were weighted with 30% assigned to bathymetry and 30% to width, reflecting their foundational importance, and 10% assigned to the other criteria. Bathymetry determines whether the water depth is appropriate for a given purpose, such as eelgrass sunlight penetration, marsh inundation, etc., while width represents the spatial extent needed to effectively attenuate waves and deposit sediment. Together, these factors establish the physical framework (e.g., bottom slope) that directly influences the feasibility and performance of shoreline habitats. Wave energy, currents, shoreline type, and land use play supporting roles in the suitability analysis and are typically less restrictive compared to bathymetry and width. For example, wave energy affects sediment deposition and plant establishment but can often be mitigated through the strategic placement of structural features. Currents influence nutrient exchange and sediment transport but are secondary to broader physical parameters. Shoreline type and land use determine the compatibility of the strategy with the existing natural and built environment. This weighting results in a final ranking formula that can be applied to each suitable strategy across the 14 SMUs:

SUITABILITY RANKINGS FORMULA

$$\begin{aligned}
 &0.1 \times \text{Wave Energy} \\
 + &0.1 \times \text{Currents} \\
 + &0.3 \times \text{Bathymetry} \\
 + &0.3 \times \text{Width} \\
 + &0.1 \times \text{Shoreline Type} \\
 + &0.1 \times \text{Land Use} \\
 \hline
 = &\text{RANKING}
 \end{aligned}$$

The spatial data on Wave Energy, Currents, Bathymetry, Width, Shoreline Type, and Land Use from each SMU were analyzed using standard geographic information system techniques. Using the formula above, numeric values were assigned to each criterion to reflect suitability: 1 for limited, 2 for moderate, and 3 for high (Appendix 3). If a criterion was not applicable, the weights of the other criteria were adjusted proportionally to total 100%. This adaptive weighting approach ensures a clear and consistent evaluation of strategy suitability across all SMUs. The final rankings were normalized into the three categories of limited, moderate, and high suitability based on the following breakdown:

SUITABILITY RANKINGS		RANGE
L	Limited	1.00 to 1.65
M	Moderate	1.66 to 2.35
H	High	2.35 to 3.00

The SMU Suitability table presents the suitability rankings of all 10 nature-based strategies in each of the 14 SMUs. This summary can be used for comparison and prioritization within and across SMUs, highlighting which strategies are more suitable within an SMU and which SMUs are more suitable for specific strategies. All suitable nature-based solutions are presented purely as options, not proposed projects nor mandatory actions, to serve as a launch point for innovative, site-specific shoreline design.



SMU Suitability

Rankings: **L** Limited, **M** Moderate, **H** High

NATURE-BASED STRATEGY	SMUs													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
 Eelgrass	H	M	M				H		H					M
 Barrier Islands	H		M				H		H					
 Nearshore Reefs	M	M	M				H		H		M		M	L
 Mudflats							H							
 Tidal Marshes			M	M	L	L	H	L	M	M	L			
 Beaches	M	M	M	M	L	M	H	L	H	H	M		M	H
 Ecotone / Embankment Slopes			M				H	L	M	M			L	L
 Ecological Armoring	H	H	M	H	H	H	M	M	L	H	H	M	H	L
 Living Seawalls			H	H	H	H	L	H	L	H	H	L	H	
 Creek-to-marsh Reconnection							H							

Limited suitability does not mean infeasible; it indicates a constrained opportunity because:

- Conditions partially conflict with suitability criteria
- Requires significant traditional gray engineering for implementation

Moderate suitability indicates an opportunity that is likely to perform as intended because:

- Conditions generally satisfy suitability criteria
- Strategy is viable with standard design practices

High suitability indicates a priority opportunity because:

- Conditions closely align with suitability criteria
- Strategy is expected to perform over time at a meaningful scale

Summaries

The following summaries for the 14 SMUs include:

- Map of existing shoreline conditions and habitat types, with a few select areas excluded.
- Map of subset of suitable nature-based strategies, showing specific segments of the shoreline that are prime for further analysis. Based on the findings of the Atlas, it is recommended that these segments be prioritized for funding opportunities to further analyze and design a sustainable shoreline solution that can be considered for future environmental review and implementation.
- Vulnerability findings from Port's Sea Level Rise Vulnerability Assessment & Coastal Resiliency Report (Port of San Diego 2019) and the City of Coronado's Sea Level Rise Vulnerability Assessment and Adaptation Plan (City of Coronado 2022) that nature-based strategies can address.
- Brief discussion of the suitability of nature-based strategies in the SMU based on our assessment of physical and ecological conditions. Note that some strategies are more appropriate or feasible for certain shoreline conditions or habitat types than others, as noted by the limited, moderate, or high suitability rankings.



CLICK HERE TO LAUNCH THE
SAN DIEGO BAY SUSTAINABLE SHORELINES ATLAS

Use online map to Zoom into areas of interest and see baywide data on existing conditions and suitable nature-based strategies





SMU 1

Tip of Point Loma to Ballast Point

Existing Conditions Map

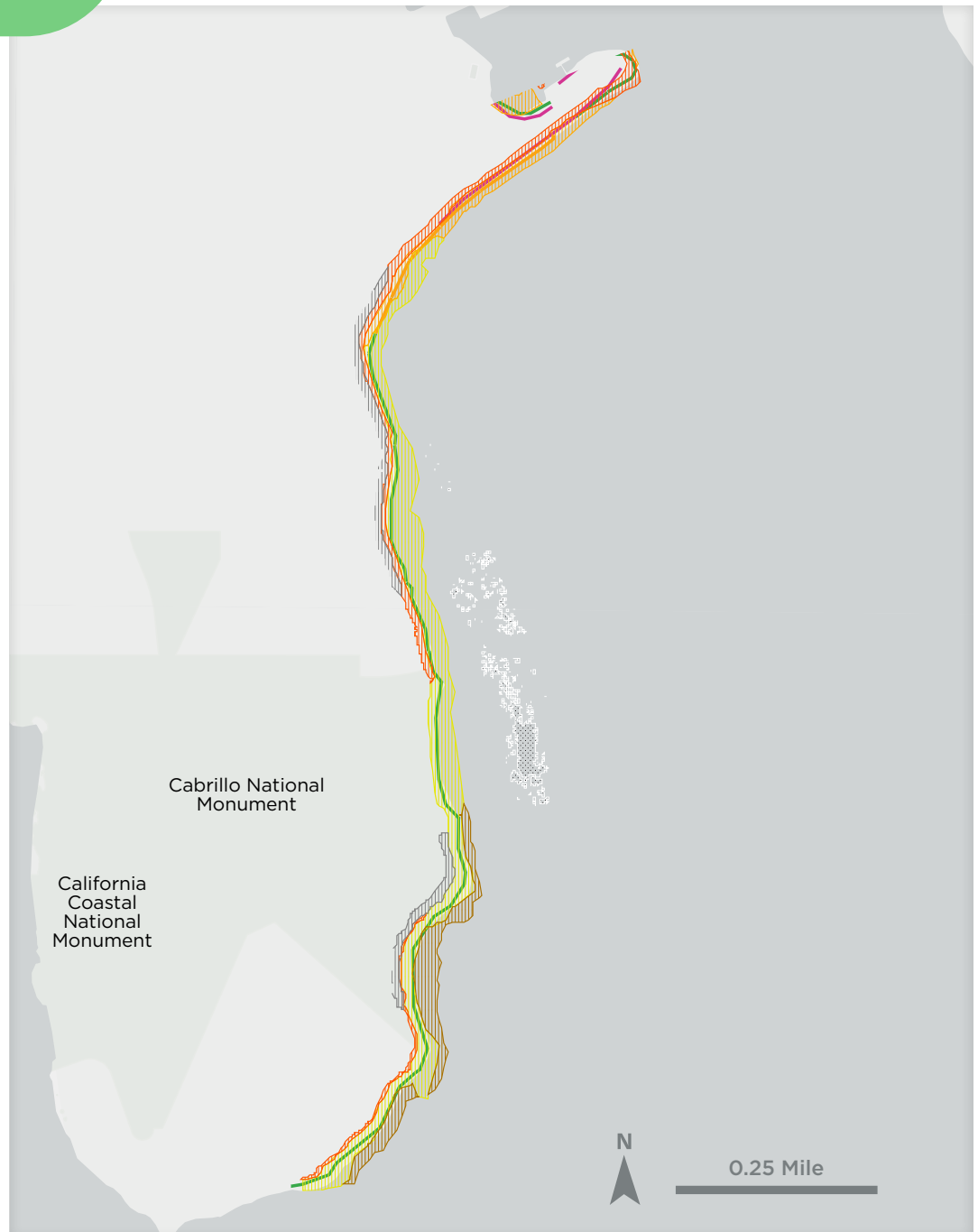
LEGEND

Shoreline Inventory

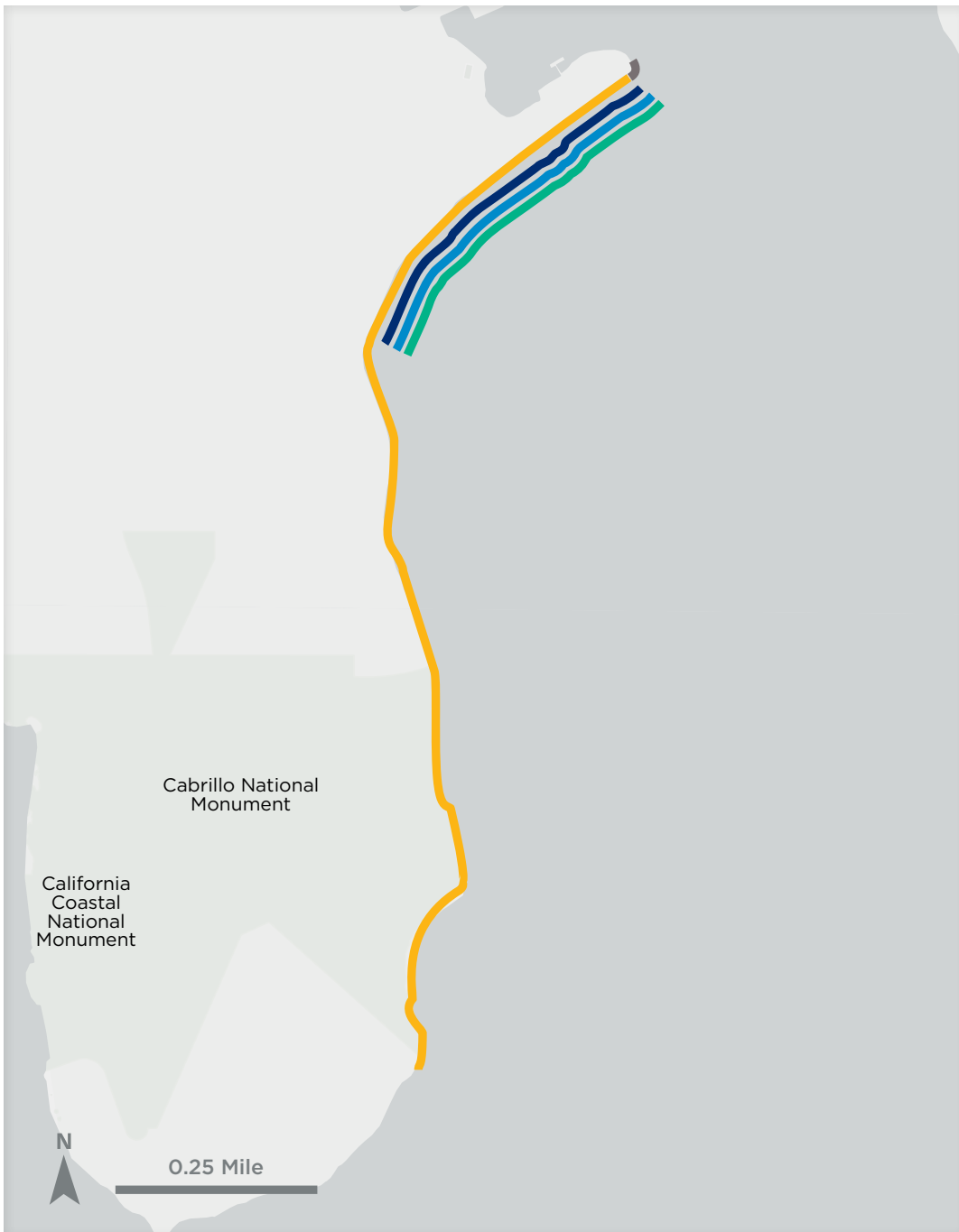
- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- Streams
- Eelgrass
- Cobble Beach
- Mudflat
- Riparian
- Rocky Intertidal
- Salt Marsh
- Salt Ponds
- Sandy Beach
- Undeveloped Upland



The shoreline south of Ballast Point is referred to as the Outer Bay and is uniquely characterized by steep, bluff-backed cobble beaches exposed to swell-driven waves. This high-wave-energy environment eliminates the possibility of sheltered habitats like oyster reefs, mudflats, and tidal marshes.



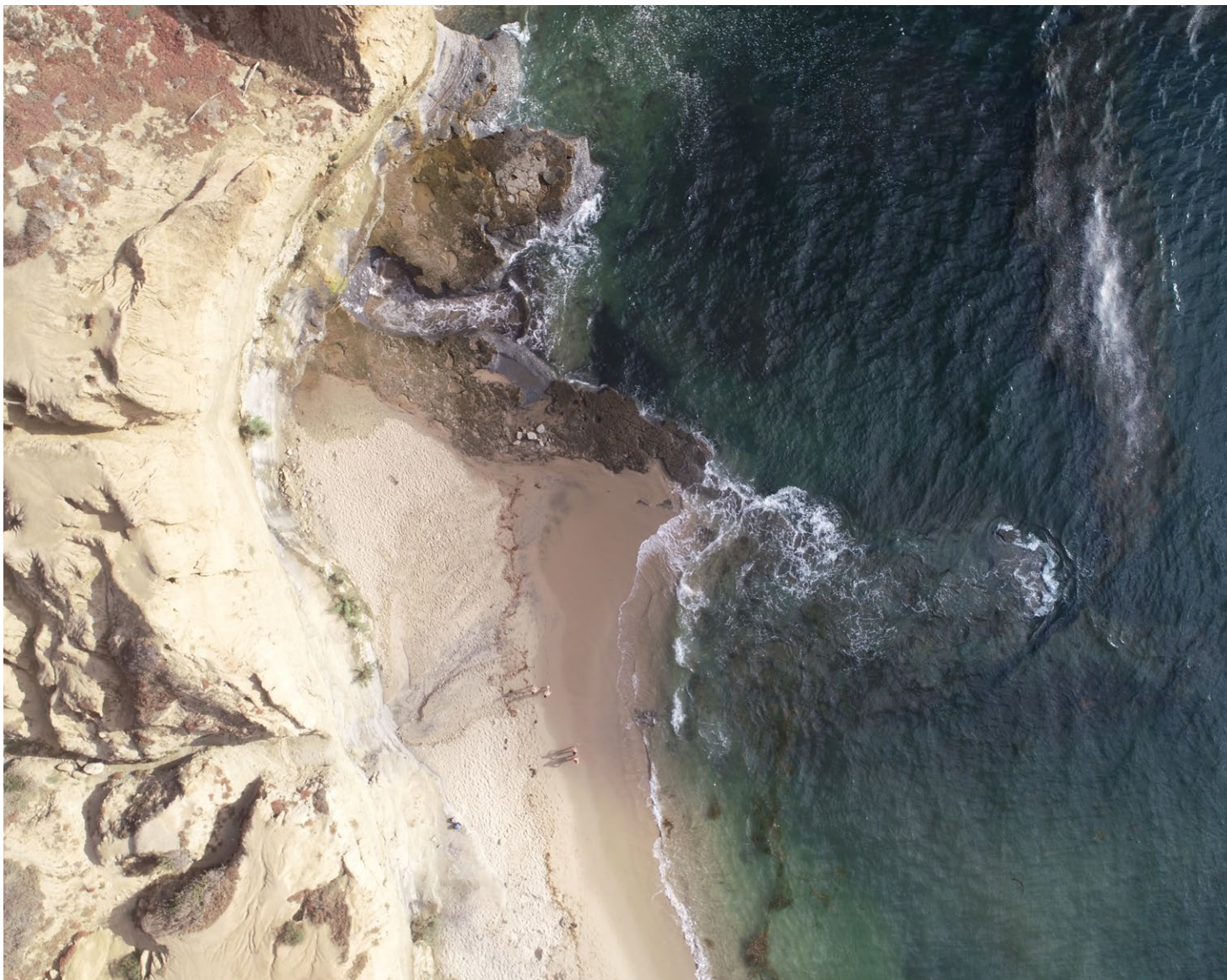
Suitable Strategies Map

LEGEND

Suitability Ranking

- L** Limited
- M** Moderate
- H** High

Suitable Strategies	Ranking
 Eelgrass	H
 Barrier Islands	H
 Nearshore Reefs	M
 Beaches	M
 Ecological Armoring	H



Sunset Cliffs

Natural reefs along the outer coast Point Loma shoreline reduce waves energy and help retain sand in their lee.

Suitable Strategies

Suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Eelgrass (H): Pacific eelgrass was present in the 1990s but suffered major declines during the 2015/2016 El Niño due to wave damage (Merkel & Associates 2024). Beds are variable and can be scoured in rough years and re-established in calmer ones. There is ample space (up to -20 feet MLLW) to reintroduce eelgrass



Barrier islands (H): The area fronting Ballast Point is exposed to high wave energy. This area has a relatively shallow subtidal zone that could accommodate a barrier island, with the concave shoreline geometry maximizing the benefits.



Looking west toward Ballast Point

Ballast Point's shallow subtidal zone and concave shoreline present an opportunity for barrier island protection in a high wave energy setting.



Looking south toward Point Loma

Drawing from Point Loma's rugged west side, elevated rocky reefs could buffer powerful ocean swells near Ballast Point and support resilient intertidal ecosystems.



Nearshore reefs (M): Mimicking the west side of Point Loma, rocky intertidal reefs could help attenuate waves approaching the area fronting Ballast Point. These reefs need to be relatively tall, resembling sea stacks, given the very high-energy oceanic swell waves and could provide a stable substrate for species adapted to these conditions.



Beaches (M): Augmenting the existing cobble beaches with coarse material could assist in mitigating erosion as the sea level rises. This shoreline is too steep and high energy for sandy beaches.



Ecological armoring (H): There are existing revetments in the area near Ballast Point, and ecological armoring could enhance the habitat value of this shoreline infrastructure.



SMU 2

Ballast Point to Shelter Island

Existing Conditions Map

LEGEND

Shoreline Inventory

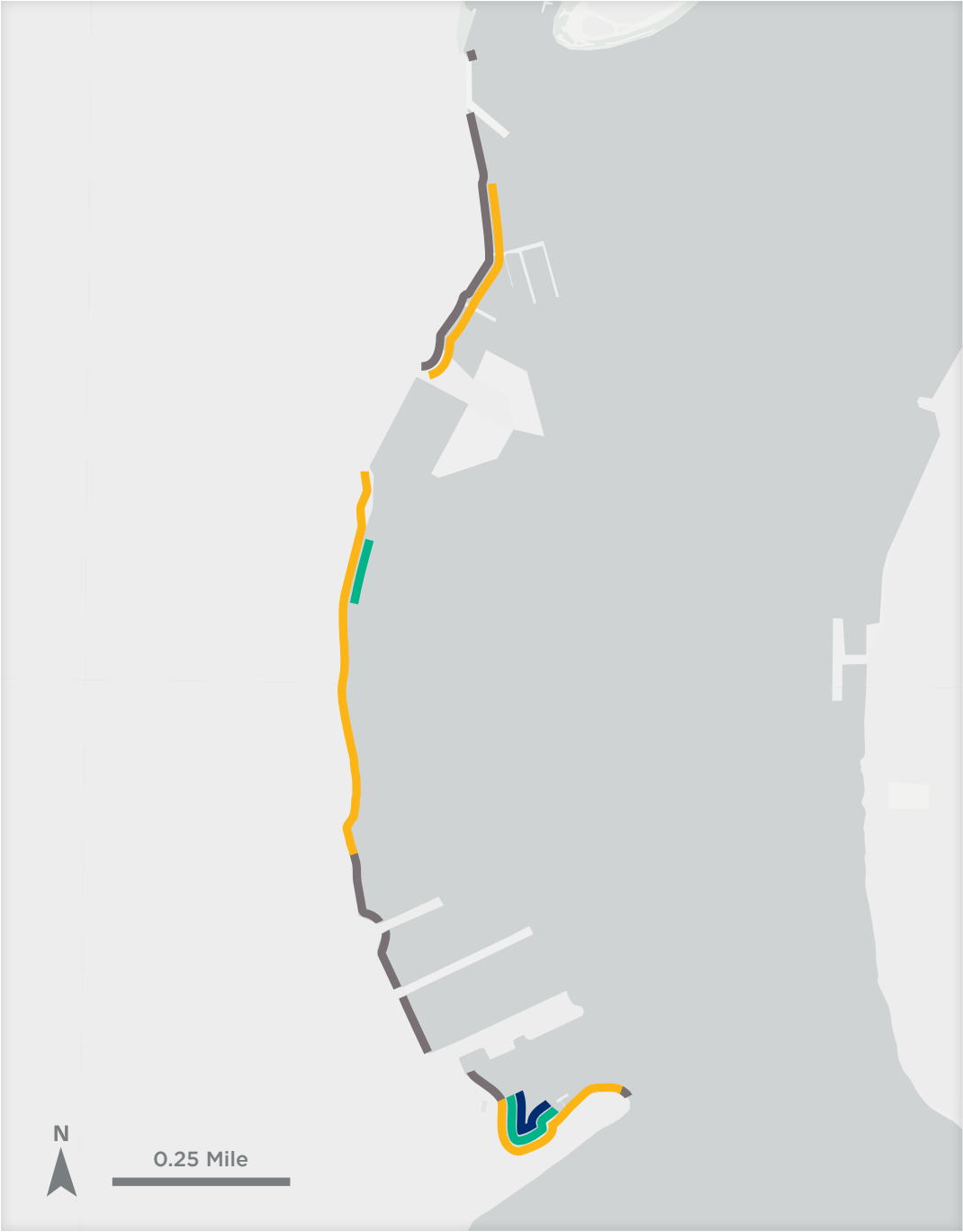
- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- Streams
- Eelgrass
- Cobble Beach
- Mudflat
- Riparian
- Rocky Intertidal
- Salt Marsh
- Salt Ponds
- Sandy Beach
- Undeveloped Upland



This shoreline is characterized by military infrastructure, hard armoring, and the relatively deep and steep nearshore environment associated with navigational basins. There are limited opportunities to implement nature-based strategies, except along specific shoreline segments such as Smuggler’s Cove.



Suitable Strategies Map

LEGEND

Suitability Ranking

L

Limited

M

Moderate

H

High

Suitable Strategies	Ranking
Eelgrass	M
Nearshore Reefs	M
Beaches	M
Ecological Armoring	H



Point Loma Naval Base

Aerial view of the Point Loma Naval Base and surrounding dock facilities along the San Diego coastline.

Suitable Strategies

Suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Eelgrass (M): Eelgrass patches could be expanded within the area north of the Degaussing Pier.



