BOTHIN MARSH OPEN SPACE PRESERVE

EVOLVING SHORELINES

INITIAL PLANNING MEMO

JUNE 22, 2020

ACKNOWLEDGEMENTS

PROJECT TEAM

WRT is a team of planners, urban designers, architects, and landscape architects based in San Francisco and Philadelphia. Through our collective approach, we serve the communities we work with by designing places that enhance the natural and social environment.

ESA is a 100% employee-owned environmental consulting firm. We plan, design, permit, mitigate, and restore—for projects across our communities, infrastructure systems, open spaces, and wildlands.

WRT and ESA are joined by technical partners:

Peter R. Baye, Ph.D.,

GHD,

Hultgren Tillis,

and Arup.

One Tam brings together inspired community members, California State Parks, Marin County Parks, Marin Municipal Water District, National Park Service with the nonprofit Golden Gate National Parks Conservancy to leverage skills and resources to support the long-term stewardship of Mt. Tam.

Sea level rise adaptation work at Bothin Marsh is primarily funded by Measure A. The conceptual design of the Evolving Shorelines project is partially funded by the California State Coastal Conservancy and the Marin Community Foundation through the Advancing Nature-Based Adaptation Solutions grant program. This program seeks to support nature-based approaches that address the risks and impacts of climate change and sea level rise to protect the Marin County bay and coastal shorelines and natural resources.

ONE TAM

Rob LaPorte, Golden Gate National Parks Conservancy

Veronica Pearson, Marin County Parks

BACKGROUND

Bothin Marsh Open Space Preserve is a well-loved county park located along the northwestern shore of Richardson Bay near the town of Mill Valley in Marin County, California. The Preserve is home to more than 70 acres of tidal marsh habitats and features one of the most popular segments of the Mill Valley-Sausalito Mulit-Use Path. Both the habitats and the trail face challenges due to coastal erosion and rising sea levels. In 2018 and 2019, One Tam partners from the Golden Gate National Parks Conservancy and Marin County Parks collaborated with community members to develop a vision for how the park will evolve and adapt to these challenges. The Evolving Shorelines Project is the next step towards making the community's vision a reality. The Conceptual Design Phase of the Evolving Shorelines Project aims to develop and evaluate potential project alternatives and will recommend a preferred alternative for detailed design and implementation.

Purpose

This memorandum, currently in draft, has been developed to support Conceptual Design of the Evolving Shorelines Project. The Project Team will review and synthesize prior studies, collect new field data, and prepare analysis to better understand existing conditions at the Preserve. The Project Team will then solicit input from the Science and Technical Advisory Committee (STAC) and stakeholders to develop a "menu" of potential project measures for improving conditions at the Preserve. These measures will then be further developed in the upcoming Alternatives Development and Evaluation stages of conceptual design.

This draft memorandum is intended to provide a brief summary of historic and existing conditions at the Preserve, to highlight key physical processes affecting the habitats and trails, and to introduce potential project measures that have been identified for future development. The Project Team hopes that this document will provide a starting point for understanding conditions at the Preserve and will help facilitate information sharing, discussions, and solicitation of feedback related to project opportunities and constraints, potential project measures, and the development and evaluation of design alternatives.

Note on Preliminary Nature of Document Materials

This document has been developed to support ongoing deliberation and planning efforts. Some of the materials presented herein include technical results and design concepts that are preliminary, and that may be refined and revised during future project planning and design. Portions of this document will be revised and further developed , and may be incorporated into final project deliverables and released for public distribution.

In particular, this document presents brief descriptions of several potential project measures that have been identified by the Project Team for consideration during the upcoming Alternatives Evaluation project stage. The Project Team expects that these preliminary measures will be updated and revised in response to feedback received from the STAC, project stakeholders, as well as the findings of ongoing technical studies. During Alternatives Evaluation, the revised measures will be developed in greater detail and will be evaluated for feasibility and to characterize anticipated benefits and impacts.

Bothin Marsh.

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1. VISION, GOALS & OBJECTIVES

PROJECT VISION

Project Overview

Bothin Marsh at first glance appears to be a natural and ecologically functioning marsh. Managers, scientists, and regulators understand the more complete story of its fragile and degraded health. In addition to at-risk natural resources, the well-used recreational trail, known as the Mill Valley-Sausalito Multi-Use Path (Bay Trail), is also compromised. The present-day effects of tidal flooding cause the trail to flood around 30 times a year. This, in addition to inadequate trail width, are critical challenges in the Preserve today. Looking ahead to the next several decades, there will be an exacerbation of these conditions if no action is taken– from an increasingly submerged marsh to complete loss of trail connectivity.

