TOMALES BAY LIVING SHORELINES FEASIBILITY PROJECT

Feasibility Study Report

Prepared for
Marin County Community Development Agency

January 2022

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EXECUTIVE SUMMARY

Tomales Bay is a narrow, 13-mile long estuarine embayment in Marin County, whose shoreline includes relatively undisturbed national seashore, state and county parks, important transportation corridors, and both historical and modern development. The shoreline has evolved significantly over the last several centuries, both in response to natural processes and human interventions. Today, both its ecological resources and human infrastructure along the shoreline are under threat of flooding and erosion from projected sea-level rise. This study examines the feasibility of living shoreline approaches for mitigating the vulnerability of the Tomales Bay shoreline to sea-level rise. This is a critical need because much of the hardened shoreline in place today (rock revetment, levees, railroad berms) have limited or no adaptability, interfere with natural sediment dynamics, and limit recreational uses (USACE 2003, Griggs 2005, Dugan 2008, Melius and Caldwell 2015). Undeveloped or protected (e.g. federal or state parks) parts of the shoreline (and their associated shoreline habitats) are also vulnerable. As sea-level rise progresses, hardened shorelines are likely to increase the difficulty of maintaining shore habitats for native species (e.g. SFEI and SPUR 2019).

This project builds on the C-SMART study developed by the County and its partners (Marin County 2016, 2018), which identified Tomales Bay's shoreline vulnerabilities and began stakeholder engagement. Using that foundational understanding of shoreline vulnerabilities to sea level rise, the current project team developed a series of 'living shoreline' adaptation measures specific to Tomales Bay. These include creek-to-bay reconnection, placement of rocky intertidal habitat features, native oyster restoration, submerged aquatic vegetation management, tidal flat restoration, tidal marsh restoration, and construction of beaches, dunes and rocky habitat appropriate to the Tomales Bay setting. These measures were developed based on a review of existing Tomales Bay habitats and shoreline features. For each proposed adaptation measure, the project team described the measure, ecosystem and flood protection services provided, and criteria for determining suitable locations for placement of specific adaptation measures along the shore. Despite the focus of this study on a small number of potential sites, these adaptation measures could be useful more broadly for future work.

The team identified 6 initial candidate sites within Tomales Bay. Sites were selected by creating a series of 'overlay maps' that compared existing site conditions, future flooding conditions with sea-level rise, and potentially suitable locations for adaptation measures. These 6 sites were evaluated further based on criteria that included future flooding and erosion risks, expected ecological benefits, public access and recreation benefits, longevity of benefits, and cost and implementation considerations. Staff from the permitting agencies were consulted and provided further input.

Based on the results of the evaluation process, the County selected two sites for design development: Cypress Grove on Tomales Bay's eastern shore, and Martinelli Park on Tomales

Bay's western shore. The project team developed conceptual designs for both sites. The intent is that, following detailed design and permitting, these projects would be constructed to serve as pilot studies, to be monitored for effectiveness over time, with the opportunity to draw from these to help inform future adaptations elsewhere within Tomales Bay.

At the proposed Cypress Grove project site, the key vulnerability is the potential for coastal flooding. This has been exacerbated in recent years as a remnant boat channel fronted by an eroding beach has become the main pathway for high coastal water levels and wave overtopping to flood the site. Natural sediment transport processes that maintain the beach that currently fronts the channel and protects the site have been disrupted over more than a century of shoreline modifications in the area. The proposed project seeks to restore natural sediment transport processes, restore and preserve the beach complex that has historically protected the site, and improve upland (dune and backshore) habitats through revegetation. The beach restoration would work in concert with offshore native oyster restoration, which would act to stabilize the new shoreline and integrate with large woody debris features that would retain sediment and enhance shoreline habitats. The project is expected to cost $1,260,000 to $2,700,000 and provide added protection to the site for up to 1.6 feet (50 cm) of sea-level rise. Beyond this point, the project would likely need to include additional adaptive measures to be successful, such as relocation or raising of the existing buildings.

At the proposed Martinelli Park project site, the key vulnerability is the low point in Sir Francis Drake Blvd adjacent to the site, which creates a flooding hazard that affects local businesses and the emergency evacuation route for most of Inverness Park and Seahaven. The road is protected by an un-engineered earthen berm, which is already vulnerable to flooding under existing conditions. In addition, First Valley Creek poses a flood risk from high rainfall events, which when paired with sea-level rise will create an increasing risk of roadway overtopping in the future. The project at this site seeks to reduce flood risk by setting back and raising the earthen embankment and by restoring natural sediment transport processes. To restore natural processes, a remnant constructed berm along the seaward portion of the creek would be lowered, reconnecting the creek with its marsh delta. Flooding on the creek would be mitigated by periodic removal of sediment and invasive plants, and potential enlargement of the creek crossing in anticipation of sea-level rise. Excavated material from this work would be placed in front of the marsh on the southern end of the site in the location of a historic beach, to encourage marsh growth in front of the earth embankment. The project is expected to cost $672,000 to $1,440,000, which is significantly lower than the expected cost of future roadway maintenance with sea-level rise by 2030. The cost assumes creek maintenance occurs on a five-year cycle as part of the project. The project is expected to provided additional protection to the site for up to 50 cm (1.6 feet) of sea-level rise. For higher amounts of sea-level rise, the project would need to be paired with work to raise Sir Francis Drake Blvd at its lowest point and expand the creek crossing to facilitate sediment discharge.

Ultimately, we found that both the Cypress Grove and Martinelli Park sites are likely feasible for protecting backshore development with living shorelines approaches which also provide ecological benefits and resilience within moderate ranges of sea-level rise, and warrant further study. In both cases, the conceptual designs we developed are expected to limit flooding for approximately 1-2 feet of sea-level rise (relative to the no-project scenario). This would preserve or enhance existing shoreline habitats while buying critical time for the County to plan for flood improvements landward of the shoreline. This study is the first phase in a potentially longer project, and recommended next steps are also provided in Section 7. These include further study of the flood potential on First Valley Creek, study of the potential for beneficial reuse of material generated from culvert maintenance in the bay, future work to characterize local tides inside the bay, and a bay-wide study of eelgrass adaptation.

CHAPTER 1
Introduction

Sea-level rise poses a significant threat to the long-term safety and livelihoods of the residents of western Marin County (West Marin), and to the long-term fate of its unique intertidal and shoreline habitats. Tomales Bay is under particular threat because of its setting: a small number of residents rely on nearly 20 miles of shoreline highways and roads for daily travel and emergency evacuation, much of which is directly threated by rising tide levels, storm surges, and wind-waves. At the same time, fragile ecosystems along the bay shoreline that have survived and adjusted to over 150 years of land-use changes and development are caught between rising sea-levels, altered sediment transport patterns, and a hard shoreline in most locations that prevents landward migration.

1.1 Project Background

The Planning Division of the Marin County Community Development Agency (CDA) initiated this project, with funding provided by the California Climate Investments program for the State Coastal Conservancy's (SCC) Climate Ready Grants Program. This study is a continuation of over a decade of planning work for sea-level rise adaptation conducted by the County and partner agencies, most recently culminating in the Collaboration: Sea-Level Marin Adaptation Response Team (C-SMART) studies.

The recently completed C-SMART study included a sea-level rise vulnerability assessment (Marin County 2016), and the Marin Ocean Coast Sea Level Rise Adaptation Report (Marin County 2018), which evaluates potential adaptation solutions for West Marin considering costs and co-benefits. This report was developed in collaboration with local stakeholders, who identified their concerns and priorities, and helped to develop ideas for adaptation. Priority actions in the report included exploring the feasibility of a number of nature-based approaches in Tomales Bay. In assessing the feasibility of these actions, and developing a series of pilot projects with conceptual designs, this project further advances living shorelines in Marin County.

As part of the C-SMART study, the County and its residents have expressed a strong desire to pursue nature-based solutions as an alternative to traditional measures such as coastal armoring. Given Marin County's wealth of protected open space and natural resources, and supportive constituency, there is strong support for identifying adaptation pathways that preserve both the built environment and also sensitive shoreline habitats and public access.

1.2 Need for the Project

Much of the urgency for sea-level rise planning in Tomales Bay stems from its vulnerability under existing conditions. Severe coastal storms in the winters of 1982, 1983, and 2006 brought abnormally high ocean levels that coincided with heavy rainfall, causing widespread flooding of shoreline properties and coastal roads (Inverness Ridge Communities Planning Group 1983). Portions of Inverness Park continue to experience flooding when high tides coincide with high rainfall (pers. Comm. J. Fox). Flooding of shoreline properties is also already observed during annual king tides[1], especially when king tides coincide with high winds, allowing wave runup to contribute to the high tide level on the shoreline. In the midst of this threat, Tomales Bay is also host to a number of sensitive species including the Olympia oyster (*Ostrea lurida*) and federally-listed threatened species such as steelhead trout (*Oncorynchus mykiss*), whose intertidal and subtidal habitats are linked to the shoreline.

Nature-based, or living shoreline, approaches provide shoreline protection services (long-term mitigation of shoreline erosion and lowering of coastal water levels) while at the same time enhancing and protecting existing habitats and providing co-benefits such as sequestering carbon. This project provides an opportunity to explore whether these approaches could be feasible for shoreline protection in Tomales Bay, and can provide additional benefits such as enhancing recreational opportunities along the shoreline.

1.3 Project Team

The project team is a multidisciplinary group of experts in coastal engineering, sea-level rise planning, aquatic and terrestrial ecology, and permitting. The team was led by Environmental Science Associates (ESA) in partnership with the University of California, Davis, the Smithsonian Environmental Research Center, Merkel and Associates, Point Blue Conservation Science (Point Blue), and consultants Peter Baye and Brad Damitz.

1.4 Stakeholder and Public Outreach

A Stakeholder Advisory Committee (SAC) was formed at the beginning of the study, with representation from local stakeholders (home and business owners, NGOs, technical experts from the scientific community) and agency representatives from the National Park Service (NPS), Caltrans, California Regional Water Quality Control Board (RWQCB), California Coastal Commission (CCC), California Department of Fish and Wildlife (CDFW), U.S. Fish and Wildlife Service (USFWS), and the Greater Farallones National Marine Sanctuary (GFNMS). The SAC and Project Team met regularly through the study timeline to review and provide input on process, analyses and draft deliverables. Attachment A includes the full membership, affiliations and structure of the SAC.

Another review panel, the Coastal Communities Working Group (CCWG), also provided oversight for this and other West Marin projects, including the parallel Stinson Beach Nature-Based Adaptation Living Shorelines Feasibility Study. This body consists of locally nominated community members and provides broader oversight for the region.

[1] King Tides are especially high tides, typically occurring in California in winter months

1.5 Structure of the Report

This study generally follows the procedure illustrated in Figure 1. The prior C-SMART studies (Marin County 2016, 2018) set the foundation for this study by mapping areas of shoreline vulnerability to sea-level rise. This study (whose goal and objectives are outlined in **Section 2**), seeks to take the next step in the planning process, studying the specific feasibility of living shorelines as an adaptation approach.

Section 3 helps to set a baseline by documenting existing conditions and the expected future conditions with sea-level rise in Tomales Bay. **Section 4** documents the development of a series of living shoreline adaptation measures that are specific to Tomales Bay. **Section 5** discusses the development of a series of overlay maps that identify areas of interest to the study, and covers the process for developing initial candidate sites and selection of the final two priority sites. **Section 6** summarizes the conceptual designs for the priority sites and discusses their feasibility. Lastly, **Section 7** outlines recommendations for next steps.

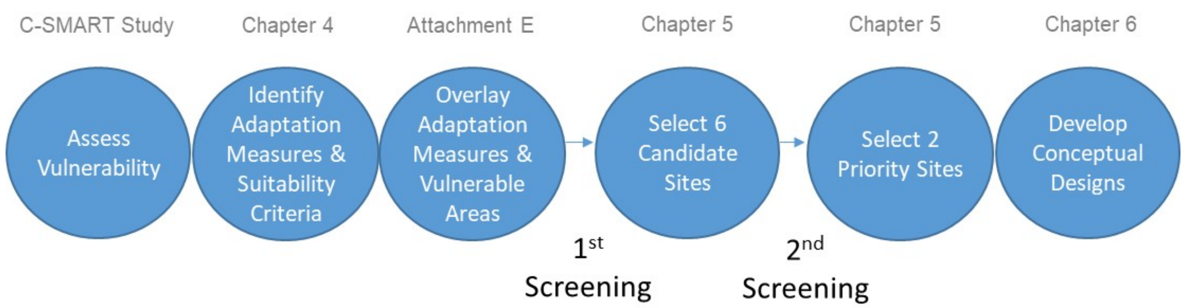

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Figure 1
Process for developing living shorelines conceptual designs for this study (and corresponding report section)

CHAPTER 2
Project Goals and Objectives

The CDA developed project goals and objectives with input from the community-based planning process. The area of study includes the eastern shore of Tomales Bay from Toms Point in the north to Bivalve in the south, and the western shore from the Highway One crossing of Lagunitas Creek to Seahaven (Figure 2).

2.1 Goal

The goal of the Project is to evaluate the feasibility of nature-based adaptations to protect the Tomales Bay shoreline from erosion and flooding as an alternative to traditional engineered methods (e.g. coastal armoring).

2.2 Objectives

Specific objectives within the overarching goal, as defined by CDA, are:

- Provide flood and erosion protection to built and natural resources against future sea-level rise,
- Maintain public access,
- Support vibrant recreational opportunities for users of all socioeconomic circumstances,
- Develop preliminary designs for shortlisted pilot projects, identified from a suite of candidate sites
- Extend living shoreline applicability for Tomales Bay by identifying feasible opportunities for living shorelines approaches.

CHAPTER 3
Existing Site Conditions and Projected Sea-Level Rise

This section discusses existing conditions and broad patterns within Tomales Bay, and introduces regional sea-level rise curves. Since vulnerability of the Tomales Bay shoreline was covered extensively as part of the C-SMART study and numerous smaller studies, this section is not intended to be exhaustive, but to provide the larger context for the project sites (Section 6), which go into greater detail at the site scale.

3.1 Site Conditions

Tomales Bay is a roughly 13-mile-long tidal estuary located in western Marin County, California, about 30 miles northwest of the Golden Gate (Figure 2). The bay lies within a rift valley of the San Andreas Fault between the Point Reyes Peninsula and the California mainland. Its geological setting has given the bay an elongated shape (the average width is less than 1 mile), which has implications for the hydrology, geomorphology, ecology, and in how humans have historically interacted with the bay and its shoreline. The bay has a total watershed area of about 220 square miles (LMER 1992), with many freshwater creeks dotting the shorelines. Oceanic tides and coastal upwelling dominate the hydrology and circulation, with an average depth of less than 20 ft (Largier et al. 1997); as a result, average characteristics of bay waters (e.g. tidal amplitude, residence time, temperature, salinity) vary along the length of the bay (Kimbro et al. 2009). The bay is host to a range of intertidal habitats, including fringing tidal marshes, extensive tidal flats and eelgrass (*Zostera marina)* beds, and a number of aquatic and terrestrial species, including sensitive and federally listed threatened species.

Much of the bay waters and shoreline are protected: the estuary is part of the Greater Farallones National Marine Sanctuary (GFNMS) and the Golden Gate Biosphere Reserve. Shoreline ownership is a mix of legacy private (residential and commercial) and public (state and county parks and wildlife sanctuaries) properties.

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Figure 2
Tomales Bay location

3.1.1 Historic Changes

The history of human interactions with the bay is complex, and the present-day shoreline bears the signs of both natural landscape processes and the cumulative effects of many human actions from the past several centuries (Munro-Fraser 1880; Niemi and Hall 1996; Avery 2006). The site was long inhabited by the local Coastal Miwok tribes before subsequent discovery by Mexican settlers and eventual large-scale development by the mid-nineteenth century (Milliken 2009). Development of the area increased in parallel with the growth of San Francisco. Since the mid-nineteenth century, some of the main human activities influencing the long term evolution of the shoreline have included:

- **Hardening of the shoreline:** On the eastern shoreline, the railroad berm was completed in 1874, creating a hardened shoreline that cut off tidal access to a number of small embayments. On both shorelines, breakwaters and piers were constructed to maintain boat access to deep water (Avery 2006).

- **Land-use changes:** Above the shoreline, logging in the hillslopes of the western Tomales Bay watersheds and extensive cattle grazing in the hills above within the eastern watersheds encouraged hillslope erosion and delivery of sediments to creek systems (Niemi and Hall 1996; Rooney and Smith 1999). This was also the case within the larger Walker Creek and Lagunitas Creek watersheds.

- **Long-term sedimentation:** As a response to land-use changes, creeks began to pass a larger amount of sediment to bay waters, causing mudflats to widen over time along the developed parts of the shoreline. This is apparent from early twentieth century photographs showing the extension of piers and docks, to maintain boat access to deep water (Avery 2006). On the eastern shore, sediment trapping on the landward side of the railroad berm converted tidal flat areas to brackish and saline marsh (Tomales Bay Watershed Council 2003).

Long-term changes have had a major impact on the morphology of the shoreline, and the resulting flood risk to coastal communities, and existing shoreline habitats (Marin County 2016, 2018).

3.1.2 Geomorphology

Geology of the western and eastern shorelines

Because of its unique setting, the geology of Tomales Bay is well studied. The San Andreas Fault zone marks the boundary between the North American tectonic plate to the east and the Pacific plate to the west (Graymer et al. 2006). Hence, the rock types are different on either side of Tomales Bay. On its east side the rocks are composed of a Cretaceous mélange of sheared sandstones and shales of the Franciscan Formation (Graymer et al. 2006). On its west shore the rocks are mainly granitic (Salinian Block, Cretaceous period), with intermittent metamorphic rocks (gneiss, schist, and marble of Cretaceous and older origin).

Long-term shoreline change

The shoreline of the bay is highly modified from its original state. A number of major step changes occurred over the last few centuries that caused dramatic shifts in sediment supply to the bay. Although it shows signs of adjustment, the shoreline is not fixed in location, and its continued movement poses an erosion risk for developed areas. Information on shoreline change was gathered from earlier studies and review of aerial images to illustrate these step changes:

- Major land-use changes occurred in the late 1800s and early 1900s in the watersheds. Much of the hillsides on the eastern shore were converted to cattle grazing, and the western shore was heavily logged prior to the 1930s. Both activities exposed soil to more frequent erosion, enhancing the sediment transport toward Tomales Bay.

- The construction of a railroad on the east side of the bay in the 1870s. Much of the railroad had been constructed at the bay's edge or on existing mudflats, effectively trapping sediment inland of the railroad berm (e.g. Etienne 2001). Over time, sediment delivered by small creeks on the eastern shore accumulated, forming significant freshwater marsh communities. The disused railroad berm has been breached in front of most of these marshes, allowing tidal exchange to the bay.

- On both the western and eastern shores, enhanced sediment transport, due to the land use changes in the watersheds, raised and expanded creek deltas on the bay. By the early 1900s, sedimentation on the western shoreline was already extensive (Figure 3), forcing local businesses to continually lengthen their docks into the bay to maintain access to deep water (Tomales Bay Watershed Council 2003). Both Walker Creek and Lagunitas Creek deltas appear to have historically expanded into the bay in the long-term (Rooney and Smith 1999).

- Most of the enhanced sediment delivery from the watersheds was borne out by the 1950s (Rooney and Smith 1999),

- A number of reservoirs were constructed from the 1870s through the 1960s, and currently trap a portion of the sediment that would normally be delivered to the bay.

- Despite signs that the system is adjusting to long-term changes due to the step changes in sediment supply, major storm events can still create significant change to the shoreline. For example, mudslides during the January 1982 flood event are associated with at least 1 foot of shoreline accretion in some areas (Anima et al. 1988; Tomales Bay Watershed Council 2003). More recent changes are also visible from recent aerial images, including slumping after 2015 at Millerton Point.

The principal ecological effects of shoreline development (hardening) and ongoing land management activities on intertidal and shallow water habitats fringing Tomales Bay include physical displacement of biota, exacerbation or cessation of shoreline erosion, and interruption of sediment supply and delivery from the Bay's contributing watersheds. These factors have the combined effect of truncating the shoreline gradient, steepening the transition at the land-sea interface along the bay margin, and changing the pattern of erosion and accretion along the shoreline. In places where the historical railroad on the eastern shoreline cut off embayments from the rest of the bay, the shoreline has steepened over time (Rooney and Smith 1999). In addition to constraints imposed by the presence of existing shoreline infrastructure, the relatively steep hillslope topography that characterizes both the western and eastern shorelines of the bay further impose limits on the capacity for shoreline transgression of habitats in response to rising sea level. This paradigm creates key challenges in the design and configuration of living shoreline strategies, particularly along the more developed eastern shore of the bay.

Source: Avery 2006

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Figure 3
Historical development of the western shoreline of Tomales Bay in the early 1900s

3.1.3 Hydrology

This section discusses the hydrology of Tomales Bay, including coastal hydrology (tides, wind waves, and storm surge), fluvial inputs, and causes of flooding.

Tides, Water Levels, and Datums

Tomales Bay experiences mixed semidiurnal tides, with two high and two low tides of unequal heights each day. In addition, the tides exhibit a strong spring-neap variability; spring tides exhibit the greatest difference between high and low tides while neap tides show a smaller than average range (PWA 2007). The interval between spring and neap periods is roughly two weeks, and peak spring tides tend to occur in the winter months (leading to so-called ‘king tide’ events). Table 1 shows the local tidal datums at Point Reyes and Inverness Park. Tidal datums are also approximated at Cypress Grove based on temporary NOAA tide stations. Cypress Grove is a useful reference point as it is roughly the halfway point of the bay.

Tides vary along the length of Tomales Bay, and can differ significantly from the oceanic tides measured by NOAA at Point Reyes[2]. Tides at the mouth of the bay are smaller than ocean tides, but these amplify along the length of the bay; The long-term average tide range (measured between MHHW and MLLW) at Point Reyes is about 5.8 feet, compared with 5.2 feet at Sand Point inside the mouth of Tomales Bay, 5.4 feet at Reynolds (8 miles upstream of the mouth), and 5.7 feet at Inverness Park (10 miles upstream from the mouth).

TABLE 1
TIDAL DATUMS AND WATER SURFACE ELEVATIONS (ABOVE NAVD88)

Event/Datum	Pt Reyes[1]	Cypress Grove[2]	Inverness[3]
Highest Astronomical Tide ("HAT")	7.5	--	--
Mean Higher High Water ("MHHW")	5.8	5.9	5.8
Mean High Water ("MHW")	5.1	5.2	5.1
Mean Tide Level ("MTL")	3.1	3.1	3.2
Mean Sea Level ("MSL")	3.1	3.1	3.1
Mean Low Water ("MLW")	1.2	1.1	1.2
Mean Lower Low Water ("MLLW")	0.0	-0.1	0.2
NAVD88	0.0	0.0	0.0

SOURCES: 1NOAA Pt Reyes Gauge ID 9415020; 2Estimated by assuming MSL is same at Cypress Grove and Inverness, and pro-rating tidal datums between the NOAA Reynolds and Sand Pt datum stations 3 NOAA Inverness Datum Site ID 9415228;

Wind and Wave Climate

Most of our understanding of the local wind climate is based on the long-term wind record at the Hog Island buoy operated by the Bodega Ocean Observing Node[3], and the nearby wind sensor at Bodega Head, which has measured winds since 1978. Several other privately-owned wind sensors are also available throughout the bay. Winds in Tomales Bay are heavily influenced by the shape of the bay; the strongest winds arrive from the northwest, but strong winds are sometimes also observed from the southeast, and from the west (coastal winds passing over the ridge tops of Point Reyes National Seashore).

Locally generated wind-waves are dominant in Tomales Bay. The dominant wind direction is along the axis of the bay, with the majority of the winds arriving from the northwest. Storm events can lead to a reversal, with winds arriving from the south or southeast. Coastal swell waves also enter the bay through its mouth, but these are largely dissipated by Pelican Point and Hog Island in the north. Wind-waves in the shallowest portions of the bay along the shoreline are depth-limited (meaning that the local shallow depths control wave height), but the length of the wind fetch is also a limiting condition, especially when winds do not align with the main axis of the bay. The Bay has a 13-mile fetch along its main axis, which allows formation of

2 https://tidesandcurrents.noaa.gov/stationhome.html?id=9415020
3 https://boon.ucdavis.edu/obs/offshore/tbb-buoy-sensor-info

1-3 foot wind-waves in most years that cause significant runup on shoreline structures and sand transport along the shoreline.

We assessed wind waves by reviewing data collected by the Bodega Marine Lab in recent years (see Attachment B), and by applying standard coastal engineering methods for fetch-limited waves (USACE 2003) We did not model wind waves for the entire bay, instead focusing on the specific project sites chosen for design (see Section 6). Our approach is summarized in Attachment C.

Salinity

Tomales Bay exhibits significant variations in salinity throughout the year, due largely to the varying strength of offshore coastal upwelling and freshwater flows (Niemi and Hall 1996; Largier et al. 1997; Tomales Bay Watershed Council 2003). Coastal upwelling tends to be strongest from April to September (coinciding with the period when freshwater input to the bay is low). Tidal flushing is strongest near the mouth of the bay and weakens with distance upstream. This leads to longer residence times and higher salinities near the head of the bay, which can be higher than oceanic salinity during the dry season due to evaporation and high residence time (Largier et al. 1997). This gradient (higher salinity upstream) is especially present in the dry season. If drought conditions become more prevalent in the future, long-term salinity data collected in the bay by the Bodega Marine Lab will be important to assess to understand multi-year changes. During the wetter months from November to May, freshwater inflow periodically reduces the bay's salinity through flushing, especially near the larger input points at Lagunitas and Walker Creeks. This sets up the more common estuarine gradient of salinity, with higher salinity near the mouth, decreasing with distance upstream.

Existing Creeks

Apart from the major perennial streams of Lagunitas Creek and Walker Creek, the shoreline of Tomales Bay is dotted with many small creeks that discharge freshwater and sediment to the bay. Though many of these are intermittent, they were the dominant pathway for excess sediment delivered to the bay in the nineteenth and twentieth centuries in response to major land-use changes (Rooney and Smith 1999). They are also often the location of intense flooding during heavy winter rainfall events. Creek deltas throughout the bay are an important source of the sediment budget for shoreline beaches.

GIS shapefiles for perennial streams were downloaded from the U.S. Geological Survey (USGS) National Hydrography Dataset website. Additionally, long-term gauged streamflow measurements are available from the USGS for Walker Creek (Site #11460750) east of Marshall and at Lagunitas Creek (Site #11460600) near Point Reyes Station. Otherwise, gauged inflows are intermittent, and information for flooding conditions was obtained from Streamstats (Ries et al. 2017), or from anecdotal observations in local literature. We also relied on local accounts of flooding, especially post-event documentation of the January 1982 flood event that caused major flooding and damage along the western shore of Tomales Bay (e.g. Anima et al. 1988).

Flooding Conditions

Flooding on the shoreline of Tomales Bay (bayward of Sir Francis Drake Blvd on the western shore and Highway 1 on the eastern shore) is mainly caused by high bay water levels. High water levels above typical astronomical tides are caused by atmospheric and oceanic processes. The processes that raise ocean water levels above normal tides are mostly associated with winter storm events, so the resulting water level increase is often termed 'storm surge'. Storm-related processes that influence surge include low atmospheric pressure and wind. In addition, changes in large-scale oceanic circulation, particularly during winters with El Niño conditions (1982-83, 1997-98, 2015-16), can cause higher-than-normal water levels for several months at a time. Depending on the intensity of each of these processes, as well as their coincident occurrence relative to astronomical tides, storm surge can result in water levels up to three feet higher than astronomic normal tides. Winter storm winds can also generate waves that may pose an additional flood hazard, particularly when the waves ride on water surface elevated by storm surge.

Flooding landward of the shoreline can occur from combined high tides, storm surge, and from riverine flooding in the creek valleys throughout the bay. This happens when high tides and storm surge coincide with high rainfall, so that strong creek flows are partially blocked at the downstream end by bay water levels. This can be compounded by increased sediment transport into the creeks during flood events. Major landslides in Inverness Park during the January 1982 storm event caused sediment to rapidly fill the creeks, reducing the capacity of the creeks to carry flood flows. Combined tidal/riverine flooding was identified by members of the public as a concern, during outreach efforts for the C-SMART study (Marin County 2016, 2018).

Flood levels in Tomales Bay and its shoreline communities can be found from several sources:

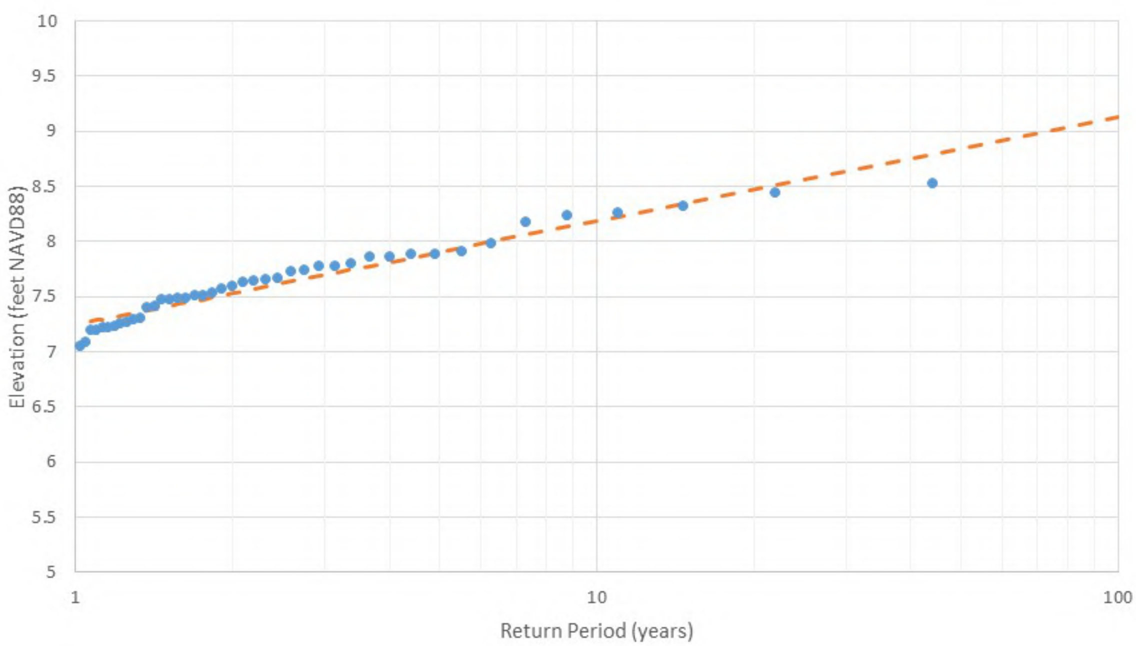
- **Tide stations:** long-term tides at the NOAA Pt. Reyes Station can be used to interpret the approximate elevation of recurrent coastal flood events inside the Bay (Figure 4). This does not account for variations in tide range along the bay, but can be used as a first approximation.

- **FEMA (2017) Base Flood Maps:** FEMA recently updated is coastal flood maps for unincorporated Marin County, including the interior of Tomales Bay. Flood maps incorporate coastal flooding from combined tides, storm surge, and wind-wave runup.

- **CoSMoS (Ballard et al. 2016):** The USGS Coastal Storm Modeling System (CoSMoS) provides flood hazard mapping that is developed using composite output from a two-dimensional model simulating extreme water levels and levee overtopping (Ballard et al. 2016). The CoSMoS dataset has 50+ combinations of sea-level rise (0 cm, 25 cm, 50 cm, … 200 cm, 500 cm) and storm scenarios (king tide, 0-year, 1-year, 20-year, and 100-year).

- **Local historical records:** The January 1982 and January 2006 floods caused widespread damage, and have been documented in photographs at a number of locations. The historical archives of the Inverness Public Library document flooding in Inverness Park, and landowners have documented flooding elsewhere (e.g. Cypress Grove, as documented by PWA (2007)). Photographs of shoreline flooding during annual king tide events are also publically available online.

Several major flood events have occurred in Tomales Bay in recent decades. Flooding has occurred during extreme rainfall events, periods of elevated coastal water levels, and during coincident high coastal and rainfall events. The January 1982 event is documented as the most destructive event of the last 40 years along the western shore, resulting from a prolonged period of heavy rainfall that triggered landslides that severely limited flood conveyance through local creeks (Inverness Ridge Communities Planning Group 1983, Anima et al. 1988). While the flooding is largely attributed to rainfall by local historians, coastal water levels were also elevated to 7 feet NAVD88 (roughly equivalent to a king tide event), which may have also contributed to the limited flood conveyance. High coastal water levels have also caused flooding throughout the bay. The most recent example occurred in January 2006. High coastal levels were recorded in the winters of 1983, 1998, 2005, and 2006.



Source: NOAA Station 9415020

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Figure 4
Flood elevations and return periods for water level measurements at the NOAA Pt Reyes tide station.

3.1.4 Biological Resources

The bay is host to a range of intertidal habitats, including fringing tidal marshes, extensive tidal flats and eelgrass (*Zostera marina*) beds, and a number of iconic aquatic and terrestrial species, including several sensitive species. For example, the bay is important habitat for native Olympia oysters and federally threatened Central California Coastal steelhead (*Oncorynchus mykiss*), and many others. The bay is a critically important habitat for migratory shorebirds, such as the federally threatened snowy plover (*Charadrius nivosus nivosus*). Both Walker Creek and Lagunitas Creek, as well as many of the small watersheds along both shorelines of the bay support steelhead.

Maps and point data on existing shoreline habitats are available from several sources, summarized in Table 2. Eelgrass (*Zostera marina*) can be found in shallow subtidal areas, especially on the eastern shore. Subtidal areas also support a range of pelagic and benthic species. Native Olympia oysters were once plentiful in the bay but are now declining.

Tomales Bay differs from nearby San Francisco Bay in that a large portion of its shoreline is rocky. Eroding bluffs on both sides of the bay provide a backdrop of rocky lag material (erosion resistant boulders and cobbles) in many areas. Sandy material delivered by the creeks allows the formation of beaches along pockets of the shoreline bounded by rocky headlands. Large deltas have formed over time at Walker Creek and Lagunitas Creek. A unique feature of Tomales Bay is the series of emergent saltmarshes formerly trapped by the 1870s railroad on the eastern shore. While most of these marsh areas are now connected to the tides, they are still mostly fronted by relict railroad berm.

While it is out of the scope of this study to review each of the existing habitats in detail throughout the bay, Table 2 presents an initial look at sources of available information. For the sites selected for design development (Section 6), we look at specific habitat types at the local level for each site that would be influenced by the designs.

TABLE 2
DATA ON EXISTING HABITATS AND VEGETATION COMMUNITIES

Name	Source	Date Collected	Extent
Eelgrass mapping from composite of aerial flight photographs	CDFW	1992, 2000, 2001, 2002	Tomales Bay
Eelgrass mapping from georectified and digitized 2010 aerial photographs	CDFW	2010 (published in 2013)	Tomales Bay
Eelgrass survey	CDFW	2015	Tomales Bay
Eelgrass survey	Merkel & Associates	2017	Tomales Bay
Olympia oyster surveys	Kimbro et al. (2019)	2010-2013	14 sites throughout the Bay
Olympia oyster surveys	Kimbro et al (2009)	2009	9 sites throughout the Bay
Inventory of existing wetlands	National Wetlands Inventory (NWI) - USFWS	variable	Tomales Bay
Marin Countywide Fine Scale Vegetation Map	GGNPC	2019	Marin County
Maps of seabird colonies	Point Blue Conservation Science	Variable	Marin County

Eelgrass

It was repeatedly noted during screening of candidate treatment sites that the shoreward extent of eelgrass beds were generally in close proximity to the developed shoreline. With The only exception of Martinelli Park in Inverness where relatively expansive intertidal flats, associated with the prograding delta at the mouth of Lagunitas Creek, provide a low-gradient transition between the marsh front and low-intertidal eelgrass beds further offshore.

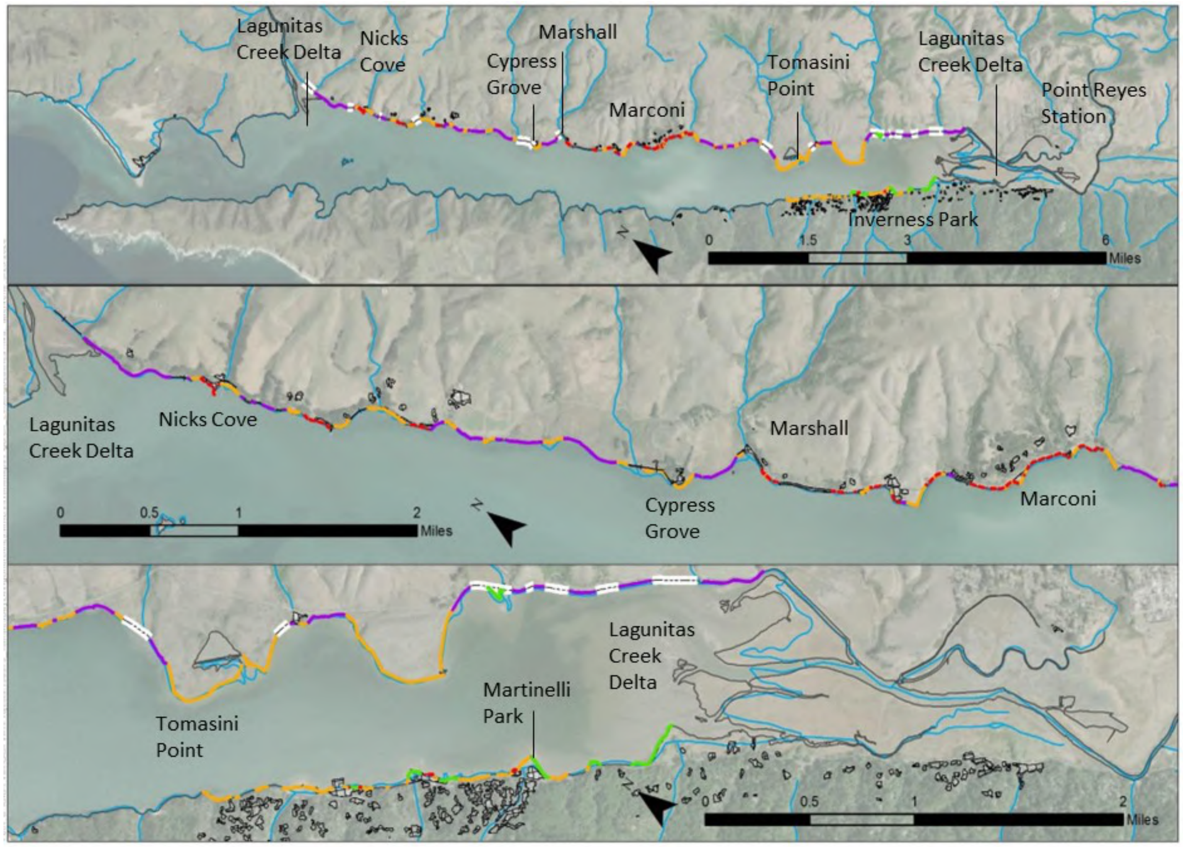
When comparing eelgrass distribution data from recent baywide surveys (Merkel and Associates 2017) with eelgrass survey data captured in June 2020 in support of commercial oyster lease permitting near Nick's Cove at the Walker Creek Delta and immediately north of Millerton Point (Merkel and Associates 2020), it was observed that eelgrass beds have expanded substantially during the last several years, particularly in the lower intertidal and shallow subtidal areas closest to shore. These areas bracket the northern and southern extent of the study area and associated candidate pilot sites located along the eastern shore of the bay. This observed expansion of eelgrass between 2017 and 2020 is broadly consistent with patterns observed between 2013 and 2017, which indicated an increase in baywide eelgrass extent had occurred since the previous baywide assessment was completed (CDFW 2015). While some of the expansion that occurred between 2013 and 2017 can be attributed to improvements in survey methodology and a more comprehensive census of subtidal areas (Merkel and Associates 2017), the expansion of eelgrass along the shallow eastern margin of the bay is consistent with observations from nearby systems during the same time frame (e.g. Bodega Bay and San Francisco Bay) and is strongly believed to be linked to the cessation of the multi-year marine heat wave event (Di Lorenzo and Mantua; 2016) beginning around 2016.

The present distribution of submerged aquatic vegetation (primarily eelgrass) habitat within Tomales Bay is largely a reflection of natural processes playing out in the absence of dredging and port development activities that are common throughout the majority of California's larger estuarine embayments. Of the five largest estuarine systems that collectively support over 80 percent of California's eelgrass habitat, Tomales Bay is the only major embayment that retains a natural configuration devoid of significant hydromodification efforts such as shoreline improvement/armoring of the bay's entrance or deepening (dredging) of interior channels. However, despite the relatively pristine character and protected status of the bay, historical changes associated with the proliferation of agriculture (ranching and farming), construction of transportation infrastructure (roads and railways), and development of bayside residential communities and associated recreational access improvements have affected ecological conditions, most notably along the shallow subtidal and intertidal margins of the bay.

3.1.5 Public and Private Infrastructure

Surrounding Land Uses and Infrastructure

The shoreline of Tomales Bay is heavily developed in several areas, as shown in Figure 5. The eastern shore from Nick's Cove to Marconi largely consists of privately-owned single family homes and neighborhood commercial buildings (restaurants, commercial fisheries, and other small businesses). Upland areas are predominantly privately-owned grazing lands. Even in areas of the eastern shore without existing development, the shoreline is still modified by the presence of the historical railroad that was constructed in the 1870s, whose artificial rock berm forms the existing shoreline edge for several miles (Figure 5). Development on the western shore is limited to the areas adjacent to Inverness Park and Seahaven, and homes along Sir Francis Drake Blvd, but includes a dense array of residential and commercial properties, as well as historical shoreline structures (former boathouses, piers, and armoring) that influence flooding exposure. Point Reyes Station in the southern extent of the bay, is the most heavily populated area of the shoreline. Dillon Beach is located at the mouth of the Bay, and includes residential and recreational (public camping site) areas.



Source: ESA review of public data provided by the County, local residents, and images from Kenneth and Gabrielle Adelman (2021)

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Legend
Armoring
Rocky or coarse shoreline
Unprotected marsh edge
remnant railroad berm
fine-grained shoreline
perennial streams
Developed areas

Figure 5
Map of existing shoreline conditions in Tomales Bay.

Property Ownership and Easements

Property ownership information was compiled by the County as part of the C-SMART project. Parcels and structures on the shoreline are also publicly available from the County's Geographical Information System (GIS) database (MarinMap 2021). As part of the site selection process (see Chapter 4), we developed a series of 'overlay maps' that show shoreline parcels and structures their location relative to sea-level rise hazard areas. The County (Marin County 2016, 2018) used a similar approach to develop a list of the number of vulnerable infrastructure vulnerable to sea level rise throughout the bay.

The Bay shoreline is owned by a mix of public and private entities. Population centers such as Nicks Cove, Marshall, and Inverness Park tend to include a mix of residential (single family homes) and small commercial properties, interspersed with public lands and commercial oyster plots. Less developed areas are generally in public ownership, with oversight from the National Park Service (NPS), Greater Farallones National Marine Sanctuary (GFNMS), County of Marin, and others.

Public Access

Shoreline roads within the bay act as key transportation corridors connecting coastal access between Marin and Sonoma County, and provide access to the Point Reyes National Seashore, and Golden Gate National Recreation Area, as well as a large number of state and county shoreline parks. State and county parks are heavily used, with Samuel P. Taylor State Park and Tomales Bay State Park drawing hundreds of thousands of tourist each year (Tomales Bay Watershed Council 2003).

3.2 Long-Term Shoreline Change

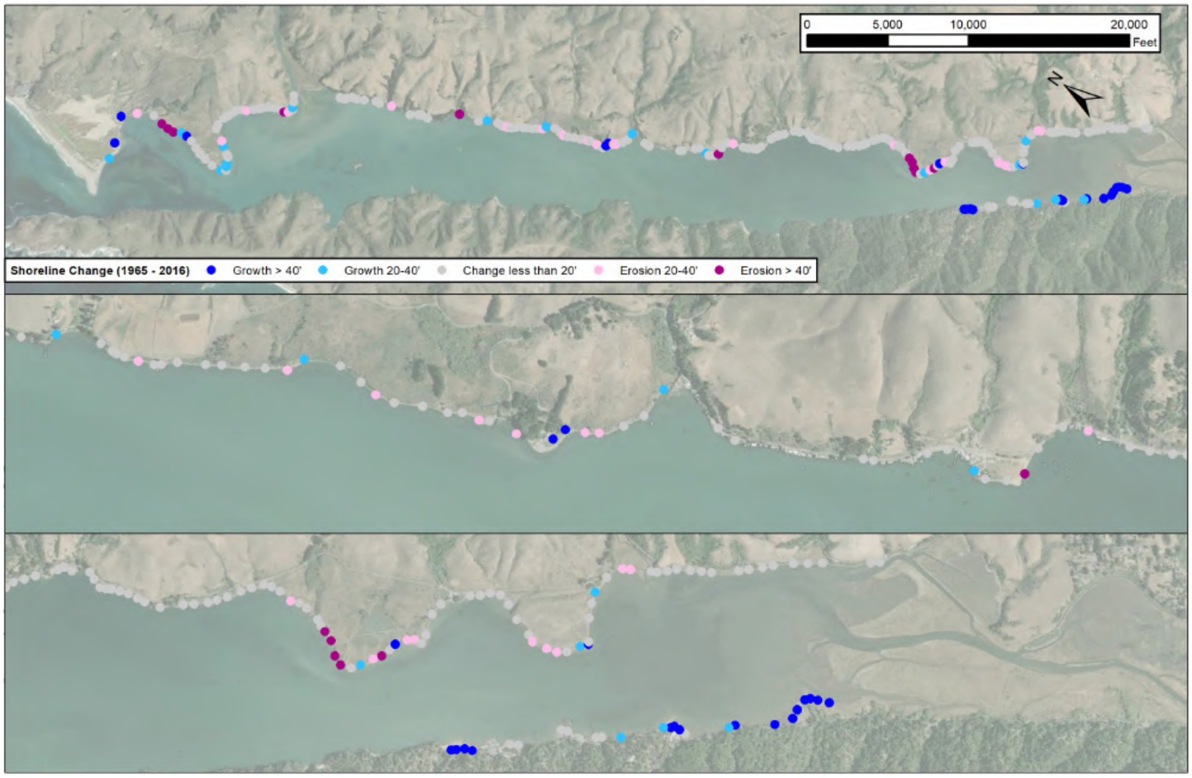
The shoreline of Tomales Bay is not fixed in place. It undergoes natural shifts resulting from coastal processes (erosion from tides, storm surge, and wind waves) and fluvial processes (supply of watershed sediment), in addition to shifts resulting from shoreline management. It was important to this study to understand the baseline in terms of ongoing changes, rather than the shoreline position at a fixed point in time. Long-term shoreline change was assessed by digitizing shorelines from aerial images from 1965 and 2016, and estimating local shoreline change rates from these two points in time.

Figure 6 illustrates the shoreline change rates from 1965 to 2016. The erosion pattern is complex, but a series of patterns are apparent:

- Erosional and depositional trends indicate a net southward movement of sediment along the shore (presumably due to wind waves from the dominant northwesterly fetch). Based on our review of shoreline position in 1965 and 2016, many of the creek deltas along the bay have shifted southward.

- Areas with greatest erosion tended to be sandy shorelines immediately downdrift (southward) of breakwater structures that interrupt the longshore transport of sediment to the south, or in sandy or bluff-backed areas that have the greatest exposure to northwesterly wind-waves.

- Areas of erosion also occur where creeks have been modified, i.e. where natural supply of sediment to the shoreline has been altered.



Source: ESA

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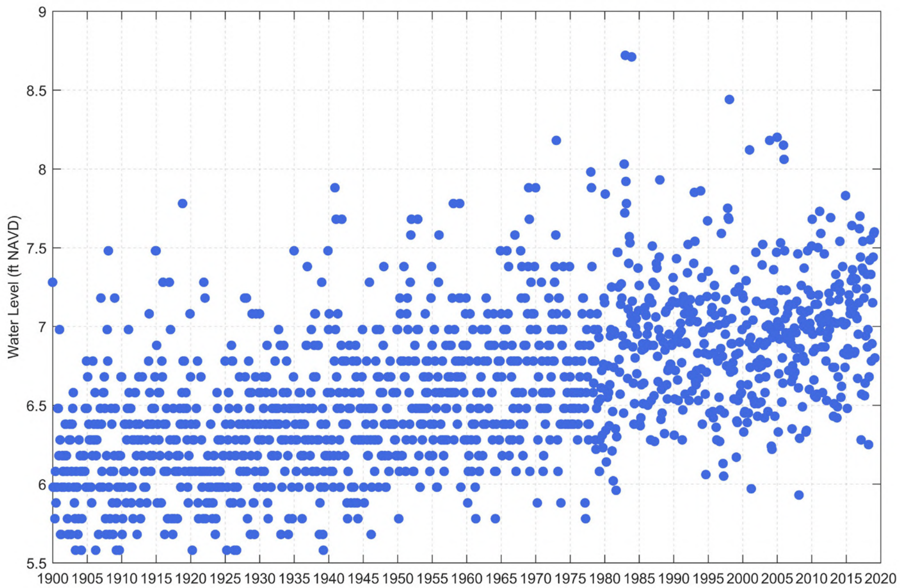
Figure 6
Shoreline position change estimated from 1965 and 2016 aerial images

3.3 Projected Sea-Level Rise

The accumulation of human-produced greenhouse gases in the Earth's atmosphere is causing and will continue to cause global warming and climate change. Along the Tomales Bay shoreline, climate change will cause sea-level rise due to thermal expansion of the ocean's waters and melting of ice sheets. Over the last century, the tide gauge in San Francisco has recorded sea-level rise of eight inches over the last century (Figure 7). In addition to these observed sea-level rise trends, the best available science, as reviewed specifically for California (Griggs et al. 2017; OPC 2018; CCC 2018), predicts that sea-level rise will continue and accelerate throughout this century and into the next century. This accounts for local movement of the land surface. In the Tomales Bay region of northern California, relative sea-level rise (accounting for land movement) is positive. Estimates of sea-level rise continue to evolve as more data become available, and there is some indication that current trends may be an underestimate (IPCC 2021). Because specifics about future greenhouse gas emissions and climate response are not fully known, the exact sea-level rise scenario that will occur is not precisely known at this time. However, considering a range of all but the most extreme scenario, sea-level rise by 2100 is projected to be between two and nearly seven feet in San Francisco Bay by 2100 (OPC 2018; CCC 2018).



Source: NOAA Station 9414290

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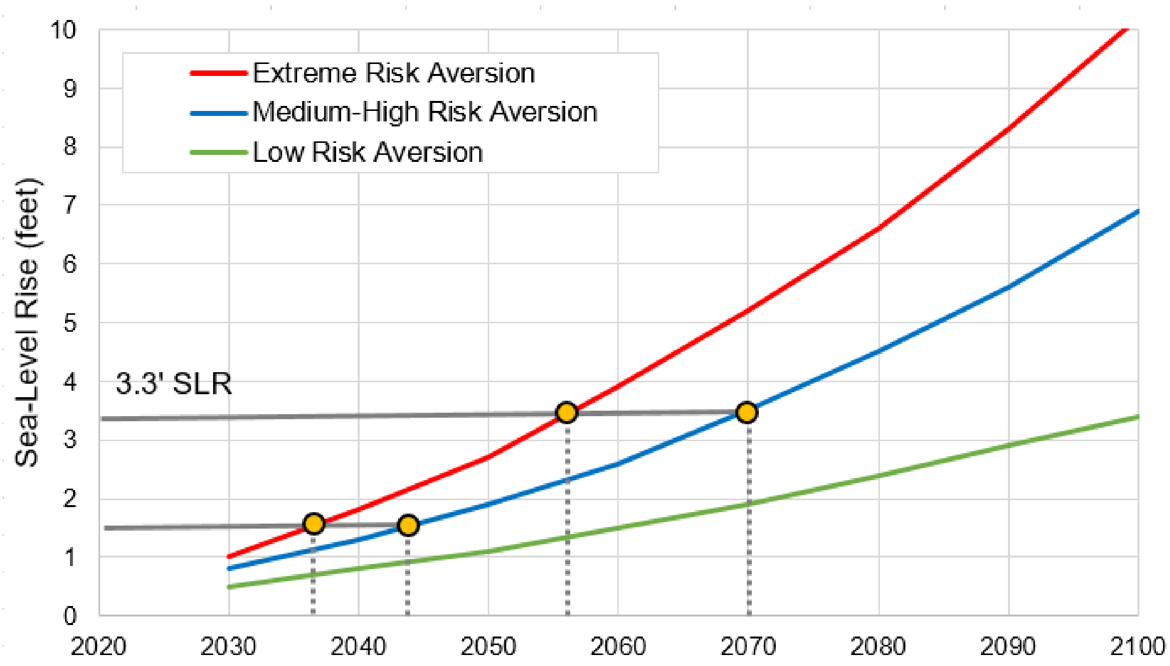
Figure 7
Monthly peak water levels at NOAA San Francisco tide station, 1900-2020

Project Time Horizons

Sea-level rise in Tomales Bay is expected to be similar to that of San Francisco Bay. While the timeline of sea-level rise is uncertain, for planning purposes it is useful to consider a range of sea-level rise amounts, to consider multiple phases of future planning. For example, the C-SMART study considered a range of 50 to 200 cm (1.6 feet to 6.6 feet).

For this study, the County has chosen to consider 1.6 feet and 3.3 feet of sea-level rise (50 cm and 100 cm), with and without a 20-year annual chance coastal flood event. The 20-year annual chance event is assessed using records of coincident extreme water levels and winds (leading to wind setup and wave heights that increase water levels at the shoreline). See Appendix C for more information. Since the portions of the shoreline under risk of erosion or flooding include critical infrastructure (including fire stations, homes, and emergency evacuation routes), we based the project time horizons on the medium-high and extreme risk aversion curves published by the Ocean Protection Council (OPC 2018) and California Coastal Commission (CCC 2018). Based on these curves (Figure 8 below), the time horizon for 1.6 ft of sea-level rise is expected to be 2038 to 2045, and for 3.3 feet of sea-level rise, 2055 to 2068. The time horizons and storm conditions considered in this study are summarized in Table 3.



Source: CCC (2018)

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Figure 8
Sea-Level Rise projections for San Francisco Bay for 2030 to 2100

TABLE 3
PROJECT TIME HORIZONS

Time Horizon	Increase in Sea Level (feet)	Storm Event	Time Horizon
Short-term, tidal flooding	1.6 ft (50 cm)	None	2038-2045
Short-term, storm flooding	1.6 ft (50 cm)	20-yr annual chance coastal flood	2038-2045
Medium-term, tidal flooding	3.3 ft (100 cm)	None	2055-2068
Medium-term, storm flooding	3.3 ft (100 cm)	20-yr annual chance coastal flood	2055-2068

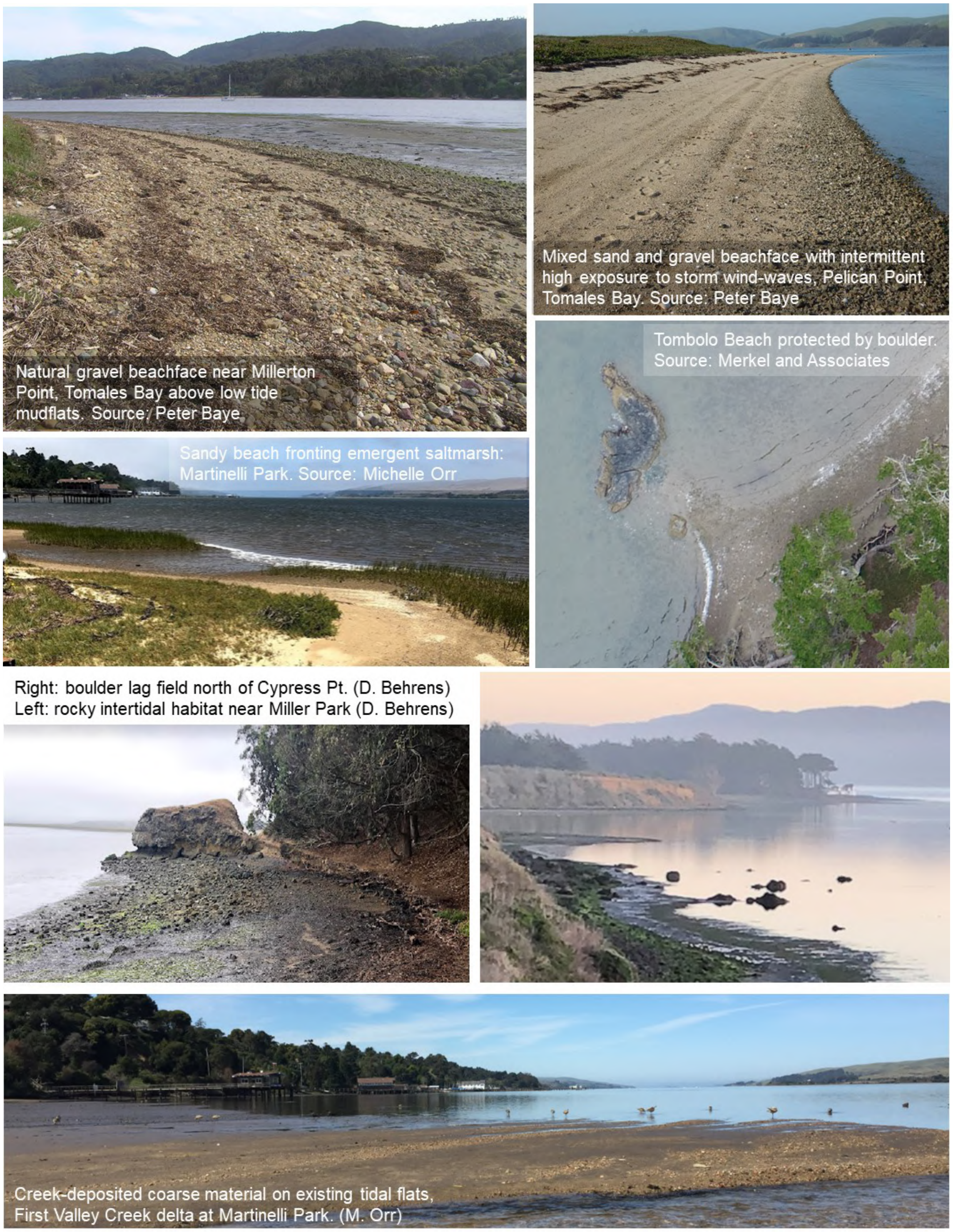
CHAPTER 4
Development of Living Shorelines Adaptation Measures

While living shorelines have increasingly been employed as a tool for sea-level rise adaptation in recent decades, determining the correct approach remains a challenge at the site scale. For example, approaches developed for San Francisco Bay or eastern Marin County (e.g. SFEI and SPUR 2019, Point Blue, SFEI, and County of Marin 2019) may not be directly applicable to Tomales Bay, given its unique setting. Likewise, approaches developed for the open coast (e.g. Newkirk et al. 2018) may also not be applicable. Therefore, developing localized approaches at Tomales Bay required an iterative process, in which we drew from regional studies, mapped existing shoreline features, examined reference sites within the Bay (i.e. locations where natural features already protect the shoreline), and developed suitability criteria for different types of shorelines.

4.1 Inventory of Existing Shoreline Features

To understand the present-day baseline conditions along the shore, we developed a shoreline inventory that identifies areas of armoring, development, existing marsh, bluff, or beach edges. We developed this through a series of site visits from 2019 through 2021, consultation with local residents, review of parcel maps available from the County, and from aerial oblique images available from the California Coastal Records Project (Kenneth and Gabrielle Adelman 2021). Figure 4 shows the map of shoreline conditions. Note that this focuses on areas of interest for this study, and does not include much of the undeveloped western shoreline within the Point Reyes National Seashore, or the eastern shoreline north of Toms Point.

As part of the process of mapping shoreline features, we also examined a number of reference sites, focusing specifically on sites where natural features showed evidence of providing a level of protection to the local backshore areas. Figure 9 illustrates a few examples of notable features, including existing rocky intertidal, beach, and marsh areas. Reference sites provided some of the basis for sizing and placement of features included within the concept designs (Section 6).



Natural gravel beachface near Millerton Point, Tomales Bay above low tide mudflats. Source: Peter Baye.

Mixed sand and gravel beachface with intermittent high exposure to storm wind-waves, Pelican Point, Tomales Bay. Source: Peter Baye

Tombolo Beach protected by boulder. Source: Merkel and Associates

Sandy beach fronting emergent saltmarsh: Martinelli Park. Source: Michelle Orr

Right: boulder lag field north of Cypress Pt. (D. Behrens)
Left: rocky intertidal habitat near Miller Park (D. Behrens)

Creek-deposited coarse material on existing tidal flats, First Valley Creek delta at Martinelli Park. (M. Orr)

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Figure 9
Example beach, marsh edge, and rocky intertidal reference sites

4.2 Summary of adaptation Adaptation Measures

After reviewing shoreline conditions and reference sites, the project team developed a list of Tomales Bay adaptation measures (also referred to in this report as 'living shorelines treatments'). These are listed in Table 4 below, and Attachment D includes a series of summary tables for each measure. This follows a similar format as the San Francisco Bay Adaptation Atlas (SFEI and SPUR 2019), and is intended to help guide the process of selecting approaches based on site constraints. Each summary considers the definition of each feature, lists reference sites, identifies the protective capabilities, and discusses criteria for determining feasibility. Figures 10 through 16 below provide definitions and maps of applicability for each measure. The tables in Attachment D provide more detailed information.

TABLE 4
SUMMARY OF TOMALES BAY ADAPTATION MEASURES

Adaptation Measure	Flood Services	Ecosystem Services	Suitability
Creek-to-Bay Reconnection	Storm surge, Erosion, Combined flooding, Fluvial flooding	Biodiversity, food supply, climate resilience, water quality improvement, recreation, other cultural services	• Applicable at modified creek connections, especially where sedimentation in culverts is an issue
Rocky Intertidal	Storm surge, erosion	Biodiversity, food supply, climate resilience, water quality improvement, recreation, other cultural services	• Applicable near existing coarse shorelines • Avoid boat moorings and oyster lease areas
Beaches	Storm surge, erosion, short-term SLR	Biodiversity, food supply, recreation, other cultural services	• Suitable where existing armoring exists • Drift-aligned shores require retention features • Existing or historical beach presence
Nearshore native Oyster Reefs	Storm surge, erosion	Biodiversity, food supply, water quality improvement, sediment stabilization and trapping, other cultural services	• Highest chance of success in mid bay • Most successful when integrated with hard substrates placed at appropriate tidal elevations • Need substrates with grooves, crevices, interstitial spaces. Apply to designs with cobbles in sandy or muddy settings (near marsh elevation range).
Submerged Aquatic Vegetation	Storm surge, erosion, short term SLR, long term SLR	Biodiversity, food supply, climate regulation, potential ocean acidification buffering, water quality improvement, sediment stabilization and trapping, recreation, other cultural services	• Wave and current exposure, substrate suitability, desiccation and light availability are limiting factors • If placing sediment to raise bed elevation, need to consider need for grade control
Tidal Flat Restoration	Storm surge, erosion	Biodiversity, food supply, water quality improvement, recreation, other cultural services	• Existing tidal flats (sandy or muddy), especially where erosion is occurring
Tidal Marsh Restoration	Storm surge, erosion, combined flooding, short term SLR, long term SLR, fluvial flooding	Biodiversity, food supply, climate resilience, water quality improvement, recreation, other cultural services	• Areas between mean tide level and highest estimated tide, with a direct connection to the bay

CREEK TO BAY RECONNECTION

COASTAL RISKS MANAGED

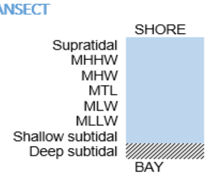
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate Resilience • Water quality improvement • Recreation • Other cultural services

IMPACT ON SHORELINE

Protect • Accommodate • Retreat

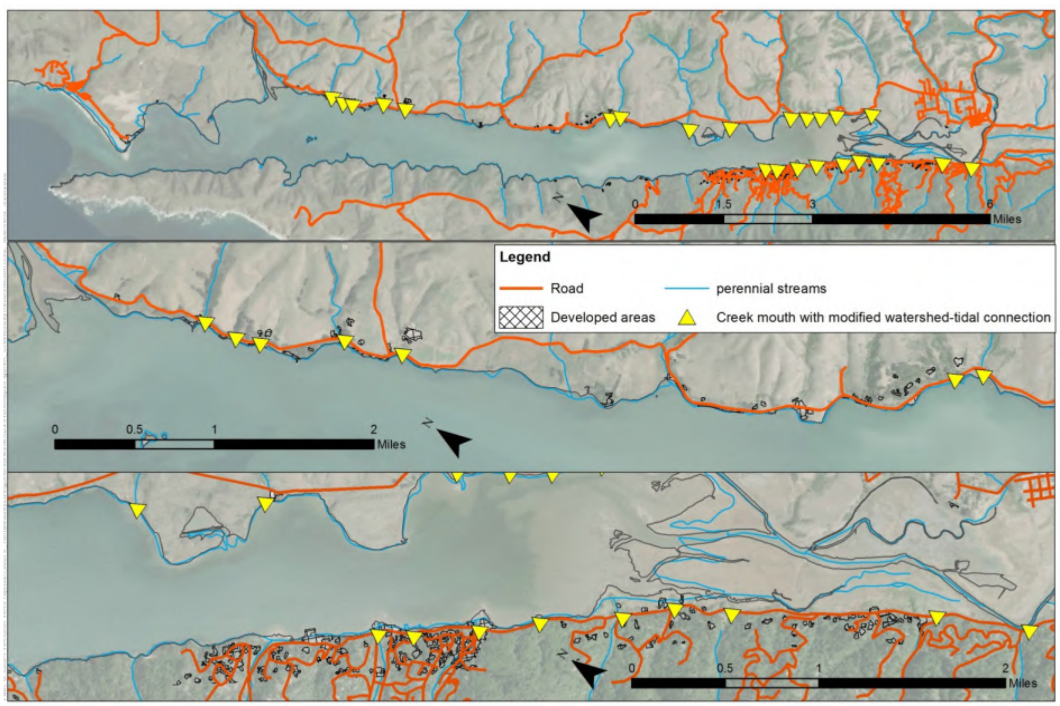
LOCATION WITHIN TIDAL TRANSECT



DESCRIPTION

Many of the creeks draining to Tomales Bay have modified connections to the bay as a result of historical development and changes in land cover and sediment supply (Rooney and Smith 1999). On the eastern shore in particular, construction of the North Pacific Coast Railroad (begun in 1874) and Highway One created physical restrictions to sediment delivery to the bay, while changes in land-use within the watershed led to a period of dramatic increases in sediment loading. On the western shore, construction of Sir Francis Drake Boulevard also modified the tidal connection of creeks near Inverness. Increased sediment loading continued for much of the twentieth century as the small watersheds flanking the bay did not have the capacity to immediately transport all of the increased supply attributed to land use changes (Rooney and Smith 1999).

While these combined factors contributed to the capture of sediment and formation of new marsh areas between the railroad and the original shoreline along the eastern shore, in some areas the breached railroad berms and both Highway One and Sir Francis Drake Boulevard continue to restrict sediment transport from the watershed and outboard marsh and mudflat areas. Culverts underneath these major roadways require periodic maintenance by the County of Marin (on the western shore) and Caltrans (on the eastern shore) to remove sediment, which is taken offsite. In some areas where the highway is directly adjacent to the Bay, creek mouths were replaced with culverts that constrain transport of potential sediment delivery to the Bay margin. While reconnecting creeks to their adjacent baylands through roadway modification is unlikely to be an option, beneficial re-use of sediments removed from upstream culverts may be an option for augmenting existing outboard tidal marshes or mudflats. This will require studying existing sediment maintenance programs to understand the quantities available and viability of the approach.



Source: Marin County

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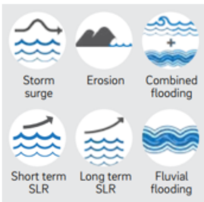
Figure 10
Map of potential opportunities for Creek-to-Bay Reconnections.

TIDAL MARSH

COASTAL RISKS MANAGED



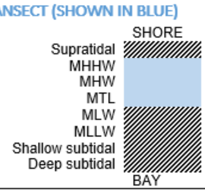
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate Resilience • Water quality improvement • Recreation • Other cultural services

IMPACT ON SHORELINE

Protect • Accommodate • Retreat

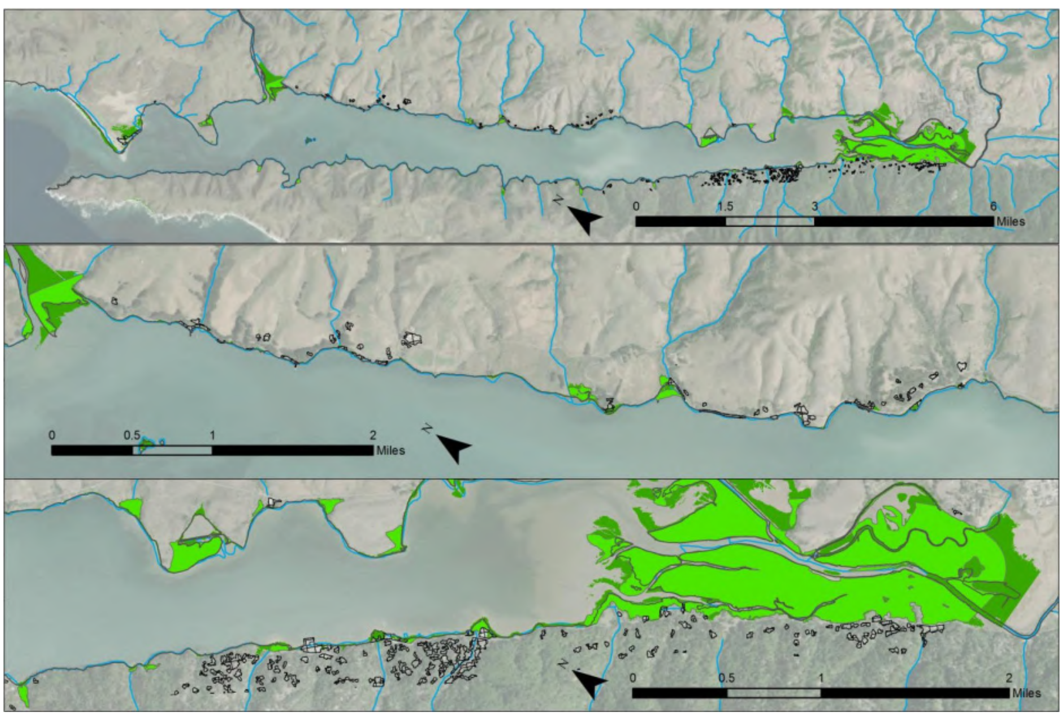
LOCATION WITHIN TIDAL TRANSECT (SHOWN IN BLUE)



DESCRIPTION

Tidal marshes are vegetated coastal wetlands subject to tidal action with or without freshwater inputs that establish estuarine, brackish marsh gradients. They can typically be found between an unvegetated mudflat and some form of wetland-upland transition shoreline type. Tomales Bay tidal wetlands include a range of inter-connected estuarine habitats like salt marsh, brackish marsh, mudflats and others. Dominant vegetation in Tomales Bay tidal marshes includes native cordgrass (*Spartina foliosa*), saltgrass (*Distichlis spicata*), and Pacific pickleweed (*Sarcocornia*). Tomales Bay salt marshes are relatively rich in native tidal marsh plant species.

Tidal marshes in Tomales Bay are predominantly found in small embayments or around creek mouths, where they are often protected from direct wave action by sandy or coarse beach berms that provide a flexible barrier between the marsh and bay. In the southern part of the bay, tidal marshes are also present where wide muddy, low-gradient tidal flats of the Lagunitas Creek delta damp wave energy. Elsewhere, tidal marshes have formed in pockets behind the remnant North Pacific Coast Railroad berm.