Nearshore reefs (M): To address the eroding beach at Ballast Point, the Smuggler's Cove Reef Project created a buttress reef across the entrance of the cove using repurposed pier demolition rubble from U.S. Coast Guard maintenance dredging to create a shallow lagoon and hold up a beach.



The lagoon was planted with eelgrass to add to the Navy's San Diego Bay Eelgrass Mitigation Bank. Additional reefs along the west side of the cove could be added to reduce wave energy and curtail sand leakage from the beach and shallow lagoon.



Beaches (M): Sandy beaches north of Ballast Point and within Smuggler's Cove could be expanded. Existing sandy beaches north of the Degaussing Pier could also be enhanced. Sand retention measures could improve the longevity of sand placements.



Ecological armor (H): Ecological armor could improve the habitat value of existing revetments, such as those along the Submarine Base, base housing areas, and the Naval Information Warfare Center shoreline.



SMU 3

Backwater Embayments from Shelter Island to Coast Guard Pier

Existing Conditions Map

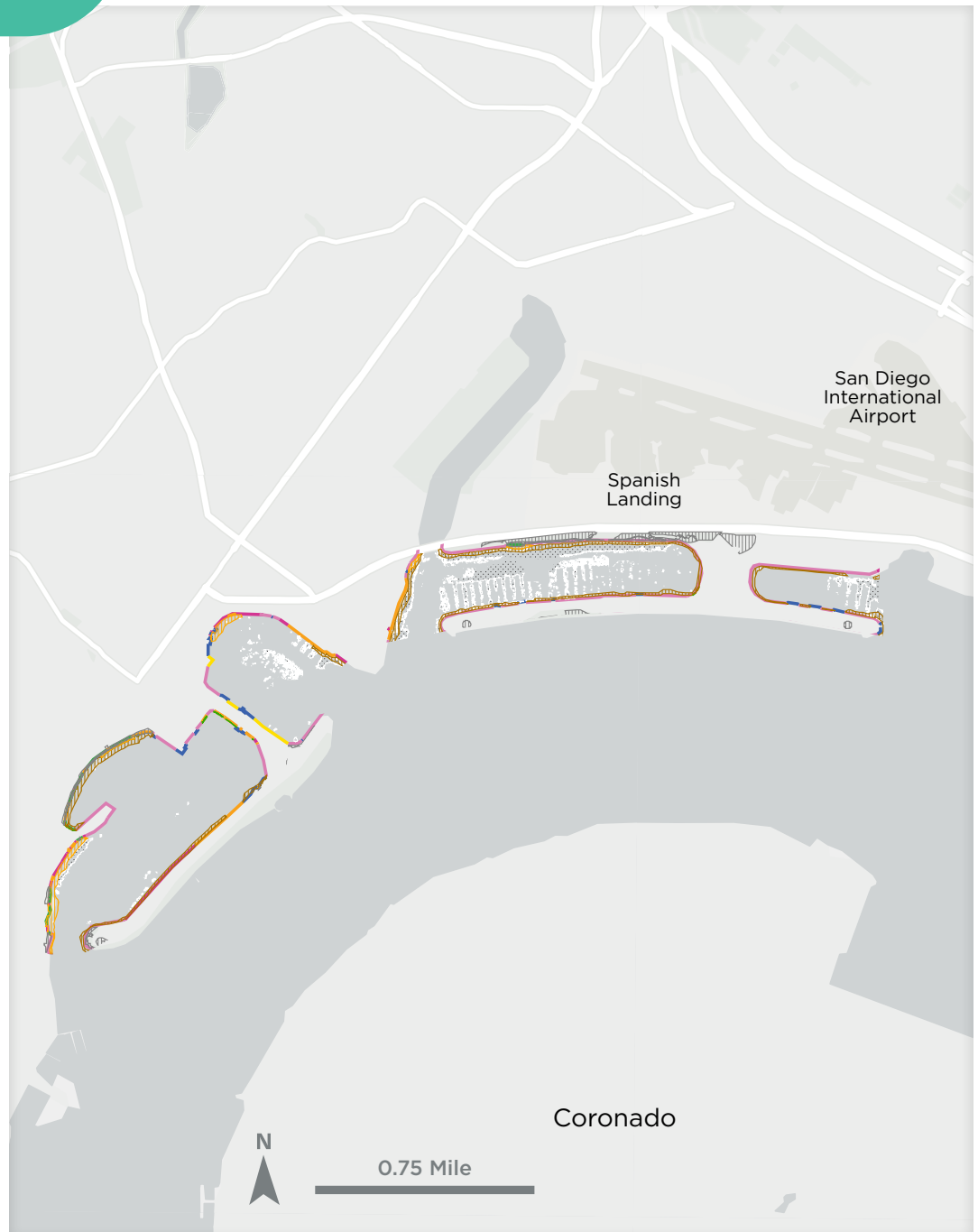
LEGEND

Shoreline Inventory

- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- ▬ Streams
- ▬ Eelgrass
- ▬ Cobble Beach
- ▬ Mudflat
- ▬ Riparian
- ▬ Rocky Intertidal
- ▬ Salt Marsh
- ▬ Salt Ponds
- ▬ Sandy Beach
- ▬ Undeveloped Upland



This shoreline is mostly hardened by revetments, seawalls, and wharves around the San Diego Yacht Club, America's Cup Harbor, Naval Base Point Loma Annex, Naval Training Center Channel, and the San Diego International Airport, with pockets of soft shoreline and open space park areas along Kellogg Beach, La Playa Cove, Naval Training Center Park, and Spanish Landing Park. Notably, the open space Naval Training Park and Spanish Landing Park areas could accommodate "pocket" strategies inland of the existing shoreline.



Suitable Strategies Map

LEGEND

Suitability Ranking

- L** Limited
- M** Moderate
- H** High

Suitable Strategies	Ranking
 Tidal Marshes	M
 Beaches	M
 Ecological Armoring	M



Spanish Landing Park

A peaceful edge of the bay with opportunities for marsh creation and eelgrass restoration.



Vulnerabilities

- **Public Safety:** Emergency access to Shelter Island
- **Transportation:** Low-lying San Diego International Airport and North Harbor Drive
- **Maritime:** Low-lying yacht club and marina facilities
- **Parks and Recreation:** Spanish Landing Park, Kellogg Beach Park

Suitable Strategies

Suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Eelgrass (M): Bathymetry off Kellogg Beach deepens quickly, but downcoast where sediment accumulates near the Southwestern Yacht Club, eelgrass could stabilize the shoreline by trapping some of the sand that escapes the beach, curtailing but not eliminating nourishment needs. Eelgrass was present along the eastern side of America's Cup Harbor and western corner of Spanish Landing in the 1990s and could be reintroduced.



Barrier Islands (M): Convair Lagoon is not used for maritime purposes, and a barrier island could leverage the concave shoreline geometry to help establish a more sheltered environment behind the island, making the area more suitable for other nature-based strategies.



Nearshore Reefs (M): The area between Kellogg Beach and Southwestern Yacht Club has high densities of native oyster and could support nearshore reefs. With its shallow bathymetry and gentle slope, Convair Lagoon could also support nearshore reefs and provide habitat enhancement and wave attenuation, which in turn could protect the adjacent shoreline from erosion and flooding.



Tidal Marshes (M): Tidal marshes could be developed along La Playa Beach near the Bessemer Path by utilizing the beach's gentle north-end slope and terracing the south end. Pockets of Naval Training Center Park and Spanish Landing Park could be reconfigured to create space for a marsh. Marsh creation is also possible in Convair Lagoon, although additional strategies would be needed to protect the area from wave action.



Beaches (M): Kellogg Beach, if artificially stabilized to reduce loss to the adjacent channel, could be augmented. Likewise, the shallow-slope beach fronting the Bessemer Path at La Playa could be expanded. A very small existing beach could be enhanced along the northern and eastern edges of America's Cup Harbor and the area fronting Chauncey Road and Nimitz Bridge. Pockets of beaches could be created to mimic existing beaches in Spanish Landing Park. The beach in Convair Lagoon could also be improved.



Ecotone Levees and Embankment Slopes (M): Ecotone levees could be used along the low-slope north side of La Playa Beach, with embankment slopes applied to the steeper southern slope. There are multiple opportunities to create space landward of the shoreline for ecotone levees in Naval Training Park. Convair Lagoon could also support an ecotone levee, although fill would likely be needed to reach proper elevations.



Ecological Armoring (M): Ecological armoring could be placed in moderate- to high-wave-energy environments, such as those along the Southwest Yacht Club, America's Cup Harbor, NCT Channel, East and West Basin, and Convair Lagoon.



Living Seawalls (H): Living seawalls could improve the habitat value of existing seawalls located in marinas, particularly along the wharves.



View above La Playa Cove Shelter Island

Overlooking San Diego Bay from above La Playa Cove, Shelter Island, with boats and the city skyline stretching across the horizon.



SMU 4

Bayward Exposure of Shelter Island to Coast Guard Pier

Existing Conditions Map

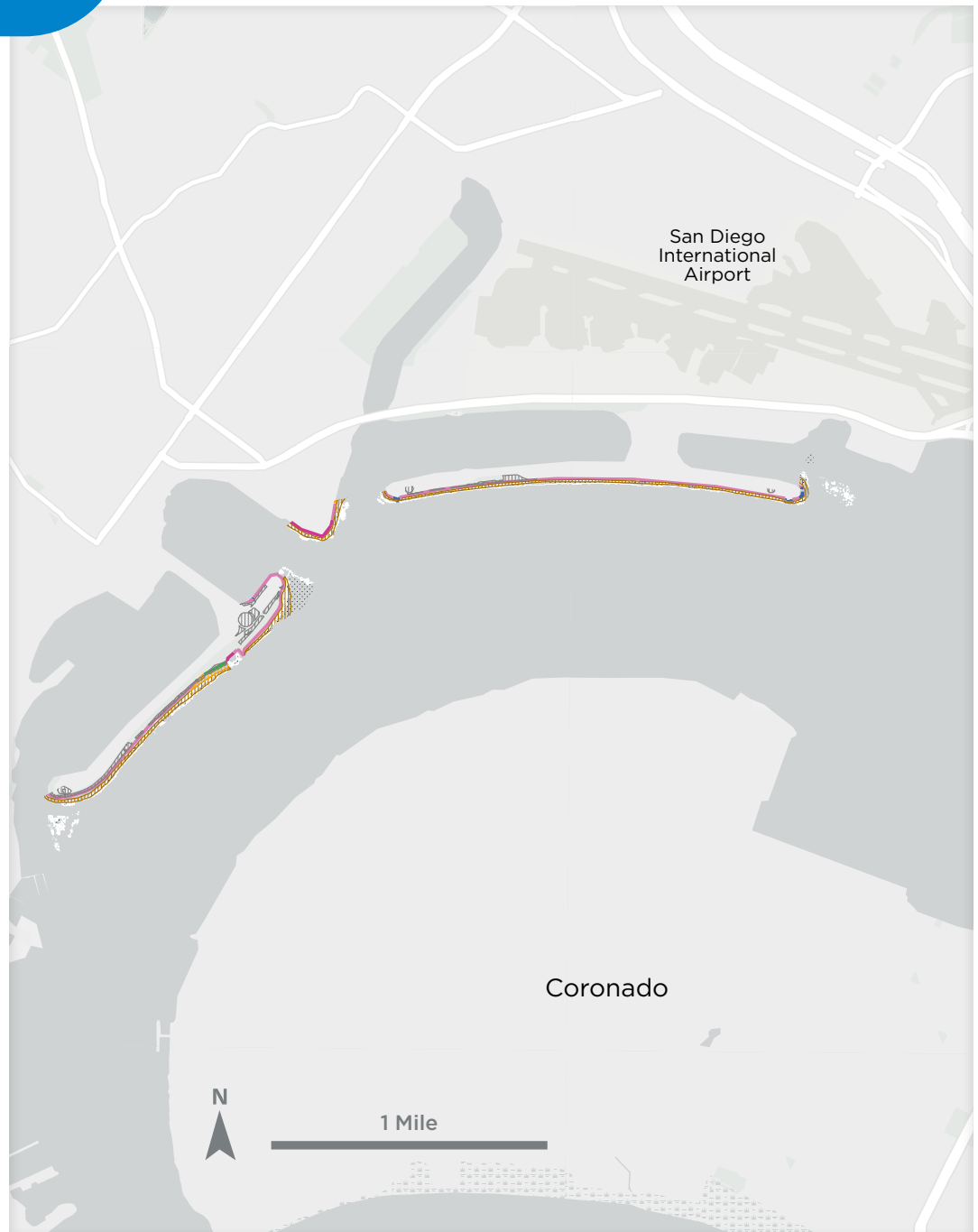
LEGEND

Shoreline Inventory

- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- ▭ Streams
- ▭ Eelgrass
- ▭ Cobble Beach
- ▭ Mudflat
- ▭ Riparian
- ▭ Rocky Intertidal
- ▭ Salt Marsh
- ▭ Salt Ponds
- ▭ Sandy Beach
- ▭ Undeveloped Upland



This shoreline is mostly hardened and exposed to high wave/wake energy. Creating lower-energy conditions appropriate for most nature-based strategies requires looking landward of armored shorelines and leveraging open space at Harbor Island to establish small marsh and beach pocket opportunities.



Suitable Strategies Map

LEGEND

Suitability Ranking

- L** Limited
- M** Moderate
- H** High

Suitable Strategies	Ranking
 Tidal Marshes	M
 Beaches	M
 Ecological Armoring	H
 Living Seawalls	H



Vulnerabilities

- **Public Safety:** Emergency access to Shelter Island
- **Transportation:** Low-lying North Harbor Drive and Bayshore Bikeway
- **Parks and Recreation:** Shelter Island Shoreline Park and Harbor Island Park

Suitable Strategies

Suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Tidal Marshes (M): The Harbor Island Park revetment could be reconfigured to create space for a pocket marsh. For example, a portion could be removed to allow water through, and open space could be graded to marsh elevations to allow for plant establishment.



Beaches (M): The Shelter Island boat ramp groins serve to retain sand on the southwest side of the island, and additional retention structures could expand the beach. Similar to tidal marshes, a part of the Harbor Island Park revetment could be reconfigured, and a small portion of the open space could be converted to a pocket beach, diversifying the recreation experience.



Ecological Armoring (H): Because much of the shoreline along Shelter Island, Harbor Island, and the U.S. Coast Guard station consists of revetment, these revetments could be enhanced with ecological armoring to improve the habitat value of the shoreline.



Living Seawalls (H): Living seawalls could improve the habitat value of discrete existing seawalls located along Shelter Island, Harbor Island, and the U.S. Coast Guard station.



Sample Pocket Beach Opportunity

EXISTING CONDITION



HARBOR ISLAND PARK:

- ① Shoreline revetment
- ② High wave energy
- ③ Narrow width of shallow subtidal/intertidal habitats

OPPORTUNITY POCKET BEACH



RESILIENT CONDITION



- ① Submerged revetment acts as sill holding up perched beach
- ② Lower wave energy landward of sill
- ③ Open space creates room along naturally steep slope



SMU 5

Coast Guard Pier to East Coronado Bridge Landing

Existing Conditions Map

LEGEND

Shoreline Inventory

- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- ▬ Streams
- ▬ Eelgrass
- ▬ Cobble Beach
- ▬ Mudflat
- ▬ Riparian
- ▬ Rocky Intertidal
- ▬ Salt Marsh
- ▬ Salt Ponds
- ▬ Sandy Beach
- ▬ Undeveloped Upland



This heavily urbanized shoreline consists of mostly revetments and seawalls exposed to high wave energy.



Suitable Strategies Map

LEGEND

Suitability Ranking

- L** Limited
- M** Moderate
- H** High

Suitable Strategies	Ranking
 Beaches	L
 Ecological Armoring	H
 Living Seawalls	H



Revetment along the Embarcadero

The inner revetment along Embarcadero Park could be redesigned in specific locations to create space for a pocket tidal marsh landward of the existing shoreline.



Vulnerabilities

- **Transportation:** Low-lying Harbor Drive and Marina Park Way
- **Maritime:** Potential damage and disruption at 10th Avenue Marine Terminal
- **Parks and Recreation:** Tuna Harbor Park and Cesar Chavez Park

Suitable Strategies

Suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Tidal Marshes (L): The inner revetment along Embarcadero Park could be redesigned in specific locations to create space for a pocket tidal marsh landward of the existing shoreline.



Beaches (L): Pocket beaches could be established along Embarcadero Park by modifying the revetment to enable water to flow into a newly formed crescent-shaped area landward of the existing shoreline.



Ecological Armoring (H): Because much of the shoreline in this SMU consists of revetment, these revetments could be enhanced with ecological armoring to improve the habitat value of this infrastructure while maintaining shoreline stability.



Living Seawalls (H): The many wharves, bulkheads, and seawalls, such as those along North Harbor Drive, provide opportunities for implementing living seawalls.



Embarcadero

Pocket beaches could be created along Embarcadero Park by modifying the revetment to allow water into new crescent-shaped areas landward of the shoreline. Existing revetments could also incorporate ecological armoring to enhance habitat while maintaining stability.



SMU 6

East Coronado Bridge Landing
to Sweetwater River Channel

Existing Conditions Map

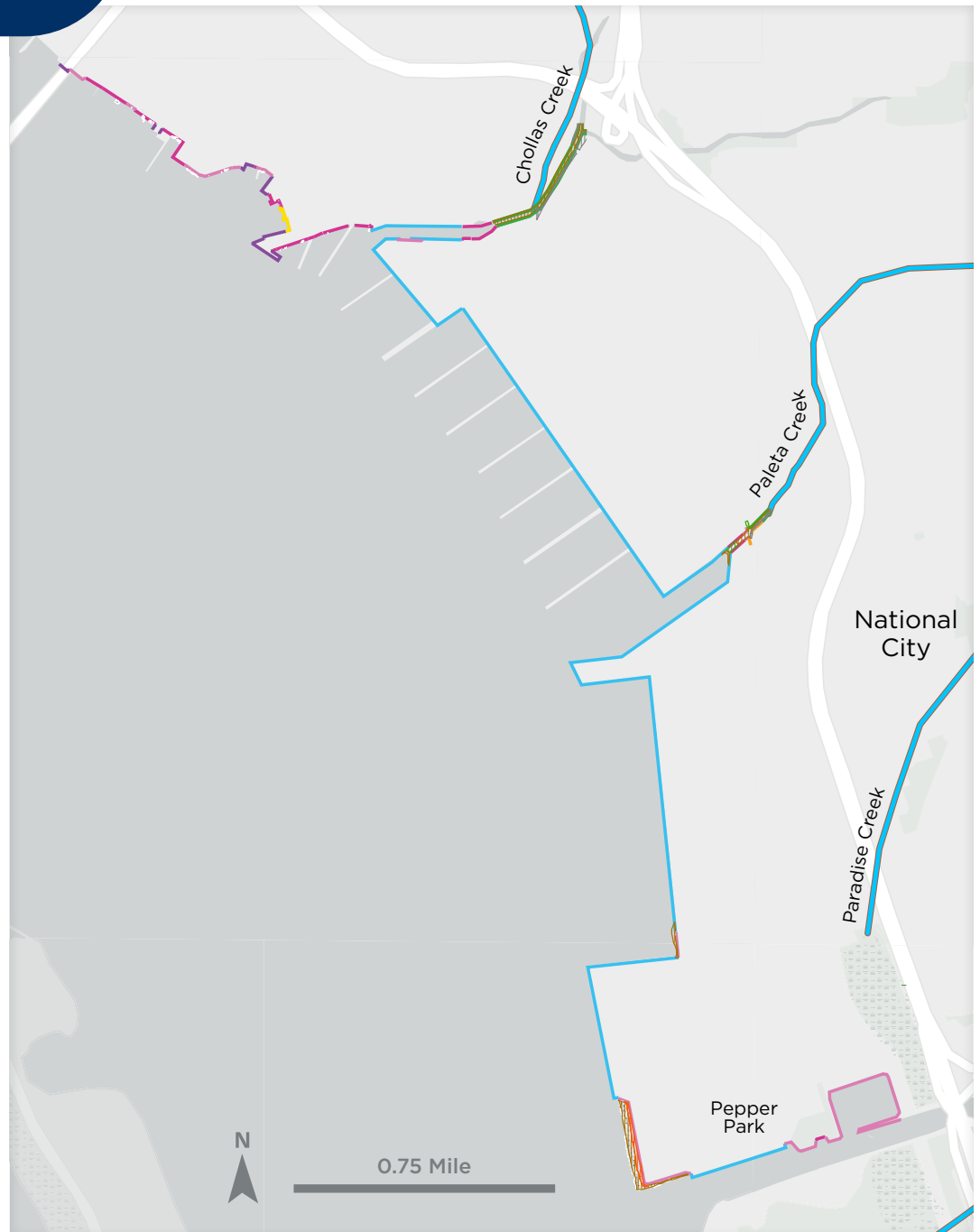
LEGEND

Shoreline Inventory

- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- ▬ Streams
- ▬ Eelgrass
- ▬ Cobble Beach
- ▬ Mudflat
- ▬ Riparian
- ▬ Rocky Intertidal
- ▬ Salt Marsh
- ▬ Salt Ponds
- ▬ Sandy Beach
- ▬ Undeveloped Upland



This shoreline consists almost entirely of military and industrial waterfront facilities. Although Chollas and Paleta Creeks are located in this SMU, creek-to-marsh reconnection is infeasible because the creek mouths are used for deepwater navigation and are surrounded by dense industrial development. Vertical walls confine the channels, causing high water velocities. Furthermore, Chollas Creek passes through a concrete box culvert beneath Harbor Drive and the Port's rail/terminal infrastructure. Debris and trash booms also impede the fluvial-estuarine transition.



Suitable Strategies Map

LEGEND

Suitability Ranking

- L** Limited
- M** Moderate
- H** High

Suitable Strategies	Ranking
 Tidal Marshes	L
 Beaches	M
 Ecological Armoring	H
 Living Seawalls	H



Pepper Park Overview

Adjoining the Sweetwater Channel, Pepper Park offers colorful play equipment, a boat launch, and a lighted fishing pier for night fishing on San Diego Bay.



Vulnerabilities

- **Transportation:** Low-lying Harbor Drive and Eighth Street Transit Center
- **Maritime:** Potential damage and disruption at National City Marine Terminal
- **Parks and Recreation:** Pepper Park

Suitable Strategies

Suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Tidal Marshes (L): Portions of the revetment fronting Pepper Park could be reworked to create room for pocket marshes landward of the existing shoreline to improve habitat value.



Beaches (M): Similar to tidal marshes, portions of the revetment fronting Pepper Park could be reworked to create room for pocket beaches landward of the existing shoreline to improve recreation while providing erosion control.



Ecological Armoring (H): Revetments along the Indian Point and National City marine terminals could be enhanced with ecological armoring to improve the habitat value of this infrastructure while maintaining shoreline stability.



Living Seawalls (H): The many seawalls, wharves, and quay walls, such as those between Piers 1 and 13, provide opportunities for implementing living seawalls.



Naval Base San Diego

Looking south over Naval Base San Diego, naval vessels and floating booms line the shoreline.

