OPERATIONAL LANDSCAPE UNITS FOR SAN FRANCISCO BAY

APPROACH DOCUMENT

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Julie Beagle, Sam Safran, Katie McKnight, Jeremy Lowe, SFEI
Laura Tam, Sarah Jo Szambelan, SPUR

PURPOSE OF PROJECT

As sea level rise accelerates in the San Francisco Bay, scientists, planners, and decision makers will need to re-envision and adapt our complex shoreline to provide ecological and social resilience.[1] An important tool for this process is a science-based spatial framework for developing climate adaptation strategies appropriate to our diverse shoreline settings.

The San Francisco Bay shoreline is both fundamentally interconnected and locally distinct. The Bay Area's varying landscape characteristics (geology, hydrology, climate etc.), land use, and demographics make different parts of the Bay shore vulnerable to sea level rise in different ways. At the same time, the region has 101 cities and towns, 9 counties, and hundreds of special districts and local government agencies and NGOs. Yet shoreline adaptation will ultimately require a coordinated, place-based, and cross-jurisdictional approach.

To that end, this project aims to define practical, science-based landscape units surrounding the shoreline (Operational Landscape Units[2]) to facilitate a geographically-specific set of integrated adaptation strategies at the appropriate scale to address issues of both the natural and built environment. These strategies include structural and nonstructural measures that address ecosystem, flood risk management, water quality, land-use planning, and social equity goals.

The result will be a spatial framework for understanding what kind of adaptations could work for real places in the Bay Area to foster a regional, collaborative, data-driven and long-term vision for regional resilience. This concept is gaining momentum as a useful input to sea-level rise planning processes, and is being integrated with vulnerability analyses in several counties. This framework can also provide guidance for the regulatory community, as well as for landscape designers, planners, and engineers.

This memo is meant to document the approach for defining and characterizing Operational Landscape Units (OLU), and pairing them with appropriate adaptation strategies, as agreed upon by the project team, and technical advisory groups.

TECHNICAL ADVISORY GROUPS + RESOURCES

This project has convened two advisory groups which have and will continue to influence the direction of this effort. The Regional Advisory Group (RAC) is comprised of high-level leaders from regional natural resource agencies, including the Bay Conservation and Development Commission (BCDC), San Francisco Estuary Partnership (SFEP), Environmental Protection Agency (EPA), California State Coastal Conservancy (SCC), and Bay Area Flood Protection Agencies Association (BAFPAA). The RAC's role is to provide high-level guidance on the regional uses of the project products, to create buy-in from key agencies, and to act as ambassadors for the product. The Technical Advisory Group (TAC) is made up of scientists,

[1] Resilience is defined as the ability to recover from setbacks, and adapt well to change; it reflects the capacity of individuals, institutions, communities, and systems to survive, adapt, and grow nomatter what kinds of acute shocks and chronic stresses they face. (Definition based on OED and Rockefeller Foundation definitions, presented in SPUR white paper, "Sizing Up Climate Resilience in the Bay Area", 2014. http://www.spur.org/sites/default/files/publications_pdfs/Sizing_Up_Climate_Resilience.pdf)

[2] Verhoeven, J. T.A., Soons, M. B., Janssen, R. and Omtzigt, N. (2008), An Operational Landscape Unit approach for identifying key landscape connections in wetland restoration. Journal of Applied Ecology, 45: 1496–1503. doi:10.1111/j.1365-2664.2008.01534.x

engineers, planners, community activists, and adaptation specialists. The role of the TAC is to provide the technical guidance necessary to delineate OLUs, and pair with adaptation strategies to ensure that the outputs of this project are technically defensible, and address the information needs of decision makers. The TAC is made up of three sub-groups, (1) scientists and engineers to help vet the approach and technical nature of the OLU delineation, (2) environmental justice professionals to ensure that the project outputs are representative of a diverse range of community perspectives, and (3) planners and design professionals who may be some of the target end users of this work. As of the end of September 2017, both the RAC and the science and environmental justice TAC have met and vetted the approach which is described in this document.

The San Francisco Bay Regional Water Quality Control Board ("Water Board") is funding Phase 1 of the OLU project to serve as a resource for its permit writers to understand the landscape characteristics of places along the Bay shoreline where projects are proposed and to provide information to land managers and decision-makers about the opportunities and constraints for integrated adaptation strategies along the shoreline. In addition, the Water Board may consider information generated as part of this effort as it reviews its regulatory policies in light of climate change and sea level rise.