Source: GGNPC (2019)

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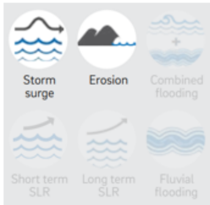
Figure 11
Areas of existing (light green) and potential (dark green) marsh areas. Dark areas are based on mapped elevations between mean sea level and highest astronomical tide (not already colonized by marsh)

TIDAL FLAT AUGMENTATION

COASTAL RISKS MANAGED



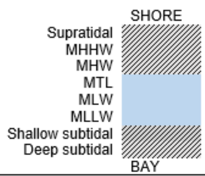
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate Regulation • Water quality improvement • Recreation • Other cultural services

IMPACT ON SHORELINE

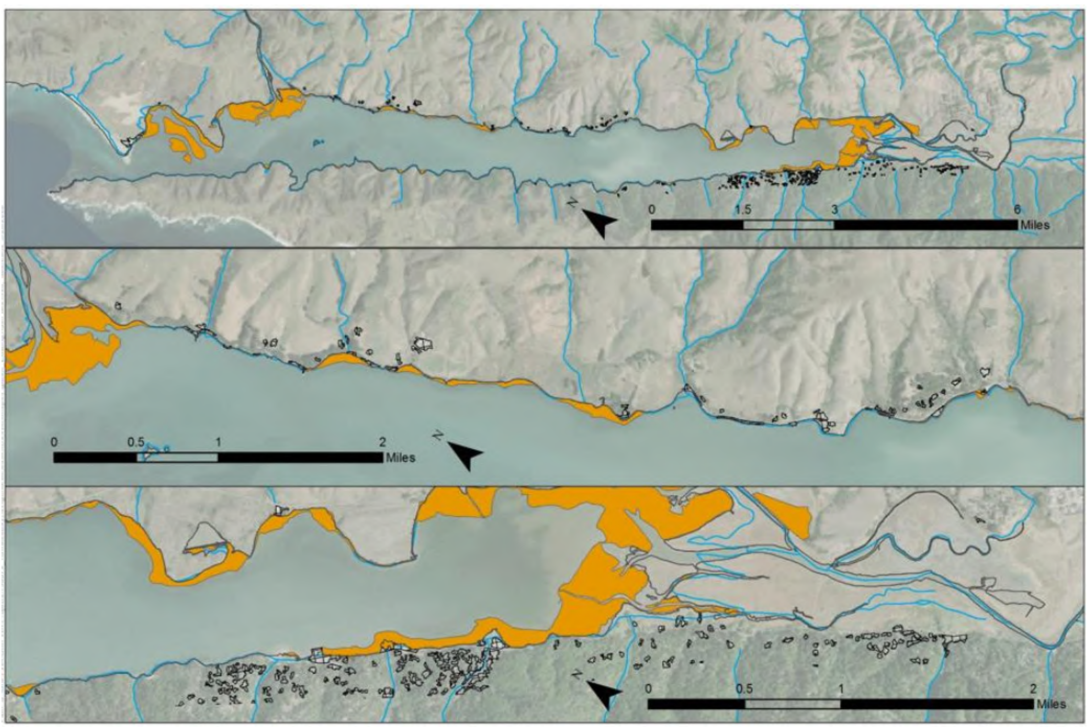
Protect • Accommodate • Retreat

LOCATION WITHIN TIDAL TRANSECT



DEFINITION

Intertidal mudflats and shallow water shoals are a common substrate in Tomales Bay. Depending on location in the bay, they are composed of fine silts, clays, and sands in variable concentrations. Areas nearer to the mouth of the bay are sandier, having direct access to coastal sediments delivered from Bodega Bay and both Estero Americano and Estero San Antonio. Moving south along the axis of the bay, tidal flats include finer-grained sediments than sand in higher quantities. Tidal flat augmentation refers to the direct or indirect placement of sediments to increase tidal flat elevation relative to the tides, which can help to protect adjacent marshes or other shoreline types. This adaptation measure differs from the 'mudflat augmentation' measure described for San Francisco Bay by SFEI (2019), since sand is much more readily-available in parts of Tomales Bay. Another important difference stems from the difference in sediment availability between Tomales Bay and San Francisco Bay. Whereas San Francisco Bay has begun experiencing a shift toward declining sediment supply and many of its mudflats are expected to be vulnerable to erosion in the near term (SFEI 2019), Tomales Bay continues to experience expansion of its tidal flats in many areas (Rooney and Smith 1999), and it is not immediately clear how much the trajectory of its tidal flats differs from those of San Francisco Bay with sea-level rise.



Source: GGNPC (2019)

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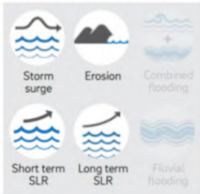
Figure 12
Existing tidal flats in Tomales Bay, mapped as the areas between MLLW and MSL elevations by GGNPC (2019)

SUBMERGED AQUATIC VEGETATION

COASTAL RISKS MANAGED



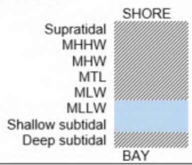
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate regulation • Ocean acidification buffering • Water quality improvement • Sediment stabilization and trapping • Recreation • Other cultural services

IMPACT ON SHORELINE

Protect • Accommodate • Retreat

LOCATION WITHIN TIDAL TRANSECT



DEFINITION

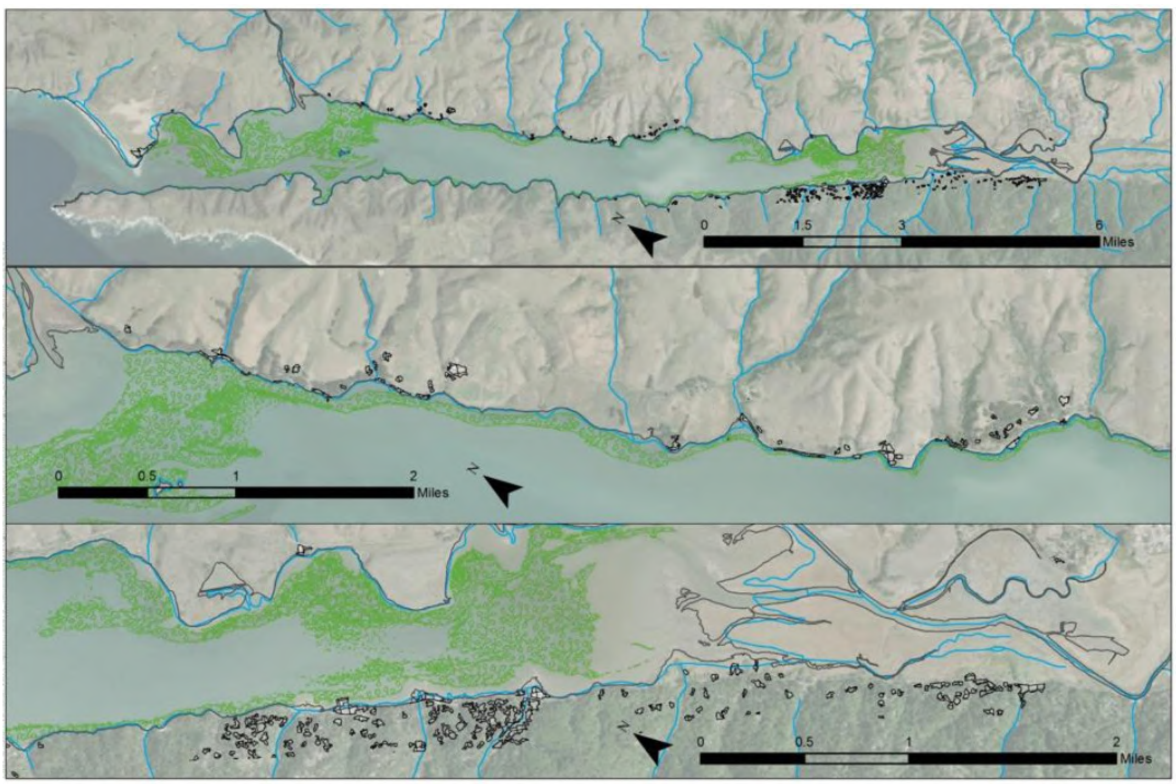
Submerged Aquatic Vegetation (SAV) includes rooted vascular plants such as the seagrasses Eelgrass (*Zostera marina*) and Widgeon Grass (*Ruppia maritima*) and attached macroalgae occurring within the shallow subtidal to lower intertidal portions of estuarine and nearshore marine environments. As primary producers with substantial capacity to capture and store dissolved atmospheric CO_2 SAV habitats (in particular seagrasses) have been recognized for their potential to help mitigate the effects of climate change in addition to providing a broad range of ecosystem services.

Eelgrass, the most widely distributed and abundant species of seagrass in Tomales Bay, provides shelter and food for many ecologically, commercially, and culturally important species of fish, wildlife and invertebrates. Eelgrass beds attenuate wave energy and stabilize sediment, reducing the effects of storm surge on coastal flooding and protecting shoreline areas from erosion. Further, eelgrass beds retain captured sediment and migrate vertically as the sediment and organic material is sequestered in below the beds. This facilitates the maintenance of shoreline profiles in response to sea level rise thus providing continued influence on the nearshore wave and sediment transport environment. In most extreme cases, the benefits of eelgrass as a sediment stabilizer extends beyond the coastal bays and estuaries and out to the outer coastline where seasonal leaf shed results in shore wrack that rolls up sand in deposits near the high tide line. This fibrous wrack serves to absorb wave energy and trap sand in a manner that protects the upper beach margins and shoreline scarps and cliffs during winter months. Eelgrass beds provide a stable source of water column nutrient uptake and facilitate deposition of suspended sediment, enhancing water quality and clarity in the bay.

While SAV provides a number of benefits to shoreline stabilization (as described above), it does not provide enough wave reduction on its own to mitigate the erosive potential of wind-waves on sandy bay shorelines. It provides the most benefit when pairing with other elements (beach or marsh restoration at the shoreline), acting as the offshore component of a suite of living shorelines measures. As discussed in Section 5.4, existing eelgrass beds are also a constraint for placement of other living shorelines treatments.

Eelgrass habitat distribution follows three general patterns within the landscape of Tomales Bay including:

- Broad, low-gradient deltaic flats consisting primarily of fine grained silts/clays derived from fluvial discharge of Bay tributaries such as the Lagunitas Creek and Walker Creek Delta areas. These areas support some of the most expansive eelgrass beds within the bay.
- Dynamic sand shoals along the eastern shore near the mouth of Tomales Bay and extending into subtidal portions of the central bay near Hog Island. These areas also support extensive eelgrass habitat within the bay.
- Narrow, shore parallel bands occurring below the relatively high-relief, steeper headlands and broadening slightly in areas where headlands are interrupted by coves; these shore fringing bands are widely distributed along both the eastern and western shorelines of the bay, but supports less eelgrass coverage than either the deltaic flats or sand shoals.



Source: Merkel and Assoc. (2017)

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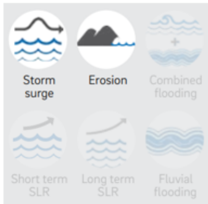
Figure 13
2017 Map of Eelgrass Locations in Tomales Bay (Merkel and Assoc. 2017)

NEARSHORE OYSTER REEFS

COASTAL RISKS MANAGED



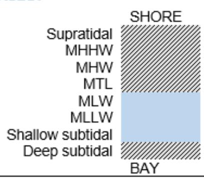
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate Resilience • Water quality improvement • Recreation • Other cultural services

IMPACT ON SHORELINE

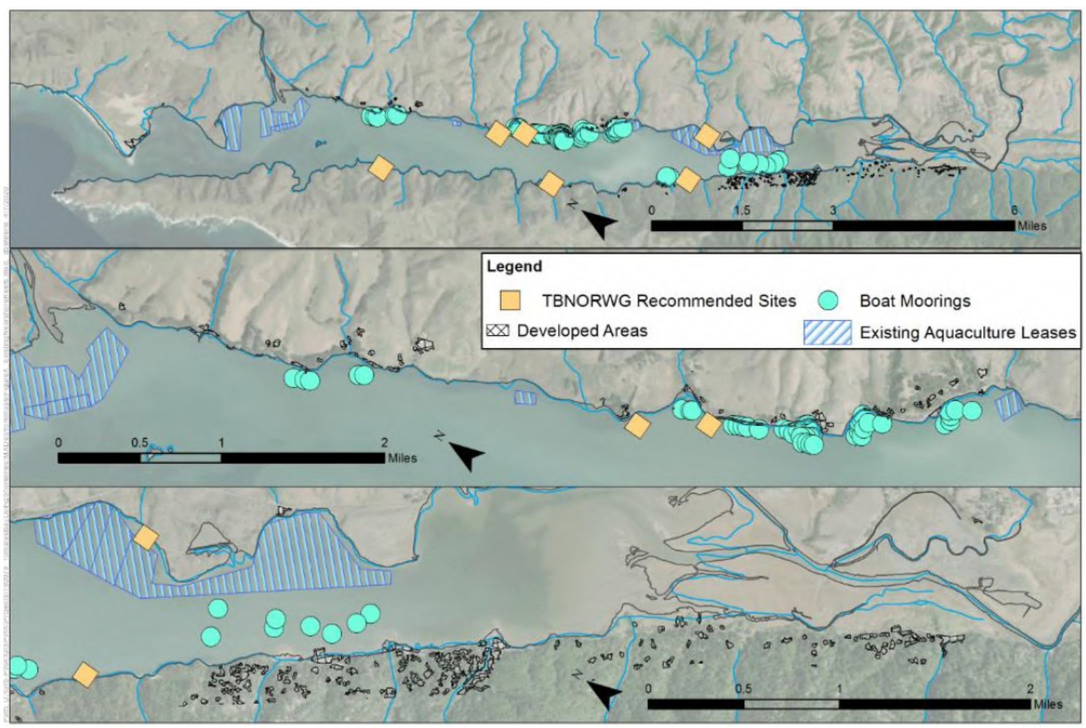
Protect • Accommodate • Retreat

LOCATION WITHIN TIDAL TRANSECT



DESCRIPTION

Nearshore oyster reefs play an essential role in the coastal zone, providing habitat value for a range of aquatic species and flood protection benefits. Certain oyster species, like native Olympia oysters (*Ostrea lurida*), are not reef building and for shoreline protection purposes are can be placed on artificial (constructed) reefs. Typical materials for artificial nearshore reefs include hard substrate like oyster shell and baycrete (cement mixture with locally derived sand and shell material). Nearshore reefs, using native and/or non-native oysters, reduce wave energy at subtidal elevations and provide wave protection for areas in their lee.



Source: TBNORWG (2019), Marin County

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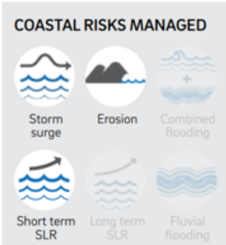
Figure 14
Locations of oyster restoration opportunities (TBNORWG Recommended Sites), commercial oyster leases, and areas constrained by boat moorings.

BEACHES

COASTAL RISKS MANAGED



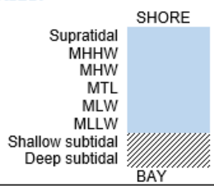
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate Resilience • Water quality improvement • Recreation • Other cultural services

IMPACT ON SHORELINE

Protect • Accommodate • Retreat

LOCATION WITHIN TIDAL TRANSECT



DEFINITION

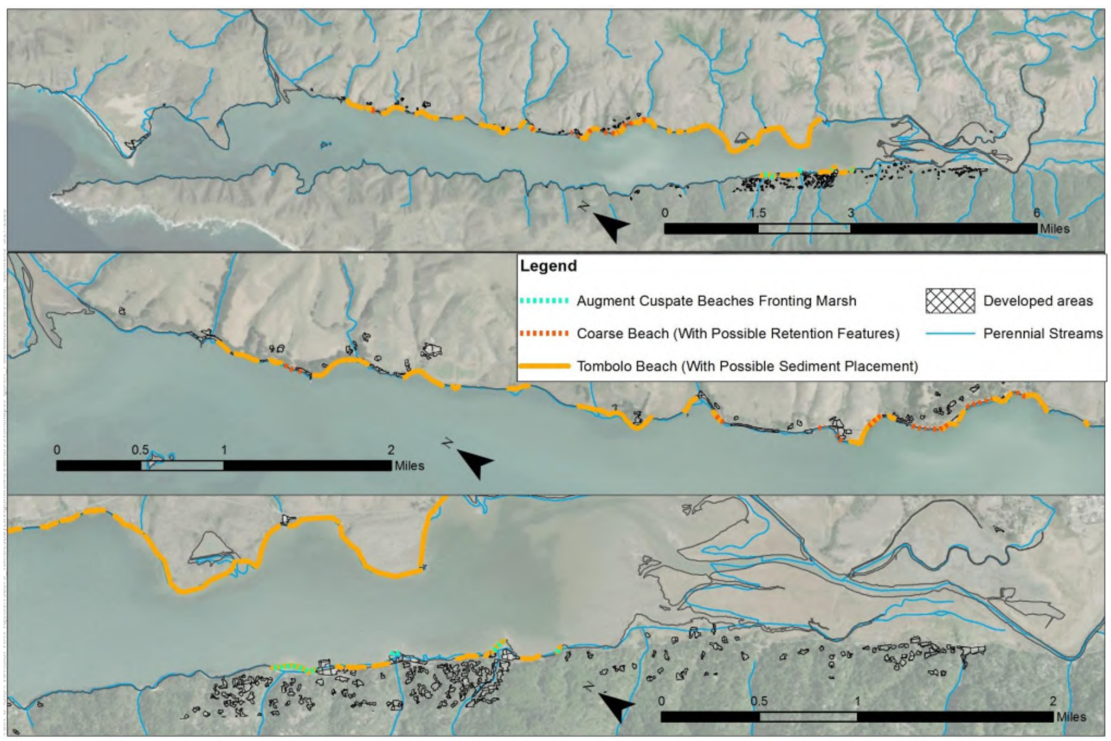
Coarse or composite estuarine beaches are dynamic features that can consist of a mixture of sand, shell, gravel, or cobble. Beaches include a supratidal beach berm and a beach face. The lowest position of the beach is often characterized by a low tide terrace and transition to tidal flat. The low tide terrace limits the duration that the beach is exposed to waves and also limits the size of the waves.

Beaches exist in several forms in Tomales Bay. Some of these forms include:

- cuspate sand and gravel beaches that form along the outer edge of creek deltas, forming peninsulas on the bay (especially along the western shore),
- sandy or coarse barrier beaches that are inset within coves – typically protecting marsh and upland terrestrial areas at the terminus of small creeks (common along the National Seashore north of Sea Ranch, and near Millerton)
- pocket beaches of coarse material (from sand to cobbles) fed by cliff or bluff erosion (more common along the eastern shore),
- fine-sand beaches on the leeward side of headlands, where exposure to wind is smaller and waves are smaller,
- tombolos formed behind natural obstructions such as large boulders.

Given this project's focus on protecting built assets, we considered three major beach types as potential adaptation measures, based on their prevalence near developed shorelines in Tomales Bay:

1. coarse (gravel, cobble, shell) beaches
2. cuspate sand and gravel beaches fronting marshes
3. tombolo beaches forming behind boulders



Source: Marin County

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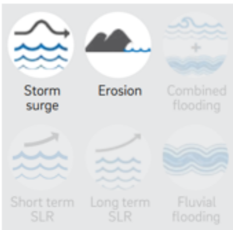
Figure 15
Map of potential opportunities for Beaches.

ROCKY INTERTIDAL

COASTAL RISKS MANAGED



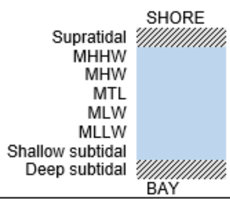
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate Resilience • Water quality improvement • Recreation • Other cultural services

IMPACT ON SHORELINE

Protect • Accommodate • Retreat

LOCATION WITHIN TIDAL TRANSECT



DEFINITION

Rocky intertidal habitat refers to a range of coastal habitat with hard rock substrate exposed to tides, such as steep cliffs, wave-cut shore platforms, rock pools, intertidal cobble and boulder lags (rocky remnants of past bluff retreat after fine sediment is eroded), and more. Rocky lag deposits are too large to be moved by wave-induced currents (e.g. boulders, bedrock), and provide stable sheltered habitat for a high diversity of native estuarine invertebrates, including native oysters and many prey items for native estuarine fish, shorebirds, and wading birds. Typically, rocky intertidal habitats are characterized by varying levels of rugosity (e.g. small-scale variations in hard surface roughness), which provide habitat diversity for a range of invertebrates, algae and fishes.

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Note: existing rocky intertidal features were not mapped as part of this study

Figure 16
Definition of 'Rocky Intertidal' living shorelines treatments

CHAPTER 5
Selection of Candidate Sites

The choice of sites for the project followed an iterative process, which is summarized in Figure 1 and in the sections below. Initial candidate sites were identified by reviewing locations with vulnerable built and natural assets along the shoreline. To facilitate this process, ESA developed a series of ‘overlay’ maps by combining information on projected sea-level rise flooding with additional layers that described asset locations, land ownership, shoreline erosion rates, local geomorphology, and existing sensitive habitats. These maps (provided in Attachment E) were reviewed by the project team to identify areas with the greatest need for shoreline protection, of which ultimately 2-5 priority pilot project sites would be chosen for further analysis and conceptual design. Initial site screening led to the selection of six candidate sites. The project team then examined the candidate sites in greater detail and provided recommendations to CDA. After additional coordination with the project team and permitting agencies, CDA selected two priority sites for further study. This process is outlined below, and more detail is available in Attachment F.

5.1 Initial Site Screening

Sites were initially screened to identify locations with assets vulnerable to current or projected future flooding and erosion by creating a series of close-up maps of the bay using geographical interface software (GIS), and including several overlays covering existing infrastructure, land ownership, habitats, geology/geomorphology, and predicted sea-level rise hazards. The following criteria were used in the screening:

- Presence of built and natural assets vulnerable to sea-level rise flooding hazards. Asset data were provided by the County of Marin, and were mapped previously as part of the C-SMART study (Marin County 2016, 2018). Assets were color-coded to identify which were vulnerable for short-term (1.6 ft) or medium-term (3.3 ft) sea-level rise.

- Assets mapped as vulnerable were further assessed to identify whether wave action contributes to vulnerability. Assets vulnerable only to still water flooding with SLR were excluded from further consideration, as living shorelines suitable for Tomales Bay would be ineffective in addressing this type of vulnerability.

- Evidence of long-term shoreline erosion threatening natural or built assets. Erosion was mapped by digitizing the 1965 and 2016 shorelines and identifying rates of change in the position of the shoreline.

- Opportunity areas for removing shoreline armoring. Shoreline armoring was identified from oblique aerial images of the Bay obtained from the California Coastal Records Project.

- Sensitive existing habitats vulnerable to sea-level rise (e.g. assets such as marsh areas) were mapped using information provided by the County, Greater Farallones National Marine Sanctuary (GFNMS), and the Golden Gate National Parks Conservancy (GGNPC).

The Point Reyes Station area was screened out during this initial step as it is not shown to be vulnerable under the sea-level rise scenarios considered for this study. We also screened out a potential site in Hamlet (within the Walker Creek delta) at this stage. The existing tidal marsh at the site and a portion of Highway 1 behind it is expected to experience flooding from still water levels for the highest sea-level rise scenario. However, given its location within a creek valley, risk of long-term erosion is limited, as is the available space for implementing living shorelines approaches to protect the highway from flooding. Although future erosion is not predicted to be a major issue at this location, living shorelines would have a limited ability to address flooding from high tides alone (i.e. flooding caused in the absence of wind wave runup). The Lagunitas Creek delta was also screened out at this stage, as it appears to be expanding into the bay in the long-term, and living shorelines techniques would be redundant with the existing features of the site (active sediment supply, extensive and expanding marsh vegetation, and low-sloping upland transition areas).

The ESA team (including all subconsultants) reviewed the overlay maps during a meeting on June 5th, 2020. Based on this meeting and further discussion of the subsequent weeks, six initial sites were selected (Figure 17).

- Nick's Cove

- Cypress Grove/Livermore Marsh

- Marshall (near Hog Island Oyster Company)

- Marconi (near Conference Center)

- Tomasini Point

- Martinelli Park

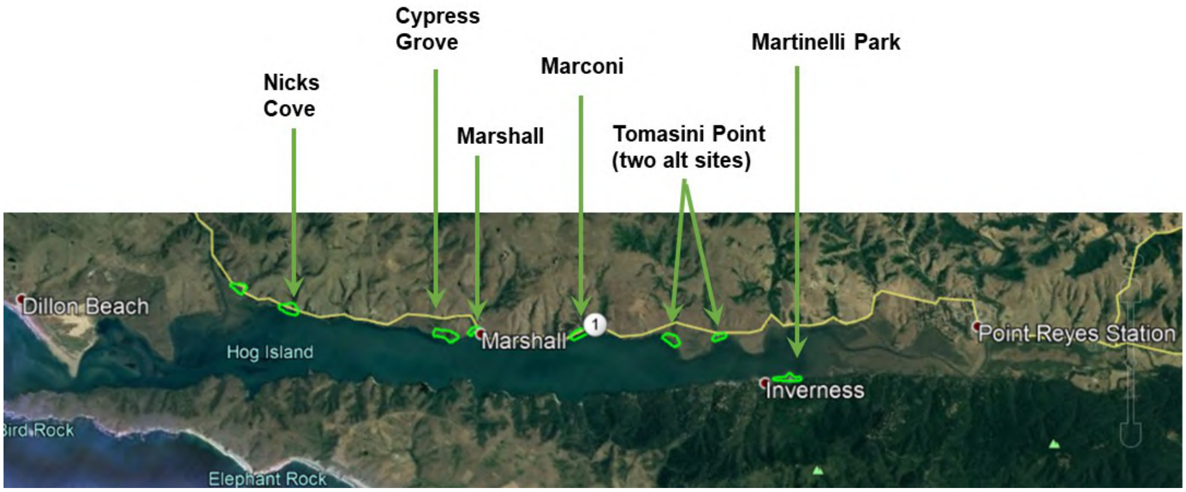

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Figure 17
Map of candidate site locations

5.2 Selection of Priority Sites

After the initial six candidate sites were chosen, the overlay maps were updated to include preliminary locations where the various living shorelines adaptation measures may be applicable (see Figures 10 through 16). Since the focus of this project is to study feasibility for a small number of priority sites, this level of placement was preliminary, and intended to be refined further for the sites that were ultimately chosen. Placement of the measures was based on the suitability criteria outlined in Section 4.

After revising the overlay maps for further review, criteria were developed to evaluate how well living shoreline treatments at the candidate sites would meet the project goals and objectives. These criteria were used to select the final sites. In developing the evaluation criteria, the team reviewed the recent C-SMART study and evaluation criteria included in recent living shorelines guidance documents, including the Marin Sea-Level Rise Adaptation Framework, Natural Shoreline Infrastructure Guidelines, San Francisco Bay Shoreline Adaptation Atlas, GFNMS Native Oyster Restoration Working Group, and others. Criteria were finalized with input from Marin CDA and input from stakeholders from a February 2020 stakeholder meeting at Point Reyes Station.

The final evaluation criteria are[4]:

1) Expectation for change in **flood hazard conditions with projected sea-level rise**. To understand whether flooding is due to still water levels or from combined still water and

[4] Note that these metrics themselves do not indicate feasibility or lack of feasibility. They are used to help identify a subset of preferred sites for developing conceptual designs. Once this is achieved, ongoing stakeholder outreach, and the process of developing the conceptual designs and supporting analyses, will give a better indication of feasibility.

wave runup conditions, we examined the sea-level rise cases with- and without the 20-year storm event. Sites where flooding only occurs during the storm case are considered to have more potential for benefits from living shorelines approaches. For each of the sea-level rise cases, we examined CoSMoS flood hazard layers for the with- and without-storm cases, to parse out which areas are predicted to experience flooding from still water levels alone (e.g. high tides), and which experience exacerbated flooding from still water levels with additional storm surge and wave runup.

2) **Erosion vulnerability**, based on historical shoreline change from 1965 to 2016 and presence of riprap (indicating historical erosion vulnerability).
3) Expectation of **ecological benefits and impacts** of a living shoreline project.
4) Opportunities for **preserving or enhancing public access and recreation**.
5) Additional **feasibility considerations**, which included constraints such as local boat traffic, space availability, and site ownership.
6) **Effectiveness/Certainty of living shorelines benefits.** This was based on sites' suitability for specific living shorelines types that would address the local underlying issue. As an example, the availability of a suitable conditions for constructing/augmenting a coarse beach could address flooding due to wave runup at some sites.
7) **Longevity of benefits**, which considers the availability of adequate space to implement living shorelines, to allow them to adjust over time to sea-level rise (and potentially to be incrementally maintained if needed) while limiting effects of sea-level rise on the shoreline behind it. This metric also considered the availability of upland transgression space, which could allow a project area to adjust in the long-term to sea-level rise.
8) **Cost and Implementation Considerations**, which include rough order-of-magnitude costs, project readiness, and permit considerations. Project readiness in this context refers to factors that would ease the long-term implementation, such as a local proponent (research institution, private landowner willing to partner on a project, public entity), or opportunities for site access, maintenance, and monitoring.

A set of first-tier candidate sites were apparent based on these metrics: **Nick's Cove**, **Cypress Grove** and **Martinelli Park**.

5.3 Final Site Selection

CDA and the project team discussed the candidate sites with the regulatory agencies through a series of meetings in November and December 2020, and January 2021. The intent of the meetings was to discuss the potential overlap of project sites with existing shoreline habitats, particularly mapped eelgrass extents (e.g. see Merkel et al. 2017), Pacific Herring spawning areas, and existing rocky habitat along the shoreline edge. This is described in more detail in Attachment G. Following input from the regulatory agencies, CDA chose **Cypress Grove** and

Martinelli Park as the preferred sites. Section 6 below describes the conceptual designs developed for each site. Nick's Cove was not selected at this stage due to close proximity of eelgrass beds adjacent to the shoreline, and lack of backshore space for long-term adjustment of the profile with sea-level rise.

5.4 Conflict Avoidance Framework for Existing Eelgrass

One of the primary challenges identified during the site prioritization and preliminary design development stage of the project has been the recognition that eelgrass habitat occurs in a more or less continuous band along the majority of Tomales Bay's eastern shoreline. In many instances, eelgrass was noted to abut the toe of the hardened shoreline, typically occupying the majority of the low intertidal and shallow subtidal area where suitable, unconsolidated sediments comprise the bay floor. In some cases, eelgrass habitat appears to be negatively affected by the presence of shoreline infrastructure interrupting otherwise suitable habitat conditions (e.g. tire reef extending from the shoreline down into the shallow subtidal at Marconi). In other cases, the presence of armoring elements appears to influence sediment transport in a manner that may enhance eelgrass abundance at a local scale. However, these observations remain anecdotal and ultimately equivocal in the absence of available historic eelgrass distribution data that predates legacy armoring and fortification efforts.

At the site scale, the presence of eelgrass may pose the greatest challenge to accommodating living shoreline designs that otherwise meet the objectives of the project, suggesting the need to consider a more programmatic approach to addressing eelgrass resources in Tomales Bay. Resolution of issues with failing shorelines and sea-level rise adaptation may be strongly hindered by eelgrass habitat that has taken hold of shoreline areas that have scoured to a configuration supporting eelgrass at shoreline toes and steep and eroding margins above. In terms of enhancing salt marsh, beach/dune ecology and native oyster populations through implementation of site specific living shoreline design strategies, the principal challenge identified has been potential conflict with and impacts to existing eelgrass beds in close proximity to candidate treatment sites. Addressing this apparent and sometimes insurmountable conflict between resources either leads to the need to abandon quality opportunities, or broaden the thinking about coupling sites as units or taking a watershed approach strategy wherein localized impacts to eelgrass may be accepted for broader adaptation gains while still ensuring that eelgrass resources are retained at the same scale, if not in the same area.

Given the spatial constraints of working with existing eelgrass beds within the bay, we recommend an approach that (1) attempts to minimize eelgrass impacts at the site-scale by conducting additional surveys throughout the planning process (to allow avoidance of eelgrass beds in continued design refinements), and (2) development of a bay-wide strategy that will ultimately have a larger effect on eelgrass with sea-level rise. The latter is discussed further in Section 7.

CHAPTER 6

Preliminary Design for Priority Sites

Preliminary designs were developed for Martinelli Park and Cypress Grove at an approximately 10 percent level, intended to be sufficient to determine whether a project is feasible at each site. For each design, we provide a brief description, plan-view and typical cross-sections for each site, and approximate quantity and cost estimates.

6.1 Design Approach

Design development followed a structured approach, building on information presented earlier in this report:

- We reviewed existing conditions at each site, focusing on historical context (understanding the trajectory of shoreline change that has led to existing shoreline configuration), and on the key vulnerabilities to erosion, flooding, and habitat loss. Vulnerabilities were identified from low points in topography of the shoreline, from documentation of past events, and from communication with local residents.
- Topographic surveys were conducted at each site to help establish a baseline[5].
- Living shorelines concepts were developed at each site. The choice of alternatives and their placement were based on an applied geomorphology approach: alternatives are intended to mesh with a landscape that is evolving, and will continue to evolve with sea-level rise.
- We evaluated potential for flooding and erosion using coastal engineering approaches, and evaluated potential ecological implications.
- Material quantities were developed for the concepts, and rough order of magnitude (ROM) costs were developed from these. Costs were also developed for some no-project scenarios, such as long-term maintenance actions expected with sea-level rise.

The concept designs are evaluated based on their ability to meet the project goal and objectives. In general, our approach in developing designs for this project has been to study local reference

[5] ESA performs land surveys and collects hydrographic data to augment traditional surveying services for the purposes of engineering, geomorphic interpretation, monitoring of project performance, and other specific uses consistent with California Business and Professions Code (Civil Engineering practice as defined by Section 6731.1. of the Professional Engineers Act and Geologic and Landscape Surveys as defined in the Professional Land Surveyors' Act). ESA does not provide traditional land survey services such as property boundaries and maps for general use by others. ESA recommends that these traditional surveying services be accomplished by a licensed, professional land surveyor either under direct contract with the client or as a sub-consultant to ESA.

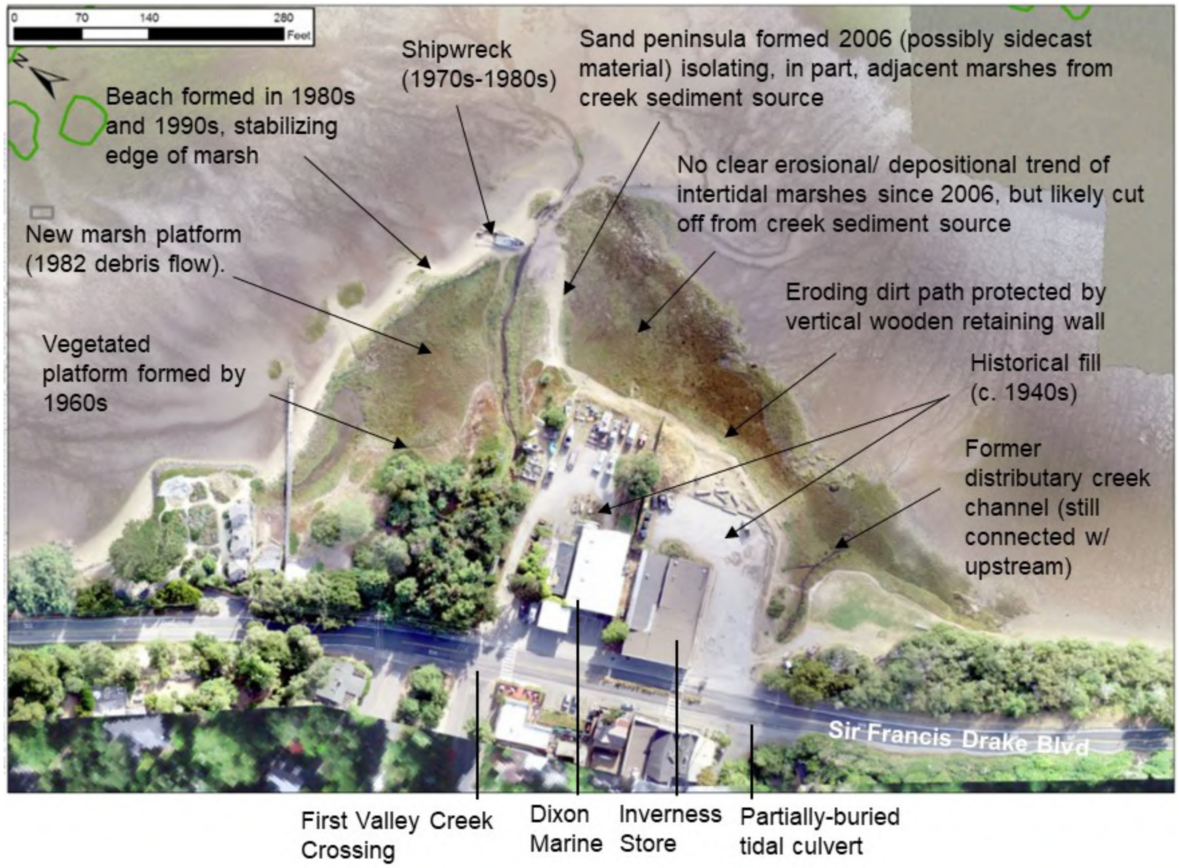
sites and work with local natural processes and landforms to the extent feasible, to meet the project goal and objectives. Though local reference sites are used to constrain the characteristics of the alternatives, we also considered lessons-learned from projects developed elsewhere in California, and considered the specific needs of each site.

6.2 Martinelli Park

6.2.1 Existing Site Conditions

Martinelli Park is a roughly 7-acre shoreline park in southern Inverness Park, backed by Sir Francis Drake Blvd (Figure 18). The site has a mix of public and private ownership, and is popular with the public, who visit the site for its direct access to the shoreline, historical features (the shipwreck of the *Point Reyes*), and its panoramic views of the Bay. Most of the site consists of a pro-grading (expanding) creek delta (the terminus of First Valley Creek) with commercial structures built onto the southern half of the historical delta. The northern half of the delta consists of an emergent saltmarsh fronted by a sandy beach, and the southern half consists of a pad of artificial fill underlying Dixon Marine and the Inverness Store, which is fronted by a slightly elevated dirt path held in place by a wooden retaining wall. The retaining wall abuts low-lying cordgrass marsh and adjacent mudflats.

First Valley Creek has been channelized with earthen berms and discharges through the center of the delta, running along the northern edge of the Dixon Marine parcel (Figure 18). The tidal portion of the creek is connected to the upstream watershed via a series of culverts under Sir Francis Drake Blvd, Hawthornden Way, and Laurel Way. A tidal channel at the southern edge of the delta is also connected to upstream areas via a culvert under Sir Francis Drake Blvd.



Source: Background aerial image form Merkel and Assoc.

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Note: historical dates based on review of public documents and aerial images, and pers. Comm. With J. Fox, D.Livingston and others.

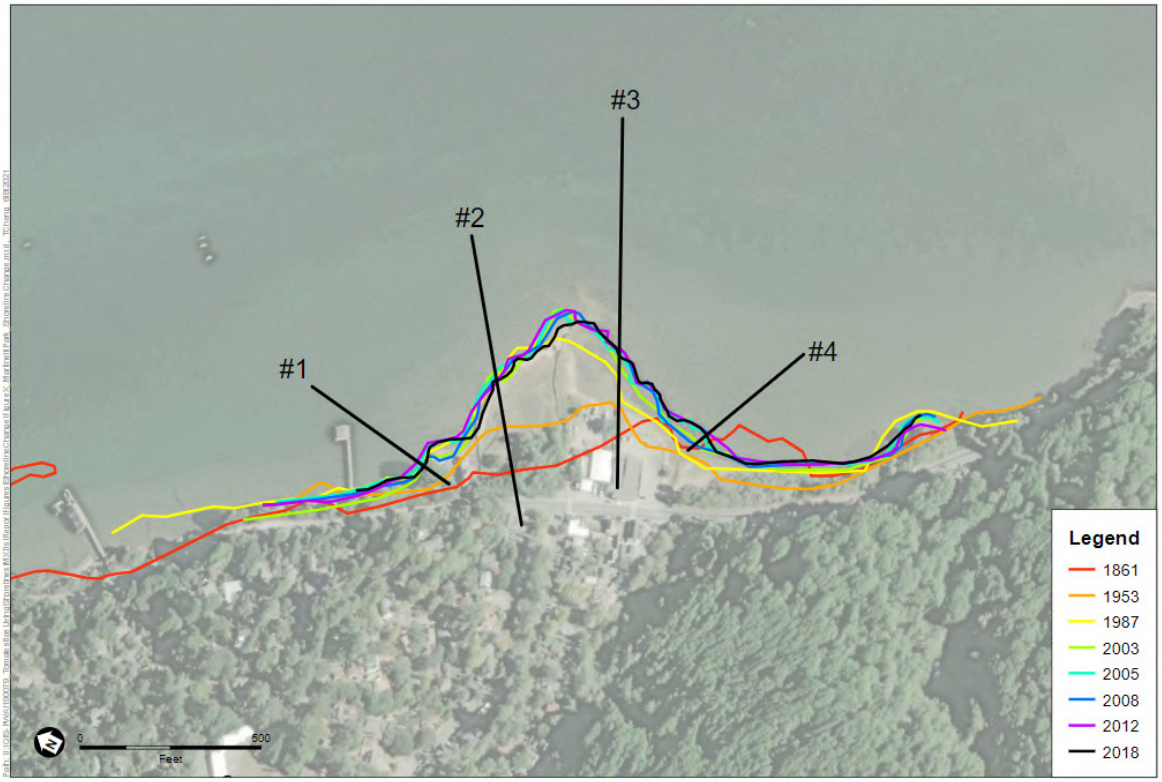
Figure 18
Site map of Martinelli Park

The park fronts a low point in Sir Francis Drake Blvd, which is already vulnerable to flooding during coastal storm events. Buildings onsite are also vulnerable and much of the marsh areas are underwater during annual king tides. The site is a focal point for the community, with a number of public amenities adjacent to the roadway, including the Inverness Public Library, a restaurant, the Inverness Store, and several other commercial properties. Sir Francis Drake Blvd is also the primary emergency evacuation route for the towns of Inverness Park and Seahaven.

6.2.1.1 Historical Context

Historical nautical charts and images suggest that the delta of First Valley Creek was originally much smaller and has pushed out onto the bay in several phases:

- Prior to development, the historical delta was smaller and farther south, near the location of the small tidal culvert on the south end of the site (see 1861 shoreline in Figure 19). It is unclear if the culvert was the main channel or a distributary channel.



Source: digitized USGS aerial images and USC&GS maps

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Note: numbered lines represent transects used to estimate shoreline change rates

Figure 19
Historical shoreline change at Martinelli Park

- The creek was later channelized and routed to its existing alignment, likely during initial development of the area in the late 1800s. Artificial fill was present in the vicinity of Inverness Store by the 1940s.

- Major sediment delivery from the first wave of land-use changes to the western shore caused extensive mudflat widening through the twentieth century. Sediment infill from the first wave of development likely peaked from 1930-1960 (Rooney and Smith 1999). By 1953 the vegetated portion of the delta was still limited to the area immediately adjacent to the roadway (Figure 19).

- Major flooding occurred during January 1982. After December 1981 brought significant rainfall (saturating soils within watershed), a very high-intensity rainfall event on January 4, 1982 triggered major landslides, which filled the creek with excess sediment that caused sheet flow over the adjacent roadways in the watershed (Inverness Ridge Communities Planning Group 1983). This rainfall event coincided with tidal levels of about 7 feet NAVD88 at Point Reyes, roughly consistent with a king tide event. The landslides within the First Valley Creek watershed eventually deposited on the delta, doubling its size and depositing at least 1 foot of material (Anima et al. 1988). Much of this material remained on site and emergent marsh formed by the 1990s.

- The appearance of the *Point Reyes*[6] shipwreck near the mouth of creek (circa 1970s or 1980s) began to arrest the normal southward movement of beach sand, causing a beach to accumulate in front of the emergent marsh on the northern half of the delta.
- A major storm during the winter of January 2006 again delivered an excess of sediment to the delta from sustained rainfall. Around this time, the southern earthen peninsula is visible along the right bank of the creek. This could have been formed as a combination of natural over-bank deposit of creek sediment and emergency removal of sediment from the creek.

6.2.1.2 Site Vulnerability

Public input gathered from the C-SMART project (Marin County 2016, 2018) identified Inverness Park as a particular area of concern for long-term flood vulnerability, with particular focus on areas of relatively dense coastal development such as Martinelli Park. Based on review of this input, and review of CoSMoS flood maps, NOAA tide information, and discussions with residents as part of this project, the major concerns include:

- Vulnerability of shoreline buildings and the road from high coastal water levels
- Vulnerability of Sir Francis Drake Blvd and underlying infrastructure (water supply lines) to damage during storm events
- Combined flooding of the roadway and buildings from high tides coinciding with high rainfall (similar to the winter 1982 and 2006 events).

A particular concern at the site is the low point in Sir Francis Drake Blvd adjacent to the Inverness Store (Figures 20 through 22). The road in this location dips to an elevation of about 8.5 feet, which places it below the existing 100-year recurrence coastal flood level. With sea-level rise, this would become a more frequent event (Figure 21). The road is currently protected by a series of ad hoc earthen berms fringing the parking lot for the Inverness Store. These are held in place by a wooden retaining wall. The surface of the berm is used as a walking path for the public, and has an uneven surface. Two low points, one on the north side, and another near where the path connects to Sir Francis Drake Blvd, are the key locations where overtopping would occur during a coastal storm event (Figures 21 and 22). Table 5 below lists their elevation, and other key elevations of the site.

Another concern is the culvert that currently passes flows from First Valley Creek to the bay (Figure 20). The culvert has an open connection to the bay (i.e. no hydraulic structures such as flapgates prevent upstream flow of tides). Since no survey data are available in the creek channel, it is unclear where the upstream extent of tidal interaction occurs on the creek, although the channel thalweg is at approximately high tide level near the downstream end of

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[6] The shipwreck of the *Point Reyes*, a boat built in 1944 as a World War II launch boat that ferried soldiers from aircraft carriers in the Bay Area to port, and then used and operated as a fishing vessel, was landed on the shore in its existing location likely in the 1970s or 1980s. https://www.sfgate.com/obscuresf/article/SS-Point-Reyes-shipwreck-Instagram-photo-Tomales-16296783.php

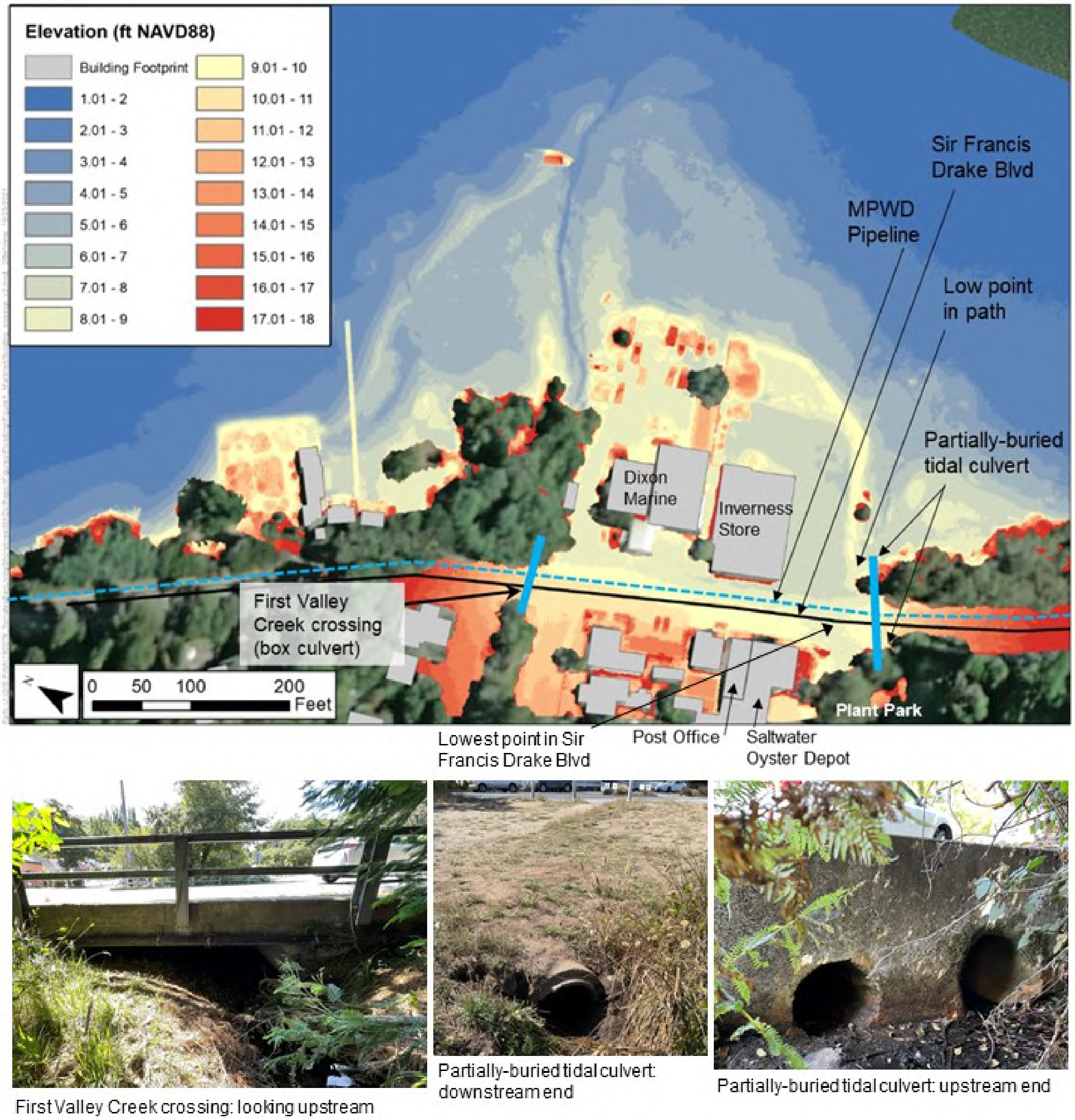
the culvert. The culvert was studied for fish passage in 2003 (Ross Taylor Associates 2003), who noted that it was likely capable of passing the 100-year event without overtopping its banks. However, heavy sediment loads associated with rainfall caused the creek to fill with sediment during the January 1982 (Inverness Ridge Communities Planning Group 1983, Anima et al. 1988) and January 2006 (pers. Comm. J. Fox) events. During the 1982 event, this severely limited capacity of the creek and led to sheet flow of water onto the roadway. With sea-level rise, high tides will increasingly limit outflow during rainfall events, increasing the likelihood of the stream again flooding along its banks and damaging structures. This could also damage or otherwise limit transport on Sir Francis Drake Blvd, the primary evacuation route for Inverness Park and Seahaven.

The site is vulnerable to the 20-year recurrence coastal storm event with 1.6 feet of sea-level rise (Figure 23; left panel). Without a project, Figure 23 shows that the extents of flooding would increase over time. These maps are based on the available CoSMoS flood maps which assume that the landscape does not change over time, so these likely underestimate changes to vulnerability that would occur if erosion occurs along the shoreline berm. The location of emergent groundwater (white hatched areas in Figure 23) will also expand with sea-level rise. For sea-level rise of 3.3 feet, groundwater levels are expected to be emergent in the vicinity of the Inverness Store and much of Sir Francis Drake Blvd.

TABLE 5
ELEVATIONS OF KEY STRUCTURES AT MARTINELLI PARK

Site Feature	Elevation (ft NAVD88)
Low point in berm near Sir Francis Drake Blvd	8-8.5
Low points in berm in front of Inverness Store and Dixon Marine	8-9.5
Inverness Store base floor	7.5-8
Lowest point in Sir Francis Drake Blvd	8.5
Bed of partially blocked tidal culvert: Outlet	5.5-6.5
Bed of partially blocked tidal culvert: Inlet	5.5-6.5
First Valley Creek: thalweg on downstream side of culvert under Sir Francis Drake Blvd	6-7[1]
Wooden retaining wall in front of Inverness Store: base	6
Wooden retaining wall in front of Inverness Store: top	9-9.5

[1]Estimated from bridge deck elevation and approximate distance to bed during time of August 2020 survey



Source: Topography from June 2020 photogrammetry from Merkel and Assoc. images taken by Maureen Downing Kunz

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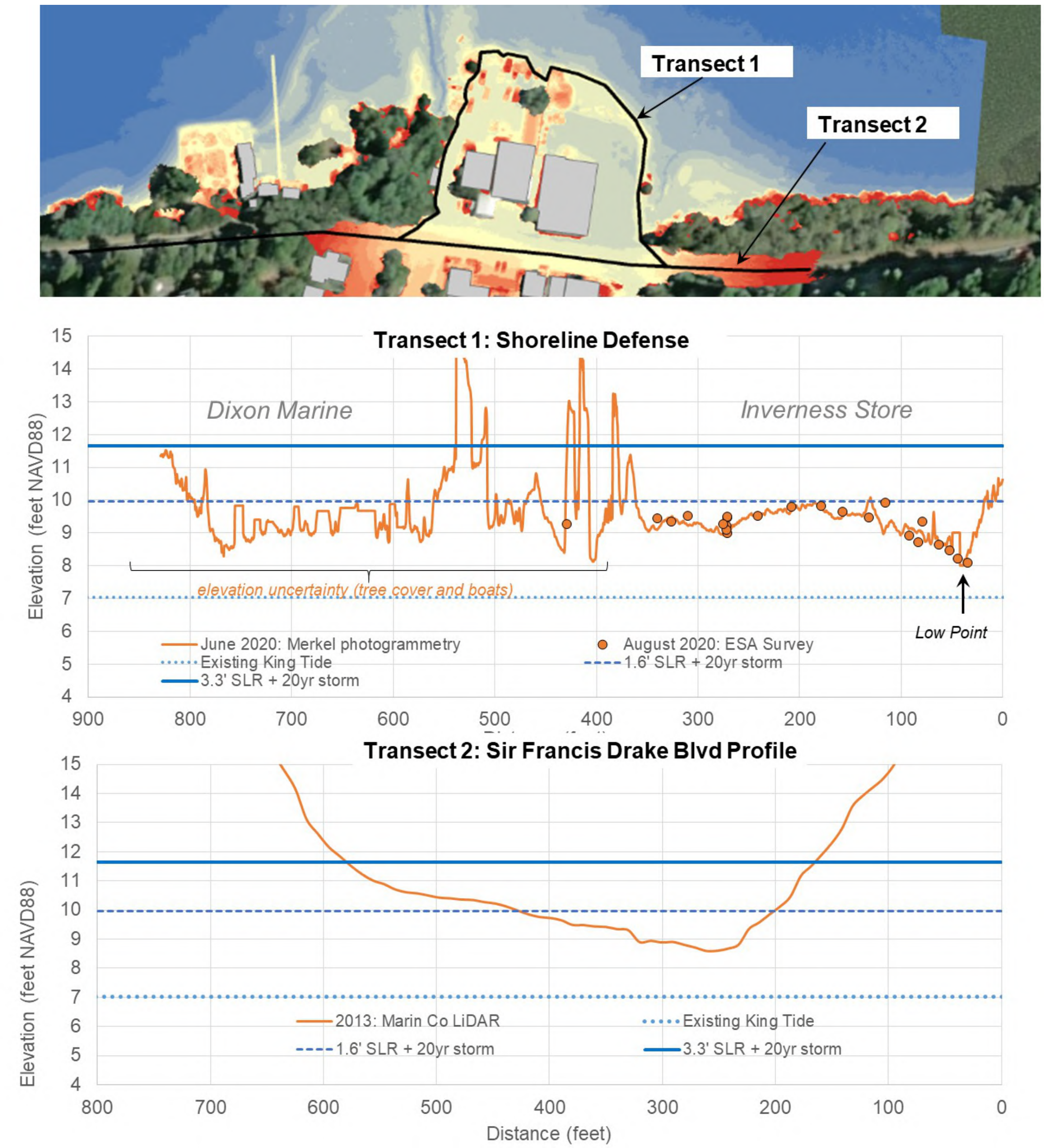
Figure 20
Topographic Map of Martinelli Park, showing key infrastructure and points of interest



Source: Elevations from ESA and Merkel & Assoc. 2020 surveys, and 2013 County of Marin LiDAR

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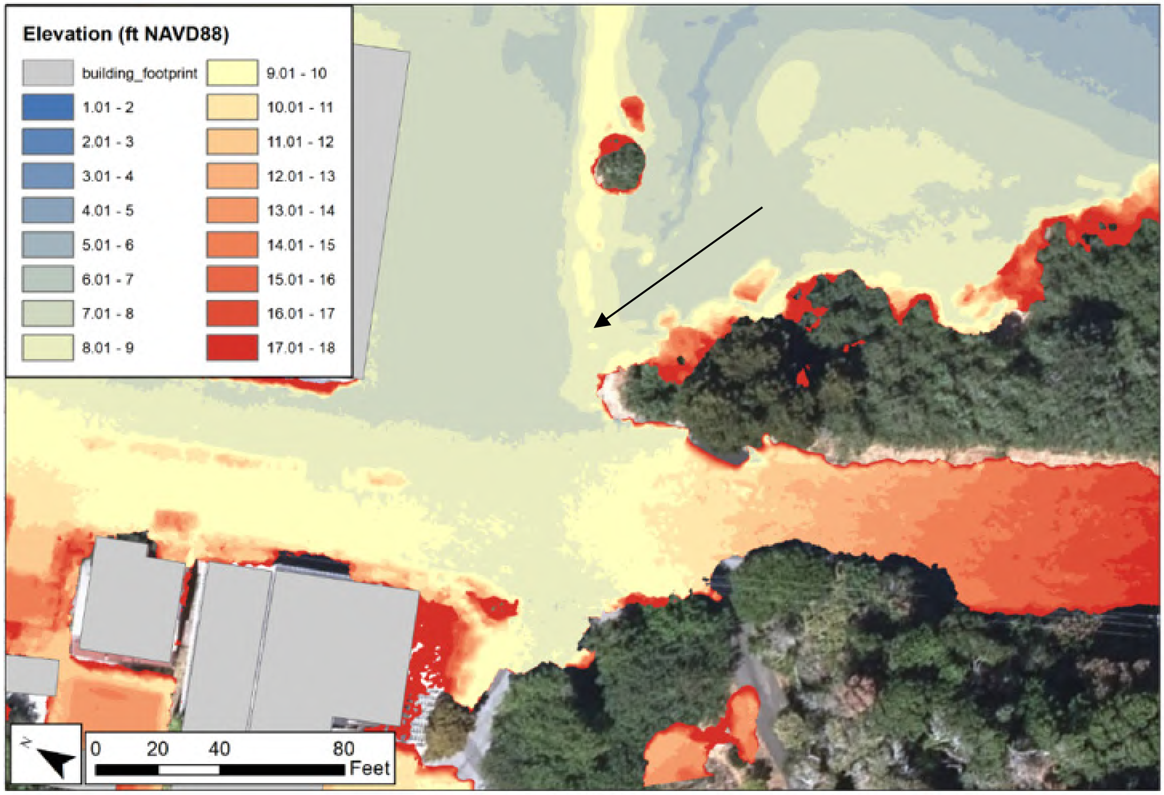
Figure 21
Topographic Map of Martinelli Park, showing Shoreline high points and Sir Francis Drake Blvd profile



Source: Merkel & Assoc photogrammetry (June 2020)

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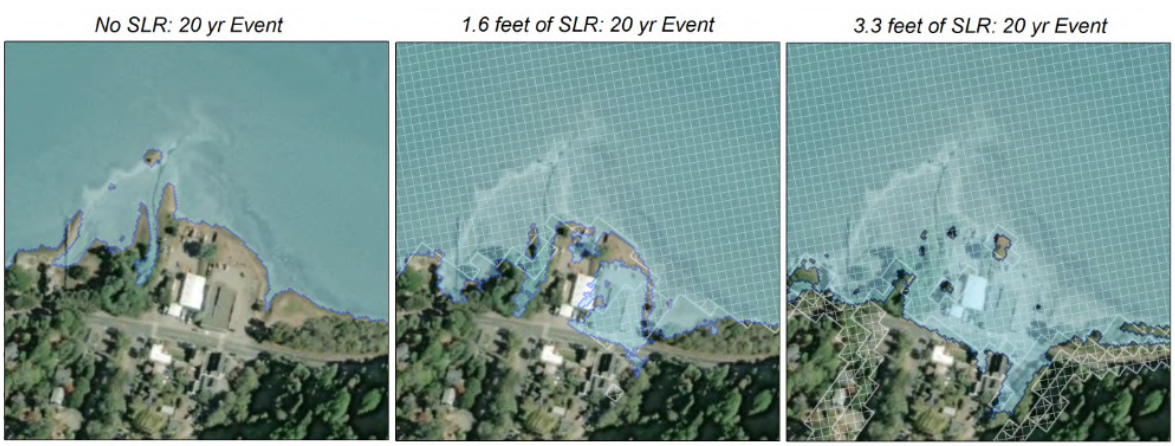
Figure 22
Close-up topographic Map of low point in Sir Francis Drake Blvd.



Source: Our Coast Our Future Website

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Figure 23
CoSMoS flood predictions for surface water flooding (solid blue layer) and groundwater emergence (white hatched layer).

6.2.2 Design Overview

Figure 24 and Figure 25 present plan-view and typical sections of the conceptual restoration design, including several options that balance the following objectives:

1) **Enhancing shoreline erosion protection** by improving sediment delivery and retention at intertidal elevations. This is achieved by lowering artificially-high lateral creek berms and fronting the southern marsh with a beach. The beach (positioned near the location of a historical beach at the site), will evolve in response to storm events and may vegetate over time.

2) **Enhancing flood protection of the roadway and shoreline properties** by laying back and raising the existing berm, providing a higher elevation crest, wider upland-transitional slope, and elevated path. The new path would have a crest elevation of 12 feet NAVD88 and a flatter slope of 7 H: to 1 V. This feature would be more resistant to future erosion and overtopping than the current path. If a beach described under (1) above is implemented, it could provide a layer of redundancy by limiting the size of waves that arrive at the interior shoreline during flood events.

3) **Lowering the likelihood of combined tidal-creek flooding upstream** by improving the channel connection (removing sediment and non-native vegetation from the creek channel, enlarging the creek culvert, and identifying future fish-passage and creek maintenance actions that could reduce the risk of sediment delivery exacerbating flooding on the creek).

Note that figures 24 and 25 represent a potential layout of the design as constructed, and that the site is expected to evolve over time. Figures 24 and 25 were used to develop approximate quantities of material. If funding is acquired for further development, the design will be refined in a future phase.

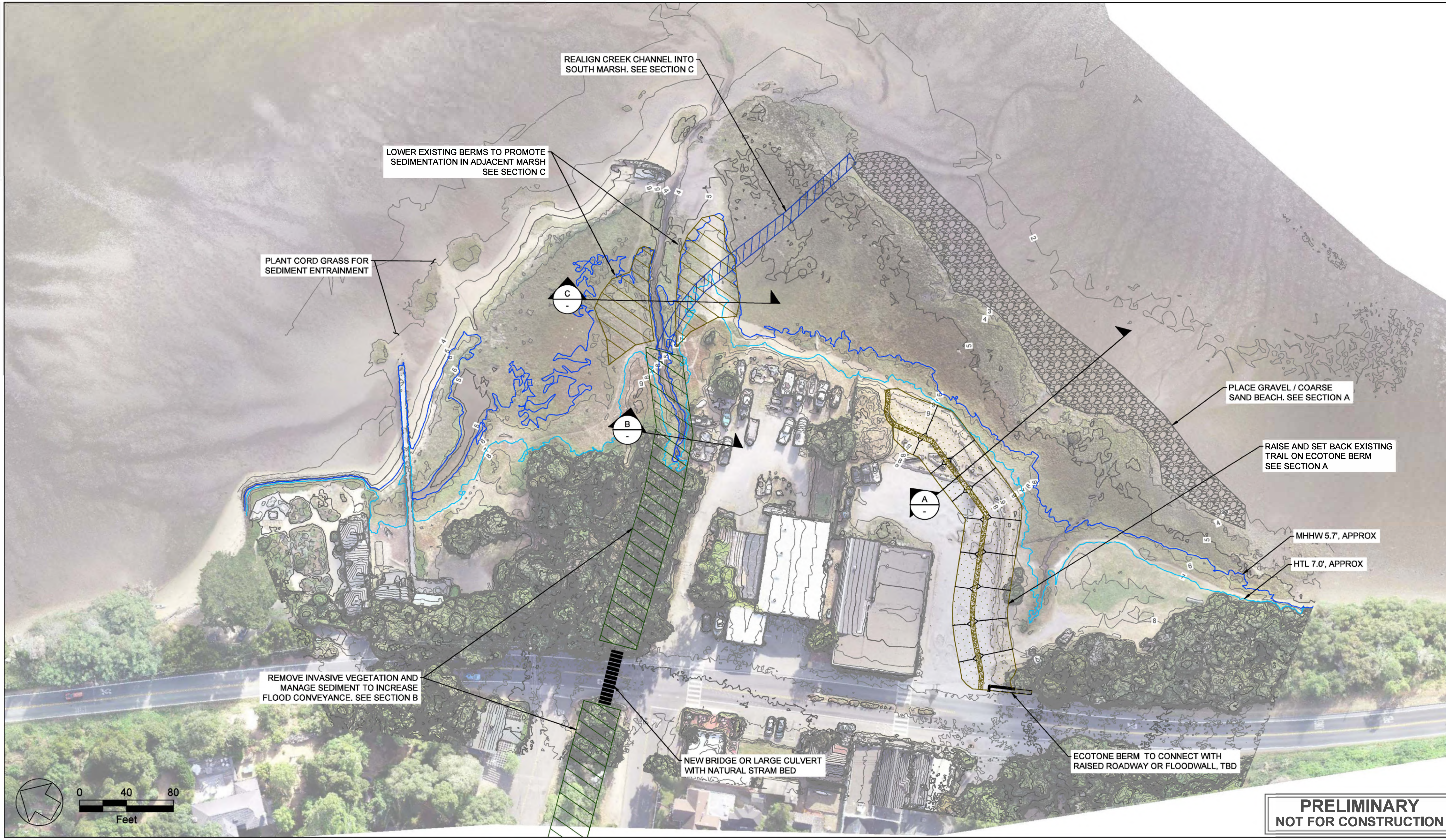
The primary ecological benefit of the project is that it would prolong the resilience of the existing marsh to sea-level rise at the site by restoring natural sediment transport processes. The project also provides a more functional upland transition space, creates opportunities to preserve fish passage in First Valley Creek, remove non-native vegetation, and explores the possibility of native oyster restoration offshore. The primary benefit to infrastructure is a reduced risk of flooding, both on First Valley Creek, and also along the shoreline.

6.2.3 Living Shorelines Design Elements

The restoration design concept for Martinelli Park comprises several strategies, including creek-to-bay reconnection, beach restoration, marsh restoration (through laying back the existing path), and native oyster restoration. The individual treatments are shown in Figures 24 and 25, and described in Table 6 below. Table 6 also lists potential opportunities and constraints.

TABLE 6 CONCEPTUAL DESIGN ELEMENTS AT MARTINELLI PARK

Adaptation Measure	Description	Benefits	Limitations and Other Considerations
1. Improve flood conveyance and sediment discharge on First Valley Creek	Implement periodic maintenance (sediment removal) of the culverts on First Valley Creek, and consider removing non-native vegetation from the creek east of Sir Francis Drake Blvd. Consider enlarging the size of the culvert under Sir Francis Drake Blvd to reduce the impact of sea-level rise on water level conditions at the culvert during creek flood events. To the extent possible, Measure 3 should include riparian shading elements along the lowered creek berms to limit future choking of the realigned channel by marsh plants.	• Reduce damage to park assets and roadway from combined creek/tidal flooding. • Increasing flood conveyance via culvert enlargement and clearing out the creek reduces the extent of inundation from 100-year extreme event and future sea-level rise.	• Non-native vegetation and sediment removal associated with existing conditions (with or without project) will incur regular maintenance costs.
2. Grade back and raise dirt path	Replace the existing wooden retaining wall (which will eventually fail), by setting back and raising the existing berm. This will create a much more stable transition with a lower slope, and can be vegetated with native upland plants. The new transition zone will provide less of a long-term erosion and flooding liability than the wooden retaining wall. The raised path would extend to the nearest high ground along the eastern face of the junction with Sir Francis Drake Blvd, and directly address the current vulnerability to flooding of the roadway. The raised path would need to connect to either a raised roadway or a floodwall fronting the road on the bay side.The graded slope would include a succession of marsh to upland plants: gumplant, saltgrass, alkali-heath, pickleweed, jaumea, and sea-lavendar at 7-8 feet NAVD88; red fescue, saltgrass, alkali-heath at 8-10 feet NAVD88; perennial native grasses at 10-12 feet NAVD88.	• Reduce flooding of Sir Francis Drake Blvd and adjacent businesses, allowing time for the County to raise the roadway • Mitigate future erosion of the shoreline in its current position. • Create functional marsh-upland transition that is currently absent.	• Does not address flooding from rising groundwater levels by 3.3 feet of SLR • May constrain future site footprint by locking the existing shoreline in place. • Could affect availability of parking space for Inverness Store users, and site visitors trying to access the shoreline
3. Realign First Valley Creek mouth and lower creek berms	Restore natural deltaic sediment transport processes by lowering the creek berms near the mouth and redirect the mouth to the south. This will increase the frequency of sediment deposition on the adjacent marshes, improving their ability to self-maintain in the face of sea-level rise. The marshes in turn will then provide better erosion protection to the shoreline.	• Support marsh accretion so that existing marsh habitats can keep pace with sea-level rise • Potentially improve flood conveyance on the creek, by increasing the size of the cross section near the mouth.	• Orientation of channel alignment is constrained due to developed fill area, so flow and sediment may continue to be deflected offshore more than desired • Channel geometry may need to be refined to for sediment delivery during different flow conditions • Redirecting the creek may impact public access by making it more difficult for the public to access the shipwreck • Redirecting the creek would result in conversion of about 0.02 acres of cordgrass marsh to tidal channel.
4a. Construct beach in front of southern marsh	Beneficially reuse coarse material obtained from creek maintenance (Measure 1) and berm lowering (Measure 3) by placing on the tidal flats to the south of the creek mouth. Over time, construct a coarse beach fronting the marsh, which will protect the marsh from erosion with sea-level rise and provide a redundant measure for shore protection (in combination with Measure 2). The beach may stabilize with marsh vegetation over time, potentially becoming a coarse marsh edge. In this case, this shoreline edge would still have a benefit for mitigating long-term erosion and wave-related flooding at the site. It is not known at this time how much of this material will be available from measures 1 and 3, but in terms of raw volumes, roughly half of the material needed could be available from these other measures.	• Limit or prevent erosion of the southern marsh with sea-level rise. • The littoral and creek-delta sediment transport pathway will be restored along the modified shore (see also 1., 2., and 3) • Will mitigate erosion and flooding by dissipating waves and is sustainable with moderate rates of sea-level rise • Provide local beneficial re-use of creek maintenance sediments	• Placed sediment may wash away in extreme event; sediment will likely have to be placed several times, as material becomes available. • Not all creek maintenance sediments will be suitable for local re-use on the beach. Sediment reuse will require a staging area for sediment sorting and screening.
4b. Place retention features in beach face for oyster recruitment	Create naturalistic groin features in the new beach fronting the marsh (Measure 4a), using coarse material (cobbles and small boulders) that are appropriate as substrate for native oysters. Groin features would also improve retention of sediment in the beach, which would otherwise be expected to drift to the south over time. This would need to be studied, as it is also possible the beach face would recruit marsh sediment over time and stabilize without the need for retention features.	• Support sediment entrainment and enhance marsh habitat longevity • Conducive to community-led monitoring and participation.	• High mudflat elevations near the proposed beach could make oyster recruitment difficult.