SMU 7

South Bay from Sweetwater River to Crown Cove
(Excluding the Coronado Cays)

Existing Conditions Map

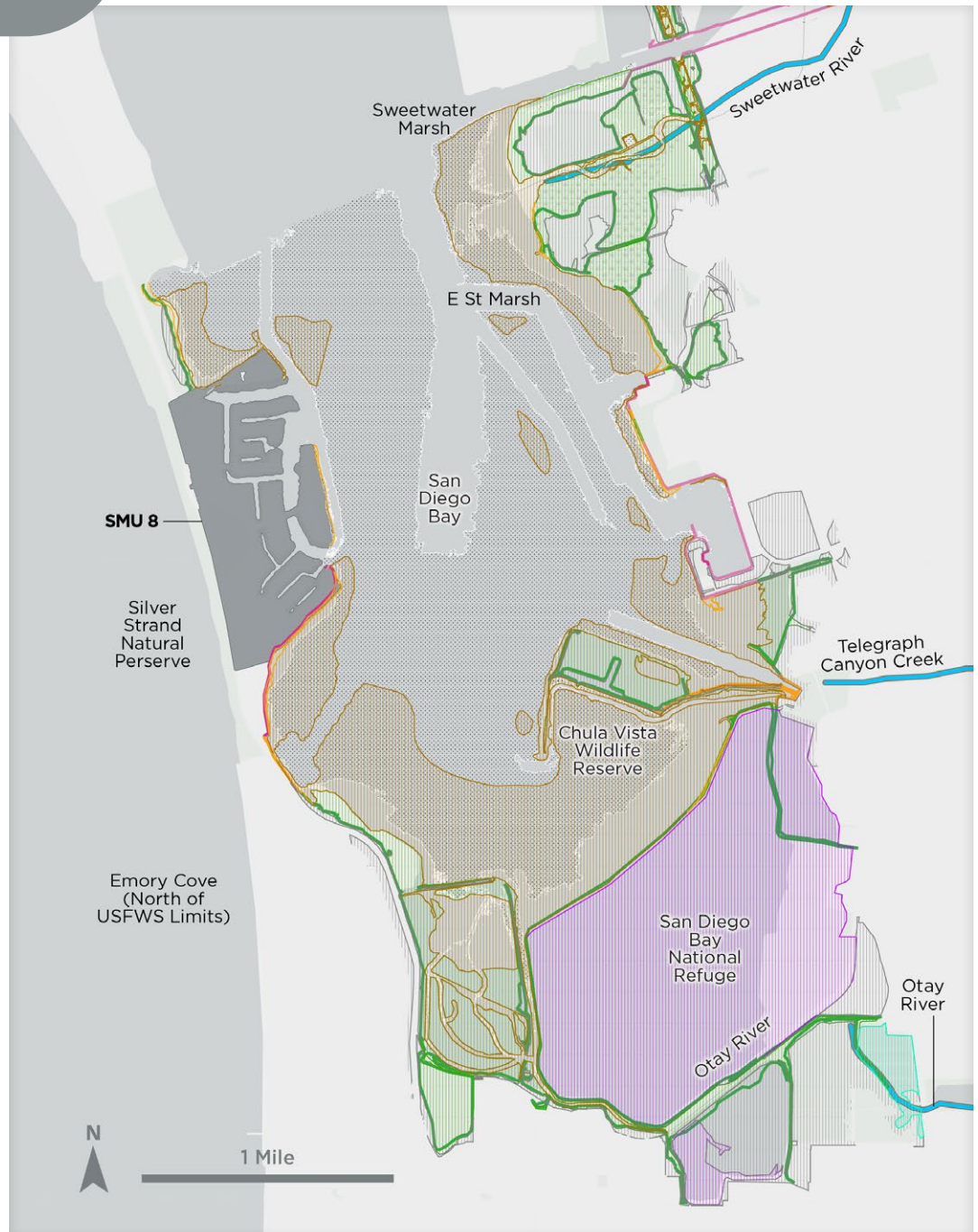
LEGEND

Shoreline Inventory

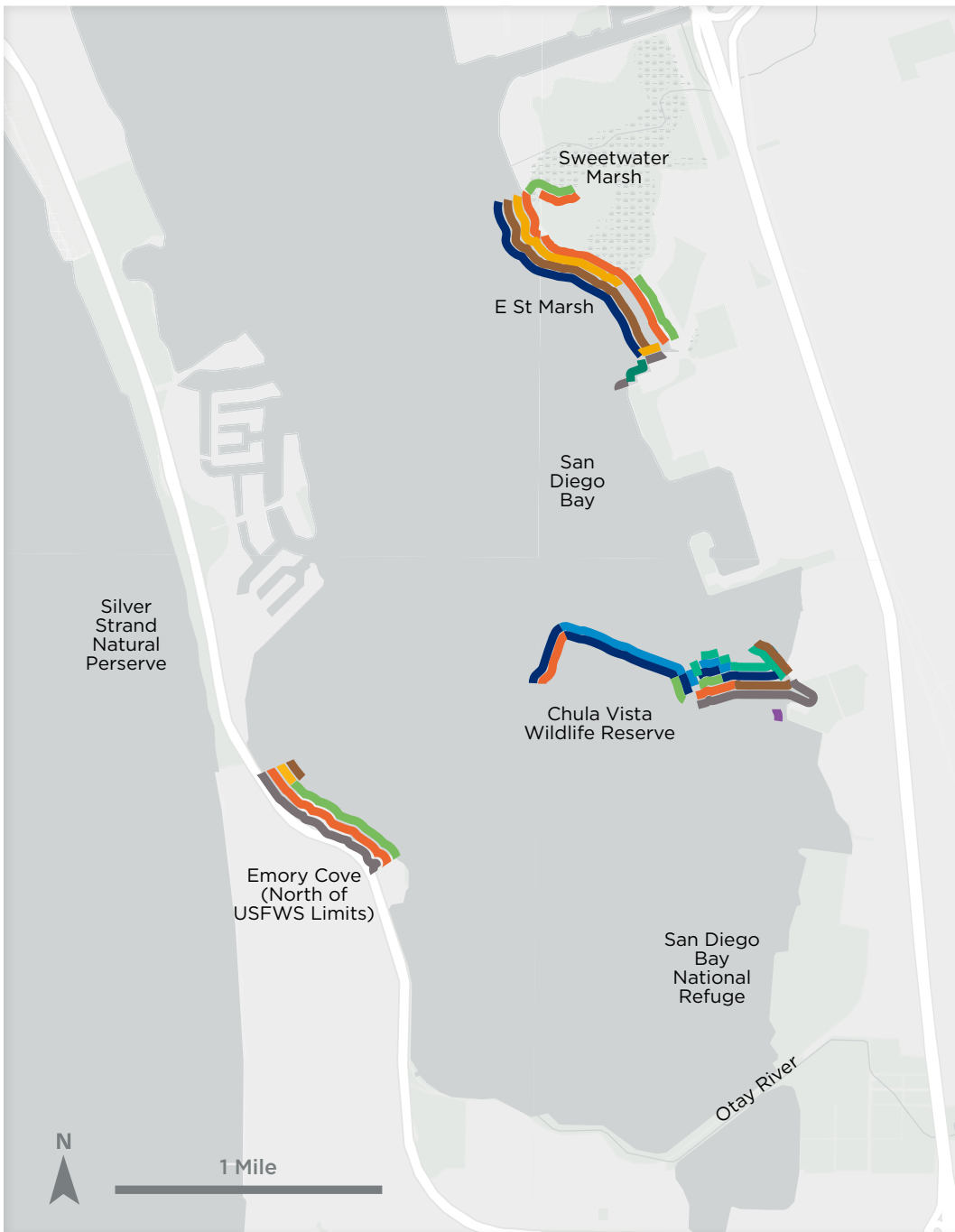
- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- Streams
- Eelgrass
- Cobble Beach
- Mudflat
- Riparian
- Rocky Intertidal
- Salt Marsh
- Salt Ponds
- Sandy Beach
- Undeveloped Upland



This is the largest SMU, which is characterized by very shallow, sheltered waters receiving occasional inputs of freshwater from the Otay and Sweetwater Rivers. There are significant opportunities for nature-based strategies (Merkel & Associates 2017), with many projects already underway. For example, former Bayside Park, with its narrow eroding beach and revetment, is being transformed into Harbor Park with a pocket marsh, perched beach, and ecotone slope. This large-scale nature-based project is intended



Suitable Strategies Map

LEGEND

Suitability Ranking

- L** Limited
- M** Moderate
- H** High

Suitable Strategies	Ranking
 Eelgrass	H
 Barrier Islands	H
 Nearshore Reefs	H
 Tidal Marshes	H
 Beaches	H
 Ecotone / Embankment Slopes	H
 Ecological Armoring	M
 Living Seawalls	L



Former Intake and Discharge Channels

Originally dredged for the South Bay Power Plant and separated by an earthen dike, these channels provide opportunities for restoration since the plant was removed.

Vulnerabilities

- **Public Safety:** Low-lying San Diego Harbor Police South Bay Substation
- **Transportation:** Low-lying State Route 75 and Bayshore Bikeway
- **Habitat:** Drowning within CVWR and salt pond berm overtopping

to act as the first line of defense for the elevated redevelopment inland while also providing habitat and recreation space. The San Diego Bay Native Oyster Living Shoreline Project is another pioneering nature-based project to evaluate how various reef designs reduce erosion and wave energy and also create habitat. In addition, the San Diego National Wildlife Refuge Comprehensive Conservation Plan provides a framework for current and future projects in the Sweetwater Marsh and South Bay Units, such as the Otay River Estuary Restoration Project.

Suitable Strategies

Suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Eelgrass (H): Eelgrass habitat west of the South Bay Power Plant Intake Channel and along the south side of the Coronado Cays could be expanded.



Barrier Islands (H): A barrier island offshore from Telegraph Creek could accelerate development of the marsh that formed following construction of the Chula Vista Marina and buffer the impacts from sea level rise. Perimeter dikes/levees in the CVWR and South Bay Unit could be strengthened and transformed into barrier islands to address wave erosion and accelerate marsh development in Ponds 11 and 15 and in potential future restorations. A smaller barrier island along Chula Vista Bayside Park could also address wave erosion, while an island north of Crown Island could take advantage of concave shoreline geometry.



Nearshore Reefs (H): Building on the San Diego Bay Native Oyster Living Shoreline Project, nearshore reefs could be added to the existing mudflats fronting the Sweetwater Marsh Unit to address shoreline erosion and support biodiversity. The area north of Crown Island has similar shallow water and gentle slopes as San Diego Bay Native Oyster Living Shoreline Project suitable nearshore reefs.



Nearshore Reef Oyster Castle

Oyster castles line the shoreline, boosting biodiversity and combating erosion in the CVWR.



Mudflats (H): Existing mudflats in the San Diego Bay National Wildlife Refuge and offshore from Telegraph Creek could be enhanced given the area's low wave energy and wide, shallow elevations. These are the only suitable locations for mudflats in the Bay because most of the remaining mudflats have established eelgrass beds or are sited for eelgrass restoration efforts (U.S. Navy 2024) that would be negatively impacted by shallow-water placement of sediment (e.g., turbidity and burial).



Tidal Marshes (H): In the Sweetwater Marsh Unit, an improved channel network with sidecast berms within D Street Fill could increase microtopography, habitat diversity, and sediment pathways to allow for increased vertical accretion as the sea level rises, while ecotone levees along the north side of Gunpowder Point could enhance the existing transition zone and potential for landward migration. Improving the tidal connection of F and G Street Marsh to the Bay and to the seasonal wetlands past Lagoon Drive could improve the resilience of this system. Additionally, in the South Bay Unit, salt ponds could be restored in the future, depending on saltworks operations and San Diego National Wildlife Refuge goals. Finally, the area north of Crown Island, with its wide intertidal zone, provides marsh development opportunities.



Otay River South San Diego Bay Unit National Wildlife Refuge

The San Diego National Wildlife Refuge Comprehensive Conservation Plan provides a framework for current and future projects in the Sweetwater Marsh and South Bay Units, such as the Otay River Estuary Restoration Project.



Beaches (H): Fringing coarse beaches north and south of Gunpowder Point could address the marsh edge retreat associated with the 1980s construction of the Sweetwater River Channel, which reduced sediment supply to the marsh and led to erosion. Similar to the Harbor Park construction, Chula Vista Bayfront Park could be modified to accommodate pocket beaches. Areas where sand naturally settle provide clear indicators for potential beach locations. Along the north and south sides of the Coronado Cays, shallow bathymetry and existing sand suggest the potential for additional beaches.



Ecotone Levees and Embankment Slopes (H): With its shallow bathymetry and undeveloped shoreline, the San Diego Bay National Wildlife Refuge is ideal for ecotone levee creation. Ecotone levees could be developed within D Street Fill, Sweetwater Marsh, and north of Gunpowder Point. In the South Bay Unit, ecotone levees could be incorporated bayward or pondward of existing perimeter dikes, as there



are natural resources in both directions that would benefit from space for marsh transgression. Additionally, ecotone levees could be considered when levees along the Otay River are damaged or fail in the future.



Ecological Armoring (M): Revetment along Chula Vista Bayfront Park and State Route 75 could be enhanced with ecological armoring to improve the habitat value of this infrastructure while maintaining shoreline stability.



Living Seawalls (L): The seawalls along the north side of the Coronado Cays provide opportunities for implementing living seawalls.



Creek-to-Marsh Reconnection (H): Telegraph Creek and Pond 15 could be reconnected to adjacent marshes to keep sediment in the system and allow marshes to build upward as the sea level rises. Marshes could also serve as bypasses when levees along the Otay River are damaged or fail in the future.



SMU 8

Coronado Cays

Existing Conditions Map

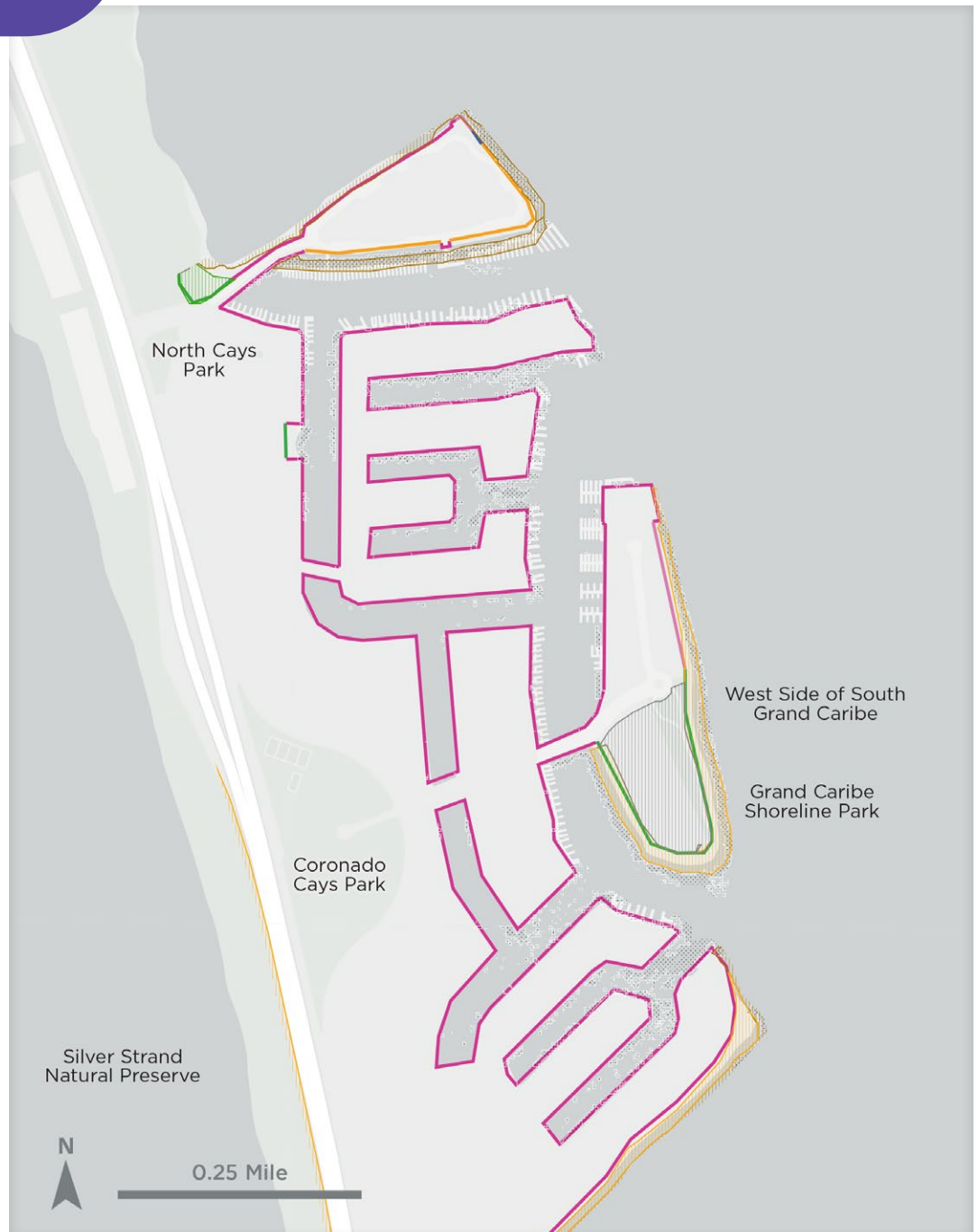
LEGEND

Shoreline Inventory

- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- ▬ Streams
- ▬ Eelgrass
- ▬ Cobble Beach
- ▬ Mudflat
- ▬ Riparian
- ▬ Rocky Intertidal
- ▬ Salt Marsh
- ▬ Salt Ponds
- ▬ Sandy Beach
- ▬ Undeveloped Upland



This shoreline is mostly hardened by seawalls, with limited revetments, soft shoreline, and open space along Grand Caribe Shoreline Park.



Suitable Strategies Map

LEGEND

Suitability Ranking

- L Limited
- M Moderate
- H High

Suitable Strategies	Ranking
 Tidal Marshes	L
 Beaches	L
 Ecotone / Embankment Slopes	L



Coronado Cays Aerial

The Coronado Cays are man-made peninsulas and waterways in southern San Diego Bay, offering private waterfront living with direct bay access.

Vulnerabilities

- **Transportation:** Low-lying Grand Caribe Causeway and Coronado Bay Road (sole access roads)
- **Maritime:** Low-lying yacht club
- **Parks and Recreation:** Grand Caribe Shoreline Park
- **Residential:** Potential damage to development

Suitable Strategies

Suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Tidal Marshes (L): A channel could be cut on the back side of Grand Caribe Shoreline Park near the Grand Caribe Causeway to introduce tidal waters in a quiescent environment and create a marsh in a portion of the park landward of the existing shoreline.



Beaches (L): Erosion is a long-standing issue along the southern part of Grand Caribe Shoreline Park. The Grand Caribe Shoreline Park coastline could be modified to enhance the existing beaches and address this erosion. Buttress structures to perch these beaches could reduce maintenance over time.



Ecotone Levees and Embankment Slopes (L): Like tidal marshes, the back side of Grand Caribe Shoreline Park could be modified to become an ecotone levee or embankment slope in a portion of the park landward of the existing shoreline to enhance marsh resilience.



Ecological Armoring (M): Revetments could be enhanced with ecological armoring to improve the habitat value of this shoreline while addressing wave erosion.



Living Seawalls (H): The many seawalls protecting residential development could be augmented with living seawalls to provide ecological benefits.



Grand Caribe

Grand Caribe Shoreline Park is located on a peninsula that was constructed of dredged material from development of the Coronado Cays. The narrow beach is submerged by high tides, with waves causing vertical scarping at the back beach.