The challenge ahead is to weave together the enhancement and preservation of the tidal wetland with improvements to the trail network so that they are resilient in a future that includes sea level rise (SLR) while the trail continues to provide a carbon-free transportation route and recreational experience of the marsh.

Critical design elements need to include the ability to capture and retain sediment on site; provide a habitat 'bridge' and migration to future suitable habitat for special status species to remain in the Preserve; and incorporate a process for evaluating resilient investments.

Importantly, this project is an opportunity for continued learning and ongoing stewardship. Work by Watson and Byrne (2012) indicates that Bothin Marsh is one of the few marshes in San Francisco Bay that has displayed signs of submergence over the past decades. Comparison of historic vegetation transect surveys at Bothin Marsh demonstrates a shift from pickleweed to cordgrass dominance, a leading indicator of ongoing submergence. It is understood the marsh is at risk of total submergence by the end of the century due to rising sea-levels.

However, there is an opportunity now to implement innovative nature-based sea level rise adaptations and to monitor the response over time to inform applications across the larger Bay Area region. Marsh restoration also provides a level of protection for the community while a larger adaptation strategy is developed to address projected SLR by 2100.

Building on the Evolving Shorelines Vision Document

The project vision and shared community values for Bothin Marsh are identified in the **Evolving Shorelines: A Vision for the Future and a Plan for Today** document prepared by One Tam in collaboration with local and regional stakeholders.

This conceptual design phase will build off of the community vision with Marin County Parks and Golden Gate National Parks Conservancy taking the lead in continuing stakeholder and community engagement in the design process, and sharing new found knowledge.

The Bothin Marsh Open Space Preserve needs to be a place where...

- *We use innovative approaches to meet the challenges of climate change so that Bothin Marsh can continue to evolve and support all life that depends upon it.*
- *Residents and visitors enjoy year-round recreation and travel using Bothin's trails for carbon-free transportation.*
- *And we embrace our responsibility to take care of our shared open spaces for benefit of current and future generations.*

- Evolving Shorelines: A Vision for the Future and a Plan for Today

PROJECT GOALS AND OBJECTIVES

Project Goals and Objectives

The project goals and objectives for the Evolving Shorelines Project have been developed by One Tam, drawing on community input from the Visioning Phase (stakeholder workshops, working group, and community engagement) and scientific and technical input from Collins, Baye, Collins (2018) (Chapter 5: Local Priorities and Strategies For Environmental Management Response to Sea Level Rise). The goals and objectives are a working draft through the conceptual design process and will be finalized at the end of the phase.

Project Phasing

The current effort, Conceptual Design of the Evolving Shorelines Project at Bothin Marsh, will identify immediate (Phase 1) and near-term (Phase 2) design solutions. Mid- and long-term planning horizons will be discussed and considered at a high level in an effort to make the immediate and near-term phases consistent with potential later phases, as possible. All design options will be evaluated as part of a long-term vision for adaptation as sea level continues to rise. Phasing takes into account the planning timeline for when actions such as design, planning, permitting, and funding need to be initiated well ahead of anticipated rising sea levels.

Goal 1. Manage the shoreline for the health and safety of the community.

- Objective 1A. Create a resilient, safe, and well-connected shoreline trail network.
- Objective 1B. Enhance access to a carbon-free transportation system.
- Objective 1C. Reduce the risk of tidal flooding utilizing nature-based strategies.

Goal 2. Restore the shoreline ecosystem's ability to adapt to sea level rise.

- Objective 2A. Improve the resilience of the marsh habitats against risks from sea level rise and climate change.
- Objective 2B. Maintain biodiversity within the marsh.
- Objective 2C. Enhance and expand the distribution, abundance, and quality of high tidal marsh habitat.
- Objective 2D. Create space for different marsh habitats to shift and migrate with sea level rise.
- Objective 2E. To the extent feasible, increase resilience through the restoration of natural processes.

Goal 3. Demonstrate leadership and innovation in developing solutions to adapt to the impacts of climate change and sea level rise.