NOTE: TOPOGRAPHIC ELEVATION DATA AND IMAGERY FROM MERKEL & ASSOCIATES (2020)

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Figure 24
Martinelli Park Living Shoreline Concept Plan

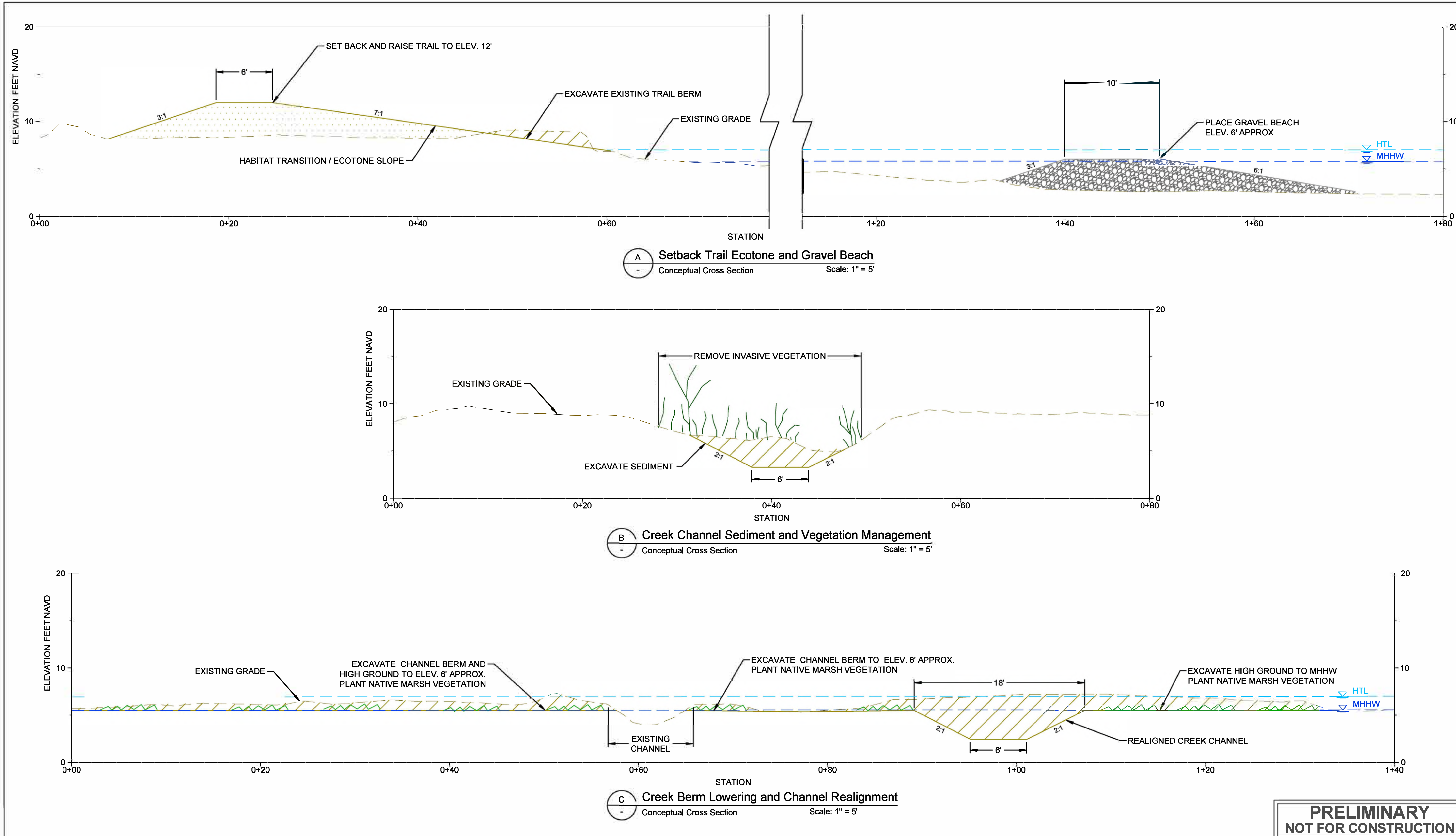

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Figure 25

Martinelli Park Living Shoreline Concept Typical Sections

6.2.3 Project Benefits

6.2.3.1 Benefits to Infrastructure

The project is expected to significantly reduce the frequency and duration of flooding of the roadway. Specifically, the proposed action of setting back and raising the path on a higher, wider berm tied into high ground (see Figure 24) will reduce flood overtopping onto the road and also reduce erosion of the berm. Offshore measures (offshore beach and/or native oyster restoration) will help stabilize the toe of the marsh and improve the longevity of the new shoreline. Such actions would be cost-beneficial by reducing the long-term cost of roadway maintenance stemming from coastal flooding.

Potential for reducing flood risk along the shoreline was evaluated with and without storm conditions with different amounts of SLR:

1. With storm (20-year event) conditions. Calculated the total water level resulting from tides and wave runup on the shoreline near the low point in the dirt path on the north side of the Inverness Store for 0, 1.6, and 3.3 feet of sea-level rise.

2. Without storm conditions. Calculated the number and duration of tidal overtopping events that would occur at the lowest point in the dirt path, near its connection with Sir Francis Drake Blvd for 0, 1.6, and 3.3 ft of sea-level rise.

Table 7 compares total water levels near the Inverness Store with and without the project for storm and non-storm conditions. The total water level was calculated using wind waves estimated as part of this study, and using standard coastal engineering methods (Attachment C). Table 7 shows that the total water level would be significantly reduced with the project. No overtopping is expected to occur during a 20-year event for sea-level rise of 3.3 ft or less with the project in place, while overtopping was predicted to occur for existing (no project) conditions for 3.3 ft of sea-level rise.

Table 8 compares the number and duration of tidal overtopping events onto Sir Francis Drake Blvd with and without project for combined tides and wind setup. The road is relatively protected from waves, but is vulnerable to flooding from (stillwater) high tides with sea-level rise because of its low elevations (8.5 to 9 feet NAVD88) near the south side of the site. To estimate tidal overtopping, we applied the observed 1980-2021 hourly time series of tides at Point Reyes, applied additional wind setup based on concurrent wind speeds reported at Bodega Head, and counted the number and noted the duration of events when levels exceeded the low point in the dirt path (Elevation 8-8.5 feet NAVD88). We then incrementally raised the tides with sea-level rise and counted overtopping events again, obtaining annual average numbers of events across the period from 1980 to 2021. As shown in Table 8, the proposed shoreline enhancements would significantly curtail the number of roadway flooding events with sea-level rise: under baseline conditions and 1.6 ft of sea-level rise, the roadway would be expected to flood from tides approximately 60 times per year, with most events lasting less than 3 hours, and 4 events lasting 3-6 hours. For 3.3 ft of sea-level rise, the road was estimated to experience short (less than 3 hour) overtopping events 179 times per year, and experience 259 events per year with overtopping lasting 3 to 6 hours. Events lasting longer than 6 hours were also predicted to occur. With the project, overtopping is not predicted to occur from tides and wind setup below sea-level rise of 4 feet (the highest value we assessed), except for the possibility of wave runup during extreme events with combined high tides and extreme winds. During storm events, the project continues to provide benefits by limiting the time that overtopping would occur, reducing flood levels (and potential damage to infrastructure) behind the shoreline.

The project is expected to reduce the risk of combined creek and coastal flooding (through sediment removal / creek channel enhancement and widening of the existing culvert), but the extent of this improvement is unknown without further study of the channel hydraulics (out of the scope of this current contract). The partially-buried culvert under the low point in Sir Francis Drake is another pathway for flood waters to move upstream. This could be addressed by installing a one-way check valve on the culvert outlet, which would allow continued drainage of the Plant Park without allowing future tidal incursions upstream. Another option would be to fill the existing culvert with permeable material (gravel or similar) that would allow groundwater exchange under the road, but limit the rate of flow. If Sir Francis Drake Blvd is not raised as part of this project, any water introduced to the site via overtopping events that occur would be expected to drain south across the roadway to Plant Park, and then pass under the roadway to the bay via the existing culvert.

TABLE 7
ESTIMATED TOTAL WATER LEVELS AT MARTINELLI PARK NEAR THE INVERNESS STORE WITH AND WITHOUT PROJECT

		Total Water Level (ft NAVD88)	
	Event	**Without Project**	**With Project**
Transect 1: armored shoreline	MHHW: No SLR	6.0	6.0 (no overtopping)
	MHHW: 1.6' SLR	9.5	8.2 (no overtopping)
	MHHW: 3.3' SLR	12.0	10.1 (no overtopping)
	20-yr Event: No SLR	11.5	9.8 (no overtopping)
	20-yr Event: 1.6' SLR	13.4	11.4 (no overtopping)
	20-yr Event: 3.3' SLR	15.1	13.1

TABLE 8
ESTIMATED OVERTOPPING EVENTS PER YEAR AT MARTINELLI PARK NEAR SIR FRANCIS DRAKE BLVD WITH AND WITHOUT PROJECT

		Without Project			With Project		
		Sea Level Rise Amount (feet)			Sea Level Rise Amount (feet)		
	Overtopping Event Duration	**0**	**1.6**	**3.3**	**0**	**1.6**	**3.3**
Martinelli Park: Near Sir Francis Drake Blvd.	0-3 Hours	0	56	179	0	0	0
	3-6 Hours	0	4	259	0	0	0
	>6 Hours	0	0	7	0	0	0

6.2.3.2 Habitat Benefits

The project is expected to provide a number of ecological benefits:

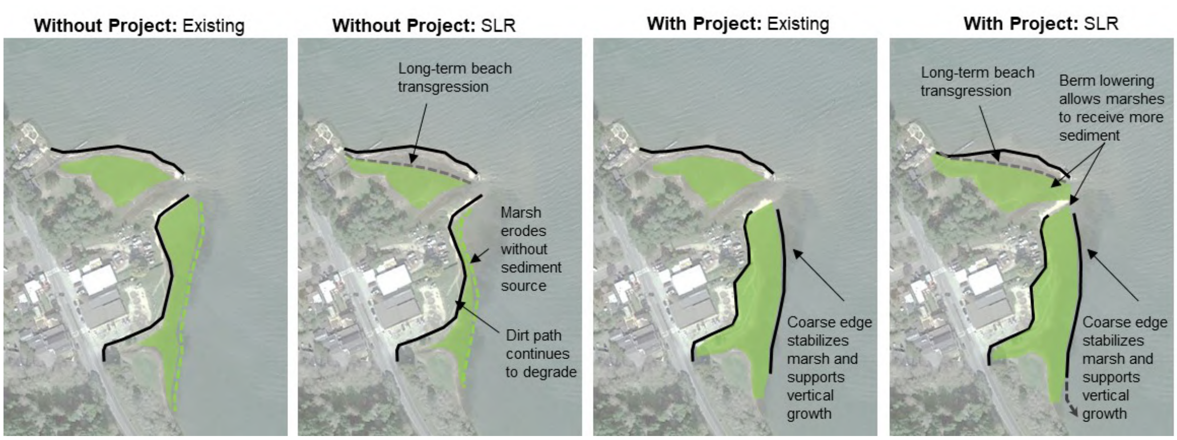
- Grading of the existing berm and wooden retaining wall into a tidal marsh-upland transition zone may benefit tidal marsh species, and can be managed in a way to provide more of a buffer for wildlife. Planting newly established upland transition zone slope with plant species that provide dense cover within at least 1 foot of the ground will increase transition zone habitat value for tidal marsh and other bird species.
- Notching the channel's south berm may increase channelization in the existing marsh which will benefit Song Sparrow, Common Yellowthroat, and rail species.
- If the placement of beach material on the southern shoreline includes small sediment retention features made of cobbles, native oyster recruitment may be possible at elevations of about 1 foot above MLLW and lower. This would need to be studied closely, and fine sediment offshore may make it difficult to maintain the interstitial spaces in coarse material needed for recruitment. Hard substrates at this location may also provide additional habitat for other intertidal rocky shore species, such as barnacles, mussels, crabs, and other small crustaceans, which may benefit some guilds of birds.
- Placement of native beach sand and targeted planting of Pacific cordgrass (*Spartina foliosa*) along the toe of the existing shoreline may protect the marsh edge from wind-wave erosion.
- Widening or otherwise enlarging the First Valley Creek connection under Sir Francis Drake Blvd will improve fish passage conditions for steelhead.

- Improved routing and delivery of fluvial sediment through channel realignment would likely increase deposition and retention of fine-grained material discharged from First Valley Creek on the delta during episodic flood events. This would enhance the capacity of this deltaic marsh platform and associated habitats to keep pace with anticipated sea-level rise under the time horizons and storm conditions considered in this study (Table 3).

6.2.5 Expected Site Evolution with Sea-Level Rise

Under baseline conditions, the creek is disconnected from its adjacent marsh areas, and we expect that sea-level rise will outpace marsh accretion over time. Occasional creek flood events will continue to transport sediment to mudflats adjacent to the site, but with limited ability to transport material laterally to the marshes. The northern beach segment would likely move toward the shore over time (Figure 26), continuing a trend observed in the past decade, and the southern unprotected marsh edge would likely convert to mudflat over time. The dirt path backing the southern half of the creek delta will likely experience erosion (and possible failure of its wooden retaining wall), leaving Sir Francis Drake Blvd and surrounding businesses more exposed to high tides and storm surge.

With the project, the lowered creek berms, re-routed creek orientation are expected to restore sediment delivery processes and contribute to a faster vertical growth of the marsh areas, which will slow their loss to sea-level rise. Setting back the dirt path and creating a vegetated upland transition would greatly limit erosion of the path, and buy time for roadway improvements and other backshore adaptations. The restored southern beach offshore of the southern marsh edge will complete the restoration of north-to-south littoral sediment transport interrupted by the prior earth fill and creek channelization, and will also protect the southern marsh from long-term erosion and act to encourage vertical accretion. Placed material is expected to either drift southward over time, or to stabilize and vegetate with marsh plants. if there is adequate sediment and wave power, the beach will migrate upward with sea-level rise.



Note: green areas represent marsh or upland vegetation

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Figure 26
Conceptual diagram of anticipated response of Martinelli Park to sea-level rise, with and without project

6.2.6 Project Quantities and Costs

The project is estimated to require about 1,000 to 1,200 cubic yards of net fill on the site (Table 9). The total amount depends in part of the quantity of usable sediment that can be derived from lowering the creek berms and the initial culvert and channel maintenance. The southern beach would require the most fill (1,300 CY), but most of this material could be derived from the culvert and channel maintenance (400 CY), from lowering the creek banks (400 CY), and from channel mouth realignment (200 CY). This would require that the material is appropriately coarse for use in constructing the beach, and needs to be explored further. We assume some of the material for beach construction would be imported, but the beach could alternatively be constructed in phases as sediment from the watershed becomes available through these activities. Setting back and raising the trail would require the second most material (800 CY).

TABLE 9
ESTIMATED QUANTITIES TO IMPLEMENT LIVING SHORELINES PROJECT AT MARTINELLI PARK

	Quantity	Units
Construction		
Southern beach (coarse sand and/or gravel)	+1,300	CY
Realign Channel	-200	CY
Lower Creek Banks/Mounds	-400	CY
Set Back and Raise Trail	+800	CY
Trail Surface (DG)	+10-20	CY
Potential coarse substrate for native oyster restoration	+10-20	CY
Channel Maintenance (assumed 5-10 year interval)		
	-400-500	CY
Vegetation		
Riparian vegetation management	0.13	AC
Ecotone (land side)	0.08	AC
Ecotone (bay side)	0.19	AC
Marsh revegetation on lowered berm areas	0.14	AC

Rough order of magnitude construction and maintenance costs for the project were estimated using the material quantities listed above and an assessment of probable unit costs from reference projects. These costs include the raw materials (sand, gravel, trail surfacing materials, plantings) summarized in Table 9 and Table 10, as well as mobilization and potential soft costs. The probable cost of the project is **$672,000** to **$1,440,000**, with an additional **$20,000** to **$40,000** per maintenance event, with an assumed 5- to 10-year interval.

TABLE 10
ROUGH ORDER OF MAGNITUDE COSTS FOR MARTINELLI PARK

Description	Cost
Construction Cost	$ 560,000
Soft Costs[1]	$ 400,000
Total	$ 960,000
Total minus 30%	$ 672,000
Total plus 50%	$1,440,000

[1] Soft costs include design, environmental compliance and permitting, project management, construction admin/inspection, and project contingency

For planning purposes, ESA developed rough order of magnitude (ROM) cost estimates for the conceptual enhancements along the shoreline. These cost estimates are intended to provide an approximation of total project costs appropriate for the conceptual level of design. These cost estimates are considered to be approximately -30% to +50% accurate, and include a 50% contingency to account for project uncertainties (such as final design, permitting restrictions and bidding climate). These estimates are subject to refinement and revisions as the design is developed in future stages of the project. This table includes estimated project costs for permitting, design, and construction monitoring. Estimated costs are presented in 2021 dollars, and would need to be adjusted to account for price escalation for implementation in future years. This opinion of probable construction costs is based on ESA project experience, bid prices from similar projects, consultation with contractors/suppliers, R.S. Means online and the ENR Cost Index Tables.

The estimated costs are considered Class 5, which reflects a conceptual level of design, and with the actual costs expected to be up to 50% higher than the estimate and as much as 30% below the estimate. The estimate accuracy typically increases as the project is refined and better defined. Please note that in providing opinions of probable construction costs, ESA has no control over the actual costs at the time of design and construction. The actual cost of construction may be impacted by the availability of construction equipment and crews and fluctuation of supply prices at the time the work is bid. ESA makes no warranty, expressed or implied, as to the accuracy of such opinions as compared to bids or actual costs. Similarly, actual design, environmental review and permitting costs are subject to physical conditions, and the requirements of various entities with discretionary authority which can be affected by public opinion and other factors that are uncertain or unknown at this time.

Comparison to No-Project Alternative

Project costs were compared to a baseline (no-project) alternative. As described above, we applied observed tides from 1980 to 2021 at Point Reyes, and lifted these by incremental amounts of sea-level rise to see how frequently Sir Francis Drake Blvd would flood at the site. We gathered probable costs related to the maintenance of the road incurred by flooding events. This included review of unit costs for road maintenance available from Caltrans, and from information on types of cost items provided by the County of Marin (pers. Comm. H.Lee and C. Choo). At a rough order-of-magnitude scale, we assume:

- Tidal overtopping of less than 3 hours would incur costs of approximately $10,000 per event (due to debris removal, signage, and the need for County staff to redirect traffic).
- Tidal overtopping of 3 to 6 hours would incur costs of approximately $90,000 per event (due to extensive debris removal, signage, County staff, permitting, and planning for future avoidance measures).
- Tidal overtopping of more than 6 hours would incur costs of $1,500,000 to $2,000,000 (due to repair and/or replacement of the low section in the road).

Table 11 lists the order-of-magnitude costs with- and without project. Note that sea-level amounts reflect the medium-high curve (Figure 7). The long-term cost of the no-project alternative is estimated to outpace the project cost by about 2030. Note that this assessment does not fully represent the risk of a major creek flood event, and the benefit of the project due to removal of sediment from the creek[7]. Note that this estimate assumes the dirt path continues to have a low point of 8-8.5 feet NAVD88, and does not degrade further. It also does not include costs incurred to local businesses that would be impacted, or costs associated with loss of transportation to the community.

TABLE 11
COMPARISON OF BASELINE AND PROJECT COSTS AT MARTINELLI PARK WITH SEA-LEVEL RISE

Year		Without Project		Project	
	Approx. SLR Amount (ft)	Cumulative # of Overtopping Events	Cumulative Maintenance Cost	Cumulative # of Overtopping Events	Project + Cumulative Maintenance Cost[1]
2021	0.49	2	$20,000	0	$960,000
2025	0.62	36	$480,000	0	$1,000,000
2030	0.81	123	$1,570,000	0	$1,040,000
2035	1.03	335	$4,300,000	0	$1,080,000
2040	1.29	879	>$10,000,000	0	$1,120,000

[1] Assumes initial project cost of $800,000 and maintenance every 5 years. Costs are reported in 2021 values

6.2.7 Uncertainties and Risks

- There is a risk that restoration of coarse beach might also benefit non-native species, such as Atlantic oyster drill, which prefer hard substrates to mudflats
- Care needs to be taken with any source material (coarse sediment, seeds, plantings, etc) with regards to the spread of non-native species .
- Non-native vegetation removal may cause temporary disturbance to the habitat and bird species. Vegetation removal should occur outside of the songbird breeding season

[7] Climate change may also increase precipitation intensity and flood flows in creeks and rivers, further increasing the risk of no project alternative.

(outside of April- July) to avoid negatively impacts to bird nesting including neotropical migrant species (e.g., Warbling Vireo, Black-headed Grosbeak, Wilson's Warbler).

- Construction would need to be timed to not interfere with migration of steelhead into the upper creek.
- It is anticipated that hydraulic modeling analysis and fish passage engineering considerations advanced during subsequent project design would minimize potential risks to anadromous fish populations associated with channel realignment and potential stream crossing improvements at Sir Francis Drake Blvd within the lower reach of First Valley Creek.
- The project could affect public access to the shipwreck by lowering the elevated creek berm that people typically traverse to the water's edge. This could be addressed by constructing a new raised walkway along a portion of the shore.
- Additional study is needed to assess the flood vulnerability of the Dixon Marine parcel (west of the Inverness Store), and the role its shoreline edge plays in protecting Sir Francis Drake Blvd. The parcel abuts the creek and its shoreline edge appears to largely be in the range of elevations between 9 and 10 feet NAVD88. Exact elevations are uncertain along this edge owing to the presence of boats and overhanging trees. If the shoreline fronting the Inverness Store is improved, the shoreline fronting Dixon Marine would become the primary pathway for flooding of the roadway.
- Refinements to this concept would need to include additional technical considerations that would occur during any subsequent design phase, such as geotechnical engineering, and potentially structural engineering.

6.2.8 Feasibility

Compared to the no-project alternative, the project is expected to significantly limit flood and erosion vulnerability Sir Francis Drake Blvd and local businesses. The project is expected to be most effective at the near-term horizon (1.6 feet of sea-level rise), but for the medium-term (3.3 feet of sea-level rise) and beyond rising groundwater levels would cause flooding of the roadway for both alternatives. This means that the project would need to be paired in the long-term with efforts to raise the roadway and potentially the buildings seaward of the road. Protections gained by the project in the short-term would buy time for the County and its partners to develop a funding plan for these improvements.

The project is expected to cost less than the no-project alternative beyond the year 2030. By restoring natural deltaic and littoral sediment transport processes, it is expected to increase the timeline that onsite marshes are able to keep pace with sea-level rise. It could also be a useful case study for restoring native oysters at relatively high elevations, in anticipation of sea-level rise. The site is highly accessible, which could assist in construction, and much of the material needed is potentially available on site, limiting the need for import of materials.

Given the factors discussed above, we consider the project to be feasible and beneficial.

6.3 Cypress Grove

6.3.1 Existing Site Conditions

The Cypress Grove project site includes the Audubon Canyon Ranch Cypress Grove Research Center (ACR Facility), a non-profit/educational facility on a natural promontory on the bay, the immediate updrift (north) and downdrift (south) shorelines, and the adjacent Livermore Marsh (Figure 27). Much of the promontory consists of erodible sedimentary rocks, and the sandy portions of the shoreline appear to be migrating southward slowly, as the northern shoreline has eroded significantly in recent decades, while the southern end has accreted. The shoreline protecting the site is highly modified from its historical (pre-development) condition. It consists of a mix of historical development and associated armoring, and existing eroding and expanding segments of shoreline. The tidal flat adjacent to the site is also undergoing long-term change.

Livermore Marsh is fronted by the former railroad berm, which is a remnant trapezoidal berm made of irregular boulders and cobbles imported to the site. A tidal channel drains the marsh directly to the tidal flats adjacent to the site. This is also the main outlet for freshwater flows arriving to the marsh from above Highway 1 upstream. The northern shoreline of the Cypress Grove peninsula consists of remnant sandy beach (with a small backbarrier saltmarsh), exposed sandstone ledge, remnant wooden shoreline defense structure, and riprap fronting a few shoreline buildings (PWA 2007).

The southern shoreline of the site consists of a sandy beach berm fronting an artificial ditch (also referred to herein as a ‘manmade swale’) which was originally constructed and used for boat access, but has filled in with sediment over time. The beach face has been expanding over time on the south side. Most of the upland and ditch areas behind the beach face are covered with ice plant (*Carpobrotus edulis*).

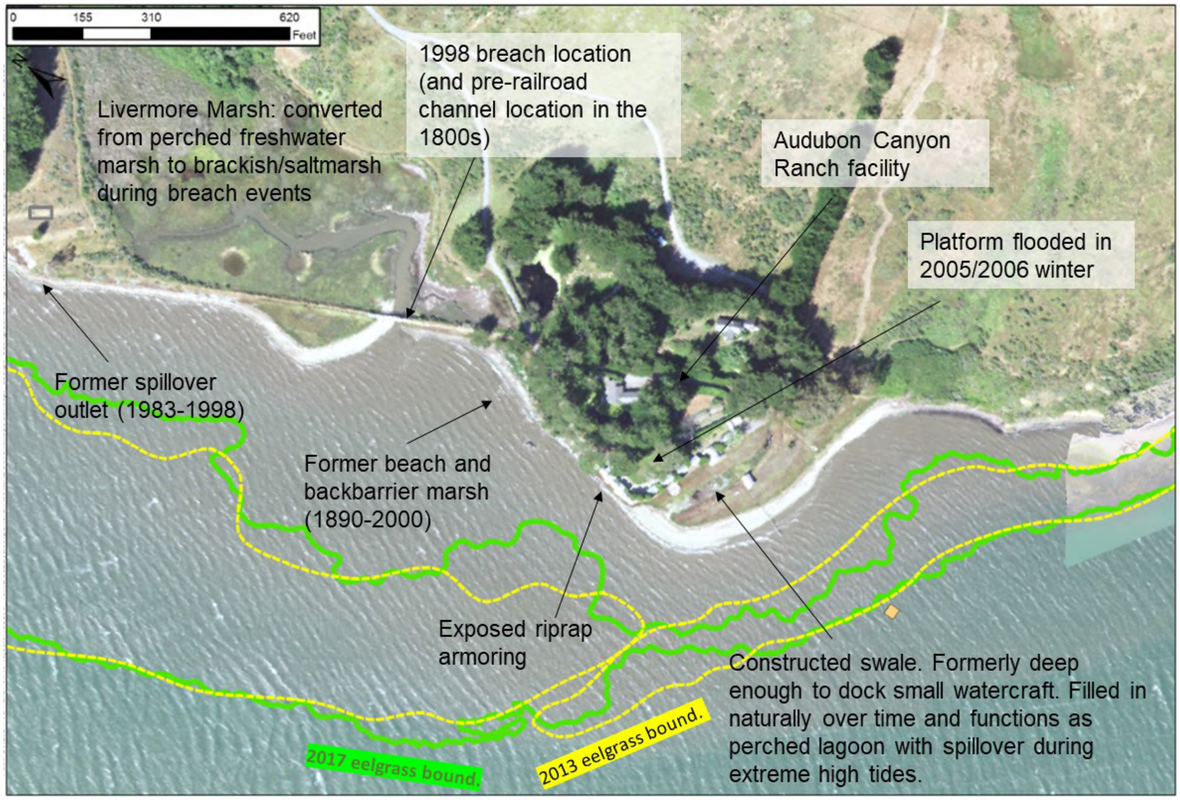
The ACR facility lies immediately landward of the southern beach. It consists of a series of buildings constructed in the early 1900s and a small patio area. The adjacent tidal flats are at least 800 feet wide on the northern side of the peninsula. It is not clear at this time whether they are stable or experiencing long-term erosion or accretion. Eelgrass beds are present below elevations of approximately MLLW on the tidal flats. One of the proposed Tomales Bay Native Oyster Working Group (TBNORWG) oyster restoration sites is targeted on the tidal flat immediately south of the peninsula.

6.3.1.1 Historical Context

Prior to breaching the railroad berm and opening the Livermore marsh, available imagery suggests a series of sandy tombolo beaches fronted the facility on the north side, and these beaches have progressively eroded in recent decades:

- Shoreline development had already occurred prior to construction of the railroad berm, as a road is visible in the available 1878 map of the site in the approximate alignment of the eventual berm. The historical opening of Livermore Marsh was along its eastern edge, near the current opening. After construction of the railroad berm in the late 1800s, the marsh was disconnected from the Bay. The heightened delivery of watershed sediment experienced throughout the Bay in the twentieth century (Rooney and Smith 1999) was captured by the railroad berm, converting the marsh to relatively high, brackish wetland.

- The manmade swale was constructed at an unknown date in the early twentieth century, intended as a storage location for boats and an access point for them to reach the bay. By the 1970s, the swale was in apparent disuse, and it showed signs of filling in with sand over time. At this point in time, a beach was present at the mouth of the swale. This has continued until present-day, and the swale currently acts as the recipient of wave washover flows during extreme high tide events. The swale's connection point to the bay is its former outlet on the north-facing side of the beach, and this is typically the lowest point in the beach fronting the ACR facility structures.
- By 1952, a beach had formed along the northwestern shoreline of the site, anchored by the bedrock outcrop adjacent to the shoreline (Figure 28, orange line). The southeastern shoreline had also significantly accreted (moved bayward) by this time. Some of this shift may be from placement of borrow material obtained from construction of the manmade swale.
- The railroad berm in front of the Livermore Marsh breached to the bay along its western edge during the 1982/1983 El Niño winter. The breach was sealed and a concrete apron was constructed to act as an overflow spillway in future events.
- The railroad berm breached a second time during the El Niño winter of 1997/1998, and remained open permanently after this event. The breach occurred at the historical location of the mouth, closer to Cypress Point, and since that time the interior Livermore marsh and channel network has continued to evolve (Etienne et al. 2001). At the time of the study conducted by PWA (2007), the marsh and restored tidal inlet was thought to be capturing sediment from updrift, potentially altering the supply of sand to the northwestern shoreline of Cypress Point. Sediment transport patterns may have also changed as a result of the ebb shoal (sandy bar forming offshore of the mouth) growing through the 2000s, which could have caused creek material to bypass the northwestern shoreline of Cypress Point.
- The beach along the northwestern edge of the site showed signs of episodic erosion during major coastal storm events, including in the winters of 1977/1978, 1982/1983, 1997/1998, and 2005/2006. This accelerated after the permanent breach of Livermore Marsh in the 1990s, and the cumulative effect of these events has been the loss of a functional beach along the northwestern shoreline, and a retreat of the beach fronting the manmade swale (Figure 28). At the same time that the northwestern shoreline has continued to erode, the southeastern shoreline of Cypress Point has accreted, shifting bayward over time (Figure 28).
- Severe flooding occurred in January 2006, when coastal storm surge created extreme high water levels adjacent to the site (approximately 8.7 to 9 feet NAVD88). This led to extended overtopping of the beach fronting the manmade swale, and caused floodwaters to enter the low lying buildings and interior patio area. The long-term effects of the storm include malfunction of equipment and damage to building floorboards.



Source:

Background Image from Google Earth. Eelgrass boundaries provided by GFNMS

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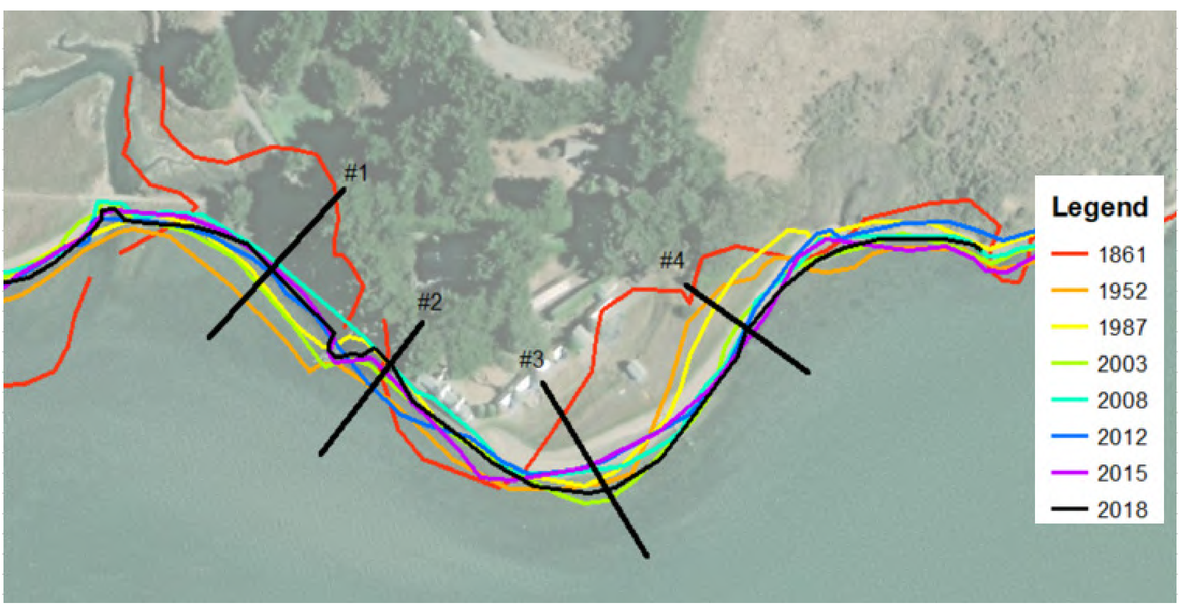
Figure 27
Cypress Grove Project Site



Source:

Digitized shorelines from USCGS T-sheet, historical aerials from USGS and USDA, and Google Earth

Note: numbered lines represent transects used to estimate shoreline change rates

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Figure 28
Change in shoreline at Cypress Grove from 1861 to 2018

6.3.1.2 Site Vulnerability

The main concerns at the site are continued erosion (threatening the ACR Facility), and the effects of erosion on the existing flood defense created by the dunes along the western and eastern edges of the facility. Flooding is predicted from high tides at both the near-term (1.6 ft) and medium-term (3.3 ft) horizons for sea-level rise. Flooding has been documented during the 1982/83 and 1997/98 El Niño events, and during coastal surge experienced in January 2006 (Figure 29). The latter caused at least one foot of standing water in and around the lower buildings, causing long-term damage to facilities. Some level of wave overtopping at the low point in the berm is observed during most king tide events. This is the primary flood pathway for flows reaching infrastructure at the site (Figure 30).

The site is already vulnerable to the 20-year recurrence coastal storm event (Figure 31; left panel). Table 12 lists key elevations, including of assets vulnerable to flooding. Note that flood extents shown in blue roughly match the flooded area observed during the January 2006 event (lower left panel in Figure 29), which was a roughly 20-year event (PWA 2007). Without a project, Figure 31 shows that the extents of flooding would increase. These maps are based on the available CoSMoS flood maps which assume that the landscape does not change over time, so these likely underestimate changes to vulnerability that would occur if the shoreline continues to shift eastward. The location of emergent groundwater (white hatched areas in Figure 31) will also expand with sea-level rise. For sea-level rise of 3.3 feet, groundwater levels are expected to be emergent in the vicinity of the lower ACR buildings and patio area.

Source: ACR facility staff

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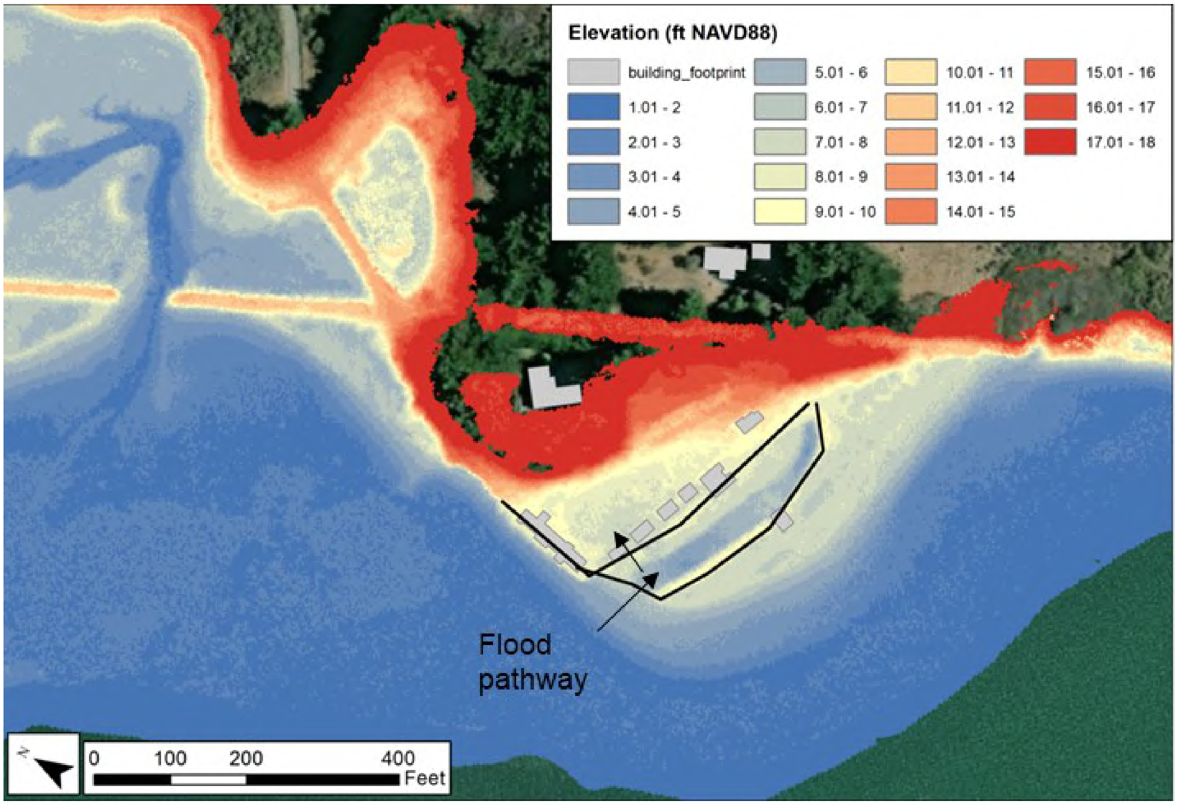
Figure 29
Photographs of January 2006 flooding event, showing patio area flooded



Source: County of Marin 2013 LiDAR

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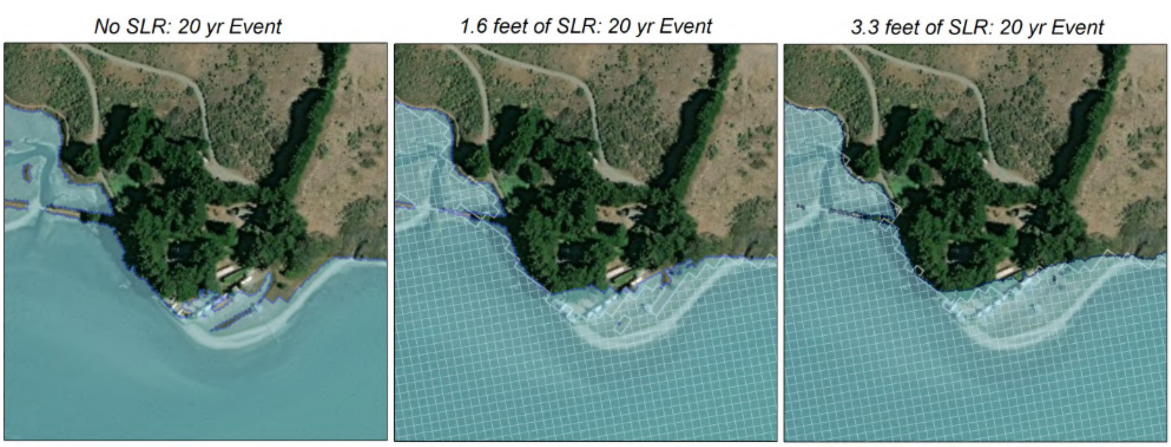
Figure 30
Topographic Map of Cypress Grove, showing shoreline elevations



Source: Our Coast our Future website

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Figure 31
CoSMoS flood predictions for surface water flooding (solid blue layer) and groundwater emergence (white hatched layer).

TABLE 12
ELEVATIONS OF KEY STRUCTURES AT CYPRESS GROVE

Site Feature	Elevation (ft NAVD88)
Top of south-facing beach (fronting dredged canal)	6.5-7.5
Seaward dunes	7.5-8.5
Landward dunes	7.5-9
Berm fronting dredged canal	9-10.5
Bed of dredged canal	5-6
ACR grounds	>8
Top of riprap	9-10.5
Surface elevation of Jan 2006 storm flood water	8.7-9

6.3.2 General Concept: Overview

The restoration design (summarized in Figures 32 through 35) includes several options, with an overall approach of:

1) **Enhancing shoreline erosion protection** by improving beach nourishment and retention adjacent to the northwestern shoreline of the site, and effectively 'softening' the shoreline to reduce wave runup and wave-related erosion. This would be achieved by sacrificial placement of approximately 300 to 500 cubic yards of sandy material immediately downdrift of the mouth of Livermore Marsh at a five year interval (roughly matching the rate of historical beach erosion at the site). Drift sills or groins would be constructed from rock and large woody debris (LWD) to reduce longshore drift and increase sand retention.

2) **Enhancing flood protection of low-lying buildings** by fronting existing riprap with sandy beach (to minimize future wave runup onto shoreline structures) and enhancing the beach along the top of Cypress Point near the mouth of the manmade swale (to block the main present pathway for wave overwash flooding at the site). The low point in front of the existing manmade swale would be blocked, and a new channel opening would be created at the other end of the swale, and the swale would function as a perched (located above high tide) lagoon that would occasionally drain to the bay. This redirected new opening would reduce flooding and allow the occasional wave overwash to drain more easily from the site. Shoreline enhancements would be designed in a way to encourage self-maintenance and long-term viability, by connecting with retention features along the beachface and oyster restoration immediately offshore, and replacing existing ice plant with native plants.

Note that figures 32 and 33 represent a potential layout of the design as constructed, and that the site would be expected to evolve over time, creating a planform that consists of a series of concave pocket beaches between features that capture a portion of the sand drifting around the point (LWD and/or rocks). Figures 32 and 33 were used to develop approximate quantities of material. If funding is acquired for further development, the design will be refined in a future phase.

Figures 34 and 35 show conceptual sketches of the expected equilibrium state of the restored beach, with embedded log retention features. LWD features would capture a portion of the longshore sand drift around the point, stabilizing the updrift beach planform at the location where it has been eroding, but allowing for drift to continue eastward and continue to nourish the areas of the downdrift beach that have been expanding over time.

We note that there are many rock outcrops that form shore salients (isolated 'points') along the Tomales Bay shore. While minimal structures (e.g. only wood or gravel) are preferred conceptually owing to the associated 'light touch', use of large boulder clusters to help anchor the other components should be considered in future design. A more detailed review of reference sites along the shore focused on rock-located sandy shore salients is recommended. Boulder clusters have the potential to provide habitat for a number of native intertidal species, including Olympia oysters, Bay mussels, rockweed, limpets, snails, and chitons. These are present on the existing bedrock outcrop and wooden retaining wall on site.

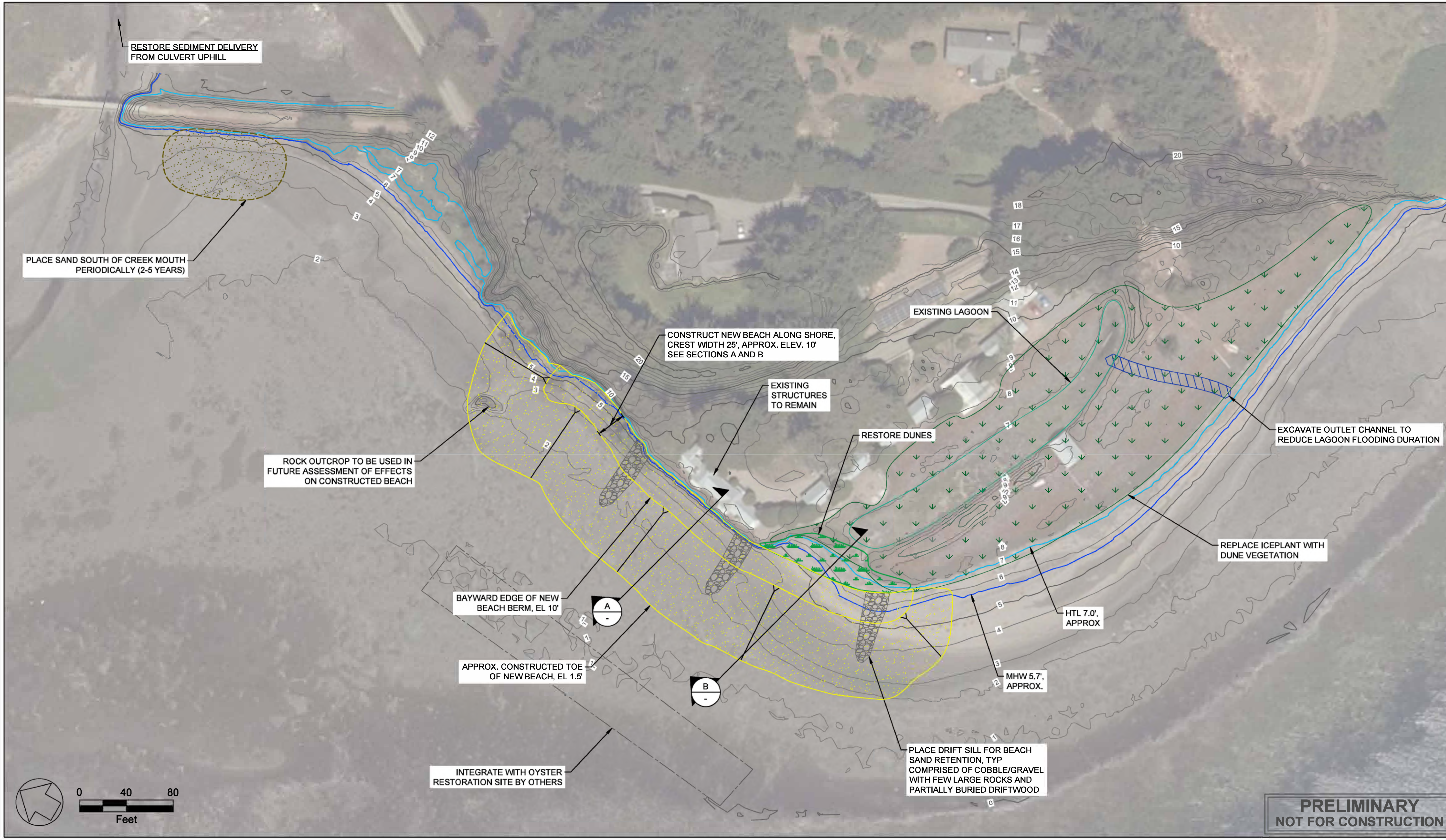
The primary habitat benefits of the project are that it preserves and enhances valuable shorebird habitat at the site, removes non-native vegetation, preserves habitat complexity, and provides an ideal setting for native oyster restoration. Because of the site's setting on a research preserve, it is ideal for long-term monitoring, and has high value as a demonstration project for living shorelines alternatives that could be studied, refined, and applied elsewhere in the bay. The primary infrastructure benefit of the project is that it would significantly reduce the risk of flooding in the near-term (1.6 feet of sea-level rise), allowing time for planning long-term modification of the site (raising the facility and/or managed retreat).

6.3.3 Living Shorelines Design Elements

The restoration design concept for Cypress Grove comprises several strategies, including creek-to-bay reconnection, beach restoration, native oyster restoration, and potential restoration of a supratidal lagoon/marsh on the site. The individual treatments are shown in Figures 32 through 35, and described in Table 13 below. Table 13 also lists potential opportunities and constraints

TABLE 13
OPPORTUNITIES AND CONSTRAINTS FOR CONCEPT DESIGN ELEMENTS AT CYPRESS GROVE

Adaptation Measure	Description	Benefits	Limitations and Other Considerations
1. Restore sediment delivery from culvert uphill of Livermore Marsh	Implement creek-to-bay reconnection improvements in the Livermore Marsh watershed by working with upstream landowners and Caltrans to develop a plan for beneficial reuse of material obtained from culvert maintenance. Material should be placed at intertidal elevations.	• Potential flood benefits upstream, where culvert blockage has led to flooding of private roads • Potential cost savings for Caltrans, who normally transport material offsite.	• Potential disruption to roadway use during construction • Sediment reuse is currently not allowed due to presence of invasive plant species. This policy may be a barrier to implementation. However, this policy could be revisited as part of a broader re-evaluation of culvert maintenance, as freshwater invasive plants would not be a constraint if material is placed at intertidal elevations.
2. Place sediment updrift at creek mouth	Place sacrificial sandy material in a feeder beach immediately south downdrift of the mouth of Livermore Creek, to restore natural littoral processes that may be interrupted by loss of the beach along the northern face of Cypress Point. This material will contribute to long-term viability of the beach that currently protects the facility from flooding during high coastal water levels.	• Restore littoral sediment supply that may still be impacted by reopening of the marsh in the 1990s. • Prevent further loss of beach and backbarrier marsh still present immediately southeast of the mouth of Livermore Marsh	• If placing sandy material, sediment may disperse offshore during an extreme event • Placement area would need to avoid existing sensitive habitats that may have formed since prior beach eroded.
3a. Beach and dune restoration near ACR facility	Place sandy beach along western edge of the ACR facility, near the tip of Cypress Point. The beach would be placed in front of existing riprap, and widen and raise the existing beach fronting the manmade swale (former boat access channel). Remove ice plant and revegetate with native beach/dune vegetation that encourages sediment trapping during storms and long-term self-maintenance of the beach.	• Provide enhanced flood protection for buildings and other assets located landward • Enhance natural ecology (e.g. replacing ice plant with native dune vegetation) • Appropriate beach sized material may be available onsite from downdrift areas to the east that have been accreting over time.	• Sediment to nourish existing dunes may have to be sourced from offsite. • Site access for construction may be difficult through the ACR facility.
3b. Place retention features to stabilize beach	As a secondary feature to Measure 3a, construct naturalistic drift sill features made from driftwood and/or coarse beach (gravel, cobble) and headland (boulder) material to encourage partial retention of sediment that drifts eastward along the point. This will stabilize the toe of the restored beach, and provide an additional measure for enhancing long-term viability.	• Support sediment retention for beach system (encourage self-maintenance and long-term viability) • Provide habitat complexity for shorebirds • Materials for retention features likely to be available on site.	• Constructability: material placement may generate impacts to existing habitat, as construction equipment may be in shallow water. This could potentially be avoided by using a long-reach excavated from constructed beach.
4. Creation of outlet channel by existing swale	As an optional measure, create an outlet channel for the manmade swale on the southeastern (non-wave-exposed) shoreline of Cypress Point. The elevation of the outlet thalweg could be set at an elevation lower than building foundations, to limit the retention time of floodwater (wave overwash, runoff, groundwater in the swale). The swale will act as a perched (located above high tide) lagoon, with seasonal ponding and a functional outlet on the eastern extent of the site that would allow drainage if the lagoon ever receives excessive wave overwash or groundwater inputs.	• Reduce risk of damage to buildings by decreasing duration of floodwater retention in swale • Potential formation of berm and lagoon from sediment deposition, which could support salt marsh vegetation	• Under higher levels of sea-level rise (+3.3 ft), presence of channel could result in still water level flooding of the site. • Lagoon mouth may require period maintenance with shovels if waves block the mouth with sand. • Lagoon mouth may impede walking access across the beach
5. Native Oyster Restoration	Place small mounds of course material (cobble and boulders) offshore of the northwestern shoreline of Cypress Point, to encourage native oyster restoration and encourage sedimentation and stabilization of the toe of the restored beach (Measure 3a).	• Nearby commercial oyster facilities could provide source of native oyster larvae for use on site • Coarse material mounds placed in low-tide areas could provide shorebird habitat	• Placement of mounds would need to be landward of existing eelgrass beds near the site.
6. Managed retreat of existing buildings	The lowest buildings within the ACR facility will be vulnerable to elevated groundwater levels for sea-level rise of 3.3 feet. As part of a long-term plan, landowners should consider potential locations for relocating or raising structures.	• Decrease future long-term risk of research operations and buildings to damage caused by sea-level rise by moving out of harm's way • Potential additional space for future intertidal habitat	• Cost and disruption of ACR use of the facility



NOTE: TOPOGRAPHIC ELEVATION DATA AND IMAGERY FROM MARIN COUNTY (2019)

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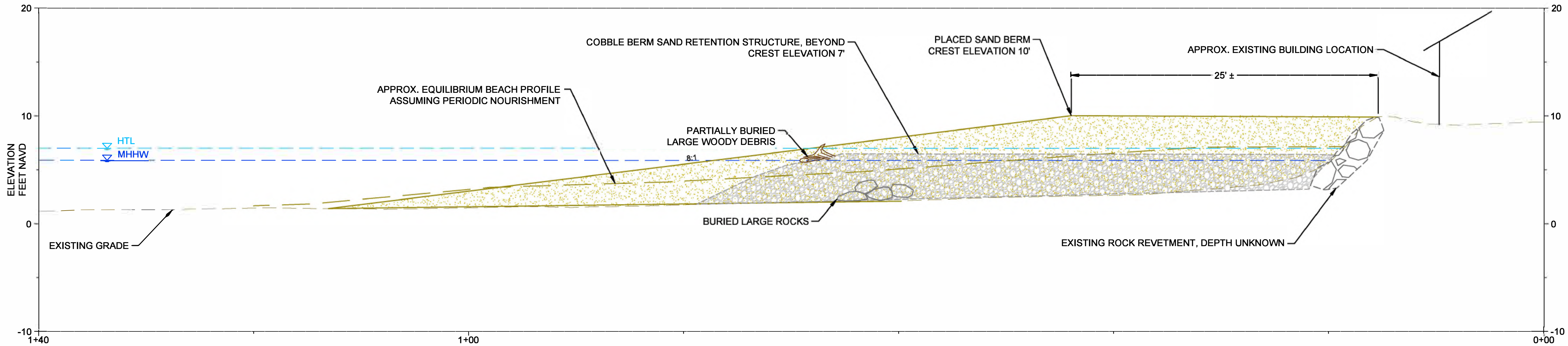
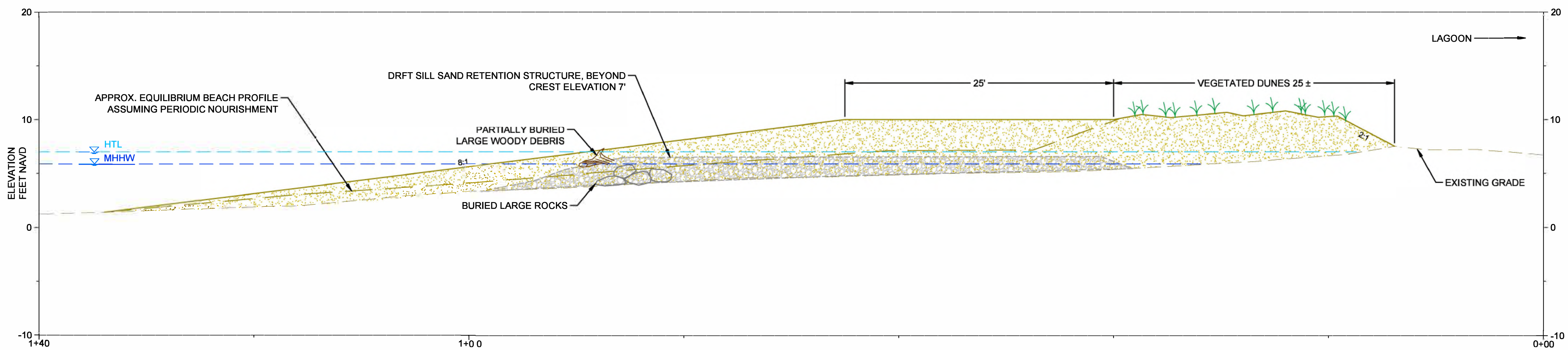
Figure 32
Cypress Grove Living Shoreline Concept Plan



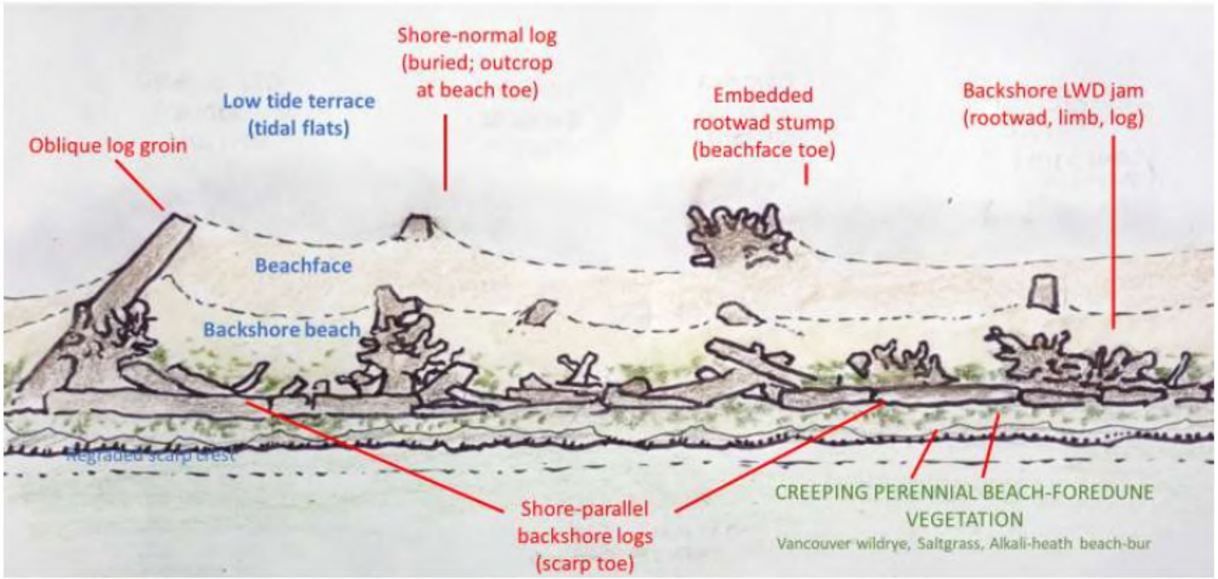
A
Beach Nourishment in Front of Revetment
Conceptual Cross Section Scale: 1" = 5'



B
Beach Nourishment and Dune Restoration
Conceptual Cross Section SCALE: 1" = 5'

PRELIMINARY
NOT FOR CONSTRUCTION

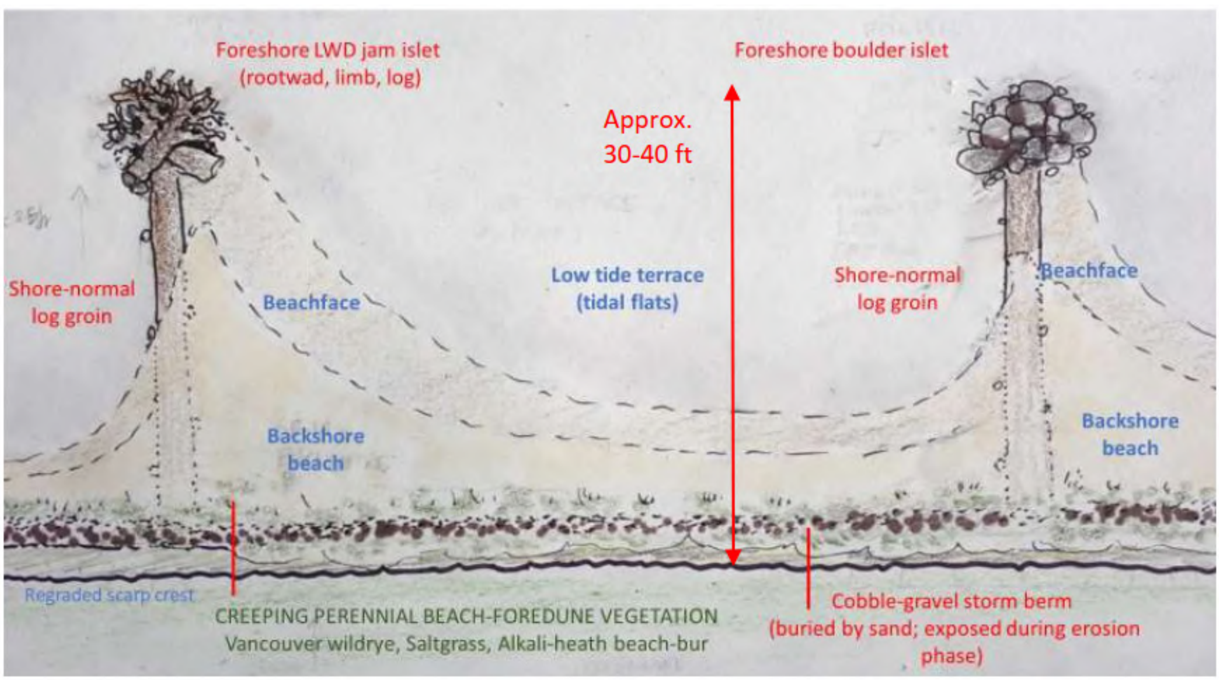
Figure 33
Cypress Grove Living Shoreline Concept Typical Sections



Source: Peter Baye D201900079.00 – Tomales Bay Living Shorelines Feasibility Study

P. Baye Notes: Impeded longshore drift is achieved by backshore LWD roughness and irregularly distributed, closely spaced (30-50 ft interval) log groins. Some gravel is added to the interstitial spaces among interlocking, shore-parallel LWD in the backshore

Figure 34
LWD-dominated "Living Shoreline" bay beach design option, integrated with backshore vegetation.



Source: Peter Baye D201900079.00 – Tomales Bay Living Shorelines Feasibility Study

P.Baye Notes: Sand is periodically re-nourished updrift (west) at a sacrificial beach location. Groin spacing and total length of the groin-islet unit are approximately scaled to the typical range of Tomales Bay beach widths observed, assumed to be 30-40 ft

Figure 35
Log groin, islet, and storm cobble-gravel berm framework option for a resilient crescentic fringing sand beach.

6.3.3 Proposed Benefits

6.3.3.1 Infrastructure Benefits

The project is expected to be effective at reducing the risk of flooding of the lower buildings within the ACR facility for the near-term sea-level rise scenario, considering 1.6 ft of sea-level rise. As shown in Table 14, the project is estimated to significantly reduce total water levels along the armored and unarmored portions of the west-facing shoreline. More importantly, stabilizing the beach would prevent long-term retreat of the beach from exposing the ACR facility to direct wave exposure. However, for the more extreme scenario of 3.3 feet of sea-level rise, the project would likely need to be combined with managed retreat or raising of some of the buildings to be successful, as groundwater levels are expected to inundate the site at this level.

The site is also likely to be valuable as a demonstration site. If the combination of beach restoration and intertidal measures (oyster reef restoration and increasing passive supply of littoral sand through nourishment near the mouth of Livermore Marsh) is successful, these types of shoreline ‘softening’ measures could be replicated elsewhere in the bay to limit erosion, and flooding from wave overtopping.

TABLE 14
ESTIMATED TOTAL WATER LEVELS (FT NAVD88) AT CYPRESS GROVE WITH AND WITHOUT PROJECT

		Site Condition	
	Event	Baseline	With Project
Transect 1: armored shoreline	MHHW: No SLR	11.3	6.7
	MHHW: 1.6’ SLR	14.1	8.4
	MHHW: 3.3’ SLR	15.9	10.1
	20-yr Event: No SLR	15.6	9.8
	20-yr Event: 1.6’ SLR	17.2	11.4
	20-yr Event: 3.3’ SLR	18.9	13.1
Transect 2: beach	MHHW: No SLR	6.0	6.0
	MHHW: 1.6’ SLR	8.0	7.8
	MHHW: 3.3’ SLR	10.0	9.7
	20-yr Event: No SLR	9.7	9.3
	20-yr Event: 1.6’ SLR	11.5	11.0
	20-yr Event: 3.3’ SLR	13.3	12.8
Transect 3: beach	MHHW: No SLR	6.0	6.0
	MHHW: 1.6’ SLR	8.0	7.8
	MHHW: 3.3’ SLR	10.0	9.8
	20-yr Event: No SLR	9.6	9.4
	20-yr Event: 1.6’ SLR	11.5	11.2
	20-yr Event: 3.3’ SLR	13.3	13.0

6.3.3.2 Habitat Benefits

Expected habitat benefits include the following:

- Potential for native oyster restoration: The Cypress Grove area was identified by the Tomales Bay Native Oyster Restoration Working Group for as a priority for oyster restoration. The site is in a section of the bay that has good conditions for oysters, in terms of food availability, relatively low predator pressure and favorable physical conditions. Eelgrass is close to shore, so oyster restoration substrates would need to be placed carefully to avoid damaging eelgrass. However, this proximity to eelgrass may have the benefit of increasing the richness of associated species compared to that of either habitat type (eelgrass or oysters) alone.

- Oyster restoration efforts may need to be aided by hatchery-reared spat if natural recruitment isn't sufficient; local growers including Hog Island Oyster Company would be able to supply native oyster spat.

- Creation of new rocky shore habitat will benefit other species associated with rocky shores, including crabs and other crustaceans, some shorebirds and fish.

- Removal of invasive ice plant and coupled planting of native vegetation will enhance coastal dune/strand habitat at the site. Dunes may also increase habitat for migrant songbirds (e.g., American Pipit, Horned Lark).
- Augmenting sediment to sustain tidal marsh habitat and re-connecting the tidal lagoon could provide habitat for Black Rail (state-listed threatened) and other tidal marsh associated bird species (e.g., Sora, Virginia Rail, Common Yellowthroat, Song Sparrow, Marsh Wren).
- Allowing a sloped habitat transition from the restored swale (converted to perched lagoon) to dune could provide habitat for Savannah Sparrows and refugia for rail species
- Relocating buildings would increase shoreline foraging habitat for shorebirds (e.g., Black Turnstones and Spotted Sandpiper in rocky areas, *Calidrid* sandpipers in gravel and sandy areas).
- Potential for native oyster establishment and habitat for herons, egrets, and scoters in the oyster restoration area.

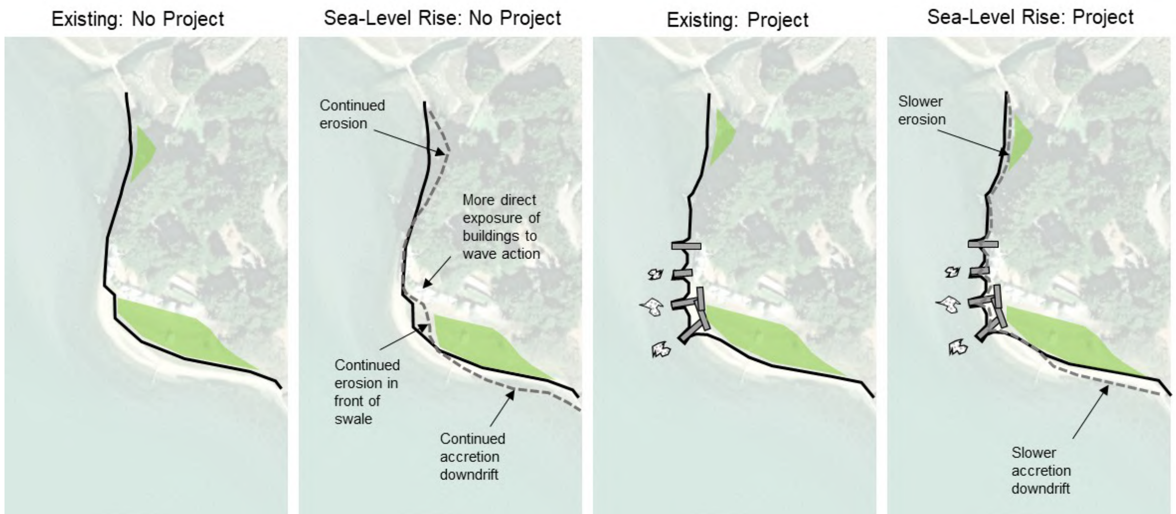
6.3.5 Expected Site Evolution with Sea-Level Rise

Under baseline (no project) conditions, the shoreline would likely continue to shift eastward, with the western beach faces continuing to erode, and the southern beach continuing to expand (Figure 36). It is unclear whether the ebb shoal in front of Livermore Marsh has reached an equilibrium shape, or will continue to grow. Continued growth could alter transport patterns and hasten the loss of the beach and marsh on the western face of Cypress Grove. Continued erosion of the beach in front of the manmade swale would eventually expose most of the lower ACR buildings to direct wave runup on an exposed shoreline. In the long-term the swale and surrounding dunes would continue to shift to the east.

Under project conditions, the same long-term shifts in the shoreline would occur, but at a slower pace that would limit exposure of the ACR facility in the short-term and allow enhancement of existing terrestrial and intertidal habitats.

The shore anchoring groins may result in the development of a trailing downdrift shoal that is somewhat disconnected from the back beach resulting in a temporary pool, transitioning to a small marsh and then to a continuous beach over time. The predictability of this feature is limited in that it is strongly controlled by multiple variables of sediment supply, tidal, wave, and wind transport of sediment, and characteristics and blend of the sediment in the beach.

At Cypress Grove (and every other site initially screened along the eastern shore of the bay), eelgrass occurs in close proximity to the shoreline and may experience minor impacts associated with proposed nearshore oyster reef arrays (coarse sediment to rock placement) and potentially in association with sediment mobilization associated with beach nourishment at that location. However, opportunities to restore eelgrass affected by legacy infrastructure have tentatively been identified in other locations within the bay (e.g. Marconi). In taking a broader view with the understanding that the current distribution of eelgrass habitat along the bay's more developed eastern shoreline is a reflection of natural and superimposed anthropogenic influences, it may be advantageous to consider developing a framework for addressing eelgrass resources that extends well beyond the site scale and addresses near term impacts as well as anticipated future conditions (see Section 5.4 and Section 7).



Note: green areas represent marsh or upland vegetation

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Figure 36
Anticipated response of Cypress Grove to sea-level rise, with and without project

6.3.6 Project Quantities and Opinion of Probable Costs

The project is estimated to require about 7,500 cubic yards of net fill on the site if all options are chosen, plus periodic placement of 300-500 cubic yards at a 5-year interval (Table 15). This interval was based on an estimate of the volumetric rate that the beach has eroded on the western side of the peninsula in recent decades. The majority of the material required is sandy beach material. There may be availability of material onsite: periodic sediment placement could potentially be derived from culvert maintenance activities upstream. Beach material for the restored beach could be derived from back beach sandy material in the eastern portion of the site, which has been expanding for several decades. This option would minimize the length of access routes, and potentially allow for modular construction of the beach.

The rough order of magnitude construction and maintenance costs for the project were estimated using the material quantities listed above and an assessment of probable unit costs from reference projects. These costs include the raw materials (sand, gravel, trail surfacing materials, plantings) summarized in Tables 15 and 16, as well mobilization and potential soft costs. The estimated cost of the project is **$1,260,000** to **$2,700,000**, with an additional **$50,000** to **$100,000** for recurrent maintenance on a 5- year interval. These values assume typical unit costs for coastal projects, and could be reduced if an onsite source of sediment is identified.

TABLE 15
ROUGH ORDER OF MAGNITUDE COSTS FOR CYPRESS GROVE

Description	Cost
Construction Cost	$1,050,000
Soft Costs[1]	$ 750,000
Total	$1,800,000
Total Range (minus 30% to plus 50%)	$1,260,000 - $2,700,000

[1] Soft costs include design, environmental compliance and permitting, project management, construction admin/inspection, and project contingency

Given that the ACR Facility has already developed a conceptual proposal to raise buildings (PWA 2007), we did not compare project costs to a no-project condition. Rather, we considered the fact that the existing exposed buildings could be raised in place or moved. Several of the buildings that were damaged during the January 2006 event required repairs (pers. Comm. J. Jensen). Based on the number of buildings within the expected flood zone (Figure 31), and estimates of cost for raising buildings within an active wave zone (ESA 2016), the estimated cost of raising buildings in place is expected to be **$1,540,000** to **$3,300,000**. Costs of relocating the buildings landward on site are included in PWA (2007). Accounting for all buildings in the flood zone, and escalating costs to 2021 dollars, the cost estimate for building relocation is **$1,250,000** to **$2,680,000**.

TABLE 16
ESTIMATED QUANTITIES TO IMPLEMENT LIVING SHORELINES PROJECT AT CYPRESS GROVE

	Quantity	Units
Construction		
Beach and dune nourishment	6,700	CY
Lagoon channel	-40	CY
Drift Sill Option: LWD	6-12	EA
Drift Sill Option: Cobble and gravel	500	CY
Oyster rock mounds	10-20	CY
Periodic sand placement (near Livermore Marsh) at 5 year intervals		
	300-500	CY
Vegetation		
Vegetate new upper beach areas	1,400	SF
Restore existing dunes	43,100	SF
Restore swale (perched lagoon/pond habitat)	8,700	SF

For planning purposes, ESA developed rough order of magnitude (ROM) cost estimates for the conceptual enhancements along the shoreline. These cost estimates are intended to provide an approximation of total project costs appropriate for the conceptual level of design. These cost estimates are considered to be approximately -30% to +50% accurate, and include a 50% contingency to account for project uncertainties (such as final design, permitting restrictions and bidding climate). These estimates are subject to refinement and revisions as the design is developed in future stages of the project. This table includes estimated project costs for permitting, design, and construction monitoring. Estimated costs are presented in 2021 dollars, and would need to be adjusted to account for price escalation for implementation in future years. This opinion of probable construction costs is based on ESA project experience, bid prices from similar projects, consultation with contractors/suppliers, R.S. Means online and the ENR Cost Index Tables.