SMU 9

Backwater Embayments from Shelter Island to Coast Guard Pier

Existing Conditions Map

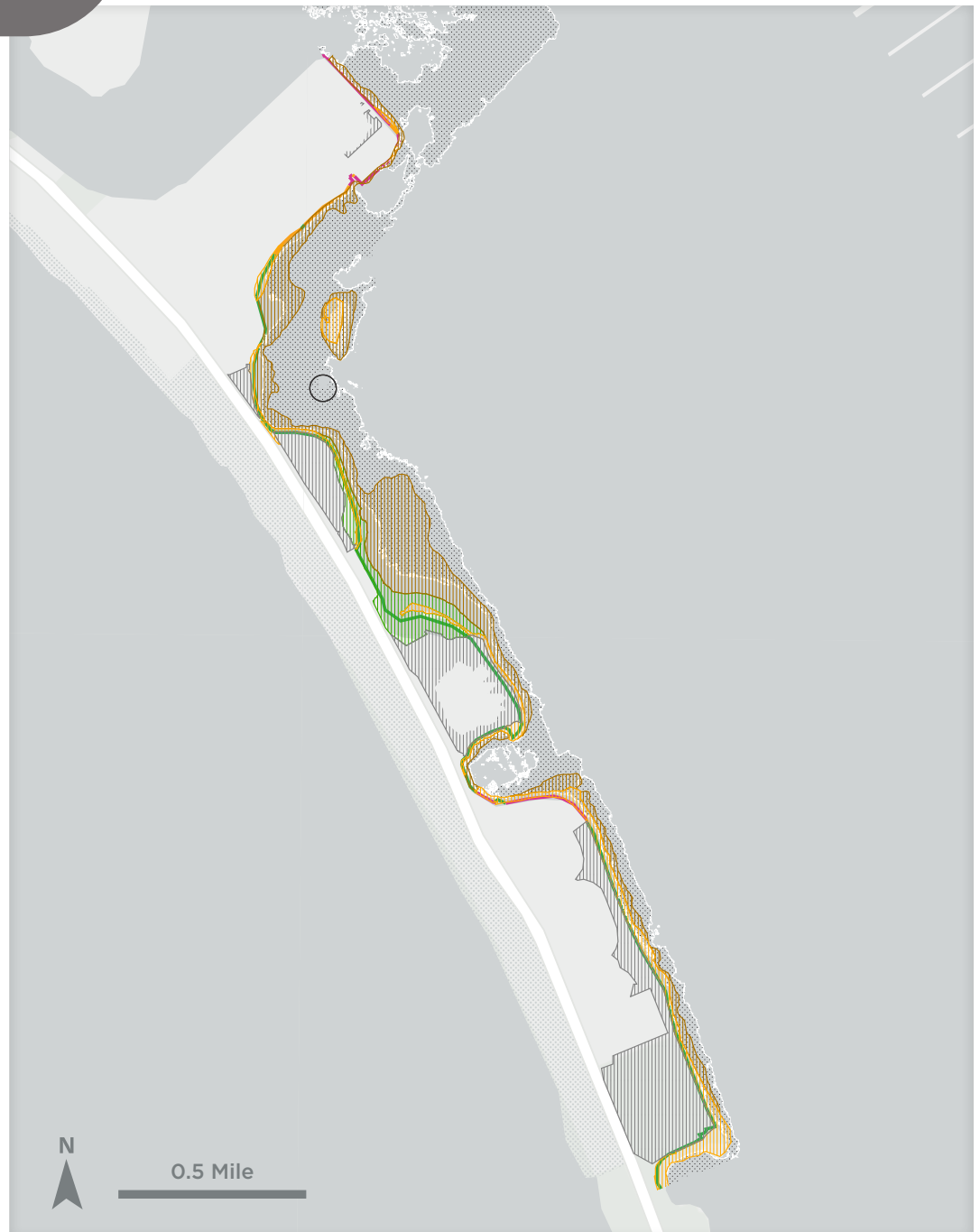
LEGEND

Shoreline Inventory

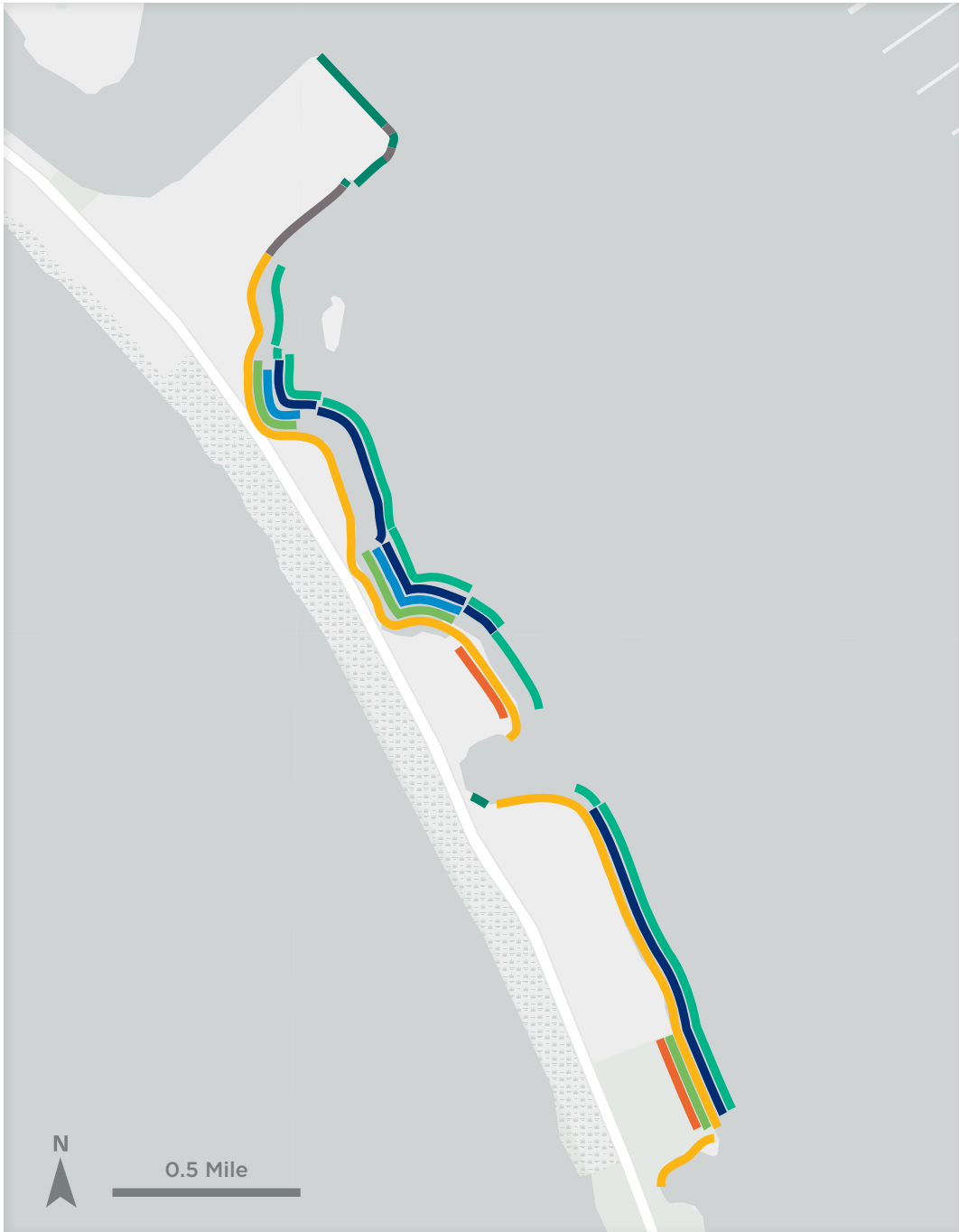
- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- ▨ Streams
- ▨ Eelgrass
- ▨ Cobble Beach
- ▨ Mudflat
- ▨ Riparian
- ▨ Rocky Intertidal
- ▨ Salt Marsh
- ▨ Salt Ponds
- ▨ Sandy Beach
- ▨ Undeveloped Upland



There are many opportunities along this predominantly soft, undeveloped shoreline, including Crown Cove, Silver Strand State Beach, Fiddler's Cove, and North and South Delta Beaches, which are important least tern nest sites. Proposed projects would need to be compatible with operations on the training beaches.



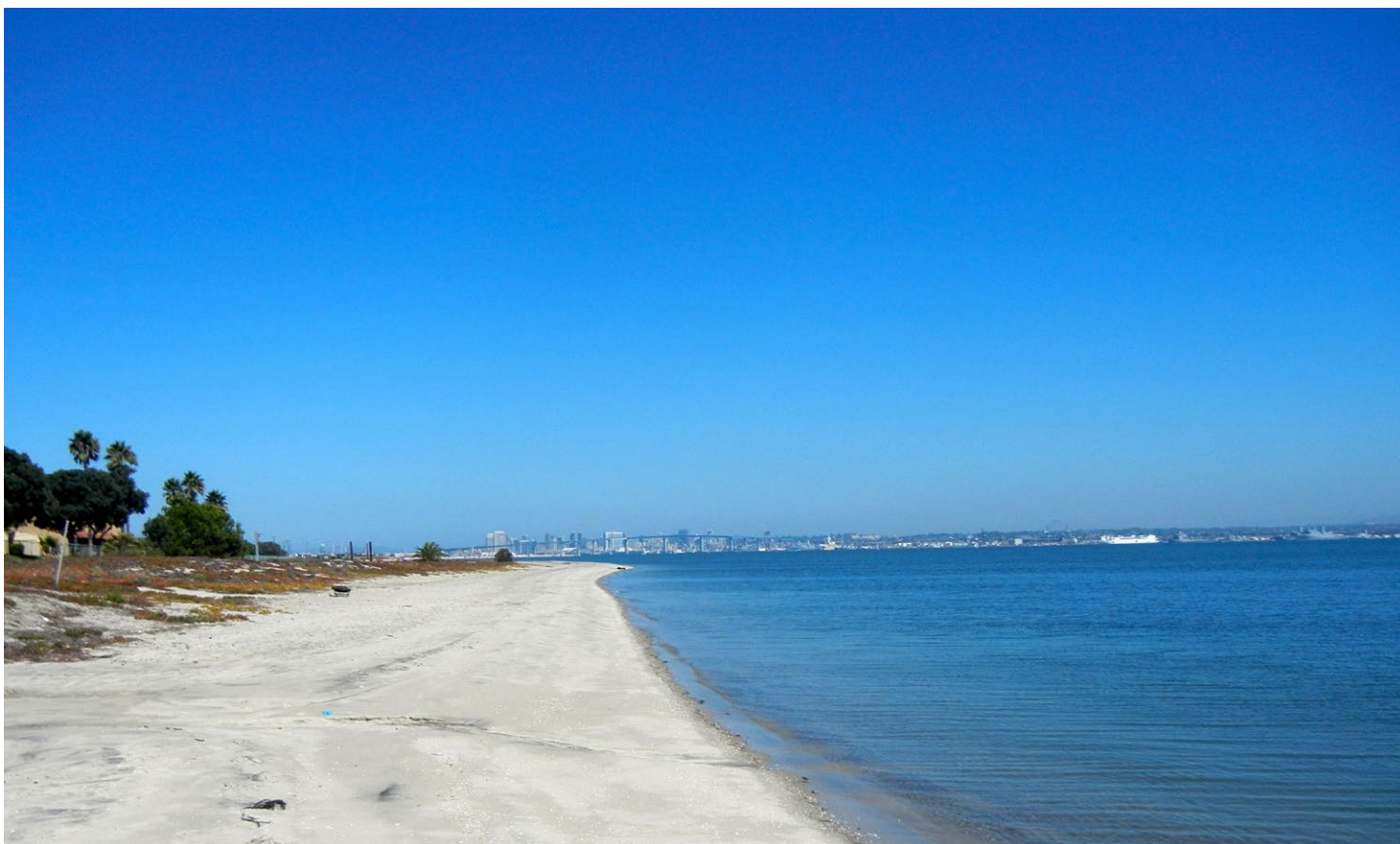
Suitable Strategies Map

LEGEND

Suitability Ranking

- L** Limited
- M** Moderate
- H** High

Suitable Strategies	Ranking
 Eelgrass	H
 Barrier Islands	H
 Nearshore Reefs	H
 Tidal Marshes	M
 Beaches	H
 Ecotone / Embankment Slopes	M
 Ecological Armoring	L
 Living Seawalls	L



Silver Strand

Looking north from Silver Strand State Beach, where tidal currents and wind waves govern sediment redistribution and favor the accumulation of fine sediments along gently sloping bay margins.

Suitable Strategies

Suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Eelgrass (H): Eelgrass habitat along almost all of the shoreline could be expanded.



Barrier Islands (H): Barrier islands could be strategically placed along the gentle slopes to provide protection from wind and waves, especially along concave shoreline geometries to maximize the benefits.



Nearshore Reefs (H): Nearshore reefs could be added along Silver Strand State Beach and North and South Delta Beaches, where shallow bathymetry and gentle slopes exist, to provide habitat enhancement.



Tidal Marshes (M): Pocket marshes could be developed within Silver Strand State Beach by reconfiguring the shoreline to create a low-wave-energy environment in a portion of the park landward of the existing shoreline. Additionally, there are shallow, protected embayments north of North and South Delta Beaches where marshes could develop.



Beaches (H): The shoreline has extensive sandy beaches, supported by shallow bathymetry and moderate wave energy and currents, that could be enhanced and expanded.



Ecotone Levees and Embankment Slopes (M): Like tidal marshes, the Silver Strand State Beach shoreline could be modified to become an embankment slope in a portion of the park landward of the existing shoreline to enhance coastal resilience.



Ecological Armoring (L): The south side of Naval Amphibious Base has a revetment that could be enhanced with ecological armoring to improve its habitat value.



Living Seawalls (L): The seawall at Fiddler's Cove and the Navy Amphibious Base could be enhanced with a living shoreline, providing habitat while maintaining structural functionality. However, due to the relatively warm water and silty, backwater environment, the strategy would enhance habitat for few species, most of them invasive.

Sample Pocket Marsh Opportunity

EXISTING CONDITION



SILVER STRAND STATE BEACH:

- ① Moderate wave energy
- ② Wide shallow subtidal/intertidal habitats
- ③ Soft shoreline

OPPORTUNITY POCKET MARSH



RESILIENT CONDITION



- ① Lower wave energy landward of shoreline
- ② Open space graded for marsh elevations
- ③ Tidal connection to San Diego Bay



SMU 10

Glorietta Bay
(Coronado Bridge Landing to Naval Amphibious Base)

Existing Conditions Map

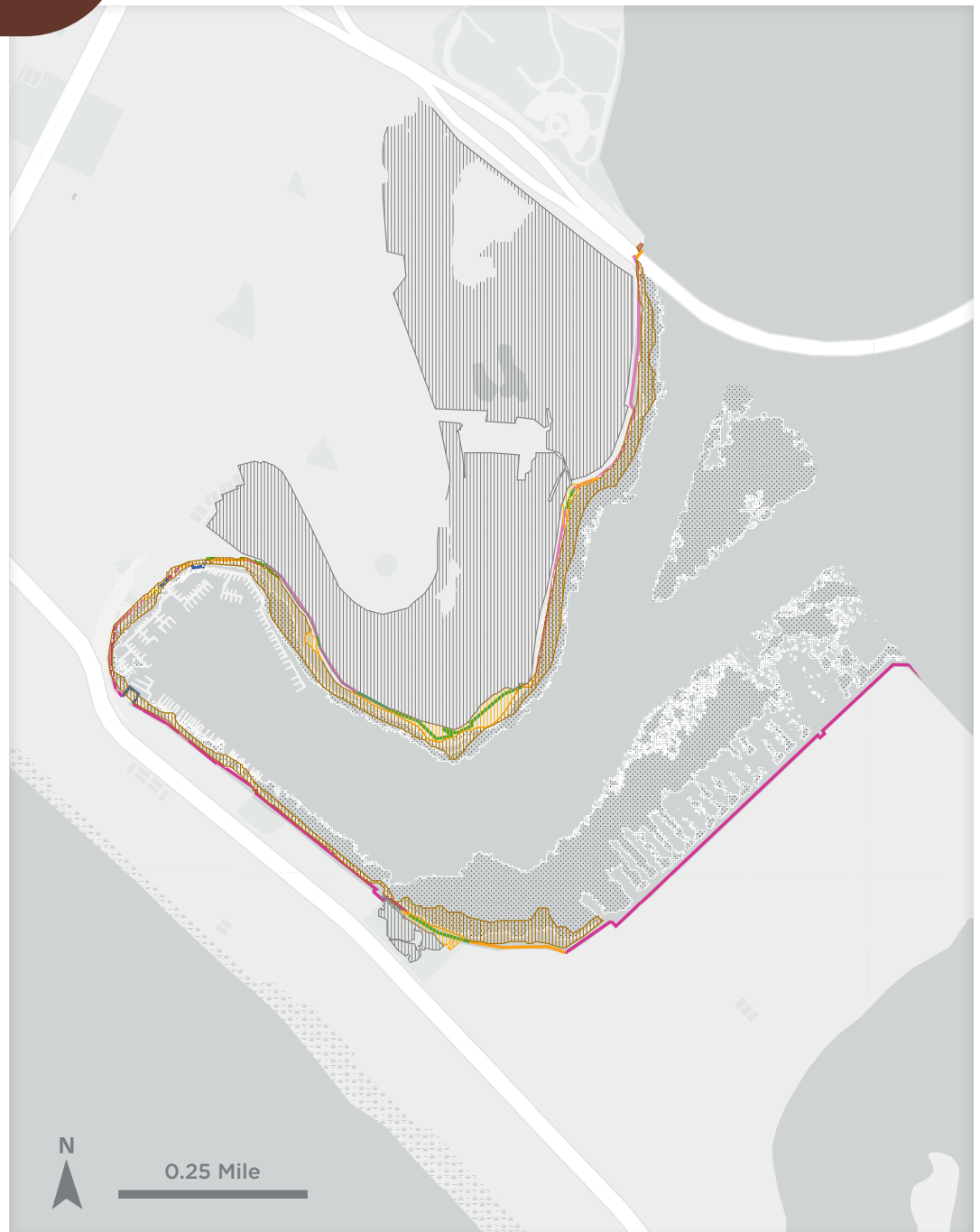
LEGEND

Shoreline Inventory

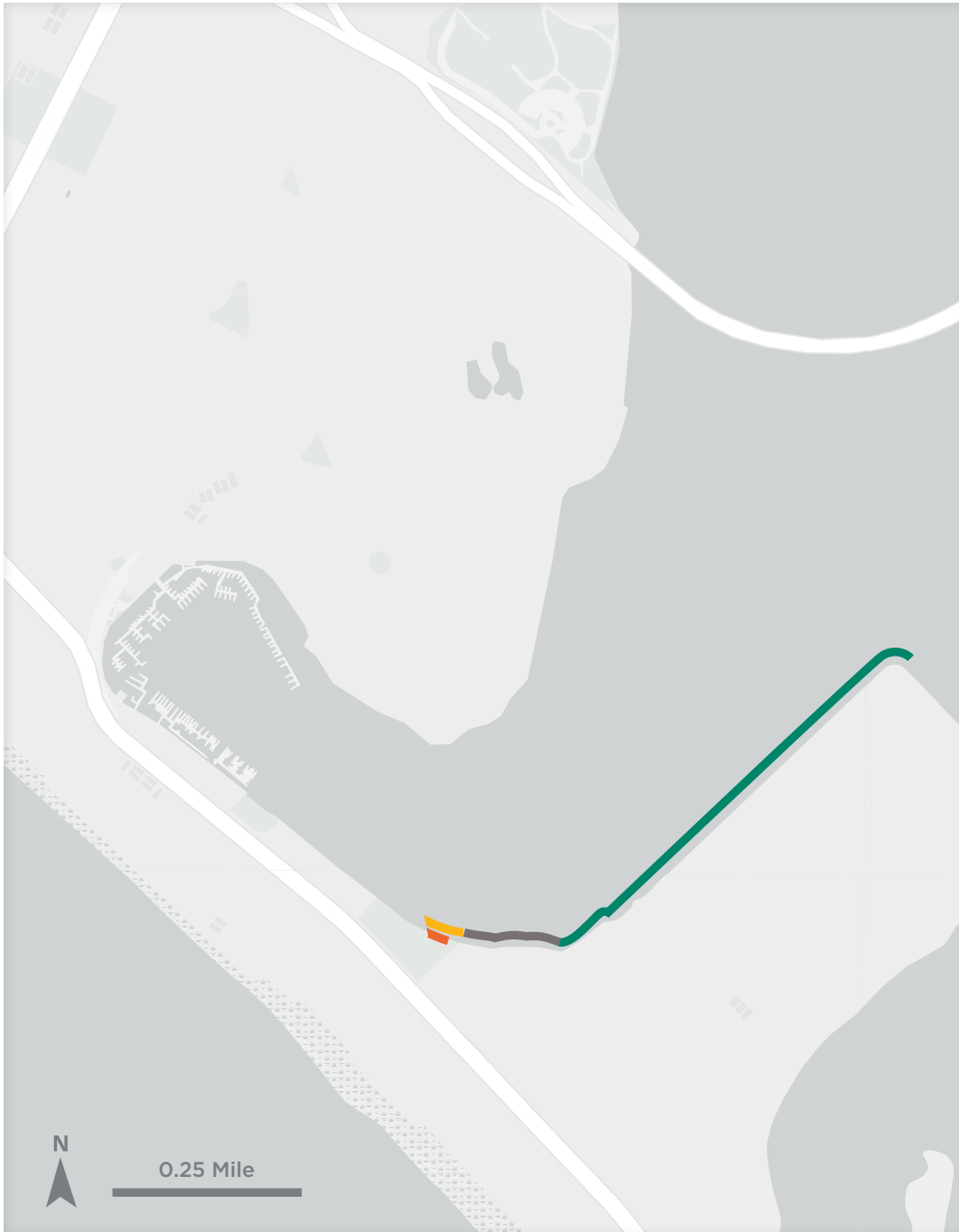
- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- Streams
- Eelgrass
- Cobble Beach
- Mudflat
- Riparian
- Rocky Intertidal
- Salt Marsh
- Salt Ponds
- Sandy Beach
- Undeveloped Upland



This shoreline is mostly hardened along the Naval Amphibious Base, Glorietta Bay, and the Coronado Golf Course. Glorietta Bay Park and the Coronado Golf Course provide opportunities for pocket shoreline habitats landward of the existing shoreline.



Suitable Strategies Map

LEGEND

Suitability Ranking

- L** Limited
- M** Moderate
- H** High

Suitable Strategies	Ranking
 Tidal Marshes	M
 Beaches	H
 Ecotone / Embankment Slopes	M
 Ecological Armoring	H
 Living Seawalls	H



San Diego Bay Aerial

An aerial view of San Diego Bay with Coronado and downtown San Diego in the background.



Suitable Strategies

Suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Tidal Marshes (M): The Coronado Golf Course shoreline could be reconfigured to create space for pocket marshes. For example, a portion of the revetment could be removed to introduce tidal action, and park space could be graded to marsh elevations to allow for plant establishment landward of the existing shoreline.



Beaches (H): Beaches could be enhanced or created along Glorieta Bay Park due to the gentle slope and pattern of sediment deposition. Like tidal marshes, pocket beaches could also be designed within the Coronado Golf Course landward of the existing shoreline.



Ecotone Levees and Embankment Slopes (M): An ecotone levee could be developed at the back of Glorieta Bay Park, preserving existing recreational opportunities and improving ecological diversity and coastal resilience. In addition, portions of the shoreline along the Coronado Golf Course could be modified to provide a gradual slope that accommodate an ecotone levee.



Ecological Armoring (H): The shoreline north of Rendova Road and along portions of Coronado Golf Course has a revetment that could be enhanced with ecological armoring to improve the habitat value.



Living Seawalls (H): Seawalls along the Naval Amphibious Base and State Route 75 could accommodate living seawalls, enhancing ecological benefits while maintaining their protective functions.



Glorieta Bay Park

A view of Glorieta Bay Park and its scenic shoreline along San Diego Bay.

Vulnerabilities

- **Public Transportation:** Low-lying State Route 75 and Bayshore Bikeway
- **Maritime:** Low-lying yacht club and marina facilities
- **Parks and Recreation:** Glorieta Bay Park, Coronado Municipal Golf Course, and City Hall
- **Stormwater:** Reduced capacity at some outlets



SMU 11

Navy Pier K to Coronado Bridge Landing

Existing Conditions Map

LEGEND

Shoreline Inventory

- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- Streams
- Eelgrass
- Cobble Beach
- Mudflat
- Riparian
- Rocky Intertidal
- Salt Marsh
- Salt Ponds
- Sandy Beach
- Undeveloped Upland



This shoreline is mostly hardened with revetment protecting residential and commercial development and various parks, such as Coronado Tidelands and Centennial Parks, from high wave energy. Development of the deep-water carrier basin (SMU 12) and narrowing of the Bay north of the Coronado Bridge creates complex sediment transport patterns, which have ultimately resulted in beach erosion in this SMU. Coronado Tidelands Park already has a large eelgrass bed that helps stabilize the slope.