TASK 1. DEFINITION OF OLUs

Operational Landscape Units (OLU) are areas that are expected to support a coherent suite of ecosystem functions as appropriate for a given place, along with the physical processes needed to sustain these functions. OLUs can be identified anywhere across the earth's surface, with their size and composition depending upon the ecosystem functions and services of interest. For the purpose of this study, an **OLU** is defined as *a delineated area that effectively provides specific ecosystem functions and services within the natural and built environment.* Each OLU represents a unique combination of environmental variables, such as geology, precipitation and topography, so management efforts need to account for the individual characteristics of each OLU.

We already recognize many of the features that may make up an OLU, such as rivers, floodplains, wetlands and watersheds. In the San Francisco Bay, our definition of an OLU consists of a number of landscape features: one or more watersheds that connect to the Bay by a tidal creek, with associated fluvial floodplains, alluvial fans and tidal wetlands. These landscape features function in a coherent manner, they are connected by the movement of sediment and water, and they evolve together.

The delineation of Bay OLUs depends on the flow of water and sediment, as governed by topography, tidal and wave energy, and the sources of the water and sediment. The delineation is relatively straightforward for a watershed in the uplands, however in the Baylands both the flatter topography and the larger Bay-scale fine sediment processes will tend to blur the boundaries of the Bay OLUs. In some places the boundaries may be easily identifiable headlands, and in other places the boundary may be a zone between adjacent creeks or tidal sloughs.

The connections between the features of the Bay OLUs are important: altering the movement of sediment or water in one part of the OLU is likely to have an impact elsewhere in the OLU. For example, detaining water and sediment behind dams in a watershed will likely have an effect on the wetland accretion downstream; leveeing fluvial channels will reduce the width of the riparian corridor and

reduce salinity gradients in the Baylands; opening a diked area to tidal action could affect the sediment supply to other parcels along the same tidal channel. Because of these close connections, effective management of one feature within the OLU should necessitate the consideration and management of other connected features within the OLU.

TASK 2. DELINEATION & CHARACTERIZATION OF SF BAY OLUs

The process for generating the OLU boundaries involved three main steps: (1) demarcating the area of analysis, including the front (bayward) and back (landward) boundaries of the OLUs, (2) demarcating breaks between OLUs along the shoreline, and (3) demarcating breaks between OLUs from the shoreline to the back boundary (side boundaries). Once OLUs were defined, we were able to begin the process of characterizing them.

Demarcating the area of analysis, including the front and back boundaries of the OLUs

To serve our goal of evaluating climate adaptation strategies for different parts of the diverse San Francisco Bay shoreline, we established an area of analysis meant to capture all areas potentially subject to the direct effects of sea-level rise over a relatively long time horizon (100-150 years). To this end, we began with the current extent of the baylands, which are the areas upstream of the Golden Gate and downstream of the Sacramento San-Joaquin Delta that are between minimum and maximum tide elevations, including the areas that would be flooded by the tides if not for levees or other unnatural water-control structures.[3] Next, we added additional areas that could be within tidal elevations with 5 m of sea-level rise, an extreme SLR scenario.[4] Finally, to this combined area we added a fixed-width buffer of 500 meters to include potential transition zone and accommodation space for long-term planning purposes.[5] Any internal holes in the resulting shape created by high points (e.g. Coyote Hills in Alameda County and the Potrero Hills in Solano County) were filled to create