The estimated costs are considered Class 5, which reflects a conceptual level of design, and with the actual costs expected to be up to 50% higher than the estimate and as much as 30% below the estimate. The estimate accuracy typically increases as the project is refined and better defined. Please note that in providing opinions of probable construction costs, ESA has no control over the actual costs at the time of design and construction. The actual cost of construction may be impacted by the availability of construction equipment and crews and fluctuation of supply prices at the time the work is bid. ESA makes no warranty, expressed or implied, as to the accuracy of such opinions as compared to bids or actual costs. Similarly, actual design, environmental review and permitting costs are subject to physical conditions, and the requirements of various entities with discretionary authority which can be affected by public opinion and other factors that are uncertain or unknown at this time.

6.3.7 Uncertainties and Risks

- Access to the site for construction of the restored beach could be difficult, which could affect constructability of the project. Site access is limited by small roads, overhanging trees, and shallow offshore mudflats.

- LWD groins would need substantial anchoring (attachment to boulders or similar) to prevent floating away during high water level events. The appropriate type of anchoring will need to be investigated further.

- The site is near an existing eelgrass bed, which in the most recent survey (2017) was farther off site than in past maps. Based on site investigations conducted in 2020, eelgrass appears to have expanded shoreward since 2017, suggesting minor impacts to eelgrass may occur as a result of the proposed design at this site. Placement of native oysters and construction of the restored beach and its retention features would need to account for potential impacts to eelgrass, based on future site surveys. Opportunities to mitigate for site-specific impacts to eelgrass at Cypress Grove have been tentatively identified at Marconi, but would need to be more fully vetted in support of advancing design and permitting efforts under a subsequent phase of the project.

- There is a risk that addition of coarse material for retention features could also benefit non-native species, such as the Atlantic oyster drill (*Urosalpinx cinerea*), which prefer hard substrates to mudflats. However, past research has indicated fewer drills in this part of the bay compared to sites closer to the head.

- Care needs to be taken with any source material (coarse sediment, seeds, plantings, etc) and equipment with regards to the spread of non-native species.

- Although beach segments would be constructed between the groins, the groins are not intended to retain all sand (i.e. there would be continued drift of sand to the east over time). Understanding the rate of longshore sand transport is critical to estimate lag time between placement of nourished shoreface sand and deposition in target shoreline segments, especially with groins. The rate of longshore sand transport should be studied further to understand the frequency that placements may be needed.

6.3.8 Feasibility

Compared to the no-project alternative, the project is expected to significantly limit flood and erosion vulnerability of the ACR facility, which would be exposed to direct wave action in the future if the shoreline continues to shift eastward. The project is expected to be most effective for the near-term horizon (1.6 ft of sea-level rise); for the medium-term (3.3 ft of sea-level rise) and beyond rising groundwater levels would cause flooding of the patio area of the facility.

The project is expected to have a net benefit to habitat, as it would soften an armored shoreline, provide an opportunity to replace ice plant with native high beach vegetation, improve roosting habitat for native birds, and would allow for native oyster restoration. The project would implement a number of novel features for the region (LWD groins, beach nourishment, sediment retention features designed to encourage native oyster colonization) and thus would have high value as a demonstration for nature-based adaptations in the Tomales Bay region. In addition, there is high potential for using the ACR facility as a location for monitoring of project performance and for NBI education. The project is not expected to affect public access, as the site is not heavily used by the public.

Given the factors discussed above, we consider the project to be technically feasible and beneficial. However, the project would require modifications to be cost competitive compared to other options. The cost of the project is estimated to be similar to the cost of raising buildings or moving buildings on site, though the benefits of the living shoreline project would be shorter lived. In the medium to long term the project would need to be paired with raising or relocating the buildings. The most cost effective approach – based on the current cost estimates – would be to raise/relocate the buildings now. However, additional design refinement could significantly reduce costs for the living shoreline project. For the project to be cost-competitive, more work is needed to find a viable local source of sediment to the site. This could either be from native watershed material (via culvert maintenance within the watershed), from reuse of culvert material from other creeks nearby, or from use of sediment from the eastern down drift edge of the beach on-site. Each of these measures holds potential to significantly lower the cost of the project. Any next steps for cost refinement should also be applied to the option of raising/relocating the buildings, to confirm or revise the conceptual estimates provided here. In addition, the project provides ecological enhancements (beach placement, revegetation) and benefits as a demonstration project that are not present in the raising/relocating approach.

CHAPTER 7

Next Steps

Assess Culvert Maintenance Programs

Both Highway One and Sir Francis Drake Boulevard cross a large number of creeks discharging to the bay. Caltrans maintains culverts on Highway One, and the County of Marin maintains culverts on Sir Francis Drake Blvd. Most of these crossings consist of single or double barrel culverts that require periodic maintenance (removal of accumulated sediment) to prevent floodwater retention upstream of the roadway. Material is typically hauled off site, and volumetric measures of material are not tabulated.

Sediment is a valuable resource for sea-level rise adaptation that will become a more important resource in the future (e.g. SFEI and SPUR 2019, Newkirk et al. 2018). Culvert maintenance programs in the bay should be revisited to identify ways that native watershed material can be retained for use in shoreline adaptation. This could include:

- Implementing a program for reporting culvert maintenance timing and volume of material removed. This will help understand the amount of material that could be available for use on the shoreline.
- Identifying potential stockpile locations along the western and eastern shores that would reduce the need for taking material to Nicasio or elsewhere offsite.
- Identifying opportunities for combining fish passage improvement projects with creek-to-bay reconnection, to encourage more natural sediment transport to the shoreline.

Investigate First Valley Creek Hydraulics with Sea-Level Rise

The low point in Sir Francis Drake Blvd was identified as a major vulnerability near Martinelli Park, however it was outside of the scope of this study to determine whether this was a larger vulnerability than creek flooding combined with sea-level rise. While First Valley Creek is thought to have adequate capacity to pass the large fluvial flood events (Ross Taylor Associates 2003), the creek is a key source of vulnerability in Inverness for several reasons:

- During the January 1982 event, the creek rapidly became overwhelmed with sediment from landslides, reducing the capacity of the creek to pass flood flows and causing sheet flow over adjacent roadways (Inverness Ridge Communities Planning Group 1983; Anima et al. 1988). Because of development, the creek has minimal floodplain available to account for losses in space due to sediment delivery.
- Non-native vegetation in the creek channel has proliferated in recent decades, especially in the portion of the channel seaward of the Sir Francis Drake Blvd (pers.

Comm. M.Sutton). This is thought to contribute to entrainment of sediment that would normally reach the bay.

- The existing culvert crossing is partially filled with sediment at the time of this study, limiting its flow capacity.
- With sea-level rise, the backwater elevation for the creek will rise, substantially limiting the ability of the existing, constrained culvert crossing to pass flood flows.

We recommend a hydraulic study be performed for the creek, considering combined creek flows and higher backwater elevations with sea-level rise. This could be accomplished with a topographic survey of the creek and application of a hydraulic model (e.g. HEC-RAS). This exercise would determine whether a larger crossing should be prioritized relative to other proposed actions.

Monitor Tides Inside the Bay

Tides within Tomales Bay differ from those measured at Point Reyes. The information available to us for this study included tidal datums provided by NOAA at a few locations within the bay, but these are generally based on short (several month) installments in the past, and are not useful for understanding differences in flood stages throughout the Bay. Other sources of information include anecdotal accounts of flood levels (PWA 2007), and several hydraulic models of the Bay, but these are difficult to use systematically to assess flood levels.

We recommend that future monitoring of water levels occur at Cypress Grove and Martinelli Park. This will help to refine design elevations for living shorelines adaptations.

Develop Baywide Comprehensive Eelgrass Management Program

Just as this study has endeavored to address future risks while balancing the need for infrastructure protection and habitat enhancement over both short and long-term planning horizons, development of a comprehensive Eelgrass Management Program for the Bay's eelgrass resources could help address conflicts that may arise between proposed living shoreline treatments and eelgrass at individual sites. A comprehensive management program could also provide a mechanism for assessing eelgrass habitat suitability, both under current conditions and future scenarios including sea level rise. This could further help in identifying areas where eelgrass is likely to persist, retreat, or expand as baseline conditions within the bay evolve through time. It may also help identify where the placement of oyster reefs and other living shoreline strategies may be anticipated to provide countervailing benefits (e.g. improved water clarity, energy attenuation, or substrate stabilization) that could be partially or wholly offsetting of site specific impacts. Just as the living shoreline design strategies have been developed to address both existing vulnerabilities to coastal flooding as well as anticipated future threats from rising sea levels, eelgrass habitat mitigation efforts that may be required in conjunction with permitting of living shoreline designs should be developed in a manner that considers both current and future conditions within the bay. This would result in greater assurance of no-net-loss of eelgrass habitat within the bay while reducing conflicts between protected habitat and development of more resilient infrastructure at the site scale.

CHAPTER 8
References and Report Preparation

8.1 References

Anima, R.J., Bick, J.L. and Clifton, H.E. 1988. Sedimentologic consequences of the storm in Tomales Bay. In Ellen, S.D. and Wiezorek, G.F. (eds). Landslides, floods, and marine effects of the storm of January 3-5, 1982, in the San Francisco Bay region, California. U.S. Geological Survey Professional Paper 1434, 283-310.

Avery, C. 2006. Tomales Bay Environmental History and Historic Resource Study. May 25, 2006.

Ballard, G., Barnard, P., Erikson, L., Fitzgibbon, M., Moody, D., Higgason, K., Psaros, M., Veloz, S., and Wood, J. 2016. Our Coast Our Future (OCOF). Petaluma, California. Available at: http://www.ourcoastourfuture.org.

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. Ecological Monographs, 81(2), 169–193. https://doi.org/10.1890/10-1510.1

California Coastal Commission (CCC). 2018. Sea-level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea-level Rise in Local Coastal Programs and Coastal Development Permits, adopted on August 12, 2015; update adopted November 7, 2018.Cheng, B.S. and E.D. Grosholz. 2016. Environmental stress mediates trophic cascade strength and resistance to invasion. Ecosphere 7(4):e01247. DOI:10.1002/ecs2.1247

Daetwyler, C.C. 1966. Marine geology of Tomales Bay, Central California. Scripps Institute of Oceanography and Pacific Marine Station Research Report No. 6.

Di Lorenzo E. and N. Mantua. 2016 Multi-year persistence of the 2014/15 North Pacific marine heatwave. Nature Climate Change 6, 1042–1047 (2016)

Dugan, Jenifer E. et al. 2008. Ecological Effects of Coastal Armoring on Sandy Beaches, 29 PSZNI: Marine Ecology 160, 160-170.

Etienne, K. 2001. Monitoring the return of tidal influence on a coastal wetland. Marsh revival. The Ardeid, 6-7Federal Emergency Management Agency (FEMA). 2005. Final Draft Guidelines, Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United State. Prepared for the U.S. Department of Homeland Security. January 2005.

Federal Emergency Management Agency (FEMA). 2017. Flood Insurance Study Marin County, California and Incorporated Areas. Study Number 06041CV001D. August, 2017.Graymer, R.W., Bryant, W., McCabe, C.A., Hecker, S. and Prentice, C.S. 2006b. Map of Quaternary-active faults in the San Francisco Bay region. U.S. Geological Survey Scientific Investigations Map 2919

Greater Farallones Sanctuary Advisory Council. 2019. Recommendations of the Greater Farallones National Marine Sanctuary Advisory Council to the Greater Farallones National Marine Sanctuary. San Francisco, CA.

Griggs, G.B. 2005. The Impacts of Coastal Armoring, 73 Shore & Beach 13, 13-22 (2005).

Griggs, G, Árvai, J, Cayan, D, DeConto, R, Fox, J, Fricker, HA, Kopp, RE, Tebaldi, C, Whiteman, EA (California Ocean Protection Council Science Advisory Team Working Group). 2017. Rising Seas in California: An Update on Sea-Level Rise Science. California Ocean Science Trust.

Gotvald, A.J., Barth, N.A., Veilleux, A.G., and Parrett, C. 2012, Methods for determining magnitude and frequency of floods in California, based on data through water year 2006: U.S. Geological Survey Scientific Investigations Report 2012–5113, 38 p., 1 pl.

Inverness Ridge Communities Planning Group. 1983. Inverness Ridge Communities Plan. Accessed online at: https://www.marincounty.org/-/media/files/departments/cd/planning/currentplanning/publications/communityandareaplans/inverness_ridge_communities_plan_1983.pdf

IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

Kimbro, D.L, J.L. Largier and E.D. Grosholz. 2009. Coastal oceanographic processes influence the growth and size of a key estuarine species, the Olympia oyster. Limnology and Oceanography 54: 1425–1437.

Kimbro, D. L., J. W. White and E. D. Grosholz. 2019. The dynamics of open populations: integration of top-down, bottom-up and supply-side influences on intertidal oysters. Oikos 128: 584-595.

Largier, J., Hollibaugh, J., and Smith, S. 1997. Seasonally hypersaline estuaries in Mediterranean-climate regions. Estuarine, Coastal and Shelf Science (1997), 45: 789-797.

Leo, K., R. Battalio, W.N. Heady, P. King, A. McGregor, B. Cohen, J. Calil, E. Vandebroek, J. Jackson, F. DePaolis, D. Revell, R. Vaughn, J. Giliam, S. Newkirk. (2017). Economic Impacts of Climate Adaptation Strategies for Southern Monterey Bay. Technical Report prepared for the California State Coastal Conservancy by The Nature Conservancy. 2017/07. ClimateReadyGrant#13-107

LMER Coordinating Committee. 1992 Understanding Changes in Coastal Environments: The LMER Program. Eos Trans. AGU 73: 481–485.

Marin County 2016. Marin Ocean Coast Sea-Level Rise Vulnerability Assessment. Accessible at https://www.marincounty.org/depts/cd/divisions/planning/csmart-sea-level-rise/csmart-publicationscsmart-infospot

Marin County 2018. C-SMART Adaptation Report. Accessible at https://www.marincounty.org/depts/cd/divisions/planning/csmart-sea-level-rise/csmart-publicationscsmart-infospot

Melius, Molly L. and Margaret R. Caldwell (2015). California Coastal Armoring Report: Managing Coastal Armoring and Climate Change Adaptation in the 21st Century, Stanford Law School: Environment and Natural Resources Law and Policy Program.

Merkel & Associates. 2017. Tomales Bay 2017 Eelgrass Inventory, Tomales, Bay, CA. Prepared for NOAA Greater Farallones National Marine Sanctuary.

Milliken, R. 2009. Ethnohistory and ethnogeography of the Coast Miwok and their neighbors, 1783-1840. National Park Service Technical Paper. Golden Gate NRA Cultural Resources and Museum Management Division Building 101, Fort Mason San Francisco, California.

Munro-Fraser, J.P. 1880. *History of Marin County, California: Also an Historical Sketch of the State of California.* Alley, Bowen.

Narayan, S., Beck, M. W., Reguero, B. G., Losada, I. J., Van Wesenbeeck, B., Pontee, N., … Burks-Copes, K. A. (2016). The effectiveness, costs and coastal protection benefits of natural and nature-based defences. PLoS ONE, 11(5), 1–17. https://doi.org/10.1371/journal.pone.0154735.

National Oceanic and Atmospheric Administration (NOAA). 2015. Guidance for Considering the Use of Living Shorelines.

Newkirk, S., Veloz, S., Hayden, M., Heady, W., Leo, K., Judge, J., Battalio, R., Cheng, T., Ursell, T., & Small, M. (The Nature Conservancy and Point Blue Conservation Science.) (2018). Toward Natural Shoreline Infrastructure to Manage Coastal Change in California. California’s Fourth Climate Change Assessment, California Natural Resources Agency

Niemi, T. and N. Hall. 1996. Historical changes in the tidal marsh of Tomales Bay and Olema Creek, Marin County, California. Journal of Coastal Research, 12(1): 90-102.

Ocean Protection Council (OPC). 2018. State of California Sea-Level Rise Guidance 2018 Update. Prepared by the California Natural Resources Agency and the California Ocean Protection Council. March 2018.

Point Blue Conservation Science. 2016. Natural resource vulnerabilities, potential adaptation strategies, and monitoring framework for Marin County's outer coast sea level rise vulnerability assessment. Prepared for the Marin County Community Development Agency

Point Blue Conservation Science, San Francisco Estuary Institute, and County of Marin. 2019. Sea Level Rise Adaptation Framework - A user guide to planning with nature as demonstrated in Marin County. Point Blue Conservation Science (Contribution #2239), Petaluma, CA. San Francisco Estuary Institute (Publication #946), Richmond, CA.

Philip Williams and Associates (PWA). 2007. Cypress Grove Shoreline Study. Prepared for Audubon Canyon Ranch. August 2007.

Ries, K.G., III, Newson J.K., Smith, M.J., Guthrie, J.D., Steeves, P.A., Haluska, T.L., Kolb, K.R., Thompson, R.F., Santoro, R.D., and Vraga, H.W. 2017. StreamStats, version 4: U.S. Geological Survey Fact 2017–3046, 4 p., https://doi.org/10.3133/fs20173046

Rooney, J. and Smith, S. 1999. Watershed landuse and bay sedimentation. Journal of Coastal Research, 15(2): 478-485.

Ross Taylor and Associates. 2003. Marin County Stream Crossing Inventory and Fish Passage Evaluation: Final Report. Prepared for the County of Marin – Department of Public Works. July 2003.

SAGE. 2015. Natural and Structural Measures for Shoreline Stabilization

SFEI and SPUR. 2019. San Francisco Bay Shoreline Adaptation Atlas: Working with Nature to Plan for Sea Level Rise Using Operational Landscape Units. Publication #915, San Francisco Estuary Institute, Richmond, CA.

Tomales Bay Watershed Council. 2003. Tomales Bay Watershed Stewardship Plan: A Framework for Action. 145 p.

U.S. Army Corps of Engineers (2003). Coastal Engineering Manual, Part. V. Coastal and Hydraulics Lab., US Army Engineer Research and Development Center, Vicksburg, Mississippi, USA

8.2 Report Preparers

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Attachment A

Technical Advisory Committee Roster

ESA

TABLE 1
TOMALES BAY LIVING SHORELINES FEASIBILITY PROJECT TAC MEMBERS

Name	Affiliation
Sara Azat	NOAA
Ben Becker	PRNS
Maria Brown	GFNMS
Nicole Fairley	RWQCB
Xavier Fernandez	RWQCB
Gary Fleener	Hog Island Oyster Company
Roger Leventhal	County of Marin
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Andrew Weltz	CDFW

Attachment B

Data Availability and Gaps

ESA

memorandum

date	March 27, 2020
to	Leslie Lacko, Jack Liebster; Marin County Community Development Agency
cc	Michelle Orr, P.E.; Environmental Science Associates
from	Dane Behrens, PhD, PE and Tiffany Cheng, PE; Environmental Science Associates
subject	Tomales Bay Living Shorelines Feasibility Project – Existing Data Inventory and Data Gaps Memorandum

1. Introduction

As part of the Tomales Bay Living Shorelines Feasibility Project (Project), Environmental Science Associates (ESA) has prepared this memorandum for the Marin County Community Development Agency (CDA) to list available datasets that characterize subtidal habitats within Tomales Bay, and other relevant datasets to the application of living shorelines. This memorandum also identifies data gaps that were found by ESA through the process of gathering available data.

The goal of the Project is to evaluate the feasibility of nature-based adaptations within Tomales Bay, as an alternative to traditional engineered methods (e.g. coastal armoring). Nature-based approaches provide flood protection services for public and private shoreline assets while enhancing existing habitat and supporting recreational activities. ESA is working with the County of Marin, Merkel & Associates, UC Davis (Ted Grosholz), Smithsonian Environmental Research Center [SERC] (Chela Zabin), Point Blue Conservation Science, and independent consultant Peter Baye to gather and inventory existing data and conditions information for the Project. Contributions to this memo were made by Dane Behrens and Tiffany Cheng, with review from Michelle Orr.

ESA gathered a series of existing publically-available data sets for the project area, including:

- Land use and ownership
- Topography and bathymetry
- Physical processes
- Habitats and vegetation communities
- Sea level rise (SLR) and asset vulnerability
- Existing hydrodynamic models of Tomales Bay

2. Summary of Findings

ESA reviewed the available data for completeness (e.g. data gaps) and identified any additional types of information required to support living shorelines adaptation development. Table 1 shows the datasets gathered for the Project and characteristics (e.g. source, date collected, extent and use limitation). Data were collected from a range of local and regional sources. Figure 1 shows data collection locations.

Table 1. Existing Datasets and Models

Name	Source	Date Collected	Extent	Use Limitation
Land Use and Ownership				
Parcel Information / Land Use	MarinMAP	2019	Marin County	N/A
Aquaculture leases	California Department of Fish and Wildlife (CDFW)	2018	California	Shapefile polygons are approximations of locations and sizes of actual state water bottom leases.
Elevation Data				
Bathymetry	USGS	2008	Tomales Bay	N/A
CA Coastal LiDAR	CA State Coastal Conservancy	2009-2011	Marin County	N/A
Marin County LiDAR	Marin County	2013	Marin County	N/A
Marin County Ortho Imagery (Preliminary)	Golden Gate National Parks Conservancy (GGNPC)	2019	Marin County	Preliminary dataset being reviewed by U.S Geological Survey; Preliminary dataset provided 1/6/2020
Water Column Conditions				
Water Temperature and Salinity	BOON[1]	2011 - Present	Tomales Bay Buoy location	N/A
	Cheng and Grosholz (2016)	2010-2013	Sacramento Landing	N/A
	Cheng and Grosholz (2016)	2010-2013	14 grab-sample sites throughout the Bay	N/A
	J.Largier and E.Grosholz (pers. comm.)	2015	Continuous data at Inverness	N/A
Turbidity	BOON	2011 - Present	Tomales Bay Buoy location	N/A
Water Temperature, Salinity, pH, Dissolved Oxygen, Chlorophyll, Conductance, Alkalinity, Dissolved Inorganic Carbon	BOAR[2]	2008-2011	11 sites throughout Tomales Bay	N/A
	CenCOOS[3]	2014-Present	Continuous data at Hog Island Oyster Company	N/A
Coastal Processes				
Wind data	Weather Underground stations	Various (see Figure 1)	Various locations	N/A
	BOON	2011 - Present	Tomales Bay Buoy location	N/A
Groundwater Inundation	USGS (CoSMoS)	TBD	Tomales Bay	Expected summer 2020
Shoreline Erosion	TBD (Identified as data gap)			
Streamflow	USGS	2007-present	Walker Creek (#11460750) and	N/A

[1] Bodega Ocean Observing Node is operated by the UC Davis Bodega Marine Laboratory (BML). More information can be found at: http://boon.ucdavis.edu/

[2] Bodega Ocean Acidification Research is operated by the UC Davis BML. More information can be found at: https://marinescience.ucdavis.edu/research-programs/climate-change/boar

[3] http://erddap.cencoos.org/erddap/tabledap/edu_ucdavis_bml_hog_island_oyster.html

Name	Source	Date Collected	Extent	Use Limitation
			Lagunitas Creek (#11460600)	
Wind-waves Predictions	USGS (CoSMoS)	TBD	Tomales Bay	Potentially summer 2020
Wave measurements	UC Davis BML [John Largier] (unpublished data)	2019-	8 locations in Tomales Bay	TBD
Existing Habitats and Vegetation Communities				
Name	**Source**	**Date Collected**	**Extent**	**Use Limitation**
Eelgrass mapping from composite of aerial flight photographs	CDFW	1992, 2000, 2001, 2002	Tomales Bay	N/A
Eelgrass mapping from georectified and digitized 2010 aerial photographs	CDFW	2010 (published in 2013)	Tomales Bay	N/A
Eelgrass survey	CDFW	2015	Tomales Bay	N/A
Eelgrass survey	Merkel & Associates	2017	Tomales Bay	N/A
Olympia oyster surveys	Cheng and Grosholz (2016)	2010-2013	14 sites throughout the Bay	N/A
Olympia oyster surveys	Kimbro et al (2009)	2009	9 sites throughout the Bay	N/A
Olympia oyster surveys	GFNMS	Ongoing	Several sites throughout the Bay	N/A
Inventory of existing wetlands	National Wetlands Inventory (NWI) - USFWS	variable	Tomales Bay	N/A
Marin Countywide Fine Scale Vegetation Map	GGNPC	2019	Marin County	Preliminary dataset reviewed by U.S Geological Survey and provided in January 2020; Final release planned for April 2021
SLR and Asset Vulnerability				
Sea Level Rise Inundation Zones	USGS (CoSMoS) and County of Marin	N/A	Tomales Bay	N/A
Existing Hydrodynamic Models	**Source**	**Processes Modeled**	**Extent**	
3D TRIM[4] Model	Edward S. Gross (Env. Consultant) and Mark Stacey (UC Berkeley)	Hydrodynamics and Salinity	Tomales Bay	Winter season only
Delft-3D	Harcourt-Baldwin and Diederick (2006)	Hydrodynamics, salinity, temperature	Tomales Bay	N/A
ROMS[5]	Kate Hewett (UC Davis BML)	Upwelling; hydrodynamics	Tomales Bay	In-development
Hydrodynamic Model	Brenann and Stacey (2005)	Currents; salinity	Tomales Bay	N/A

[4] Tidal, Residual, Intertidal Mudflat Model. More information can be found here by Cheng et al (1993): https://www.sciencedirect.com/science/article/pii/S0272771483710164

[5] Regional Ocean Modeling System is a three-dimensional, free-surface ocean model. More information about ROMS can be found here: https://www.myroms.org/

3. Data Review

The following sections list and summarize the most relevant documents, data sets and studies collected for each category. The data review summary is the beginning of an annotated bibliography for the study.

3.1. Land Use and Ownership

Boat mooring locations and aquaculture sites were downloaded to characterize shallow water land use around Tomales Bay. Aquaculture site information was provided by the Greater Farallones National Marine Sanctuary. Boat mooring locations are compiled by the California State Lands Commission (SLC) as part of the Tomales Bay Mooring Program[6]. Existing boat moorings are clustered around the middle eastern shore and southern end of the Bay, by Marconi and Inverness, respectively. A number of these vessels are recreational (e.g. sailboat, power boat) and belong to local residents.

3.2. Elevation Data

New light detection and ranging (LiDAR) for Marin County was flown at low tide in January 2019 by the Golden Gate National Parks Conservancy (GGNPC) and is presently being reviewed by USGS (a funding partner on the collection). The preliminary dataset was provided to the CDA on January 6th, 2020. The dataset provides continuous coverage of the nearshore zone in Tomales Bay. County-wide 6-inch ortho-imagery data from 2018 is also available. Several other sources for topography and bathymetry around Tomales Bay exist, including the 2013 Marin County Lidar, 2009-2011 CA Coastal LiDAR and 2008 bathymetry dataset by USGS.

3.3 Water Column Conditions

A large amount of water quality and nutrient data are available at a number of sites within the Bay, spanning almost continuously from 1985 to the present. These data were initially collected as part of the Biogeochemical Reactions in Estuaries (BRIE) and Land-Margin Ecosystems Research (LMER) programs[7], until the mid-1990s. As part of these programs, water column profiles were taken monthly at 2 km intervals along the axis of the Bay (Figure 1). Since that time, various researchers have either continued collecting periodic water column profiles at the same 2 km stations, continuous measurements at individual locations (Sacramento Landing, Inverness, Hog Island), or grab-samples on an opportunistic basis to support various studies. Most recently, the Bodega Ocean Acidification Research (BOAR) program collected water column profiles at the same 2 km locations along the bay from 2008 to 2011, and continuous water quality sampling is conducted at the BOON buoy and at Hog Island Oyster Company (Figure 1). The continuous datasets are publicly-available as part of the Central California Ocean Observing System (CenCOOS) program.

[6] https://www.slc.ca.gov/leases-permits/tomalesbay/
[7] http://lmer.marsci.uga.edu/tomales/

3.4 Coastal Processes

Continuous measurements of wind speed and direction (along with other meteorological data) are available from the BOON buoy station, which has been collecting data since 2011. There are few other sources of wind data throughout the Bay, with the exception of personal wind measurement stations from several homeowners that are available via the Weather Underground site (Figure 1).

Long-term historical records of wave conditions within the Bay are unavailable. The nearest offshore wave buoy to the project site is the NOAA Bodega Bay station (Station #46013), operating at a water depth of approximately 123 m. The station provides a continuous record from 1981 through 2018. No buoys collect wave data directly within Tomales Bay. The Coastal Storm Modeling System (CoSMoS) developed by the USGS, has not modeled wave conditions within Tomales Bay, although wave modeling may be performed in a future model update that could occur in 2020 (pers. comm. L. Erikson).

Professor John Largier is currently collecting measurements of wave height and frequency at 8 locations along the Bay using pressure sensors, focusing on sites along the western shoreline. These data are intended to help understand how beach morphology changes along the axis of the bay, as ocean swell waves entering the mouth of the Bay begin to lose energy and wind-waves begin to dominate. These data are anticipated to be collected through 2020 (pers. comm. J. Largier), and will be incorporated into the conceptual designs as they become available.

GIS shapefiles for perennial streams were downloaded from the U.S. Geological Survey (USGS) National Hydrography Dataset website, in order to ascertain the location of freshwater flows relative to nearshore habitat. Additionally, long-term gauged streamflow measurements are available from the USGS for Walker Creek (Site #11460750) east of Marshall and at Lagunitas Creek (Site #11460600) near Point Reyes Station.

3.5 Existing Habitats and Vegetation Communities

Merkel & Associates, Inc. developed a complete map of eelgrass presence within Tomales Bay in 2017. The surveys indicate the presence of large swaths of eelgrass in the northern part of Tomales Bay offshore of Vincent’s Landing and Hamlet as well as at the southern end. Overall, eelgrass was found around much of the the perimeter of the Bay in the most recent 2017 mapping effort.

Cheng and Grosholz (2016) collected species count data for Olympia oysters, oyster drills and crabs on both the east and west shorelines of Tomales Bay and examined the impact of various environmental stressors (e.g. hypoxia, warming) on these species. A number of other studies have looked at the presence and growth rates of Olympia oysters throughout the Bay. Kimbro et al. (2009) developed a time series of Olympia oyster growth rates for a number of sites along the western and eastern shores of Tomales Bay, showing an increasing gradient in growth rates with distance inland.

An existing inventory of wetlands areas is available from the National Wetlands Inventory[8] provided by the U.S. Fish and Wildlife Service (USFWS), although this dataset is relatively coarse in resolution. To supplement this, the recently-flown LiDAR dataset provided by GGNPC was used to develop a preliminary ‘Marin Countywide

[8] https://www.fws.gov/wetlands/data/mapper.html

Fine Scale Vegetation Map', which is anticipated in final form by April 2021 (pers. comm. D.Franco). The preliminary dataset will be assessed for the current project, and the final form will be incorporated when it becomes available.

3.6 Sea Level Rise (SLR) and Asset Vulnerability

Areas inundated by sea-level rise were downloaded from the Marin County GIS clearinghouse in 1 ft increments, from 0 to 6 feet. For comparison, future flood extents due to sea level rise are also available from the Our Coast Our Future (OCOF) website.

3.7 Currents and Circulation from Hydrodynamic Models

Several hydrodynamic models characterizing tidal circulation, currents, salinity and other physical processes in Tomales Bay have been developed in order to characterize seasonal transport patterns within the Bay in response to changes in runoff, tides, winds, and coastal upwelling. Given the depth and orientation of Tomales Bay, and the location of its mouth within a dynamic coastal area, currents and water quality in the Bay are strongly influenced by year-to-year changes in coastal upwelling (Largier et al. 1997). The average tidal currents in the Bay, as well as wind-induced currents, may be an important consideration for placement of oyster or eelgrass elements as adaptive measures.

Gross and Stacey (2012) used the TRIM model to simulate hydrodynamics and salinity patterns within distinct bathymetric regions of Tomales Bay. Brennan and Stacey (2005a-2005c) developed a 3D hydrodynamic model of the Bay to evaluate pollutant transport from fresh water creeks into the Bay under winter hydrologic conditions. Harcourt-Baldwin and Diedericks (2006) developed a Delft-3D model of the Bay to look at density-driven circulation of seasonally warm water. At present, Prof. John Largier and Kate Hewett are developing a ROMS model to understand the effect of upwelling on currents in the Bay.

4. Data Needs

ESA has requested but not yet received the following documents and datasets:

- Groundwater inundation – expected in Summer 2020 from CoSMoS (pers. comm. L.Erikson)
- Modeled wind-wave conditions – potentially available from CoSMoS in 2020 (pers. comm. L.Erikson)

ESA has identified the following remaining data gaps:

- ESA has not found any studies on historic erosion trends around the Tomales Bay shoreline. Previous studies by Hapke and Reid (2007) and C-SMART (Marin County Community Development Agency 2018) examined erosion on the outer California coastline but did not include Tomales Bay. A comparative shoreline analysis, based on tracing shorelines from historic aerial photographs and identifying erosion hotspots would supplement data needed to characterize subtidal habitats around the Bay, and assist in targeting focus areas for restoration or planning efforts. A preliminary version of this will be provided by ESA as part of the process of identifying shoreline adaptation measures.

- To date, no effort has been undertaken to collect all of the disparate water quality datasets collected by various researchers since 1985, provide consistent QAQC, assign geographic location, and make available via a public data portal (pers. comm. J. Largier). Future efforts could benefit from funding an effort to streamline these data sets and make them public, as part of process to inform further long-term monitoring.

- This memo provides data sources for habitats and vegetation communities. Additional datasets are available for shorebirds[9], marine mammals, and other biological resources. We focused at this time on datasets related to the primary drivers for developing and screening living shoreline actions, including habitat types that could be part of a living shoreline design, and will look at more detailed bio resources information later in the process as relevant to screening and site-specific planning and design. Despite the present data gaps, ESA anticipates that the objectives of the current feasibility project can still be met with the available data.

References

Brennan, M. and M. Stacey. 2005a. Modeling the Fate and Transport of Tracer Concentration of Walker Creek Discharge into Tomales Bay. University of California, Berkeley. Dept of Civil and Environmental Engineering. Report to Regional Water Quality Control Board, San Francisco Region. February 2, 2005.

Brennan, M. and M. Stacey. 2005b. Modeling the Fate and Transport of Tracer Concentration of Walker Creek Discharge into Tomales Bay. University of California, Berkeley. Dept of Civil and Environmental Engineering. Report to Regional Water Quality Control Board, San Francisco Region. May 3, 2005.

Brennan, M. and M. Stacey. 2005c. Modeling the Fate and Transport of Tracer Concentration of Walker Creek Discharge into Tomales Bay. University of California, Berkeley. Dept of Civil and Environmental Engineering. Report to Regional Water Quality Control Board, San Francisco Region. June 30, 2005.

Cheng, B. S. and E.D. Grosholz. 2016. Environmental stress mediates trophic cascade strength and resistance to invasion. Ecosphere 7(4): 1-13.

ESA. 2015. Geomorphic Response of Beaches and Marshes (West Marin County). Technical memorandum prepared for Marin County Community Development Agency. August 31, 2015.

Hapke, C. J., and D. Reid. 2007. National assessment of shoreline change part 4: Historical Coastal Cliff Retreat along the California Coast. U. S. Geological Survey.

Harcourt-Baldwin, J.L., and G.P.J. Diedericks. 2006. Numerical modelling and analysis of temperature controlled density currents in Tomales Bay, California. Estuarine, Coastal and Shelf Science 66: 417-428.

Hearn, C. J. and J.L. Largier. 1997. The summer buoyancy dynamics of a shallow mediterranean estuary and some effects of changing bathymetry; Tomales Bay, California. Estuarine, Coastal and Shelf Science 45: 497–506.

[9] For example, long term monitoring data sets (1964- present) on shore birds (species and counts) in Tomales Bay and adjacent riparian areas have been collected by Point Blue and eBird[9] observations. These are available for download from the California Avian Data Center.

Hearn, C.J. and B.J. Robson. 2001. Inter-annual variability of bottom hypoxia in shallow Mediterranean estuaries. Estuarine, Coastal and Shelf Science 52: 643-657.

Kimbro, D.L. and E.D. Grosholz. 2006. Disturbance influences oyster community richness and evenness, but not diversity. Ecology 87: 2378-2388.

Kimbro, D. L., Largier, J. and E. D. Grosholz. 2009. Coastal oceanographic processes influence the growth and size of a key estuarine species, the Olympia oyster. Limnology and Oceanograph. 54: 1425–1437

Kimmerer, W.J. 1993. Distribution patterns of zooplankton in Tomales Bay, California. Estuaries 16: 264-272.

Largier, J. L., Smith, S.V., and J. T. Hollibaugh. 1997. Seasonally hypersaline estuaries in Mediterranean-climate regions. Estuarine, Coastal and Shelf Science 45: 789–797.

Marin County Community Development Agency. 2018. Collaboration: Sea-Level Marin Adaptation Response Team (C-SMART). Marin County Community Development Agency. February 2018.

Oberdorfer JA, Valentino MA, Smith SV. 1990. Groundwater contribution to the nutrient budget of Tomales Bay, California. Biogeochemistry 10: 199–216.

Point Blue Conservation Science. 2016. Natural Resources Vulnerabilities, Potential Adaptation Strategies, and Monitoring Framework for Marin County's outer coast sea-level rise vulnerability assessment. Prepared for the Marin County Community Development Agency.

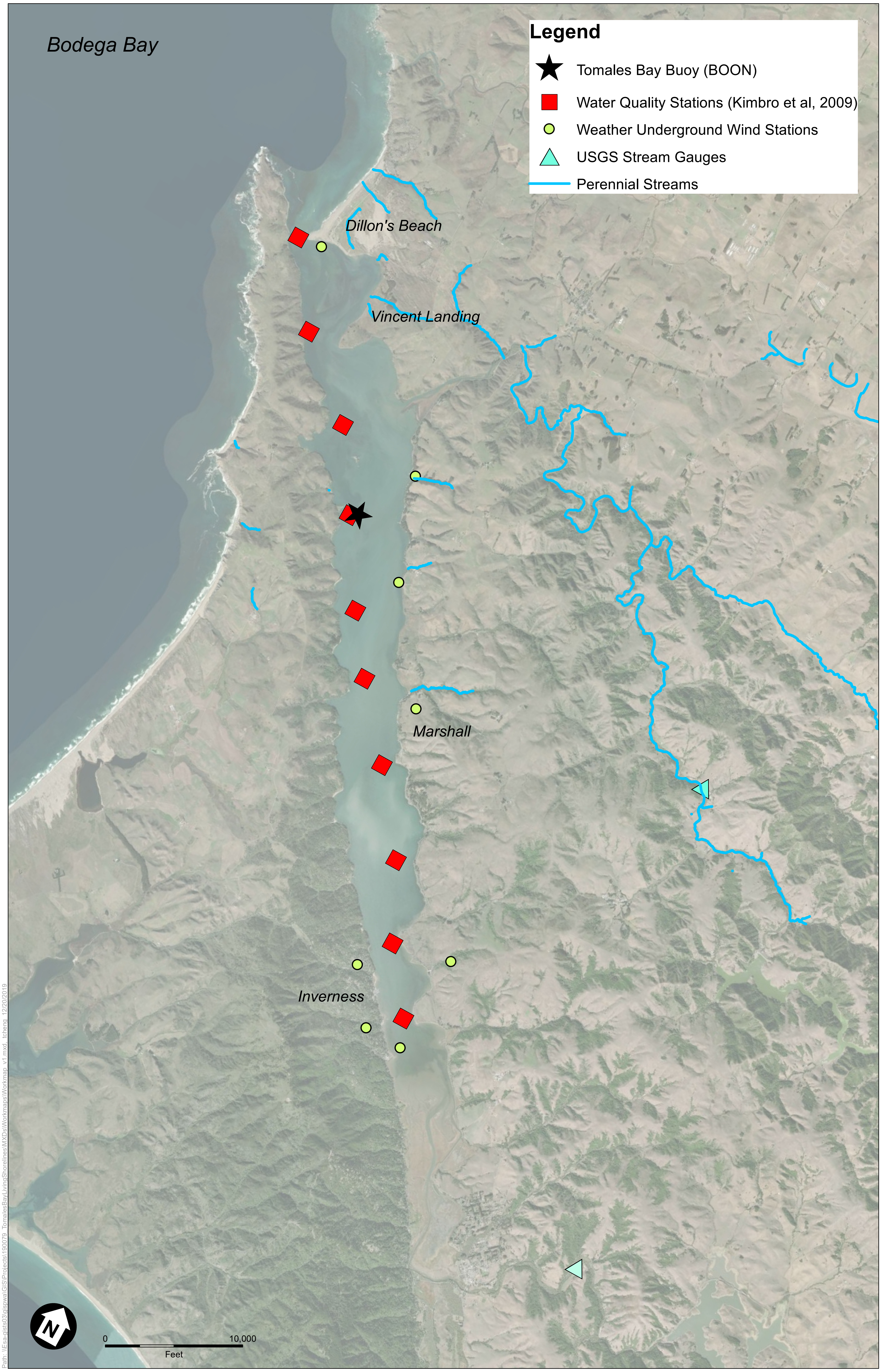
Point Blue Conservation Science. 2019. California Avian Data Center. Web portal for collected bird monitoring data from publically available sources. Accessible at: http://data.prbo.org/cadc2/index.php?page=137

Regional Water Quality Control Board (RWQCB). 2005. Pathogens in Tomales Bay Watershed Total Maximum Daily Load (TMDL). Staff Report, San Francisco Bay Region. September 14, 2005.

Smith, S. V., Hollibaugh, J. T., Dollar, S. J. & Vink, S. 1991a. Tomales Bay Metabolism: C-N-P stoichiometry and ecosystem heterotrophy at the land-sea interface. Estuarine, Coastal and Shelf Science 33: 223–257

Smith, S. V., Hollibaugh, J. T., Dollar, S. J. & Vink, S. 1991b. Tomales Bay, California: A case for carbon controlled nitrogen cycling. Limnology and Oceanography 34: 37–52

Smith, S.V., Hollibaugh, J.T., and S. Vink. 1989. Tomales Bay, California – a case for carbon-controlled nitrogen cycling. Limnology and Oceanography 34: 37-52.



SOURCE: Weather Underground (2019), US Geological Survey (2019), UC Davis Bodega Marine Laboratory (2019), Kimbro et al (2009) (Locations approximate for water quality stations)

Tomales Bay Living Shorelines Feasibility . D190079.00

Figure 1
Data Collection Locations in Tomales Bay

Attachment C

Coastal Analyses

ESA

ESA

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memorandum

date October 12, 2021

to Project File

cc

from Dane Behrens, PhD, PE.

subject Tomales Bay Living Shorelines Feasibility Project: Coastal Analyses

This attachment summarizes a series of coastal analyses developed by ESA to understand (1) potential for erosion on the shoreline and (2) potential coastal water levels resulting from combined tides, storm surge, and wave runup. This builds on a previous effort at Cypress Grove (PWA 2007), incorporates new wind data, and examines wave conditions at both Cypress Grove and Martinelli Park. We developed wind-wave estimates using a Wave98 model (Task 5.3) at both sites (Section C1), and also compared these estimates at Cypress Grove to prior estimates that used standard coastal engineering approaches (Shore Protection Manual 1984). These wave estimates are also used with water level exceedance curves to understand potential for erosion (Section C2) and total water levels (Section C3) along the backshore at both sites.

PWA (2007) previously hindcasted waves at Cypress Grove for a January 2006 event in which winds reached 45 miles per hour. They applied a parametric approach (Shore Protection Manual 1984), and hindcasted wave heights and water levels observed at the site by Audubon Canyon Ranch staff who were present during the storm. However, since this study did not examine waves at Martinelli Park, there was a need to develop a model for both sites as part of this effort. As described below, we first developed statistics of wind data available from Bodega Head and Tomales Bay (near Hog Island), and used this to develop a Wave98 model. We compared this to the results of the 2007 study to check that values were consistent, and then applied the model to understand conditions at Martinelli Park.

The findings of this analysis are used to inform engineering design of living shoreline treatments at both pilot sites in Task 5.5. The wind-wave modeling includes evaluation of site-specific information, such as historic wind records and critical fetch lengths as inputs into the Wave98 model to generate design wave conditions.

Contributions to this memo were made by ESA staff Tiffany Cheng, PE, Maureen Downing-Kunz, PhD, and Dane Behrens, PhD, PE, with senior review from Louis White, PE and Bob Battalio, PE.

Background

ESA supported CDA in identifying locations within Tomales Bay with assets vulnerable to current or projected future flooding and/or erosion related to sea-level rise in Task 3 of the study. ESA developed a series of overlay maps illustrating projected sea-level rise flooding with shoreline erosion rates, existing sensitive habitats, local geomorphology and other pertinent environmental data. For each location, ESA evaluated coastal hazards driving vulnerability at the site, including wave action, still water level flooding from sea-level rise, long-term erosion and other stressors. Based on these data, the Project Team identified six initial sites as having greatest need for protective structures and evaluated feasibility and applicability of living shorelines adaptation measures in Tasks 5.1 and 5.2.

Following input from regulatory agencies, CDA selected two priority pilot sites in locations where living shorelines may be feasible: 1) Cypress Grove and 2) Martinelli Park (**Figure C1**). This memo describes data collected and modeling conducted in order to develop design wave characteristics to support conceptual design (10% level) of nature-based adaptation measures at the pilot sites.

Figure C1. Location of Cypress Grove and Martinelli Park in Tomales Bay, CA

The wave climate in Tomales Bay is characterized by wind-waves created by wind imparting energy to the Bay water surface. Coastal swell from offshore sources enter the Bay through the mouth; however, the narrow shape of the Bay and local land features (e.g. Pelican Point, Hog Island) dissipate these waves before they penetrate the Bay further. Wave action in the central and southern portions of the Bay are primarily wind-waves. Most of the wind-waves in the bay are depth-limited (meaning that the local depth controls wave height more than the wind fetch). The Bay has a 12 mile fetch along its main axis, which allows formation of wind-waves that can at times exceed 1-2 feet and cause significant runup on shoreline structures and sand transport along the shoreline.

C1. Wind-Wave Modeling (Wave98)

The following section describes meteorological and environmental data collected in a desktop analysis to support wind-wave modeling at the two pilot sites.

C1.1 Tides

Tides in Tomales Bay can be described as mixed semi-diurnal tides, which are characterized by two high and two low tides of unequal heights each day. The shape and orientation of Tomales Bay with respect to the ocean produces variation in tides along the length of the Bay. Tides at the mouth of the Bay are smaller than ocean tides; however, the elongated shape of the Bay produces amplification of the tidal signal further south. The long-term average tide range (measured between MHHW and MLLW) at Point Reyes is about 5.8 feet, compared with 5.2 feet at Sand Point inside the mouth of Tomales Bay, 5.4 feet at Reynolds (8 miles upstream of the mouth), and 5.7 feet at Inverness Park (10 miles upstream from the mouth).

TABLE C1
TIDAL DATUMS AND WATER SURFACE ELEVATIONS IN TOMALES BAY, CA

Event/Datum	Pt Reyes[1]	Cypress Grove[3]	Inverness[3]
100-year FEMA Base Flood Elevation[2]	--	12	9
January 2005 flood level	8.4	8.7-9[4]	--
Mean Higher High Water ("MHHW")	5.8	5.9[5]	5.8
Mean High Water ("MHW")	5.1	5.2[5]	5.1
Mean Tide Level ("MTL")	3.1	3.1[5]	3.2
Mean Sea Level ("MSL")	3.1	3.1[5]	3.1
Mean Low Water ("MLW")	1.2	1.1[5]	1.2
Mean Lower Low Water ("MLLW")	0.0	-0.1[5]	0.2
NAVD88	0.0	0.0[5]	0.0

SOURCES: [1]NOAA Pt Reyes Gauge ID 9415020; [2]Estimated by assuming MSL is same at Cypress Grove and Inverness, and pro-rating tidal datums between the NOAA Reynolds and Sand Pt datum stations [3] NOAA Inverness Datum Site ID 9415228;

C1.2 Fetch Profiles

Wave98 requires average fetch depth information for the distances that wind-wave generation is occurring on. Due to the narrow and elongated shape of the Bay, a middle-of-bay location was chosen offshore of the Cypress Grove and Martinelli Park sites, since depths in the middle of the bay are greater and would provide a more conservative estimate of wave growth. The longest fetch lengths for Cypress Grove and Martinelli Park are approx. 7 and 11 miles, respectively.

ESA drew fetch radials around the selected locations and extracted fetch profiles from available topo-bathymetric information for Tomales Bay, including the 2019 and 2013 Marin County LiDAR. Where necessary, the 2013 Marin County LiDAR was used to fill in gaps in the terrain. Average fetch depths were computed over 2/3 of the fetch profile closest to the sites. The average fetch depth for the Cypress Grove profiles was approximately 20 feet. Since Martinelli Park is located by the tidal marsh and mudflat environments in southern Tomales Bay, the average fetch depths are shallower (approx. 3- to 5-feet depth). The longest fetch at Martinelli Park, corresponding to the 325° compass direction, has an average fetch depth of 16 feet.

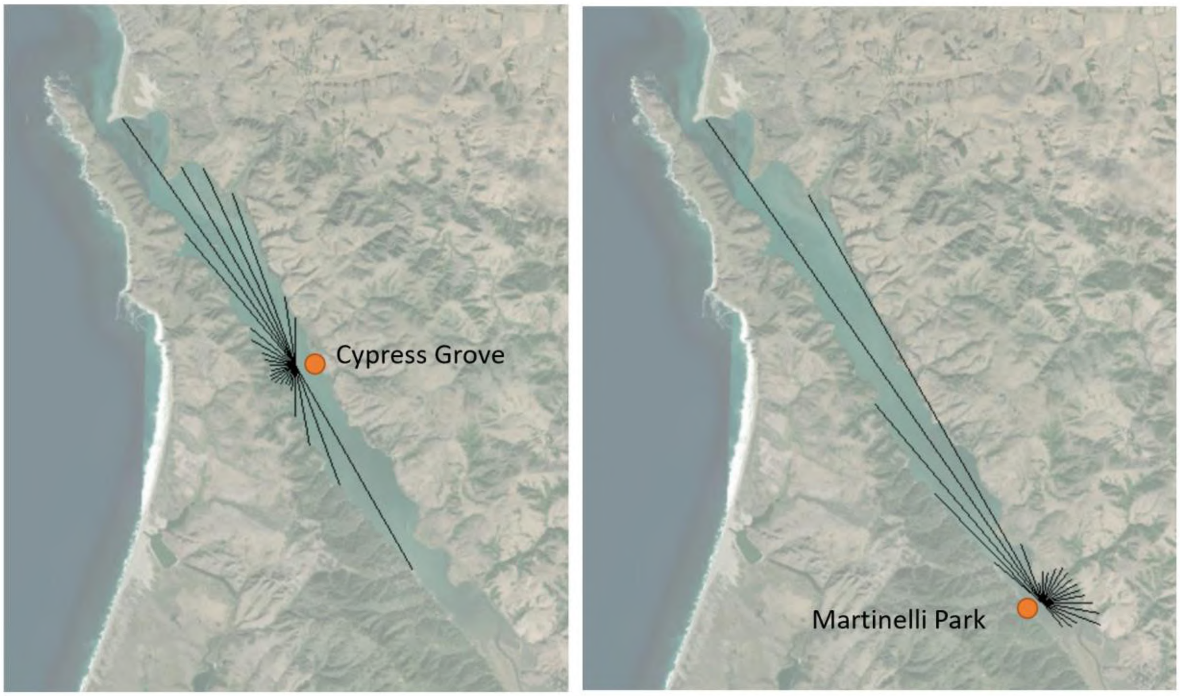


Figure C2. Wind Fetch Distances at Cypress Grove (left) and Martinelli Park (right)

C1.3 Wind

Wind-wave generation across Tomales Bay is a significant contributor to wave action at both the Cypress Grove and Martinelli Park shorelines. Key design parameters (e.g. elevations) for living shoreline treatments are tied to design wave heights and corresponding extreme wind speeds. Extreme wind speeds for a range of recurrence intervals (e.g. 5-yr, 10-yr, 20-yr) can be estimated by fitting annual maximum wind speeds to multiple probability distributions and selecting a curve that exhibits a 'best fit' to the observed data.

Long-term historical wind records are collected by the UC Davis Bodega Marine Laboratory (BML) at Bodega Head, by Bodega Bay and within Tomales Bay, at Hog Island, as part of the Bodega Ocean Observing Node (BOON)[1]. Wind data gathered at Bodega Head are measured by a land-mounted anemometer while meteorological information at the Hog Island, Tomales Bay location are collected from a buoy on the water surface. **Figure C3** shows the location of the wind sensors. The length of the Tomales Bay wind record extends from 2013 to present-day; the Bodega Bay wind record spans a longer duration, from 1988 to 2021. Due to the shorter record length at the Tomales Bay location, wind data (e.g. hourly-averaged speeds and directions) from the Tomales and Bodega Bay locations were downloaded from the BML website and used to inform extreme wind speed estimates.

[1] Wind data from UC Davis Bodega Marine Laboratory (BML)'s BOON system can be accessed at this address: https://boon.ucdavis.edu/

Figure C3. Location of BML Wind Sensors

Several corrections were applied to the wind records to account for differences in wind speed measurement conditions, such as gage height and effects of topography, according to Resio and Vincent (1977) and USACE (2006). The Bodega Bay anemometer is located at a height of 20 m while the Tomales Bay buoy is located on the water surface (z = 1 m). The wind speed vertical profile follows the power law equation; this was used to calculate the wind speed at the 10 m elevation, for both locations. Since the Bodega Head anemometer is located on land and design wind speeds for wind-wave generation will be traveling over water, a land-to-water correction was applied to the Bodega Head wind speeds. This same correction was not applied to the Tomales Bay location, since the buoy is located on water already. No corrections related to wind speed duration averaging were applied, since the wind speed data were averaged hourly. It is optimal to use longer duration wind speeds as the estimated design wind speeds, as they are more representative of sustained wind conditions across the water. **Figure C4** shows the corrected hourly wind speed records at the Bodega Bay and Tomales Bay locations.

ESA applied in-house MATLAB scripts to identify annual wind speed maxima for each water year in the available record (October 1 through September 30) and estimate extreme wind speeds using extreme value analysis.

The Tomales Bay wind record is shorter in duration and has several significant gaps (particularly in years 2013 through 2016), which affect the quality of the extreme wind speed estimates since the annual maximum selected from the available data may not be truly representative of real conditions. Due to the proximity of Bodega Bay to Tomales Bay, it is possible to determine an approximate ratio by which to predict wind speeds at Tomales Bay based off of the available record at Bodega Bay. **Figure C5** shows a scatter plot of wind speeds between Tomales Bay and Bodega Bay for dates/times where both sensors recorded measurements. Wind speeds at Tomales Bay are roughly 60% of those recorded at Bodega Bay. However, storm events sometimes cause deviations in the relationship between the two sensors. For this reason, we performed two sets of wave conditions: one with wind speeds adjusted by a factor of 60%, and a more conservative (stronger winds) set based on using the raw Bodega

Head wind data. To prevent underestimating coastal flood levels caused by wave setup, we ultimately applied the more conservative set.

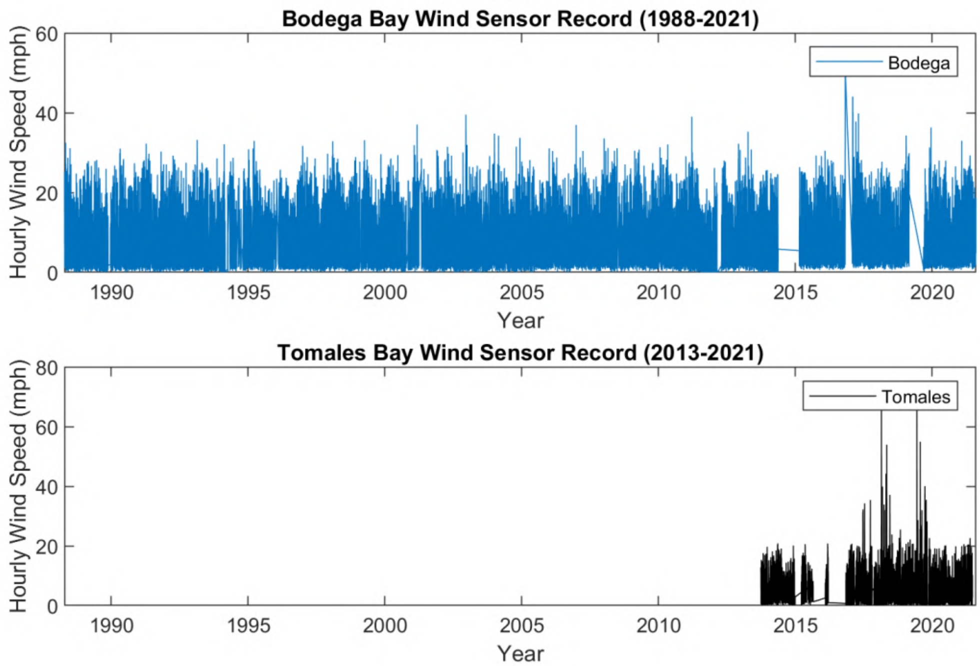


Figure C4. Historic wind speed records at Bodega Bay and Tomales Bay stations

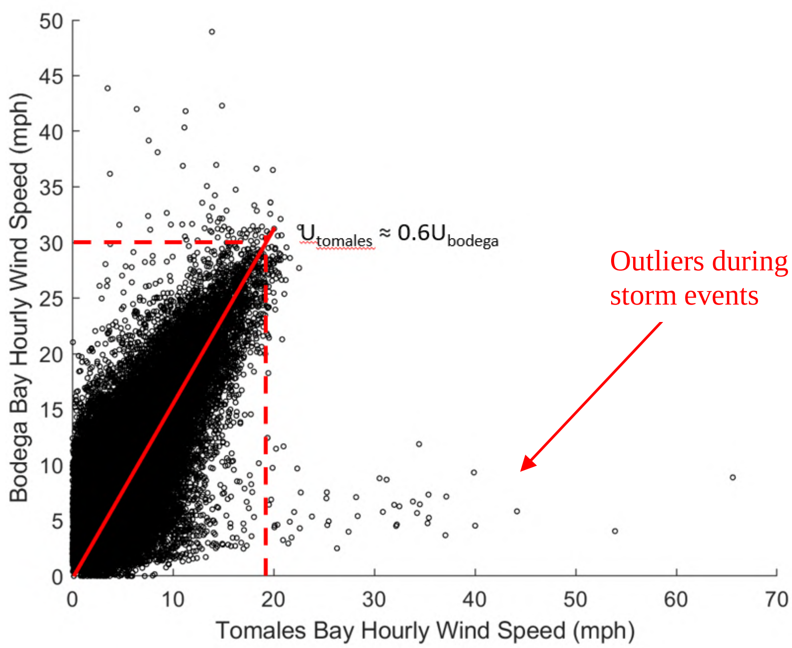


Figure C5. Scatter plot of overlapping wind record values (2013-2021) from Bodega Bay and Tomales Bay stations

Extreme wind speed values were estimated using annual maxima derived from the Bodega Bay measurements, due to the longer and higher quality wind record. These data were fitted the Gumbel, Weibull and General Extreme Value (GEV) Distributions, as shown in **Figure C6**. For this study, the GEV PWM fit was determined to be the best fit to the data points. **Table C2** summarizes the extreme wind speeds obtained from the GEV distribution for different return periods.

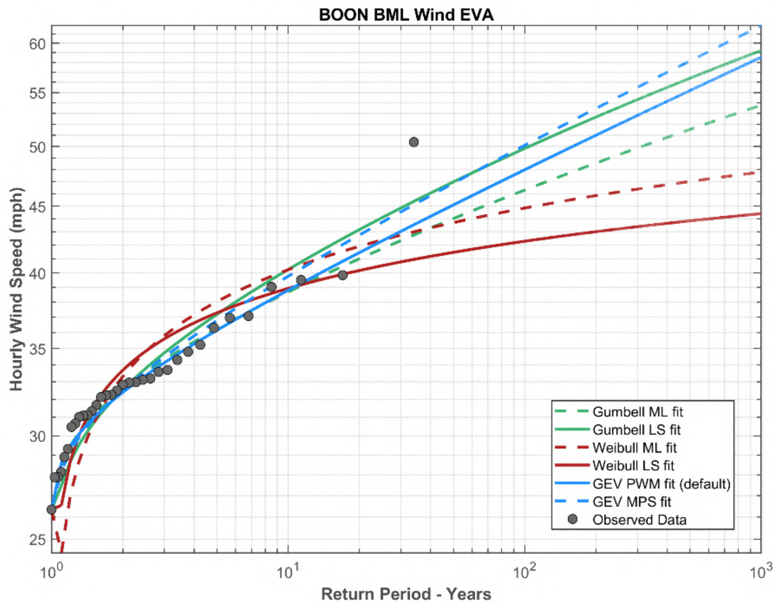


Figure C6. Extreme Value Analysis of Bodega Bay Wind Speed Record (1988-2021)

TABLE C2

EXTREME WIND SPEEDS BY RETURN PERIOD (HOURLY AVERAGED)

Return Period (yrs)	Wind Speeds (mph) – Bodega Bay	Wind Speeds (mph) – Tomales Bay
1	26.0	15.6
2	32.5	19.5
5	36.0	21.6
10	39.0	23.4
20	41.5	24.9
50	45.0	27.0
100	48.0	28.8

C1.4 Wave98 Model Results

ESA ran the Wave98 model for wind speeds corresponding to a range of typical and extreme events up to the 100-yr recurrence interval for both the Tomales Bay and Bodega Bay wind speeds. The Tomales Bay extreme wind speeds were estimated as a fraction of the Bodega Bay wind speeds (see previous section). Wave98 estimates the significant wave height and periods at the project site based on the average fetch depths, fetch lengths and extreme wind speeds. Average fetch depths were calculated from the fetch profiles extracted from the bathymetry datasets covering Tomales Bay, assuming depths corresponding to 0 ft Local Mean Sea Level (LMSL). Due to its central location in Tomales Bay, the longest fetch distances to Cypress Grove correspond to both the northwest (325°) and southeast (160°) directions. For Martinelli Park, the largest fetch distance (approx. 11 miles) is associated with the northwest (325°) direction. ESA constructed wind speed duration curves as inputs to the model and computed wind stress factors for each design wind speed (Simiu & Scanlan, 1996; USACE, 1984).

Wave98 calculates estimated wave heights for the distinct compass directions as well as an average value over the fetch (e.g. composite fetch method, which assumes a cosine squared distribution). Extreme wind speeds were simulated over a 180 degree fetch fan, with ten (10) degree increments to account for variances in the wind angle over the fetch length. Because of the Bay's narrow and elongated shape, the topography may "channel" wind direction such that the directional distribution of wind and wave energy is narrower, compared to a unobstructed wind field across open water (wide fetch). The averaging in the composite fetch method may result in artificially low wave height estimates; therefore, the wave heights for the primary fetch direction were considered to be representative of waves generated over a long, narrow fetch.

Table C3 summarizes the estimated significant wave heights and peak periods at the pilot site locations from the northwest, assuming extreme wind speeds in Tomales Bay are 60% those of Bodega Bay. A 20-year wind event generated 2.1 ft and 2.3 ft significant wave heights at Cypress Grove and Martinelli Park, respectively. Peak periods at both sites ranged between 2 to 3.5 seconds.

TABLE C3

WAVE98 MODEL RESULTS FOR WINDS ARRIVING FROM 325° - TOMALES BAY EXTREME WINDS

		Cypress Grove		Martinelli Park	
Return Period (yrs)	Wind Speeds (mph)	Wave Height (ft)	Peak Period (s)	Wave Height (ft)	Peak Period (s)
1	15.6	1.3	2.7	1.4	2.6
2	19.5	1.6	2.6	1.8	2.9
5	21.6	1.8	2.7	2.0	3.0
10	23.4	1.9	2.8	2.2	3.1
20	24.9	2.1	2.9	2.3	3.2
50	27.0	2.3	3.0	2.5	3.3
100	28.8	2.4	3.1	2.7	3.4

As a point of comparison, PWA (2007) noted that wind waves were higher during the January 2006 event, which was estimated at the time to be roughly a 5 to 15 year return period for Tomales Bay. Using a wind speed reported at Bodega head of 45 miles per hour, their analysis resulted in a predicted significant wave height and peak period of 4.5 ft and 4.0 seconds. Based on wind data aggregated since the time of the 2006 event, its wind speed may be more in line with a 20 to 50 year event (Table C3)

Since the extreme wind speeds in Tomales Bay (assuming the reduction factor) do not include these higher wind speeds, ESA also evaluated the wave characteristics corresponding to extreme wind speeds from Bodega Head. **Table C4** summarizes the wave heights and peak periods corresponding to Bodega Bay extreme wind speeds (no reduction factor). A 45.0 mph wind speed produces a roughly 4-ft wave height with 4 s peak period at both locations, which is comparable to the wave height calculated in the previous 2007 PWA study. To note, the wave heights estimated by Wave98 for this fetch direction use shallow water equations; the parametric equations used in the PWA study are deep water equations, which result in a slightly larger wave height value, since they don't take into account the effect of depth on wave height.

Note that the updated wind recurrence assessment (including years after 2007) indicate that the January 2006 event was closer to a 50-year event. At Martinelli Park, a 45 mph wind event corresponded to a roughly 4.2-ft wave height and 4.1 second period.

TABLE C4

WAVE98 MODEL RESULTS FOR WINDS ARRIVING FROM 325° - BODEGA BAY EXTREME WINDS

		Cypress Grove		Martinelli Park	
Return Period (yrs)	Wind Speeds (mph)	Wave Height (ft)	Peak Period (s)	Wave Height (ft)	Peak Period (s)
1	26.0	2.2	3.0	2.4	3.3
2	32.5	2.9	3.3	3.0	3.6
5	36.0	3.2	3.1	3.3	3.7
10	39.0	3.5	3.6	3.6	3.8
20	41.5	3.7	3.6	3.8	3.9
50	45.0	4.0	3.8	4.2	4.1
100	48.0	4.3	3.9	4.5	4.3

C2. Assessment of Erosion Potential

We applied the wind wave estimates above to assess the susceptibility of Cypress Grove and Martinelli Park to erosion by wave action, by determining expected wave power (the work done by waves breaking on the shoreline) for combinations of expected wave heights and water levels. Erosion potential was investigated along cross-shore transects at the two pilot sites for three events (combinations of wind-waves and water levels) at three sea-level rise (SLR) scenarios. For each cross-shore transect, a reference point (the approximate location of wave breaking) was identified and its elevation was used in the analysis. At Martinelli Park, we considered a transect in front of the Inverness Store (reference elevation of 6 feet NAVD88 at the toe of a wooden retaining wall). At Cypress Grove, two cross-shore transects were considered—one along the riprapped region protecting several buildings (reference elevation 4 feet NAVD88) and one along the beach (reference elevation 7 feet NAVD88), both for baseline and with-project conditions.

Erosion potential was computed at each location for the following three events:

1. 100-y wind plus 1-y water level
2. 1-y wind plus 100-y water level
3. 10-y wind plus 20-y water level

Wind-event return intervals were determined using the Wave98 model (Section C1); We applied wind wave heights estimated from Bodega Head winds (Table C4). Water level return intervals were determined from the annual exceedance probability curve for observed hourly water levels at Point Reyes, CA (NOAA Station ID 9415020) for the period 1980 – present (Figure C7).

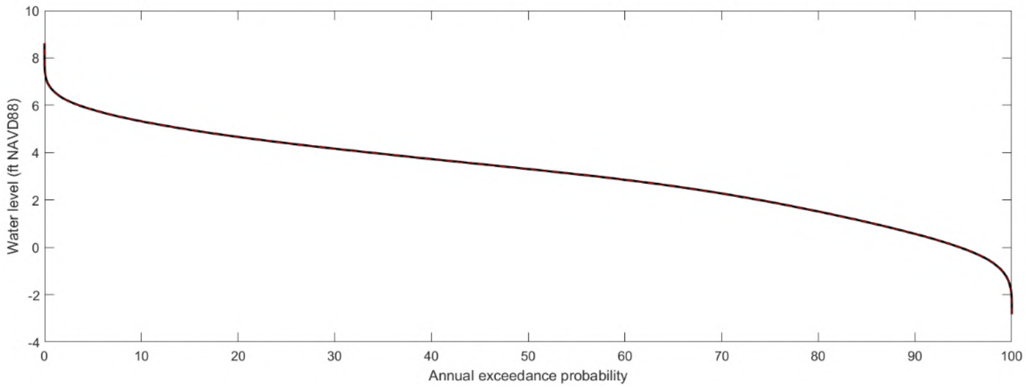


Figure C7. Annual exceedance probability curve for observed hourly water levels at Point Reyes, CA (NOAA Station ID 9415020) for the period 1980 – present. Values on x-axis are reported in percent (%).

For these transects and events, erosion potential was further investigated for three SLR scenarios (consistent with the main body of the report): 0 ft (Present conditions); 1.6 feet; and 3.3 feet. These scenarios were implemented by increasing the water level by the amount of SLR.

C2.1 Example calculation of erosion potential for Martinelli Park

The results from Martinelli Park for the 10-y wind plus 20-y water level event with 3.3 feet of sea-level rise are presented here to demonstrate this analysis. First, the water level exceedance curve is generated for the project site based on nearby historical water levels. These water levels are adjusted for the three SLR scenarios (Figure C8).

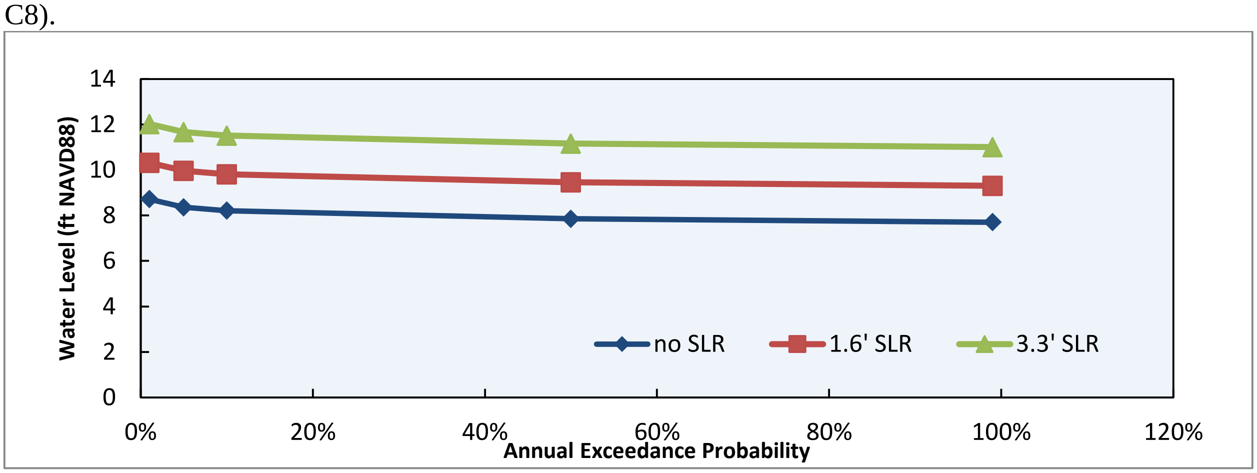


Figure C8. Water level exceedance at Martinelli Park for three sea-level rise (SLR) scenarios.

Next, wave height as a function of water level was computed based on the reference elevation at the site. Wave height was determined as the minimum of the depth-limited wave height or the modeled (fetch-limited) wave heights from Table C4. As water depth increases, potential wave height increases until reaching the modeled wave height (Figure C9).

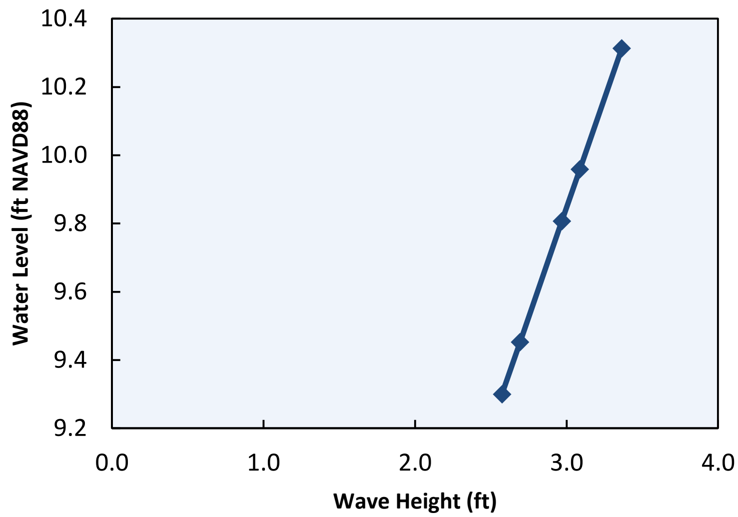


Figure C9. Water level versus wave height at Martinelli Park for 20-y horizon SLR (1.6 ft).

