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Memorandum

date June 27, 2022

to Karina Nielsen, EOS Center, San Francisco State University

cc Bob Battalio, PE

from Tiffany Cheng, PE, Michelle Orr, PE

subject SFSU Nature-Based Restoration of an Armored Shoreline – Conceptual Design Memorandum

Environmental Science Associates (ESA) prepared this memorandum for San Francisco State University (SFSU) Estuary & Ocean Science (EOS) Center to present the development, screening and analysis of conceptual design alternatives for nature-based restoration and climate adaptation of the armored shoreline on the Romberg Tiburon Campus (RTC). The study was funded by a grant from the Marin Community Foundation (MCF) administered by the California State Coastal Conservancy (SCC). The shoreline study was used to inform a larger campus master planning effort for the entire RTC and is intended to be incorporated into the master plan. Contributions to this memo were made by Tiffany Cheng, PE (ESA Project Manager), Michelle Orr, PE (ESA Project Director) and Bob Battalio, PE (ESA Chief Engineer). This memorandum presents the results of planning, engineering and physical processes studies conducted by ESA in coordination with the EOS Center and others. Related biological data collection and analysis led by Drs. Karina Nielsen and Chela Zabin are presented separately. The work documented here was conducted in 2019 and 2020.

1. Introduction

SFSU is interested in implementing nature-based solutions to restore an existing armored shoreline (seawalls, riprap, rubble) along its 53-acre, bayside campus, as part of the first formal master plan for this campus since it was owned and operated by the US Navy. Located in Tiburon, CA, the campus houses a university research center focused on coastal and marine environments, marine research facilities, a conference center, and a number of historic resources. The campus has approximately 1.6 km (1 mi) of shoreline on central San Francisco Bay. Approximately 0.8 km (0.5 mi) of the shore is filled and armored, flanked on the north and south by natural pocket beaches and headlands (**Figure 1**). Segments of the armored shoreline are severely degraded and eroded, and some areas overtop during high tides and winter storms. The campus will become increasingly vulnerable to coastal flooding and erosion under future sea-level rise conditions. The use of appropriate nature-based adaptations for rocky and cobble shores will enhance the biodiversity and natural ecology at the campus, reconnect the network of pocket beaches, and allow for climate ready improvements to the campus in the uplands. These nature-based restorative adaptations will reduce the risk of sudden failure and rapid erosion of existing armoring and fill, especially where it is already failing. The variety of armoring approaches used on the shore,

and the mix of infrastructure, and cultural and natural resources, provide the opportunity to implement different types and degrees of nature-based restorative adaptations. In addition, because the campus is part of a public university research center, there will be ample opportunity for ongoing monitoring, research, education, and public engagement on the value and efficacy of these nature-based restoration and climate adaptation strategies.

Project planning was led by a project team consisting of SFSU and ESA staff. The project team evaluated site conditions, developed conceptual approaches, screened potential solutions, and wrote this memorandum to document conceptual alternatives. This document summarizes the conceptual designs based on input from the shoreline planning charrette (July 2019) and conceptual design workshop (December 2019), and valuable coordination and review by a Technical Advisory Committee (TAC) comprised of nature-based restoration and adaptation experts. A full list of TAC members is provided in Attachment A.

A note on units: this memo uses both metric and English units. We use metric units with English units in parentheses in most sections. English units are used in select engineering sections (Sections 3.2, 3.4) and in the concept graphics in AutoCAD.

2. Study Objectives

2.1 Study Objectives

The purpose of this study is to develop conceptual design for the restoration and climate adaptation of approximately 0.8 km (0.5 mi) of armored shoreline along campus. This study has the following objectives:

- Develop nature-based approaches to restore habitat and ecological function along the campus shore and improve adaptability to sea level rise
- Develop options to enhance native species habitat availability and biodiversity, improve ecological connectivity across ecotones to upland habitats, and restore natural erosion and sediment transport processes.
- Develop feasible, cost-effective adaptation pathways that are consistent with the priorities identified for the overall campus master plan and provide flexibility for future decisions with respect to campus facilities

2.2 Nature-Based Solutions

SFSU has agreed to pursue nature-based restoration and climate adaptation approaches for the RTC shore. Nature-based solutions, also referred to as *living shorelines* or *natural infrastructure*, refer to use of physical and biogenic landscape features to work in concert with (or mimic) natural processes to provide a range of co-benefits (e.g. protection, recreational, ecological, aesthetic). Examples common to the Bay Area and elsewhere along the West Coast include oyster reef and eelgrass restoration, mudflat augmentation, and coarse sediment beach placement. In Washington State, examples of nature-based approaches have also included placement of dynamic cobble beaches or berms and large woody debris, as well as habitat enhancements added to needed infrastructure such as seawalls and bulkheads. Characteristics of the shoreline in a study area, such as the geomorphic setting, dominant physical processes and land use, affect the type, suitability, and efficacy of different nature-based measures (Bilkovic et al. 2017).

Recent guidance on nature-based solutions for Bay Area shorelines include the San Francisco Bay Adaptation Atlas by San Francisco Estuary Institute (SFEI) and the Natural Shoreline Infrastructure: Technical Guidance for

the California Coast (SFEI and SPUR 2019). These documents provide suitability information and technical guidance for design and implementation for a wide spectrum of nature-based adaptation measures.

2.3 RTC Master Planning Process

This shoreline study is integrated into a larger university master planning effort for the campus being led by Page Southerland Page, Inc. (Page). The university adopted the Living Community Challenge (International Living Future Institute/<https://living-future.org/lcc/>) as its planning framework. The framework prioritizes regenerative spaces for people and natural ecosystems. This shoreline climate adaptation and nature-based habitat restoration plan is highly well aligned with the Living Community Challenge planning framework.

Through Spring 2019, the project team attended several master planning charrettes, facilitated by Page, to coordinate with the master plan team on sea-level rise criteria and provide engineering subject matter expertise related to sea-level rise to inform the campus master plan. Major assumptions about future campus layout, space usage and anticipated programming (see Section 4.1) also influenced the conceptual design alternatives developed for this shoreline adaptation and restoration study. The conceptual design alternatives for shoreline restoration, climate adaptation, and habitat enhancements will be incorporated into the final RTC Master Plan for SFSU.

2.4 Planning Horizon and Future Sea-level Rise

For this shoreline study, the Project team assumed 0.9 m (3 ft) of sea-level rise within the planning horizon. This maps to the amount projected for 2050 under the H++/Extreme Risk Aversion scenario and 2070 under the Medium-High Risk Aversion scenario. The State of California recommends using values from higher risk aversion scenarios. **Table 1** shows predicted sea-level rise estimates for San Francisco Bay:

TABLE 1
SEA-LEVEL RISE ESTIMATES FOR SAN FRANCISCO BAY

Year	Sea-level rise (m)			Sea-level rise (ft)		
	Low Risk Aversion	Medium-High Risk Aversion	H++/Extreme Risk Aversion	Low Risk Aversion	Medium-High Risk Aversion	H++/Extreme Risk Aversion
2030	0.15 m	0.24 m	0.30 m	0.5	0.8	1.0
2050	0.34 m	0.58 m	0.82 m	1.1	1.9	2.7
2070	0.58 m	1.1 m	1.6 m	1.9	3.5	5.2
2100	1.0 m	2.1 m	3.1 m	3.4	6.9	10.2

SOURCE: CalNRA and OPC (2018)

Given the uncertainty in sea-level rise estimates in late century (2070 and beyond) and resultant impacts on long-term future planning for the campus, an adaptation pathways approach was used to describe multiple possible futures for the campus shoreline until 2050 and potential long-term options afterwards (see Section 4). This approach identifies decision points triggered by external factors (e.g. environmental or social) and allows for clearer understanding of phasing for adaptive actions.

3. Site Conditions

The RTC is located on the northeast shore of the Tiburon Peninsula, between Paradise Cove and Bluff Point. The campus shoreline is divided into three reaches for planning purposes, based on distinct land characteristics and usage: South, Central, North (**Figure 2**). The university also owns tidelots subject to the public trust easement in front of the terrestrial portion of the campus, and to the north and south of the developed campus shoreline. These flanking tidelots are bounded on the upland side by private properties at mean high water (MHW; 5.2 ft [1.6 m] above MLLW) and extend to a depth of 9 ft (2.7 m) below low tide.

3.1 Land Use

3.1.1 *Historic Land Use*

Prior to human modification, a natural cove and large pocket beach was located where the slab exists today and was likely used by Coast Miwok for encampment and fishing. In the North Reach, the shoreline followed the edge of the coastal bluffs prior to the addition of the seawall and backfill. The existing site topography and shoreline is the result of fill placement and construction of the slab.

ESA digitized shorelines from NOAA's historic coastal surveys (T-Sheets) conducted in years 1899 and 1943, as shown in **Figure 3**. The 1899 shoreline confirms that much of the existing shoreline in the Central and North Reaches were built out on fill. During this time period, the site was used as a cod fish warehouse, with platforms for receiving and discharging cargo. The 1943 shoreline reflects the construction of the seawall in the North Reach by John Roebling Sons & Co., who reeled suspension cables for the Golden Gate Bridge, and the slab in the Central Reach when a US Navy Net Depot was established at the site (Page & Turnbull, 2018). The existing concrete slab on fill was constructed in two phases by the U.S. Navy. Initially, it served as a naval fuel depot to store and load coal on naval vessels. Subsequently, in World War II the site served as a submarine net depot (Page & Turnbull, 2018). Changes in land use since 1943 have not resulted in any significant changes to the shoreline.

3.1.2 *Present-Day Land Use*

The South Reach of the campus includes the southern edge of the existing slab, which terminates with a narrow boat launch/ramp and inoperative sewage treatment plant along the shore. The upland property line of the campus ends here as well and follows the steep wooded ridgeline extending down from Paradise Dr. and the Tiburon ridge above. Figure 4 shows the existing infrastructure located in the South Reach. A small, channelized creek flows down from Paradise Dr. from behind Delta Hall and discharges to the Bay along this edge of the campus and slab. During storm events, flows exceed the concrete channel and result in ponding on the slab. A wrack line from overtopping was visible at the top portion of the boat ramp during ESA site reconnaissance (February 2019), evidencing overtopping by wave action during existing high water conditions. The existing boat ramp bordered with rip rap is located at the edge of the slab. Boats launched off this ramp are subject to strong currents which make safe maneuvering difficult. Beyond the inoperative sewage treatment plant there is access to a narrow pocket beach with cobble, coarse sand and rocky bench habitats. The pocket beach is the northernmost portion of the tidelot that extends in front of private properties and additional pocket beaches for approximately 0.6 km (0.4 mi) to Bluff Point.

The Central Reach is where the bulk of the campus buildings are located, supporting university-level marine and coastal research and teaching activities. The existing concrete slab on fill currently supports university operations. Steep ravines back this portion of the shoreline and two streams flow down the northern and southern edges of the slab. An active research pier with a water quality sonde and a weather station¹ is maintained as part of the Central and Northern California Ocean Observing System (CNCOOS) with publicly available data. A number of physical parameters are collected at this location including water and air temperature, salinity, wind speed and direction, etc. A former naval theater (eligible for national historic listing) is located on the northern edge of the slab along the seawall in the Central Reach. Figure 5 shows the slab in its existing condition. Recent geotechnical studies have deemed the slab to be in good condition and able to sustain vertical loading into the future, which may enable raising the slab in the future, if desired (Tipping Structural Engineers, 2017).

The North Reach extends from the northern edge of the existing concrete slab up to the northern site boundary. Backed by a steep hillside and coastal bluffs, a former roadway provides access to this segment of campus from the slab on the central reach. A flat area of fill bounded by riprap at the water's edge (called the 'field' for the purposes of this study) is located in the southern portion of the North Reach. A prior survey indicates leftover small metal debris buried in the field area (Tetra Tech EM Inc., 2001). A failing bulkhead and seawall retains extensive fill, likely mined from the adjacent bluffs, in the northern section of this reach, extending about 213 m (700 ft). Three remnant dolphin-style pilings laden with creosote are located immediately offshore. **Figure 6** shows these pilings and the seawall area. Rubble is found on much of the shoreline and at the base of the seawall. Much of the seawall and backfill is in deteriorated condition and poses a number of safety concerns. Along the northernmost portion of the upland campus, three-four rows of large square concrete blocks, formerly used as weights for naval anti-submarine nets, are arranged as a form of riprap, terminating with a small jetty-like structure used to support a now degraded hurricane fence at the landward property boundary. Beyond this structure, the campus property continues as a tidelot terrace. It is the southern third or so of a pocket beach with intertidal cobble and bedrock rocky benches formed by exposed bedrock along the coastal terrace.

3.2 Physical Setting

Site topography/bathymetry, tides, wave climate, streamflow, and predicted future flooding are described below. Additional detail is available in Attachment B.

3.2.1 Topography and Bathymetry

ESA collected topographic and bathymetric survey data around the campus to document existing site conditions. These datasets include:

- 2005 Bathymetric survey of Tiburon, CA, performed by California State University Monterey Bay (CSUMB)
- 2010 San Francisco Bay Area Light Detection and Ranging (LiDAR)
- 2019 Ground survey along the campus shoreline and limited transects across the south pocket beach using RTK GPS, performed by ESA

Several key elevations for points of interest were documented and groundtruthed, since they inform project phasing for the concept designs along the shoreline under future sea-level rise conditions. The slab in the Central

¹ Sonde: an instrument probe that automatically transmits information about its surroundings underground, under water, in the atmosphere, etc.

reach is relatively flat at 11.0 ft NAVD. The existing seawall in the North Reach is at approximately 12.0 ft NAVD, with higher ground (14.0 ft NAVD) around the field. **Figure 7** shows the combined elevation datasets.

3.2.2 Tides

Located in Central San Francisco Bay, the project site experiences mixed semi-diurnal tides. ESA gathered tidal datum information from the closest NOAA tide station to the project site – Presidio, NOAA ID #9414290. Tidal datums from this station are presented in **Table 2**.

TABLE 2
TIDAL DATUMS FOR NOAA STATION #9414290

Datum	Elevation (ft)	Description
MHHW	5.84	Mean Higher-High Water
MHW	5.23	Mean High Water
MSL	3.12	Mean Sea Level
MLW	1.13	Mean Low Water
MLLW	0.00	Mean Lower-Low Water
NAVD88	-0.06	North American Vertical Datum

SOURCE: NOAA, 2019.

NOAA Tide measurements were compared to tide measurements available from the RTC-operated sonde located on the research pier on campus. RTC has managed the instrument since 2015. However, the existing sonde is exposed to wave action as it is suspended from the pier by a cable rather than being fixed to the pier; therefore, its reported elevations may not be reliable. The tide signals between the two locations are similar. Since tidal datums are not available for the RTC data, the study assumes the tidal datums from the Presidio location are appropriate for the project site.