Suitable Strategies Map

LEGEND

Suitability Ranking

- L** Limited
- M** Moderate
- H** High

Suitable Strategies	Ranking
 Tidal Marshes	L
 Beaches	M
 Ecological Armoring	H

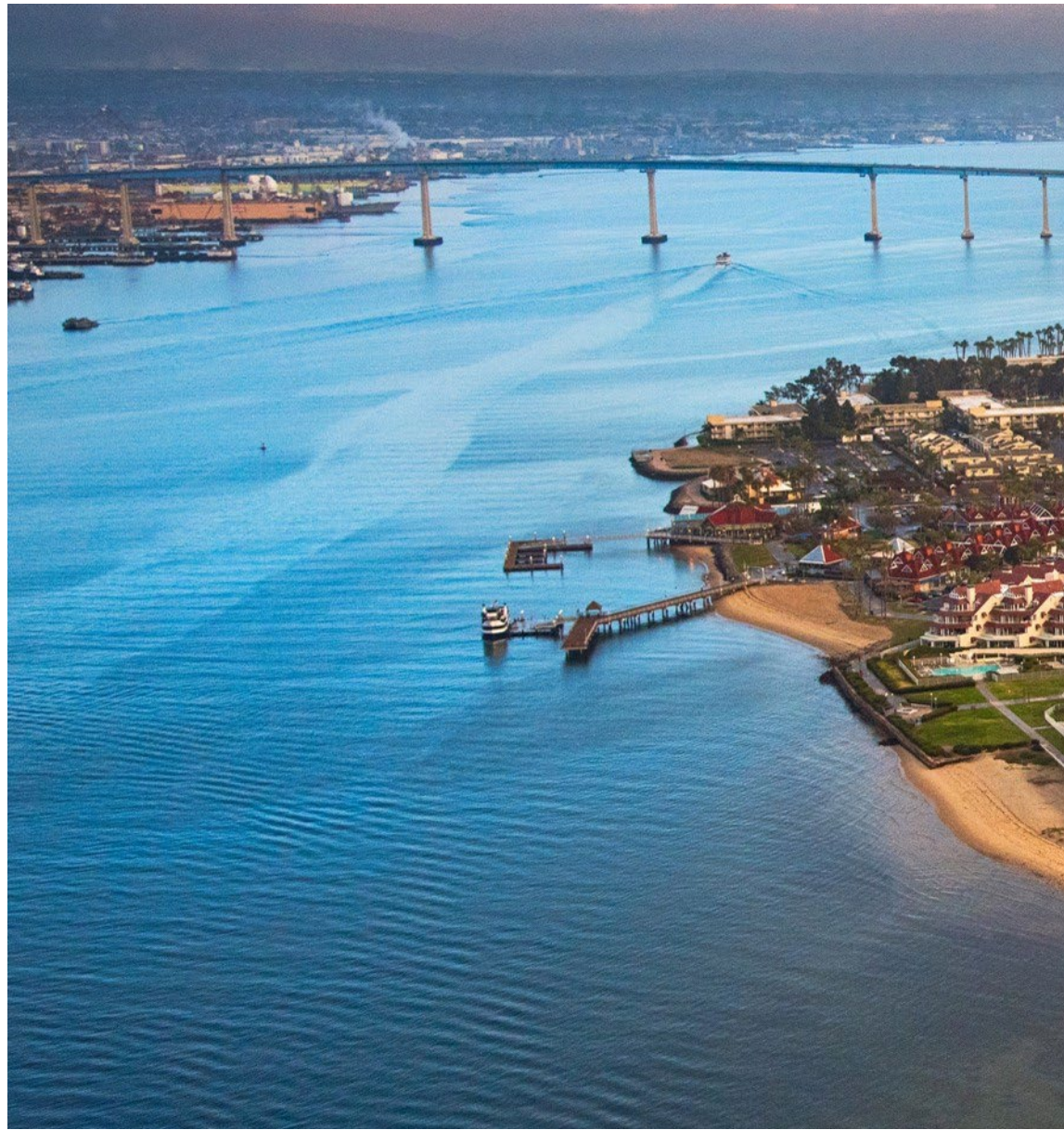


Coronado Ferry Landing

Looking toward the Coronado Ferry Landing, where shallow bathymetry and protected shoreline conditions create opportunities for habitat enhancement and the design of a pocket beach within Coronado Tidelands Park.

Vulnerabilities

- **Public Transportation:** Low-lying roads near Coronado Ferry Landing and Bayshore Bikeway
- **Maritime:** Low-lying ferry facilities
- **Parks and Recreation:** Coronado Tidelands Park and Centennial Park
- **Stormwater:** Reduced capacity at many outlets
- **Residential:** Potential damage to development



Suitable Strategies

Other suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Nearshore Reefs (M): Nearshore reefs could be placed along the northern portion of the shoreline in the lee of Navy Pier K, where the bathymetry is shallower and more gentle slopes exist, to provide oyster habitat and wave attenuation.



Tidal Marshes (L): Pocket marshes could be developed within Coronado Tidelands Park by reconfiguring the revetment to create a low-energy environment in a portion of the park landward of the existing shoreline.



Beaches (M): Existing beach areas with shallow bathymetry, including the northern portion of the shoreline in the lee of Navy Pier K and around the Coronado Ferry Landing, could be enhanced. Like tidal marshes, a pocket beach could also be designed within the Coronado Tidelands Park landward of the existing shoreline.



Ecological Armoring (H): Given that the shoreline is mostly hardened with revetment, there are many opportunities for habitat enhancement with ecological armoring.



Living Seawalls (H): Seawall segments along the northern portion of the shoreline in the lee of Navy Pier K could accommodate living seawalls, enhancing ecological benefits while maintaining their protective functions.

SMU 12

Carrier Basin

Existing Conditions Map

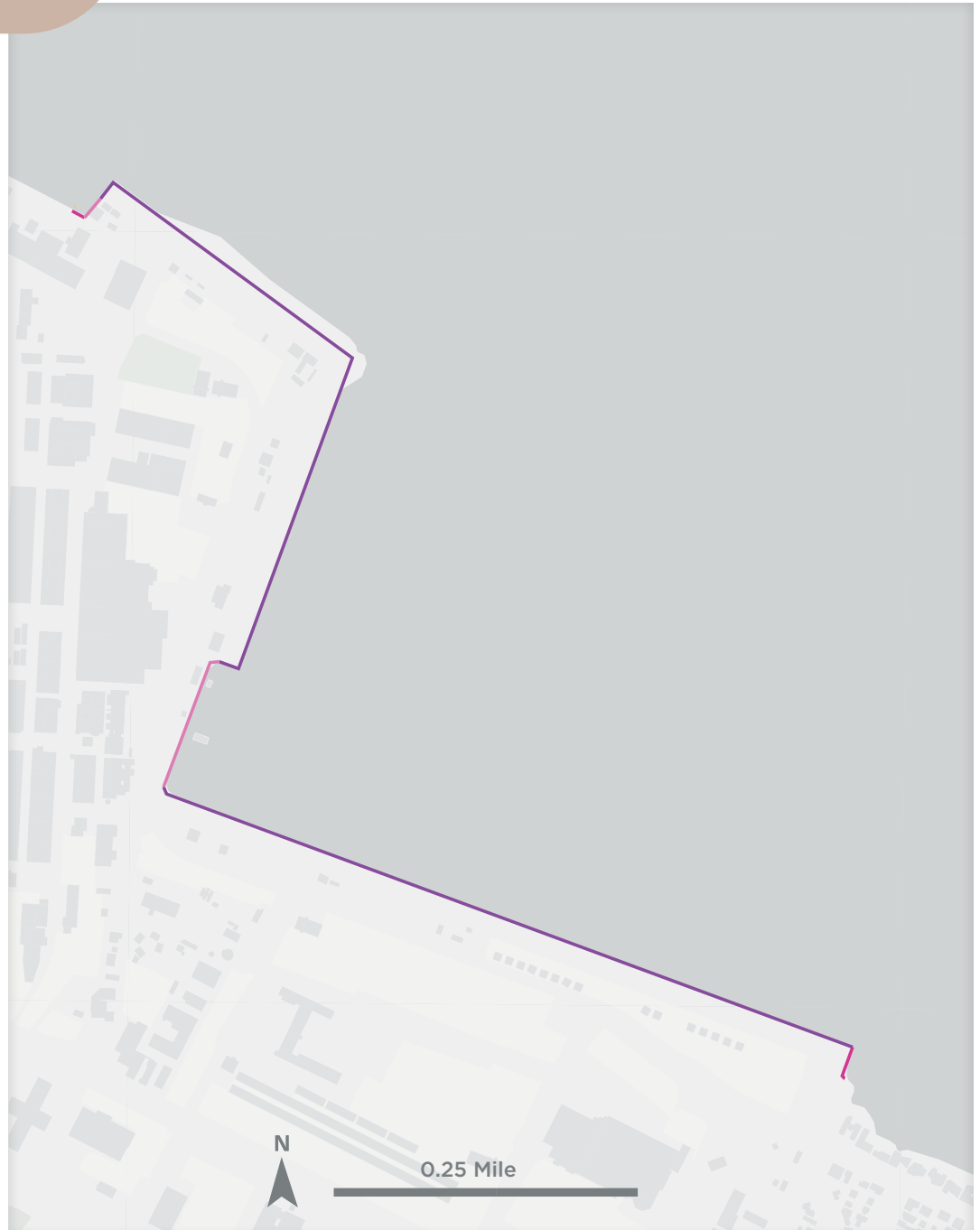
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Shoreline Inventory

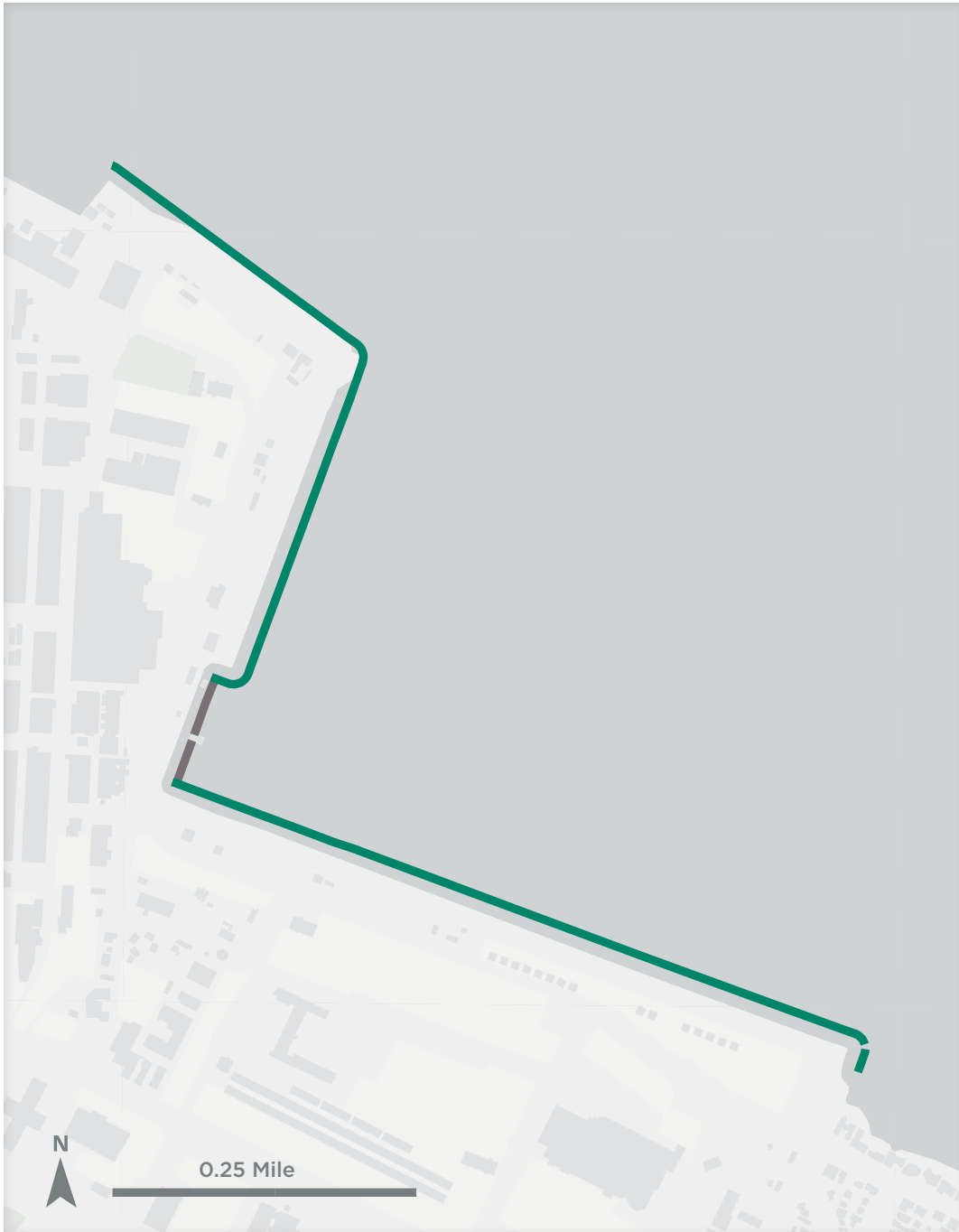
- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- Streams
- Eelgrass
- Cobble Beach
- Mudflat
- Riparian
- Rocky Intertidal
- Salt Marsh
- Salt Ponds
- Sandy Beach
- Undeveloped Upland



This shoreline is adjacent to deep water to accommodate aircraft carriers and is entirely hardened by marginal wharves and a small section of revetment. The water depth, shoreline geometry, and wave attenuator off Piers J through L dampen wave energy.



Suitable Strategies Map

LEGEND

Suitability Ranking

- L** Limited
- M** Moderate
- H** High

Suitable Strategies	Ranking
 Ecological Armoring	M
 Living Seawalls	L



Marginal wharf along Pier L

View of Marginal Wharf along Pier L. With no existing seawalls, living seawalls would need to be mounted on piles in configurations that avoid interfering with Navy operations.

Suitable Strategies

Given the military uses, there are limited suitable nature-based strategies that would be suitable in this SMU (with rankings in parentheses):



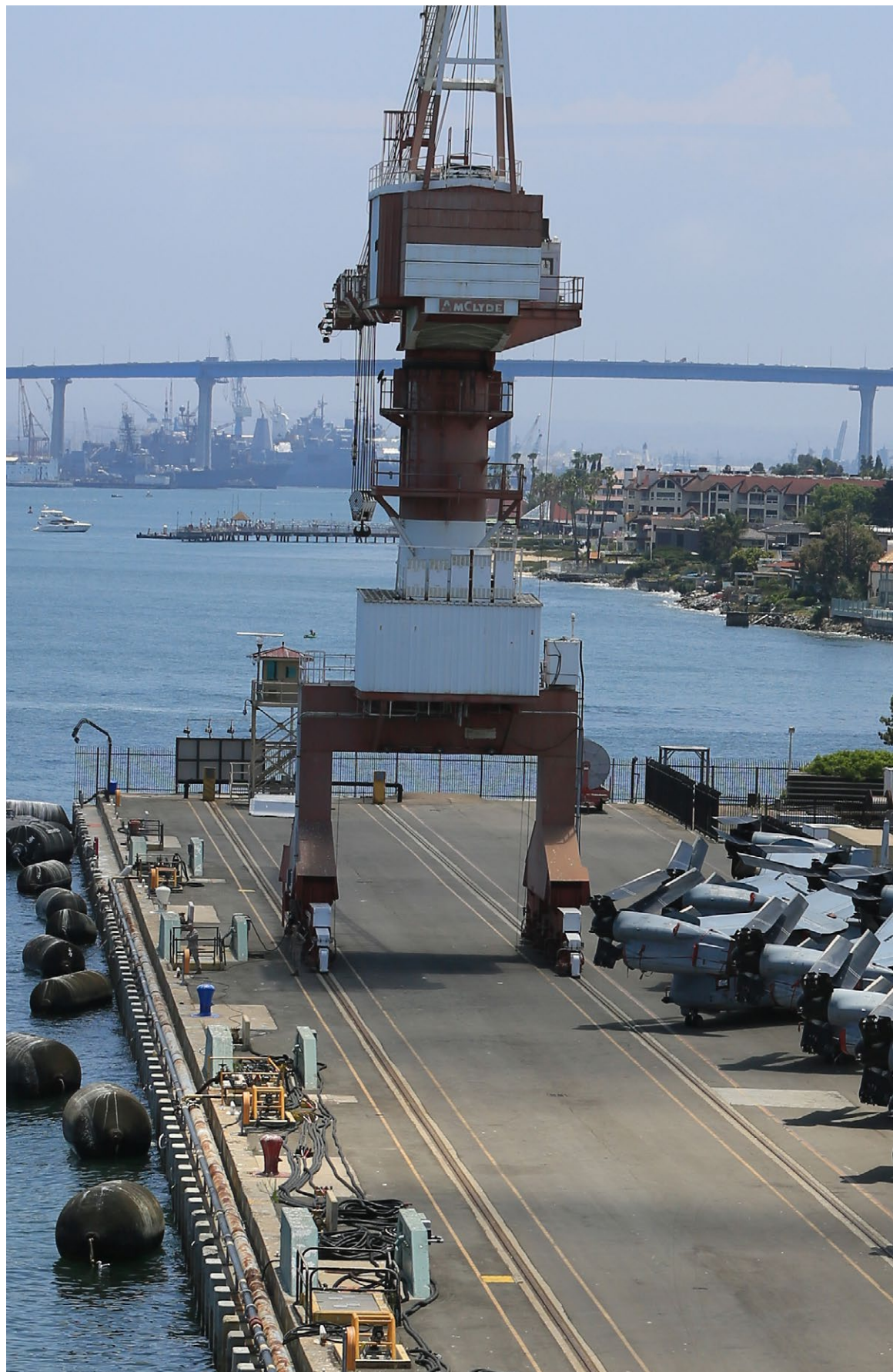
Ecological Armoring (M):

A small section of revetment could enhance habitat value with ecological armoring.



Living Seawalls (L):

Because there are no seawalls, living seawalls would need to be installed on piles in a way that does not conflict with Navy operations.





SMU 13

Zuniga Jetty to Navy Pier L

Existing Conditions Map

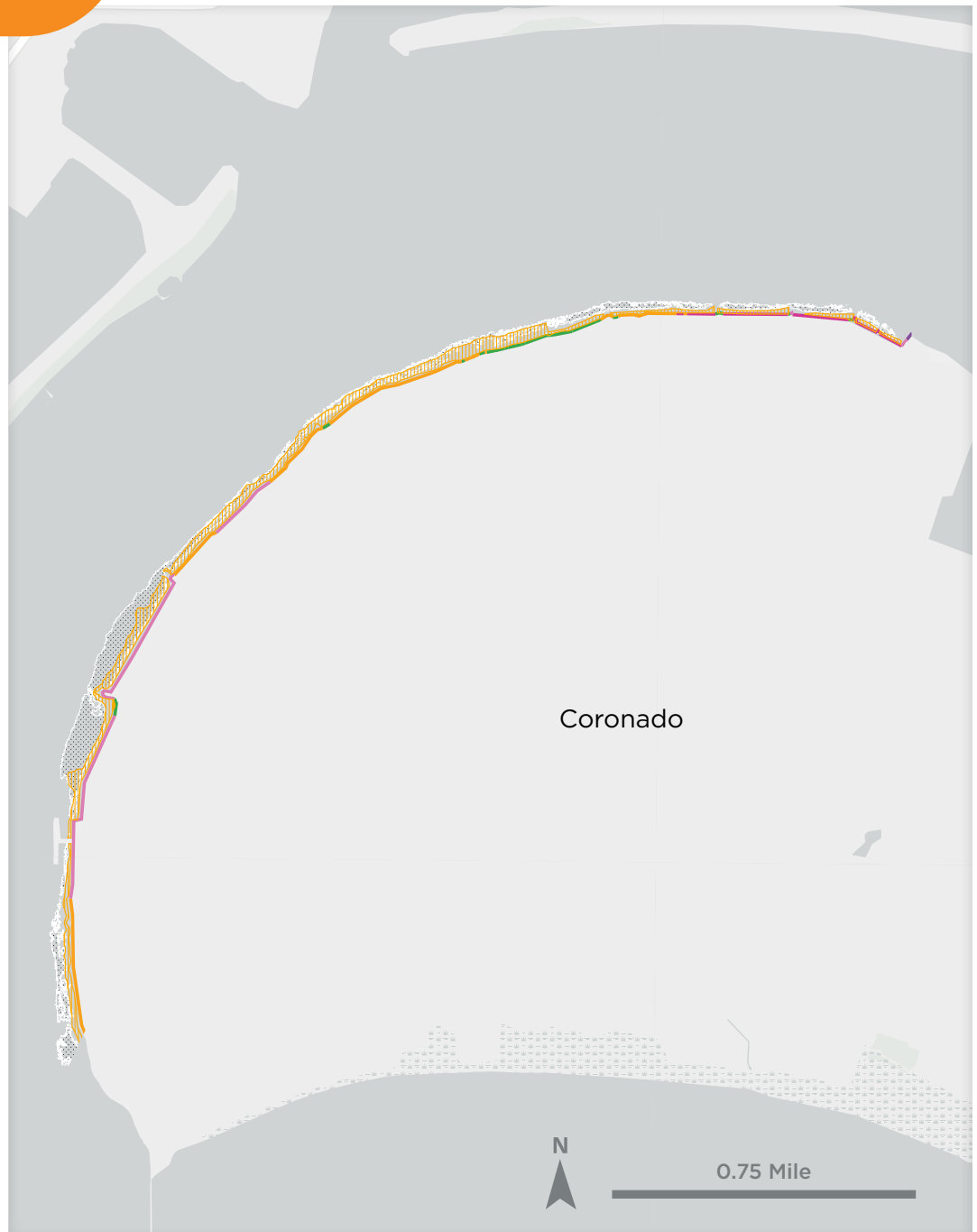
LEGEND

Shoreline Inventory

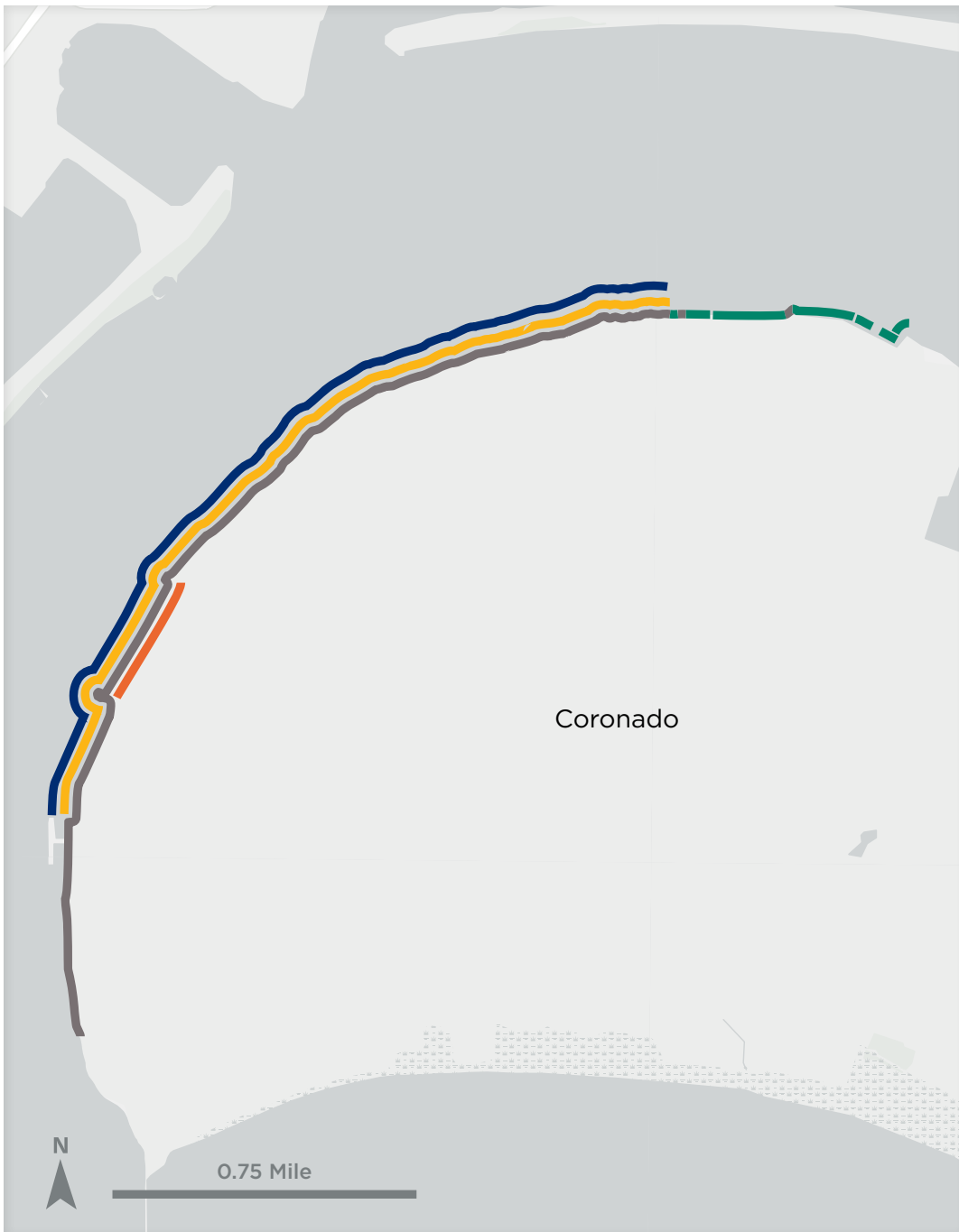
- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- Streams
- Eelgrass
- Cobble Beach
- Mudflat
- Riparian
- Rocky Intertidal
- Salt Marsh
- Salt Ponds
- Sandy Beach
- Undeveloped Upland



This shoreline is mostly hardened with revetment to protect against high wave energy and erosion, with small sections of seawall and soft shoreline near Navy Pier L and the start of the Seawall Running Trail (Moffatt Road).