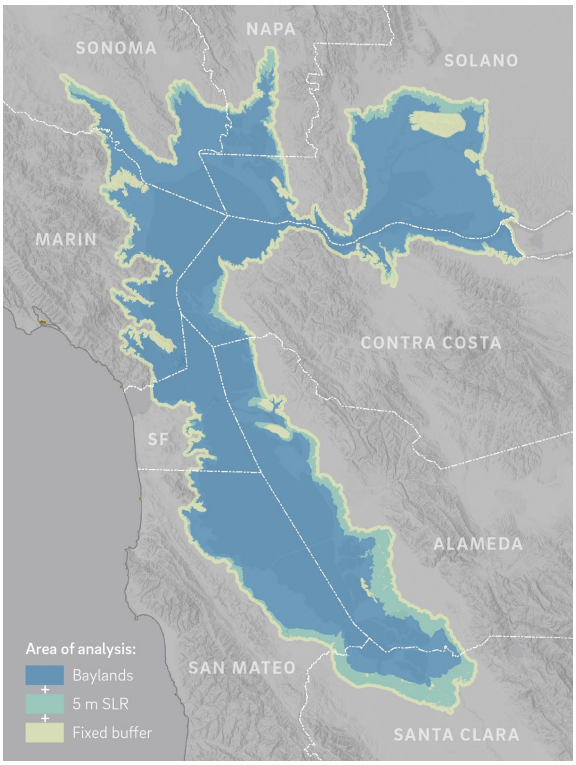


Figure 1. The area of analysis was delineated by combining the extent of existing baylands with 5 meters of sea-level rise and a fixed buffer of 500 meters.

[3] This definition of the baylands was derived from the Baylands Ecosystem Habitat Goals (Goals Project 2015), which also provided the spatial data demarcating the baylands. For the purposes of the Habitat Goals (and for this project), the boundary between the Bay and the Delta was defined as Broad Slough.

[4] 5 m of sea-level rise is the most extreme sea-level rise scenario modeled by the Coastal Storm Modeling System (CoSMos). Data for this scenario (500 cm SLR, no storm) were obtained from the Our Coast Our Future (OCOF) Flood Map, accessed 6/28/2017. There is more than a 50% chance that sea-level rise meets or exceeds this value by 2150 under the "H++" scenario modeled by Griggs et al. (2017), which "represents a world consistent rapid Antarctic ice sheet mass loss."

[5] A fixed-width buffer of 500 m was included for two reasons. First, the buffer fills "gaps" in the CoSMos output where the slope of the shoreline leads to a SLR zone that is narrower than can be represented by the scale of the output raster. Second, the buffer ensures that transitional areas upslope of the SLR zone are captured. This transition zone is critical to the ecological function of the baylands and should be accounted for in adaptation planning efforts. The 500 m width–identified by SFEI-ASC's T-Zone Project–captures the spatial extent over which most key physical and biological transition-zone processes occur.

a contiguous area of analysis (Figure 1). For the purposes of drawing explicit OLU front boundaries, we used the "shoreline" as defined by SFEI's Bay Shore Inventory project.[6]

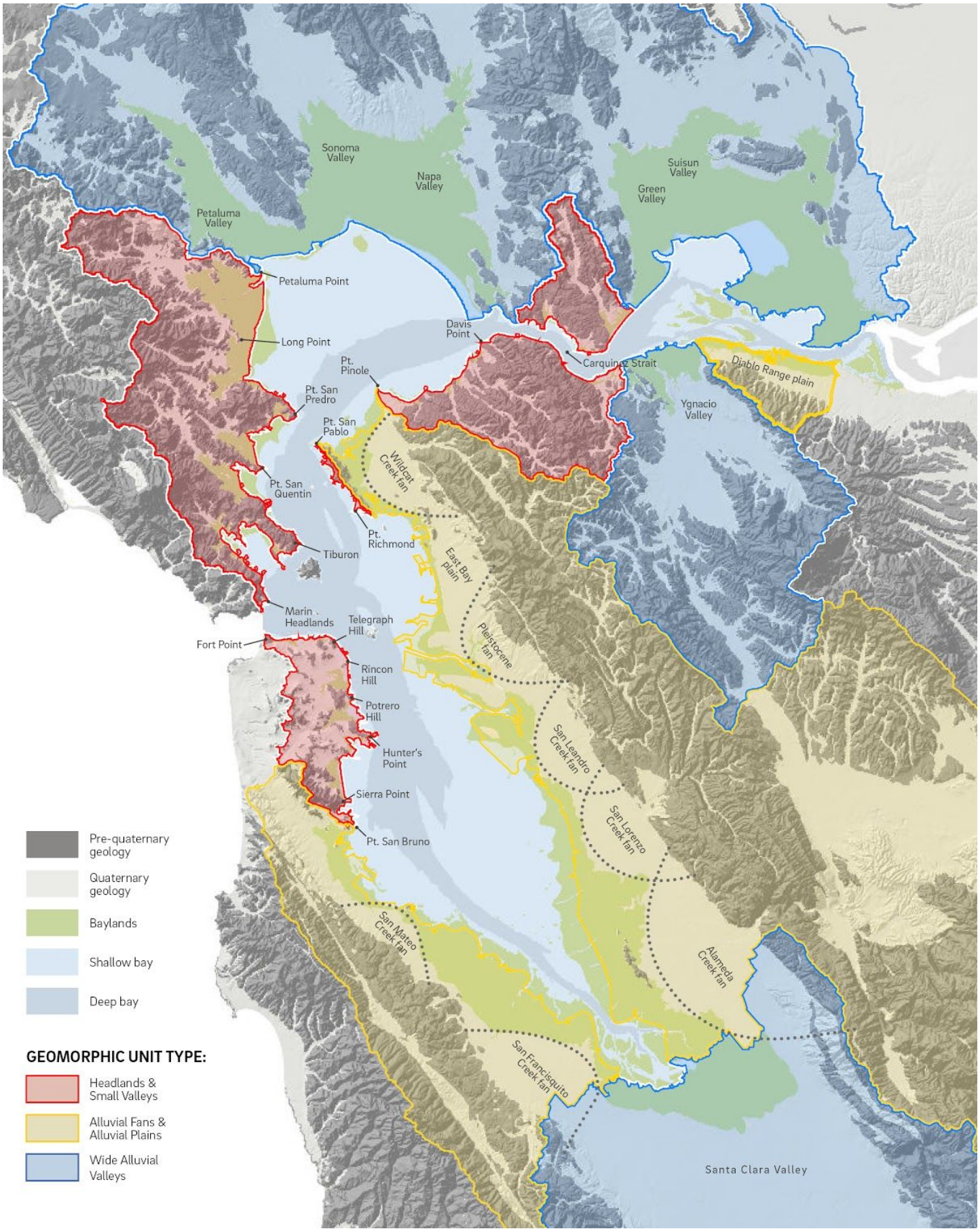
Demarcating breaks between OLUs along the shoreline