- Objective 3A. Use Bothin Marsh as a living laboratory to test innovative nature-based approaches to sea level rise adaptation that will benefit the local community and inform strategies for the broader region.
- Objective 3B. Identify adaptation pathways that anticipate changing climate and sea levels and that balance near-term and long-term outcomes.

Photos from One Tam, 2019. Counter-clockwise from top: One Tam-led scavenger hunt; Typical King Tide; Bothin Marsh community engagement event

CHALLENGES FACING THE BOTHIN MARSH OPEN SPACE PRESERVE

ANTICIPATED ENVIRONMENTAL CHANGES

- Climate Change
- Marsh Submergence
- Loss of Biodiversity
- Shoreline Erosion
- Trail Flooding
- Infrastructure Degradation

SITE SPECIFIC OPPORTUNITIES

- Legacy fills provide a platform supporting existing tidal marsh habitats and public access trails. This landscape offers special opportunities for public shoreline access and habitat preservation in a regionally important area.
- Bothin Marsh currently supports exceptional high marsh plant diversity, including the largest population of Point Reyes bird's-beak in SF Bay.
- The project could improve resilience of these habitats through increasing sediment delivery. The adjacent creek channels are a potential source of fluvial sediment to build up mudflats and marshes and keep up with sea level rise.
- This project offers the opportunity to demonstrate nature-based adaptation strategies that integrate public shoreline access and the preservation and enhancement of shoreline and tidal marsh habitats.