Suitable Strategies Map

LEGEND

Suitability Ranking

- L** Limited
- M** Moderate
- H** High

Suitable Strategies	Ranking
 Nearshore Reefs	M
 Beaches	M
 Ecotone / Embankment Slopes	L
 Ecological Armoring	H
 Living Seawalls	H



Coronado shoreline looking west toward rubble and an outfall

This area offers opportunities to enhance shallow beach zones in combination with nearshore reefs. The storm drains act like groins, showing how retention strategies could support wider, more stable beaches.



Suitable Strategies

Suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Nearshore Reefs (M): Nearshore reefs could be placed at locations along the shoreline from the start of the Seawall Running Trail (Moffatt Road) to the North Island Ammunition Pier, where there is a moderately wide shallow subtidal and intertidal zone and good circulation. These reefs could enhance the marine habitat value of the shoreline while helping to reduce wave energy and erosion.



Beaches (M): In combination with nearshore reefs, existing beach areas with shallow bathymetry could be enhanced. The storm drains along the northern portion of the shoreline act like groins and demonstrate how retention strategies could be used to widen and stabilize beaches (Griggs et al. 2020).



Ecotone Levees and Embankment Slopes (L): Bayward of Moffatt Road at the end of northwest-southeast trending runway, there is unique space to create an ecotone levee or embankment slope landward of the existing revetment slope.



Ecological Armoring (H): Given that the shoreline is mostly hardened with revetment, there are many opportunities for habitat enhancement with ecological armoring.



Living Seawalls (H): Seawall segments along the northern portion of the shoreline near Navy Pier L could accommodate living seawalls, enhancing ecological benefits while maintaining their protective functions.



View looking east along Moffatt Road

The moderately wide, well-circulated shallow nearshore zone between the Seawall Running Trail and the North Island Ammunition Pier offers potential sites for reefs that could boost marine habitat and dampen wave energy.



SMU 14

Zuniga Shoal

Existing Conditions Map

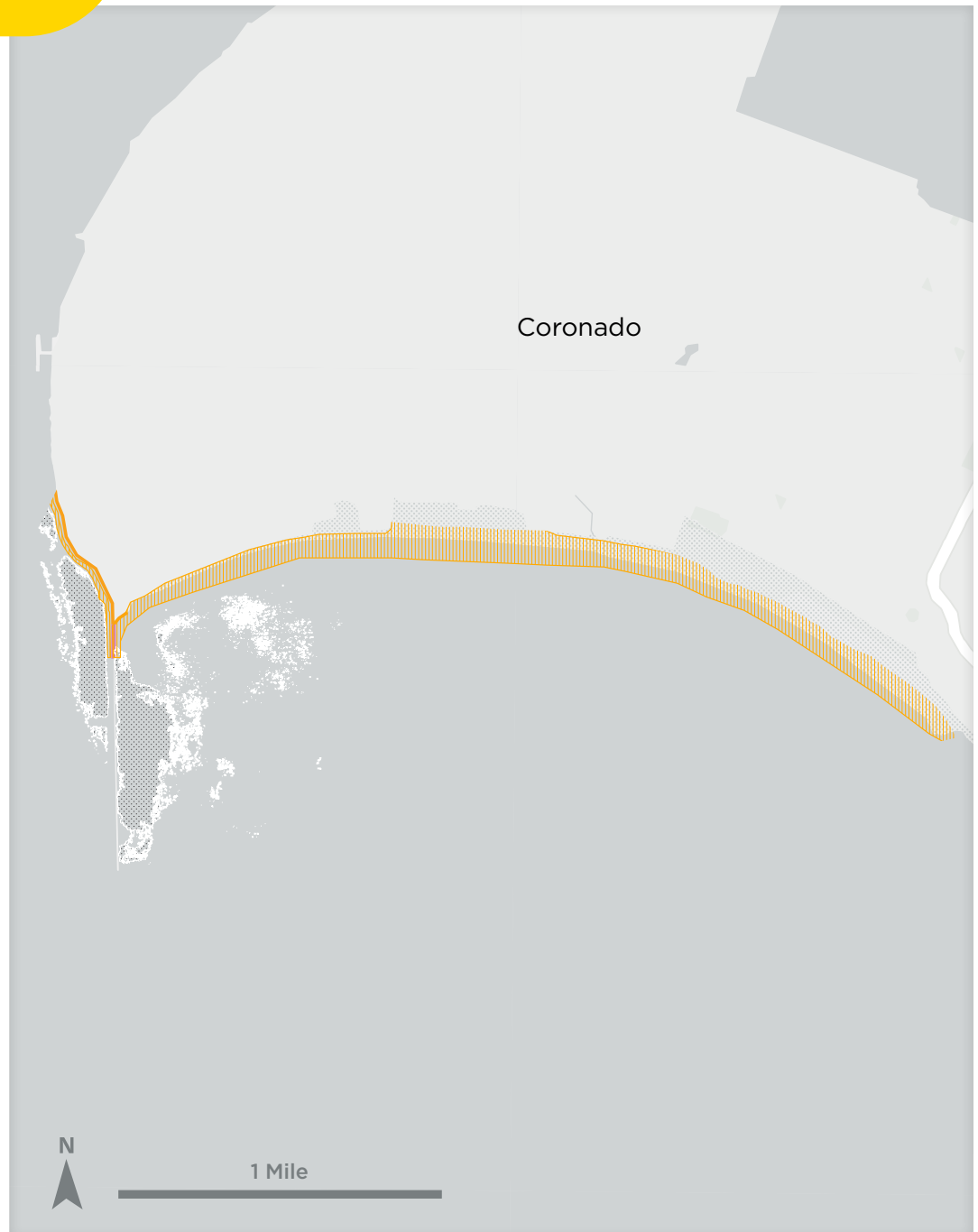
LEGEND

Shoreline Inventory

- Bulkhead
- Engineered Revetment
- Marginal Wharf
- Quay Wall
- Relaxed Rubble
- Seawall
- Soft Shoreline
- Wharf

Habitat

- Streams
- Eelgrass
- Cobble Beach
- Mudflat
- Riparian
- Rocky Intertidal
- Salt Marsh
- Salt Ponds
- Sandy Beach
- Undeveloped Upland



This SMU is outside of the Bay, separated by Zuniga Jetty, which was built off North Island parallel to Point Loma to stabilize the harbor entrance. The shoreline is a broad beach exposed to very high-energy waves from ocean swell. Point Loma and the jetty blocks north swell waves that could erode the beach, while the jetty helps to retain sand transported from south swell waves and stabilizes the beach. Proposed projects would need to be compatible with on- and offshore training operations and activities.



Suitable Strategies Map

LEGEND

Suitability Ranking

- L** Limited
- M** Moderate
- H** High

Suitable Strategies	Ranking
 Eelgrass	M
 Nearshore Reefs	L
 Beaches	H
 Ecotone / Embankment Slopes	L
 Ecological Armoring	L

Suitable Strategies

Suitable nature-based strategies in this SMU include the following (with rankings in parentheses):



Eelgrass (M): Pacific eelgrass beds can be expanded downcoast from current beds.



Nearshore Reefs (L): Similar to the taller reefs designed to attenuate oceanic swell waves in SMU 1, these reefs could provide rocky habitat (like Zuniga Jetty) and encourage sand retention behind them, which could reduce the erosion of the beach and prevent landward encroachment into Navy facilities.



Beaches (H): Nourishing the existing sandy beaches and creating dunes could assist in mitigating erosion as the sea level rises. The Navy and U.S. Coast Guard currently place material from maintenance dredging (from the same sources used in the Smuggler's Cove Reef Project) offshore of Breaker's Beach, and this material replenishes the beaches to the north and south.



Ecotone Levees and Embankment Slopes (L): Immediately inland of Zuniga Jetty and landward of Moffatt Road, there is space to create an ecotone levee or embankment slope landward of the existing revetment slope, avoiding high wave energy and erosion.

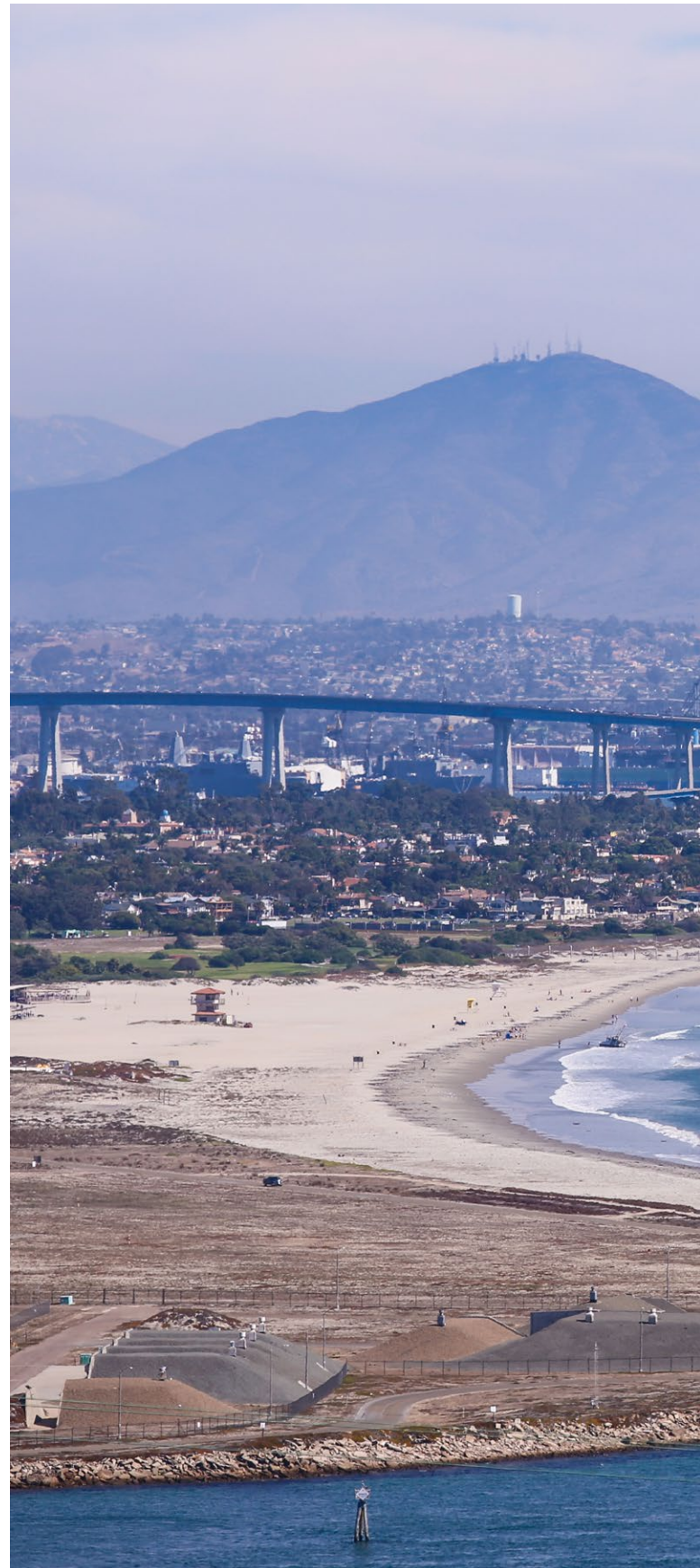


Ecological Armoring (L): Although there is revetment along the harbor entrance and ecological armoring could improve the habitat value of this shoreline, opportunities are limited due to the very high wave energy.



Zuniga Shoal

Zuniga Shoal, where nourishing sandy beaches and building dunes could offset erosion. Dredged material placed offshore of Breaker's Beach by the Navy and U.S. Coast Guard helps replenish nearby beaches.



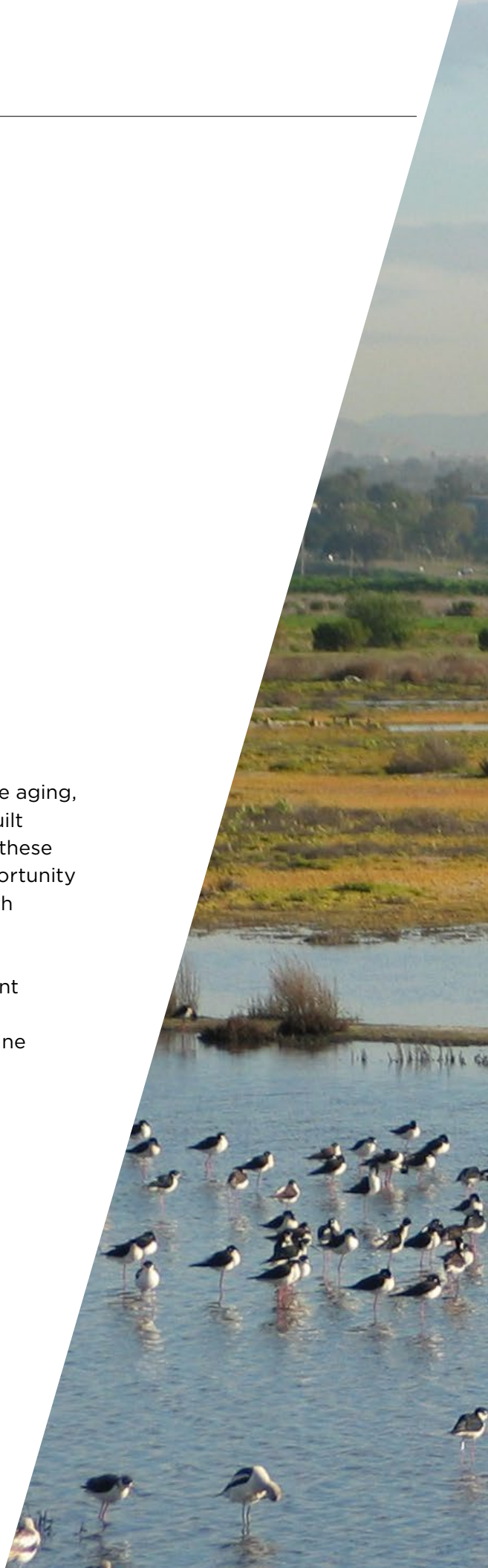


5

Conclusion

Many of San Diego Bay’s hard engineered shorelines are aging, with revetments, seawalls, bulkheads, and wharves built decades ago reaching the end of their design life. As these structures deteriorate or require repair, there is a unique opportunity to retrofit them with nature based strategies that provide both shoreline protection and ecological benefits. The Atlas offers a comprehensive, baywide framework to help identify where such strategies can be integrated into shoreline redevelopment efforts. In this context, nature based strategies provide a pathway to improve the habitat value and resilience of shoreline infrastructure through innovation, experimentation, and interdisciplinary design.

By consolidating historical, existing, and projected conditions, the Atlas illustrates how drastically the Bay’s natural systems have been altered over the last century—and how these altered conditions influence the suitability of nature based strategies today. Across the ten strategies evaluated—eelgrass, barrier islands, nearshore reefs, mudflats, tidal marshes, beaches, ecotone levees/embankment slopes, ecological armoring, living seawalls, and creek to marsh reconnection—suitability depends on factors such as shoreline shape, local wave patterns, existing development, and the amount of physical space remaining for natural features.





The 14 SMU suitability rankings highlight this spatial variation and reveal where strategies have the highest potential for success. SMUs with shallow bathymetry, wide intertidal zones, and adjacent open space—particularly in the South Bay—offer significant opportunities for multi benefit shoreline design. Conversely, highly developed shorelines with deep water and operational constraints—such as the working waterfront, naval facilities, and much of the Central and North Bay—are best suited to smaller scale, space efficient strategies such as ecological armoring and living seawalls. Open space and recreation areas around the Bay also offer prime opportunities for pocket beaches and pocket marshes—strategies that can be integrated landward of existing shorelines to provide habitat, improve resilience, and enhance public access.

Because nature based strategies depend on the ability of habitats to persist, build elevation, and—where space allows—migrate landward as sea levels rise, a clear understanding of habitat vulnerability and sediment availability is critical to their long term performance. Improving our understanding of habitat vulnerability, strengthening beneficial sediment management, and expanding opportunities for permitting pilot projects will be essential to advancing nature based shoreline adaptation. The following baywide initiatives would facilitate use of the Atlas:

- **Assess habitat vulnerability:** Building on the Port’s 2019 Sea Level Rise Vulnerability Assessment, there is a need for refined analysis of shoreline habitat vulnerability that goes beyond presence and elevation mapping. Updated bathymetric and topographic data would improve understanding of how habitats sit within the tidal frame, their exposure to increased flooding and wave action, and their capacity to persist or migrate under rising seas. Scenario based marsh accretion models (e.g., SLAMM) can help compare relative vulnerability and guide prioritization of restoration and adaptation strategies.
- **Strengthen sediment management:** A baywide study assessing sediment supply and demand under different sea level rise scenarios would help guide beneficial use opportunities (SFEI 2021). Coordination with the U.S. Army Corps of Engineers Dredged Material Management Team and precedent regional plans—such as the Sediment for Wetlands Adaptation Project Action Plan—can inform a cohesive sediment management approach for San Diego Bay.
- **Develop a regulatory framework focus group:** Following the strong interagency engagement during this project, convening a working group to explore programmatic permitting mechanisms would improve the regulatory pathway for multi benefit shoreline projects, especially pilot projects. A programmatic framework would reduce project by project permitting burdens, align agency expectations, and enable adaptive, lower risk testing of nature based strategies at a regional scale.



As climate change accelerates, San Diego Bay's shorelines face increasing risk, but also unprecedented opportunity. The Atlas is not prescriptive. Instead, it provides a palette of suitable strategies, a data driven method for identifying where they may be most effective, and a shared foundation to support cross jurisdictional coordination. This technical groundwork can help guide site specific studies, regulatory review, plan consistency analysis, public engagement, and interagency collaboration. Together, these efforts will support the development of shoreline projects that sustain the Bay's communities, infrastructure, and natural resources into the future.



Photo of looking east from South Bay

A golden view looking east across South Bay as the sun sets over the horizon.



CLICK HERE TO LAUNCH THE
SAN DIEGO BAY SUSTAINABLE SHORELINES ATLAS

A

Appendices





Appendix 1

Baseline Data

The first step to delineating Shoreline Management Units (SMUs) and performing subsequent suitability analysis is to present baseline data to characterize the San Diego Bay shoreline. We leveraged the San Diego Bay Integrated Natural Resources Management Plan (INRMP; U.S. Navy and Port of San Diego 2013) to synthesize the regional setting. Based on this understanding, we obtained regional datasets from the Dudek team, Port of San Diego (Port), U.S. Navy (Navy), and publicly available sources. Having a complete and accurate basemap is the data-driven foundation for the project. It was necessary to create some new datasets specifically for this project because there was either no data or available data was inaccurate (for shoreline types and current habitat, respectively). The following sections describe the methods for assessing the conditions along the San Diego Bay shoreline, with a focus on the data layers created by the project team.

1 Geographic Information System Database

We created an Esri geodatabase with the baseline data organized by four groups (Table 1):

1. Geomorphic context, such as topography-bathymetry and watersheds
2. Shoreline context, such as physical processes and shoreline types
3. Ecological context, such as historic and current habitat
4. Land use characteristics, such as jurisdictional boundaries and development patterns

Table 1. Baseline Data

Baseline Data Layer	Source	Retrieved From
Geomorphic Context		
Topography-Bathymetry	NOAA Digital Coast, 2014 USGS QL 2 Lidar: San Diego, California Point Cloud files with Orthometric American Vertical Datum of 1988 (NAVD88) using GEOID 18.	https://coast.noaa.gov/digitalcoast/data/
Surficial Geology	California Geological Survey Special Report 217 (Revised): Geologic Compilation of Quaternary Surficial Deposits in Southern California, 2012.	https://www.conservation.ca.gov/cgs/publications/sr217
Watersheds	California Interagency Watershed Map of 1999 (Calwater 2.2, updated May 2004, "calw221").	https://gispublic.waterboards.ca.gov/portal/home/item.html?id=816893ddab33434989eda92dbc0e126f#overview
Streams	U.S. Department of the Navy, Naval Facilities Engineering Command Southwest (NAVFAC SW), and Port of San Diego. 2013. San Diego Bay Integrated Natural Resources Management Plan, Final September 2013. San Diego, California. Prepared by Tierra Data Inc., Escondido, California.	Port of San Diego (5/22/24)
Storm Drains	Port of San Diego (6/4/24); NAVFAC SW (6/18/24)	

Table 1. Baseline Data

Baseline Data Layer	Source	Retrieved From
Shoreline Context		
FEMA	FEMA National Flood Hazard Layer	https://www.fema.gov/flood-maps/national-flood-hazard-layer
Shoreline Inventory	Dudek team	
Ecological Context		
Historic Habitat	U.S. Department of the Navy, Naval Facilities Engineering Command Southwest (NAVFAC SW) and Port of San Diego. 2013. San Diego Bay Integrated Natural Resources Management Plan, Final September 2013. San Diego, California. Prepared by Tierra Data Inc., Escondido, California.	Port of San Diego (5/22/24)
Current Habitat	Dudek team	
Least Tern Nesting Sites	Dudek team	
Artificial Reefs and Groins	Dudek team	
Land Use Characteristics		
Municipal Boundaries	San Diego Geographic Information System (SanGIS). 2024. Municipal Boundaries. Regional Data Warehouse.	http://web.sangis.org/
Port Jurisdiction	Port of San Diego (6/4/24)	
Naval Installations	NAVFAC SW (6/18/24)	
Land Use	San Diego Geographic Information System (SanGIS) (2024). Land Use. Regional Data Warehouse.	http://web.sangis.org/
USFWS Wildlife Refuges	U.S. Fish and Wildlife Service, FWS National Realty Tracts Simplified, 2024.	https://gis-fws.opendata.arcgis.com/datasets/fws::fws-national-realty-tracts-simplified/explore
Public Access	San Diego Geographic Information System (SanGIS). 2024. General Plan Trails. Regional Data Warehouse.	http://web.sangis.org/
Coastal Hazards		
Sea Level Rise and Storm Scenarios	U.S. Geological Survey. 2024. <i>Coastal Storm Modeling System (CoSMoS) Version 3.0.</i>	https://ourcoastourfuture.org/hazard-map/

2 Geomorphic Context

San Diego Bay is a natural, nearly enclosed harbor. To the northwest is the 400-foot-high, flat-topped Point Loma peninsula; to the north is the flat delta where the San Diego River used to flow into the bay (where the airport was

built); to the east and south are low-lying coastal plains; and to the west is a long, narrow, sandy strand connected to Coronado and North Island that separates the bay from the sea. Zuniga Jetty was built off North Island parallel to Point Loma to stabilize the harbor entrance.