The Bay's natural history, varied geology, including the location and orientation of major faults, and physical landscape drivers are key factors in understanding how the bayshore and its habitats evolved and can be sustained, and are the first considerations in delineating Bay OLUs. The Bay formed less than 10,000 years ago, when rising seas entered a gap, known today as the Golden Gate, through the outer Coast Range and filled the interior valleys. In some places, steep headlands thrust into the Bay and its deeper waters, leaving little room for intertidal habitats. Elsewhere, wide valleys and alluvial fans have filled with more recent alluvium delivered by local creeks, creating broad, gently sloping plains with wide intertidal zones occupied by tidal flats, marshes, and salt pannes. Despite being heavily altered by urbanization and farming, these geomorphic characteristics are still evident in the Bay Area today and determine the way the landscape functions on a fundamental level that cannot be easily changed. This leads to the first consideration that defines Bay OLUs: geomorphic unit. The landscape was classified into three major geomorphic unit types: (1) headlands and small valleys, (2) alluvial fans and alluvial plains, and (3) wide alluvial valleys (Figure 2). Although each classification reflects how the landscape behaves on a geologic timescale, it reflects the physical form and functions, such as sediment supply, watershed size, and configuration of wetlands near the shore - which will be key to identifying adaptation strategies that can be naturally sustained.

Transitions along the shoreline from one geomorphic unit type to another were marked as breaks between OLUs. Individual geomorphic units were further divided using methods that differed by geomorphic unit type. Within reaches characterized as *headlands and small valleys*, OLU breaks were placed along the shoreline at the apex of major points or promontories, using the distance to deep water of the shoreline as a guide (breaks were placed where distance to deep water reached a local minimum). Within reaches characterized as *alluvial fans and alluvial plains*, OLU breaks were placed along the shoreline at the apex of each individual alluvial fan, which generally fall at places where the baylands are relatively narrow. For areas characterized as wide alluvial valleys, we relied on watershed boundaries to demarcate the boundaries between individual OLUs along the shoreline.

When demarcating breaks between OLUs, we also considered factors such as shoreline orientation, incident wave height, bayland width, and distance to deep water (areas deeper than 18 feet below mean lower low water) as a proxy for mudflat width. Variation in many of these factors was found to closely correspond with the geomorphic properties described above (e.g., the location of points, alluvial fans, and watershed boundaries).

[6] The Bay Shore Inventory project (SFEI 2016) defined the shoreline as the line of features that would provide the 'first line of defense' to coastal flooding. This included vegetated wetlands, where present, at the approximate elevation of mean higher high water (MHHW).