Marsh Submergence

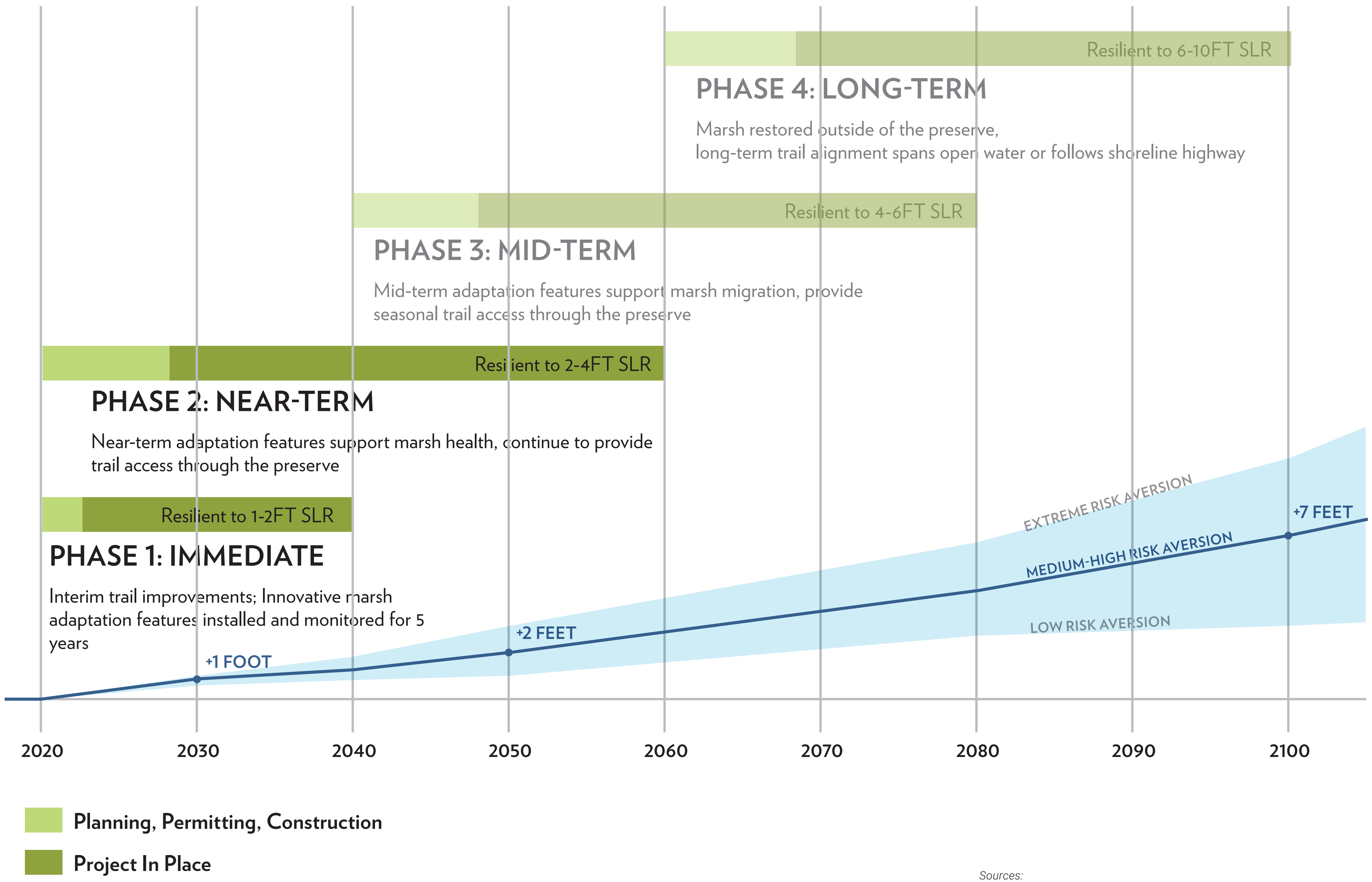
Erosion

Trail Flooding

Evidence of Artificial Fill in Bothin Marsh Today

Enlargement of Trail Conditions

PLANNING HORIZONS & CONCEPTUAL PHASING



Sources:

SLR Scenarios based on OPC's State of California Sea-Level Rise Guidance, 2018, Table 1: Projected Sea-Level Rise (in feet) for San Francisco.

Planning Horizons & Conceptual Phasing

Phase 1 - Immediate

(Current project): Interim improvements and smaller-scale actions that can be implemented quickly (in ~2 years) and provide an immediate benefit in terms of increased resilience and/or learning for future phases. This includes, for example, trail resurfacing and bridge repairs to maintain use of the existing trail, and small-scale and innovative marsh adaptation measures such as marsh mounds and tidal channel improvements. The SLR resilience of Phase 1 measures will vary, though are generally intended to provide resilience to the marsh over the shorter term, +1-2ft SLR (~2040)

Phase 2 - Near-term

(Current project): Near-term adaptation measures that require a longer lead time than Phase 1. For example, significant in-place trail improvements and realignment of lower Coyote Creek. Phase 1 includes measures implementable within the Preserve; measures outside the Preserve boundaries would be explored for the mid-term. Phase 2 Implements measures that are resilient through +2-4ft SLR (~2060)

Phase 3 - Mid-term

Major trail re-alignment and landscape transition. Phase 3 measures that are resilient through +4-6ft SLR (~2080)

Phase 4 - Long-term

Marsh restored outside of the Preserve. Longterm trail alignment +10 ft either as a future bridge or along Shoreline Highway. Phase 4 Implements measures that are resilient through +6-10ft SLR (~2100)

2. EXISTING CONDITIONS

BOTHIN MARSH: HISTORIC CHANGES AND TODAY

View of Arroyo Corte Madera del Presidio from the Bay Trail

A walk along the Bay Trail through Bothin Marsh offers picturesque views of the Richardson Bay shoreline and tidal marshes. A visitor might not realize that the Preserve and its extensive tidal marsh habitats and coastal habitats have been strongly influenced by human interventions.

Chapter 3 of L.Collins et al., 2018 presents a detailed history of north Richardson Bay, and a few events that contribute to significant landscape changes are highlighted below and illustrated on the next page.

BOTHIN MARSH: EXISTING CONDITIONS
BIRD'S EYE PERSPECTIVE

BOTHIN MARSH: HISTORIC CHANGES AND TODAY

Pre-1851 – Historic Baylands

Shell middens dating from over 5,000 years old to recent centuries confirm that Richardson Bay has been occupied and influenced by paleoindians and Coast Miwok communities throughout the late Holocene prehistoric period (Moratto, 1984; Anderson and Morratto, 1996). The likely environment of Richardson Bay included tidal wetlands which are depicted based off of what is known from the 1851 U.S. Coast Survey map which provides the best record of the historic Baylands extents. Under the mapped historic conditions, the area that is now the Preserve is mostly inter-tidal mudflat and the mouth of Coyote Creek is nearly a quarter-mile farther inland than its present day location. A narrow band of tidal marsh ("Almonte Marsh") existed along the west side of North Bothin Marsh. Extensive tidal marsh areas are mapped along the mouths of both Coyote Creek and Arroyo Corte Madera del Presidio. Europeans arrived in San Francisco Bay the late 1700s, and the growing influence of Europeans over the subsequent years led to significant changes in land uses and development.