3.2.3 Waves

Wind-generated waves and wakes resulting from vessel traffic are understood to be the main sources of wave action at the project site. The Corte Madera Channel is located approximately 2000 feet offshore of campus; roundtrip ferry service passes through this area on a half-hour basis. Since no wave measurements are available at the project site, ESA performed a limited wind-wave generation analysis based on wind data collected onsite at the research pier and at other available data sources in the area to characterize the local wave climate. **Figure 8** shows the range of wind fetch² from all compass directions.

Wind Analysis

A wind analysis was conducted to describe typical wind conditions and extreme winds near the site. Wind data measured at the site from the Tiburon Pier Station (NOAA, ID TIBC1) was used to describe local wind conditions and wind distribution. A longer data record at the Oakland Airport (WMO, ID: 72493) with a record of 70 years (1948 to 2018) was used to estimate extreme wind conditions (**Table 3**) (IEM, 2019). The raw data was evaluated and questionable values were removed. Data were adjusted to a standardized height of 33 feet (~10m)

² Fetch is defined as the distanced traveled by wind across open water.

and a duration of 2 min and corrected from wind overland to wind over water according to Resio and Vincent (1977) and USACE (2006).

TABLE 3
WIND DATA RECORDS USED IN ANALYSIS

Station Name	ID	Years of Record	Source
Tiburon Pier Station	TIBC1	2006-2018	NOAA, 2019
Oakland Airport	OAK, 72493	1948-2018	IEM, ASOS, 2019

Wind Distribution

Table 4 shows a summary of the wind speed percentile of the recorded events based on ESA’s analysis (Attachment B). The distribution shows that 50% of the recorded wind events are higher than 4.5 mph and that only 1 percent of the wind events are higher than 17.5 mph.

TABLE 4
WIND SPEEDS PERCENTILE (TIBURON PIER STATION)

Percentile (%)	Wind Speed (mph)
0.1	23.5
1	17.5
2	15.5
10	10.5
25	7.5
50	4.5
75	2.5
90	1.5
99	0.5
99.9	0.5

The wind directional distribution recorded at the Tiburon Pier Station is shown in **Table 5**. **Figure 9** shows the annual wind rose distribution and **Figure 10** shows the wind rose seasonal distribution. Wind climate at the Tiburon Pier Station are characterized by three main directional components with winds from the southwest, southeast and northwest. Winds from the southwest (are the most predominant (~30%). Wind events larger than 30 mph come primarily from the southeast.

TABLE 5
WIND SPEED AND DIRECTION JOINT DISTRIBUTION EVENTS (TIBURON PIER STATION)

		Wind Direction (Degrees)																#	%
Wind Speed (mph)		0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5		
0	5	1,987	2,859	2,587	2,922	4,906	9,509	12,054	10,679	13,158	22,842	28,722	21,178	18,706	14,660	10,886	7,547	185,202	54.9%
5	10	1,094	1,594	634	381	1,316	10,612	16,921	8,726	8,550	14,476	4,794	2,385	4,833	16,070	10,504	4,859	107,749	31.9%
10	15	235	293	32	9	59	2,994	6,517	2,200	2,816	6,586	1,520	566	284	5,180	4,991	1,420	35,702	10.6%
15	20	19	9	1	1	1	644	1,424	191	207	638	347	115	29	1,483	1,840	377	7,326	2.2%
20	25	1	0	0	0	1	92	279	22	5	30	41	16	4	269	494	63	1,317	0.4%
25	30	1	0	0	0	0	9	28	5	0	1	3	3	0	46	57	7	160	0.05%
30	35	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	1	5	0.00%
	#	3,337	4,755	3,254	3,313	6,283	23,860	37,226	21,823	24,736	44,573	35,427	24,263	23,856	37,709	28,772	14,274	337,461	100%
	%	1.0%	1.4%	1.0%	1.0%	1.9%	7.1%	11.0%	6.5%	7.3%	13.2%	10.5%	7.2%	7.1%	11.2%	8.5%	4.2%	100%	

NOTE: 0° corresponds to compass direction north, 90° to east, 180° to south and 270° to west.

The seasonal directional distribution of the wind shows springs and summer with a strong southwest component. The southwest winds are less frequent on the autumn and the winter. Constant and strong winds from the northwest and the southeast are present in winter. Strong winds from the northwest are present all the year except for the summer season.

Wind Wave Prediction

The wind speed and direction, the duration of the wind, the length of the fetch and the water depth are the parameters that determine the wave height and the wave period of the locally generated wind waves at the site. ESA used parametric wind-wave generation relationships following the guidance described by Seymour (1977), Shore Protection Manual (USACE, 1984b) and the Coastal Engineering Manual (USACE, 2006) were used to estimate wave height and wave period based on the recorded wind speed and direction time series at Tiburon Bay. **Table 6** summarizes the design wave heights for events of different recurrence intervals.

The directional distribution of the waves at the site is shown in **Figure 11**. Most waves had a southeast direction with the rest of the waves coming from the north and northwest. Waves higher than 2 ft come from the southeast. The following wave height values were estimated using extreme value analysis (EVA):

TABLE 6
DESIGN WAVE HEIGHTS ESTIMATED FROM TIBURON PIER STATION WIND RECORD

Description	Design Wave Height (ft)
H ₁₀ , average of top 10% of wave heights	30.9
H ₁ , average of top 1% of wave heights	36.4
2-year event	40.1
5-year event	42.5

Extreme Wind Analysis

Extreme value analysis was conducted to determine wind speeds and corresponding wave heights for a range of recurrence intervals. Predictions of extreme events requires a sufficiently long record of observations to ensure accuracy, especially for greater recurrence intervals (e.g. 50-year, 100-year). Therefore, an extreme value analysis of the 70 years of the recorded wind data at Oakland Airport from 1948 to 2018 was conducted. From the wind time series, the maximum wind speed events from each year were obtained and fit to a Gumbel and the General Extreme Value Distribution (GEV) (Attachment B). Several distributions are examined in order to find the best distribution for the data set. For this case the GEV PWM distribution provides a good fit to the majority of the extreme events. **Table 7** summarizes the extreme analysis results obtained from the GEV PWM.

TABLE 7
EXTREME WIND SPEED (MPH) [OAKLAND AIRPORT STATION]

Return Period (years)	GEV
1	30.9
2	36.4
5	40.1
10	42.5
20	44.7
50	47.6
100	49.6

Extreme Wave Height

Using parametric wind-wave generation relationships established by USACE, a design wave event for a 50-year wind arriving from the southeast direction (120 degrees) is estimated to have a significant wave height of 4.7 ft with a peak wave period of 4.4 seconds. Prior analyses by Coast & Harbor Engineering (2007) provided an assessment of the local wave climate during the March 2006 storm, which resulted in significant erosion of uncompacted fill along the shoreline. Design wave characteristics for a 50-year storm in that analysis were evaluated to be a significant wave height of 4.3 feet, peak period of 5.2 seconds and peak wave direction of compass direction SE.

Extreme waves at the study site also originate from boat wakes from ferry service traveling by the Corte Madera channel. Roundtrip ferry trips occur every half hour from San Francisco to Larkspur, totaling 38 one-way trips daily.³ Boat wakes are understood to have larger erosive potential for the shoreline for a given wave height, compared to typical wind-generated waves, due to the potential for higher associated wave energy. These can be generalized into two different types of waves: 1) leading divergent waves, which have long periods but are rarely the highest in the wave train and 2) short period divergent waves that have higher amplitudes. Both types of waves should be quantified, since the highest wave energy in a wave train generated by a vessel is not always associated with the maximum wave height. Longer periods contribute to total wave energy since these result in a longer wavelength and associated erosive force.

³ As of February 2020, prior to Covid 19-related schedule changes.

Boat wake heights and periods were estimated based off of known vessel characteristics (e.g., vessel length, speed, displacement). Vessel particulars were determined from the ship type, available from the San Francisco Bay Ferry website (<http://sanfranciscobayferry.com>). Waves characterized as leading diverging waves were predicted to have a wave height of approx. 0.25 ft and a wave period of 7.6 s. The largest wave heights from ferry activity were estimated to be 1.6 ft with a wave period of 3 s.

3.2.4 Streamflow

The study area features three watersheds and two primary drainage paths which divert flow from the uplands to the Bay (**Figure 12**). There are existing campus buildings located in both natural drainage paths. The south drainage path runs behind and alongside Delta Hall in a narrow, concrete channel and discharges next to the existing boat ramp. Large precipitation events result in flows exceeding channel capacity and ponding on the slab by the parking lot in front of Delta Hall.

As part of concept development for the South Reach, ESA downloaded peak flow estimates from StreamStats⁴, a water resources planning and management tool developed by the U.S. Geological Survey (USGS). ESA coordinated with Sherwood Engineers, who developed a HydroCAD model of the campus as part of the storm water detention pond component of the overall campus master plan, during the study process to ascertain watershed areas and estimated peak flows through the campus. **Table 8** shows a comparison between flows reported by StreamStats and the HydroCAD model. The StreamStats estimates generally agree with the those computed from HydroCAD model for the southern watershed; values reported by StreamStats for the northern watershed seem to be under-predicted.

TABLE 8
PEAK FLOW ESTIMATES

Recurrence Interval	Peak Flows (cfs) [StreamStats]		Peak Flows (cfs) [HydroCAD model]	
	Northern Watershed*	Southern Watershed*	Northern Watershed	Southern Watershed
2 Year	3.68	5.58	2.6	5.6
10 Year	12.5	18.8	9.0	16.1
100 Year	26.9	40.4	23	37.6

* Location selected represents flows entering campus from Paradise Drive. StreamStats does not return peak flow estimates for points located closer to the Bay for the northern watershed.

3.2.5 Predicted Future Flooding Extent

Since the slab is predominantly flat, it is expected that wave overtopping in one section of the central seawall will result in shallow flooding throughout the central part of campus. Present-day site observations have confirmed that wave run up from high tide wave events produce flooding around the existing boat ramp. Local flood map web tools (e.g. Adapting to Rising Tides⁵ [ART] and Our Coast Our Future [OCOF]) were used to determine a preliminary estimate of additional water level from sea-level rise and storm surge that would overtop the seawall. **Figure 13** shows that the middle of the seawall in the Central Reach is first predicted to be overtopped with 3 feet

⁴ The USGS StreamStats tool can be accessed at: https://www.usgs.gov/mission-areas/water-resources/science/streamstats-streamflow-statistics-and-spatial-analysis-tools?qt-science_center_objects=0#qt-science_center_objects

⁵ Flood Explorer at Adapting to Rising Tides (ART) can be accessed at: <https://explorer.adaptingtorisingtides.org/explorer>

of added water level (ART, 2019; OCOF, 2019). This is approximately equivalent to 2 feet of sea-level rise and monthly king tide.

It was noted that future predicted flooding extents closely resemble the extent of the historic shoreline prior to seawall construction. This influenced development and phasing of conceptual designs in the study.

4. Nature-Based Shoreline Concepts

The Project team developed conceptual designs by reach for increasing rocky intertidal and natural habitat along the campus shoreline that would be congruent with campus use. The project team worked with the Master Plan team and the TAC to identify the target types of nature-based shoreline enhancements to be applied to the project site shoreline. The project team identified the following restored habitat types – pocket beach, back barrier wetland, rocky shoreline, and living seawall.

This section provides a description of the planning approach, descriptions of the concepts for each of the three reaches, adaptation pathways for phased implementation, and order of magnitude cost estimates. Exhibits 1 – 5 show plan views and typical cross-sections for each concept design. To aid in the conceptual design, the project team identified reference sites for the target shoreline enhancement types, discussed in Section 5.

4.1 Planning Approach

The conceptual design for nature-based enhancement of the campus shoreline was developed by the project team with input from the project TAC, and in coordination with the larger Campus Master Planning and Living Community Challenge. The shoreline was divided into three reaches (South, Central and North) for planning, and separate shoreline concepts were developed for each segment.

Collaborative Planning Process. In Spring 2019, the project team participated in a series of campus master planning charrettes, led by the PAGE master plan team, and engaged with University academic staff and students in the planning process. Preliminary opportunities and constraints and restoration concepts were developed for the shoreline. In July 2019, the project team convened a Technical Advisory Committee (TAC) to provide input on the initial concepts and to brainstorm shoreline restoration concepts independent from the previous campus master planning processes. As part of the conceptual design process, guidance on relevant design criteria (e.g. tidal datums for species recruitment) and reference sites were gathered. The project team further developed the conceptual design alternatives for the shoreline reaches (e.g. graphics, planning-level cost estimates) with follow-up coordination with individual TAC members/experts. A conceptual design workshop was held in December 2019 to gather a final round of feedback from experts on the designs, cost and feasibility.

Master Plan Context The conceptual designs for the campus shoreline were informed by planning assumptions and decisions developed during the Campus Master Plan process. Analysis of the existing space usage by the Master Plan team suggests that a significant amount of future programming on campus could be located within a smaller footprint. Figure 14 shows the preliminary future campus program zones, with an emphasis on expanding the teaching and research program and potential community spaces. The following points summarize assumptions around timing and future campus use relevant to the nature-based shoreline planning:

- Delta Hall will remain until 2050 or until the end of its useful life and then decommissioned.

- The slab will remain for flexible use in future campus programming – e.g. parking, storage, open space for community gatherings. The slab is assumed to remain in place for all shoreline enhancements considered.
- Maintain options to preserve the historic Bayside Theater building indefinitely for now, until further decision. The theater is located at the northeast corner of the slab and was assumed to remain in place. Some of the adjacent small buildings may be removed.
- Campus users (e.g. students, researchers, faculty) will require a safe, accessible and efficient way to launch boats now and in the future.
- The campus may potentially be used as a disaster relief/evacuation site.

4.2 Opportunities, Constraints and Design Criteria

ESA and SFSU developed a list of opportunities and constraints for the site based on existing data review, input collected from the campus master planning charrettes, and the July 2019 shoreline study-specific meeting. These opportunities and constraints were used to help guide development of the conceptual design alternatives. The project team identified the following opportunities relevant to all three shoreline reaches:

- Prior use of the site as a naval base resulted in an abundance of concrete weights around the campus shoreline. These could potentially be re-used in shoreline treatments, as hard points or ground up for material re-use.
- Removal of defunct infrastructure across campus can create space for new shoreline treatments.
- Fill generated from excavation for nature-based shorelines could potentially be re-used to elevate campus buildings as sea levels rise.
- The relatively undisturbed beach to the north of campus could potentially provide propagules to any constructed rocky shore and enhanced seawall
- Potential to use a restored/constructed site for student learning opportunities/graduate student research

Additional opportunities and constraints are presented by reach in the sections below.

ESA developed conceptual design criteria for each reach (**Tables 9 through 11**) based on available documents, reference site information, and discussion with members of the TAC for each of the shoreline reaches.