Sonoma Valley
Napa Valley
Suisun Valley
Green Valley
Petaluma Valley
Petaluma Point
Long Point
Davis Point
Carquinez Strait
Diablo Range plain
Ygnacio Valley
Pt. Pinole
Pt. San Pedro
Pt. San Pablo
Wildcat Creek fan
Pt. San Quentin
Pt. Richmond
Tiburon
East Bay plain
Marin Headlands
Telegraph Hill
Fort Point
Pleistocene fan
Rincon Hill
Potrero Hill
Hunter's Point
San Leandro Creek fan
Sierra Point
San Lorenzo Creek fan
Pt. San Bruno
San Mateo Creek fan
Alameda Creek fan
San Francisquito Creek fan
Santa Clara Valley
Pre-quaternary geology
Quaternary geology
Baylands
Shallow bay
Deep bay
GEOMORPHIC UNIT TYPE:
Headlands & Small Valleys
Alluvial Fans & Alluvial Plains
Wide Alluvial Valleys

Demarcating breaks between OLUs from the shoreline to the back boundary (side boundaries)

Once OLUs boundaries were identified along the shoreline, we then used the National Hydrography Dataset and other local watershed maps to identify each OLU's drainage area. These watersheds served as the "side boundaries" between individual OLUs. When working in low-gradient areas of the baylands, we also often relied on historical and modern "tidalshed" boundaries to demarcate OLUs.

We also used four variables of density to help validate side boundaries, as a way of understanding the distribution of land use and economic development across the Bay Area. The four variables include population density, job density, housing units per acre, and non-residential square footage per acre. Our underlying theory is that these types of density show us where the sea level rise and other hazards of climate change will have the greatest impact on people.

Where there is less geomorphic specificity for defining the side boundaries between OLUs, natural breaks in density can help keep like-kinds of land uses together when considering appropriate adaptation strategies for a region. Density mapping also helps identify which cities and neighborhoods need to be involved in any future planning processes for adaptation that utilize OLUs as a framework or tool. Ideally the density mappings also help avoid breaking up distinct communities or cities into multiple OLUs.


6 Petaluma
Napa - Sonoma 7
Suisun Slough 9
10 Montezuma Slough
Novato 5
Carquinez North 8
Gallinas 4
13 Carquinez South
11 Port Chicago
14 Pinole
San Rafael 3
12 Walnut
Corte Madera 2
15 Wildcat
Point Richmond 16
Richardson 1
17 East Bay Crescent
Golden Gate 30
18 San Leandro
Mission - Islais 29
Yosemite - Visitacion 28
19 San Lorenzo
Colma - San Bruno 27
20 Alameda
San Mateo 26
21 Mowry
Belmont - Redwood 25
v0.1
San Francisco Bay
Operational Landscape Units
24 San Francsiquito
Stevens 23
22 Santa Clara Valley

Characterizing OLUs

Defined by their physical setting and watershed boundaries, OLUs are then characterized by a suite of variables which will likely influence the applicability of different adaptation measures. Many of these variables are continuous (such as wave energy, suspended sediment concentrations, land uses etc), and thus characterization of OLUs will be generalized to a degree that allows these variables to be summarized and compared across OLUs.

The categories of attributes to the OLUs have been considered in four different bins - oceanic processes, estuarine processes, watershed processes, and land use drivers - which will be integrated to determine appropriate strategies. Oceanic and estuarine processes describe the conditions of the shoreline; estuarine processes describe the conditions of the baylands; watershed processes and land use characteristics describe the backshore and inputs around the baylands. The following table details the information that will be summarized for each OLU. In addition to describing each OLU in terms of these factors, we will create representative illustrative transects of OLUs.

DRIVERS	ATTRIBUTES FOR OLUs
Oceanic Processes	Bathymetry, Wave energy, fetch, wave height at shore, tidal range, salinity
Estuarine Processes	Suspended sediment concentration, mudflat width and shape, distance from shoreline to deep water, water quality, tidal marsh width, shoreline evolution
Watershed Processes	Geomorphic units (elevation, slope, geology), contributing watersheds (watershed size, sediment yields, sediment caliber, sediment transport characteristics), T-zone (existing and potential)
Land use characteristics	Zoning or place-type, infrastructure, parcel density, land ownership, impervious surface, open space/undeveloped land by type, hazardous materials, liquefaction and ground shaking, planned densification