1850-1924: Roads and Railroads

Early European development of present day Tam Valley skirted the perimeter of the historical Coyote Creek Marsh along steep hillsides. The first railroad bridge constructed across Richardson Bay in the 1870s bypassed the Coyote Creek embayment, following a route similar to present day Highway 101. In the 1880s a second track was installed running on a wooden trestle along the current Bay Trail alignment. Also around this time, State Route 1 (SR1) was established along an earthen levee that cut across the marshes and floodplain of Coyote Creek. These early transportation corridors have left a lasting mark on the landscape, and are still in active use today.

1924-1942 – Fill and Build

The timber railroad trestle is replaced with an earth embankment with a single, wide bridge at the mouth of Coyote Creek. This embankment blocks wave energy from Richardson Bay, and sediment from Coyote Creek begins to accumulate in the sheltered area west of the embankment (the area that is now South Bothin Marsh). Artificial fill is placed near SR1 to support commercial development. Berms are constructed across portions of North Bothin Marsh and fill is placed in the diked area to the west to support planned development.

1942-1968 – Channelize the Creeks, Block the Tides (and more fill)

Both Coyote Creek and Arroyo Corte Madera del Presidio are re-routed into new engineered channels.

The straightening of Coyote Creek into an US Army Corps flood control channel dramatically alters the hydrology of South Bothin Marsh. The original long bridge at the mouth of Coyote Creek is removed and replaced with an earthen embankment, and a new tidal flap gate is constructed farther south, establishing the mouth of Coyote Creek in its present location. A flood control levee was constructed along the entire north side to prevent tidal access to South Bothin Marsh. After the embankment and berm construction, the marsh is completely disconnected from the tides and stormwater drainage is provided by a single culvert with a tide gate that is located near the location of the current south marsh bridge.

During this time period there is also a major effort to place fill in North Bothin Marsh to support planned development. A new set of containment berms is built along the marsh edge, and fill is placed, significantly increasing the size of North Bothin Marsh.

Construction begins on a third set of berms farther out into the bay, and deep channels are dredged to allow barges to deliver dredge material. However, after decades of fill placement, the development plans were abandoned and while a significant amount of fill material had been placed, no structures had been built on the shoreline that would become North and South Bothin Marsh (other than the bridges, railroad/trail and power lines).

1968 - 1982 – Preservation and Public Access

Around 1970, the railroad line is decommissioned, and in 1975 the Trust for Public Land purchases the Bothin Marsh area from the railroad. In 1981 the Marin County Parks and Open Space District acquire the property, leading to the establishment of the Bothin Marsh Open Space Preserve and the opening of the Mill Valley/Sausalito Multi-Use Path (Bay Trail). Under County ownership, additional fill placement is halted and the dikes around North Bothin Marsh were allowed to gradually degrade. Small gaps and breaches in the North Marsh perimeter berm gradually grew in size.

Present Day - Tidal Action and Erosion

Tidal flows were re-introduced to South Marsh in 1987 when the tide gate was replaced by a 26-foot long pedestrian bridge. However, the bridge is not large enough to provide full tidal prism to the South Marsh. This undersized bridge continues to constrict tidal flows into and out of South Marsh.

Over subsequent decades, the berms around North Bothin Marsh have not significantly eroded and no new breaches have appeared. The channel at the original levee breach has enlarged, which increased the tidal prism and concomitantly increased sediment supply and subsequent marsh elevation. Wave-induced erosion has occurred along the edges of the fringing salt marshes east of the trail, and along the south-facing shoreline of North Marsh. Erosion has also been observed along the banks of Coyote Creek and Arroyo Corte Madera del Presidio. Vertical slumping marsh scarps and exposed rocky fill now occur in areas along each creek channel that were formerly cordgrass and pickleweed marshes. Small nick-points and vegetated swales have been observed along the north bank of Coyote Creek where high ebb tides flow from the marsh into the creek. These nick-points and swales could evolve into full channel connections over time, however their growth has been slowed by the coarse constructed levee fill and dense marsh vegetation.

Bothin Community Context

Today, the Bothin Marsh Open Space Preserve is surrounded by an urbanized environment and is heavily used by the public who travel through the marsh daily. The trail has become a popular recreational and commuter route for pedestrians and bicyclists. However, the relatively low elevation of the trail means that it is prone to flooding during high tides and storm events.