Next, for each wave height in Figure C9, a wave power index was computed to provide a relative measure of potential work (i.e., erosion) of waves impacting the shore. This index is computed as the product of the squared significant wave height and the wave period, as follows:

$$\text{Wave power index} = H_s^2 T$$

Finally, erosion potential is determined as the product of the wave power index and the annual exceedance probability for the range of water levels of interest (Figure C10). Combining the potential wave power with the percent time that elevated water levels may occur reveals the zone where the greatest wave energy will occur. By selecting a threshold value of erosion potential equal to the peak value minus the standard deviation, the range of land elevations at the site that require erosion control is evident.

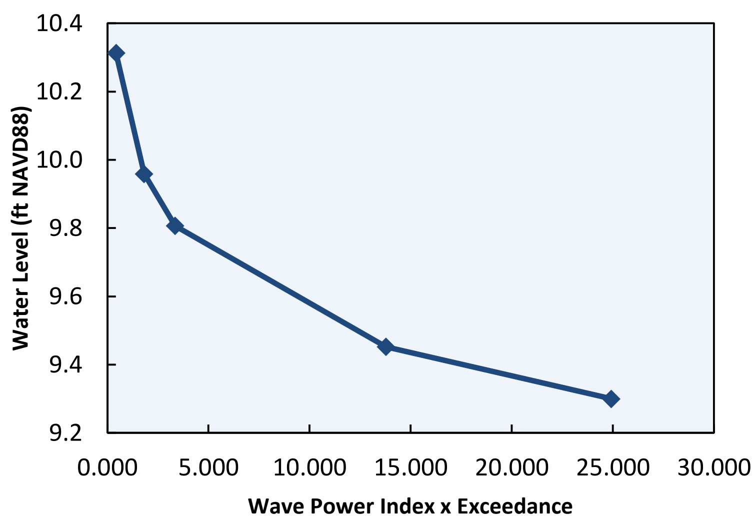


Figure C10. Water level versus erosion potential at Martinelli Park for 20-y horizon SLR (3.3 ft). The threshold value of erosion potential is 14.5, meaning the range of land elevations needing erosion control is below approximately 9.4 ft.

C2.2 Erosion potential for Martinelli Park for the 10-y wind plus 20-y water level event

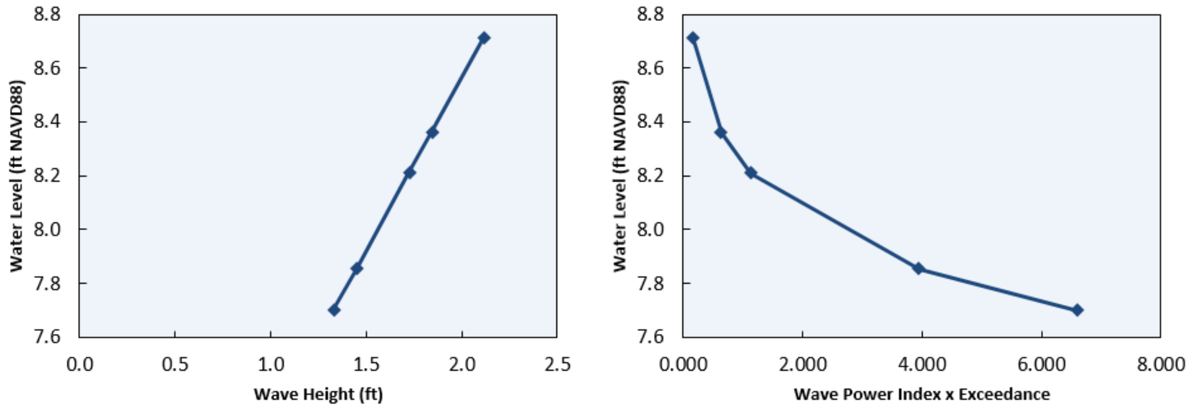


Figure C11. Left: Water level versus wave height and Right: Water level versus erosion potential at Martinelli Park for no SLR.

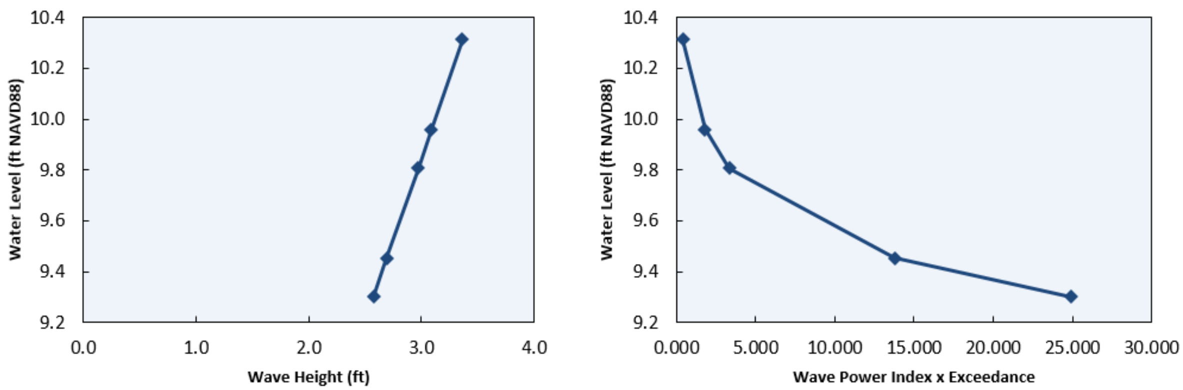


Figure C12. Left: Water level versus wave height and Right: Water level versus erosion potential at Martinelli Park for 20-y horizon SLR (1.6 ft).

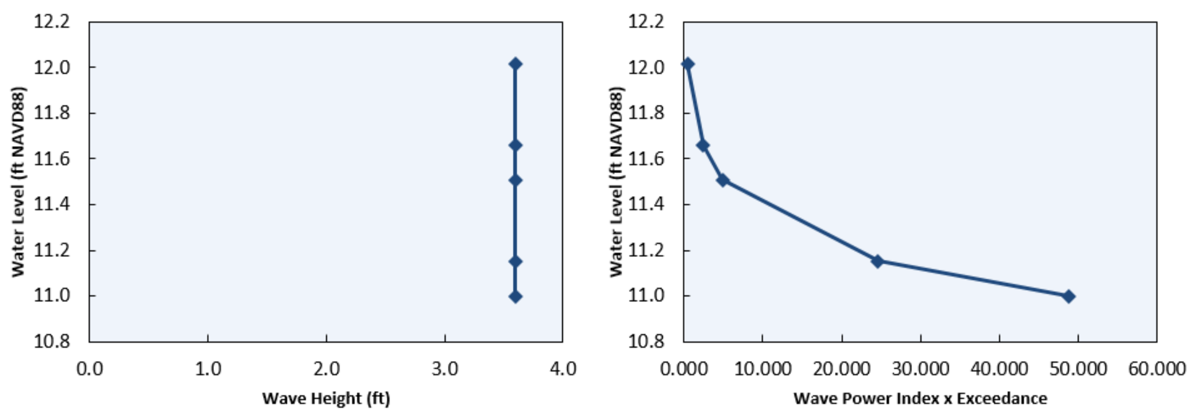


Figure C13. Left: Water level versus wave height and Right: Water level versus erosion potential at Martinelli Park for 40-y horizon SLR (3.3 ft).

C2.3 Erosion potential for Cypress Grove (riprap section) for the 10-y wind plus 20-y water level event

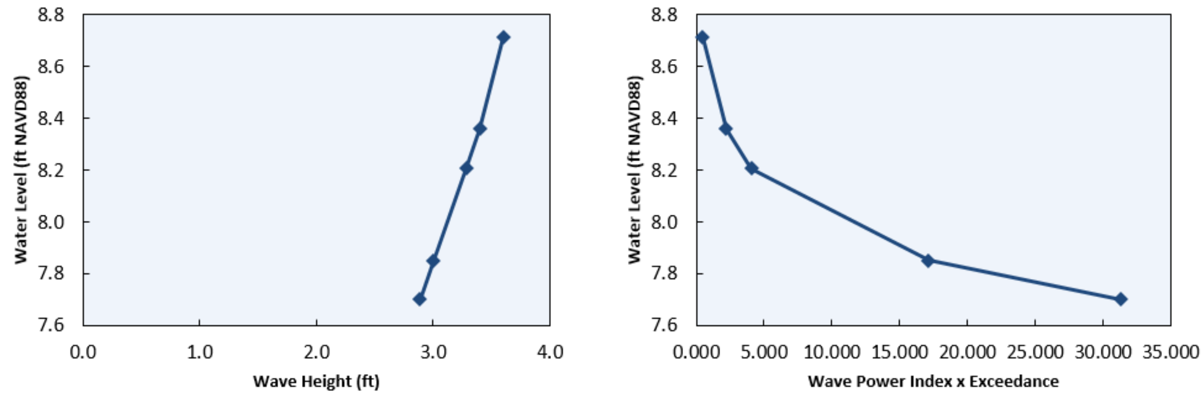


Figure C14. Left: Water level versus wave height and Right: Water level versus erosion potential at Cypress Grove for no SLR.

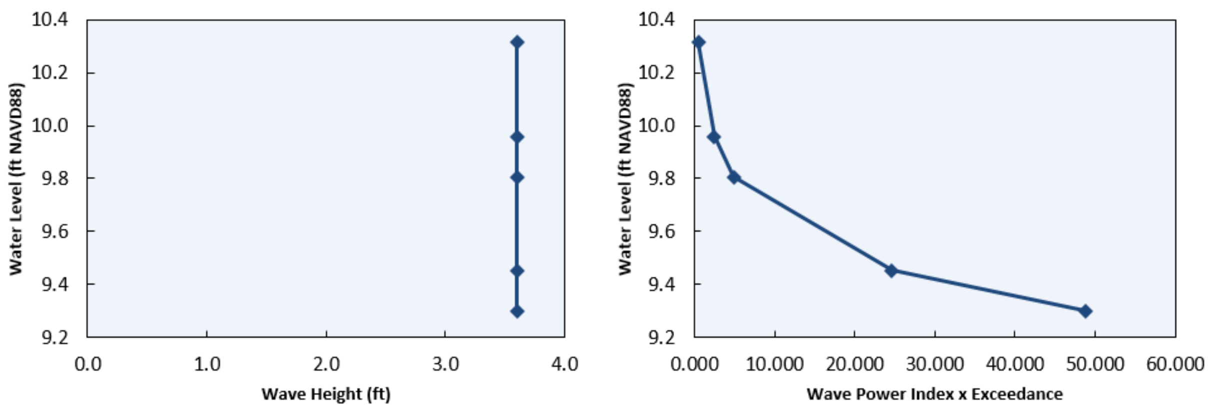


Figure C15. Left: Water level versus wave height and Right: Water level versus erosion potential at Cypress Grove for 20-y horizon SLR (1.6 ft).

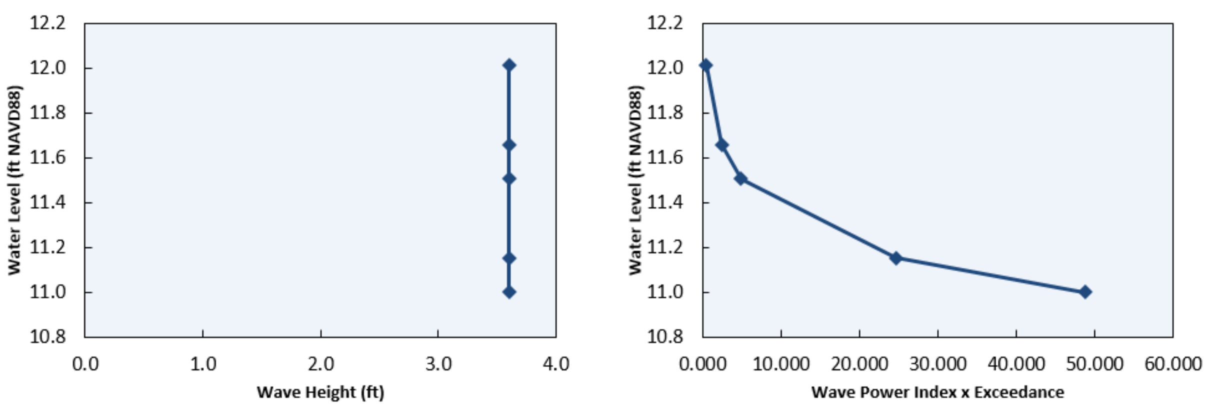


Figure C16. Left: Water level versus wave height and Right: Water level versus erosion potential at Cypress Grove for 40-y horizon SLR (3.3 ft).

C2.4 Erosion potential for Cypress Grove (beach section) for the 10-y wind plus 20-y water level event

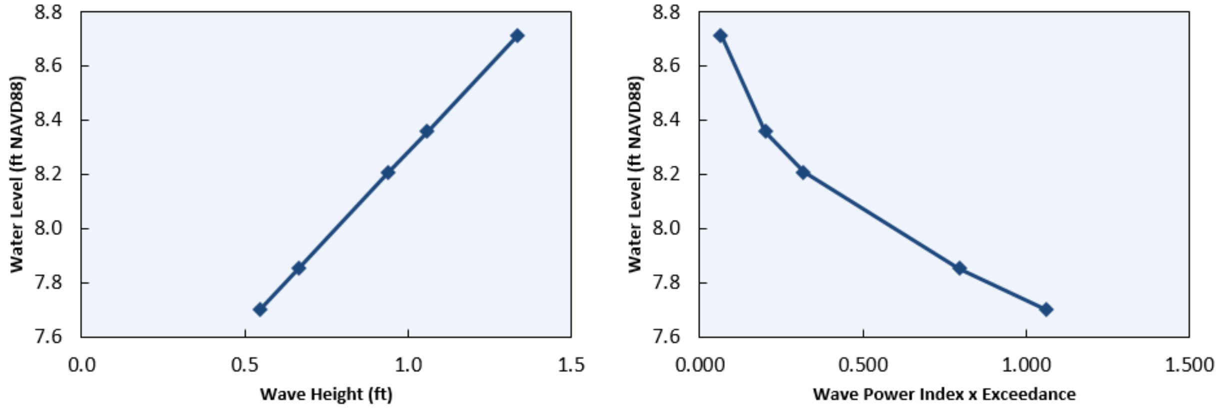


Figure C17. Left: Water level versus wave height and Right: Water level versus erosion potential at Cypress Grove for no SLR.

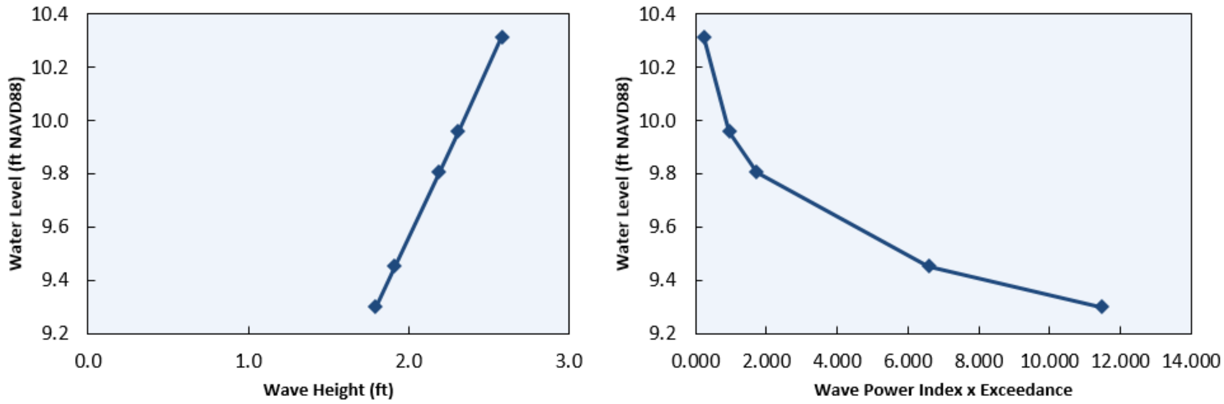


Figure C18. Left: Water level versus wave height and Right: Water level versus erosion potential at Cypress Grove for 20-y horizon SLR (1.6 ft).

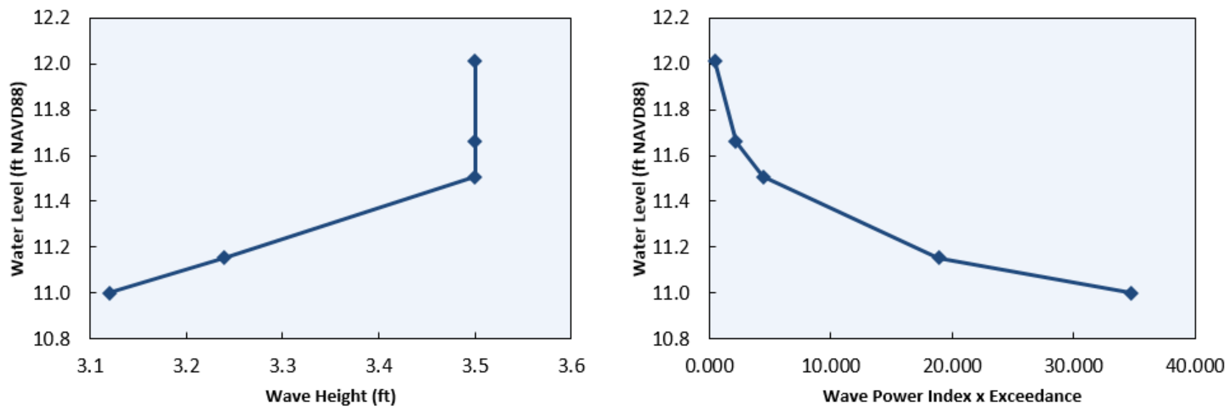


Figure C19. Left: Water level versus wave height and Right: Water level versus erosion potential at Cypress Grove for 40-y horizon SLR (3.3 ft).

C2.5 Summary of erosion potential results

Comparison of erosion potential for the three events explained above is summarized in Table C5. For the 100-y wind plus 1-y water level (event 1), erosion potential was greatest of the three events, because the wave heights were largest, and increased with increased SLR. For the 1-y wind plus 100-y water level (event 2), erosion potential was present but at small values (erosion potential less than 0.2) that were independent of SLR. For the 10-yr wind plus 20-yr water level (event 3), erosion potential was intermediate between the other events and generally increased with increased SLR.

The 10-yr wind plus 20-yr is intended to simulate an approximate 20-yr combined event, and is most relevant for the concept designs discussed in the main body of the report. The elevation bands where erosion is likely to be highest for this event range from approximately Mean Higher High Water (MHHW) to either 8 or 8.5 feet based on location (Table C6). This implies that the design needs to consider erosion protection measures at this band of elevations.

Table C5. Summary of erosion potential (EP) analysis for each event and sea-level rise (SLR) amount at each transect. H: wave height; T: wave period; %: exceedance probability

			Martinelli (Ref Elev = 6 ft NAVD88)		Cypress Grove Riprap (Ref Elev = 4 ft NAVD88)		Cypress Grove Beach (Ref Elev = 7 ft NAVD88)	
Event*	**SLR amount (ft)**	**Water level (ft)**	**H (ft)**	**EP H^2*T x %**	**H (ft)**	**EP H^2*T x %**	**H (ft)**	**EP H^2*T x %**
1	0	7.7	1.3	7.5	2.9	32.2	0.5	1.2
1	1.6	9.3	2.6	28.2	4.1	66.0	1.8	12.4
1	3.3	11.0	3.9	64.7	4.3	71.4	3.1	37.6
2	0	8.7	2.1	0.1	2.2	0.1	1.3	0.1
2	1.6	10.3	2.4	0.2	2.2	0.1	2.2	0.1
2	3.3	12.0	2.4	0.2	2.2	0.1	2.2	0.1
3	0	8.2	1.7	1.1	3.4	2.2	1.1	0.2
3	1.6	9.8	3.0	3.3	3.6	2.5	2.3	1.0
3	3.3	11.5	3.6	4.9	3.6	2.5	3.5	2.2

*Event description:
1. 100-y wind plus 1-y water level
2. 1-y wind plus 100-y water level
3. 10-y wind plus 20-y water level

TABLE C6
ESTIMATED TOTAL WATER LEVELS (FT NAVD88) AT MARTINELLI PARK WITH AND WITHOUT PROJECT

Location	Elevations with Highest Erosion Potential
Martinelli: Near Inverness Store	MHHW to 8 feet NAVD88
Cypress: Riprap Shoreline (West)	MHHW to 8.5 feet NAVD88
Cypress: Beach Shoreline (South)	MHHW to 8.5 feet NAVD88

C3. Total Water Level

The primary risk of flooding is from elevated bay water levels associated with high tides, coastal storm events, and wind-wave action on the shoreline (PWA 2007). While flooding can occur from elevated groundwater tables and failure to convey stormwater to the bay, the primary concern is overtopping of the shoreline levees from the combined action of elevated bay levels and wind-waves. Together, these result in a so-called 'Total Water Level (TWL)', which is equal to the tide plus wave runup on the shoreline (note that 'tides' in this case can include storm surge). When this exceeds levee elevations, waters typically spill ('overtop') over the levees and flood adjacent low-lying areas. We estimated TWL at both sites for an approximately 20-year event, with sea level rise of zero, 1.6, and 3.3 feet. We considered wind-waves generated by a 20-year wind event, and assumed this occurred at the same time as each high water level event. For the high water level event, we applied water levels of 9 feet NAVD88, which corresponds to the approximate level of tides and storm surge observed during the January 2006 event at Cypress Grove (PWA 2007).

We computed wave runup using the TAW method (FEMA 2005), which is based on the Iribarren number (also called the surf similarity parameter), a non-dimensional ratio of shore steepness to wave steepness. TWL values were generated for baseline and project conditions, with and without sea-level rise.

For baseline conditions at Martinelli Park, we estimated TWL at a single transect on the south side of the peninsula, in front of the Inverness Store. While the northern half of the peninsula is more exposed to waves, it fronts a higher part of the shoreline that is not as vulnerable to sea-level rise. The transect in front of the Inverness Store traverses mudflat, fringing marsh, and the dirt path and its wooden retaining wall that currently protect the site. We characterized the slopes and elevations with topographic data collected by ESA in the summer of 2020. For project conditions, we assumed a 7:1 slope and higher path elevation, based on the conceptual design described in the main body of the report. We considered losses in wave height around the tip of the peninsula due to wave refraction and diffraction around the point, and roughness losses due to vegetation for project conditions.

For baseline conditions at Cypress Grove, we estimated TWL at three transects, one on the western side of the peninsula where the shoreline is backed by riprap, one on the western side near the mouth of the manmade swale, and one on the southern side, which is backed by a sandy berm but is exposed to the strongest wind waves during storm events. We used transects collected from our own survey of the site in August 2021 to characterize the shore slope and elevations. For project conditions, we incorporated the restored beach, which generally increased the backshore elevation and reduced the slope (due to widening of the beach). We applied unaltered wave conditions for the southern transect, and applied losses due to wave refraction at the two western transects, consistent with PWA (2007).

Tables C7 and C8 summarize results at Martinelli Park and Cypress Grove, respectively. In general the proposed projects at both sites are estimated to result in a significant reduction in total water levels at both sites. The largest reduction is predicted at the riprap shoreline of Cypress Grove, and at the dirt path in Martinelli, both of which are currently steep and conducive to high runup under existing conditions.

TABLE C7
ESTIMATED TOTAL WATER LEVELS (FT NAVD88) AT MARTINELLI PARK WITH AND WITHOUT PROJECT

		Total Water Level (ft NAVD88)	
	Event	**Without Project**	**With Project**
Transect 1: armored shoreline	MHHW: No SLR	6.0	6.0 (no overtopping)
	MHHW: 1.6' SLR	9.5	8.2 (no overtopping)
	MHHW: 3.3' SLR	12.0	10.1 (no overtopping)
	20-yr Event: No SLR	11.5	9.8 (no overtopping)
	20-yr Event: 1.6' SLR	13.4	11.4 (no overtopping)
	20-yr Event: 3.3' SLR	15.1	13.1

TABLE C8
ESTIMATED TOTAL WATER LEVELS (FT NAVD88) AT CYPRESS GROVE WITH AND WITHOUT PROJECT

		Site Condition	
	Event	**Baseline**	**With Project**
Transect 1: armored shoreline	MHHW: No SLR	11.3	6.7
	MHHW: 1.6’ SLR	14.1	8.4
	MHHW: 3.3’ SLR	15.9	10.1
	20-yr Event: No SLR	15.6	9.8
	20-yr Event: 1.6’ SLR	17.2	11.4
	20-yr Event: 3.3’ SLR	18.9	13.1
Transect 2: beach	MHHW: No SLR	6.0	6.0
	MHHW: 1.6’ SLR	8.0	7.8
	MHHW: 3.3’ SLR	10.0	9.7
	20-yr Event: No SLR	9.7	9.3
	20-yr Event: 1.6’ SLR	11.5	11.0
	20-yr Event: 3.3’ SLR	13.3	12.8
Transect 3: beach	MHHW: No SLR	6.0	6.0
	MHHW: 1.6’ SLR	8.0	7.8
	MHHW: 3.3’ SLR	10.0	9.8
	20-yr Event: No SLR	9.6	9.4
	20-yr Event: 1.6’ SLR	11.5	11.2
	20-yr Event: 3.3’ SLR	13.3	13.0

References

Coastal Engineering Manual, 2003. Part 2, Chapter 2, Meteorology and Wave Climate. United States Army Corps of Engineers, July 2003.

Federal Emergency Management Agency (FEMA). 2005. Final Draft Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States. Prepared for U.S. Department of Homeland Security.

Resio, D.T. and Vincent, C.L. 1977. Estimation of winds over the Great Lakes. Amer. Soc. Civil Eng. Waterway, Port and Coast. Ocean. Div. J. 102:265-283.

Philip Williams & Associates (PWA). 2007. Cypress Grove Shoreline Study (PWA Ref. #1855.00). Prepared for Audubon Canyon Ranch.

United States Army Corps of Engineers. 1984. Shore Protection Manual. Waterways Experiment Station, Vicksburg, Mississippi.

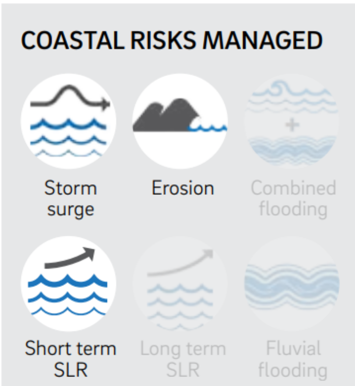
USACE, 2006. Coastal Engineering Manual. 2006. Part 2, Chapter 2, Meteorology and Wave Climate. US Army Corps of Engineers.

Attachment D

Living Shorelines Treatments

BEACHES

COASTAL RISKS MANAGED



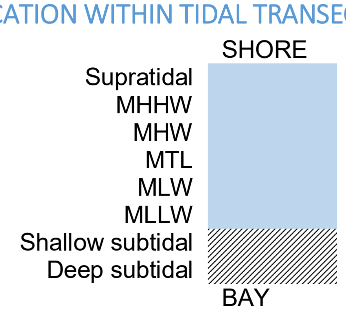
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate Resilience • Water quality improvement • Recreation • Other cultural services

IMPACT ON SHORELINE

Protect • Accommodate • Retreat

LOCATION WITHIN TIDAL TRANSECT



DEFINITION

Coarse or composite estuarine beaches are dynamic features that can consist of a mixture of sand, shell, gravel, or cobble. Beaches include a supratidal beach berm and a beach face. The lowest position of the beach is often characterized by a low tide terrace and transition to tidal flat. The low tide terrace limits the duration that the beach is exposed to waves and also limits the size of the waves.

Beaches exist in several forms in Tomales Bay. Some of these forms include:

- cuspate sand and gravel beaches that form along the outer edge of creek deltas, forming peninsulas on the bay (especially along the western shore),
- sandy or coarse barrier beaches that are inset within coves – typically protecting marsh and upland terrestrial areas at the terminus of small creeks (common along the National Seashore north of Sea Ranch, and near Millerton)
- pocket beaches of coarse material (from sand to cobbles) fed by cliff or bluff erosion (more common along the eastern shore),
- fine-sand beaches on the leeward side of headlands, where exposure to wind is smaller and waves are smaller,
- tombolos formed behind natural obstructions such as large boulders.

Given this project's focus on protecting built assets, we considered three major beach types as potential adaptation measures, based on their prevalence near developed shorelines in Tomales Bay:

1. coarse (gravel, cobble, shell) beaches
2. cuspate sand and gravel beaches fronting marshes

EXAMPLES Coarse beaches: natural gravel-sand beaches fed by bluff erosion near Marconi, Millerton. Pelican Point. Cuspate beaches fronting marsh: Stream deltas fronted by beach in Seahaven and Inverness: e.g. Chicken Ranch Beach, Martinelli Park. Tombolo Beaches: Boulder-lag tombolo beaches on east shore south of Marconi.	3. tombolo beaches forming behind boulders LANDSCAPE CONFIGURATION, DESIGN AND PROCESS GUIDELINES Beaches could potentially be created in many places in Tomales Bay to attenuate waves. They can, for instance, be placed in front of portions of Highway One or Sir Francis Drake Blvd that are adjacent to open water and protected by rip rap. Another strategy could include augmenting existing beaches in front of marshes, which are already providing a level of protection to the backshore. Ultimately, there will be significant differences in beach function and form depending on the problem a beach is meant to address, the type of beach material used, and the incident wave energy. A predominantly coarse beach is highly permeable, needs less space compared to a composite or fine beach, and can form a step profile in response to storm events. The surf zone on a coarse beach is often narrow or even absent and the beach face is dominated by swash and backwash processes. A special feature of a coarse beach is the wave-deposited beach ridge or crest. The elevation of the crest depends primarily upon the maximum run-up and sediment availability. During storms the movement of particles on a coarse beach is predominantly landward and the beach crest will increase in height and roll landward if there is sufficient volume of beach sediment and space landward. The sand and shell materials that comprise the beach face may be intermittently lost to longshore drift but also naturally redeposited by the tides and waves. Groins or other retention structures (e.g., woody debris, microgroins, buried rough on-site material) could be considered for beaches implemented along high-drift shorelines, but are not necessary for naturally constrained pocket beaches. In several places along the bay, boulders remaining from long-term cliff or bluff erosion form natural sediment retention features. An important consideration for beach placement is that beaches are not static, and are expected migrate inland with sea-level rise. ESA (2015) previously mapped beaches along a portion of the eastern shoreline of Tomales Bay and identified their width from a digitized 2010 shoreline to the backshore (whether cliff, dune, armoring, or other structure). Based on expected transgression rates, they tabulated a risk level for the shoreline based on beach width: • Low risk: beaches having width greater than 15 m (~50 feet) • Medium risk: beaches having width between 10 m and 15 m (~33 feet and 50 feet) • High risk: beaches having width less than 10 m (~33 feet) ESA mapped the shoreline adjacent to Marshall, and found that there were few beaches present, all of which were within the high risk

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SUITABILITY CRITERIA

Before mapping the shoreline suitability for beaches, ESA first studied the shoreline using publically-available aerial images, oblique coastal images from the California Coastal Records Project, and historical maps:

- Areas with existing rip rap, sea walls, or other coastal structures (indicative of high wave energy environments), were identified visually from aerial images (California Coastal Records Project 2019) and an online database from the California Coastal Commission (2014)
- Areas with finer-grained beaches (assumed to be predominantly gravel and smaller sizes) were identified visually.
- Areas of the shoreline defined by the remnant railroad berm were identified from images and historical maps.
- Overwater structures, marinas, or deep tidal channels were identified using data provided by the County of Marin.
- To the extent practical, historical locations of beaches in Tomales Bay were also identified for reference from historical maps (NOS 1861-1862 nautical chart, 1931 U.S. Coast and Geodetic Survey T-sheet). This process was limited by the focus of the 1861-1862 nautical chart on water depths rather than shoreline features, and by the existence of the railroad along the eastern shore prior to the 1931 survey, which had already led to widespread change in the shape of the eastern shoreline.

Suitability maps for each of the three beach adaptation measures were developed using the following criteria:

Course Beaches:

- Assumed to be suitable where existing armoring is mapped (similar to approach of SFEI 2019), as long as sufficient space is available for beach footprint: 15 m cross-shore, at least 100 m alongshore (based on Natural Infrastructure Guidelines). May require retention features (e.g. groins or boulders) if located along exposed headlands.
- Shorelines with greater than 20 degree angle from main wind fetch assumed to require additional features such as boulders or other natural groins to limit alongshore drift (modified from Natural Infrastructure Guidelines)

Cuspate Beaches Fronting Marshes:

- Focus of this measure is to add resilience to existing features through adding sediment retention features, so suitability mapping identifies existing cuspate beaches fronting marshes
- consider potential to increase sediment volume by placement to increase elevation and or bayward extent so that there is adequate sediment for adjustment to sea-level rise without as much landward migration / drowning

Tombolo Beaches:
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	• Mapped suitable areas based on pre-existance of finer-grained beaches (gravel and finer material), proximity to sediment source (creek mouth or erodible bluff), and offshore slope. • Placement may be helpful where there is a need to build the shore bayward to protect exposed assets (e.g. Highway 1 near Marconi), especially on headland shorelines that are exposed to more wave action. • Consider pilot project: placing sediment in lee of existing outcrops that are not fully "charged" with sediment, and then measure subsequent equilibrium geometry and dynamics to assess feasibility and inform subsequent design: The resulting equilibrium beach geometry should be a function of (i) rock-outcrop geometry and spacing to the shore and also other outcrops (ii) wave exposure and (iii) sediment size.

Reference Sites: Tombolo Beach

Reference Sites: Tombolo Beach

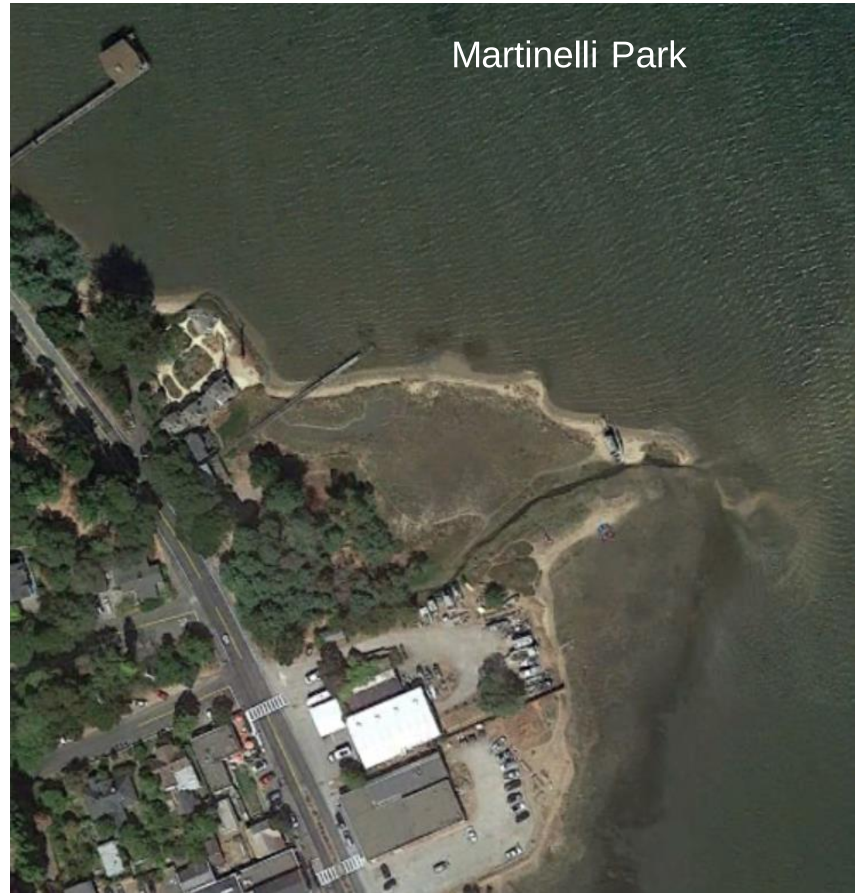
Reference Sites: Coarse-beach to upland transition

Mixed sand and gravel beachface, Pelican Point

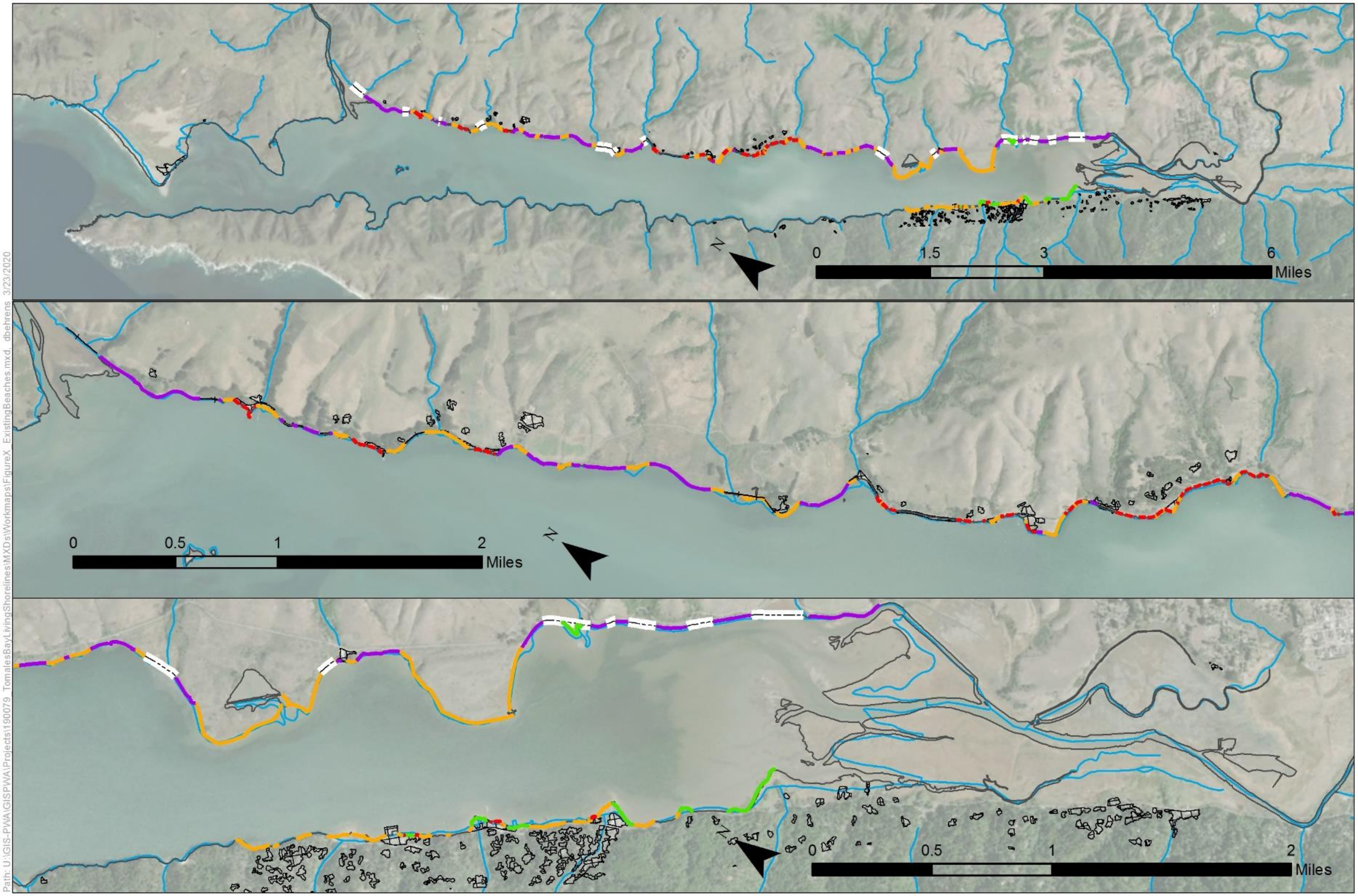
Reference Sites: Coarse-beach to upland transition

Natural gravel and coarse sand bay beach/salt marsh berm near Millerton Point

Reference Sites: Cuspate Beach to Fronting Marsh



Existing Shoreline Types



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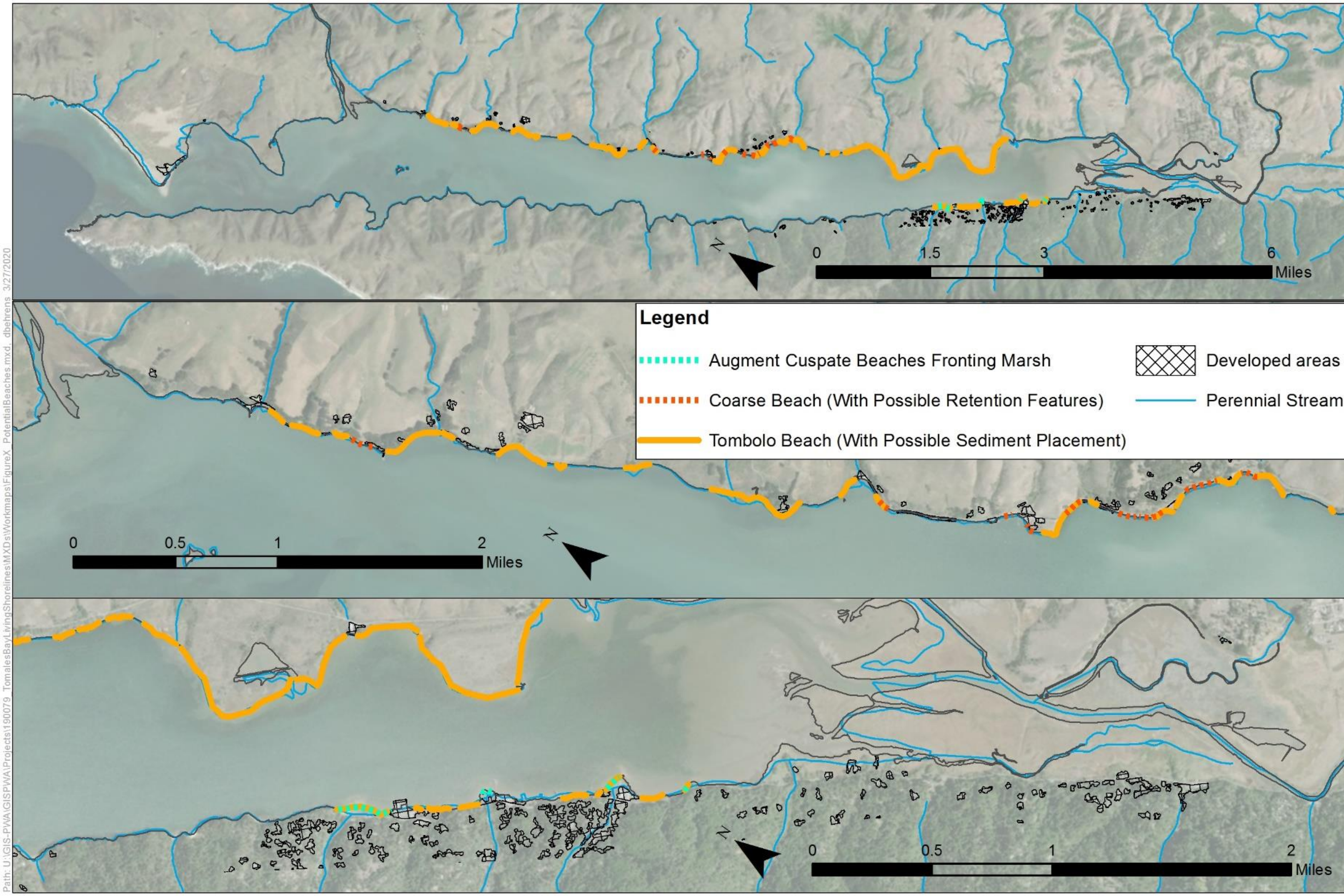
SOURCE: Weather Underground (2019), US Geological Survey (2019), UC Davis Bodega Marine Laboratory (2019), Kimbro et al (2009) (Locations approximate for water quality stations)

Tomales Bay Living Shorelines Feasibility . D190079.00

Legend

Armoring
Unprotected marsh edge
fine-grained shoreline
Developed areas
Rocky or coarse shoreline
remnant railroad berm
perennial streams



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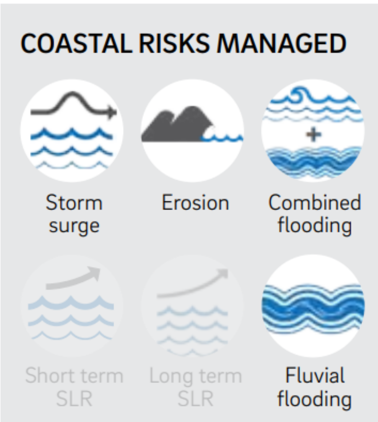
SOURCE:

Tomales Bay Living Shorelines Feasibility . D190079.00

ESA Preliminary delineation of potential beach areas based on backshore type, geology, slope, development, professional judgment

CREEK TO BAY RECONNECTION

COASTAL RISKS MANAGED



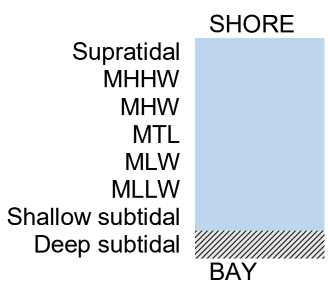
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate Resilience • Water quality improvement • Recreation • Other cultural services

IMPACT ON SHORELINE

Protect • Accommodate • Retreat

LOCATION WITHIN TIDAL TRANSECT



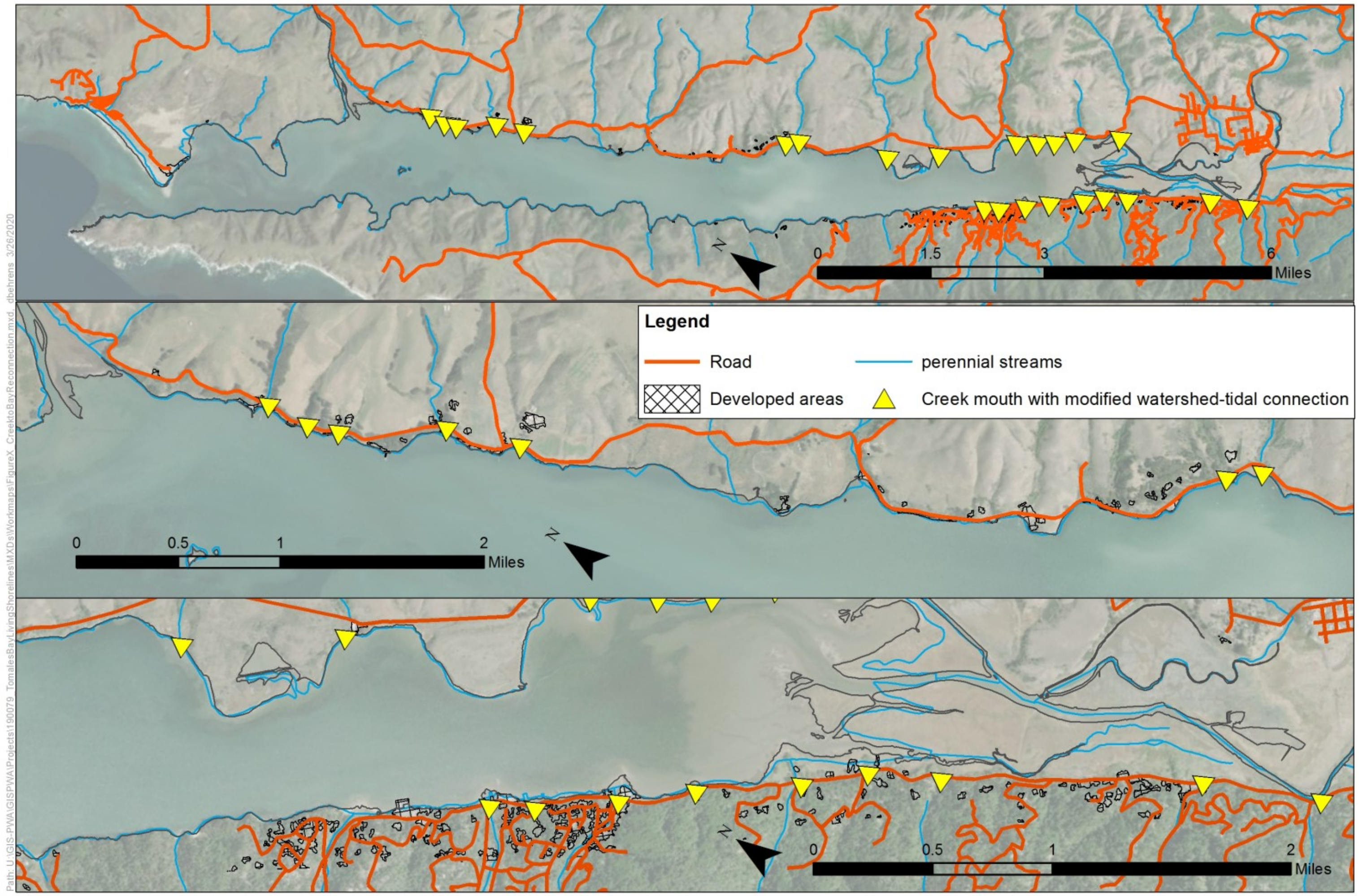
DESCRIPTION

Many of the creeks draining to Tomales Bay have modified connections to the bay as a result of historical development and changes in land cover and sediment supply (Rooney and Smith 1999). On the eastern shore in particular, construction of the North Pacific Coast Railroad (begun in 1874) and Highway One created physical restrictions to sediment delivery to the bay, while changes in land-use within the watershed led to a period of dramatic increases in sediment loading. On the western shore, construction of Sir Francis Drake Boulevard also modified the tidal connection of creeks near Inverness. Increased sediment loading continued for much of the twentieth century as the small watersheds flanking the bay did not have the capacity to immediately transport all of the increased supply attributed to land use changes (Rooney and Smith 1999).

While these combined factors contributed to the capture of sediment and formation of new marsh areas between the railroad and the original shoreline along the eastern shore, in some areas the breached railroad berms and both Highway One and Sir Francis Drake Boulevard continue to restrict sediment transport from the watershed and outboard marsh and mudflat areas. Culverts underneath these major roadways require periodic maintenance by the County of Marin (on the western shore) and Caltrans (on the eastern shore) to remove sediment, which is taken offsite. In some areas where the highway is directly adjacent to the Bay, creek mouths were replaced with culverts that constrain transport of potential sediment delivery to the Bay margin. While reconnecting creeks to their adjacent baylands through roadway modification is unlikely to be an option, beneficial re-use of

EXAMPLES • see map on following page	sediments removed from upstream culverts may be an option for augmenting existing outboard tidal marshes or mudflats. This will require studying existing sediment maintenance programs to understand the quantities available and viability of the approach. **LANDSCAPE CONFIGURATION, DESIGN AND PROCESS GUIDELINES** Seasonal and perennial stream channels that transition to an estuarine channel, or discharge into alluvial fans, could be considered for creek-to-baylands reconnection. Creeks with abundant adjacent space (e.g., baylands, diked baylands, or undeveloped upland) have the most options in terms of design and configuration of reconnection (e.g., channel realignment, ecotone implementation) and could support the greatest degree of ecosystem functions. Adjacent areas undergoing or slated for habitat restoration would benefit from additional sediment, nutrient, and freshwater deposition through creek reconnection, which would improve the baylands' resilience to sea-level rise. Stream power and watershed sediment supply are important considerations to evaluate whether creeks have the appropriate landscape setting to move sediment to the baylands. Hybrid solutions that employ a combination of creek-to-baylands reconnection and beneficial sediment reuse may be necessary for creeks with less stream power, sediment supply, or adjacent open space. In Tomales Bay, sediment removed from culverts under Highway One or Sir Francis Drake Blvd could potentially provide a periodic, opportunistic source of sediment for augmenting marsh platforms or other shoreforms that have formed bayward of the remnant railroad berm. **SUITABILITY CRITERIA** To map suitable areas for creek to bay reconnection, we used the following approach: • We identified creeks within Tomales Bay using the hydrology data provided by the County of Marin, which delineates intermittent and perennial streams and their watershed areas. • We identified creeks whose connections to Tomales Bay have been modified by examining the 1861-1862 NOS nautical map, 1931 U.S. Coast and Geodetic Survey T-Sheet, and recent aerial images. Comparing these maps made it possible to see which reaches of shoreline near creek mouths have undergone extensive change in shape due to development. Creeks with a potential disconnection between watershed supply of aterial and delivery in the estuarine zone, whether from the railroad berm or

	from Highway One or Sir Francis Drake Blvd, were identified on a map of the bay. • Suitability will require more information on ediment availability from culvert maintenance activities, and the suitability of the material for use in augmenting supply to nearby shoreforms.



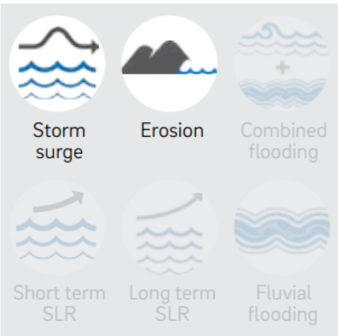
SOURCE: Weather Underground (2019), US Geological Survey (2019), UC Davis Bodega Marine Laboratory (2019), Kimbro et al (2009) (Locations approximate for water quality stations)

Tomales Bay Living Shorelines Feasibility . D190079.00

Map of Potential Opportunities for Creek-to-Bay Reconnections

ROCKY INTERTIDAL

COASTAL RISKS MANAGED



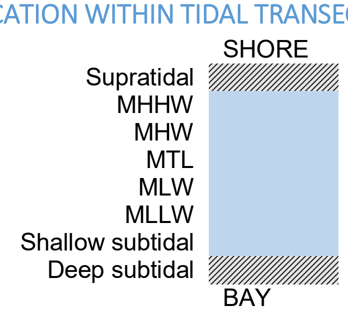
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate Resilience • Water quality improvement • Recreation • Other cultural services

IMPACT ON SHORELINE

Protect • Accommodate • Retreat

LOCATION WITHIN TIDAL TRANSECT



DEFINITION

Rocky intertidal habitat refers to a range of coastal habitat with hard rock substrate exposed to tides, such as steep cliffs, wave-cut shore platforms, rock pools, intertidal cobble and boulder lags (rocky remnants of past bluff retreat after fine sediment is eroded), and more. Rocky lag deposits are too large to be moved by wave-induced currents (e.g. boulders, bedrock), and provide stable sheltered habitat for a high diversity of native estuarine invertebrates, including native oysters and many prey items for native estuarine fish, shorebirds, and wading birds. Typically, rocky intertidal habitats are characterized by varying levels of rugosity (e.g. small-scale variations in hard surface roughness), which provide habitat diversity for a range of invertebrates, algae and fishes.

LANDSCAPE CONFIGURATION, DESIGN AND PROCESS GUIDELINES

Rocky intertidal habitats naturally create complex tidal flow and shelter patterns due to irregularities in bottom topography, and can provide important substrate for attachment of mollusks and other organisms. Some fish (e.g. Pacific herring) and invertebrates use hard substrate and attached macroalgae for spawning. Shorebirds and wading birds use rocky intertidal habitat for foraging. Ecological goals for a particular area will influence the use and design of rocky intertidal habitat as a nature-based adaptation measure.

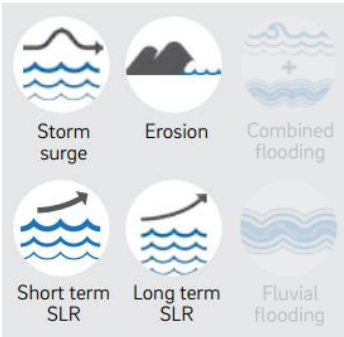
Boulder lags are present in the intertidal zone at various locations through Tomales Bay (e.g. northwestern shoreline, Nicks' Cove, Marconi).

Local quarry stone composed of rock types with weathering and erosion properties matching natural intertidal rocks, may be a potential

EXAMPLES • lag fields from bluff erosion along eastern shore of the bay, and along National Seashore	analog for rocky lag material found in the rocky intertidal zone along portions of the eastern and western shorelines in Tomales Bay. Reference sites can help guide rocky habitat design and placement (e.g. approximate extents, rock sizing, etc.) The creation of rocky intertidal habitat could be linked with native Olympia oyster placement, since it would provide the hard substrate needed by the oysters for recruitment. SUITABILITY CRITERIA Areas with potential suitability for rocky intertidal habitat were mapped using the following criteria: • Applicable wherever the tombolo-beach class is mapped as suitable • Applicable along existing coarse shorelines with steep drop-offs • Locations close to boat moorings and oyster lease areas were deemed unsuitable, due to potential navigation hazards.

SUBMERGED AQUATIC VEGETATION

COASTAL RISKS MANAGED



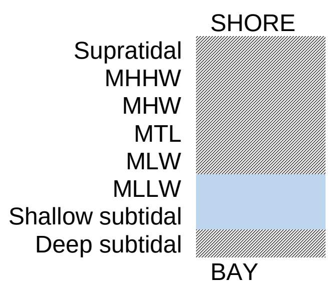
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate regulation • Ocean acidification buffering • Water quality improvement • Sediment stabilization and trapping • Recreation • Other cultural services

IMPACT ON SHORELINE

Protect • Accommodate • Retreat

LOCATION WITHIN TIDAL TRANSECT



EXAMPLES

- Eelgrass meadows associated with fine grained fluvial/deltaic deposits at the mouth of Lagunitas and Walker Creeks
- Eelgrass beds on intertidal and shallow subtidal sand shoals near the mouth of Tomales Bay
- Fringing eelgrass beds growing in narrow, shore parallel bands below steep headlands along both the

DEFINITION

Submerged Aquatic Vegetation (SAV) includes rooted vascular plants such as the seagrasses Eelgrass (Zostera marina) and Widgeon Grass (Ruppia maritima) and attached macroalgae occurring within the shallow subtidal to lower intertidal portions of estuarine and nearshore marine environments. As primary producers with substantial capacity to capture and store dissolved atmospheric CO2, SAV habitats (in particular seagrasses) have been recognized for their potential to help mitigate the effects of climate change in addition to providing a broad range of ecosystem services.

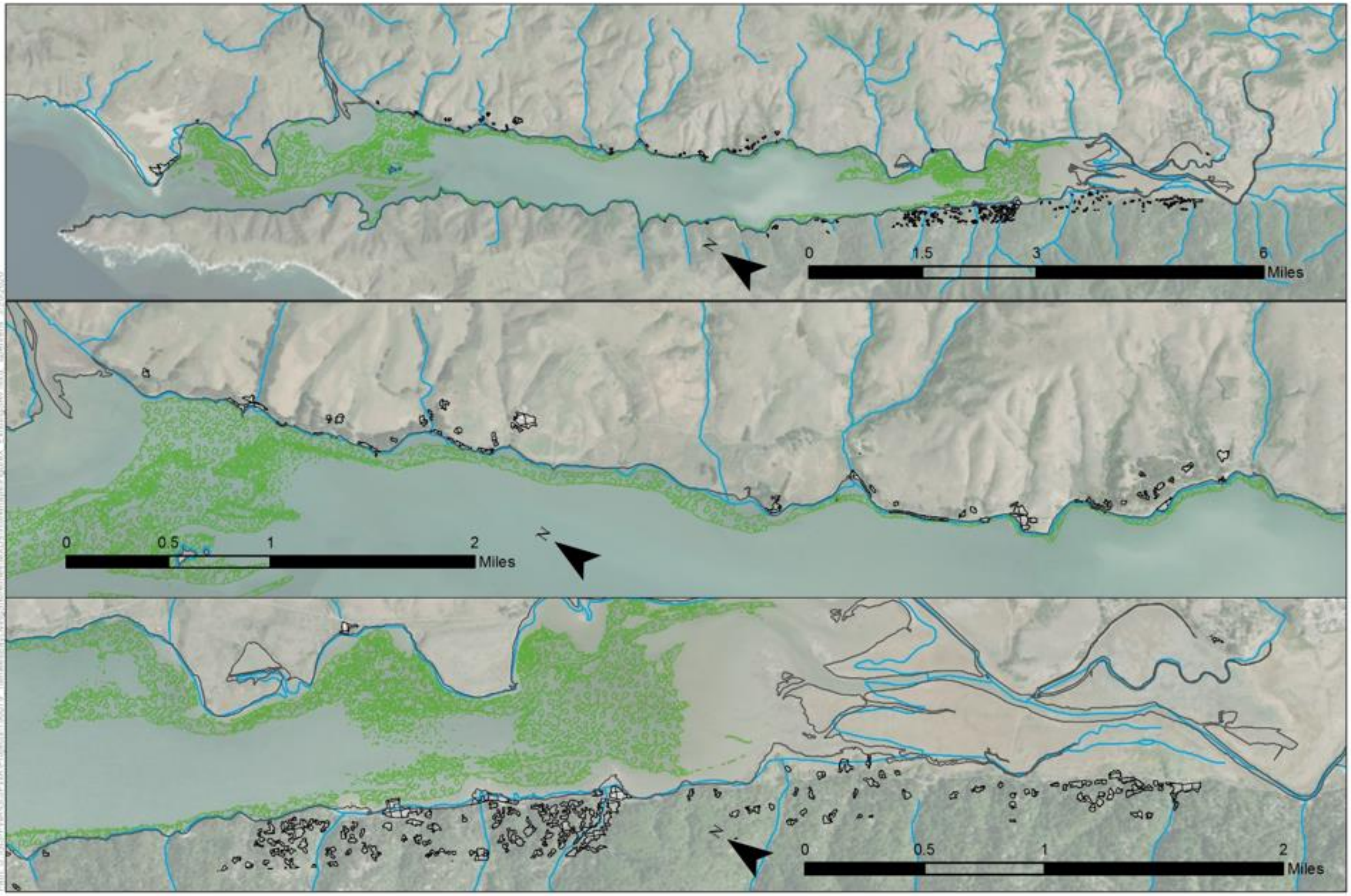
Eelgrass, the most widely distributed and abundant species of seagrass in Tomales Bay, provides shelter and food for many ecologically, commercially, and culturally important species of fish, wildlife and invertebrates. Eelgrass beds attenuate wave energy and stabilize sediment, reducing the effects of storm surge on coastal flooding and protecting shoreline areas from erosion. Further, eelgrass beds retain captured sediment and migrate vertically as the sediment and organic material is sequestered in below the beds. This facilitates the maintenance of shoreline profiles in response to sea level rise thus providing continued influence on the nearshore wave and sediment transport environment. In most extreme cases, the benefits of eelgrass as a sediment stabilizer extends beyond the coastal bays and estuaries and out to the outer coastline where seasonal leaf shed results in shore wrack that rolls up sand in deposits near the high tide line. This fibrous wrack serves to absorb wave energy and trap sand in a manner that protects the upper beach margins and shoreline scarps and cliffs during winter months. Eelgrass beds provide a stable source of water column nutrient uptake and facilitate deposition of suspended sediment, enhancing water quality and clarity in the bay.

While SAV provides a number of benefits to shoreline stabilization (as described above), it does not provide enough wave reduction on its own to mitigate the erosive potential of wind-waves on sandy bay shorelines. It provides the most benefit when pairing with other elements (beach or marsh restoration at the shoreline), acting as the offshore component of a suite of living shorelines measures. As discussed in Section 5.4, existing eelgrass beds are also a constraint for placement of other living shorelines treatments.

Eelgrass habitat distribution follows three general patterns within the landscape of Tomales Bay including:

- Broad, low-gradient deltaic flats consisting primarily of fine grained silts/clays derived from fluvial discharge of Bay tributaries such as the Lagunitas Creek and Walker Creek Delta areas. These areas support some of the most expansive eelgrass beds within the bay.
- Dynamic sand shoals along the eastern shore near the mouth of Tomales Bay and extending into subtidal portions of the central

eastern and western shores of the bay.	bay near Hog Island. These areas also support extensive eelgrass habitat within the bay. • Narrow, shore parallel bands occurring below the relatively high-relief, steeper headlands and broadening slightly in areas where headlands are interrupted by coves; these shore fringing bands are widely distributed along both the eastern and western shorelines of the bay, but supports less eelgrass coverage than either the deltaic flats or sand shoals. **LANDSCAPE CONFIGURATION, DESIGN, AND PROCESS GUIDELINES** Eelgrass beds occur across a broad range of unconsolidated sediment deposits spanning the spectrum from silts and clays to coarse sand and even fine gravel in Tomales Bay; with the location and characteristics of the substrate largely indicative of the weathering and landscape processes from which the sediments were derived. Hydrodynamics within the bay (wind waves and tidal currents) and its larger tributaries (fluvial discharge) influence large-scale sediment transport, sorting, erosion and deposition processes within the bay which drive eelgrass distribution at large; while at a finer scale, the presence of eelgrass modifies the hydrodynamic regime, attenuating wave energy and reducing bottom shear stress, thereby enhancing deposition and retention of fine grained sediment. It is these characteristics of eelgrass habitat that make it an important component of a sea level rise adaptation planning framework for Tomales Bay. From a living shoreline perspective, eelgrass habitat enhancement efforts would be synergistic with and incumbent upon modification of the geomorphic and/or hydrodynamic regime in a manner that enhances eelgrass habitat suitability within the bay rather than serving as a standalone effort. Conceptually, this could include such efforts as augmenting tombolo beaches and/or cuspate beaches fronting marshes, creek to bay reconnection, tidal flat enhancement, and nearshore reef placement. From this perspective, efforts to identify sites conducive to the application of eelgrass (SAV) as a shoreline protective measure should be focused on identifying where primary adaptation strategies of modifications to the physical environment at higher elevations may support expansion of eelgrass habitat and add a secondary measure of resilience. Once primary strategies are conceptually identified, it would make sense to then consider how or if eelgrass may be used to support these strategies, such as through reducing incident energy, or trapping and retaining sediment that may otherwise leave the treatment area. **SUITABILITY CRITERIA** • Wave and current exposure, substrate suitability, desiccation and light availability are limiting factors. • Need to consider sea level rise and potential need for grade control to retain placed fill if raising bed elevation. • Consider co-locating with beach and/or tidal flat enhancement, creek to bay reconnection, nearshore reefs

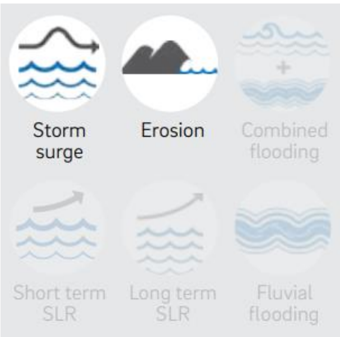


SOURCE: Merkel and Assoc. (2017)

2017 Map of Eelgrass Locations in Tomales Bay (Merkel & Assoc. 2017).

TIDAL FLAT AUGMENTATION

COASTAL RISKS MANAGED



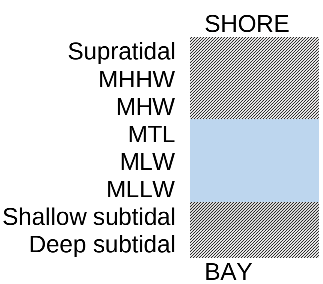
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate Regulation • Water quality improvement • Recreation • Other cultural services

IMPACT ON SHORELINE

Protect • Accommodate • Retreat

LOCATION WITHIN TIDAL TRANSECT



DEFINITION

Intertidal mudflats and shallow water shoals are a common substrate in Tomales Bay. Depending on location in the bay, they are composed of fine silts, clays, and sands in variable concentrations. Areas nearer to the mouth of the bay are sandier, having direct access to coastal sediments delivered from Bodega Bay and both Estero Americano and Estero San Antonio. Moving south along the axis of the bay, tidal flats include finer-grained sediments than sand in higher quantities. Tidal flat augmentation refers to the direct or indirect placement of sediments to increase tidal flat elevation relative to the tides, which can help to protect adjacent marshes or other shoreline types. This adaptation measure differs from the 'mudflat augmentation' measure described for San Francisco Bay by SFEI (2019), since sand is much more readily-available in parts of Tomales Bay. Another important difference stems from the difference in sediment availability between Tomales Bay and San Francisco Bay. Whereas San Francisco Bay has begun experiencing a shift toward declining sediment supply and many of its mudflats are expected to be vulnerable to erosion in the near term (SFEI 2019), Tomales Bay continues to experience expansion of its tidal flats in many areas (Rooney and Smith 1999), and it is not immediately clear how much the trajectory of its tidal flats differs from those of San Francisco Bay with sea-level rise.

LANDSCAPE CONFIGURATION, DESIGN AND PROCESS GUIDELINES

Tidal flats dissipate wave energy through shoaling processes in shallow water and limit the size of waves reaching the shoreline, which can limit erosion of the shoreline consists of erodible material. The degree of shoaling depends on the width, depth, and surface roughness of the tidal flat. Where silts and clays are more abundant, the cohesive properties of

EXAMPLES

- Tidal flats are widespread throughout Tomales Bay. Sandy flats are present near the mouth of the bay and at progressively fine towards the head of the bay.
- Relatively sandy tidal flats are located near the mouth (between Toms Point and Dillon Beach) and at the Walker Creek delta.
- Relatively fine (silty or clayey) tidal flats are located south of Marconi, including the Inverness Park shoreline, eastern shoreline near Tomasini Point and Bivalve, and along the Lagunitas Creek delta.

the fine sediment, together with biological activity such as burrowing organisms, microalgae, and biofilm, also increase the resistance of the tidal flat to erosion.

Tidal flats and shoals act as a sediment reservoir, storing fine silt, clay, and sandy sediments from winter floods. The continued resupply of fine sediment to mudflats is therefore essential to maintaining their present form and allowing them to respond to sea-level rise. They are also intimately linked to the adjacent tidal marshes since they act as a reservoir of erodible sediment to supply the marshes and limit the amount of wave energy reaching the marsh scarp. Recently-deposited fine sediment is suspended by strong tidal currents and wind waves and is gradually winnowed out through the dry, windy summer and fall and redeposited in tidal marshes.

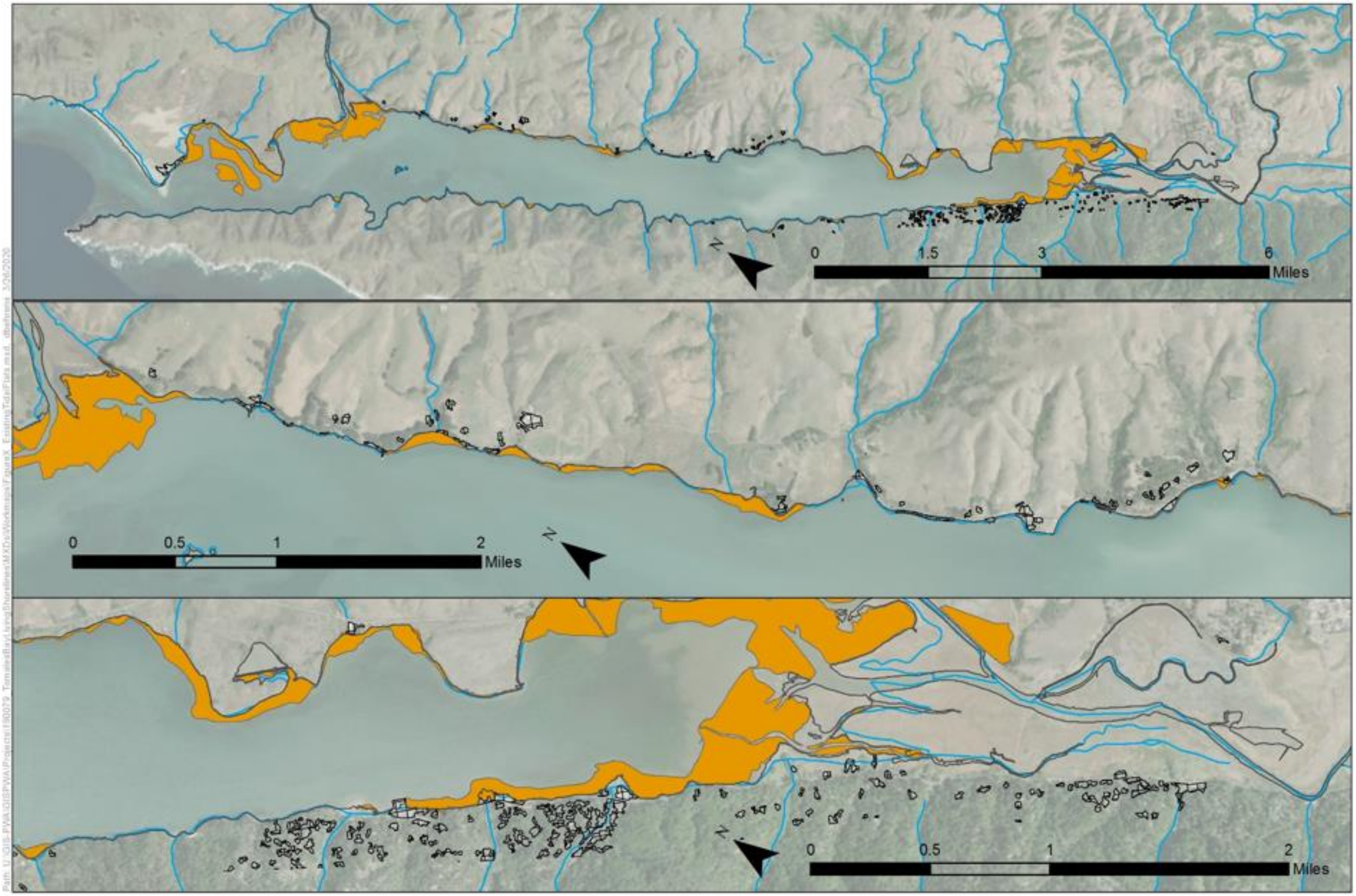
In San Francisco Bay, direct placement of fine dredged sediment on lower mudflats and shallow subtidal areas is considered effective at supplying local mudflats and marshes with sediment (SFEI and SPUR 2019). The USACE is currently exploring the viability and potential ecological impacts of sediment placement on mudflats, through the use of a small-scale pilot study and numerical modeling (Bever et al. 2014).