TASK 3. ADAPTATION MEASURES

Flood protection measures are engineering and land management strategies meant to reduce the risk of damage and loss of life or property from watershed and coastal flooding. The nonlinear nature of sea level rise underscores the need for communities to select flood protection measures that can withstand periodic flooding now and more severe flooding in the future. We envision OLUs as a type of planning unit for which a single adaptation strategy or suite of coherent adaptation strategies can be implemented over time, also known as "adaptation pathways.[7]" The strategy for selecting adaptation

[7] Urban Waterfront Adaptive Strategies p. 117
https://www1.nyc.gov/assets/planning/download/pdf/plans-studies/sustainable-communities/climate-resilience/urban_waterfront.pdf

strategies will be based on evaluating landscape characteristics for each OLU, considering risk, conservation, development, and resilience goals, and creating adaptation pathways in the context of sea level rise with a focus on natural infrastructure. In this project, we aim not to select any preferred pathways for an OLU – that must be left to public planning processes - but to define those that may be well-suited given the OLU's geomorphic setting, and land use and economic characteristics.

To develop a comprehensive list of adaptation strategies we consulted several reports that discuss adaptation strategies at length: New York City Planning Department's Urban Waterfront Adaptive Strategies, Georgetown Climate Center's Adaptation Tool Kit, the Lincoln Institute of Land Policy's report Buy-in For Buyouts, Louisiana Coastal Protection and Restoration Authority's Coastal Master Plan, and prior research by both SFEI and SPUR weighing the local relevance of various ecological and engineering strategies for sea level rise.

We will group these strategies into a large table to describe them in more detail, including such evaluative criteria as:

- Location (in the water, on the shoreline, inland)
- Type (structural, nonstructural)
- Function (protect, accommodate, retreat)
- Ecosystem benefits
- Coastal risks mitigated (surge, erosion, SLR, combined flooding)
- Seismic resilience
- Adaptability over time to SLR (high, medium, low)

We will also define or describe each strategy, its co-benefits beyond risk reduction (such as improving habitat or public waterfront access), design considerations, examples, and relevant permitting authorities necessary to allow the adaptation strategy to proceed. Currently, our working list of 35 adaptation strategies includes both structural and nonstructural approaches.

To determine whether we have captured the full suite of potential adaptation measures that could be applied to OLUs we will have the project Technical Advisory Committee peer-review our table and we will also peer-review the list with subject matter experts such as earthquake and flood control engineers, planners, scientists and others.

Pairing Adaptation strategies with OLUs

To determine how we will identify the scope and sequencing of potential adaptation pathways for any given OLU we will conduct a three-step vetting process.

First, we will convene three subgroups of our Technical Advisory Committee focused on 1. communities and environmental justice, 2. ecology & science, and 3. planning & land use. With each group we will hold a workshop to discuss what criteria they would use to select adaptation strategies to protect the uses they are interested in, under various levels of future sea level rise. To assist these discussions, we will create maps of several representative-type OLUs including characterization information (many layers of descriptive data), and show these against varying levels of future SLR. We will ask each group to tell us under what landscape + SLR conditions they would choose protecting, accommodating, or retreating from sea level rise.

Second, following and concurrent with these workshops, the project team will study each OLU's characteristics and future coastal risks under several scenarios of sea level rise. The project team will use a literature review of documented adaptation strategy suitability, best professional judgement, and input from the TAC, to narrow down the set of available adaptations based on the key flooding risks and landscape opportunities associated with each OLU, focusing on natural infrastructure where possible. We will also create rules or criteria around sequencing strategies into adaptation pathways recognizing some strategies cannot be modified in the future without great expense, or may not be possible following on earlier choices (e.g. beach nourishment cannot readily follow construction of shoreline hardening enabling denser development, such as a seawall or super levee). For example, for each OLU we will develop a table, as seen below. Note: this is just an example of the type of product we will create; this specific one is not vetted and likely incomplete.

Mission - Islais OLU

The SF Waterfront OLU's key coastal hazards are *storm surge* and *long-term sea level rise*.

SLR SCENARIO	ANTICIPATED TIMING	KEY IDEA	POSSIBLE IMPLEMENTATION STRATEGIES
1.5 ft	2030-2050	Protect	Plan for 2050 needs now and start saving $
3 ft	2050-2100	Protect	Raise seawall, elevate/realign transportation, new flood walls or surge barriers @ inlets, strategic site elevation
6 ft	2100-2150	Accommodate	Building codes + permit conditions, easements, building retrofit requirements, develop TDR to encourage building on higher ground, establish GHAD
H++		Retreat	Buyouts, floodplain regulations, new polders, rezoning, rebuilding restrictions, rolling easements

The Key Idea column, reading top to bottom, constitutes one option for this OLU's adaptation pathway. Some of the tools in later stages of the pathway could be adopted sooner to make future adaptation easier. Ultimately the timing, selection, and sequencing of specific strategies will be determined in a community planning process - not by this project – but identifying pathways can help make this project useful to future planning and regulatory processes.