4.3 South Reach

The South Reach of the campus includes the tidelots to the south of campus up to southern edge of the slab, where the existing boat launch and inoperative water treatment facility are located. The following opportunities were noted during ESA site visits and project discussions:

- Removal of defunct water treatment plant to create space for shoreline enhancement
- Relocation of existing sub-optimal boat launch to create space for shoreline enhancement
- Creek located in Southern Reach (currently channelized) could be naturalized and reconnected to the Bay
- Discussions from the campus master planning charrettes identified the potential for removal of part of the slab in the South Reach and restoration of natural habitat.

4.3.1 South Pocket Beach, Back-Barrier Marsh and Creek Restoration

The South Reach concept restores a small pocket beach, a back-barrier marsh, and a more natural creek channel connecting from Delta Hall through the marsh to the Bay (Exhibit 2). The existing boat ramp, defunct water treatment plant, and slab in front of Delta Hall would be removed. Coarse sediment (gravel and cobble) would be placed to form a pocket beach of approximately 200 feet length. The large concrete blocks that constitute the sides of the existing boat ramp would be relocated to act as a hard point to retain beach sediment. A channelized freshwater creek flows alongside Delta Hall and into the Bay. The existing concrete creek channel between Delta Hall and the Bay would be removed and the creek realigned into a more natural planform and earthen channel. The creek would flow into a restored back-barrier marsh and drain through the beach berm, intermittently overtopping the beach berm during high runoff events. Depending on final site elevations, the transition from creek to beach would be primarily freshwater habitat (above Bay water levels) or more saline. The part of the marsh closest to shore would experience periodic saline input from wave overtopping events. Excavated pavement and fill would be stockpiled on campus.

The concept creates a gradient of freshwater to saline wetland habitat between the Bay and Delta Hall. The restored creek would flow into freshwater wetland habitat, which could support the California red-legged frog *Rana draytonii*. Habitat closer to the Bay would receive more saline influence and could support vegetation found in brackish wetlands (e.g. clustered field sedge, saltmarsh tuber-bulrush, marsh *Jaumea*, saltgrass). This concept would be combined with a coarse beach, for a combined back barrier beach-wetland complex. The entire area would provide natural open space to be enjoyed by students, faculty and staff. The transition from the slab down to the marsh could be terraced to allow seating along with ecological enhancements around the marsh edge.

In the near-term, improvements to the existing boat ramp (e.g. widening and setting back the slope) would be made in order to maintain boat access while the University pursues funding to relocate the boat launch to the pier. The defunct water treatment plant could be removed at any time and is identified as a near term action.

4.3.2 South Reach Design Criteria

The following design criteria (Table 9) were developed by the project team and used in the concept design in Exhibit 2.

TABLE 9
CONCEPTUAL DESIGN CRITERIA (SOUTH REACH)

Criteria	Parameter	Design Feature	Relevant Guidance/Source
Useful Life	30-years, no maintenance	All	SFSU, pers. comm.
Sea Level Rise	Resilient for 2-3 feet of rise by 2050	Beach and berm crest elevation	OPC 2018
Overtopping	2-yr SWL	Berm crest elevation and width	Reference Sites
Beach profile average slope	8H:1V	Beach slope and fill volume	Reference Sites
Rock static stability	Top 1% of waves	Rock size, slope, thickness	USACE (2002)

4.4 Central Reach

The Central Reach includes the slab and is where the majority of campus operations, including marine and coastal research activities, take place. The following opportunities and constraints were noted for this segment of the campus shoreline:

- The slab is assumed to remain in place for all shoreline enhancements considered.
- The historic Bayside Theater, located at the northeast corner of the slab, was assumed to remain in place. Some of the adjacent small buildings may be removed.
- The university desired little to no maintenance of shoreline enhancements in the Central Reach.

The creek that flows immediately north of the slab, and outlets on the slab behind the old studio buildings, was considered for enhancement at its downstream reach. However, the mouth of this creek is highly constrained by buildings to remain and adjacent uplands and was ultimately considered a poor candidate for enhancement.

Given the desire to maintain the existing slab and associated bulkhead (aka seawall), a living seawall was identified as the preferred shoreline treatment in the Central Reach (Exhibit 3). Traditional concrete seawalls are typically flat with minimal crevices. Living seawalls refer to a shoreline treatment where texture and rugosity of seawall structures are enhanced to maximize habitat area where marine organisms can colonize, rest and feed. The university plans to use the slab area as part of campus operations for the next several decades; thus, at least part of the existing seawall edge is assumed to stay. Surface modifications to the seawall would be a relatively easy-to-install, inexpensive way to increase intertidal and subtidal habitat for native marine species. For retrofitting existing structures, options include affixing additional material such as concrete panels, drilling pits, grooves, and pools, and transplanting desirable species (O'Shaughnessy et al., 2020).

The concept introduces living seawall enhancements along the length of the existing slab (approx. 1460 linear m [4800 linear ft]). The concept would design texture and possibly moisture-retaining features into the seawall to create more surface area to support native species that use rocky habitats. The texture could be created in the form of steps, shelves, or cobble protrusions as at the Elliott Bay Seawall or tiles as at the Volvo Living Seawall (see Living Seawalls References, Section 4). There is an opportunity to vary the living seawall enhancements along the existing seawall, rather than using the same treatment for the entire area (e.g. design one section of the wall to focus on oyster habitat and another to support fish feeding/foraging). EOS scientists will collaborate with other scientists, such as those at Smithsonian Environmental Research Center and San Francisco Bay National Estuarine Research Reserve, to conduct a pilot test of various seawall treatments at different locations and tidal elevations to inform the full living seawall design.

A living seawall is expected to support macroalgae species, such as those found on the weights and natural shoreline to the north of the seawall, and increase the density of native oysters and the diversity of native gastropods, small crabs and other small crustaceans over what is currently observed on the seawall. These organisms provide food for numerous Bay species, including fish and birds.

Future pier improvements are also proposed in the Central Reach to allow removal of the existing boat launch and subsequent shoreline enhancement the South Reach. More information on planned pier improvements can be found in Attachment D.

Previous structural analysis by Tipping Engineers (2017) recommends additional seismic studies and potentially seismic retrofits along the seawall to avoid future damage in a seismic event. Additional seismic studies and potentially retrofits will be required in subsequent design development.

4.5 North Reach

The North Reach was subdivided into areas A and B. North Reach A consists of the earthen field; North Reach B consists of the filled area behind the seawall further north (Exhibit 1).

The following opportunities and constraints were noted for the North Reach of the campus shoreline:

- Open space along the North campus shoreline could potentially be converted to a more natural landscape, with enhanced ecological, educational and recreational value for the community.
- The pathway connecting the upland trail system and RTC campus in the North Reach is planned to be renovated.
- Buried materials under the “field” area in the north reach contain debris of unknown origin and are assumed to be expensive to excavate. Additionally, the field area provides desirable space for student activities and programming. For these reasons, the concept assumes no excavation would occur in this area.

4.5.1 North Reach A – Rocky Shoreline and Stabilized Field

The University has prioritized the field area as a location where people of all abilities could enjoy and learn from the Bay shore restoration. The concept would maintain a space for student activities and provide additional rocky intertidal habitat. A new/improved rock revetment would be constructed to stabilize the eroding shoreline between the Bayside Theater and the northern seawall (Exhibit 4). The concept avoids expensive excavation of materials of dubious origin. The revetment will provide rocky shoreline habitat.

Conceptual design criteria developed for North Reach A are shown in **Table 10**. Due to the planned future recreational usage of the field and continued erosion of poor-quality fill soils, stabilization of the shore edge would occur in the near-term. S

TABLE 10
CONCEPTUAL DESIGN CRITERIA (NORTH REACH AREA A – FIELD AREA)

Criteria	Parameter	Design Feature	Relevant Guidance/Source
Useful Life	30-years, no maintenance	All	SFSU, pers. comm.
Sea Level Rise	Resilient for 2-3 feet of rise by 2050	Beach and berm crest elevation	OPC 2018
Overtopping	2-yr SWL	Berm crest elevation and width	Reference Sites
Beach profile average slope	8H:1V	Beach slope and fill volume	Reference Sites
Rock static stability	Top 1% of waves	Rock size, slope, thickness	USACE (2002)

4.5.2 North Reach B – Pocket Beach Restoration and Bay Shoreline Access and Education Area

The concept proposes creating a pocket gravel beach (approx. 61 m (200 ft) extent), restoring connection to the natural hillslope to the north, and removing creosote pilings (Exhibit 5). The existing seawall in North Reach B is in poor condition and is at risk for overtopping and structural failure under future sea-level rise conditions. Construction of a coarse-grained beach (e.g. gravel, cobble) is proposed to restore this part of the campus shoreline to a more natural setting and provide educational and recreational value for the university community.

The gravel beach restoration would entail removing the existing bulkhead and seawall, removing earthen fill, constructing artificial headlands and placing coarse sediment to form a pocket or cove beach. Beach sediments are likely gravel and cobble and will reuse onsite coarse sediments as appropriate. The headlands will likely be a combination of existing structures to remain and renovation with (onsite) boulders or large concrete blocks. The hillside to the north of the pocket beach may opportunistically accrete coarse sediment due to the location of the artificial headlands. The concept layout was developed using professional judgment and consideration of geomorphology and tidal and wave conditions and informed by a reference site south of the EOS Center.

Removal of the creosote pilings offshore of the seawall is recommended in the near-term, followed by construction of gravel beach in the medium-term.

A beach with coarse-grained sediment is characterized by its dynamic stability, which refers to beach sediment remaining largely within the beach face, despite active mobilization and redistribution by tide and wave action. Choosing gravel or cobble as the beach material reduces the probability of beach sediment loss under extreme events; this sediment size is predicted to be mobilized by only the top 1% of waves experienced at the study site, based on analysis of the existing wind-wave record. The reference pocket beach located adjacent to the south of campus is comprised of mixed cobble and gravel with a sand veneer, potentially from local drainage or hillside sediment source. Survey data from the south pocket beach show a 8H:1V beach slope. A proposed coarse-beach restoration would assume a similar beach slope. Conceptual design criteria developed for North Reach B are shown in **Table 11**.

TABLE 11
CONCEPTUAL DESIGN CRITERIA (NORTH REACH AREA B – UNIVERSAL BAY SHORELINE ACCESS AND EDUCATION AREA)

Criteria	Parameter	Design Feature	Relevant Guidance/Source
Useful Life	30-years, no maintenance	All	SFSU, pers. comm.
Intertidal Habitat Creation		Rock size	

4.6 Adaptation Pathways

The conceptual designs developed in this study are part of a larger, integrated vision, though they can also be implemented separately. Some design components are more easily implementable on a shorter timescale; others will require further planning, design and evaluation. The project team developed initial adaptation pathways for the shoreline reaches to capture relevant assumptions from the campus master plan, trigger points and phased implementation for various shoreline treatments. Figures 15 and 16 show the proposed adaptation pathways diagrams for the South, Central and North Reaches. The pathways identify short-term actions that can be taken now as further study or fundraising efforts for medium-term actions are being carried out. The adaptation

pathways are meant as an organizing framework to assist decision makers and stakeholders in evaluating multiple courses of action. As new information arises, the pathways are meant to be updated accordingly.

4.7 Cost Estimates

For planning purposes, ESA developed reasonable order of magnitude (ROM) cost estimates for the conceptual designs along the three reaches (**Table 12**). These cost estimates are assumed to be approximately -30% to 50% accurate and include a 35% design contingency to account for project uncertainties. These estimates are subject to refinement and revisions as the design is progressed in future stages of the project. Estimated costs are presented in 2020 dollars and would need to be adjusted to account for price escalation for future implementation. This opinion of probable construction costs is based on: ESA project experience, bid prices from similar projects, consultation with contractors/supplies, R.S. Means online and the ENR Cost Index Tables. Please note that in providing opinions of probable construction costs, ESA has no control over the actual costs at the time of construction.

TABLE 12
ROM ESTIMATES FOR CONCEPTUAL DESIGNS BY REACH

Item #	Description	Extended Price
1	South Pocket Beach, Back Barrier Wetland Creation and Enhanced Creek (South Reach)	\$2,200,900
2	Living Seawall Enhancement (Central Reach)	\$625,000
3	Universal Bay Shoreline Access and Education Area (North Reach)	\$889,500
4	Gravel Beach and Shore Restoration (North Reach)	\$2,433,800
5	Mobilization*	\$614,920
6	Environmental Protection**	\$307,460
Total		\$7,071,580
Rounded Total		\$7,100,000

* Estimated as 10% of total

** Estimated as 5% of total

5. Reference Sites

To aid in the conceptual design, the project team identified reference sites for pocket beaches, back barrier wetlands, and rocky shorelines. The team collected field data on physical conditions, ecological conditions, or both for the sites; not all data were collected at each site. Physical conditions data are presented below; ecological conditions data are documented separately. In the case of living seawalls, the team used reference sites from the literature. The references include natural and restored sites.

5.1 Pocket Beach Reference Site

The project team used the pocket beach adjacent to the south of campus as a reference site for pocket beach morphometry. ESA collected limited transects and sediment samples from the south pocket beach as part of the February 2019 ground survey. The pocket beach is approximately 260 feet long (shore length) and is bounded by the defunct water treatment plant infrastructure to the north and a headland to the south. The beach is bluff-

backed and neighboring residential properties are located immediately further up the hillslope. The sediment composition of the beach is primarily cobble and gravel. A sand veneer was visible on top of gravel on the northern part of the beach, indicating wave-driven sediment transport. **Figure 17** shows sediment composition at four locations on the beach. A folding ruler was used to visually assess the sediment variation. Several intertidal species (e.g. rockweed) were observed at the rocky shoreline at the southern end of the beach adjacent to the headland.

Figure 18 shows the locations of the profiles and elevation profiles taken during the survey. Sediments immediately offshore were observed to be muddy and finer than those on the beach face. The average beach slope for the south pocket beach was 8H:1V, which is within the typical range of slopes for beaches with cobble and gravel sediment. This area was used as a reference site for developing a coarse-grained beach restoration concept, e.g. sediment size, slope.

5.2 Back Barrier Wetland Reference Sites

To support conceptual design development of an estuarine beach that would be appropriate for the South Reach in the vicinity of the southern drainage, ESA worked with TAC member Dr. Peter Baye to identify back barrier beach lagoon and wetland systems around San Francisco and Tomales Bay and collected key hydrologic (e.g. watershed size, creek flow) and geomorphic (e.g. crest elevation) parameters. Elevations at these sites and maximum wind fetch were determined using Google Earth and available LiDAR. Hydrologic information and known base flood elevation (BFE) information were downloaded from the USGS StreamStats and FEMA websites, respectively. ESA analyzed these data to establish any spatial trends between physical parameters and compared surveyed values from the south pocket beach adjacent to campus to other, local sites. **Table 13** presents the information collected for these systems.