In Tomales Bay, sediment placement on existing sand flats in the outer estuary needs to account for the fact that the network of tidal channels and flats that are currently in place are highly mobile and evolve over time. Elsewhere, tidal flats are also highly mobile near the deltas of creek mouths, which are experiencing continued growth over time as a result of long-term sediment delivery from the watershed.

SUITABILITY CRITERIA

In its assessment of mudflats in San Francisco Bay, SFEI and SPUR (2019) relied on existing maps of mudflats (SFEI-ASC 2017) as a starting point to identify areas for mudflat augmentation. For Tomales Bay (considering both mud- and sand flats) we followed a similar approach, with several modifications:

- Tidal flats (both finer scale and sandy) were mapped based on bathymetry collected in 2018 (GGNPC). Tidal flats were mapped where bed elevations were between MLLW and MSL.

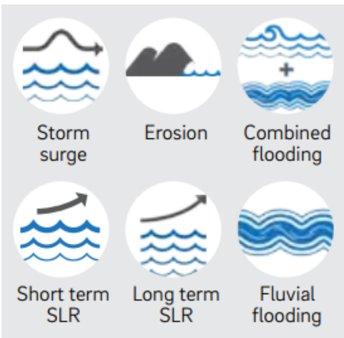


SOURCE: GGNPC (2019)

Existing tidal flats in Tomales Bay, mapped as the areas between MLLW and MSL elevations by GGNPC (2019).

TIDAL MARSH

COASTAL RISKS MANAGED



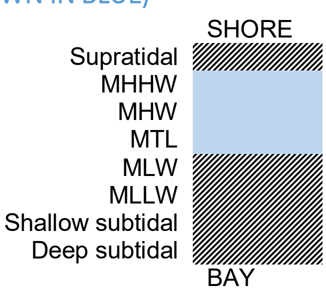
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate Resilience • Water quality improvement • Recreation • Other cultural services

IMPACT ON SHORELINE

Protect • Accommodate • Retreat

LOCATION WITHIN TIDAL TRANSECT (SHOWN IN BLUE)



DEFINITION

Tidal marshes are coastal wetlands subject to tidal action and/or freshwater inputs. They can typically be found adjacent to an unvegetated mudflat or some form of wetland-upland transition shoreline type. Tidal marshes include a range of estuarine habitats like salt marsh, freshwater marsh, mudflats and others. Vegetation common to tidal marshes include alkai bulrush (*Bolboschoenus maritimus*), native cordgrass (*Spartina foliosa*), and pickleweed (*Salicornia, Sarcocornial).*

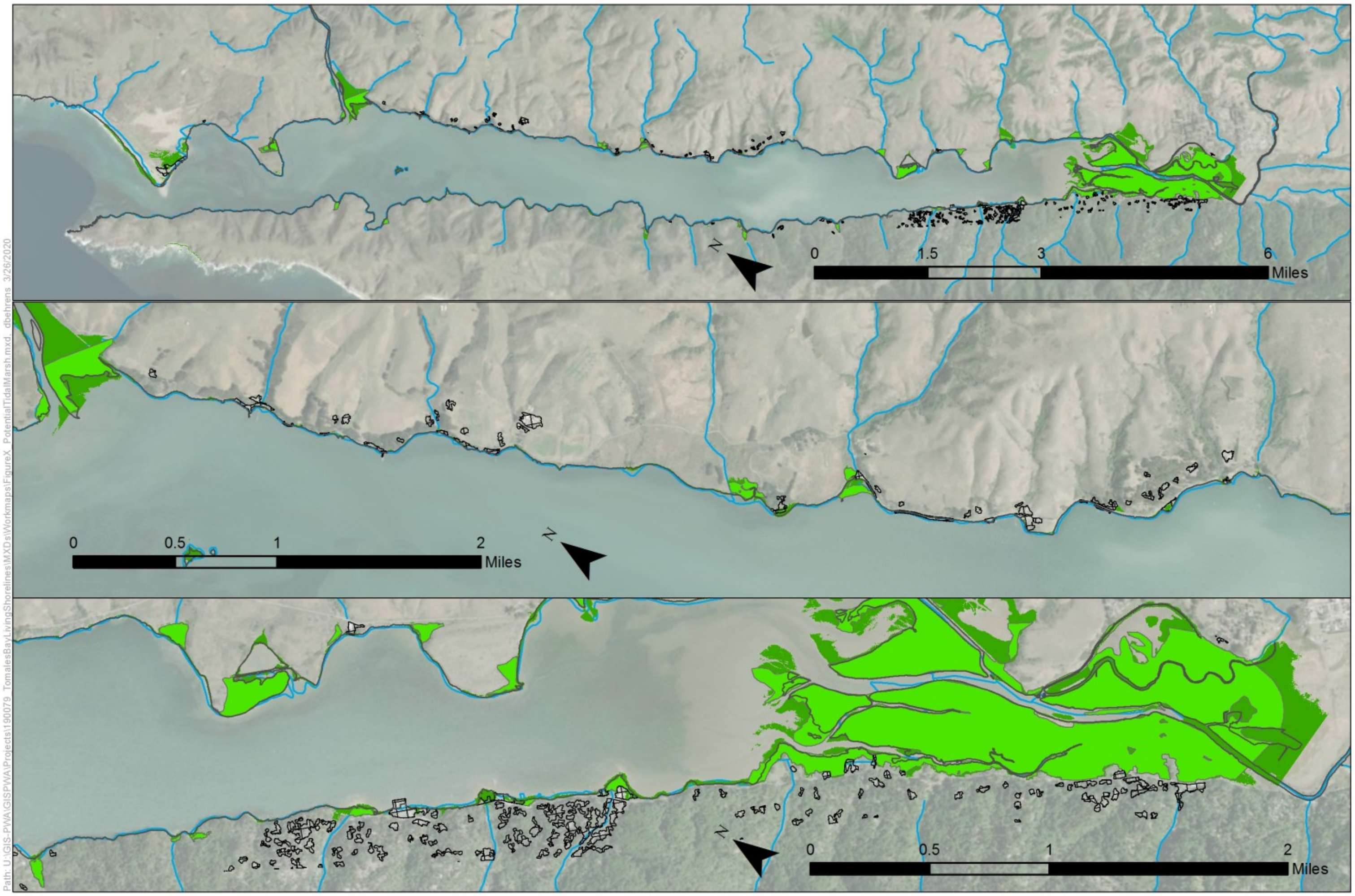
Tidal marshes in Tomales Bay are predominantly found in tidal portions of creek drainages, where they are typically protected from wave action by sandy or coarse beach berms that provide a barrier between the marsh and bay. In the southern part of the bay, tidal marshes are also present without fronting beaches in locations where wave action is limited due to shielding from adjacent landforms. Elsewhere, tidal marshes have formed in pockets behind the remnant North Pacific Coast Railroad berm.

LANDSCAPE CONFIGURATION, DESIGN AND PROCESS GUIDELINES

Tidal marshes encourage shoreline stabilization by dissipating wave energy and contributing biomass and sediment to maintain the elevation of the marsh platform. This reduces erosion and protects shoreline located behind the marsh.

Marsh extent, topography and vegetation control the amount of wave energy reduction and marsh influence on wave processes (e.g. wave refraction, shoaling, breaking). At the marsh edge, features such as marsh scarps contribute to significant wave attenuation as waves shoal

EXAMPLES • Tidal marshes behind barrier beaches along the western shore (e.g. Heart's Desire, Indian, Pita Beaches). Unprotected marshes along the southern shores of the bay in wave-protected areas. Pocket marshes behind the remnant railroad berm on the eastern shore.	and break over a rapid change in elevation. Within the marsh, features with elevation variations (e.g. marsh mounds, tidal channels) affect wave propagation. Generally speaking, wider extents of tidal marsh attenuate greater wave energy due to longer wave exposure to bottom friction. Vegetation also contributes to wave dampening, with the degree of attenuation dependent on characteristics like canopy height, density, stem diameter and stiffness. Within Tomales Bay, the use of tidal marsh as an adaptation measure may be applicable to shallow embayments or bay heads (sheltered from wind-waves) and in the lee of barrier beaches. Tidal marsh may potentially be combined with stream-to-bay reconnection, tidal flats, and beaches (see those sections) to provide a wider range of co-benefits. **SUITABILITY CRITERIA** • Areas between mean tide level (MTL) and highest estimated tide (HAT) around Tomales Bay were mapped as potentially suitable for tidal marsh creation. In the areas marked as suitable, preference for natural infrastructure function is given to zones protecting roadway or other built assets. • To achieve wave attenuation benefits along the backshore, marsh areas included in conceptual designs should consider marsh width, elevation, and vegetation type (roughness).



SOURCE: GGNRA (2019)

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Areas of Existing (light green) and Potential (dark green) Tidal Marsh

Note: based on mapped areas between mean sea level and highest astronomic tide


Tidal marsh protected by barrier beach, Martinelli Park
Photo credit: M.Orr

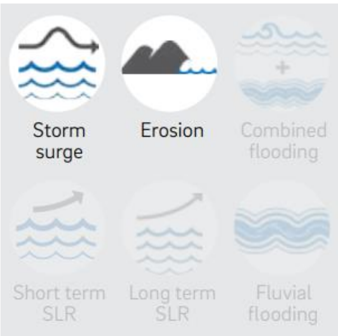

Fringing tidal marsh in the distance,
near the northern extent of the
Lagunitas Creek delta
Photo credit: D.Behrens


Fringing tidal marsh south of Inverness
Photo credit: D.Behrens


Inverness
Sir Francis Drake
© 2020 Googl

NEARSHORE OYSTER REEFS

COASTAL RISKS MANAGED



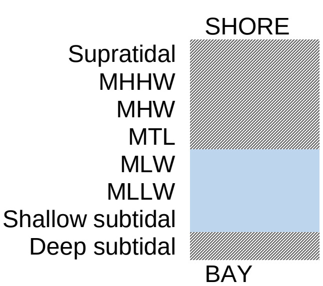
OTHER ECOSYSTEM SERVICES

• Biodiversity • Food supply • Climate Resilience • Water quality improvement • Recreation • Other cultural services

IMPACT ON SHORELINE

Protect • Accommodate • Retreat

LOCATION WITHIN TIDAL TRANSECT



DESCRIPTION

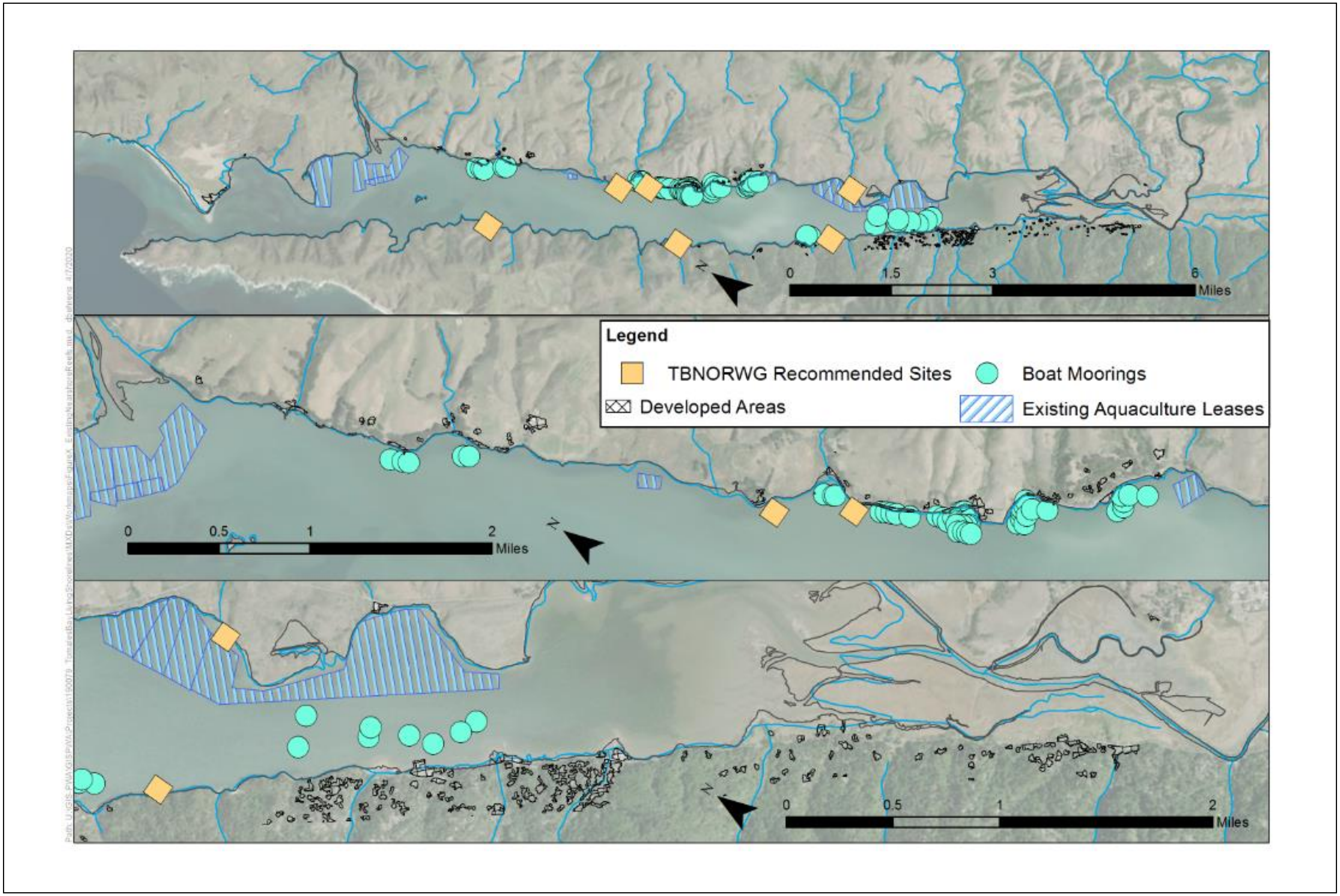
Nearshore oyster reefs play an essential role in the coastal zone, providing habitat value for a range of aquatic species and flood protection benefits. Certain oyster species, like native Olympia oysters (*Ostrea lurida*), are not reef building and for shoreline protection purposes are can be placed on artificial (constructed) reefs. Typical materials for artificial nearshore reefs include hard substrate like oyster shell and baycrete (cement mixture with locally derived sand and shell material). Commercially grown (Japanese) oysters, which are cultivated in Tomales Bay, are cultivated on floating structures that may mitigate some wave energy adjacent to the shoreline. Nearshore reefs, using native and/or non-native oysters, reduce wave energy at subtidal elevations and provide wave protection for areas in their lee.

LANDSCAPE CONFIGURATION, DESIGN AND PROCESS GUIDELINES

Nearshore reef placement is ideal in areas of shallow water with low wave action. Reefs attenuate wave energy directly, by acting as a low-crested wave break, and indirectly, by encouraging sediment accumulation at the bed. Typically, nearshore oyster reefs are arranged in rows and/or implemented with other nature-based adaptation measures to enhance wave protection benefits.

Use of nearshore oyster reefs in Tomales Bay could include placement of native Olympia oysters on intertidal rock formations or working with commercial oyster farms on opportunistic placement of Japanese oyster racks to achieve co-benefits (commercial farming and protection of shoreline assets). Native oyster restoration could invlude placement of hatchery-reared native oysters onto existing intertidal rock

EXAMPLES • See recommended native oyster restoration sites suggested by the Tomales Bay Native Oyster Working Group • Native oysters are generally present along rocky intertidal portions of the shoreline, and are less prevalent in areas where local freshwater sources and predation by oyster drills are limiting factors	formations, creating or adding to intertidal rock formations to increase natural settlement, placement of artificial reefs, or encouragement of native oysters to settle on other shoreline protection structures by adding texture or seeding with hatchery-reared native oysters. Commercial (Japanese) oysters cultured on floating or suspended platforms have potentially more direct applicability for mitigating wave action as they are cultivated on suspended platforms, and leases are already in place along the eastern shore of Tomales Bay. Like native Olympia oysters, these would be a complimentary approach that would be used as part of a mosaic of adaptation measures within a single treatment area to protect shoreline assets. Both native and non-native oysters are sensitive to water quality variables like salinity, temperature, and turbidity. In particular, recruitment success for native Olympia oysters is affected by freshwater or fresh-brackish pulses during storm runoff events, which are associated with tributary stream mouths. Both oyster species are also preyed upon by non-native snails. Site placement for nearshore oyster reefs would need to consider long-term monitoring data on water quality patterns along the bay as well as distribution and density of predators. **SUITABILITY CRITERIA** Native oysters will be most successfully integrated into shoreline protection projects where hard substrates are placed at appropriate tidal elevations. Substrates with grooves, crevices and interstitial spaces are most likely to attract natural recruitment of oysters and can mitigate heat stress during low tides. In Tomales Bay, oyster restoration will be most successful at sites in located in the mid bay, as opposed to close to the mouth or head. Water quality conditions are more consistently good for oysters here. Predation by snails is highest at the head; near the mouth of the bay oyster larvae may be swept out to sea. Oyster recruitment in Tomales Bay is sporadic. In many years there is little to no natural set of oysters. Projects in Tomales Bay may benefit from the use of hatchery reared Olympia oysters which could be seeded onto hard substrates.



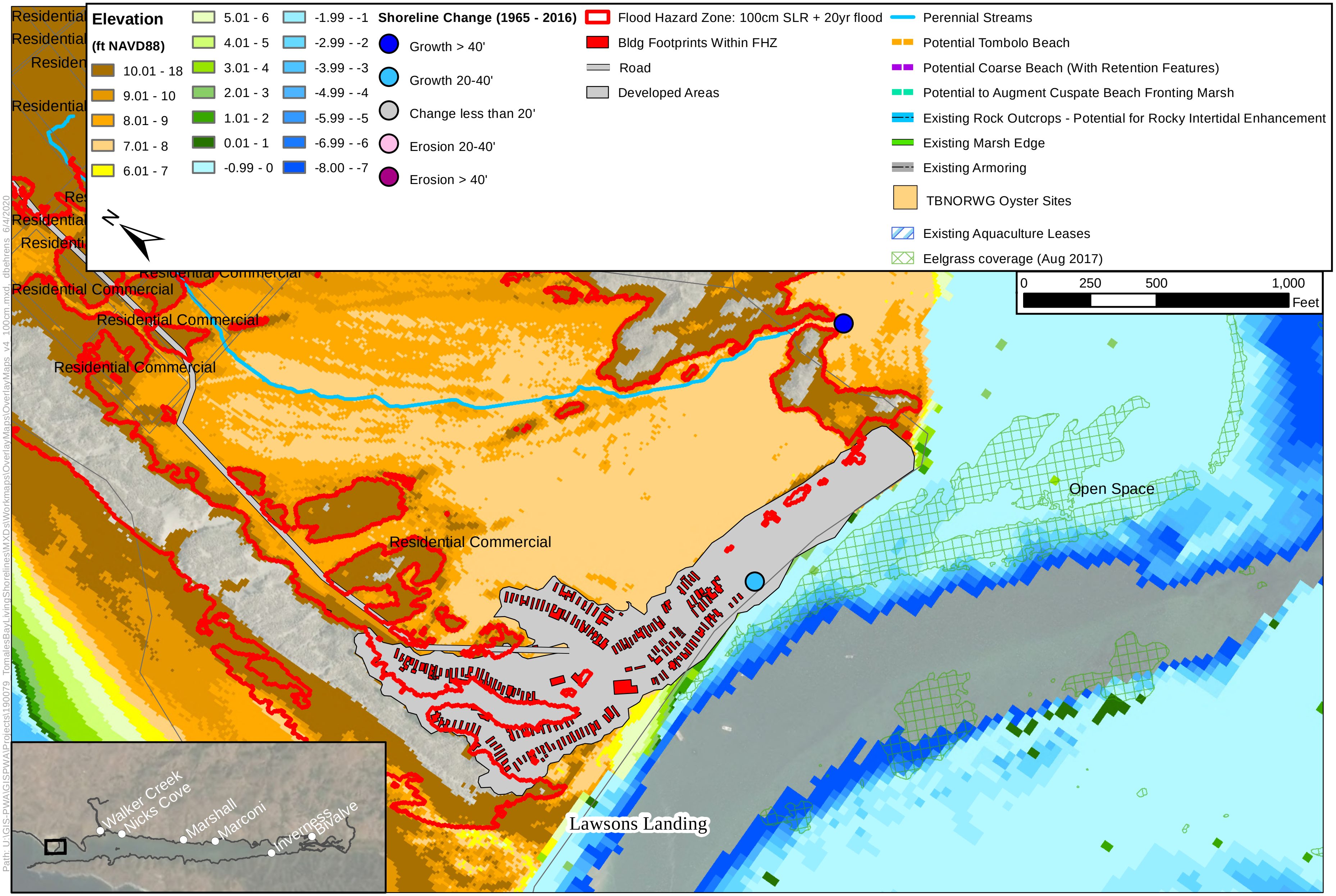
SOURCE: Marin County, TBNORWG (2019)

Locations of oyster restoration opportunities (TBNORWG Recommended Sites), commercial oyster leases, and areas constrained by boat moorings.

Attachment E

Overlay Maps

ESA



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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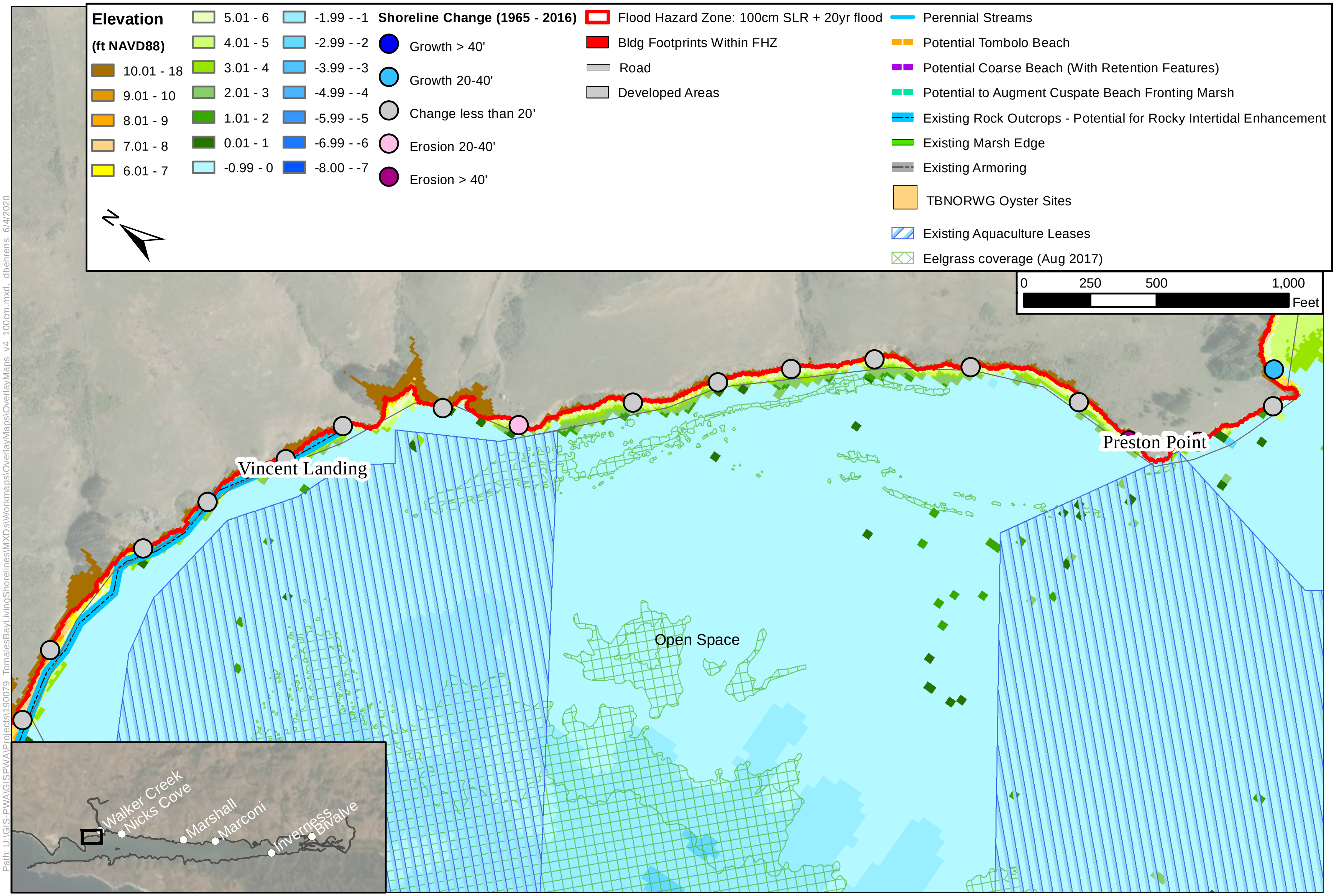
Figure 1
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

Tomales Bay Living Shorelines Feasibility . D190079.00

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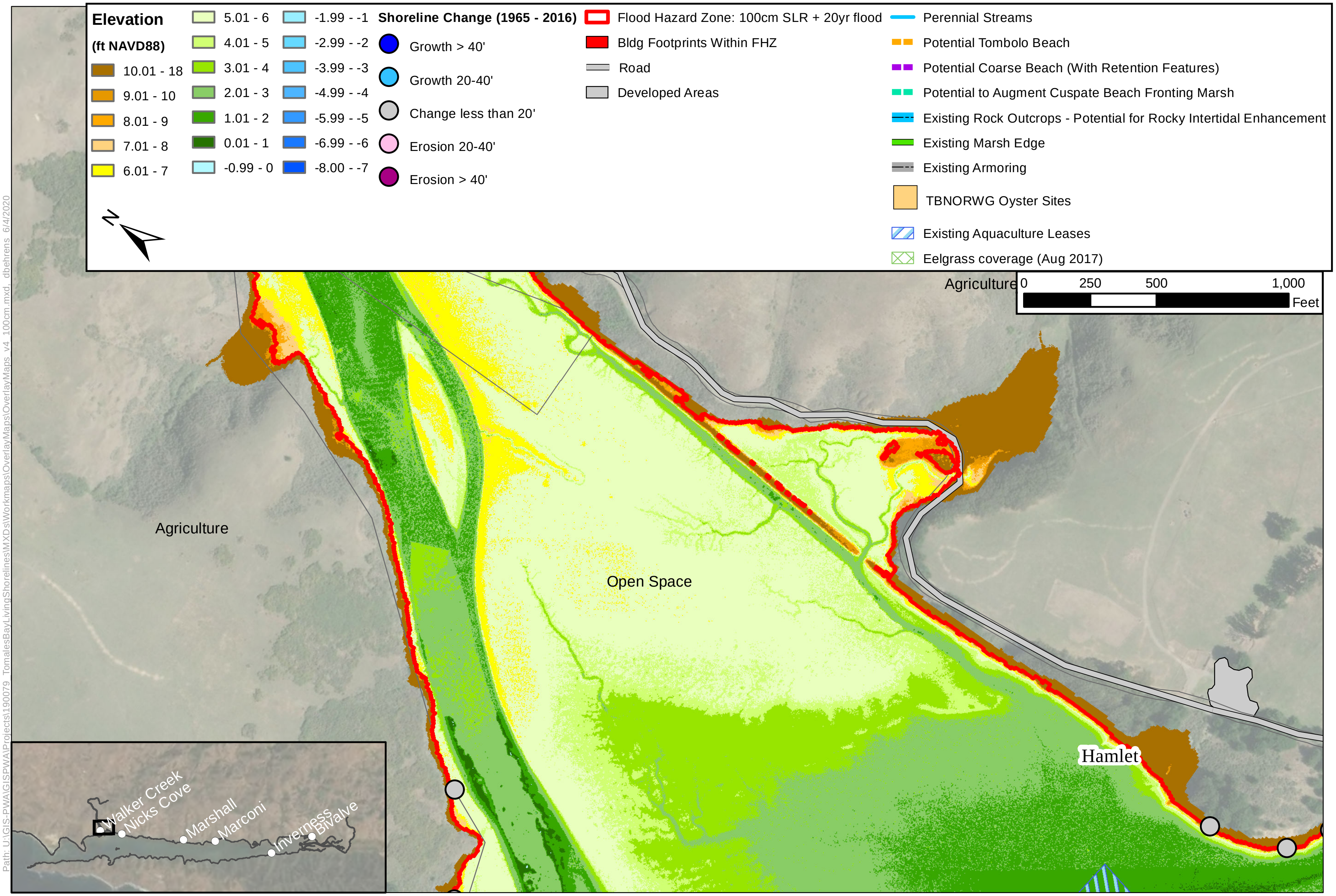
Figure 2
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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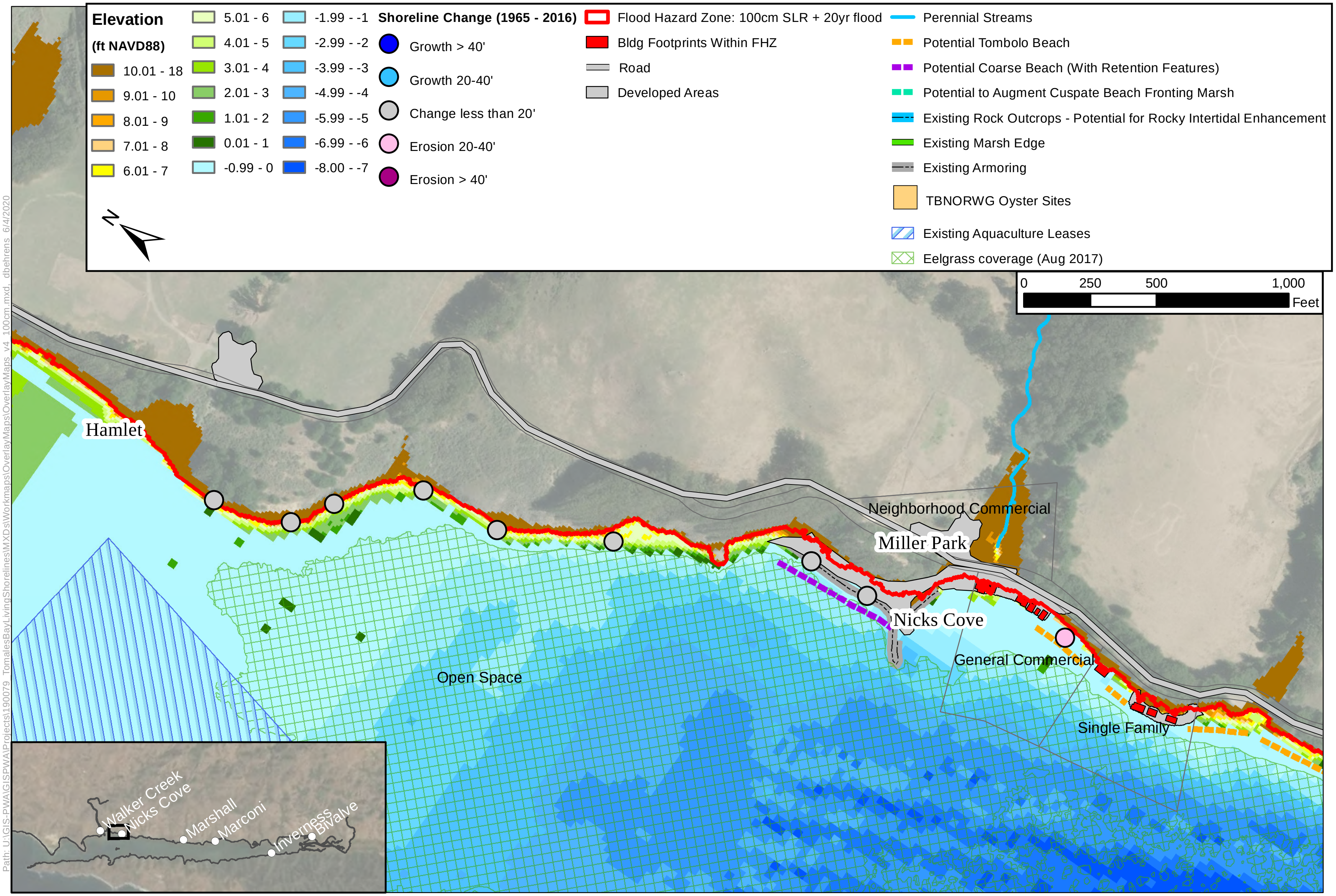
Figure 3

Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

Tomales Bay Living Shorelines Feasibility . D190079.00

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Figure 4
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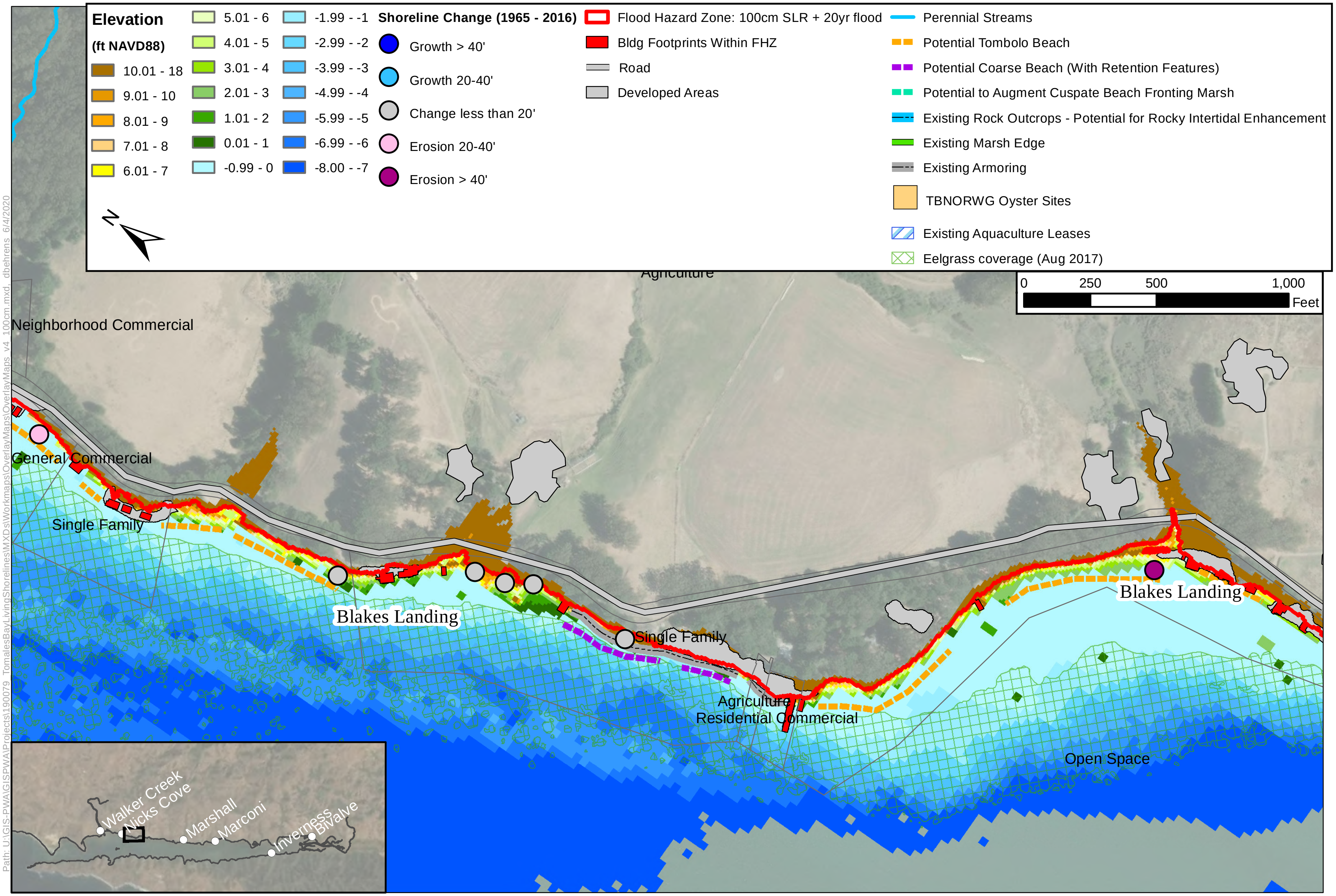

SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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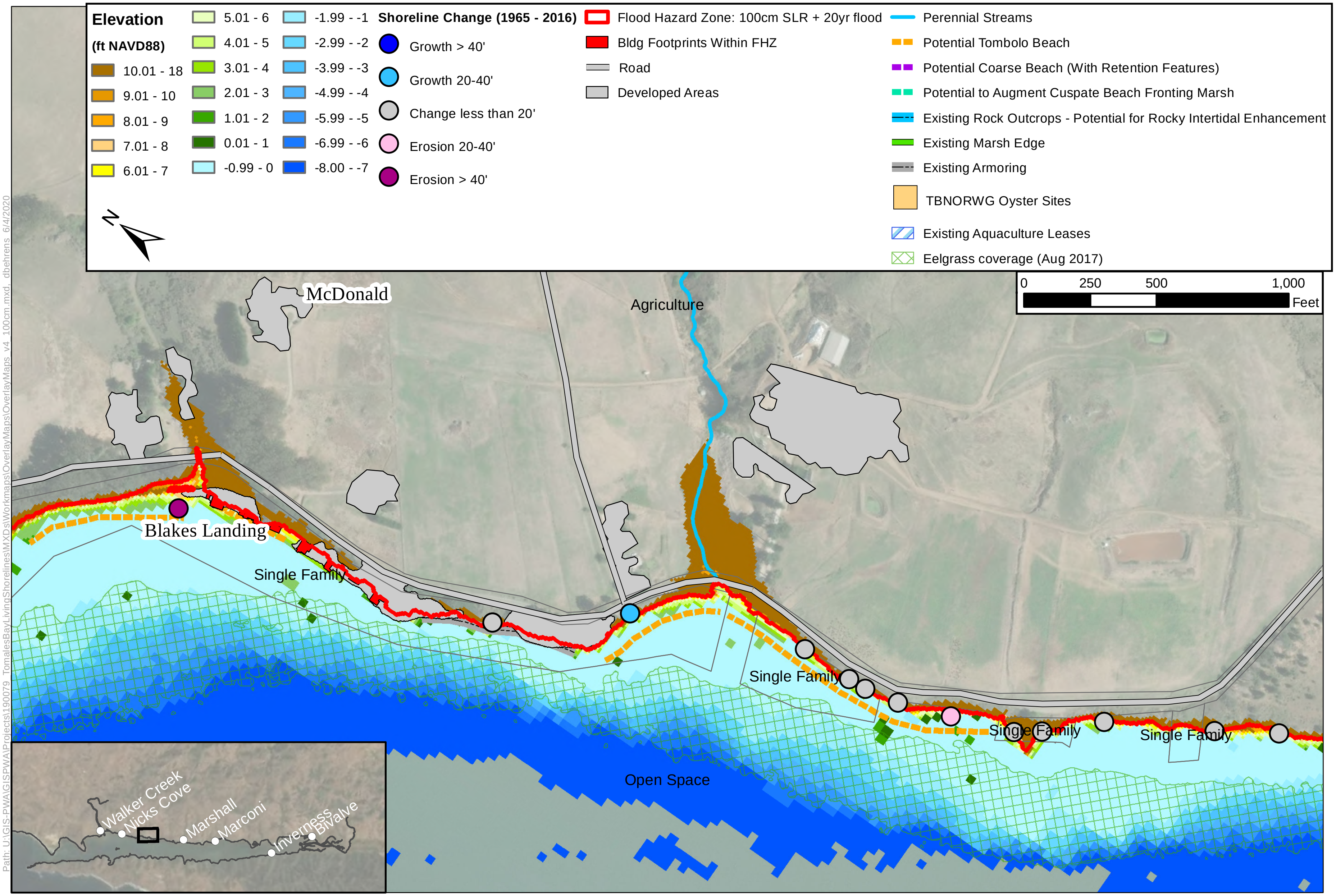
Figure 5
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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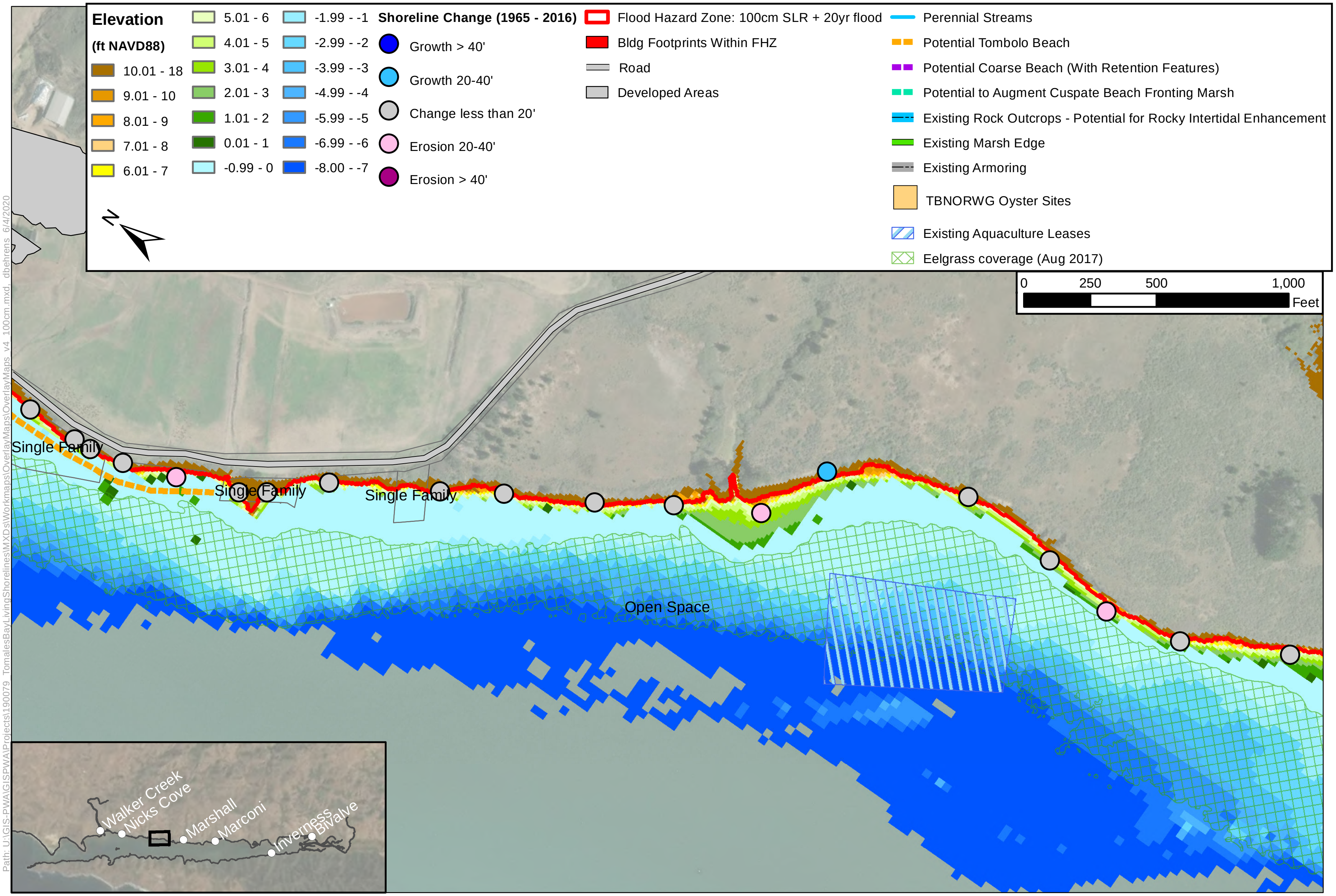
Figure 6
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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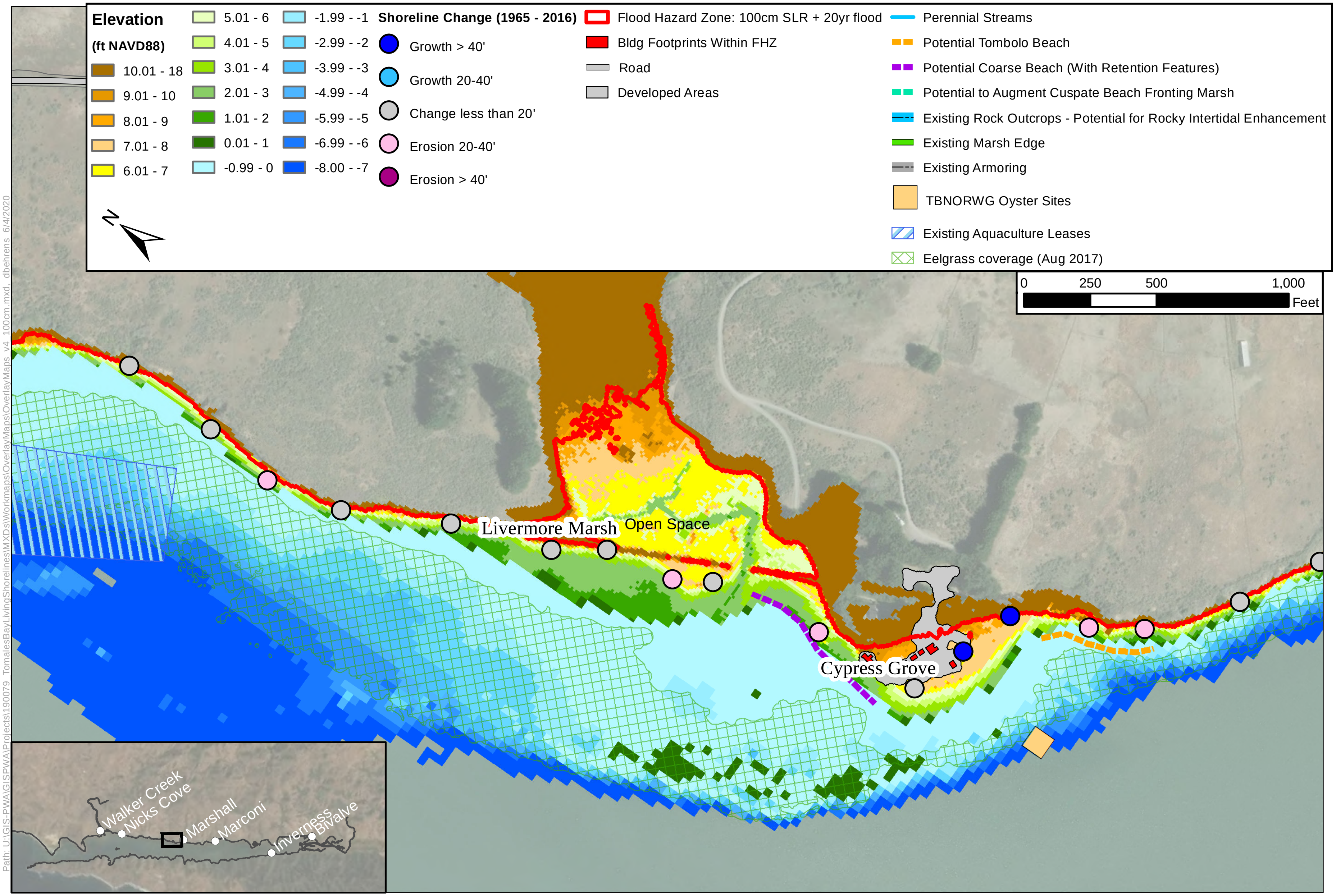
Figure 7
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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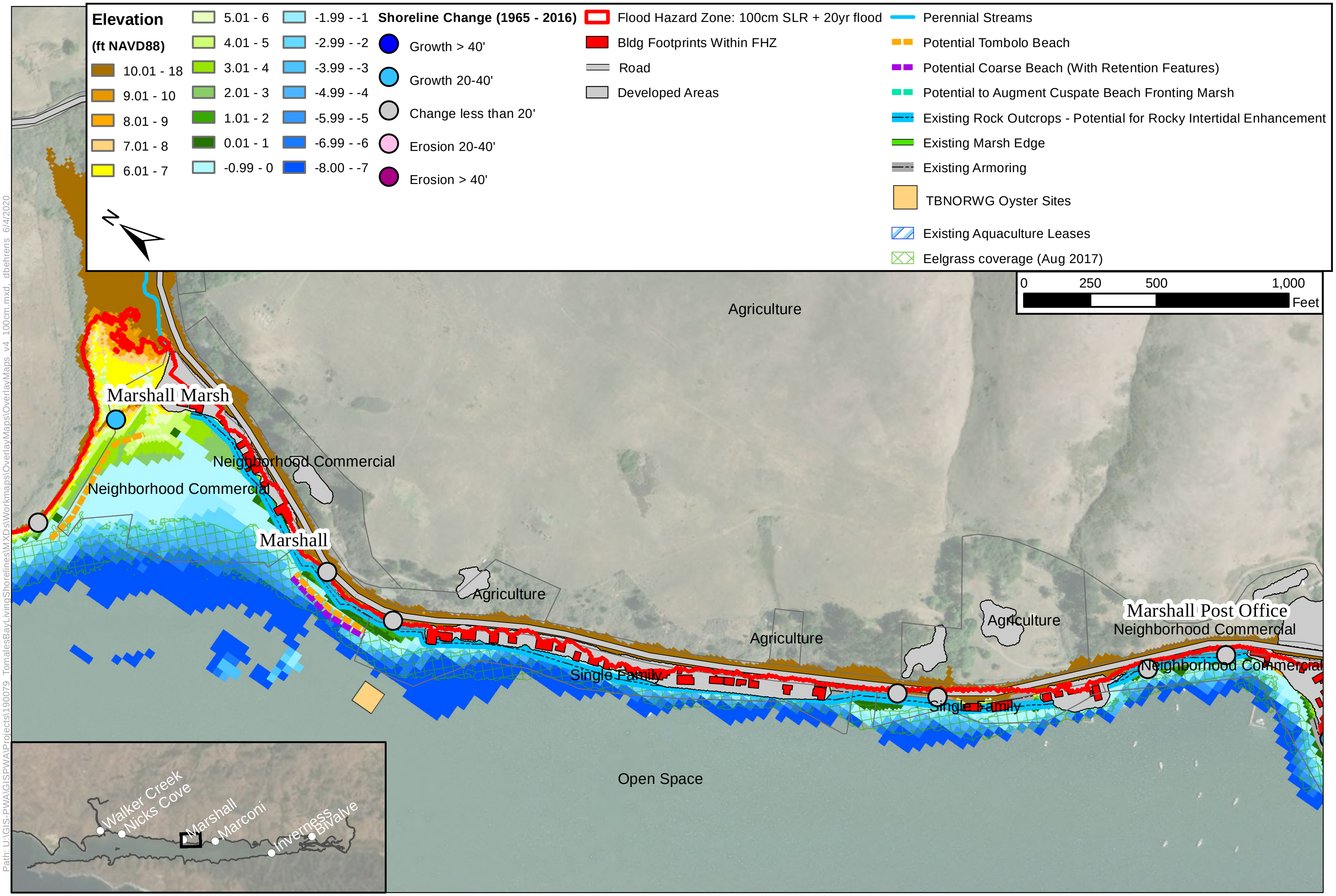
Figure 8
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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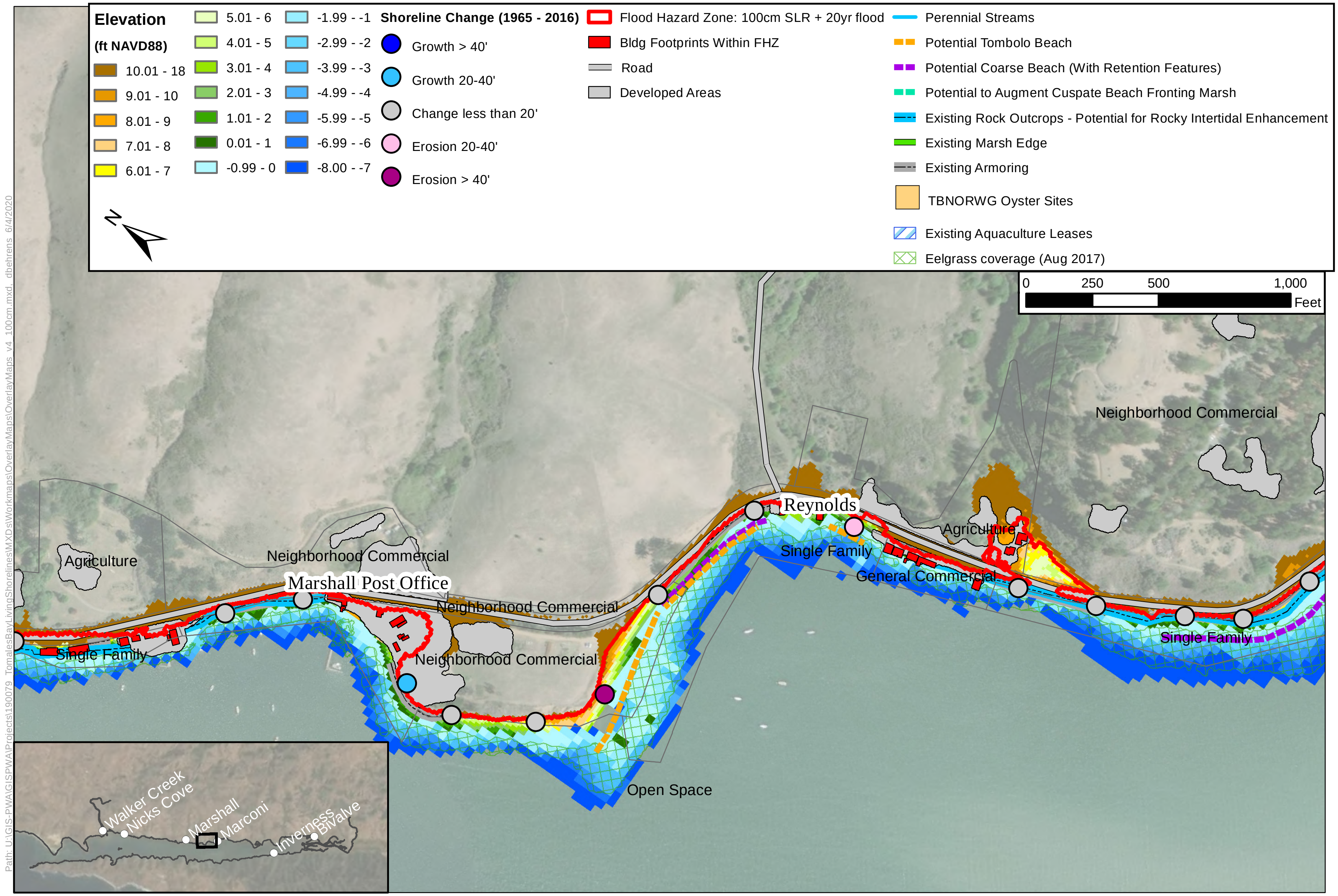
Figure 9
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams);
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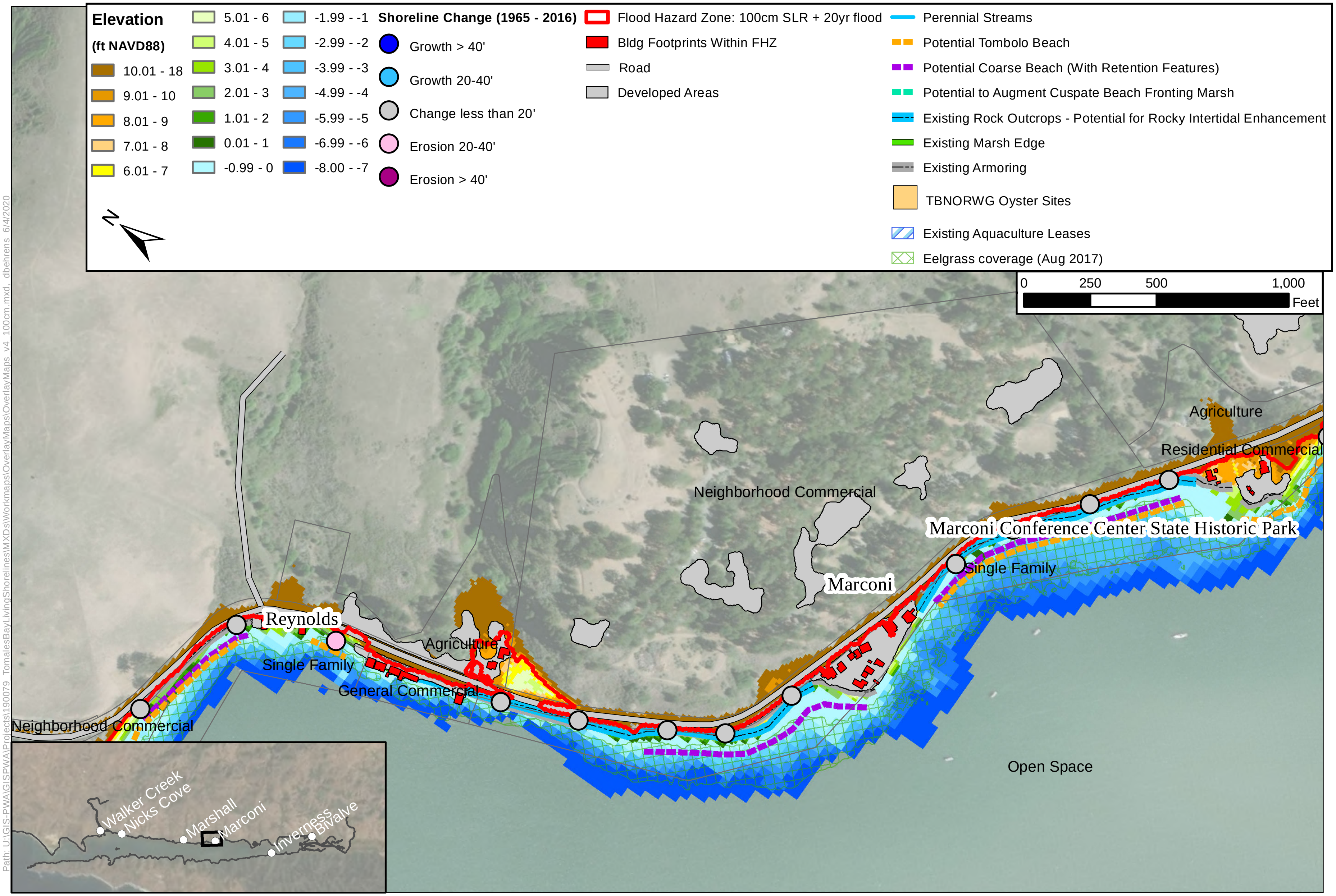
Figure 10
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams);

USGS (flood hazard zones); GGNPC (elevations)

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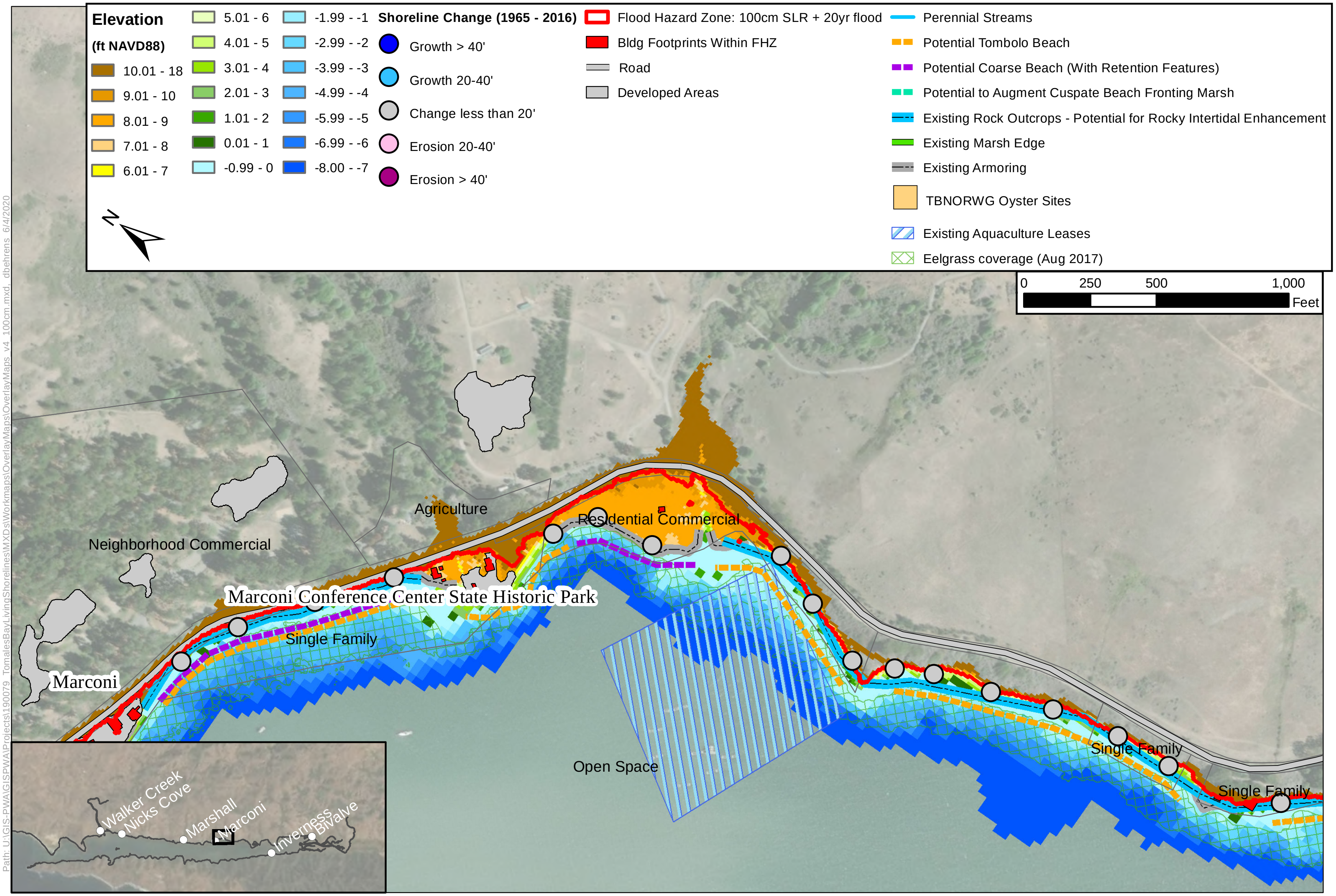
Figure 11

Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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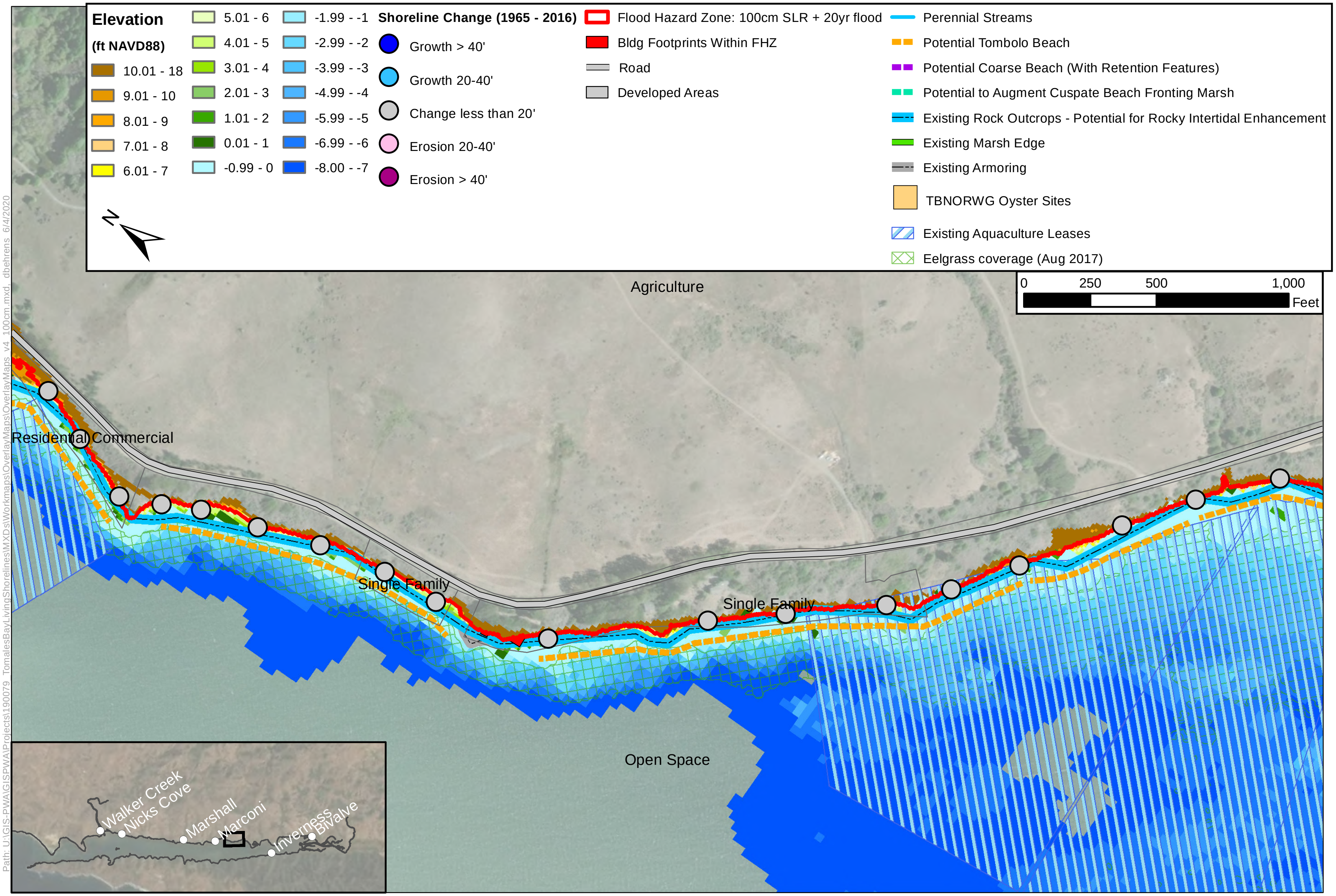
Figure 12
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

Tomales Bay Living Shorelines Feasibility . D190079.00

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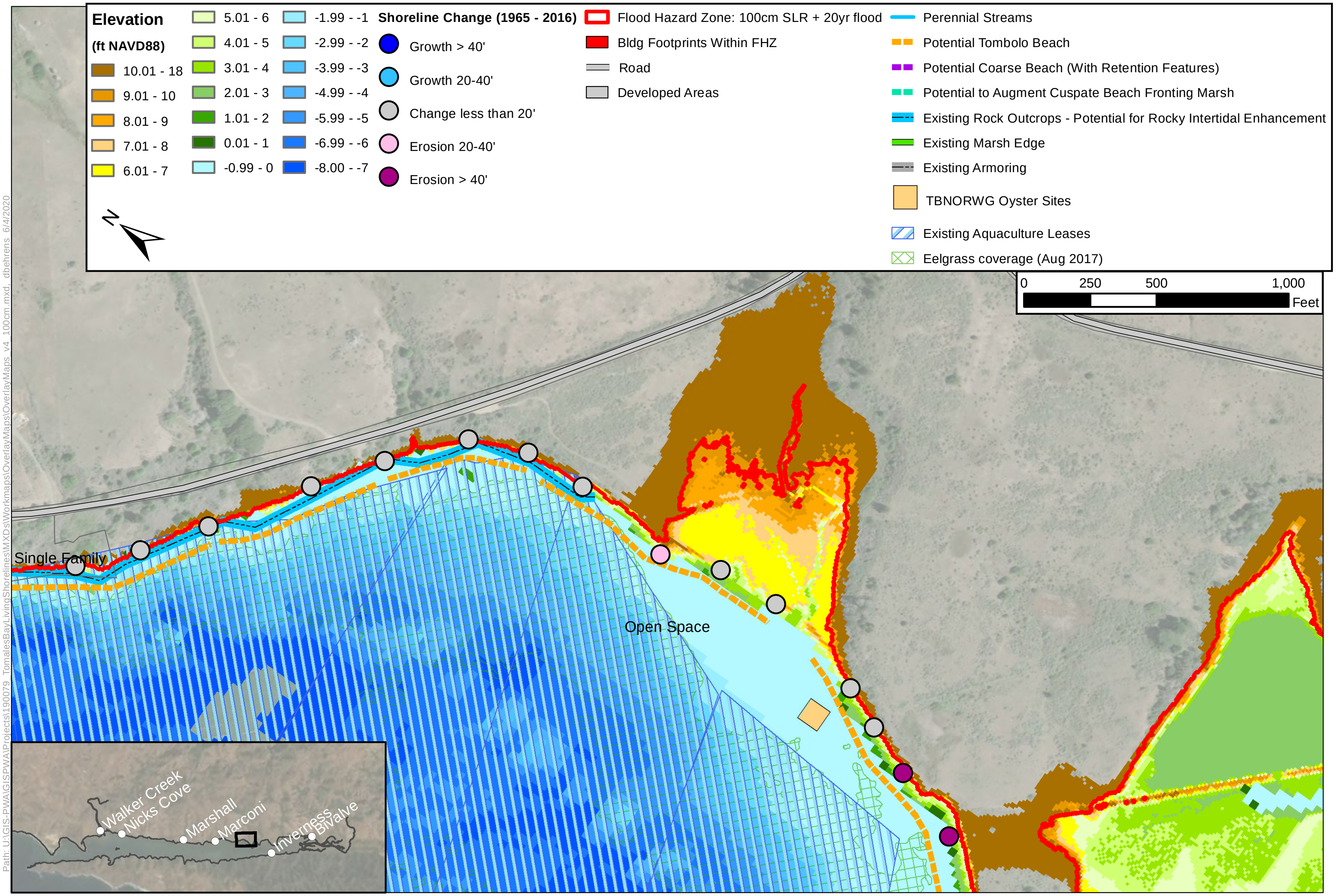
Figure 13
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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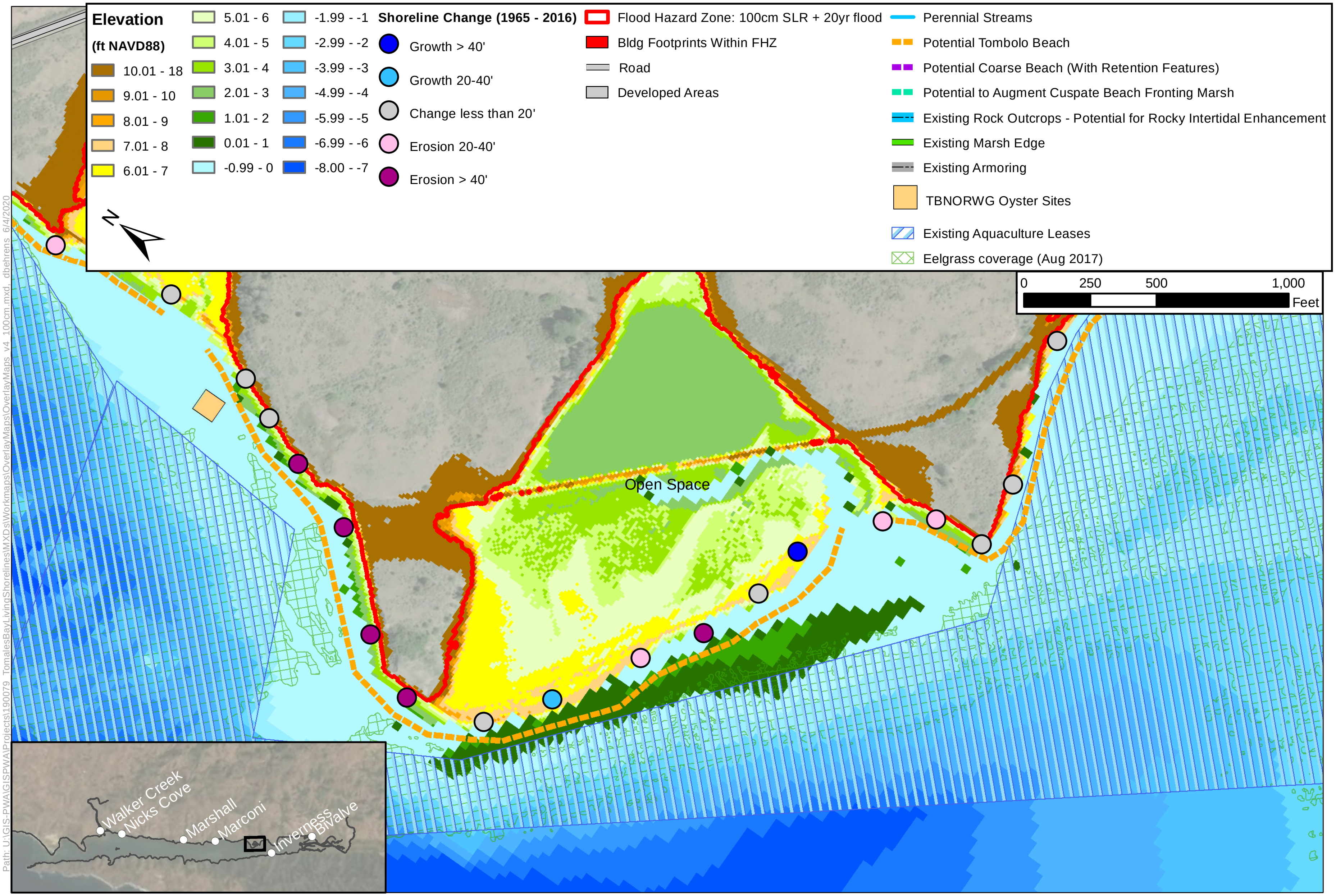
Figure 14

Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams);

USGS (flood hazard zones); GGNPC (elevations)

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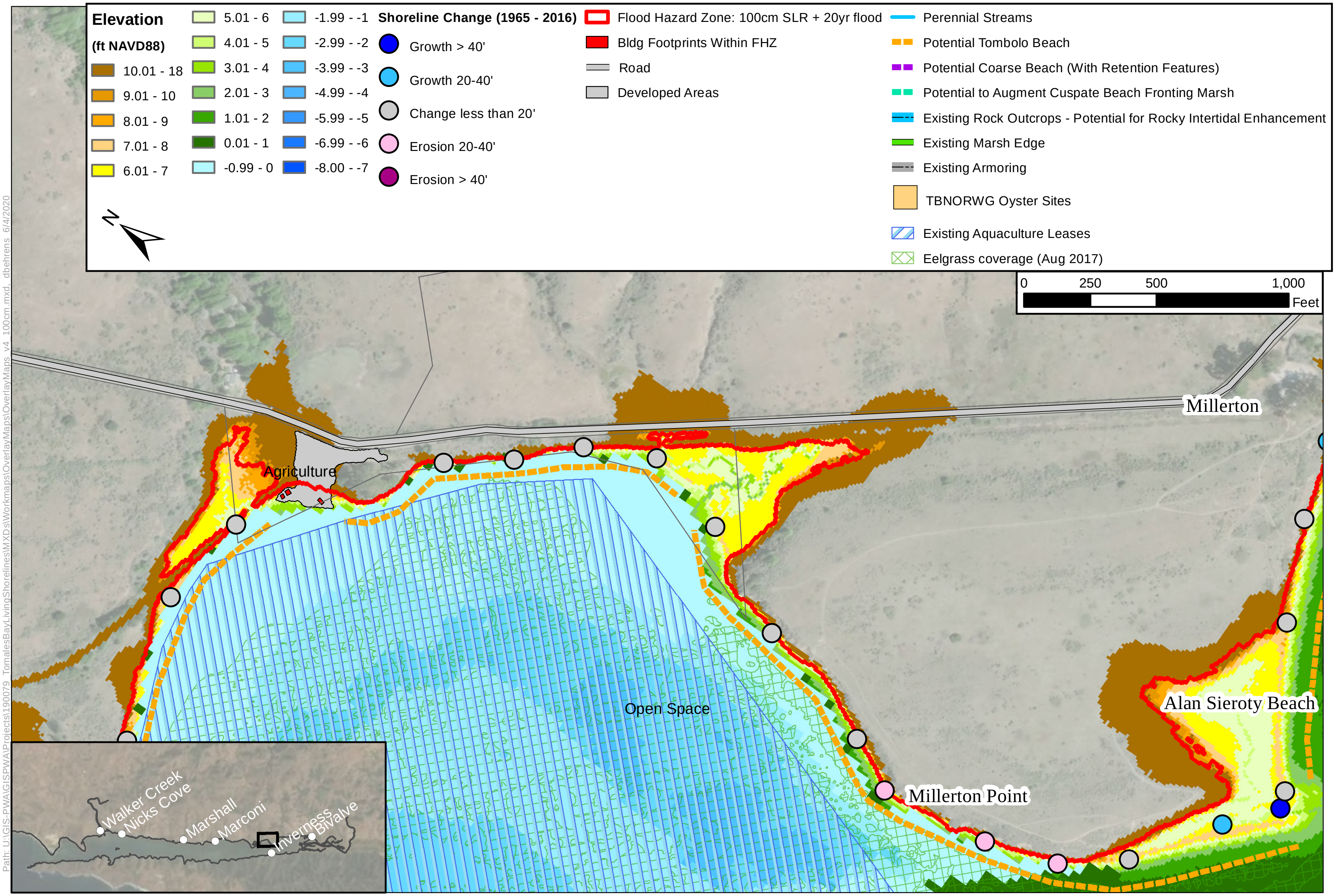
Figure 15

Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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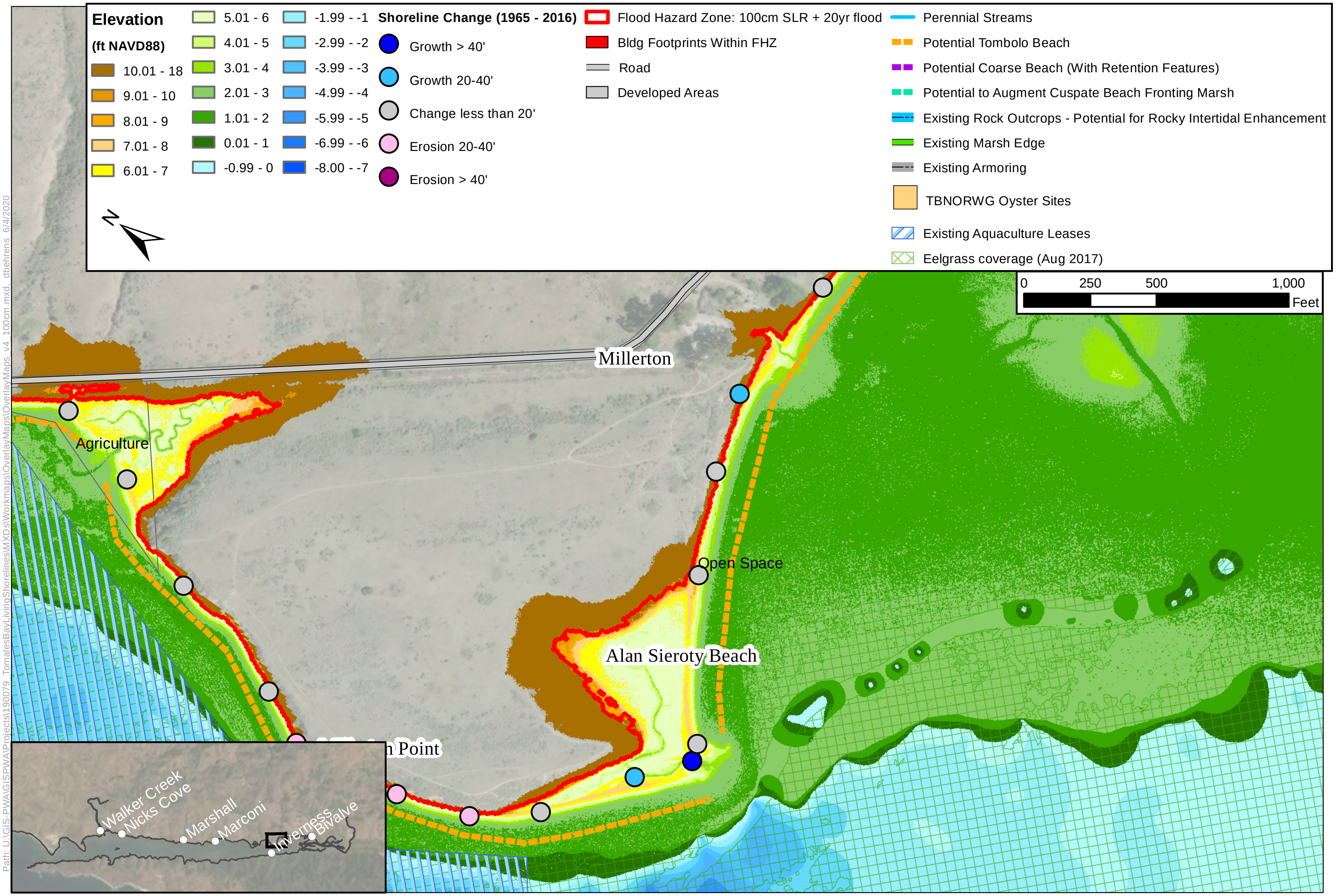
Figure 16
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

Tomales Bay Living Shorelines Feasibility . D190079.00

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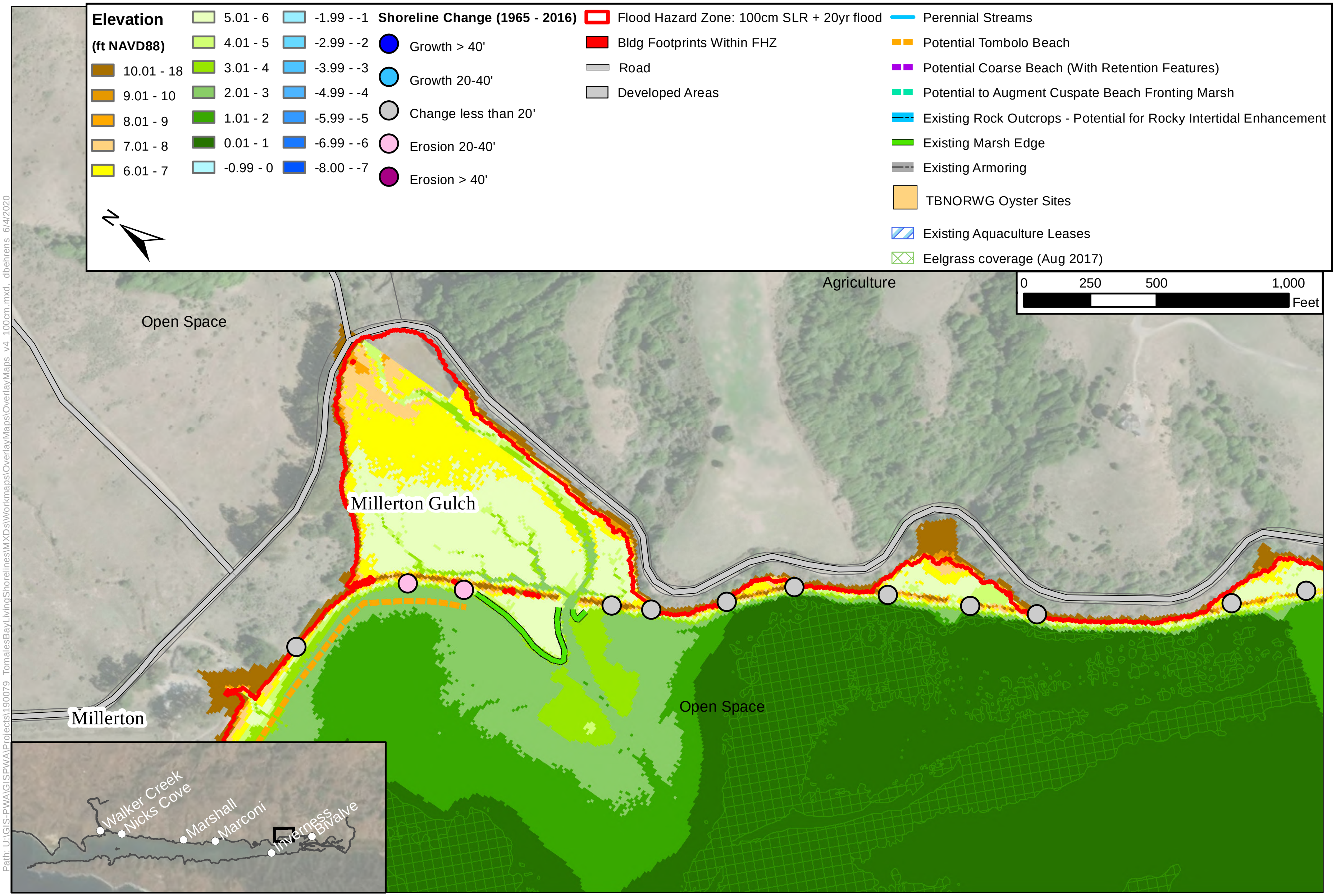
Figure 17
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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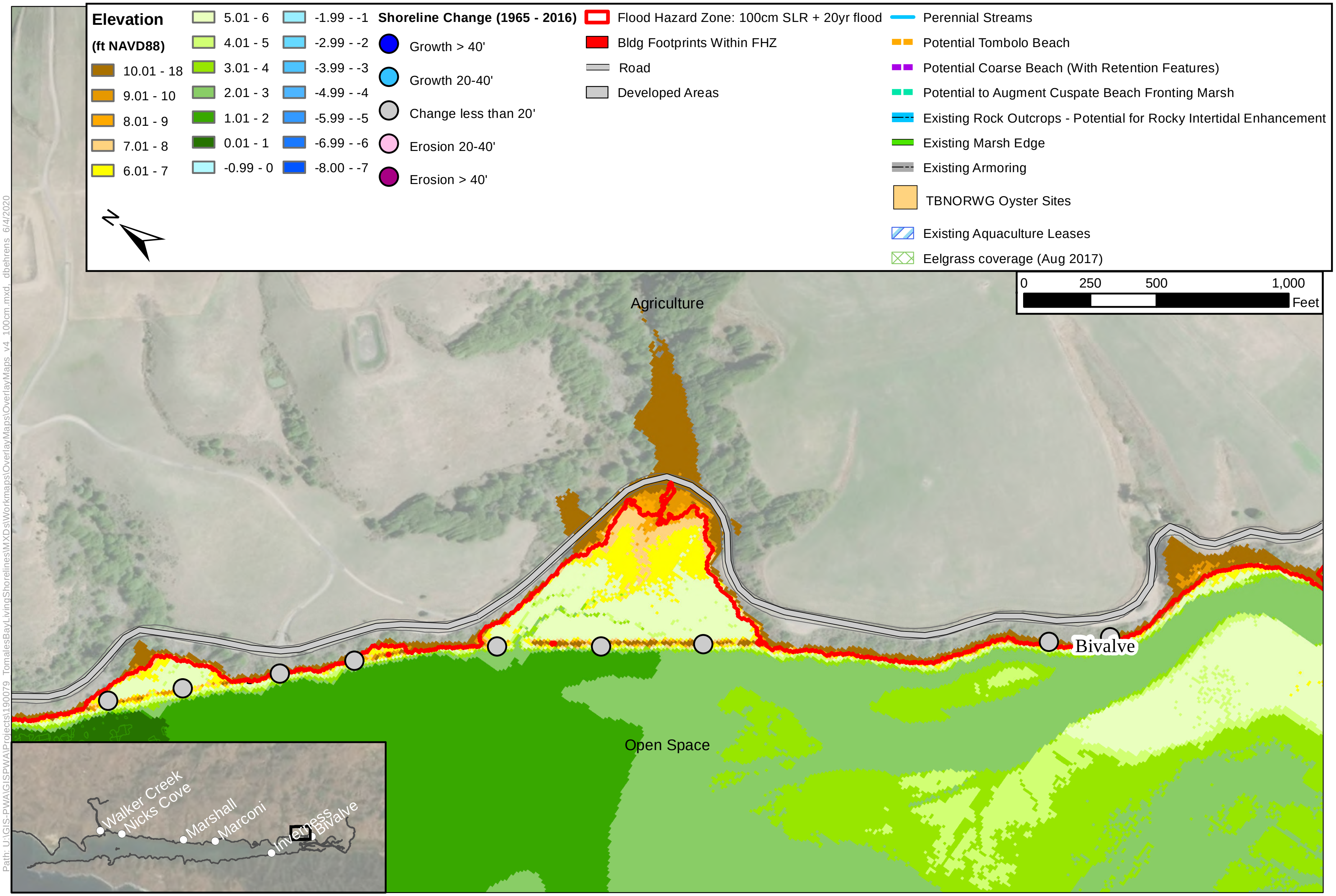
Figure 18
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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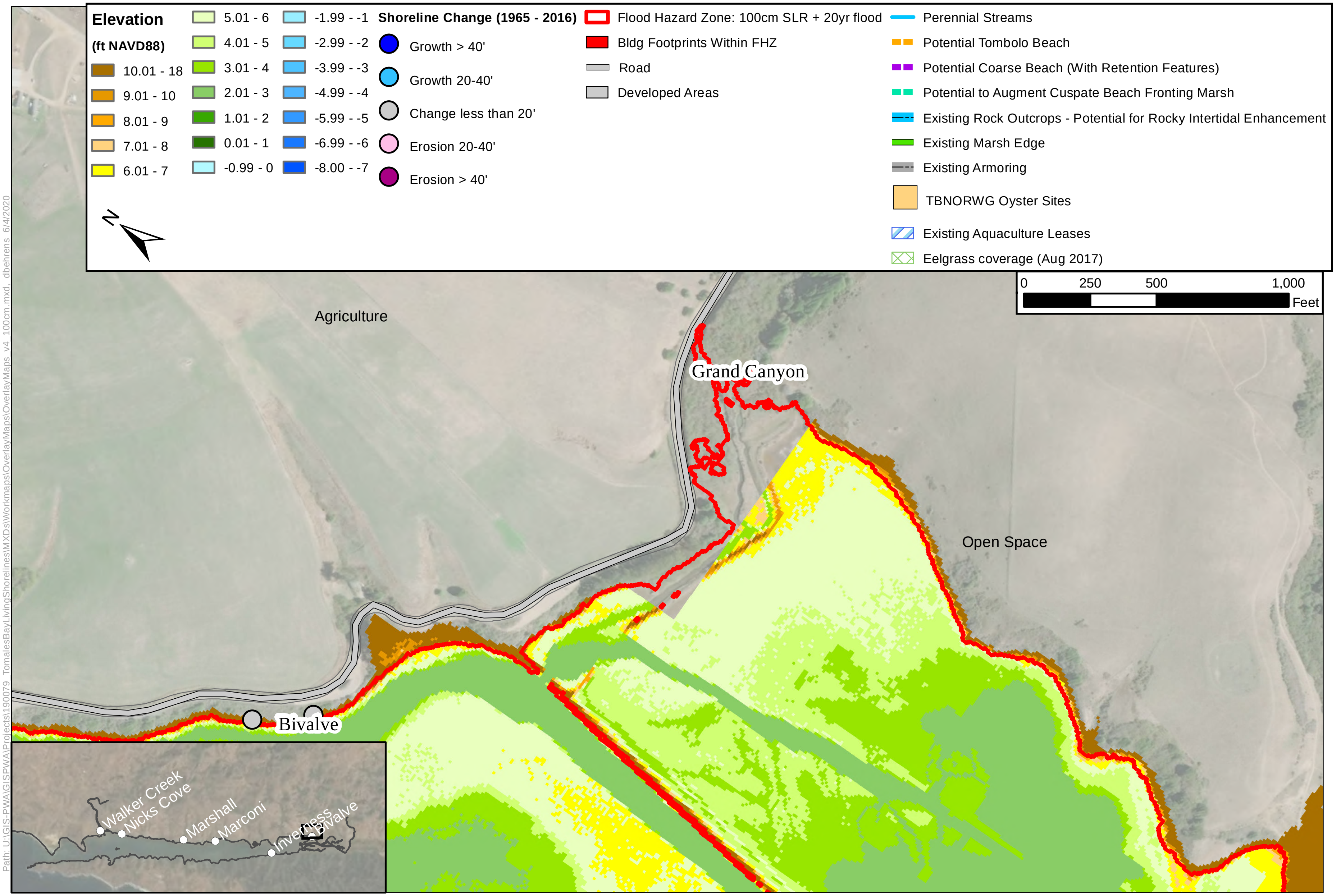
Figure 19
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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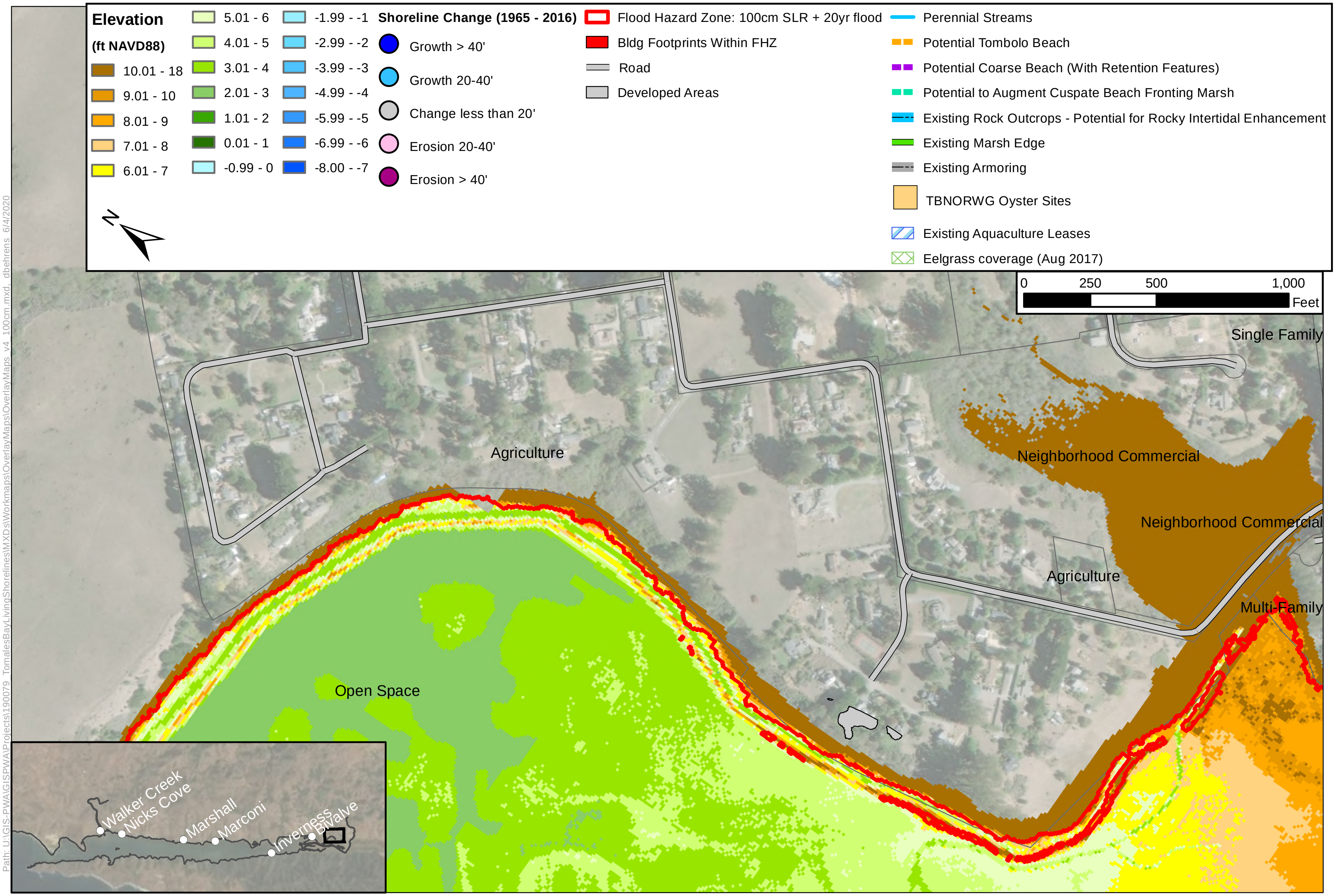
Figure 20
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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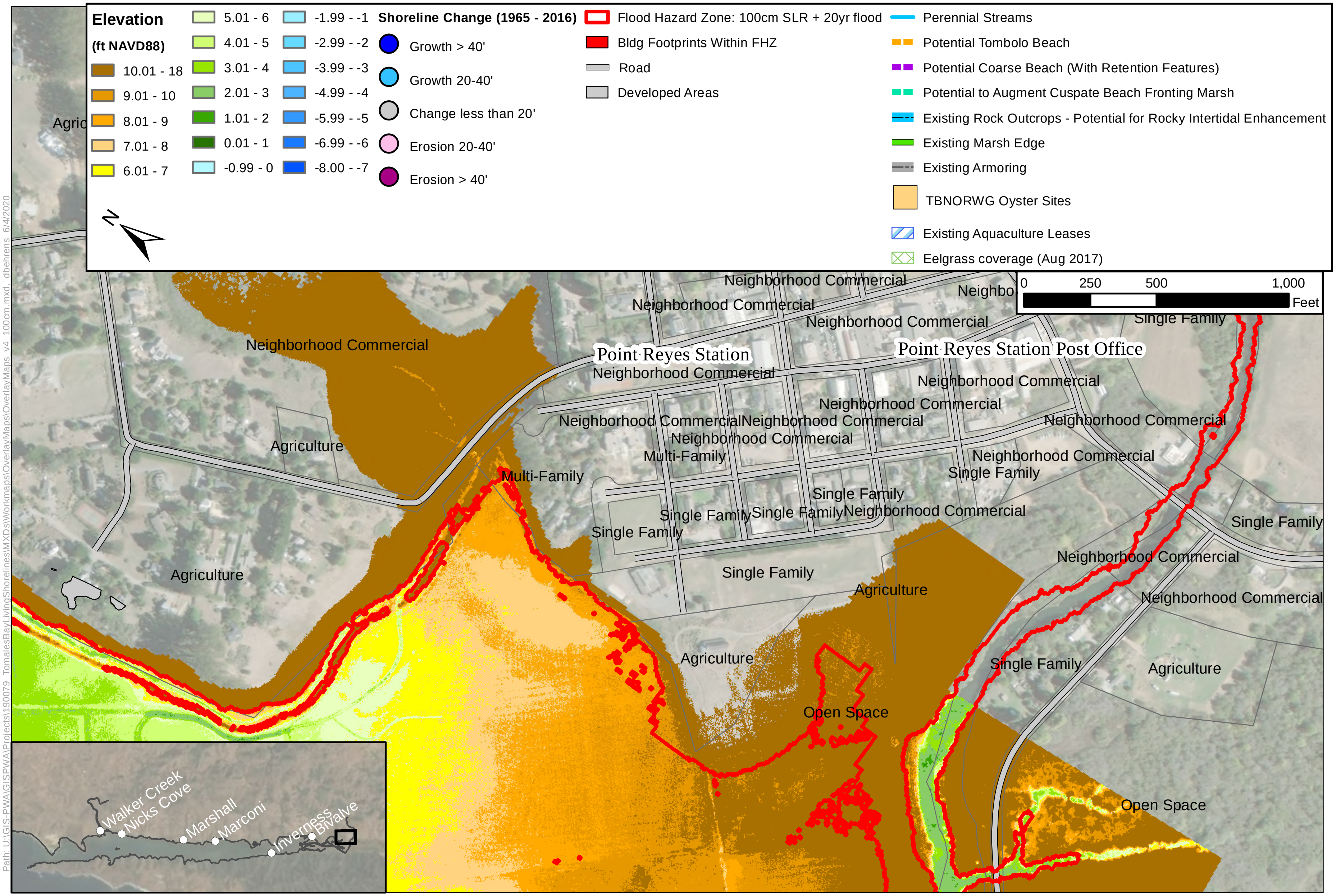
Figure 21
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams);
USGS (flood hazard zones); GGNPC (elevations)

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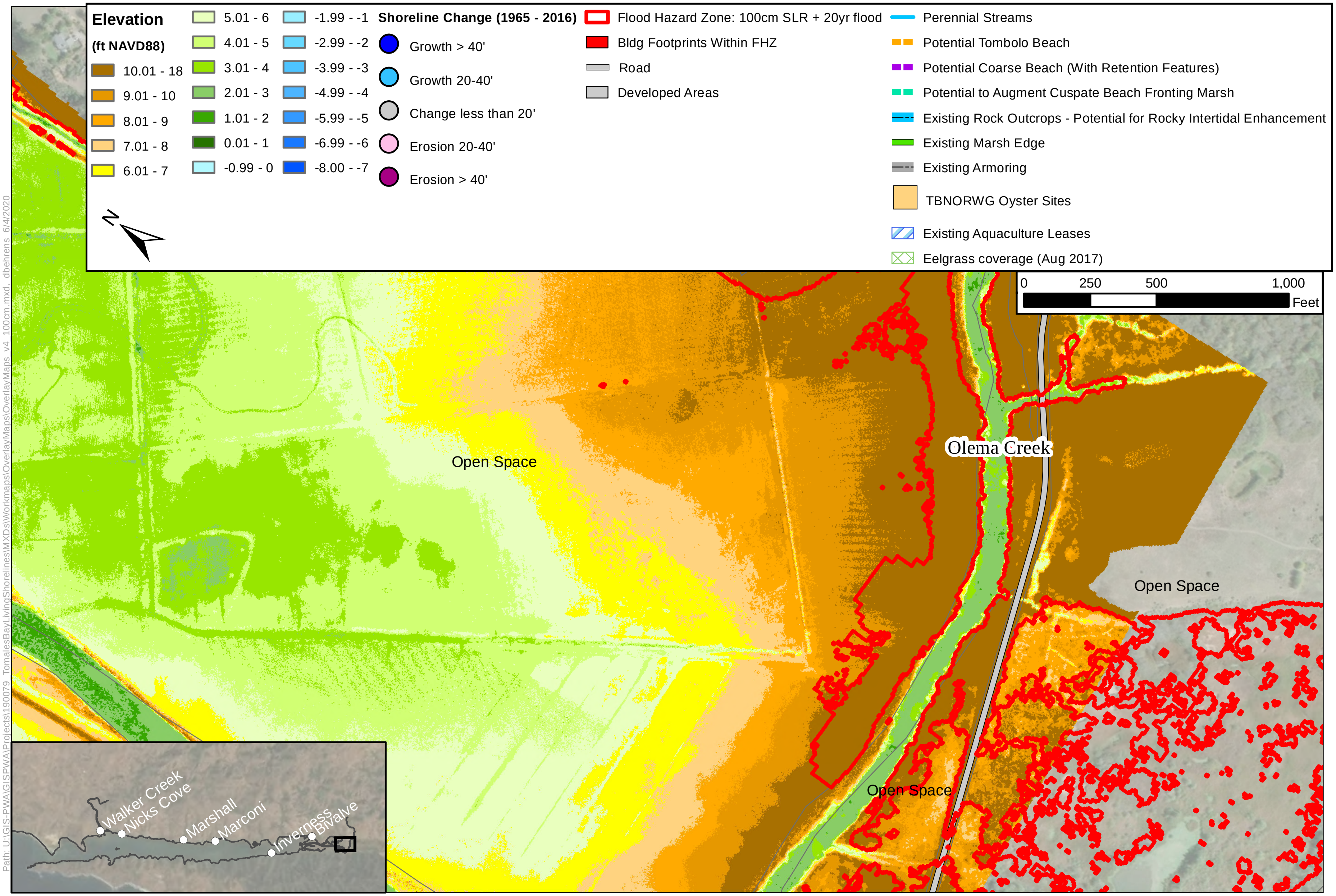
Figure 22
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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Figure 23
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites

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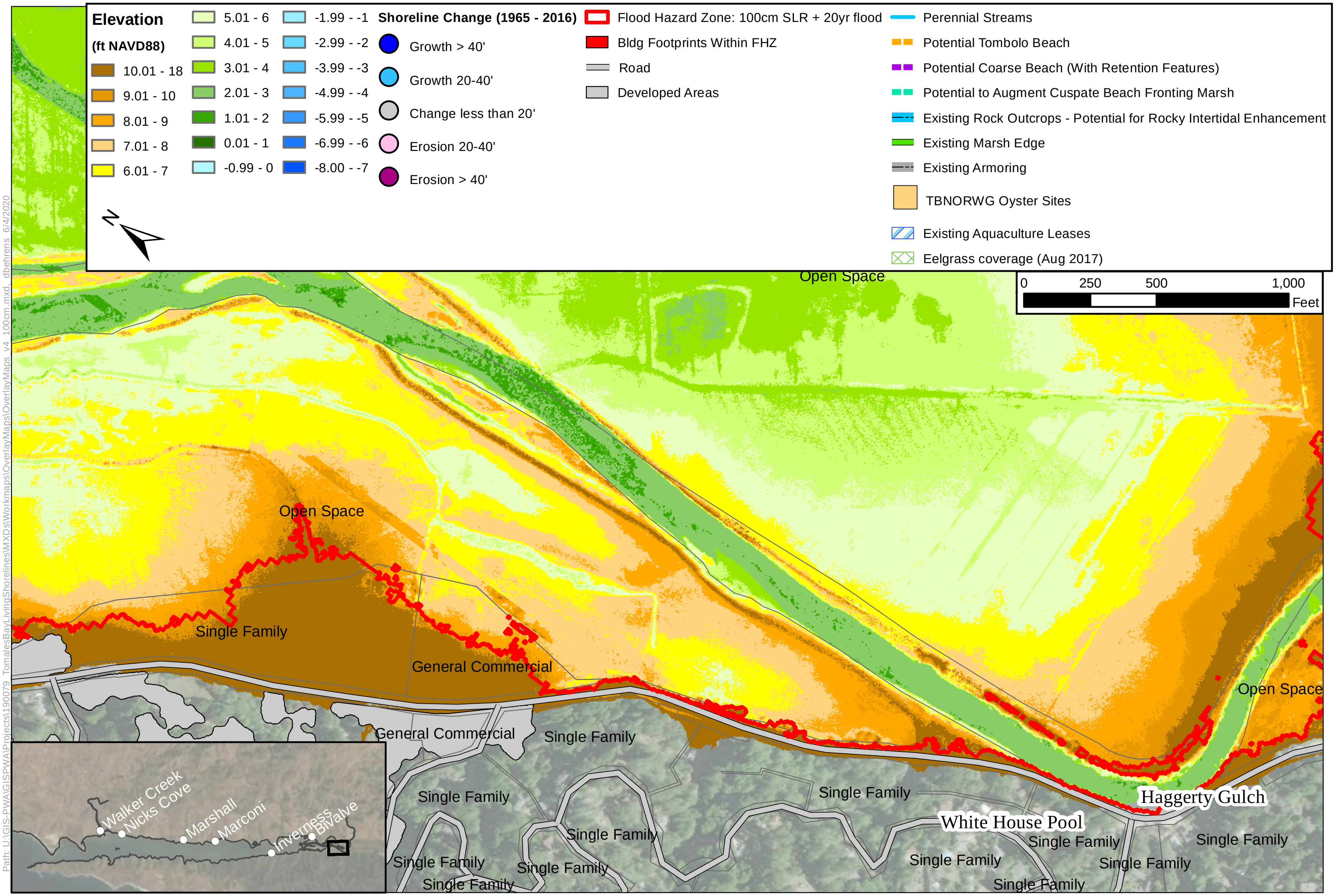

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SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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Figure 24
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites

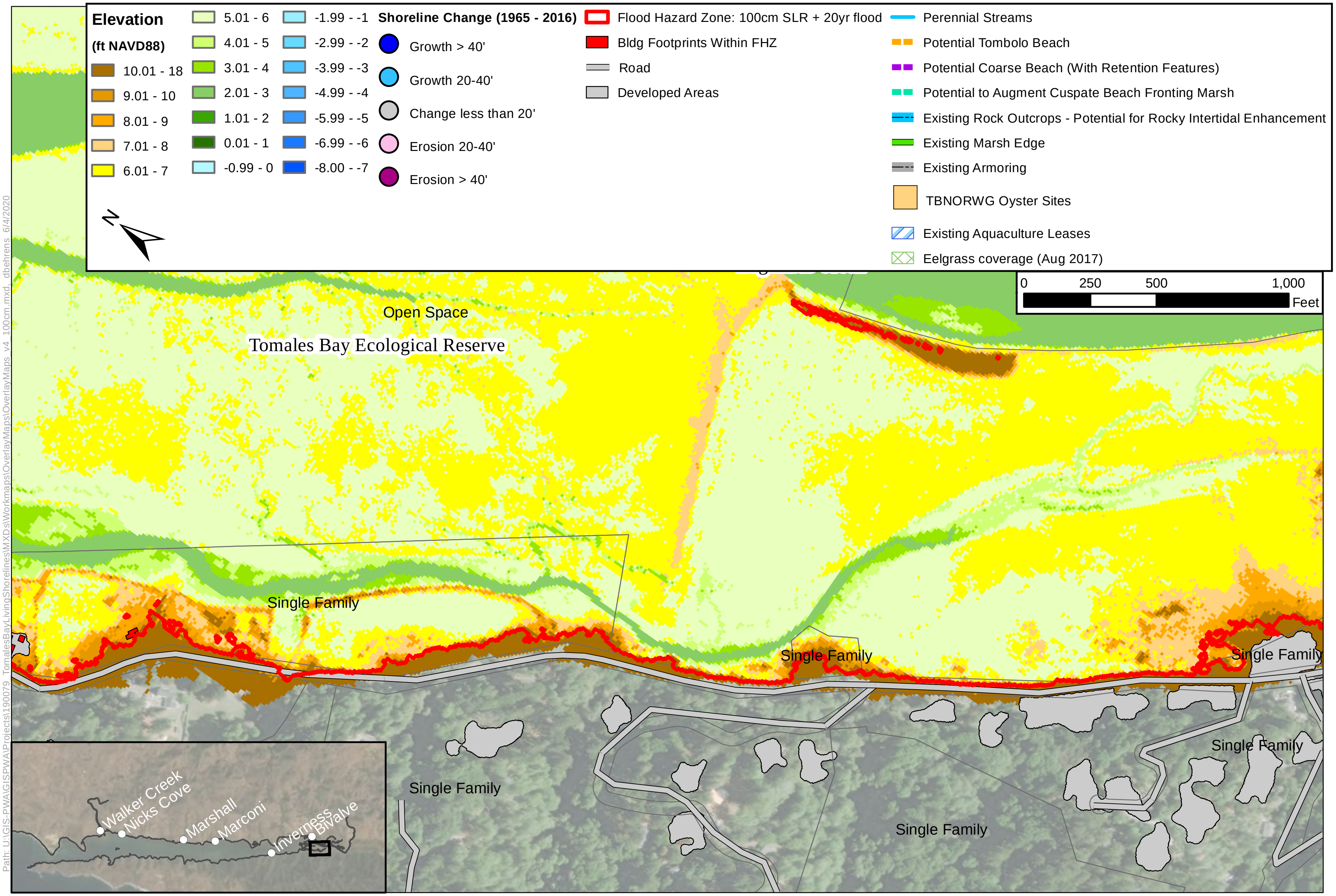

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Figure 25
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites

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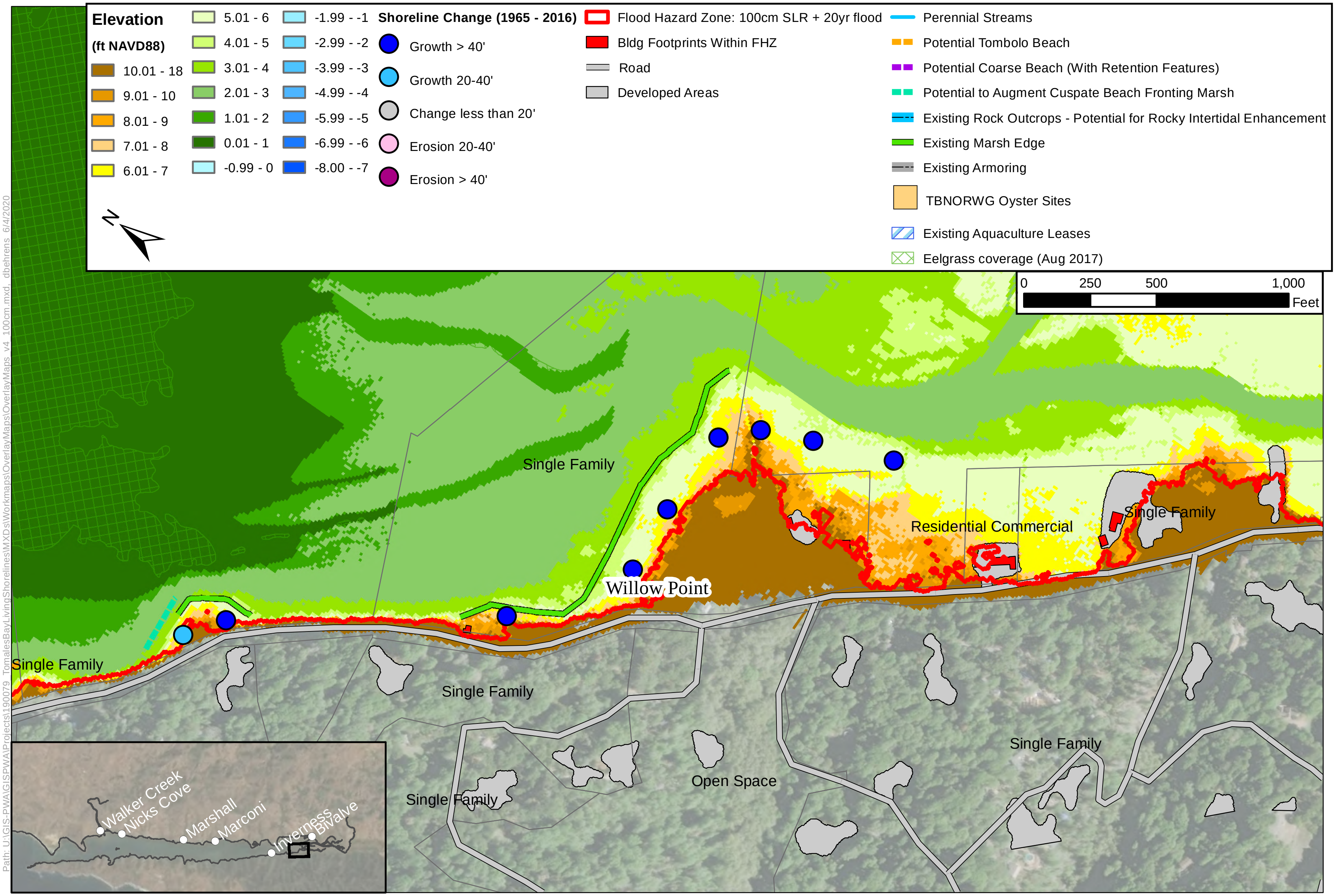

SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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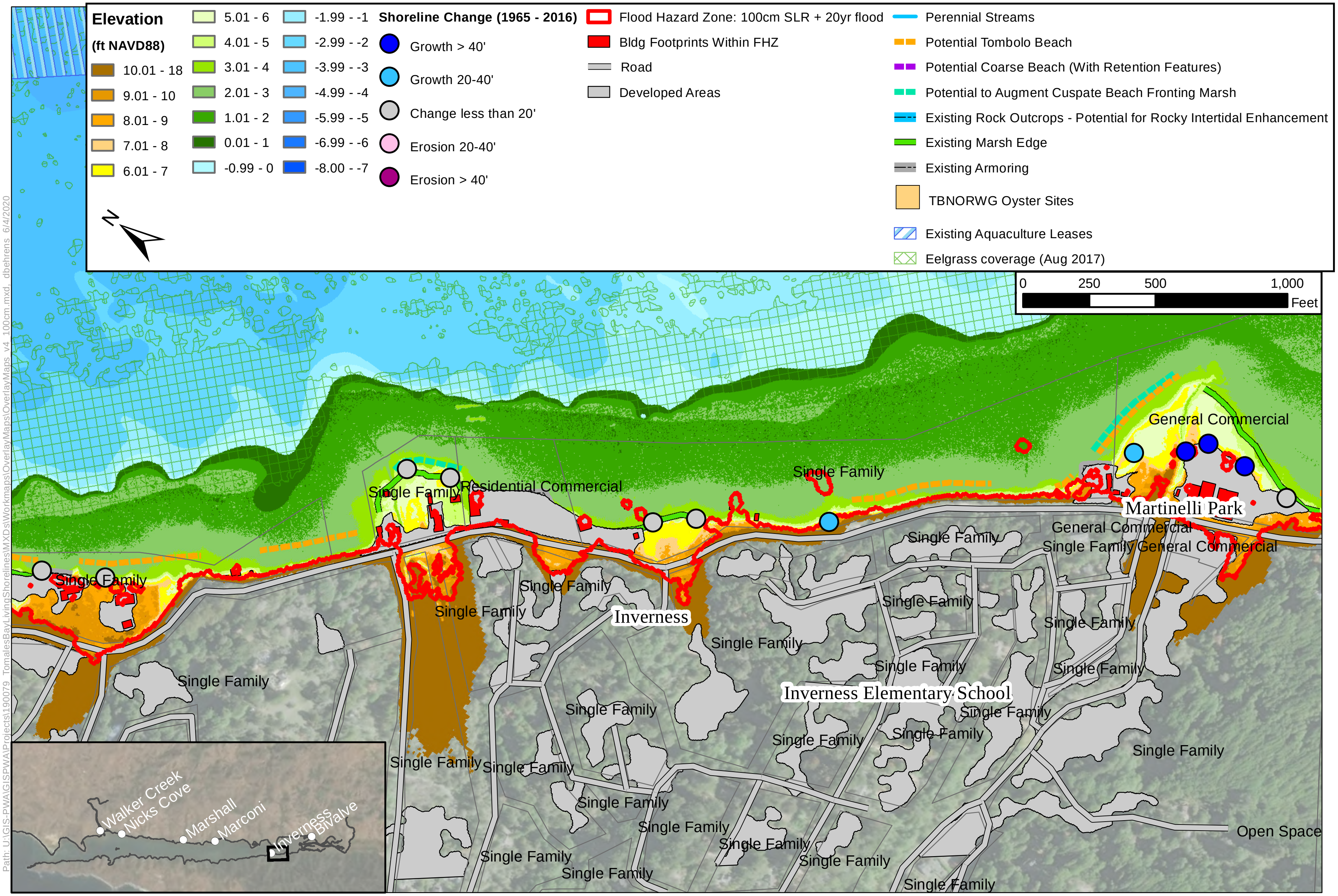
Figure 26
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites



SOURCE: Merkel & Assoc. (eelgrass); GFNMS (oyster layers); Marin County (Development layers, land use, geology, streams); USGS (flood hazard zones); GGNPC (elevations)

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Figure 27
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites

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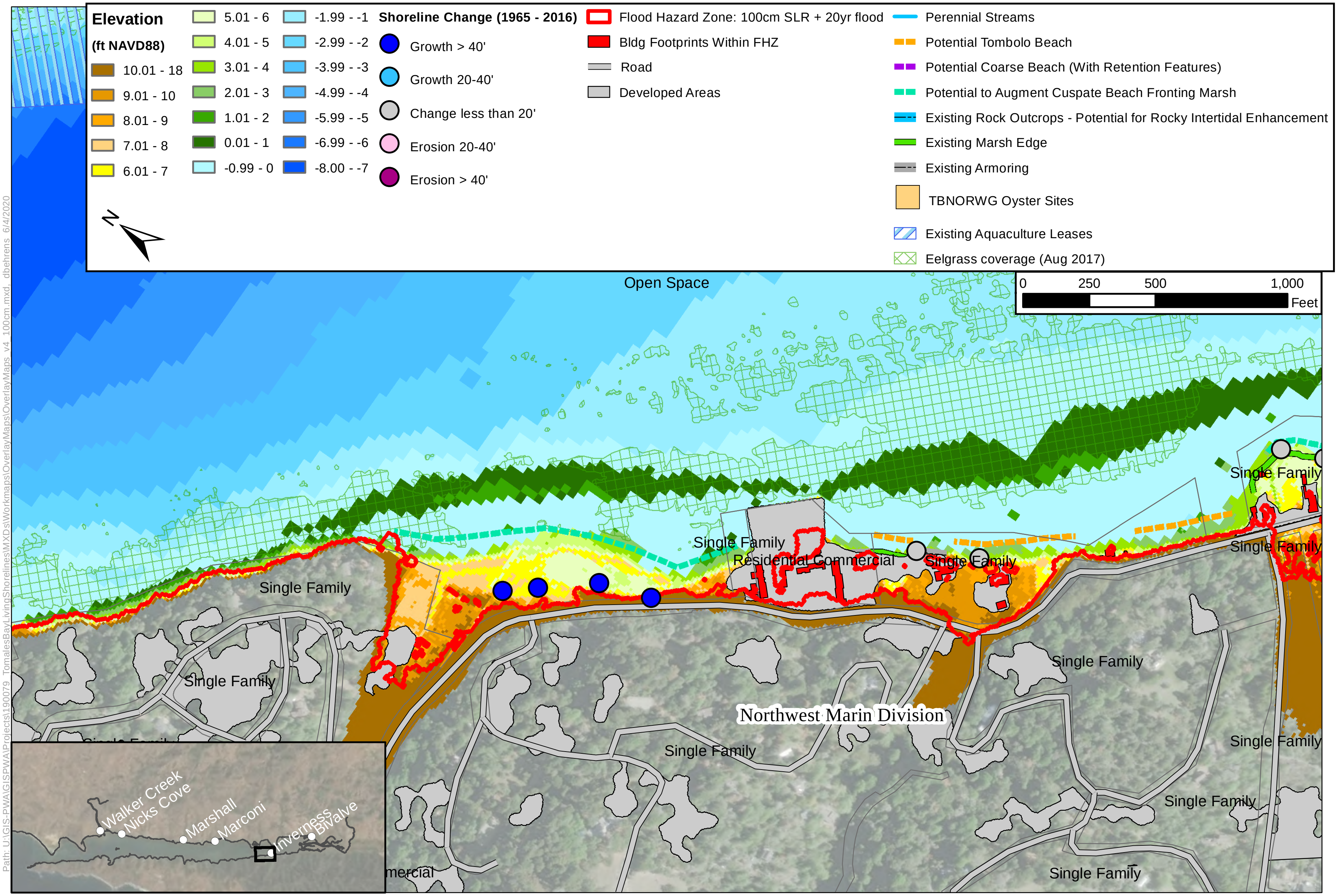

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Figure 28
Overlay Map of SLR Inundation Areas, Existing Features, and Potential Living Shorelines Screening Sites

Attachment F

Candidate Site Evaluation

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ESA 50 YEARS 1969-2019

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memorandum

date	October 28, 2020
to	Leslie Lacko, Jack Liebster, Marin County Community Development Agency
cc	
from	Dane Behrens, Environmental Science Associates
subject	Tomales Bay Living Shorelines Project: Draft Site Screening and Initial Evaluation

This memorandum was developed in summer and fall 2020, to inform the selection of priority sites for the Tomales Bay Living Shorelines Feasibility Project. The project team initially selected six candidate sites, and developed a series of sketches of potential site layouts (shown below) and discussed potential implications of implementing a living shorelines project at each site. This information is intended to assist the Marin County Community Development Agency (CDA) in selection of priority sites for further developing living shorelines concepts.

Contributors included Environmental Science Associates (Dane Behrens, Michelle Orr, Tiffany Cheng, Bob Battalio), Point Blue Conservation Science (Sam Veloz and Maya Hayden), Merkel and Associates (Keith Merkel and Whelan Gilkerson), Smithsonian Environmental Research Center (Chela Zabin), UC Davis (Edwin Grosholz, John Largier, Sam Winter), Peter Baye, and Bradley Damitz.

Methods

Defining the Project Boundaries

Prior to screening potential candidate sites, ESA worked with the Marin County Community Development Agency (CDA) to define a project area. The project area encompasses the developed shoreline of Tomales Bay - on the eastern shore of the Bay from Walker Creek on the north end to the Lagunitas Creek Delta on the south end, and on the western shore from Seahaven southward (Figure 1). The Bay shoreline near Dillon Beach is not included for this study, but will be assessed under 'next steps' as part of the final Feasibility Study Report. The Dillon Beach area geomorphology is influenced significantly by long-period ocean swell waves entering the mouth of the Bay, and would require more study to develop a separate set of adaptation measures specific to coastal geomorphology and processes.

Defining Project Timeline and Sea-Level Rise Scenarios

Based on coordination with the CDA in January 2020, the project will consider the 50cm (~1.6 feet) and 100cm (3.3 feet) sea-level rise horizons. This corresponds to a roughly 50-year planning horizon under different SLR risk scenarios, and is consistent with the parallel Stinson Beach Living Shorelines Feasibility Project. Sea-level rise hazard zones (modeled by the Coastal Storm Modeling System [CoSMoS][1]) were provided by the CDA for two cases: 50 cm + 20 year flood event, and 100 cm + 20 year flood event. Based on the most recent guidance from OPC (2018) at the Point Reyes location, these roughly correspond to the 'likely range' and '1-in-200 chance' of sea-level rise for the high emission, mid-century (2070) time horizon. They are also referred to as the 'low risk aversion' and 'medium-high aversion' scenarios, respectively.

Initial Screening and Selection of Candidate Sites

Sites were initially screened to identify locations with assets vulnerable to current or projected future wave action by creating a series of close-up maps of the Bay using geographical interface software (GIS), and including several overlays covering existing infrastructure, habitats, geology/geomorphology, and predicted sea-level rise hazards. This initial screening was used to identify sub-areas of the Bay where living shorelines may be feasible, of which ultimately 2-5 priority pilot project sites would be chosen for further analysis and conceptual design. Living shorelines entail use of natural habitats in shoreline management to achieve both physical and ecological outcomes. The following criteria were used in the screening:

- Presence of built and natural assets vulnerable to sea-level rise flooding hazards. Sensitive existing habitats vulnerable to sea-level rise (e.g. assets such as marsh areas) were mapped using information provided by the County and the Greater Farallones National Marine Sanctuary (GFNMS).

- Assets mapped as vulnerable were further assessed to identify whether wave action contributes to vulnerability. Assets vulnerable only to still water flooding with SLR were excluded from further consideration, as living shorelines suitable for Tomales Bay would be ineffective in addressing this type of vulnerability.

- Evidence of long-term shoreline erosion threatening natural or built assets. Erosion was mapped by digitizing the 1965 and 2016 shorelines and identifying rates of change in the position of the shoreline.

- Opportunities areas for removing shoreline armoring. Shoreline armoring was identified from oblique aerial images of the Bay obtained from the California Coastal Records Project.

Applying these criteria resulted in three areas being carried forward for further evaluation: (1) a 2-mile stretch of shoreline encompassing Nicks Cove and Blakes Landing, (2) a 3-mile stretch of shoreline from Cypress Grove to Marconi, and (3) the entire Inverness/Seahaven portion of the western shoreline (shown in Figure 1).

The Point Reyes Station area was screened out during this initial step as it is not shown to be vulnerable under the sea-level rise scenarios considered for this study. We also screened out a potential site in Hamlet (within the Walker Creek delta) at this stage. The existing tidal marsh at the site and a portion of Highway 1 behind it is expected to experience flooding from still water levels for the highest sea-level rise scenario. However, given its location within a creek valley, risk of long-term erosion is limited, as is the available space for implementing living shorelines approaches to protect the highway from flooding. Although future erosion is not predicted to be a major issue at this location, living shorelines would have a limited ability to address flooding from high tides alone (i.e. flooding caused in the absence of wind wave runup). The Lagunitas Creek delta was also screened out

[1] Additional information about the CoSMoS dataset can be found on the United States Geological Survey (USGS) website: https://www.usgs.gov/centers/pcmsc/science/coastal-storm-modeling-system-cosmos?qt-science_center_objects=0#

at this stage, as it appears to be expanding into the bay in the long-term, and living shorelines techniques would be redundant with the existing features of the site (active sediment supply, extensive and expanding marsh vegetation, and low-sloping upland transition areas).

The ESA team (including all subconsultants) reviewed these sites during a meeting on June 5th, 2020. Based on this meeting and further discussion of the subsequent weeks, six initial sites were selected. Sites were reviewed using overlay maps that graphically displayed the criteria listed above, and ultimately the six final 'candidate sites' were selected based on the need for sea-level rise protection and feasibility of living shorelines. The sites are described in the section below and are shown in Figure 2.

180 Grand Avenue
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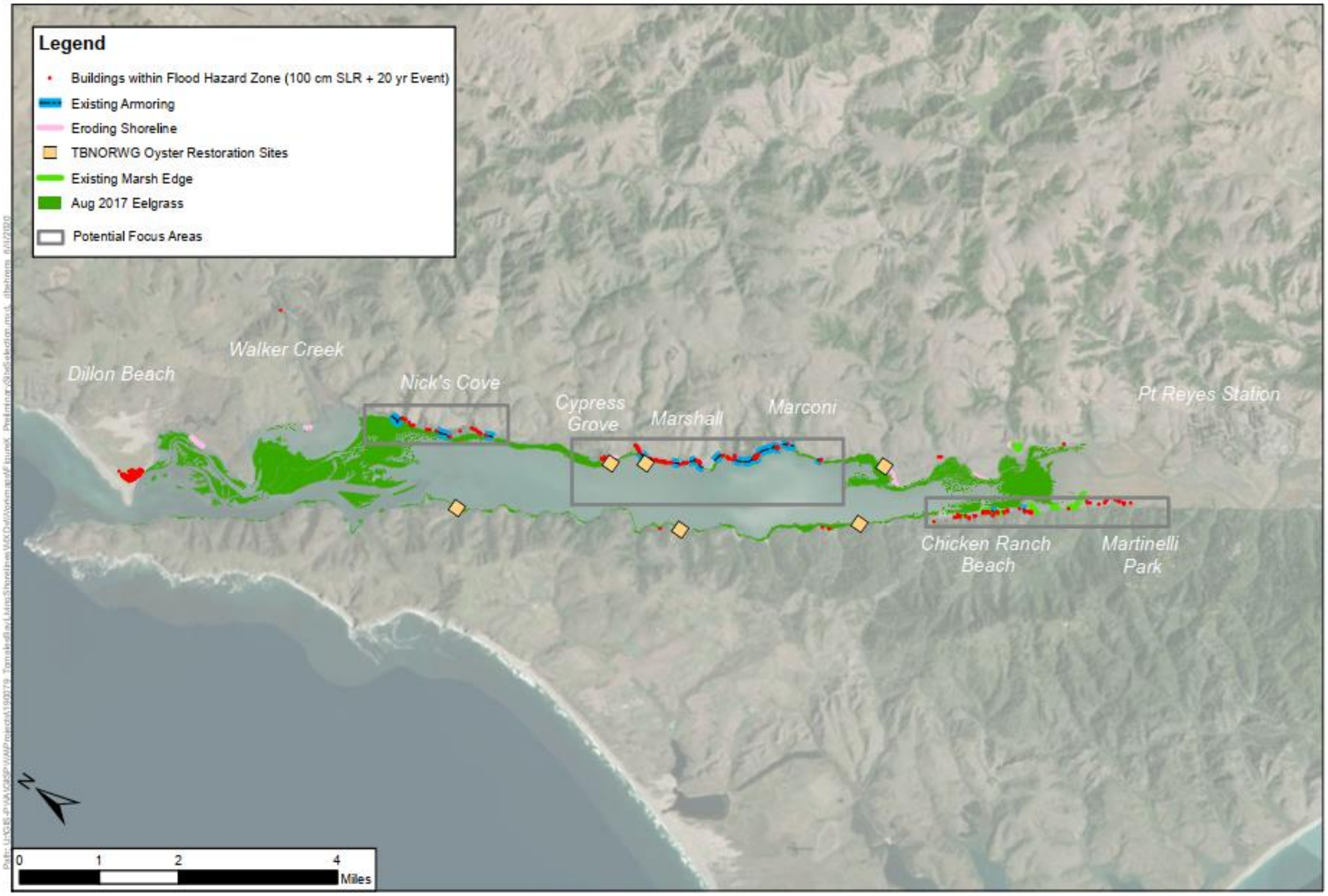

Tomales Bay Living Shorelines Feasibility Project – D201900079.00

Figure 1
Project area and initial focus regions

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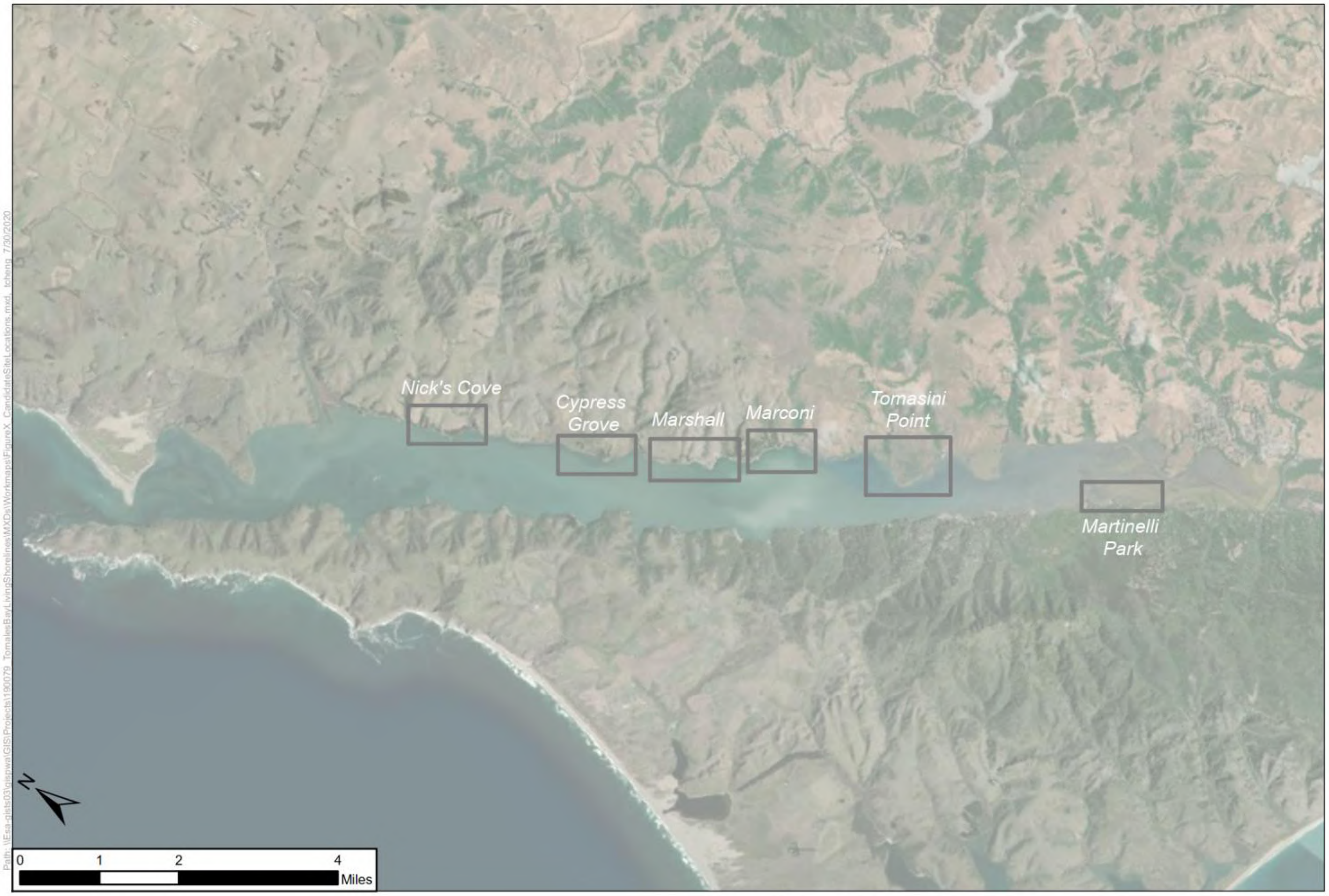

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Figure 2
Candidate sites considered for the feasibility study

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Candidate Sites

Candidate Site 1: Nicks Cove

The Nicks Cove candidate site (Figures 3a, 3b) encompasses about 2,000 feet of shoreline, including the Miller Boat Launch facility, the immediate shoreline to the north and south, and nearby commercial and residential properties. The launch facility is heavily used by the public as a popular kayak and fishing location. The nearby properties are inset within a small creek valley. The armored jetty in the center of the site blocks northerly waves from reaching many of these properties; however, the jetty crest shows signs of wave overtopping from prior extreme events. This is an indication that the jetty would become less effective over time at protecting infrastructure from wave runup with sea-level rise. Coarse (gravel and cobble) pocket beaches occur immediately north of the jetty and on the northern jetty face, and south of the jetty the local pocket beach at the creek mouth consists of fine- and medium-grained sand. The source of the coarse beaches to the north appears to be lag from the adjacent hillslope, but may have contributions from former railroad embankment material and existing riprap. The source of the sandy material to the south is likely the adjacent creek. The creek passes under Highway 1 via a corrugated metal culvert and discharges directly beneath the Nicks Cove Restaurant onto the sandy beach.

The main concern at the site is flooding of the local properties and roadway from a combination of high tides and wave runup. Eventual overtopping of the jetty will eliminate wind-wave protection to the properties to the south. The boat launch facility and parking lot flood due to high tides and wave runup for the 1.6 feet sea-level rise case, and the roadway and local structures along the road flood during the 3.3 feet case.

There is an opportunity to front the existing armoring along the jetty with coarse (gravel and cobble) material to form a beach berm. If given enough space, this could provide more adaptive capacity to long-term sea-level rise than the static jetty structure. This is because a coarse beach would be expected to respond to sea-level rise by moving upwards and inland over time. The upward shift provides more long-term adaptability (if given enough room for the beach footprint) than a static jetty or riprap shoreline. Offshore eelgrass beds provide a space constraint that would need to be more fully considered. In its present condition, there is adequate space for similar methods along the shoreline immediately to the north. A complementary approach could be to place a feeder beach near the northern edge of the parking lot and placing short wooden groins along the existing riprap and jetty to encourage entrainment and beach stabilization (Figure 3b). South of the jetty, the creek could provide an opportunity for creek-to-bay reconnection of sediment for the beach. If the creek is an insufficient supply, sediment obtained from elsewhere nearby could be opportunistically applied near the creek mouth to bolster the beach.

Ecological Considerations

- Ensure any action and additional large material placement will not negatively impact established eelgrass beds

- Replacement of rip rap with coarse gravel may reduce native oyster habitat.

- Drift sill could reduce area of intertidal beach habitat for invertebrates, fish, and fish-eating birds.
- Potential for increased use of coarse gravel areas by plovers, *Tringa* species, and potentially other shorebirds.
    - o Uncertainty: shorebird use will vary dependent on the material/sediment type and settling along the tidal gradient – smaller finer sediment will be attractive to a broader suite of shorebird species.
- Potential for native oyster establishment and habitat for herons, egrets, and scoters in the oyster restoration area.