Bathymetry outside of the navigation channel reflects the history of dredge and fill activity. The INRMP describes that most of the material was dredged prior to 1970 and was used for filling deltas and wetlands and developing the bayfront, such that less than 18% of the original bay floor remains undisturbed (U.S. Navy and Port of San Diego 2013). In general, the northern end of San Diego Bay is deepest (30 feet to 40 feet), the central area has more uniform depths (9 feet to 12 feet), and the southern end has the shallowest areas (less than 6 feet).

The surficial geology of the San Diego Bay shoreline is predominately artificial fill with alluvial valley deposits, underlain by paralic deposits. San Diego Bay watersheds have similar geology.

3 Shoreline Context

As detailed below, water levels in the bay are relatively consistent, except for around the harbor entrance and potentially along the mudflat/tidal marshes in the south bay. Waves are relatively modest within the bay and along the shoreline, with swell-driven waves limited to the area south of Ballast Point and locally generated wind waves up to 3 feet in height occurring only under the highest storm/wind events.

3.1 Water Levels

Water levels are dominated by the tides. Water level observations in San Diego Bay are available from National Oceanic and Atmospheric Administration station 9410170, located at Broadway Pier in the Embarcadero District area from 1906 to present day (Tides & Currents 2024). Tides are mixed, with two unequal highs and lows each day. The daily difference in Mean Lower Low Water to Mean Higher High Water is about 5.7 feet (Table 2).

Table 2. Tidal Elevations from National Oceanic and Atmospheric Administration Tide Station No.9410170, Located in San Diego Bay (Tidal Epoch 1983-2001)

Abbreviation	Description	Elevation (ft MLLW)	Elevation (ft NAVD88)
HOWL	Highest Observed Water Level	+8.24	+7.81
HAT	Highest Astronomical Tide	+7.62	+7.19
MHHW	Mean Higher High Water	+5.72	+5.29
MHW	Mean High Water	+4.99	+4.56
MSL	Mean Sea Level	+2.94	+2.51
MLW	Mean Low Water	+0.94	+0.51
NAVD88	North American Vertical Datum of 1988	+0.43	+0.00
MLLW	Mean Lower Low Water	+0.00	-0.43
LAT	Lowest Astronomical Tide	-2.06	-2.49
LOWL	Lowest Observed Water Level	-3.09	-3.52

Extreme high and low water levels can occur from a combination of factors, such as astronomical tides; meteorological effects, like strong winds and high/low atmospheric pressures; and climate oscillation patterns, such as El Niño, reaching approximate elevations of +8 feet and -3 feet NAVD88, respectively. Overall, water level differences

throughout the Bay are considered minor. There may be slight differences that are episodic and ephemeral, such as wave setup due to prevailing winds or localized higher water levels around river mouths during storm events.

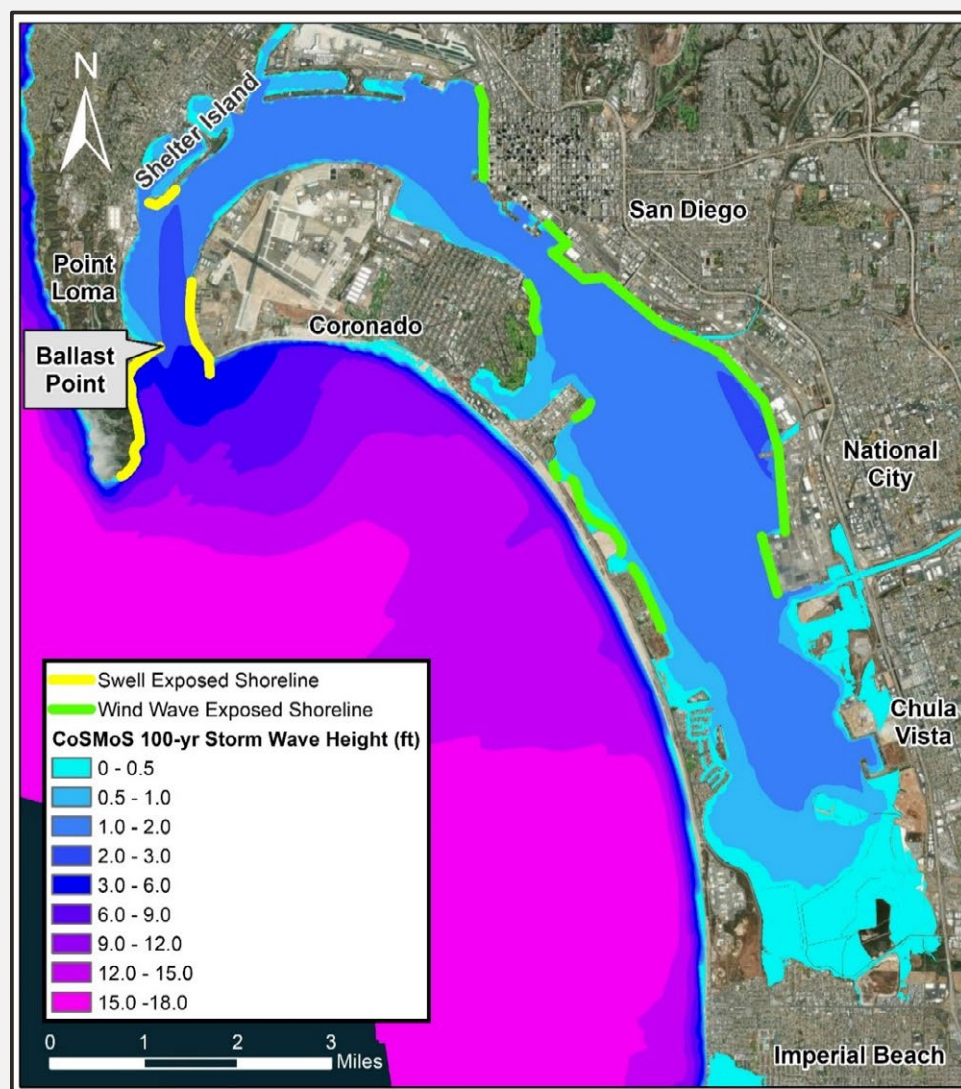
3.2 Waves

San Diego Bay is naturally sheltered from waves from the Point Loma peninsula. South swell can propagate into the bay near the entrance, but most wave energy dissipates through friction with the seabed before entering the bay. Ballast Point further attenuates this wave energy. Westerly winds often pick up in the afternoon but are mostly below 6 knots, resulting in low potential for wind-driven waves to develop. Therefore, locally generated wind waves are limited by mild winds and low fetch area, causing primarily tidal-driven circulation in San Diego Bay.

Occurrence of waves in San Diego Bay is associated with extreme storm events, with stronger winds and wave heights up to 3 feet (Figure 2). However, because exposure to ocean swell is minimal beyond the immediate entrance near Point Loma and significant wind waves do not form under normal conditions, waves are not a driving factor along the San Diego Bay shoreline. Similarly, boat wakes are not considered a significant source of wave energy, in part due to regulated speeds and “no wake zones.”

Because the majority of the shoreline is hardened by revetments, seawalls, bulkheads, and wharfs, there are limited soft shorelines that could be eroded by waves and contribute sediment to the bay. Furthermore, most of the soft shorelines are on the lee side of prevailing winds (the western shoreline), resulting in even less potential sediment contribution. The result is that wave erosion of natural shorelines is a minimal sediment contributor to the bay.

Figure 1. CoSMoS 100-Year Wave Heights and Locations of Wave Exposure in San Diego Bay (USGS 2024)



3.3 Shoreline Inventory

The Dudek team created a new dataset to document the existing type and condition of shorelines around San Diego Bay (SFEI 2016). This information is critical to identify opportunities to soften the bay’s shoreline and consider nature-based design alternatives to maintain and strengthen existing structures as well as incorporate natural processes into flood risk management.

Mapping the shoreline was accomplished by extracting the 8-foot NAVD88 contour line (from the bathymetry-topography dataset; Table 1), which aligns with the highest water levels based on present-day conditions (Table 2), and digitizing the various shoreline types along this contour in ArcGIS. The shoreline was mapped using Nearmap aerial high-resolution satellite imagery for the San Diego Bay region taken on January 15, 2024 (Nearmap 2024). Google Earth 3D imagery including “Street View” first-person surface photographs within and outside of the bay waters

were used to supplement to the aerial imagery for shoreline type identification and cross-verification (Google Earth 2024). In select locations where the highest water line deviated from the 8-foot NAVD88 contour (e.g., the conspicuous vegetation line along sandy beach shorelines), the shoreline was identified based on best professional judgement.

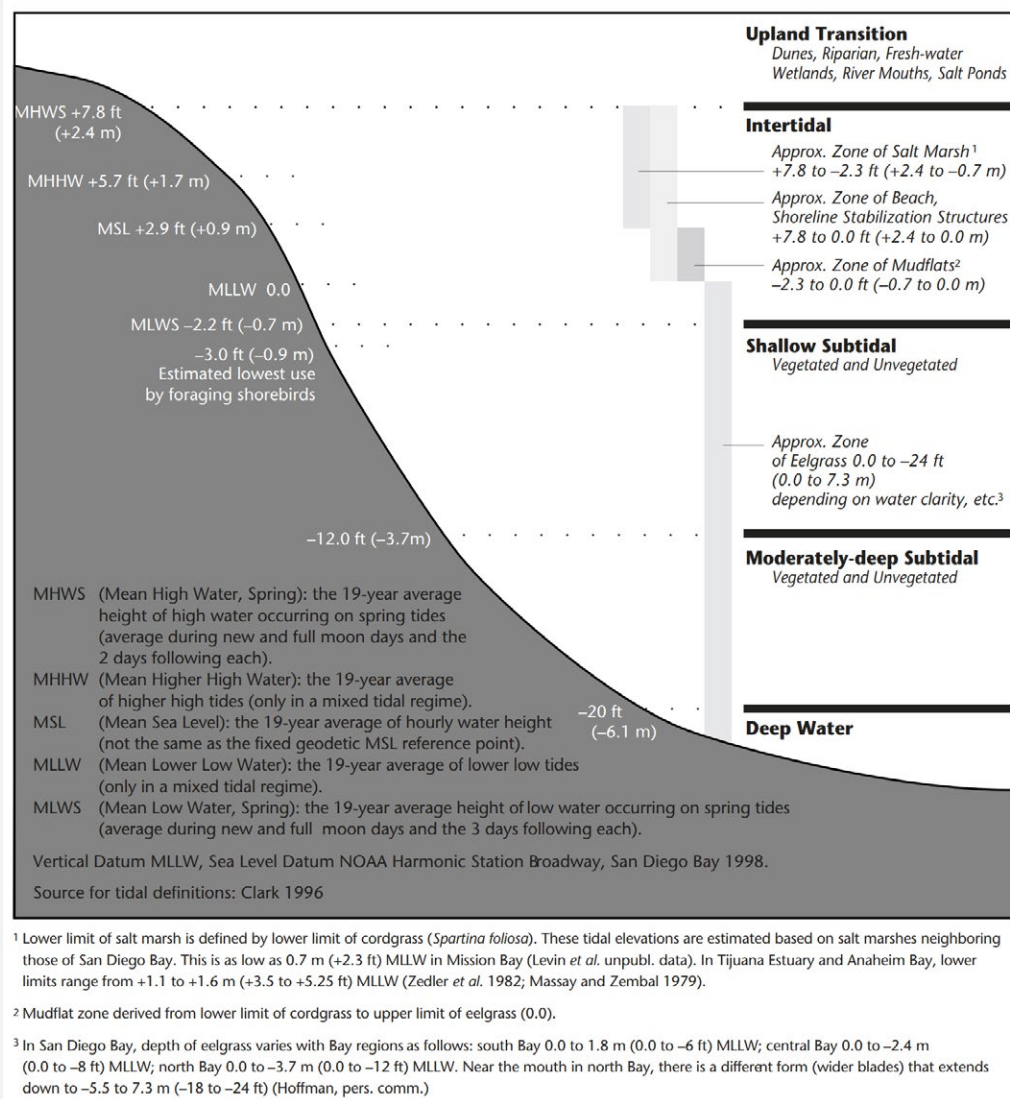
The focus of this inventory is on hard shoreline types. Hard shorelines represent over half of the shoreline, with the largest areas of soft shorelines in the south bay and around the Silver Strand. Soft shorelines are mapped as a single category and broken down into more detailed types in the current habitat dataset (described later). Table 3 describes the different shoreline types along the approximate 77.5-mile-long San Diego Bay shoreline. The bay has long, straight armored stretches (Navy, Port terminals, downtown waterfront), but also many highly irregular reaches such as the Chula Vista Wildlife Reserve, tidal channels, and salt pond dikes. When you include all of those indentations, the shoreline length increases substantially. It should be noted that pile-supported piers or docks were excluded from identification, and instead the shoreline was characterized by its type where these structures met the shoreline edge.

Table 3. Shoreline Types as Identified in the Shoreline Inventory Layer

Types	Description	Example
Seawall	Massive structure composed of concrete or other impermeable material along the shore. Usually vertical. Metal and wooden components may be present on the leading edge as well. Includes angled features such as boat ramps.	Northern and western shores of Naval Amphibious Base
Engineered Revetment (Riprap)	Well-organized, intact stone or concrete blocks placed on a sloped surface. May contain fill. Generally along urban or military waterfronts.	Most of Harbor Island
Relaxed Rubble (Revetment)	May superficially resemble engineered revetment but is more poorly consolidated debris material, often of varying sizes, types, and structural integrity. Generally along residential or smaller-scale commercial zones.	Shoreline along Naval Air Base Coronado Island from Zuniga Jetty north to Ammunition Pier
Bulkhead	Vertical retaining wall typically composed of asphalt-covered artificial fill that produces an artificial, raised, hardened shoreline and coastal platform. Generally used for commercial purposes/facilities.	Broadway Pier and USS Midway Museum Pier
Quay Wall	Similar to bulkhead but contains fender piles or buoys along the bayward edge to allow docking of vessels for loading and unloading. Commonly found in industrial, port, or military installment areas.	Naval Base San Diego Pier area
Wharf	Pile-supported structure that extends over the water's edge but is not considered a pier. Unlike a bulkhead, contains intertidal habitat underneath the structure. Typically topped by wooden planking or concrete material. Generally supports less weight than bulkheads. Common in smaller scale commercial a	Balboa Landing docking area
Marginal Wharf	Similar to wharf but contains fender piles or buoys on the bayward side to support berthing of vessels.	Northeast corner of the head of Coronado Island along Naval Base Coronado (Piers J and K)
Soft Shoreline	Sandy or cobble beach, salt marsh, or bluff.	Point Loma shoreline from entrance into San Diego Bay to Naval Base Point Loma, Kellogg Beach, San Diego Bay National Wildlife Refuge

4 Ecological Data

With its warm, nutrient-rich shallow waters, intertidal shorelines, and shelter from waves, San Diego Bay has various habitat types along its shoreline. The Dudek team created a new dataset to document the current habitat types in San Diego Bay. The team reviewed the INRMP (U.S. Navy and Port of San Diego 2013) habitat data and found it was outdated and inconsistent. The team concluded that using this data would limit our ability to delineate SMUs and evaluate the suitability of nature-based shoreline design alternatives. The team evaluated alternative regional data sources (e.g., San Diego Geographic Information Source) but found the resolution was too coarse to be useful. Therefore, the team applied the INRMP (U.S. Navy and Port of San Diego 2013) tidal elevation habitat framework to the topography-bathymetry- data and digitized the various habitat types within these elevation bands in ArcGIS (Table 4). Like the shoreline inventory, habitat identification was determined using aerial imagery. In select locations where the imagery deviated from the framework, the habitat types were identified based on best professional judgement.

Figure 2. Habitats in Relation to Tidal Elevation

Source: U.S. Department of the Navy *et al.* 2013.

San Diego Bay is characterized by pockets of natural beaches and salt marsh, with the largest areas in the south bay and around the Silver Strand.

Table 4. Habitat Types as Identified in the Current Habitat Layer

Type	Description	Example	Elevation (ft NAVD88)
Undeveloped Upland	Undeveloped open space, including natural areas, vacant lands, public open space, and intact upland scrub.	Upper elevations of Silver Strand State Beach	Above +7.57
Riparian	Undeveloped uplands upstream along creeks and rivers containing fresh water–dependent flora.	Upstream areas of Sweetwater River	Above +7.57
Sandy Beach	Conspicuously sand-dominated beaches, typically observed by light-colored sand, in wildlife areas and public use areas and fronting residential/commercial development. May form along shoals adjacent to the shoreline.	Kellog Beach in the northwest portion of San Diego Bay	–2.73 to +7.57
Cobble Beach	Beaches dominated by cobblestone or larger-sized material, typically backed by bluffs containing material that erodes to form the beach.	Concentrated along the southeast portion of the Point Loma shoreline	–2.73 to +7.57
Salt Marsh	Vegetated wetlands, often containing meandering tidal channels, adapted to tidal action. Some areas have remained intact while others have been recently restored. Can be found in small pockets of developed shorelines.	San Diego Bay National Wildlife Refuge	+2.57 to +7.57
Salt Pond	Former managed ponds for salt works operations containing hyper saline soils.	South bay, north of Otay River	+2.57 to +7.57
Mudflat	Typically observed as flat and barren areas subject to tidal action, though it can also support vegetation.	Found throughout San Diego Bay, with large areas in the south bay	–2.73 to +2.57
Rocky Intertidal	Rocky shorelines in the intertidal zone containing organisms and vegetation adapted to tolerate high wave action and exposure to air. Due to its variability, general elevation guidelines were not used to map this habitat type.	Concentrated along the southeast portions of the Point Loma shoreline	Unique habitat type determined by visual inspection (not elevation)
Shallow	Vegetation adapted to surviving in the subtidal zone.	Found throughout San Diego Bay.	Below –2.73

5 Land Use Characteristics

Density and development patterns vary along the San Diego Bay shoreline. The Point Loma peninsula is largely dedicated to military use. The north bay contains many marinas, and a large portion of the area is taken up by the San Diego International Airport, along with some military uses. The middle of the bay, near National City, is predominantly military and industrial uses, as well as the marine terminal. The south bay contains large amounts

of open space and the San Diego Bay National Wildlife Refuge. Coronado is a mix of recreational areas, such as parks, and single-family residential. Each of these areas faces unique coastal hazards and demand different design alternatives to make them more resilient to increasing risks due to sea level rise and climate change. It should be noted that for this project existing development is fixed. This means that, in subsequent analysis, suitable design alternatives must be compatible with existing land use characteristics. The team will not convert land use types to take advantage of natural processes.

The team reviewed the latest SanGIS land use data and organized them into major categories (Table 5) based on San Diego Association of Governments definitions (SANDAG 2023). The team also added jurisdictional boundaries and public access within this group of data.

Table 5. Land Use Types as Identified in the Land Use Layer

Category	Description
Single-Family Residential	Low-density residential, including single-family detached, rural residential
Multi-Family Residential	Multi-family residential buildings, single-room occupancy buildings, mobile homes, and group quarters facilities
Commercial	Range of commercial developments, including strip commercial, shopping centers, offices, stadiums, hotels/resorts, etc. with extensive parking lots
Industrial	Light industrial, warehousing, and heavy industrial with potential hazardous materials
Transportation	Parking lots, road/railroad right-of-way, transit centers, airports, marina, and marine terminal
Open Space and Recreation	Natural areas, preserves, vacant land, active/passive beaches, and recreational parks
Facilities/Institutions	Places of worship, schools, fire stations, convention centers, hospitals, libraries, and other facilities
Military	All branches of military use including barracks and airports
Utilities	Communications and other utilities, service stations
Extractive Industry	Includes San Diego Bay National Wildlife Service Salt Pond Restoration
Intensive Agriculture	Small amount of agriculture fields east of Interstate 5 near open space and industrial uses
Junkyard/Dump/Landfill	Landfills and auto wrecking/dismantling and recycling centers

6 Coastal Hazards

This report does not constitute a vulnerability assessment. The Dudek team presents coastal hazards at a broad, landscape scale to highlight the most vulnerable SMUs and where projects may be needed first. The California Coastal Commission recommends evaluating the Intermediate-High SLR scenario for most development (CCC 2024). Based on sea level rise scenarios for San Diego (Ocean Protection Council OPC 2024) and assumptions about the design life and construction timing for nature-based projects, 1.6 feet and 3.3 feet of sea level rise for 2060 and 2080–2090 are appropriate intermediate-high risk aversion projections to consider.

The strategies do not address groundwater hazards. As sea levels rise in San Diego Bay, shallow groundwater underneath low-lying coastal communities will also rise. Low-lying inland areas could flood from emergent groundwater before coastal floodwaters overtop the shoreline. Rising groundwater could increase infiltration rates into sewer systems flood basements, and damage underground infrastructure. Rising groundwater could also interact with contaminated lands, creating potential exposure pathways that could harm the environment and public

health. Assuming moderate permeability as a starting point to screen for potential groundwater hazards (useful when little is known about the local subsurface geology or current groundwater depths), CoSMoS shows shallow groundwater rising with 1.6 feet of SLR, especially around the Chula Vista Bayfront and Silver Strand Training Complex. With 3.3 feet of SLR, these areas remain vulnerable as well as the land north of San Diego International Airport and the northern portion of Coronado.

Appendix 2

Shoreline Management Units

Using the baseline data and best professional judgement, the Dudek team delineated 14 contiguous Shoreline Management Units (SMUs) that share common physical and ecological characteristics and would accordingly be suitable for a particular suite of nature-based strategies. The following sections detail the methods for delineating and characterizing the SMUs.

1 Delineating SMU boundaries

To delineate SMUs, the Dudek team identified boundaries on the upland side, the bay side, and between SMUs.

1.1 Upland Boundary

The upland boundary was drawn to conservatively capture the area affected by end-of-century SLR conditions. The Ocean Protection Council advises caution when designing for projections beyond 2100 due to greatly increased uncertainty and divergence in model results beyond this timeframe. The 4.9-foot SLR with 100-year storm scenario, which represents the intermediate-high risk aversion projection for 2100, is especially helpful because San Diego Bay is a hydrologically bounded system uninfluenced by flooding in adjacent watersheds such as the San Diego River and Tijuana River.

1.2 Bayward Boundary

The bayward boundary is the –10-foot North American Vertical Datum of 1988 (NAVD88) contour, capturing the maximum water depth at which sediment resuspension occurs in the bay and the feasible limit that fill can be placed for restoration. It avoids most Bay areas dredged for commercial and military navigational uses. For the bayside portion of Point Loma south of Ballast Point and Zuniga Jetty/Shoal considered the Outer Bay, the bayward boundary is –20-foot NAVD88 because within these ocean-influenced areas, the maximum water depth at which wave and swell-driven sediment resuspension occurs is much deeper than within the more protected inner Bay waters. In these locations, the –20-foot NAVD88 contour marks the bottom of the beach slope where waves begin to interact with the bottom and experience drag, whereas deeper than the –20-foot NAVD88 contour, there are likely limited effects of oceanic swell energy on the seafloor or seafloor influence on energy transfer to the shore margin. This suggests the –20-foot NAVD88 elevation is near the depth of closure within these areas.