Based on these sites, no identifiable relation between beach crest elevation and back-barrier pond elevation was obvious. An initial comparison of beach crest and back barrier pond elevations show that there exist a range of values in both San Francisco and Tomales Bay. To some extent this is an expected result given the large variations in geology, watershed slope, and lagoon mouth conditions among sites. For instance, two nearby sites with similar watershed or beach sizes may have different lagoon mouth morphologies related to difference in local wave exposure. A site with less direct, consistent wind-wave exposure may experience deeper stream-related scour in the mouth and thus lead to lower pond elevations. Wind-wave exposure information was not available from the public datasets we assessed, as wind data collection tends to be sparse.

Despite the differences in beach, watershed, and pond characteristics at each site, there were some commonalities, especially within groups of sites within short geographical distance of each other. The summary information gathered in **Table 13** informed concept design development for the South Reach.

TABLE 13
KEY PARAMETERS FOR SAN FRANCISCO BAY AND TOMALES REFERENCE SITES

Site Name	Watershed Size (acres)	10-Yr Creek Flow (cfs)	Longest Wind Fetch (mi)	FEMA BFE (ft, NAVD)	Beach Crest Elevation (ft, NAVD)	Back Barrier Pond Elevation (ft, NAVD)
San Francisco Bay Sites						
Project Site	40	19	4	10	-	-
Keil Cove	64	19	8	10	8.8	<6
EOS-South Pocket Beach	-	-	16	12	Bluff toe at 8.25	-
Rat Rock Cove	12	-	10	10	8.4	7
Peacock Gap	256	67	20	12	9.6	<6
Richmond Harbor	-	-	8	-	9	-
Tomales Bay Sites						
Pita Beach	105	23	2	-	7.8	5
Pelican North Beach	128	43	2	10	8.6	8
Duck Cove	68	22	2	-	8.8	7
Indian Beach 1	20	-	4	-	8.0	4
Indian Beach 2	213	75	4	-	8.0	5
Shallow Beach	215	75	2	-	8.2	5
Shell Beach 1	116	41	8	13	7.9	6
Shell Beach 2	18	-	8	13	7.4	7

5.3 Rocky Shoreline Reference Sites

Drs. Karina Nielsen and Chela Zabin conducted field data collection at natural rocky shoreline reference sites along the northern and southern boundaries of the project area. Discussion of these studies and applicability to the conceptual design are documented separately.

5.4 Living Seawall Reference Sites

Living seawall reference sites were identified from the scientific literature, as no local reference sites were available for assessment. The team reviewed publications that assessed living seawall sites from around the globe (Dyson and Yocom 2015; Morris et al. 2018; Mayer-Pinto et al. 2019; Morris et al., 2019; O'Shaughnessy et al., 2020) and collected reference site data from TAC members with living seawall expertise.

Living seawall approaches relevant for consideration at the EOS Center site include drilling pits, grooves, and crevices; affixing precast concrete panels or tiles; affixing artificial rock pools; and transplanting desirable species. These are approaches that can be implemented retrospectively (e.g., retrofits) to an existing seawall structure. O'Shaughnessy et al. (2020) provide a catalogue of living seawall approaches, discuss where these approaches have been implemented, whether they were successful, and provide literature citations.⁶ There are examples of successful living seawall projects for all approaches, though success varies depending on conditions.

⁶ See particularly tables in the Supplemental Information.

One novel approach of interest to the project team is using 3D printing to create concrete tiles that can be affixed to the seawall. This approach has been used at several locations in Australia and in other locations such as Wales and Singapore (Reuters, 2021). The Living Seawalls project, in Sydney, Australia, a program of the Sydney Institute of Marine Science in collaboration with Reef Design Lab, installed 1,000 3D-printed, concrete, hexagonal tiles affixed to a seawall. In this case, the texture of the tiles mimics the root structure of native mangrove trees. Monitoring of initial test tiles indicate that the tiles support native intertidal biodiversity (Living Seawalls, 2022; Reuters 2021). After 1-2 years, the living seawall panels support 30% to 40% more species than unmodified parts of the seawall, with up to 85 species of invertebrates, seaweeds and fish living and growing on the panels. This performance is similar to conditions on nearby natural rocky reefs, which are considered desirable in terms of biodiversity. Researchers hypothesize that the Living Seawalls project will attract more species over time.

A prominent living seawall example from the west coast of the U.S. is the Elliott Bay Seawall in Seattle, Washington, which incorporates living seawall techniques to support local fish species (e.g. Chinook, pink and chum salmon). The seawall makes use of benches, steps and other small protrusions along the structure to create spaces for marine organisms to colonize, rest and feed. Several members of the TAC were involved in the Elliot Seawall study and the Project team consulted them through the design process. Early on, researchers affixed test panels to the Seattle seawall. Test panels with three treatments of habitat enhancement (flat, finned, stepped) with 2 textures (smooth and cobbled) were implemented in 2008 and monitored for 4 years (Cordell et al. 2017). Results from the test panel formed the foundation for the larger project design, which included construction of seawall panels with added benches in conjunction with improvements to the seawall.

While much progress has been made in the area of implementing and testing living seawalls, many designs have been implemented only once, or only in certain environmental conditions (e.g., exposed or sheltered) or climates with varying levels of similarity to the project site (Evans et al. 2019; O'Shaughnessy et al. 2020). This is a limitation in applying the outcomes of other living seawall sites to the project. Site specific testing of seawall enhancement approaches is needed and is proposed during subsequent planning and design phase, prior to construction.

6. Future Steps

This phase of the study concludes with conceptual designs and initial adaptation pathways for the shoreline reaches. The overall goal is to move the project forward to implementation, in conjunction with the Campus Master Plan. Major next steps are summarized below:

- **Perform additional technical studies to refine the concepts, including:**
 - ***Conduct bathymetry survey offshore of the Central seawall.*** Additional bathymetric information in front of the Central seawall will inform future boat access design and management of the area for short-term boat mooring.
 - ***Conduct geotechnical analysis for Central seawall and seawall by the historic Bayside theater.*** Further geotechnical analysis of the seawall structure is needed in order to assess seawall stability under a seismic event. Seismic stability for the Central seawall affects University marine research operations and water access. Seismic stability for the Bayside Theater seawall affects whether or not the theater would be retained. If the theater is not retained, the North Reach could be considered for the new boat launch location (not considered here) and construction access to the north reach would be less costly.

- **Conduct sediment sampling/coring for North Reach** (*field area and area behind seawall*). Existing reports available to the study indicate data gaps in sediment sampling in the North campus shoreline. Soil quality and composition will impact decision making around future potential re-use of the fill elsewhere on campus and potential to further enhance the existing field area.
- **Supplement the reference site studies** for more complete physical and biological data collection.
- **Develop preliminary designs for the shoreline reaches.** Based on the results of the technical studies and input from the campus master planning committee, advance the preliminary designs for the shoreline reaches and revise the adaptation pathways as necessary to reflect new information.
- **Implement other near-term actions identified in the adaptation pathways**
 - **Remove defunct water treatment plant.** The existing water treatment plant and adjacent space is not being used by SFSU; the infrastructure can be removed in order to create space for future adaptation actions.
 - **Interim improvements to existing boat launch.** In addition to the nature-based near-term actions outlined in this memo SFSU can make short-term improvements to the existing boat launch, including widening and laying back the slope for improved safety and accessibility. These improvements will maintain boat launching capabilities in the interim until funding is secured for pier improvements in the Central Reach.

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8. Figures and Exhibits

Figure 1. Project Location

Figure 2. Campus Shoreline Reaches

Figure 3. Historical Shoreline and Future Predicted Flood Extent

Figure 4. South Reach - Site Photos

Figure 5. Central Reach - Site Photos

Figure 6. North Reach - Site Photos

Figure 7. Combined Topography and Bathymetry

Figure 8. Wind Fetch across Compass Directions

Figure 9. Annual Wind Rose

Figure 10. Seasonal Wind Rose

Figure 11. Annual Wave Rose

Figure 12. Watershed & Drainage Paths on Campus

Figure 13. Future Predicted Flood Extent, +3 ft Sea-Level Rise

Figure 14. Master Plan: Draft Preferred Plan

Figure 15. Shoreline Adaptation Pathways, South and Central Reaches

Figure 16. Shoreline Adaptation Pathways, North Reach

Figure 17. South Pocket Beach Reference Site Sediment Composition

Figure 18. Survey Profile Locations & Elevations

Exhibit 1. Project Concepts Plan View

Exhibit 2. South Reach Concept Plan View and Cross Section

Exhibit 3. Central Reach Concept Plan View and Cross Section

Exhibit 4. North Reach A Concept Plan View and Cross Section

Exhibit 5. North Reach B Concept Plan View and Cross Section

9. Attachments

Attachment A. Technical Advisory Committee (TAC) Roster

Attachment B. Physical Processes Supplemental Information

Attachment C. Charrette Materials

Attachment D. Pier Improvements and Boating Access

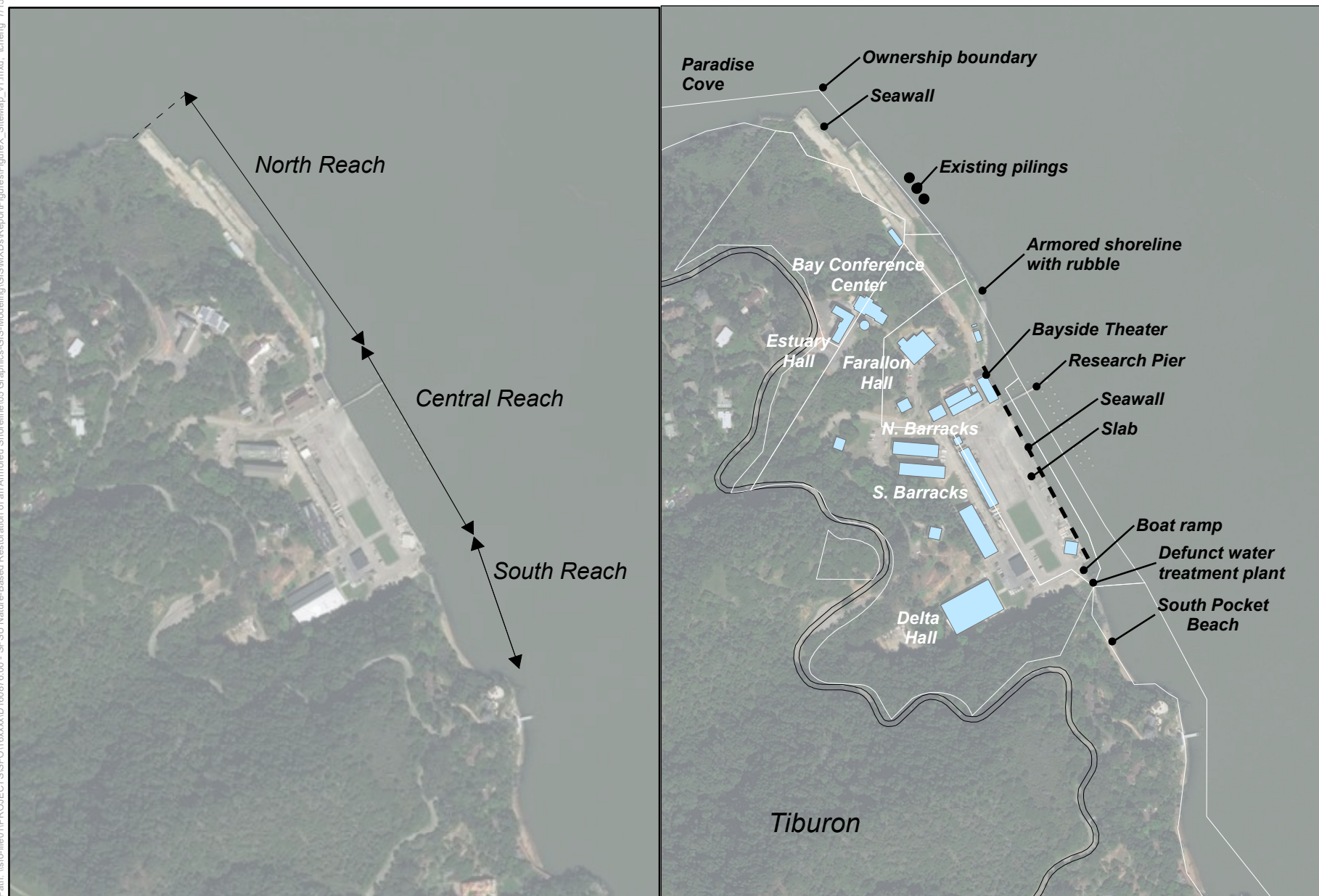


SFSU Nature-Based Restoration of Armored Shoreline D160876.00

Source: ESRI Aerial (2019), San Francisco State University (2019)

Figure 1
Project Location

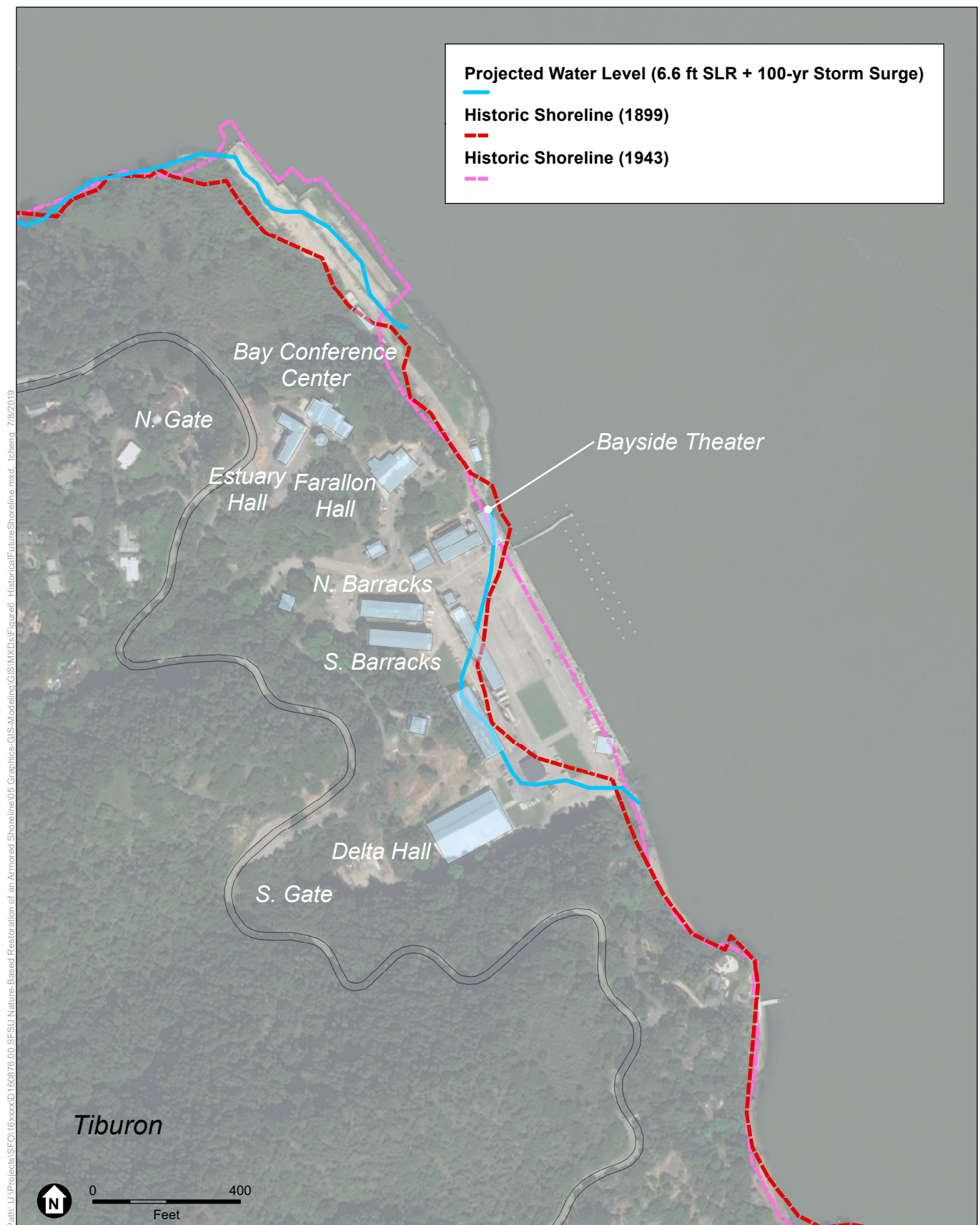
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SOURCE: ESRI Aerial (2019); San Francisco State University (Parcel Boundaries)