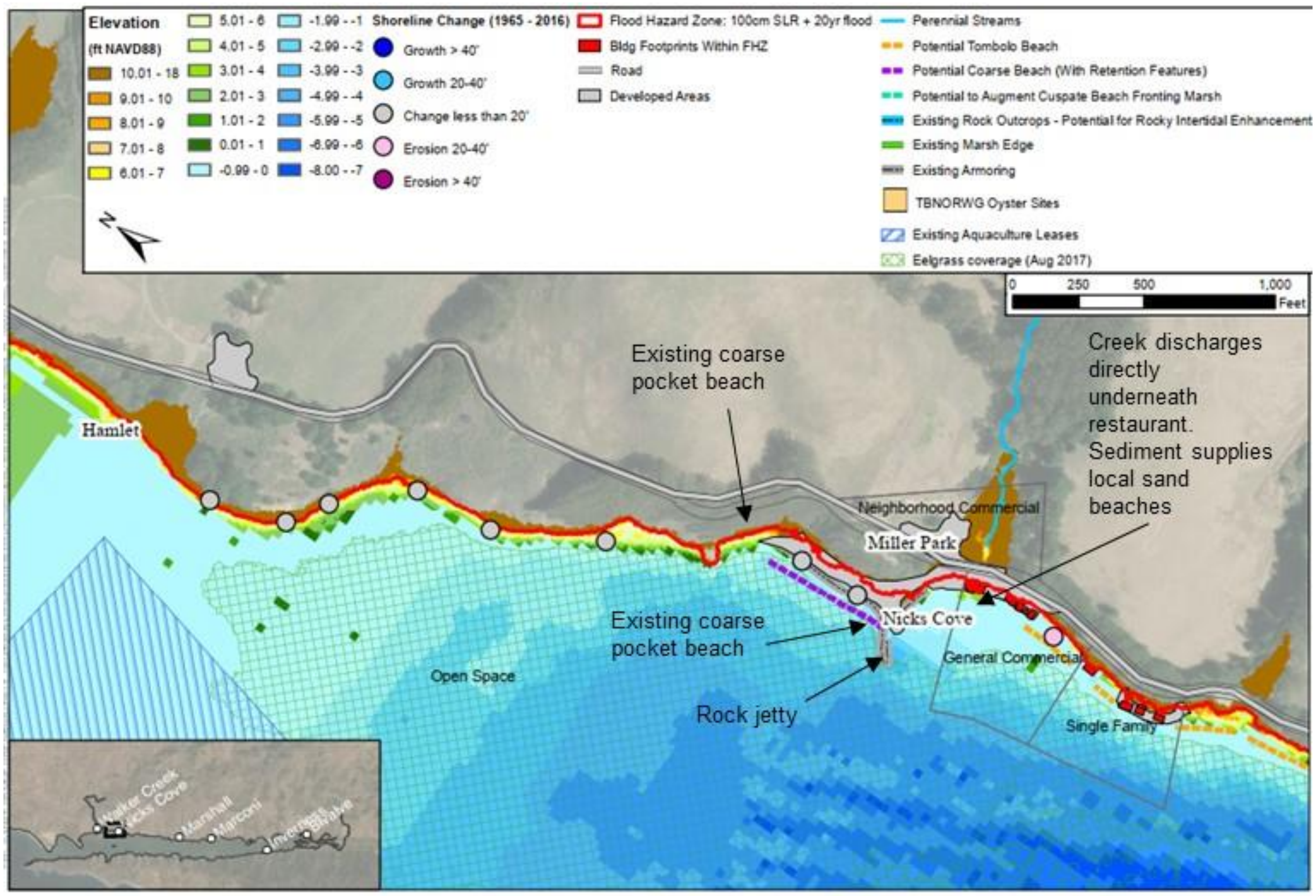

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Figure 3a
Nicks Cove detail map

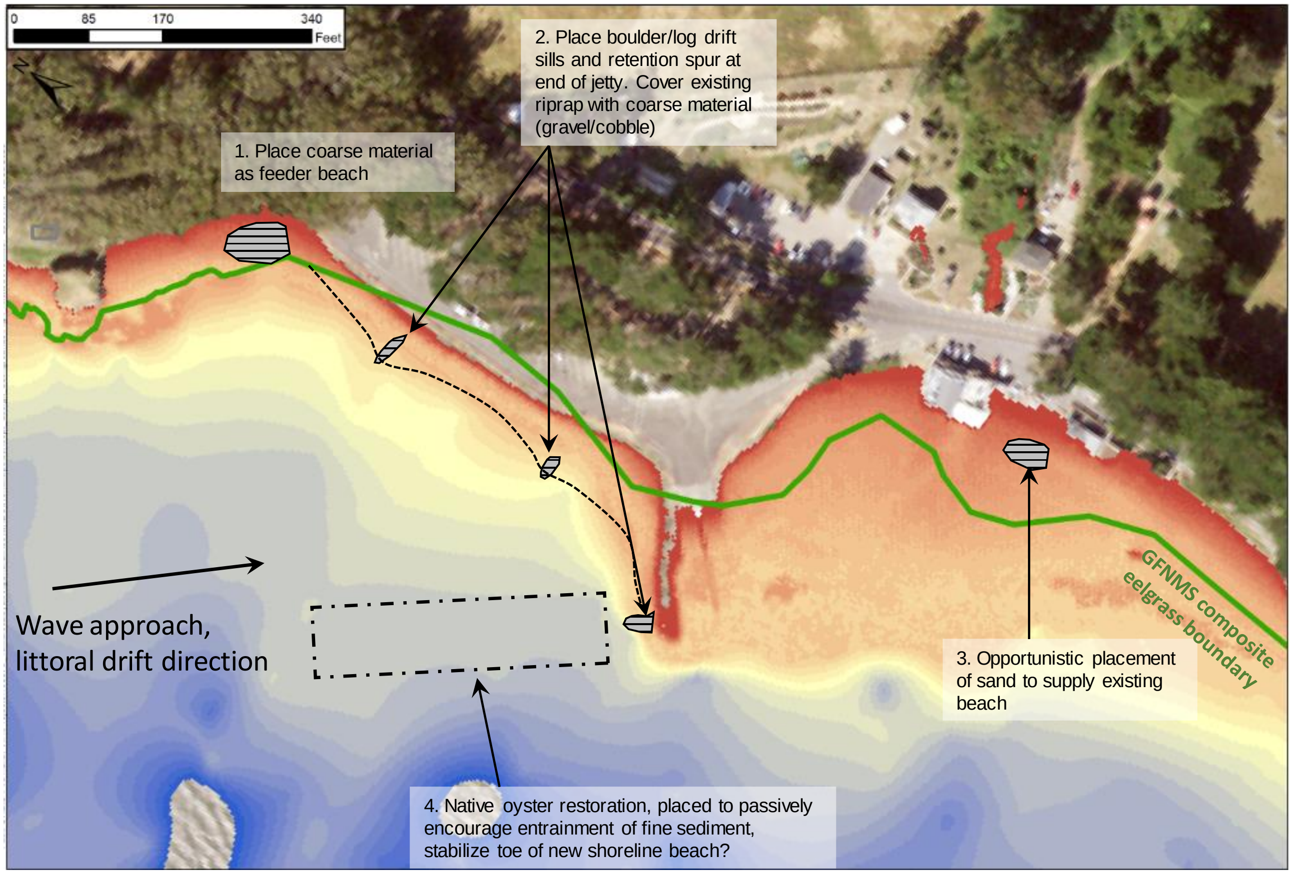

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Figure 3b
Nicks Cove detail map with possible concept design features

Candidate Site 2: Cypress Grove/ Livermore Marsh

The second candidate site includes both the Audubon Canyon Ranch Cypress Grove Research Center, a non-profit/educational facility on a promontory on the bay, the immediate updrift (north) and downdrift (south) shorelines, and the adjacent Livermore Marsh (Figure 4a). Much of the promontory consists of erodible sedimentary rocks and appears to be migrating southward slowly, as the northern shoreline has eroded significantly since 1965, while the southern end has accreted. The marsh is fronted by the former railroad berm, which was breached relatively recently in the 1990s. Prior to opening the marsh, available imagery suggests a series of sandy tombolo beaches fronted the facility on the north side, and these beaches have progressively eroded in recent decades. The main concerns at the site are continued erosion (threatening the Audubon Canyon Ranch facility), and the effects of erosion on the existing flood defense created by the dunes along the western edge of the facility. Flooding is predicted from high tides at both the 1.6 feet and 3.3 feet horizons for sea-level rise. Flooding has been documented during the 1982/83 and 1997/98 El Niño events, and some level of wave overtopping at the low point in the berm is observed during most king tide events. One of the proposed Tomales Bay Native Oyster Working Group (TBNORWG) oyster restoration sites is located immediately south of the peninsula.

Offshore eelgrass beds are present near the shoreline, which provide a space constraint for shoreline treatments. However, opportunistic sediment placement updrift and placement of retention features (e.g. logs supporting tombolo formation) could widen the beach along the northern edge of the site and mitigate some of the long-term erosion. On the south side, the eroded dunes could be restored to provide new habitat and protect against flooding in the short-term (Figure 4b). The existing man-made swale on the south side could be breached on the eastern side of the peninsula to create new back-barrier marsh and provide a mechanism for sediment accumulation in the long-term. Livermore Marsh is still evolving, and its influence on the supply of sediment to the site could be investigated in more detail. If Audubon Canyon Ranch is a partner in a project, this could assist in project readiness, implementation, and long-term monitoring. Audubon Canyon Ranch has shown prior interest in stabilizing this segment of the shoreline and addressing long-term flood vulnerability (PWA 2007).

Currently, the site is open to the public by appointment. The site's proximity to the Audubon Canyon Ranch could also be an opportunity if the organization is willing to be a partner on the project. This could help with the planning process and long-term monitoring of living shorelines at the site.

Ecological Considerations

- Ensure any action and additional large material placement will not negatively impact established eelgrass beds
- Construction from sediment and rock placement may cause short term disturbance and reduce eelgrass habitat, negatively impacting fish and diving duck (e.g. scaup and scoter) foraging opportunities
- Restoring dunes may increase habitat for migrant songbirds (e.g. American Pipit, Horned Lark) and shorebirds (e.g. Snowy Plover).
- Augmenting sediment to sustain tidal marsh habitat (3) and re-connecting the tidal lagoon (5) could provide habitat for Black Rail (state-listed threatened) and other tidal marsh associated bird species (e.g., Sora, Virginia Rail, Common Yellowthroat, Song Sparrow, Marsh Wren).
- Allowing a sloped habitat transition from tidal lagoon to dune could provide habitat for Savannah Sparrows and refugia for rail species
- Relocating buildings (6) would increase shoreline foraging habitat for shorebirds (e.g., Black Turnstones and Spotted Sandpiper in rocky areas, *Calidrid* sandpipers in gravel and sandy areas).
- Potential for native oyster establishment and habitat for herons, egrets, and scoters in the oyster restoration area

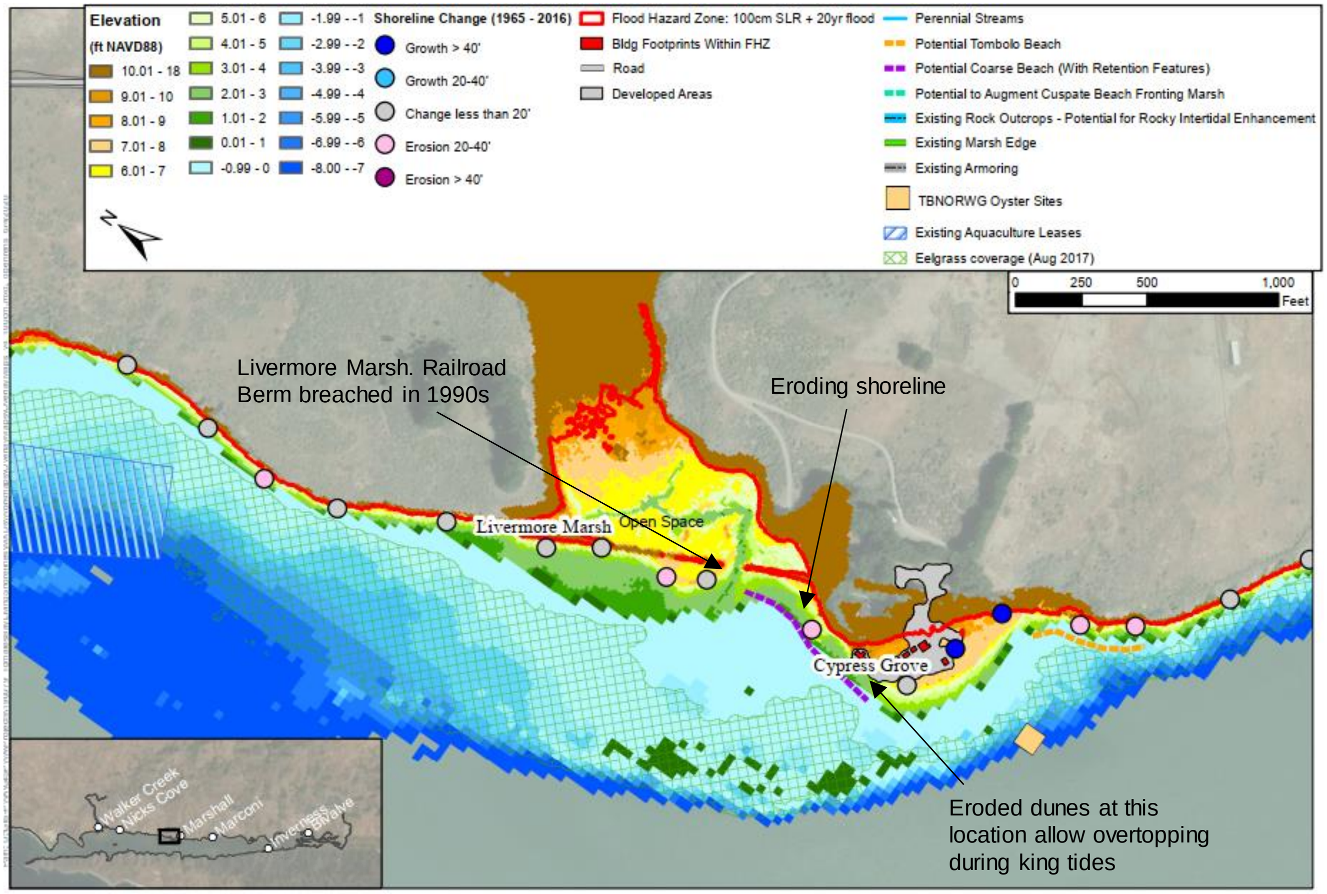

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Figure 4a
Cypress Grove detail map

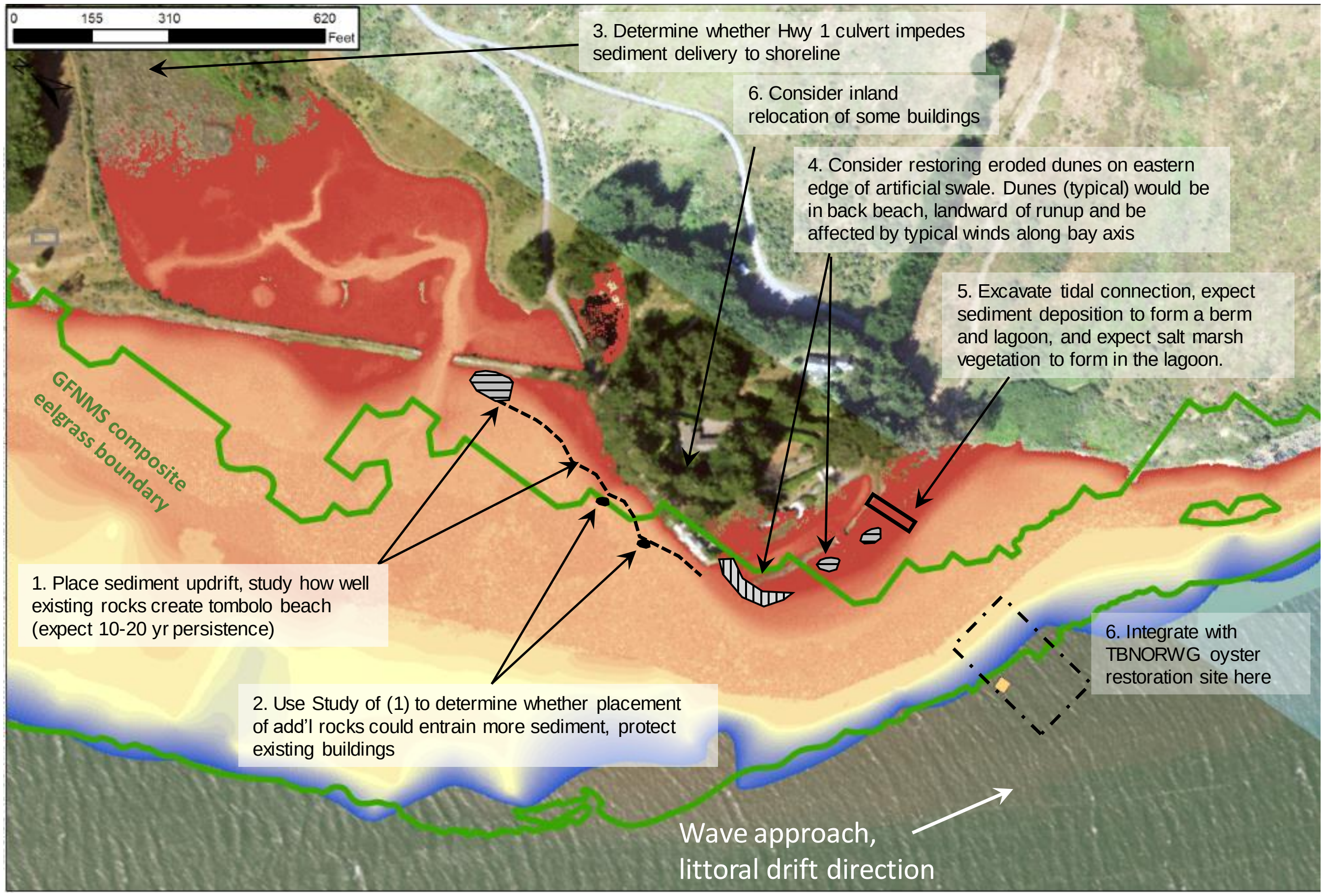

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Figure 4b
Cypress Grove detail map with possible concept design features

Candidate Site 3: Marshall near Hog Island Oyster Company

The third candidate site is located immediately south of the Hog Island Oyster Company (HIOC), along the southern shoreline of the embayment for a small creek (Figure 5a, 5b). The roadway here has a narrow shoulder and is protected by riprap along the shoreline. Boulders along the shoreline have created small coarse (gravel) beaches pocket beaches that are drowned above mean sea level. The site does not appear to have eroded since 1965, but nearby residential and commercial properties are within the flood hazard zone (from combined tides and wave runup) for both the 1.6 feet and 3.3 feet horizons for sea-level rise. This site is within the 'Marshall Mile', identified in the County's C-SMART vulnerability assessment as a site of concern. A row of houses south of the embayment are built over the water and appear to be especially exposed to flood risk in the future. The site is also the location of a proposed TBNORWG oyster restoration site.

The underlying concern at the site is future wave runup onto the roadway, flooding of roadside properties from high tides, and exposure of properties to the east to wind-waves with sea-level rise. The shoreline includes areas where former foundations and retaining walls over the water create an artificial littoral barrier and an artificially steep profile, which could eventually create conditions for wave reflection and future erosion along the toe of the roadway embankment.

Working within the site space constraints, the site could potentially accommodate a coarse berm that could be created by opportunistically placing coarse (gravel and cobble) material on the existing riprap, and grading back parts of the shoreline that include former building foundations. This would ‘soften’ the shoreline profile, creating a more natural transition, and could be stabilized at the toe with rocky features placed to enhance native oyster habitat. These changes would come with the risk of impacting offshore eelgrass, as would passively encouraging wider beaches with new retention features that could take advantage of the potential creek sediment supply updrift of the site. Any shoreline features that influence local sediment movement should consider the effects on sediment supply to the exposed houses immediately to the south. Given its location in the middle bay (identified by TBNORWG as being more suitable for native oysters), the site could be appropriate for tying together rocky intertidal and oyster restoration measures with features at the shoreline. However, given the steep dropoff of the mudflat at the site, it is unclear if these measures would provide major infrastructure protection benefits to the site, as predicted flooding corresponds to extreme high tide events.

Ecological Considerations

- Ensure any action and additional large material placement will not negatively impact established eelgrass beds

- Potential for native oyster establishment and habitat for herons, egrets, and scoters in the oyster restoration area

- Increase in coarse beach habitat from actions (1 and 2) may benefit shorebird species (e.g., Killdeer, Spotted Sandpiper).

- Protecting and encouraging the expansion of a softer transition incorporating native eelgrass beds and wave-protected areas could increase foraging for wintering diving ducks (e.g. Scaup and scoters)

- Uncertainty: shorebird use will vary dependent on the material/sediment type and settling along the tidal gradient – smaller finer sediment will be attractive to a broader suite of shorebird species

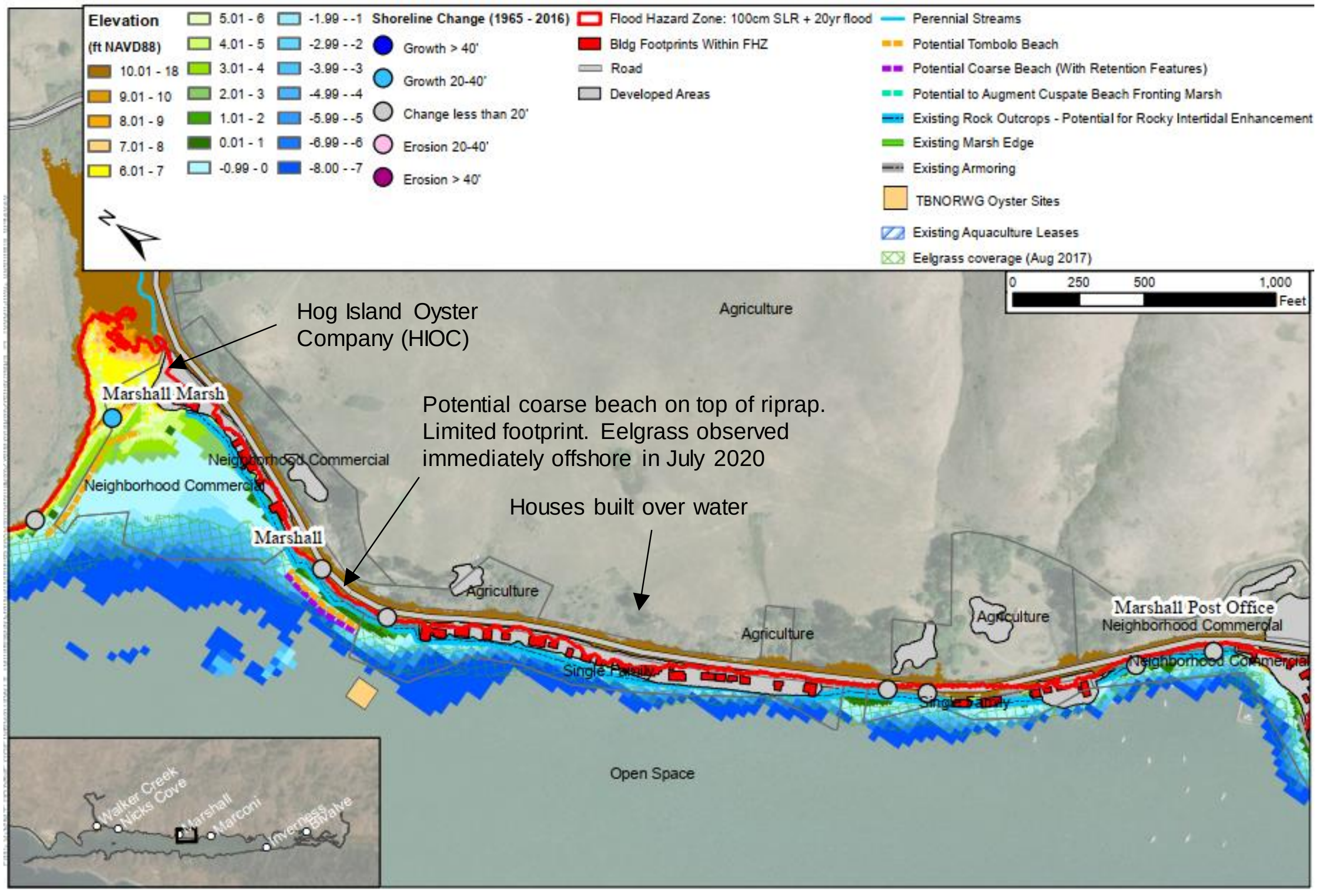

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Figure 5a
Marshall detail map

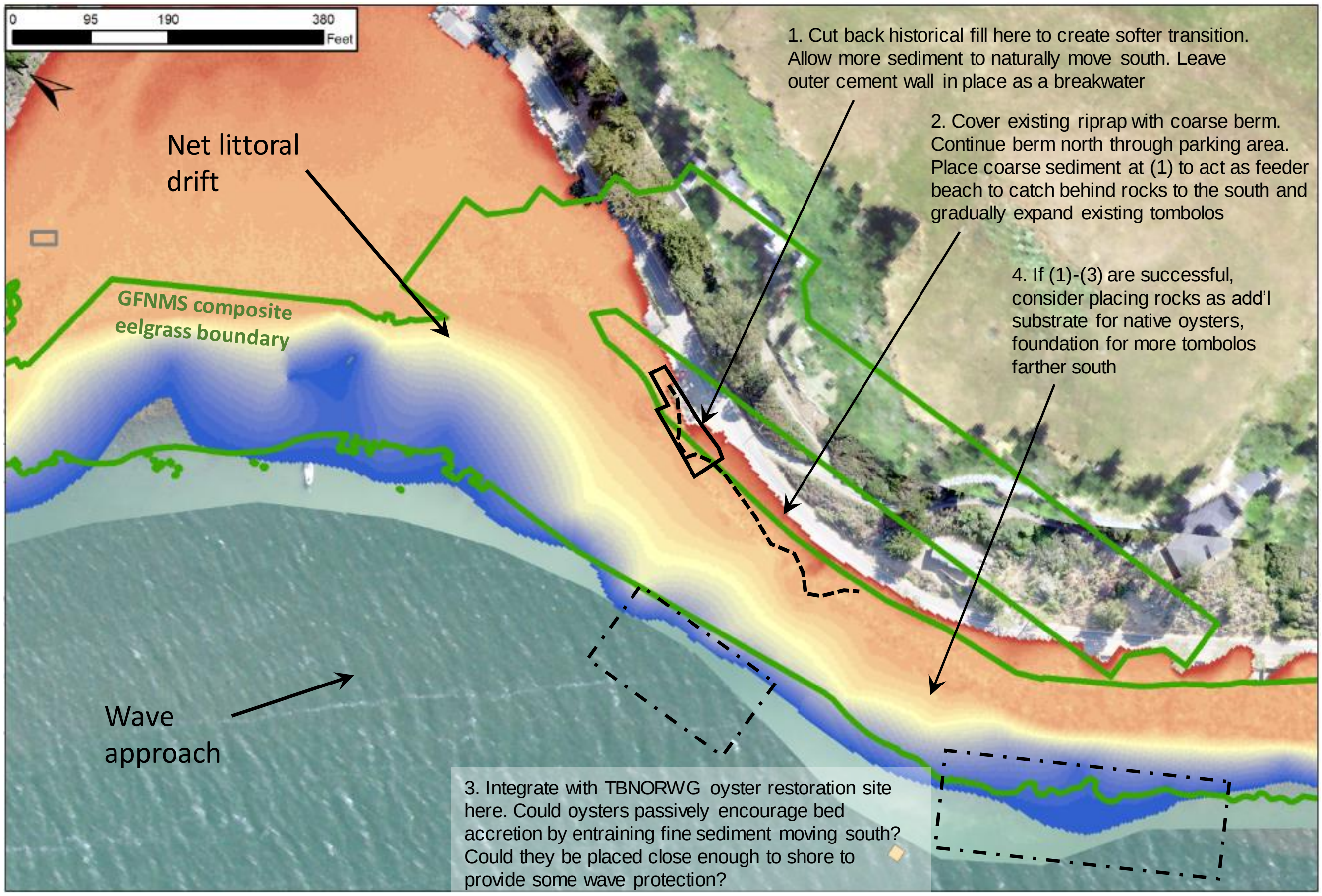

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Figure 5b
Marshall detail map with possible concept design features

Candidate Site 4: Marconi near Conference Center

The fourth candidate site consists of about 4,000 feet of shoreline adjacent to the Marconi Conference Center, immediately south of a small headland (Figure 6a, 6b). Most of the shoreline is drift-aligned and armored by riprap, and is interrupted by a developed promontory that includes several commercial and residential structures. Historical maps and photographs suggest the promontory is a natural geological feature that was present before modern times. The shoreline does not appear to have changed significantly since 1965. The main underlying concern at the site is flooding of properties and the highway from combined high tides and wave runup. Several residential buildings and a small portion (250 to 300 feet) of the roadway is in the flood hazard zone for 1.6 feet of sea-level rise, and this zone expands to include several commercial properties and a greater length of the highway for the 3.3 feet case.

Since the shoreline is currently armored, and flooding from high tides and wave runup are predicted despite this, the measure with the highest chance of mitigating flooding would be the placement of a coarse beach fronting the armoring. This would present an opportunity to improve shorebird habitat at the site and incorporate more public access elements (current access is via parking on the road shoulder and walking to the existing gravel-lag beach below the riprap when it is exposed at low tide). Alternately, sediment could be placed in a series of feeder beaches on either side of the promontory and allowed to drift east over time. This could provide a more passive method for softening the shoreline. A beach placed at the segment of roadway most at-risk of future flooding could be stabilized at its toe by placing several offshore boulders and to capture sediment drifting east.

the presence of eelgrass very close to the shoreline limits the space available for this type of measure. The existing armoring will eventually become a wave-reflective shoreline with sea-level rise, causing increased erosion and high turbidity along the shoreline, complicating the future eelgrass habitat in a future without project.

Ecological Considerations

- Reduced eelgrass habitat from placed materials in (1) may negatively impact fish and diving ducks.
- Potential for native oyster establishment and habitat for herons, egrets, and scoters in lower intertidal areas with coarse material placement.
- Potential for increased mudflat habitat behind placed materials (1) would benefit different shorebird species (e.g., Marbled Godwit, *Tringa* shorebirds, *Calidrid* sandpipers) depending on substrate elevations and sediment/material type.

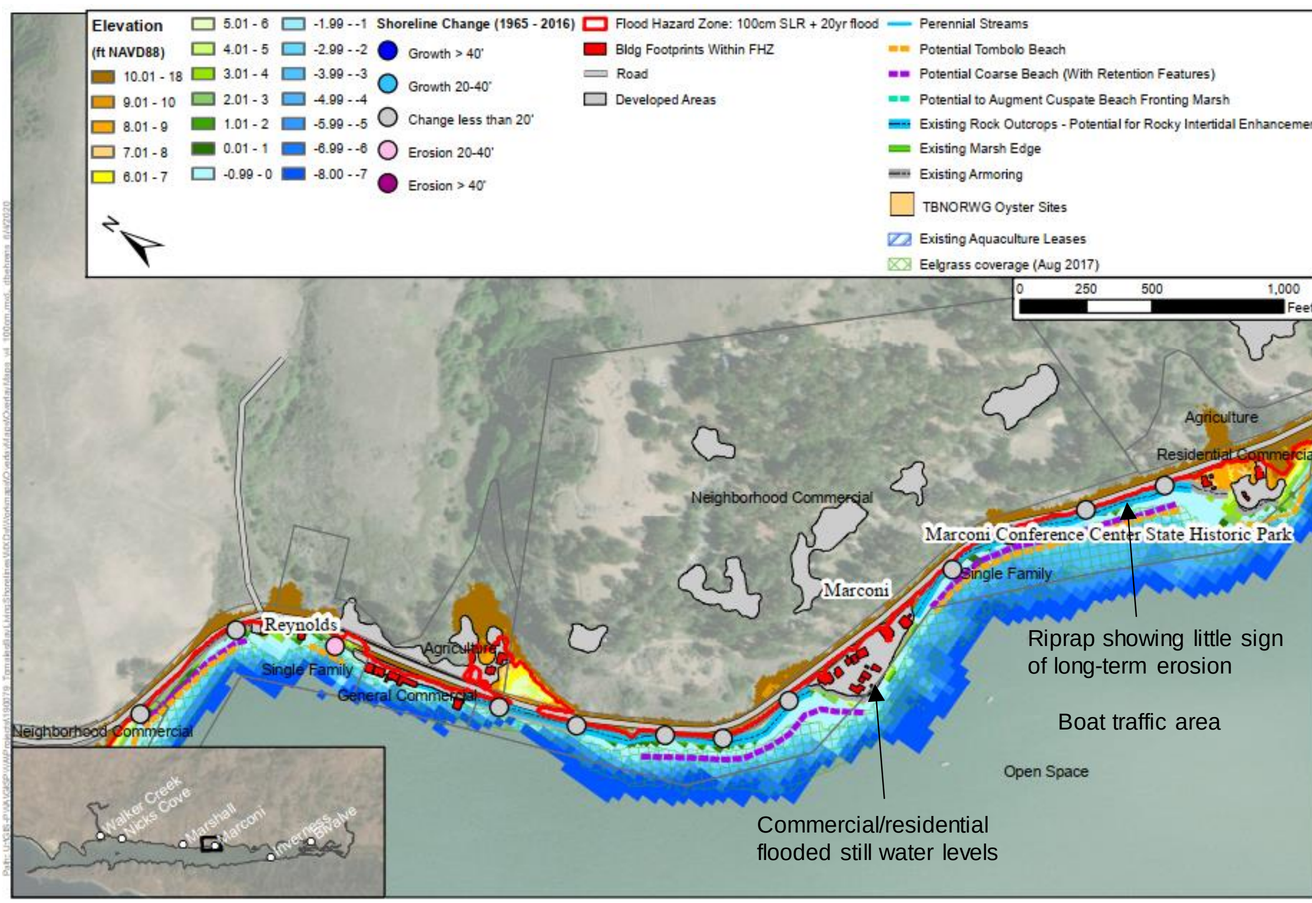

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Figure 6a
Marconi detail map

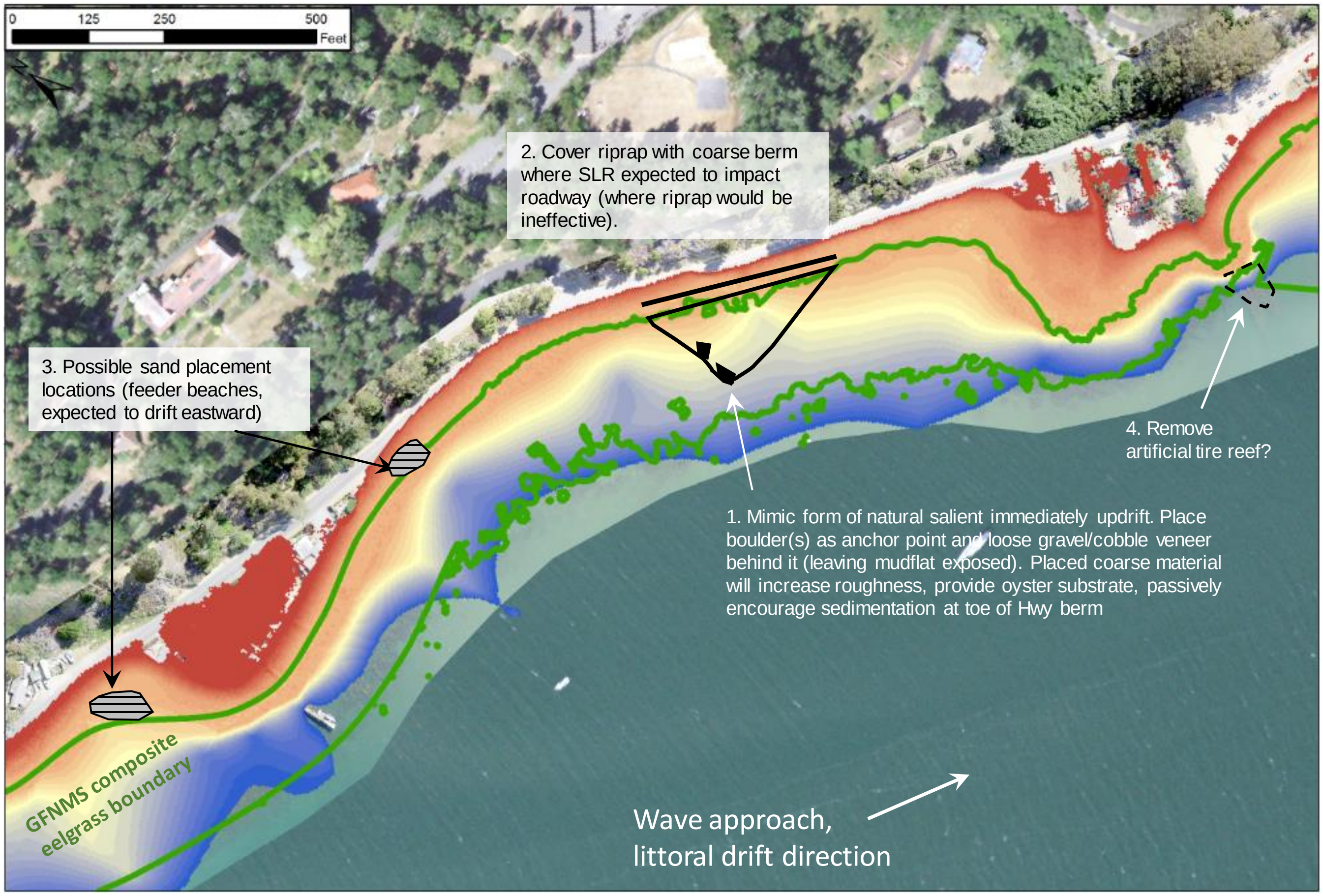

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Figure 6b
Marconi detail map with possible design concepts

Candidate Site 5: Tomasini Point

Tomasini Point is a sandy headland at the southern edge of the middle bay. The northern half of the peninsula (Figure 7a) is exposed to wind-waves, includes a large swash-aligned beach and back-barrier estuary, and has experienced significant shoreline erosion since 1965. The southern half (Figure 7b) is less-exposed, but the shoreline is also mobile and the Tomales Bay Oyster Company (TBOC) facilities are within the flood hazard zone from high tides and wave runup for the 1.6 feet and 3.3 feet sea-level rise horizons. This candidate site includes two alternate locations, the northern shoreline and bar-built estuary, and the TBOC site. The northern edge of the peninsula includes one of the proposed TBNORWG oyster restoration sites, and has also hosted commercial oyster farming activities immediately offshore for many decades.

While addressing the erosion of the northern shoreline would improve resilience of the existing tidal estuary there, the site currently has room to migrate upland with sea-level rise. The site also does not include built infrastructure within the flood hazard zones considered for the study.

On the southern end, addressing the flooding hazard at TBOC could include a number of measures given the low slope of the shoreline. A small tidal marsh is present next to TBOC at the terminus of a creek that runs underneath Highway 1. This connection could be investigated as a potential local supply of sediment for living shorelines enhancements along the shoreline. However, since the site is not exposed to significant wind-wave fetches, flooding from tides will be difficult to mitigate. A more effective long-term plan would likely require moving some facilities out of the flood hazard zone.

Ecological Considerations

- Loss of tidal marsh (absent sufficient sediment delivery from alluvial or artificial processes) will negatively impact tidal marsh associated bird species (see spp previously listed) and reduce foraging, spawning, and rearing habitat for fish.

- Any existing riparian and coastal scrub areas upslope from the tidal marsh may be negatively impacted with increases in ground and surface water salinity. SLR may outpace the riparian and coastal scrub's area's ability to migrate upslope which is also impeded by Hwy 1.

- Aside from potential restricted movement towards Hwy. 1, if tidal marsh has expansion space to move upslope with SLR, continued use will occur from tidal marsh species (rails, Song Sparrow, Marsh Wren, Common Yellowthroat)

- Allowing for native plant establishment in transition areas from tidal to upland may attract Savannah Sparrows and Northern Harriers

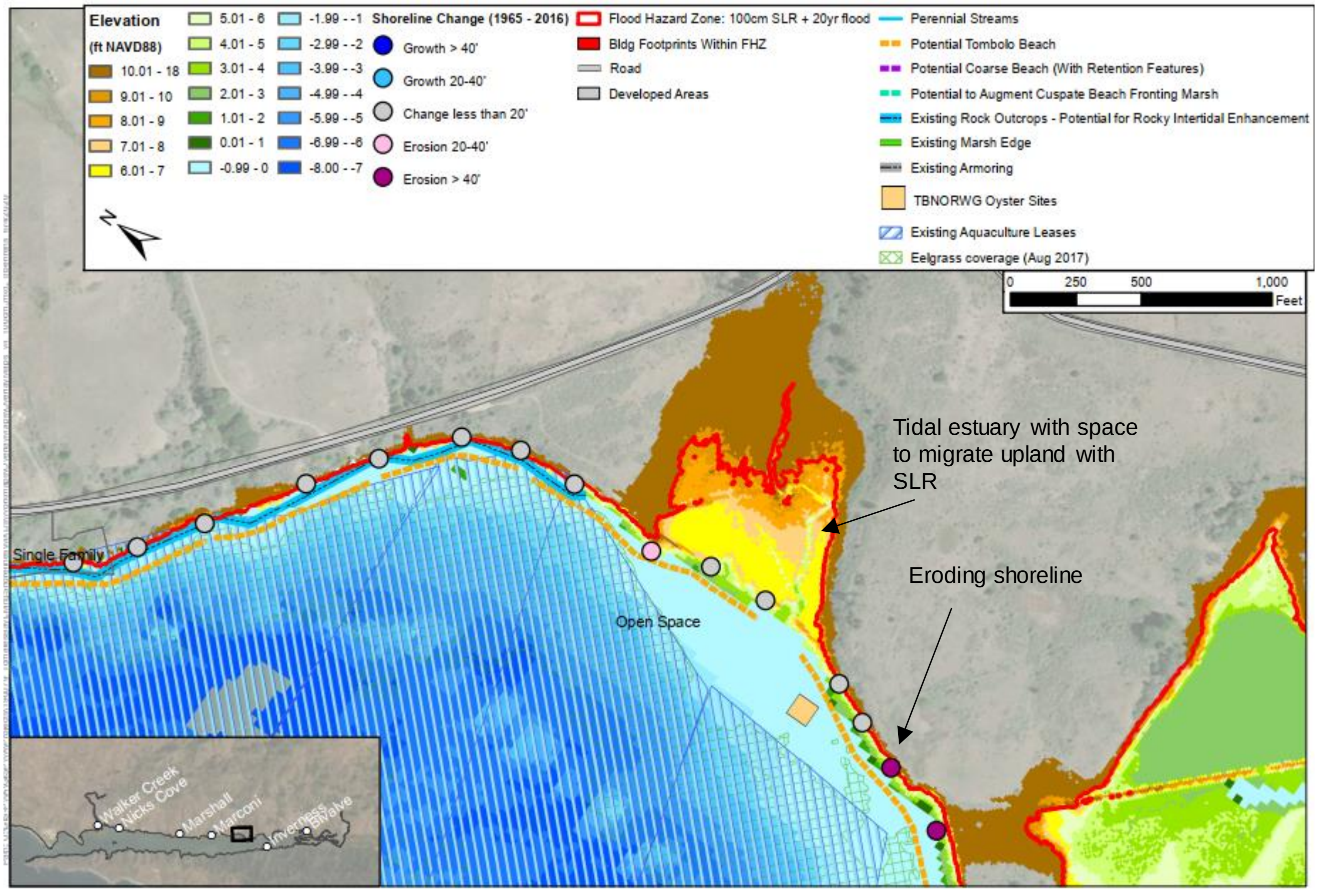

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Figure 7a
Tomasini Point detail map #1

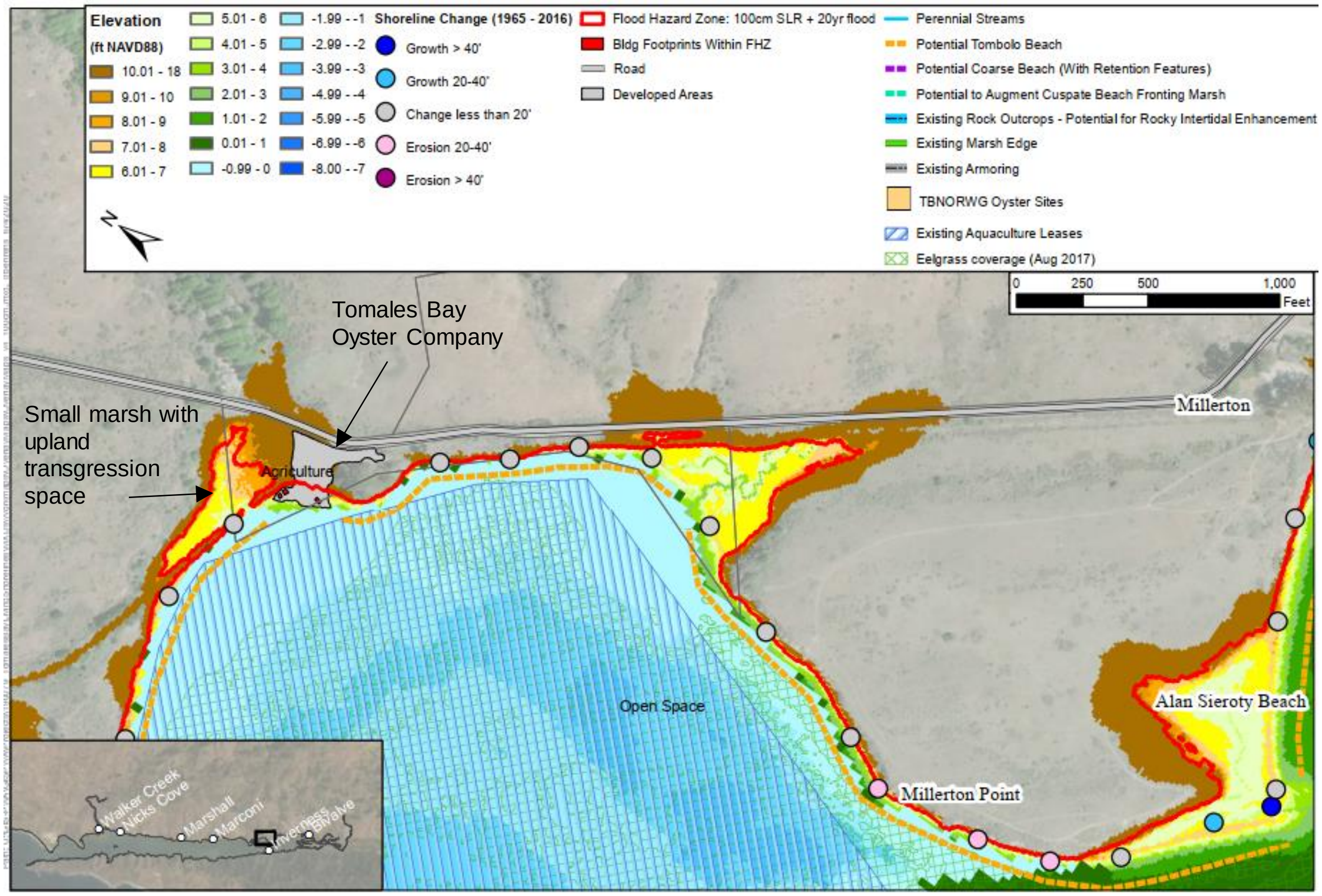

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Figure 7b
Tomasini Point detail map #2

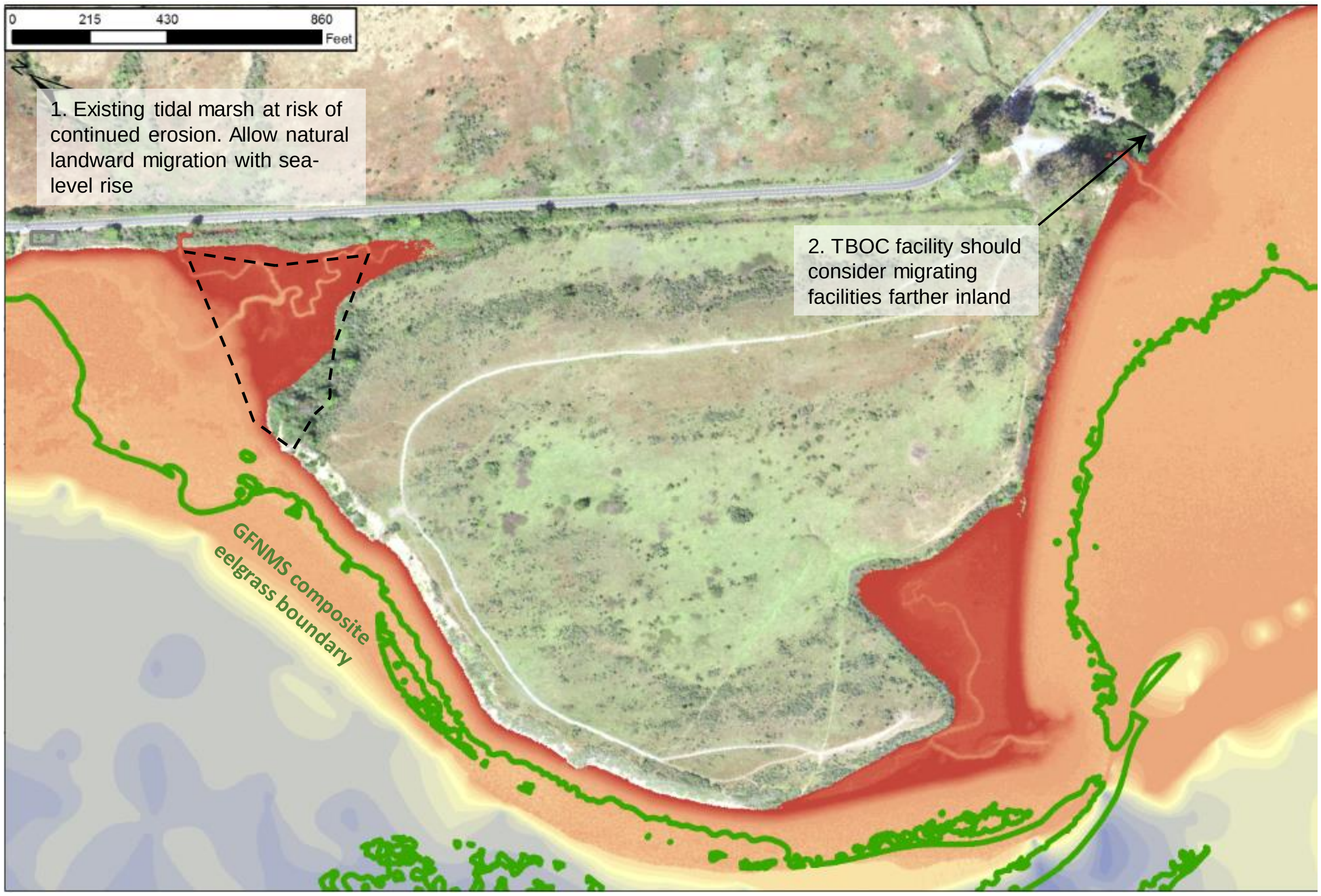

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Figure 7c
Tomasini Point detail map with potential design concepts

Candidate Site 6: Martinelli Park

The final candidate site includes Martinelli Park and the shorelines immediately to the north and south, in Inverness (Figure 8a, 8b). Most of the site consists of a prograding creek delta backed by Sir Francis Drake Boulevard and with commercial structures built onto the historical delta. Historical images suggest long-term progradation of the delta since 1965, but this may not tell the whole picture, as eroding dock piers at the Dancing Coyote resort immediately to the north may suggest that localized erosion may be possible in some areas near the site (i.e. that the overall trend may not be towards accretion in all areas). As with other sites along the Bay, the site is known to have experienced severe flooding during the 1982/1983 El Niño winter and in the winter of 2005 (pers. comm. M. Sutton). The main underlying concern at the site is combined tidal and wave runup flooding of the commercial buildings on the creek delta, and also of the roadway behind it. Commercial buildings and the roadway are vulnerable at both the 1.6 feet and 3.3 feet sea-level rise horizons.

The site has low topographic relief offshore, which presents the opportunity to integrate several integrated living shorelines approaches that could achieve the main goal of limiting flooding from wave runup on the creek delta buildings and roadway. The southern (wave-shielded) portion of the delta has no beach and emergent cordgrass along a wide-muddy offshore slope toward the leading edge of the Lagunitas Delta. Planting cordgrass could be investigated as an experimental approach to encourage sediment recruitment (to increase roughness and mitigate wave energy at mid- and low-tides). The northern half of the delta has a sandy beach fronting a back-barrier saltmarsh. The beach morphology appears to be influenced by localized retention and wave refraction effects from a few isolated stands of cordgrass and the historic shipwreck at the mouth of the creek. The beach was observed to form relatively rapidly after the introduction of the littoral barrier created by the shipwreck (pers. comm. M. Sutton). Compared to most of the east shore sites, this site is less suitable for native oyster restoration given its location near the southern end of the bay.

The creek delta may at one time have had more active sediment distribution (through cycles of channel erosion during floods, subsequent migration, and abandonment/new channel formation during later storms), but currently the creek channel exits the delta in a central location, and may have been locked in place by sediment placement on the channel berms to limit migration. The channel's riparian corridor on the delta both upstream and downstream of Sir Francis Drake Boulevard includes non-native vegetation that appears to add significant roughness to the channel and may influence sediment delivery to the edge of the delta. Long-term flood control measures on the creek performed by the County of Marin could be considered and incorporated into a plan for distributing flood sediments along the delta in a way that preserves the existing beach. Opportunistic placement of sandy sediment updrift could also mitigate long-term losses of supply, and additional retention features (logs groins or similar) could add to retention at the site. The buildings on the delta and the road could be protected from still water flooding by raising the existing earthen berm and trail, and from some of the wave runup during the highest tides, and including a flatter slope down to the marsh and cordgrass transition where possible. Additionally, portions of the berms fringing the main channel could be notched, to allow deposition of sediment to the marsh area to the south or to the mudflat to the south, to encourage long-term sedimentation.

Project readiness will depend on the willingness of local commercial entities to partner in the planning process, as well as other stakeholders in Inverness. The project could tie into work to upgrade public access and stream maintenance efforts. Permitting considerations will depend on the types and extents of living shorelines methods applied (ranging from planting to raising trails and modifying the creek channel).

Ecological Considerations

- Planting cordgrass (5) carries risk of contamination with hybrid forms. Consult with State Coastal Conservancy's Invasive Spartina Project before develop plans to restore cordgrass.

- Non-native vegetation removal may cause temporary disturbance to the habitat and bird species. Vegetation removal during the songbird breeding season (April- July) will negatively impact bird nesting including neotropical migrant species (e.g., Warbling Vireo, Black-headed Grosbeak, Wilson's Warbler) and should be avoided.

- Regrading tidal marsh-upland transition zone may benefit tidal marsh species (see spp listed previously). Planting newly established tzone slope with plant species that provide dense cover within at least 30 cm of the ground will increase tzone habitat value for tidal marsh and other birds species

- Notching the channel's south berm (4) may increase channelization which will benefit Song Sparrow, Common Yellowthroat and rail species.

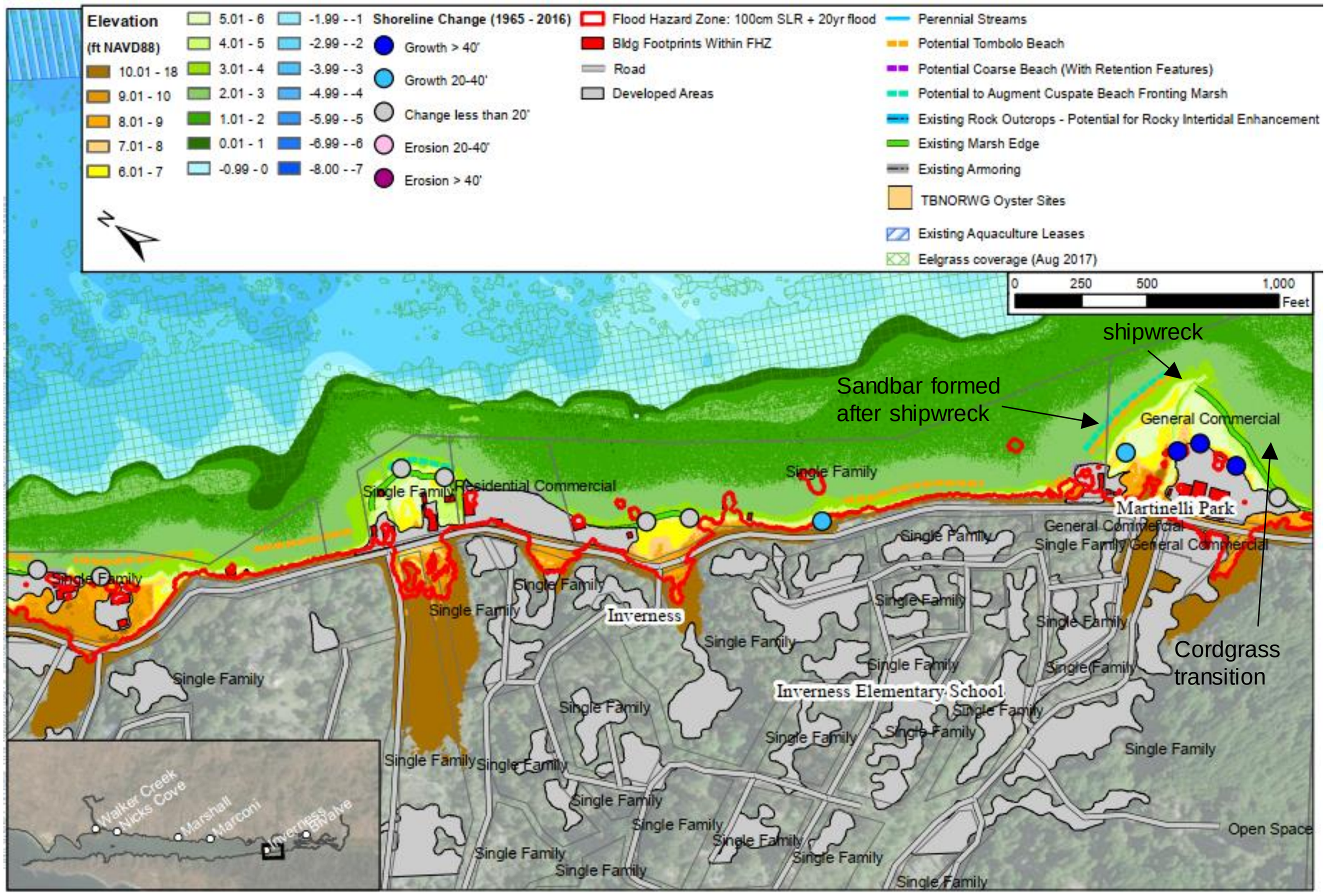

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Figure 8a
Martinelli Park detail map

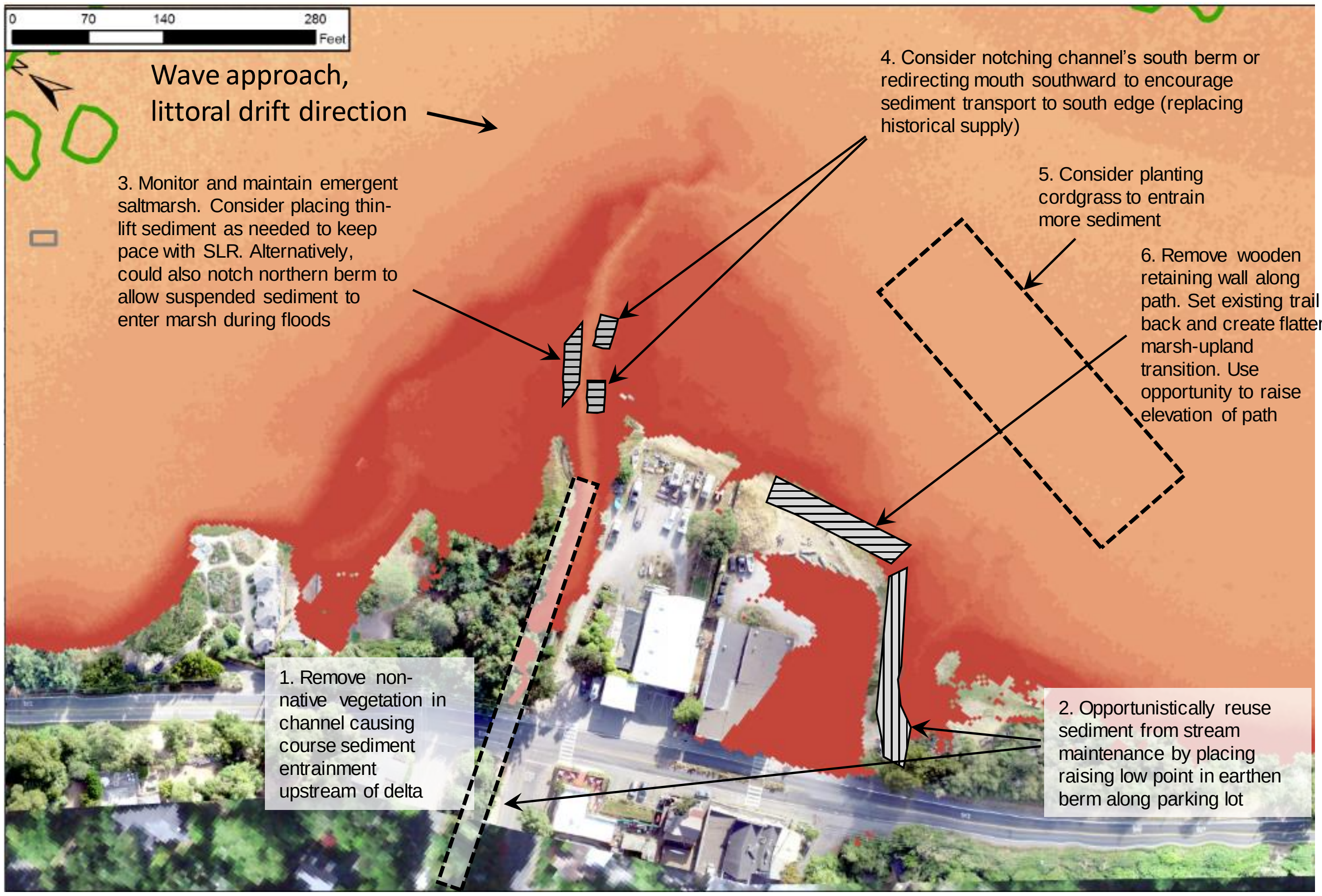

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Figure 8b
Martinelli Park detail map with potential design concepts

Evaluation of Candidate Sites

The ESA team worked with CDA to develop a set of evaluation criteria and evaluation matrix for ranking the set of potential candidate sites. At the highest level, the evaluation criteria are based on how well the candidate sites meet the overall project goals. The project goals, as defined by CDA are:

- Provide flood and erosion protection against future sea-level rise,
- Maintain public access,
- Support vibrant recreational opportunities for users of all socioeconomic circumstances,
- Develop preliminary designs for pilot projects
- Extend living shoreline applicability.

To identify specifics of the evaluation criteria, ESA reviewed the recent C-SMART study, and evaluation criteria included in recent living shorelines guidance documents, including the Marin Sea-Level Rise Adaptation Framework, Natural Shoreline Infrastructure Guidelines, San Francisco Bay Shoreline Adaptation Atlas, GFNMS Native Oyster Restoration Working Group, and others. While the team considered many evaluation metrics, the review of candidate sites focused on the most relevant criteria to the study, based on interaction with the client and community input gathered from a February 2020 stakeholder meeting at Point Reyes Station.

Several major criteria for placing living shorelines treatments were common themes among these studies and overlapped with several of the project goals: underlying erosion and flood vulnerability of the site, presence of vulnerable assets (a fundamental requirement for the present study), environmental suitability for living shorelines, range of co-benefits offered by living shorelines, and potential impacts to existing natural resources. Specific criteria[2] were developed based on these themes to provide an objective framework for evaluating how well living shoreline treatments at the candidate sites would meet the goals and objectives of the overall study and maximize co-benefits. The evaluation matrix includes:

1) Background information on **the site setting**.

2) **Applicable living shorelines types.**

3) Expectation for change in **flood hazard conditions with projected sea-level rise**. To understand whether flooding is due to still water levels or from combined still water and wave runup conditions, we examined the sea-level rise cases above with- and without the 20-year storm event. Sites where flooding only occurs during the storm case are considered to have more potential for benefits from living shorelines approaches. For each of the sea-level rise cases, we examined CoSMoS flood hazard layers for the with- and without-storm cases, to parse out which areas are predicted to experience flooding from still water levels alone (e.g. high tides), and which experience exacerbated flooding from still water levels with additional storm surge and wave runup.

4) **Erosion vulnerability**, based on historical shoreline change from 1965 to 2016. based on historical shoreline change from 1965 to 2016 and presence of riprap (indicating historical erosion vulnerability).

5) Expectation of **ecological benefits and/or impacts** of a living shoreline project.

6) Opportunities for **preserving or enhancing public access and recreation**.

7) Additional **feasibility considerations**, which included constraints such as local boat traffic, space availability, and site ownership.

[2] Note that these metrics themselves do not indicate feasibility or lack of feasibility. They are used to help identify a subset of preferred sites for developing conceptual designs. Once this is achieved, ongoing stakeholder outreach, and the process of developing the conceptual designs and supporting analyses, will give a better indication of feasibility.

8) **Effectiveness/Certainty of living shorelines benefits.** This was based on sites' suitability for specific living shorelines types that would address the local underlying issue. As an example, the availability of a suitable conditions for constructing/augmenting a coarse beach could address flooding due to wave runup at some sites.

9) **Longevity of benefits**, which considers the availability of adequate space to implement living shorelines, to allow them to adjust over time to sea-level rise (and potentially to be incrementally maintained if needed) while limiting effects of sea-level rise on the shoreline behind it. This metric also considered the availability of upland transgression space, which could allow a project area to adjust in the long-term to sea-level rise.

10) **Cost and Implementation Considerations**, which include rough order-of-magnitude costs, project readiness, and permit considerations. Project readiness in this context refers to factors that would ease the long-term implementation, such as a local proponent (research institution, private landowner willing to partner on a project, public entity), or opportunities for site access, maintenance, and monitoring.

Appendix X outlines the evaluation summary for all six candidate sites. While much of this process is qualitative, sites that meet the project's goals and objectives are prioritized. The other conditions listed above are also considered, but have a lower weight than those meeting the goals and objectives. A set of first-tier candidate sites were apparent based on these metrics: Nick's Cove, Cypress Grove and Martinelli Park.

Table 2 summarizes environmental suitability for the range of living shoreline approaches considered within this study, with rankings of 'low suitability', 'some suitability' and 'high suitability'. These were based on analysis of the site setting, dominant physical processes at the site, available space for a living shoreline approach and whether or not underlying issues of erosion or flooding could feasibly be addressed by some combination of living shoreline treatments.

The candidate sites and evaluation process will be further discussed at an additional ESA team meeting to take place in August 2020. Additional refinements may be made to the evaluation criteria table from this discussion, with the intent of recommending 2-5 candidate sites to recommend for further survey (Task 5.2) and conceptual design (Task 5.3). CDA will review the recommended sites and the final sites selected will be presented to the public in September 2020.

ESA 50 YEARS 1969-2019

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Table 1. Candidate Site Evaluation

	Nick's Cove	Cypress Grove	Marshall (nr HIOC)	Marconi (nr conf center)	Tomasini Pt	Martinelli Park
Setting	Armored shoreline inset within a small creek valley	Exposed erodible peninsula adjacent to a formerly diked marsh	Exposed armored shoreline	Armored steep shoreline partially protected by Millerton Point	Erodible peninsula with existing nearshore estuarine habitats	Developed creek delta with historical modification to flood hydraulics
Applicable LS Types	• rocky shoreline, • creek to Bay reconnection • oyster reef • beaches • potentially eelgrass	• tidal marsh, • intertidal flats, • oyster reef, • creek to bay reconnection • Potential eelgrass • Potential rocky shoreline	• rocky shoreline • oyster reef • creek to bay reconnection • Potential eelgrass	• rocky shoreline • oyster reef • potential eelgrass	• beaches • eelgrass • rocky shoreline • oyster reef • potential tidal marsh • potential intertidal flats	• beaches • eelgrass • tidal marsh • rocky shoreline • potential intertidal flats
Assets Vulnerable to Flooding with SLR	Boat launch, public access, commercial & residential bldgs	Cypress Grove facility, Livermore Marsh	Residential & most commercial properties, tidal marsh adjacent to HIOC	Commercial bldgs & Hwy 1	Tidal estuary on northern side of peninsula, TBOC and operations bldgs	Commercial bldgs existing back-barrier marsh, roadway
Erosion Vulnerability	**Low:** armored	**High:** sandy substrate and loss of updrift supply (0 – 20' erosion observed since 1965). Audubon Cyn Ranch facility vulnerable	**Low:** armored, and long-term accretion observed near HIOC	**Low:** armored, and no sign of erosion	**High:** sandy substrate (20-40' erosion observed). Estuary on north side of peninsula vulnerable to erosion	**High:** loss of updrift supply. Commercial bldgs built onto the delta are at risk
Ecological Benefits	Native oysters, fish (rays), shorebirds, upland plants	Native oysters, eelgrass, firsh, birds, marsh plants, dune and upland plants, connectivity between habitat types	Native oysters, eelgrass, fish, birds, marsh plants	Native oysters, birds	Marsh plants	Birds, marsh plants
Maintain public access/ provide opportunities for recreation	●	Public access by permission				●
Feasibility Considerations	• Frequent boat use of the dock facility • Commercial/ residential bldgs. built over water	• Vulnerable areas not readily accessible by vehicle • Private ownership of land	• Commercial/ residential bldgs. built over water. • Private ownership of most of the shoreline	• Private ownership of vulnerable parts of the shoreline • Heavy boat use	• Vulnerable areas not readily accessible by vehicle	• Private ownership of land

	Nick's Cove	Cypress Grove	Marshall (nr HIOC)	Marconi (nr conf center)	Tomasini Pt	Martinelli Park
Effectiveness/ Certainty of Living Shoreline Benefits	**Higher certainty:** Wave runup at site exacerbates limited flooding by elevated still water levels at 1.6 and 3 ft of SLR. Can use LS to incrementally provide flood protection benefits.	**Higher certainty:** Augmenting beaches and/or restoring dunes along the northern side of the point could limit the frequency and/or severity of wave-induced flooding events	**Lower Certainty:** Flooding primarily from increase in still water level, with runup increasing damage into commercial areas (including HIOC)	**Lower Certainty:** LS not appropriate for sites primarily flooded by still water level increase.	**Lower Certainty:** Wave runup at site exacerbates limited flooding by elevated still water levels at 1.6 ft of SLR. LS can be used to provide limited flood protection benefits.	**Higher Certainty:** LS can provide some flood benefits in the 1.6 ft SLR + wave runup scenario. Future SLR of 3 ft will result in flooding of roadway and landward assets.
Longevity of Benefits	**Long-term:** Adequate space gives potential for incremental improvements and buying time for SLR adjustment	**Short-term:** still water flooding predicted under future conditions.	**Short-term:** still water flooding predicted under future conditions. LS may be used to incrementally provide protection for specific locations within sites.	**N/A**	**Long-term:** Adequate space gives potential for incremental improvements and buying time for SLR adjustment	**Short-term:** still water flooding at 3 ft SLR without runup will flood the roadway.
Cost and Constructability						
Relative Project Readiness	High County-owned	Medium Limited land access for construction	Medium Multiple private land-owners	Low	High County-owned Good land access	High
Permit Considerations	Potential impacts to eelgrass	Fill placement on mudflat	Potential impacts to downdrift shoreline	Fill placement on mudflat	Fill placement on mudflat	Fill placement on mudflat
Relative Cost	Moderate/High	Moderate	Low/Moderate	Moderate	Low	Moderate

[1] 66% probability sea-level rise is between 0.8 and 1.9 feet by 2070 (OPC 2018)
[2] 1-in-200 probability sea-level rise meets or exceeds range of 3.1 to 3.5 feet by 2070 (OPC 2018)

Table 2. Living Shorelines Suitability

Living Shorelines Suitability	**Nick's Cove**	**Cypress Grove**	**Marshall (nr HOIC)**	**Marconi (nr Conference Center)**	**Tomasini Point**	**Martinelli Park**
Beaches	●	●	◐	○	●	●
Eelgrass	◐	◐	◐	◐	●	●
Tidal Marsh	○	●	○	○	◐	●
Existing intertidal flats (>x feet width)	○	●	○	○	◐	◐
Rocky intertidal	●	◐	●	●	●	●
Native oysters	●	●	●	●	●	○
Opportunity for reconnecting watershed sediment	●	●	●	○	○	○

○ = Low Suitability

◐ = Some Suitability

● = High Suitability

Attachment G

Public Agency Feedback

ESA

Although living shorelines features are intended to protect the shoreline using nature-based approaches, and are thus meant to enhance or work with existing habitats, the potential for projects to have impacts on existing habitats is a key concern that requires ongoing coordination with regulatory agencies. This coordination would be expected to continue through the design process, but is important to recognize at this feasibility stage.

After completion of a draft candidate site evaluation (Appendix F), CDA and the project team coordinated with the regulatory agencies through a series of meetings in November and December 2020, and January 2021. The intent of the meetings was to discuss the potential overlap of project sites with existing shoreline habitats, particularly mapped eelgrass extents (e.g. see Merkel et al. 2017), Pacific Herring spawning areas (provided by NMFS), and existing rocky habitat along the shoreline edge. Participants included staff from GFNMS, the California Regional Water Quality Control Board (Regional Board), California Dept of Fish and Wildlife (CDFW), U.S. Fish and Wildlife Service (USFWS), State Lands Commission (SLC), California State Coastal Conservancy (SCC), and California Coastal Commission (CCC).

Table G1 below summarizes the specific questions asked by the CDA, and agency responses. A key outcome of the process was the determination that project sites must function as restoration sites (i.e. provide a net ecological benefit even as they protect shoreline infrastructure). This is consistent with the goal and objectives of the project, as outlined in the main body of the report.

TABLE G1
PROJECT QUESTIONS FOR PERMITTING AGENCIES

	Question	Agency Response(s)
Question 1: Eelgrass	Some sites have eelgrass that may not be dense and healthy, but it is, nevertheless there. Does your project evaluation allow you to weigh a short-term loss of less robust eelgrass against the potential long-term benefits of more robust eelgrass and additional habitat types as well?	Policies do not allow for comparisons of the value of different eelgrass areas. Rather they identify eelgrass areas. What is most important is the habitat functions. Regarding long-term vs short-term, see column D (Fill 1)
Question 2: Eelgrass	This project could involve more than one site. If one "project" involves two sites, can a loss of eelgrass on one site be considered along with the gains on the second project site for a no net loss project.	Generally, the project could include two sites with mitigation on a second site for impacts on a first site, provided that: (1) the purpose of the project is for restoration of existing habitat; (2) the mitigation is for in kind habitat; and (3) there are no impacts to herring spawning sites.
Question 3: Fill Placement	Some candidate sites involve placing sediment to extend an existing beach or mudflat. Over time, these actions would improve habitat for a number of bird species. If placement of fill has short-term impacts to existing habitat, does your project review allow consideration of the long-term benefits of improved habitat so that mitigation is not required in the short-term?	Generally, there do not appear to be policies that allow agencies to consider long-term benefits vs short-term impacts. Furthermore, there is no way to substitute one type of habitat for another, even if the other habitat type will endure further into the future. There are also questions about the definitions of short-term and long-term.
Question 4: Riprap	Some of the candidate sites include a riprap shoreline. Does your project review consider placement of coarse material (cobbles etc…) that would eventually end up in the riprap to be an impact to habitat?	Across the board, riprap is not considered to provide habitat benefits. Efforts to create habitat from riprap don't appear to be an issue.
Question 5: Oysters	Would your project review allow for a reef built from all natural materials including oysters to be used for habitat (and wave attenuation)?	If the purpose of the reef is for restoration, it can be reviewed as habitat.
Question 6: Oysters	Does your agency consider non-native oysters to be beneficial and permittable as an enhancement rather than aquaculture?	Non native oysters can only be permitted in areas with aquaculture leases and for specific purposes. This is subject to an agreement with GFNMS, CCC, CF&W, & SLC and administered by CF&W.