1.3 Side Boundaries

Delineation between SMUs began with the four ecoregions of the Bay (U.S. Navy and Port of San Diego 2013):

1. **North Bay**, the Marine Region: This region is dominated by tidal exchange with the ocean; residence time of Bay water is just a few days.
2. **North-Central Bay**, the Thermal Region: Currents are driven primarily by surface heating—vertical exchange of water resulting from cold oceanic plug with the flood tide, then the receding of warm Bay surface water with the ebb tide.
3. **South-Central Bay**, the Seasonally Hypersaline Region: Water is stratified by salinity gradients induced by evaporation.
4. **South Bay**, the Seasonally Estuarine Region: This region receives occasional inputs of freshwater discharge from the mouth of the Otay and Sweetwater Rivers. Residence time of Bay water can exceed 1 month and may approach much longer times. It is the only part of the Bay with native bottom contours (other regions have lost greater than 90% of the intertidal habitat and have been dredged for navigation purposes and Bay shore fill generation).

Three primary physical factors were then determined to further differentiate different areas of the shoreline:

1. Wave energy
2. Width of the shallow subtidal and intertidal zone
3. Shoreline type

1.3.1 Wave Energy

While San Diego Bay is a relatively low wave energy environment due to its sheltering from oceanic swell energy by Point Loma headland and Silver Strand/Coronado Beach, generally low vessel speeds outside of the main navigation channel, and limited fetch available for wind-wave generation, relative differences in wave energy at the shore can determine how exposed an area is to wave erosion, runup, and overtopping, which determines what design alternatives may be appropriate.

Relative wave energy affecting the shoreline was determined using an **annual event** based on in-situ measurements, historic wind/wave records, and experiential observations since CoSMoS does not provide wave data within San Diego Bay. The relative wave energy in the bay was evaluated and qualitatively rated as:

- **Very High:** Outside of the sheltering and limited fetch of the Bay, the Outer Bay is exposed to south Pacific open ocean swells as well as shorter-period, higher amplitude storm waves associated with passing frontal and/or tropical systems. These types of swells contain wave energies that are orders of magnitudes greater than those produced by the short-period wind waves and boat wakes that occur within the bay itself. As a result, these areas experience much more extreme wave forces that drive shoreline dynamics within their boundaries.
- **High:** Vessel wakes propagating from the navigation channel are the dominant wave energy in North and North-Central Bay. While short-lived, these waves are larger than wind waves.
- **Moderate:** Adjacent to Piers K and L in North Island and along the east side of South-Central Bay, vessel wakes are reduced by barriers (piers, docks, and wave attenuators) that can act to reduce the incipient wave energy as it approaches the shoreline edge¹; the west side of South-Central and South Bay are affected by Santa Ana- and locally-generated wind waves.
- **Low:** Backwater environments where the shoreline is sheltered by landforms, e.g., Shelter and Harbor Islands and Coronado Cays.

1.3.2 Width of Shallow Subtidal and Intertidal Zone

The relative width of the shallow subtidal and intertidal habitats was qualitatively rated to capture the extent of the area in which waves interact with the Bay bottom, thereby buffering the shoreline from wave energy and indicating potential space for bayward adaptation (e.g., to address habitats at risk of drowning with sea level rise).

The relative width of the shallow subtidal and intertidal habitats ratings are:

- **Narrow:** Thin band of shallow subtidal and intertidal habitats adjacent to the navigation channel and heavily developed shoreline (e.g., marine terminals and Navy installations)
- **Moderate:** Mostly backwater environments, where sedimentation can occur
- **Wide:** Outer Bay areas with more significant sediment transport and portions within the Bay with soft erodible shorelines

¹ It is not anticipated that these barriers would be removed or significantly modified in the short- to mid-term future, thus including them and their influence on wave energy was determined most representative of shoreline processes.

- Very Wide: South Bay, notably excluded from a history of dredge and fill

1.3.2 Shoreline Type

Based on a qualitative review of the shoreline inventory, shoreline type was evaluated to assess the vulnerability and adaptability of the shoreline. While hard structures can provide a specific level of protection, they cannot adapt over time and often have unintended consequences on the surrounding environment and communities, e.g., loss of beach for wildlife and public access. Conversely, soft shorelines can be more vulnerable to wave energy, but present opportunities for nature-based adaptation, which can evolve over time and provide multiple benefits. For example, tidal mudflat/marsh complexes can reduce flooding by attenuating waves, enhance water quality by filtering out and breaking down contaminants, provide nurseries for fish and shellfish and nesting sites for birds, sequester carbon, and provide important recreational opportunities. The shoreline type ratings are:

- Hard: Shoreline predominantly composed of engineered structures/armoring, e.g., seawalls, revetments, bulkheads, wharfs
- Mixed: Roughly equal amounts of hard and soft shorelines
- Soft: Shoreline predominantly composed of natural edges/habitat, e.g., sandy or cobble beach and salt marsh

2 Characterizing SMUs

Natural processes set the boundaries around the 14 SMUs. Almost all SMUs have unique combinations of the three primary factors that influence the suitability of nature-based strategies along the shoreline (Table 1).

Table 1. Shoreline Management Units Characterized by Three Primary Factors

SMU	Description	Relative Wave Energy	Width of Shallow Subtidal/Intertidal Habitats	Shoreline Type
1	Tip of Point Loma to Ballast Point	Very High	Wide	Mixed
2	Ballast Point to Shelter Island	High	Narrow	Mixed
3	Backwater embayments from Shelter Island to Coast Guard Pier	Low	Moderate	Mixed
4	Bayward exposure of Shelter Island to Coast Guard Pier	High	Narrow	Hard
5	Coast Guard pier to East Coronado Bridge Landing	High	Narrow	Hard
6	East Coronado Bridge Landing to Sweetwater River channel	Moderate	Narrow	Hard
7	Entire South Bay from Sweetwater River to Crown Cove (excluding the Coronado Cays)	Moderate	Very Wide	Soft
8	Coronado Cays	Low	Narrow	Hard
9	Crown Cove to south side of Naval Amphibious Base	Moderate	Wide	Soft
10	Glorietta Bay (Coronado Bridge Landing to Naval Amphibious Base)	Low	Moderate	Mixed
11	Navy Pier K to Coronado Bridge Landing	High	Moderate	Hard
12	Carrier Basin	Moderate	Narrow	Hard
13	Zuniga Jetty to Navy Pier L	High	Moderate	Mixed
14	Zuniga Shoal	Very High	Wide	Soft

Appendix 3

SMU Suitability Analysis

The assessment of the San Diego Bay shoreline through Shoreline Management Unit (SMU) delineation and strategy suitability analysis and ranking provides a comprehensive foundation for sustainable shoreline decision-making, as envisioned by the Integrated Natural Resources Management Plan.

The shoreline within each SMU was assessed for the suitability of the 10 nature-based strategies using specified criteria. For suitable strategies, a qualitative evaluation was conducted, assigning rankings of 1, 2, or 3 to each suitability criterion, representing low, moderate, and high suitability, respectively. The following tables show the criteria rankings for each SMU. Additional study, planning, and engineering will be required to refine opportunities.

SMU 1

Table 1. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Eelgrass	2	2	3	2	0	0
Barrier islands	3	2	3	3	0	0
Nearshore reefs	2	2	2	2	0	0
Beaches	2	2	2	2	2	2
Ecological armoring	3	3	2	3	3	0

SMU 2

Table 2. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Eelgrass	1	1	2	2	0	0
Nearshore reefs	3	1	2	2	0	0
Beaches	2	2	2	2	3	2
Ecological armoring	3	3	2	3	3	0

SMU 3

Table 3. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Eelgrass	2	2	2	2	0	0
Barrier islands	2	1	2	2	0	0
Nearshore reefs	3	2	2	2	0	0
Tidal marshes	3	2	2	1	3	3
Beaches	2	2	2	2	3	3

Ecotone levee / embankment slopes	2	2	3	1	2	3
Ecological Armoring	2	2	2	2	3	0
Living Seawalls	3	2	3	3	3	0

SMU 4

Table 4. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Tidal marshes	1	1	3	1	2	3
Beaches	1	1	3	1	2	3
Ecological armoring	3	3	3	3	3	0
Living Seawalls	3	3	3	3	3	0

SMU 5

Table 5. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Tidal marshes	1	1	2	1	2	3
Beaches	1	1	2	1	2	3
Ecological armoring	3	3	3	3	3	0
Living seawalls	3	3	3	3	3	0

SMU 6

Table 6. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Tidal marshes	1	1	2	1	2	3
Beaches	2	1	2	1	2	3
Ecological armoring	2	2	3	3	3	0
Living seawalls	3	2	3	3	3	0

SMU 7

Table 7. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Eelgrass	3	2	3	3	0	0
Barrier islands	3	3	3	3	0	0
Nearshore reefs	3	2	3	3	0	0
Mudflats	3	3	3	3	3	0
Tidal marshes	3	3	3	3	3	3
Beaches	3	2	3	3	3	2
Ecotone levee / embankment slopes	2	3	3	3	3	3
Ecological armoring	1	1	3	1	3	0
Living seawalls	2	1	2	1	2	0
Creek-to-marsh reconnection	3	3	2	3	2	3

SMU 8

Table 8. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Tidal marshes	2	1	3	1	3	3
Beaches	2	1	1	1	3	3
Ecological armoring	2	1	2	3	3	0
Living seawalls	3	1	2	3	3	0

SMU 9

Table 9. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Eelgrass	2	2	3	3	0	0
Barrier islands	3	1	3	3	0	0
Nearshore reefs	2	2	2	3	0	0
Tidal marshes	1	1	2	3	3	3
Beaches	3	3	3	3	3	3

Ecotone levee / embankment slopes	1	2	2	2	3	3
Ecological armoring	2	2	3	1	1	0
Living seawalls	2	2	2	1	1	0

SMU 10

Table 10. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Tidal marshes	2	2	2	1	2	3
Beaches	3	3	3	3	2	3
Ecotone levee / embankment slopes	3	3	3	1	2	3
Ecological armoring	2	2	3	2	3	0
Living seawalls	3	2	3	2	3	0

SMU 11

Table 11. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Nearshore reefs	3	3	2	2	0	0
Tidal marshes	1	1	2	1	2	3
Beaches	2	2	2	2	3	3
Ecological armoring	3	2	3	2	3	0
Living seawalls	3	3	3	2	3	0

SMU 12

Table 12. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Ecological armoring	1	1	2	3	3	0
Living Seawalls	2	2	2	1	1	0

SMU 13

Table 13. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Nearshore reefs	3	3	2	1	0	0
Beaches	1	1	2	2	3	1
Ecotone levee / embankment slopes	1	1	1	1	3	3
Ecological armoring	2	3	3	3	3	0
Living seawalls	3	3	3	2	3	0

SMU 14

Table 14. Suitable Opportunities in the SMU and Their Corresponding Ranking

Nature-based and Hybrid Strategy	Wave Energy	Currents	Bathymetry	Width (Shallow Subtidal and Intertidal)	Shoreline Type	Land Use
Eelgrass	1	1	2	2	0	0
Nearshore reefs	1	1	1	1	0	0
Beaches	2	2	3	3	3	1
Ecotone levee / embankment slopes	1	1	1	2	3	1
Ecological armoring	1	1	1	2	3	0

Appendix 4

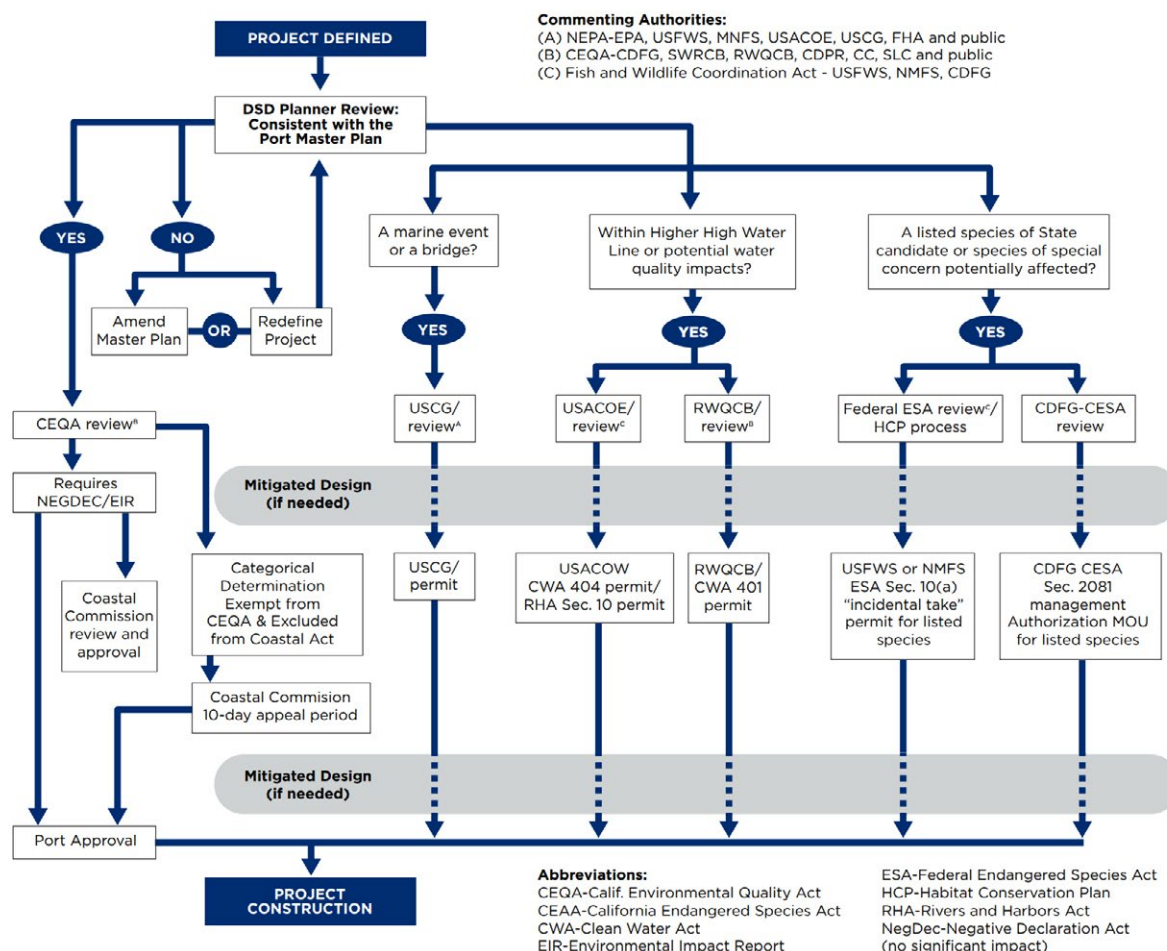
Regulatory Framework

This section describes regulatory framework considerations and challenges associated with the project-by-project approach. Using examples and feedback from an interagency meeting, this section identifies programmatic permitting as a potential approach for streamlining the regulatory process for nature-based adaptation projects in light of anticipated significant losses due to sea level rise and storm impacts. Programmatic permitting can allow for a more comprehensive evaluation of project impacts and benefits at a regional scale and can provide regulatory efficiencies.

1 Project-by-Project Approach

Currently, regulatory permitting for nature-based design projects requires individual project-by-project review by numerous agencies with overlapping jurisdictions and policy mandates. There are many challenges that can result from the current project-by-project approach:

- **Reactive rather than proactive approach** – Agencies review projects only after permit applications are submitted, which does not allow for ways to ensure consistency among the various agencies' requirements.
- **Ecosystem, watershed, or littoral cell level effects overlooked** – Without placing individual projects in the context of a larger-scale view or plan, important information on the overall condition of aquatic resources, cumulative impacts, and mitigation effectiveness in a region cannot be tracked as easily.
- **Regional restoration and management goals not developed/tracked** – Individual project review and permit issuance does not give agencies the opportunity to develop and track regional goals to better understand how discrete project goals can benefit resources at a larger ecosystem scale. For example, the conversion of one type of waters of the state/United States to another type, such as salt ponds into tidal marshes, can be challenging to evaluate in project-based permit review.
- **Administrative resources sometimes misplaced** – Project-by-project review involves more regulatory agency person-hours per project and lacks a comparative perspective to understand which projects warrant more stringent review. As a result, undue emphasis may be placed on a project with fewer impacts than one with greater impacts, and the timely review of simpler, beneficial projects may be adversely impacted.



Project Processing Flowchart: A step-by-step overview of the project workflow from project definition through to construction, outlining key stages and the commenting authorities responsible for design review at each phase.

The Integrated Natural Resources Management Plan (INRMP) provides recommendations that include conducting baywide mitigation planning and developing interagency agreements and permit mechanisms to achieve ecosystem-level strategies. Although the INRMP provides the overall vision for achieving these strategies, a comprehensive regulatory framework is needed to provide an implementation mechanism.

2 Programmatic Permitting

A programmatic permitting approach is one in which permitting processes and mechanisms are established to apply to multiple forthcoming projects within an established spatial and temporal reach. Programmatic permits can allow for a more comprehensive evaluation of project impacts and benefits at a regional scale and can provide regulatory efficiencies.

The Port has prepared several programmatic environmental impact reports (EIRs) pursuant to California Environmental Quality Act (CEQA) Guidelines Section 15168. Port EIRs include those for the Port Master Plan Update, the Chula Vista Bayfront Master Plan, the North Embarcadero Port Master Plan Amendment, America's Cup Harbor, and the 10th Avenue Marine Terminal Redevelopment Plan. These EIRs were prepared to allow for analysis of a broader, program-level series of actions that were characterized as one large project. The Port usually uses this

programmatic approach when a project is being carried out in stages, or it involves a series of smaller projects in one geographic area and the Port wants to streamline future CEQA review of later, site-specific projects consistent with the program. Future projects “tier” off the programmatic EIR under CEQA Guidelines Section 15152, allowing subsequent environmental documents to focus on project-specific impacts while relying on the program EIR for the broader analysis. As an alternative to tiering, where there is any caution associated with the linkage of a proposed project to a document or program it is being tiered from, the Port has also incorporated by reference a previously certified EIR to provide an efficient streamlining process.

A programmatic permitting approach begins with a thorough assessment of baseline abundance, diversity, and the condition of resources, providing a solid foundation of information and data within a set spatial boundary and a basis for tracking program effectiveness over the course of program implementation. This approach ensures predictable notifications, authorizations, and reporting, which streamlines the permitting process and enhances transparency. Enacting a “get ahead and stay ahead” policy can provide a framework to track gains across an ecosystem, demonstrating no net loss and retaining credit for net gains for the system as a whole. Regional monitoring and success criteria, along with updated and consistent data, allow for ongoing evaluation and improvement. Additionally, adaptive management and the potential for program renewal ensure that the approach remains flexible and responsive to changing conditions and new information.

Several regional examples exist that demonstrate the benefits of programmatic permitting, including U.S. Army Corps of Engineers (USACE) Regional General Permit (RGP) 16, issued by the Sacramento District. RGP 16 authorizes aquatic habitat restoration and enhancement projects, including activities such as fish passage and screening improvements, bioengineered bank stabilization, engineering/designing with nature, nature-based solutions, water conservation, aquatic habitat restoration and enhancement, and in-water structure removal. RGP 16 allows applicants to provide information demonstrating that proposed long-term benefits outweigh short-term adverse effects in order for USACE to document no net loss of aquatic resources. The RGP has a standardized set of notification requirements, which shortens project review timelines. Additionally, there are complementary permitting mechanisms that can be utilized by the other regulatory agencies, including programmatic biological opinions issued by the U.S. Fish and Wildlife Service and the National Marine Fisheries Service.



Kopta Slough: Kopta Slough Multi-Benefit Project. Photo source: California Department of Water Resources / acceleratingrestoration.org

Another Southern California example is USACE's RGP 54 for the Newport Beach Maintenance Dredging Program, which authorizes maintenance dredging, discharges for beach nourishment, and disposal sites, and incorporates an eelgrass protection and mitigation plan. In this case, the City of Newport Beach reviews and approves applications, adding a level of efficiency to the project review by acting as a clearinghouse to ensure permit compliance. Additionally, the program's eelgrass plan tracks eelgrass throughout the Bay as a singular resource on a coarser scale, allowing no net loss to be documented on a baywide basis as opposed to project-by-project. The program allows for consistent tracking and regular ongoing data collection on eelgrass function.



Newport Bay: A scenic view of Newport Bay with boats and waterfront homes along the shore, with the Pacific Ocean stretching out in the distance.

The North Coast Corridor Public Works Plan (PWP)/Transportation and Resource Enhancement Program is another California Coastal Commission (CCC) programmatic permit model. A PWP must be sufficiently detailed, but once the CCC approves a PWP, no Coastal Development Permit (CDP) for future project implementation is required if the development remains consistent with the PWP. Instead of project-by-project approval through the CDP process, the permittee provides a Notice of Impending Development to the CCC and other parties. Thus, PWPs expedite approval for a large range of activities over a long timeframe within multiple jurisdictions because they eliminate the need to coordinate individual coastal development permits separately through multiple jurisdictions.



LOSSAN Corridor, San Elijo Lagoon: Photo of the LOSSAN rail corridor running alongside San Elijo Lagoon, with an Amtrak Coaster train on the tracks.

The benefits of these programmatic permitting mechanisms include:

- **Efficient Process** – A programmatic approach allows for a more consistent and predictable process for applicants and regulatory agencies. It optimizes limited agency resources by increasing review efficiency. Additionally, efficiency is increased via improved interagency communication.
- **Minimized Agency Risk** – Agencies specify terms and notification requirements in advance, ensuring that all parties are aware of the expectations and procedures before any activities commence. Permit conditions are grouped by activities that are similar in nature, which makes it easier to manage and enforce compliance. Additionally, these permits incorporate appropriate avoidance and minimization measures to mitigate potential environmental impacts, promoting sustainable and responsible project execution.
- **Comprehensive Process** – Aligning permit requirements and schedules across agencies ensures a cohesive and efficient regulatory process, reducing redundancy and ensuring consistency of project approvals. This coordinated approach allows for better planning and execution, ultimately enhancing the protection of natural resources. By working together, agencies can implement projects that collectively contribute to more robust and effective environmental standards and measures.

On February 20, 2025, a potential approach for programmatic permitting of Bay nature-based adaptation projects, which could involve several coordinated steps across different agencies, was discussed during an interagency stakeholder meeting. Initial agency feedback was positive, with the CCC, U.S. Fish and Wildlife Service, and Regional Water Quality Control Board in particular indicating their agencies would be supportive of developing a programmatic approach for nature-based adaptation projects within the Bay.

- USACE might issue an RGP or develop a Letter of Permission procedure, while the U.S. Fish and Wildlife Service, and National Marine Fisheries Service could implement Programmatic Section 7, Endangered Species Act and Essential Fish Habitat consultations related to the USACE permit.
- The Regional Water Quality Control Board could issue a 401 Water Quality Certification of the USACE permit or utilize the Statewide Restoration General Order or Small Habitat Restoration General Order for projects under 5 acres.
- The California Department of Fish and Wildlife might issue an Incidental Take Permit for state-listed species or a Consistency Determination for both federal and state-listed species, if necessary.

This integrated approach ensures comprehensive regulatory oversight and protection of natural resources, with the benefits described above. The next step would be further development of this framework and more interagency meetings to begin drafting specific permitting mechanisms. The Atlas supports this approach.

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