San Francisco State University Nature-Based Restoration of Armored Shoreline

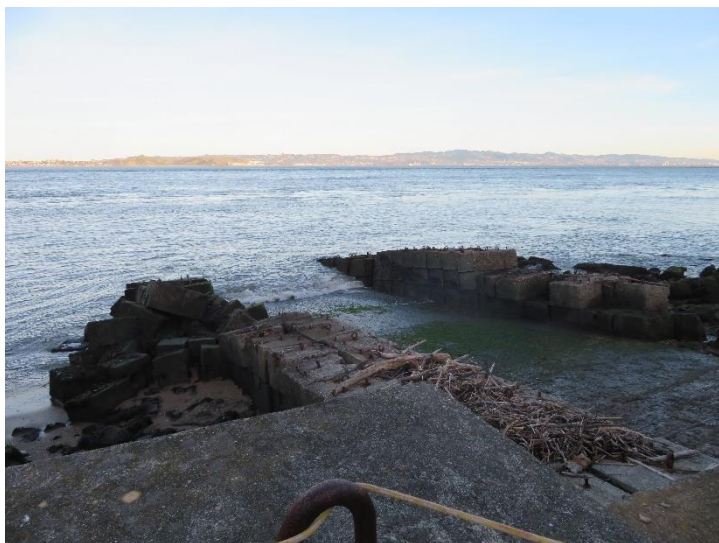
Figure 2
Site Map



ESRI Aerial (2019), NOAA (Historic T-Sheets), Our Coast Our Future (2019)

SFSU Nature-Based Restoration of Armored Shoreline . D160876.00

Figure 3
Historic Shoreline and Future
Projected Water Level



Existing Boat Ramp



Defunct Water Treatment Plant



Channelized Creek



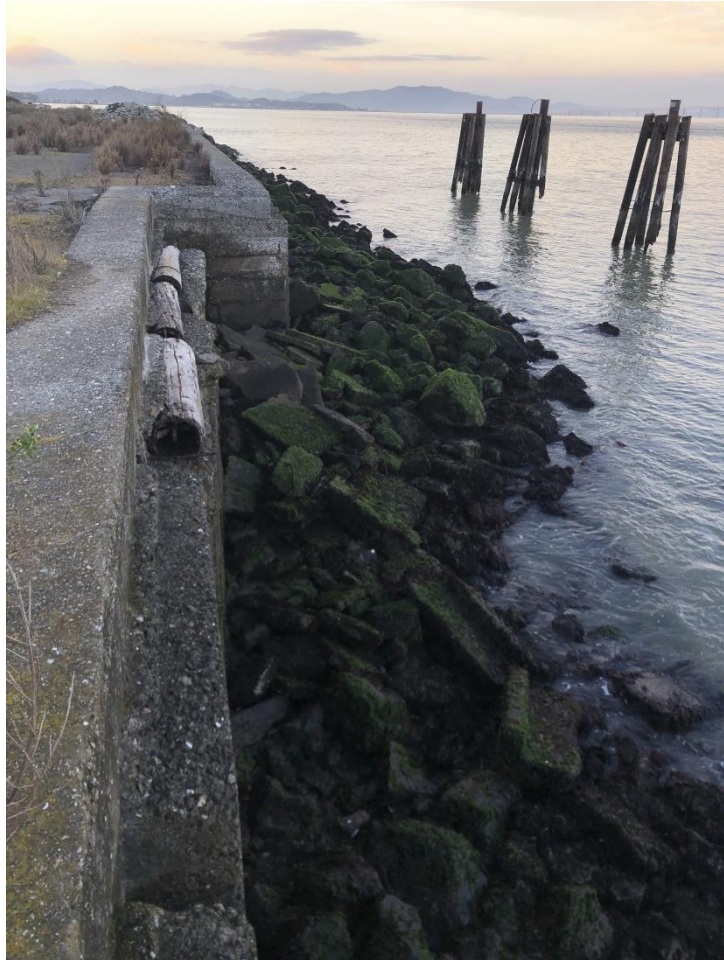
Looking South to Pocket Beach, from Boat Ramp



Existing Seawall, Slab and University Buildings in Central Reach



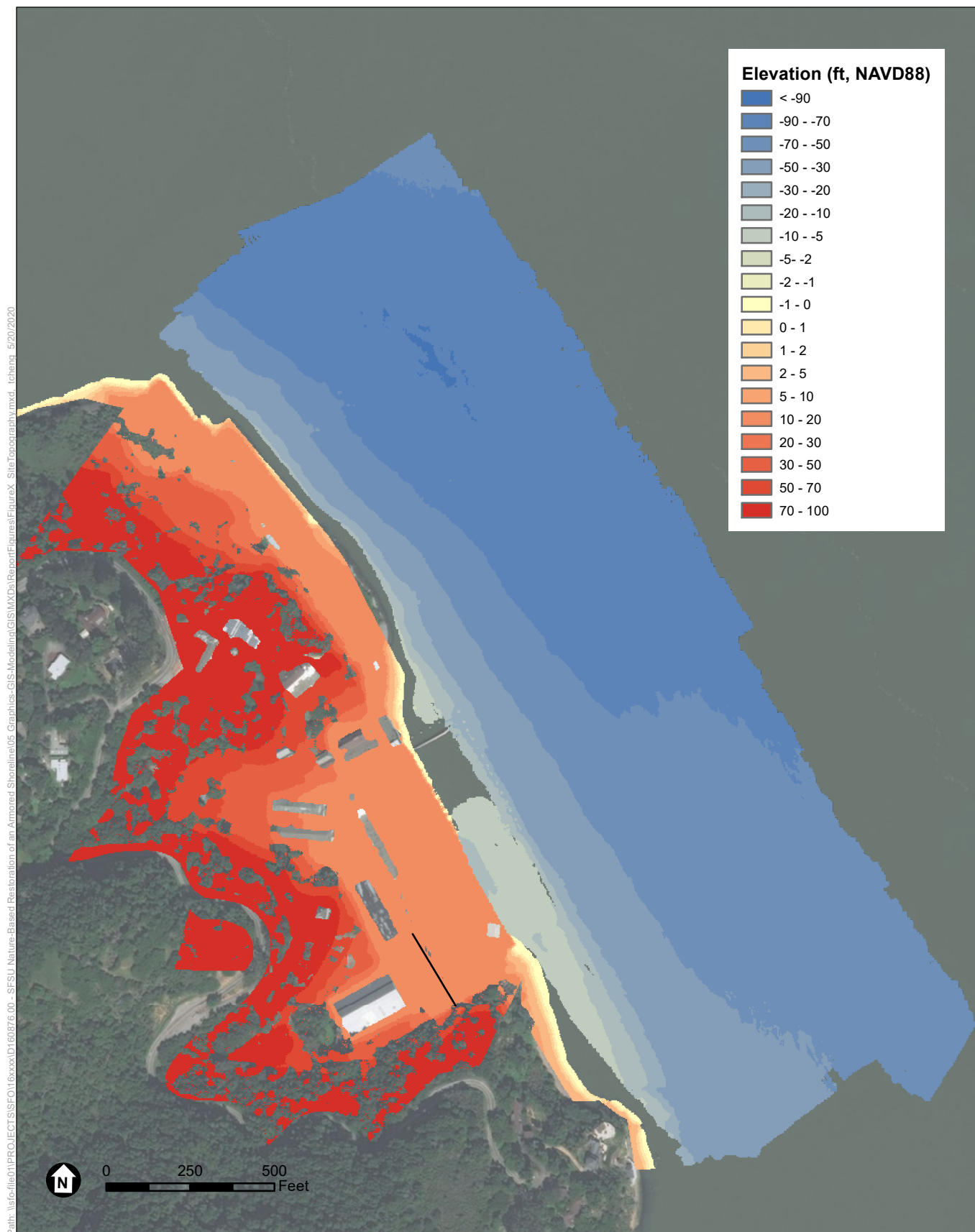
View of Caissons Offshore from Slab



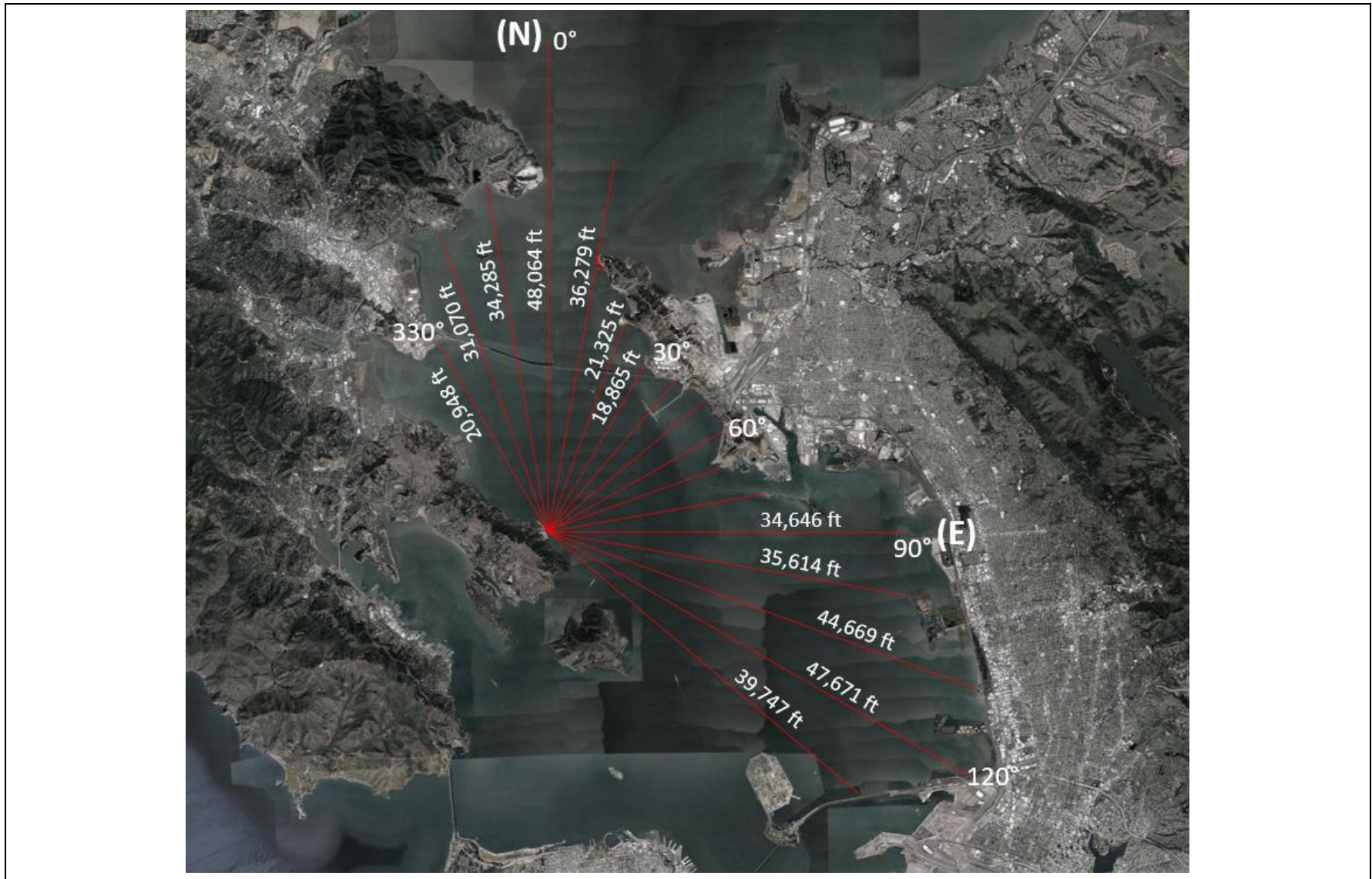
Existing Seawall with Rubble and Creosote Pilings Offshore