To visualize this a different way (like a Gantt chart), we could include an element of lead time for planning pathways of strategies as sea levels rise. For a more natural, existing marsh-type of shoreline, that visualization could look like this:

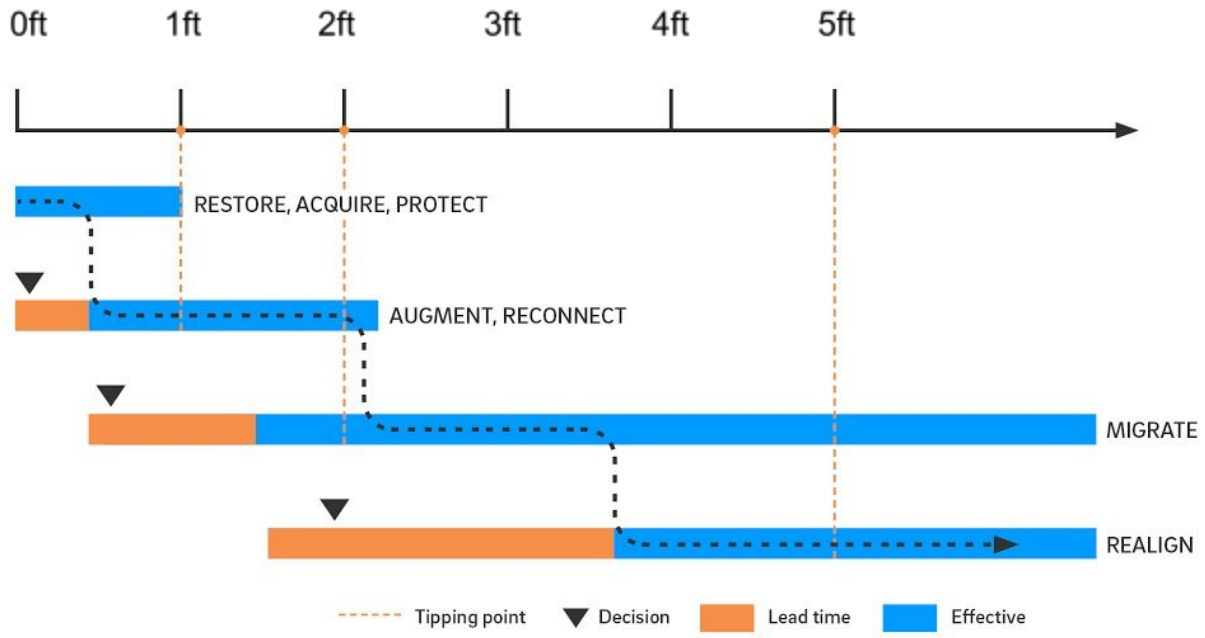


Figure 2. Planning efforts will need to consider the rate of sea level rise and identify lead times, triggers and tipping points to effectively implement adaptation strategies.

Third, following these workshops and further refinements to our adaptation strategy list and descriptive information, we will convene the project's Regional Advisory Committee (RAC) in the spring or early summer to present these initial results and conduct a similar exercise as with the focus groups: asking the committee members to consider adaptation pathways under various scenarios of sea level rise for representative OLUs, and identify applicability issues, concerns and "deal breakers".

NEXT STEPS

In future phases of the project, including those yet to be funded, we will conduct workshops within certain OLUs with selected groups of key stakeholders from those locations. For each OLU we will present a limited set of strategies and pathways consistent with our workshops in this phase of the project, and ask participants to describe how and what they would choose among available strategies to plan for each OLU's adaptation pathway. This will help test the idea of OLUs as a viable planning unit and hopefully build enthusiasm for cross-jurisdictional collaboration to plan for sea level rise adaptation.

We will finalize OLU delineation and characterization in March 2018 and adaptation strategies by May 2018. The final report will be done by the end of 2018, and final results will be integrated into the Resilience Atlas online mapping platform.