Backfilled area behind seawall, looking NE



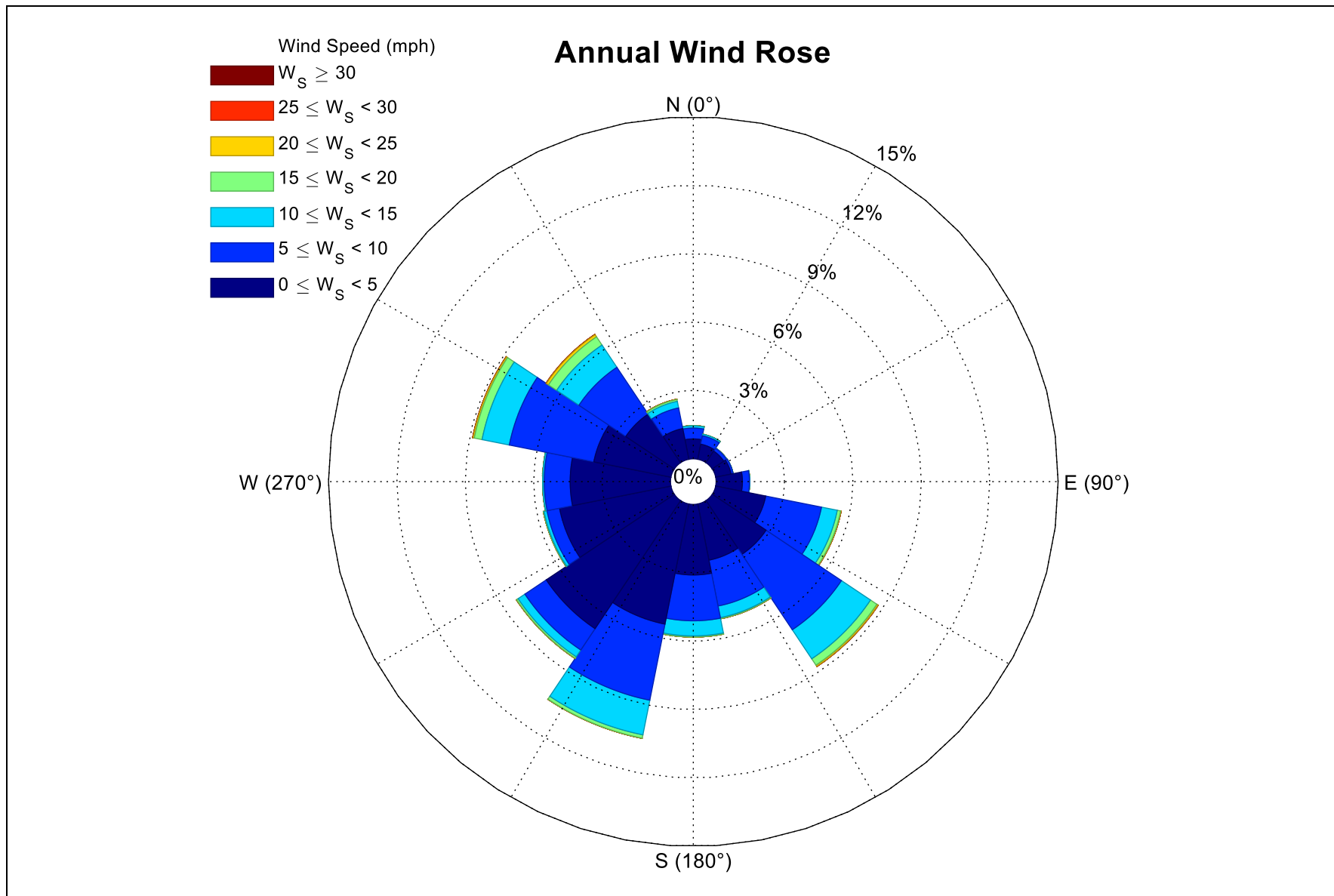
D160876.00 Nature-Based Restoration of Armored Shoreline at EOS Romberg Tiburon Center
 SOURCE: ESRI (2019), San Francisco Bay Area Lidar (2010), California State University Monterey Bay (2005)

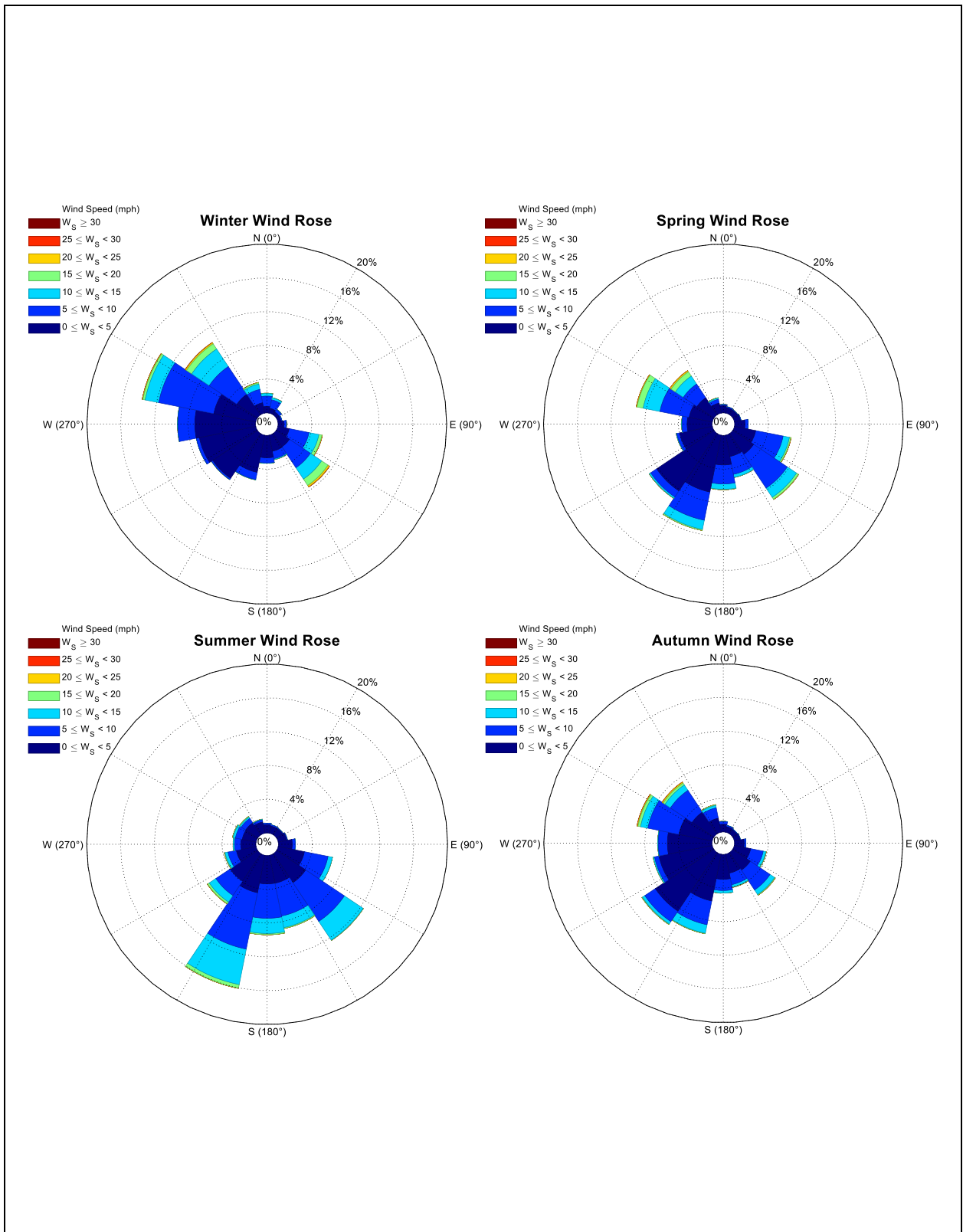


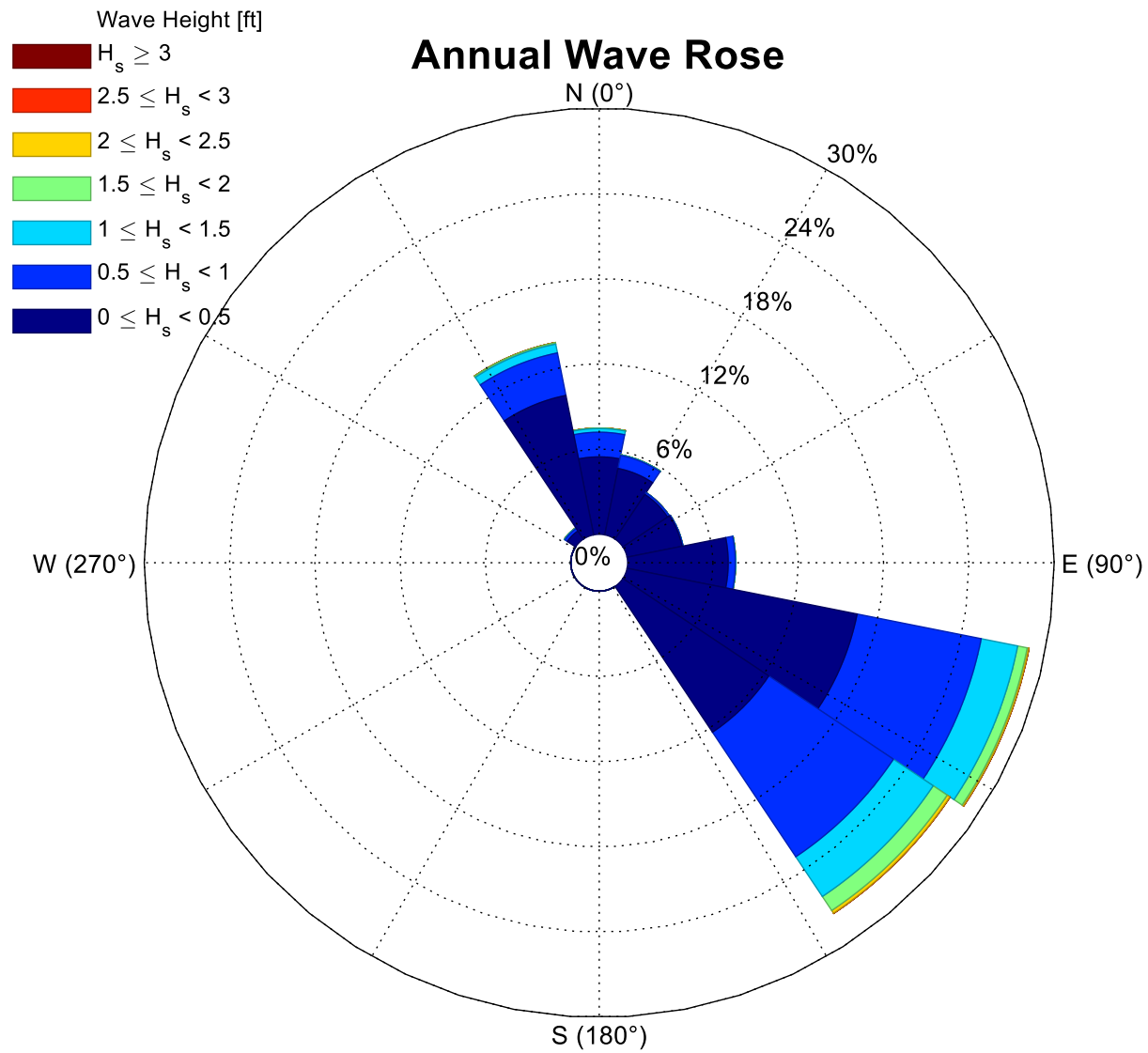
SOURCE: ESA (2019)

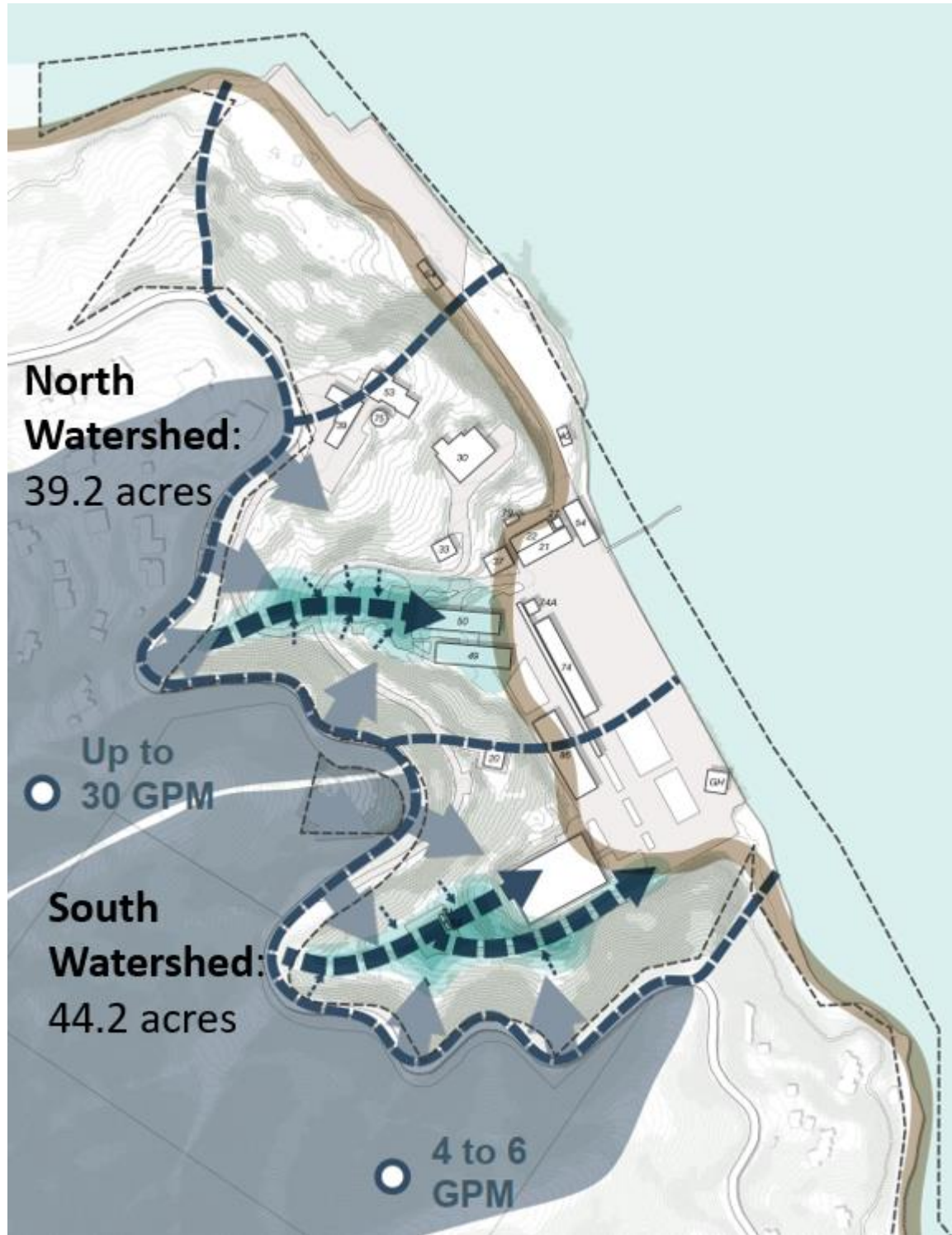
SFSU Nature-Based Restoration of an Armored Shoreline. D160876.00

Figure 8
Wind Fetch Across Compass Directions





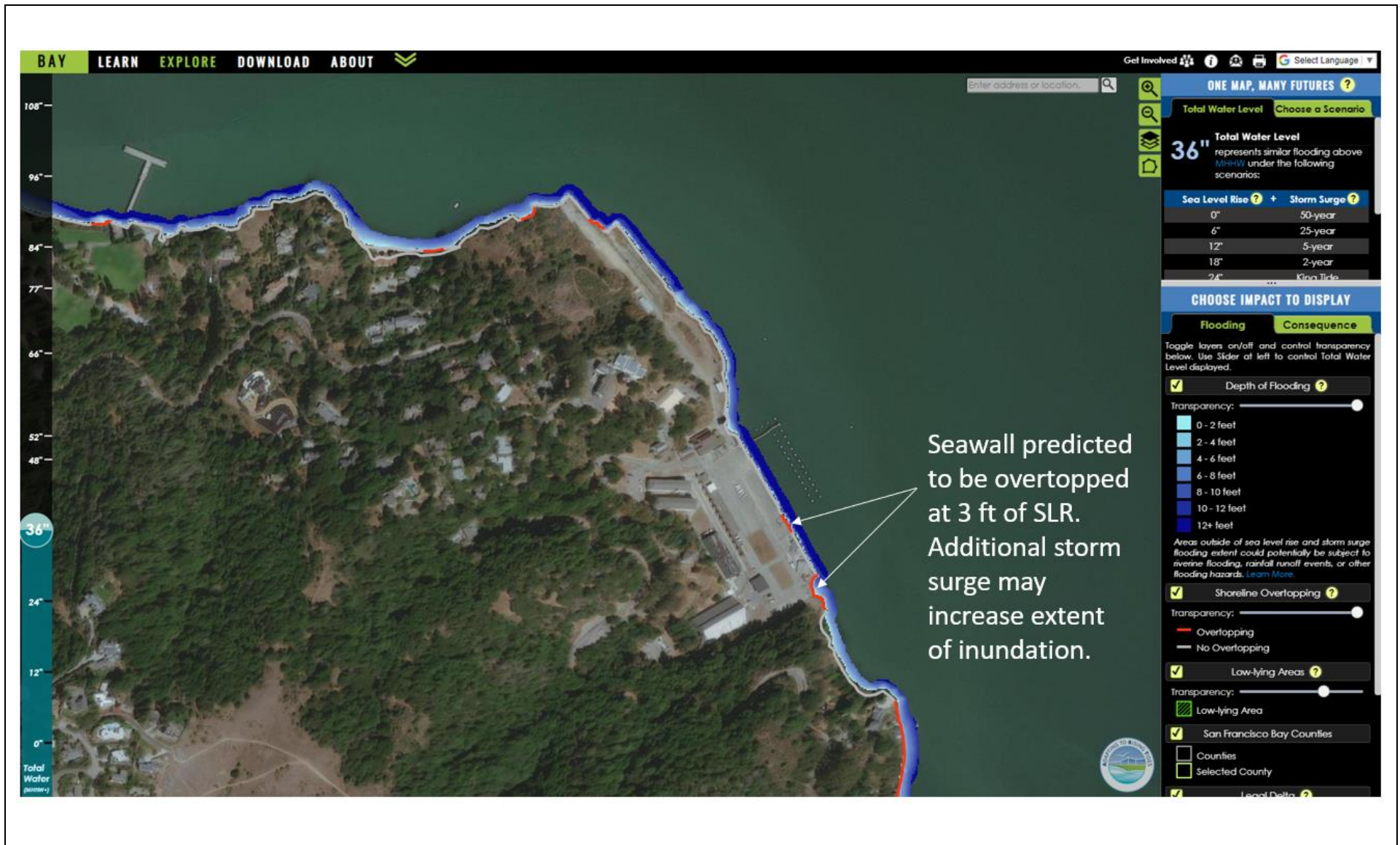




SFSU Nature-Based Restoration of an Armored Shoreline. D160876.00

SOURCE: Sherwood Engineers (2019)

Figure 12
Watershed & Drainage Paths on Campus



SOURCE: Adapting to Rising Tides (2019)

SFSU Nature-Based Restoration of an Armored Shoreline. D160876.00

Figure 13
Overtopping of Central Reach Seawall
3 ft of SLR



SOURCE: PAGE (undated)

SFSU Nature-Based Restoration of an Armored Shoreline. D160876.00

Figure 14
Romberg-Tiburon Center Master Plan
Draft Preferred Plan

Campus Master Plan

Retreat and “hold the line” at existing gantry structure.

Delta Hall to be decommissioned by mid-century; Regular overtopping of seawall along both Central and South Reaches with sea level rise (+3' estimate from H++ scenario, OPC 2018) and storm surge*.

Maintain university operations on slab

Present Day

Medium-term

2030

Near-term

Consider north watershed reconnection, if Bayside Theater is moved



Remove slab to allow for retreat. Potential for seawall terracing.



Expansion of South Reach coarse-grained beach restoration into Central Reach. Potential reconnection of North Watershed to Bay.



Future campus master planning effort to determine space usage in Central Reach



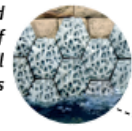
Design and implementation of new boat access system and floating breakwater and dock.



Southern watershed reconnection and coarse-grained beach restoration for South Reach



Design and implementation of living seawall enhancements



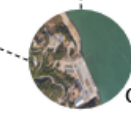
Improvements to existing Boat launch



Removal of defunct water treatment plant



Baseline Conditions



+3'

Sea Level Rise

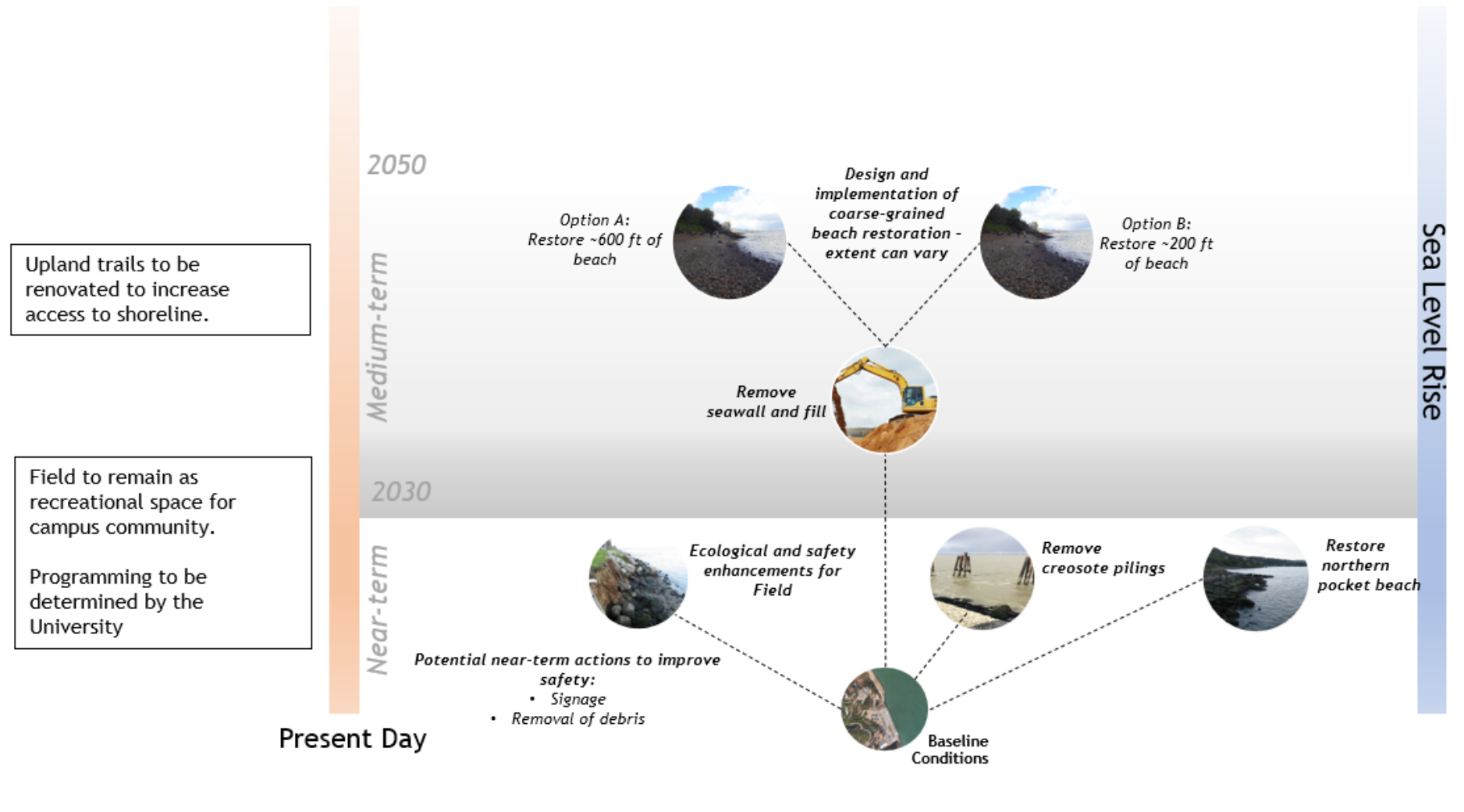
*Based on flood extents provided by Adapting to Rising Tides (ART) and Our Coast Our Future (OCOF) for site

SFSU Nature-Based Restoration of an Armored Shoreline. D160876.00

SOURCE: ESA (2019)

Figure 15
Shoreline Adaptation Pathways
South and Central Reaches

Campus Master Plan



SOURCE: ESA (2019)

SFSU Nature-Based Restoration of an Armored Shoreline. D160876.00

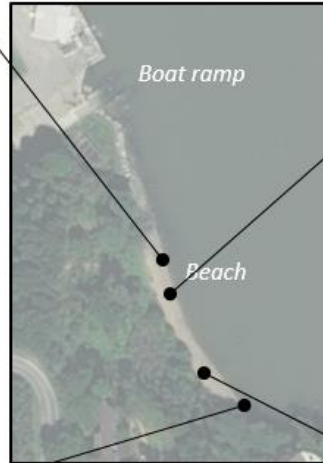
Figure 16
Shoreline Adaptation Pathways
North Reach



North end of beach
populated by coarse grain
sand and pebbles



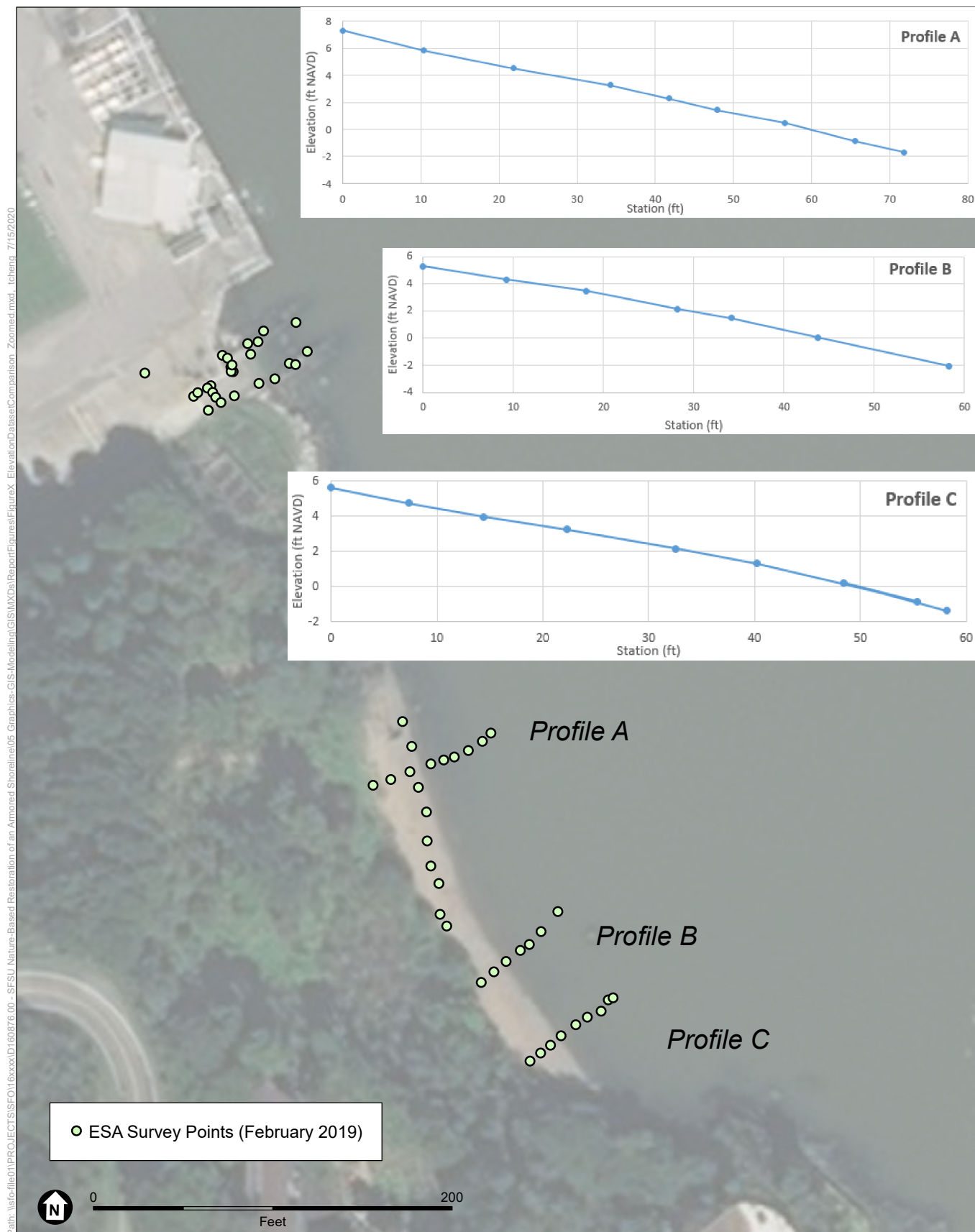
Rocky substrate
providing habitat
area for aquatic
species



Middle of beach intermediate
in sediment size



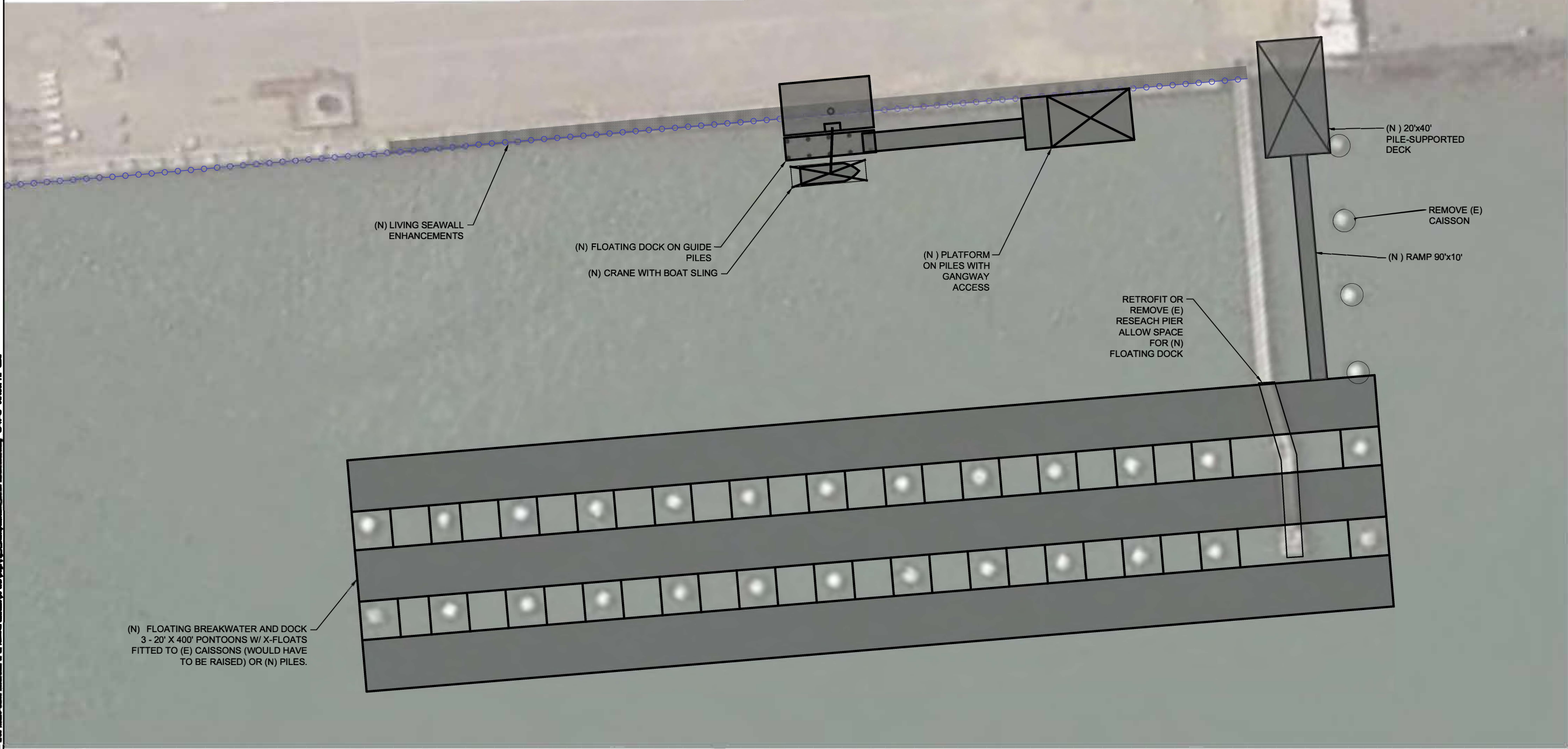
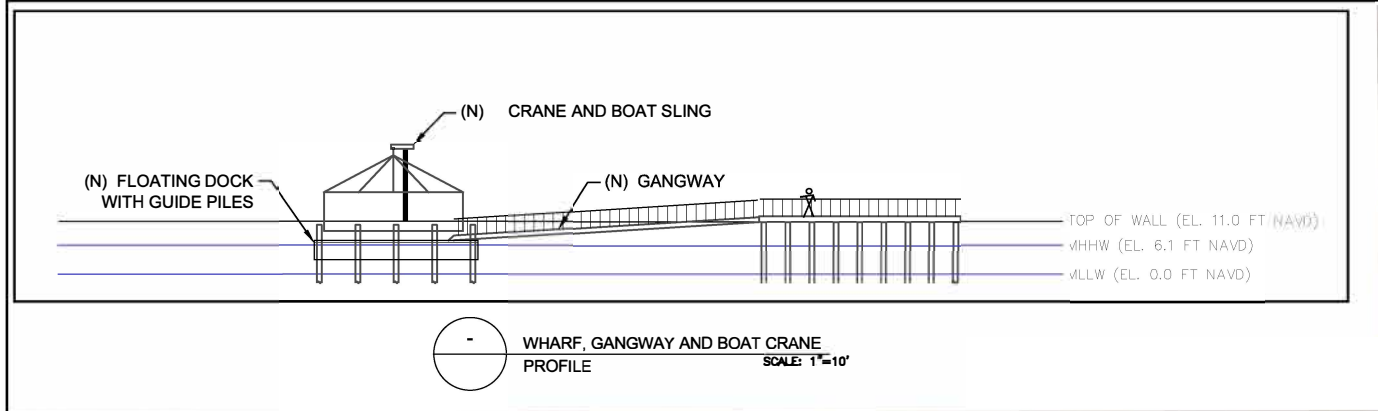
South end of
beach populated
by cobble



SOURCE: ESA Survey (2019), ESRI (2019)

San Francisco State University Nature-Based Restoration of Armored Shoreline

Figure 18
Survey Locations and Profiles



**CONCEPTUAL
NOT FOR CONSTRUCTION**



PREPARED BY:

ESA

Environmental Science Associates
1000 California Street, Suite 100
San Francisco, CA 94109
(415) 774-2000

SHEET TITLE

**CENTRAL REACH: LIVING SEAWALL
ENHANCEMENTS AND PIER
IMPROVEMENTS**

**SFSU NATURE-BASED RESTORATION
OF AN ARMORED SHORELINE**

PREPARED FOR:

SAN FRANCISCO STATE UNIVERSITY
ROMBERG TIBURON CAMPUS
3150 PARADISE DR.
TIBURON CA 94920

APPROVED

DESIGNED B. BATTALIO

DRAWN AMF

INCHARGE B. BATTALIO
CXXXXX

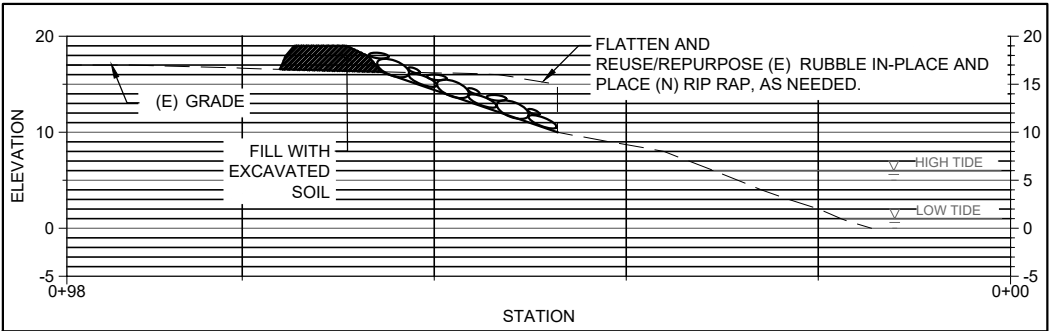
SCALE AS NOTED

DATE 12/1/2019

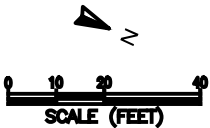
SHEET

3
3 OF 5

\\sfsu\gsf\projects\2019\20190525_05 - 2019 Water-based Protection of an Armored Shoreline\20190525_05.dwg 12/11/19 09:02:01 PM 1440



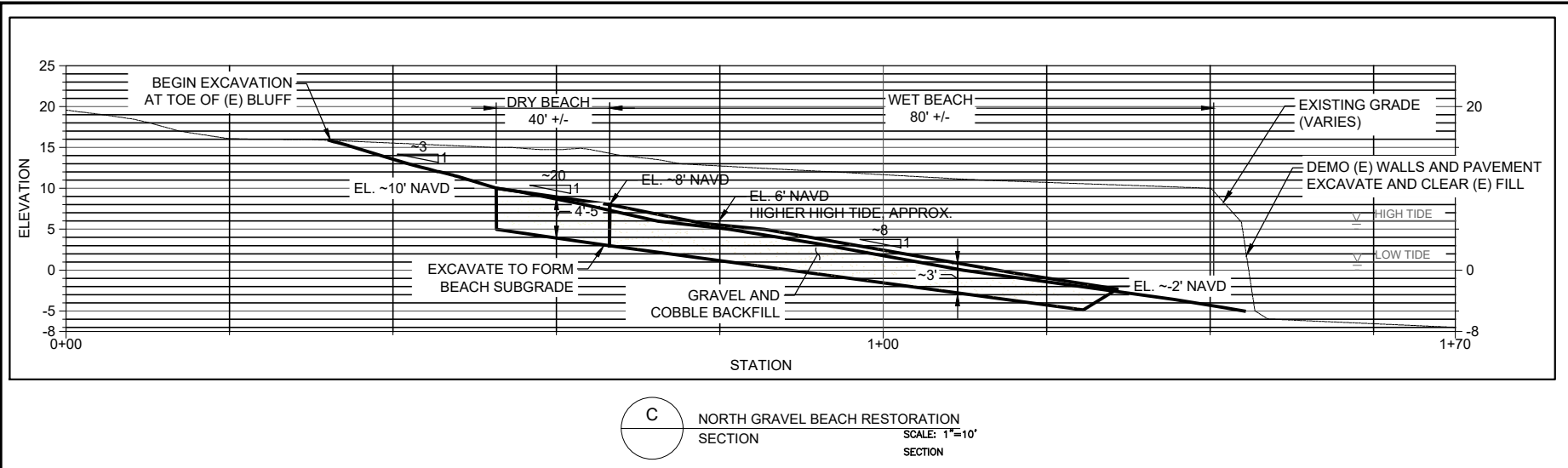
B ROCK REVETMENT SHORELINE SECTION
SECTION SCALE: 1"=10'



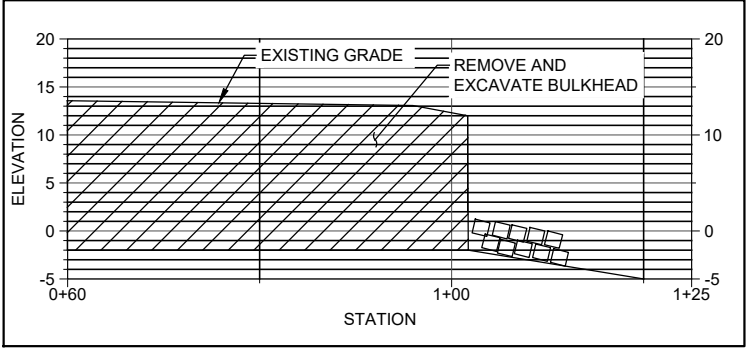
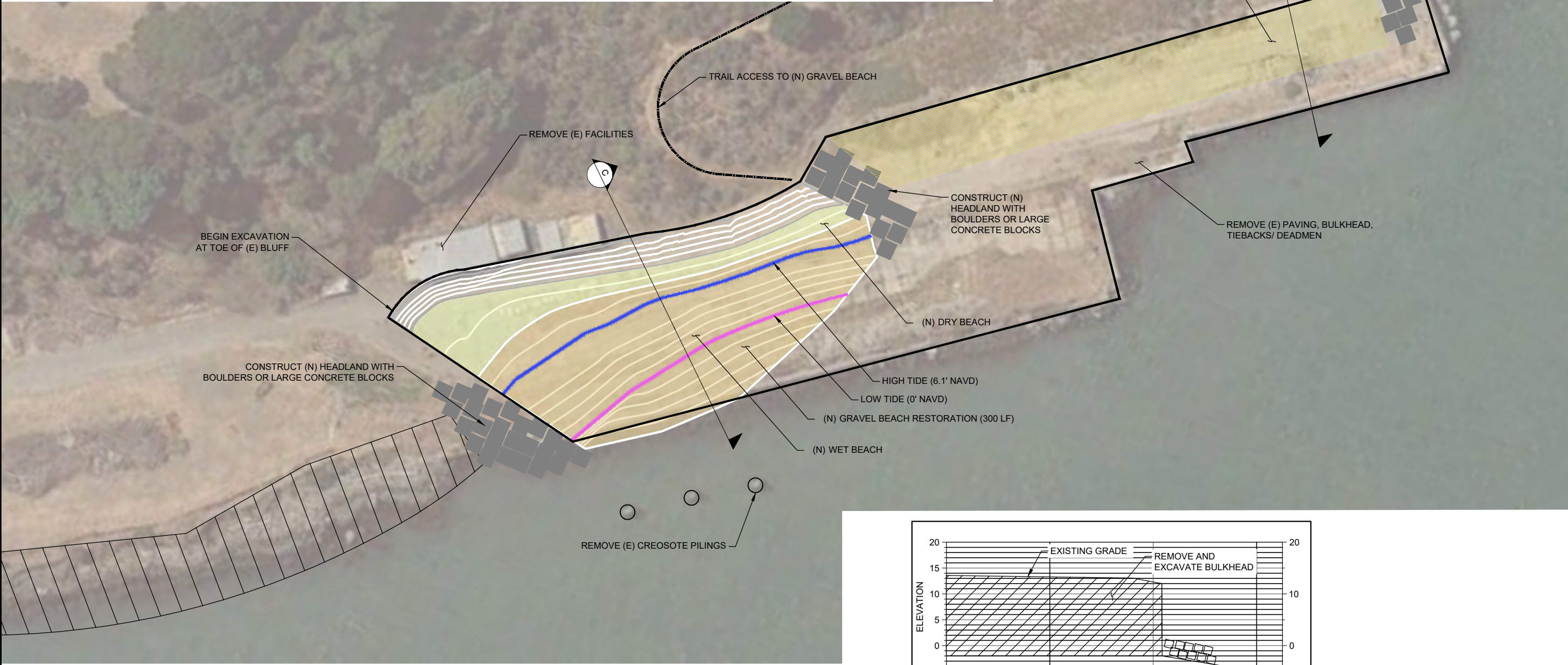
**CONCEPTUAL
NOT FOR CONSTRUCTION**



PREPARED BY:		 ESA 100 Montgomery Street San Francisco, CA 94102 (415) 261-2000	
SHEET TITLE	PROJECT	NORTH REACH A: RECREATIONAL SHORELINE PROTECTION	
		SFSU NATURE-BASED RESTORATION OF AN ARMORED SHORELINE	
PREPARED FOR:		SAN FRANCISCO STATE UNIVERSITY ROMBERG TIBURON CAMPUS PARADISE DR TIBURON CA	
APPROVED			
DESIGNED		B. BATTALIO	
DRAWN		AMF	
INCHARGE		B. BATTALIO CXXXXX	
SCALE		AS NOTED	
DATE		12/11/2019	
SHEET		4 OF 5	

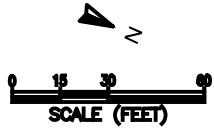
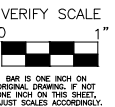


C NORTH GRAVEL BEACH RESTORATION SECTION SCALE: 1"=10' SECTION



D BULKHEAD REMOVAL SECTION SCALE: 1"=10'

CONCEPTUAL NOT FOR CONSTRUCTION



PREPARED BY:	 1000 University Street San Francisco, CA 94108 415.774.2000	
	SHEET TITLE	
PREPARED FOR:	NORTH REACH B: NORTH GRAVEL BEACH RESTORATION	
	PROJECT	
APPROVED	SAN FRANCISCO STATE UNIVERSITY ROMBERG TIBURON CAMPUS PARADISE DR TIBURON CA	
	DESIGNED	
DESIGNED	B. BATTALIO	
	DRAWN	
DRAWN	AMF	
	INCHARGE	
INCHARGE	B. BATTALIO CXXXXX	
	SCALE	
SCALE	AS NOTED	
	DATE	
DATE	12/11/2019	
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5		5
5 OF		