The Preserve is surrounded by a wide range of land ownership. To the west and upstream of Coyote Creek is the unincorporated community of Tam Valley and Marin County Flood Control District property. To the south, the Bay Trail remains owned by the County. It passes through a range of adjacent properties owned by Caltrans, County of Marin, and private lands. The Bay Trail traverses lands owned and managed by the City of Mill Valley to the north.

North Richardson Bay is bordered by the City of Mill Valley on the north, and several unincorporated neighborhoods including Marin City to the south, Tam Valley and Almonte to the west, and Strawberry to the east. This mosaic of landownership and management influences the planning and management of the Preserve.

The trail is enjoyed by a wide range of users who cycle, walk, and jog along the route at varying paces. Students use the trail as a route to school. The trail is also used by those who enjoy communing with nature and observing wildlife. The close proximity of varying user groups has lead to a number of collisions. Current trail guidance by regional agencies recommends a wider trail to better separate cyclists and pedestrians which may reduce the potential for future collisions. For example, the Bay Trail Design Guidelines recommend a minimum of 12 feet of paved clearance for a multi-use trail, whereas the existing width accommodates 10 feet typically.

The marsh is highly visible to the public. Views are afforded to many nearby residences around the surrounding hillsides and from Highway 101. Recent planning for Miller Avenue conducted by the City of Mill Valley highlights the unique visual asset of the marsh. Views across the natural landscape are celebrated as part of the local community character.

Looking to the Future – Resilience, Adaptation, Challenges and Change

Bothin Marsh is a constructed landscape that was created through extensive fill placement on historic mudflat and open water areas. This has resulted in a marsh landscape that is largely divorced from the geomorphic processes that support tidal marsh formation under natural conditions. Nonetheless, the existing marsh is biodiverse and provides high value habitat for resident and migratory species, provides important ecological services to the community, and the Preserve supports a highly valued recreational and commuter trail that is enhanced by proximity to the Bay and marsh habitats.

Left unmanaged, the "natural" trajectory for the landscape will generally be a slow transition towards the area's original mudflat and open-water morphology. The marshes will slowly be submerged by rising tides and the trail will flood with greater frequency. Yet there are numerous opportunities for interventions over the coming decades that can improve resilience and prolong the life of these important ecological and recreation resources. As time passes, the Preserve will face increasing stress from rising sea levels, coastal erosion, upland stream flooding, changes in sediment and climate change. Some management strategies that could provide great benefits in the near-term will grow less effective over time, meanwhile new tools and management strategies may emerge. The Evolving Shorelines Project aims to identify and implement management strategies that will allow the Preserve managers and community at large to navigate these evolving challenges over the coming decades, including the following fundamental challenges facing the Preserve:

Marsh Submergence

Tidal marshes accumulate sediment over time, allowing the marshes to increase in elevation as sea-levels rise. But there are limits to how fast a marsh can accrete based on the amount of sediment that is available. Bothin Marsh receives very little sediment due to human intervention, and as sea-levels rise the marsh will be submerged with greater frequency, resulting in a gradual conversion from high marsh to

low marsh to mudflat and open water habitats. These habitat shifts will impact the rare, threatened and endangered species found within the Preserve. There is the potential to restore hydrological connections and processes to reconnect sediment supply to the marsh. This, in addition to artificial sediment placement techniques, will be evaluated as a potential design element to help reduce the rate of marsh submergence over time.

Shoreline and Creek Bank Erosion

While Richardson Bay is somewhat sheltered from waves compared to other areas of San Francisco Bay, high wind-wave events that do reach the area often erode salt marsh edges along the bay. There are indications of ongoing erosion along many of the shorelines and channel banks at Bothin Marsh, including vertical marsh scarps and formation of lag-covered flats along the edges of former fill placement areas.

Trail Flooding

The Bay Trail segment at Bothin Marsh is at a relatively low elevation and is subject to periodic tidal flooding. The risk of flooding will increase with rising sea-levels. Trail flooding disrupts recreational and commuter uses of the trail, and also degrades the trail surface and embankments, increasing the frequency of required re-surfacing and other maintenance. The Bay Trail segment continuing south to Marin City and Sausalito, outside of the Preserve boundaries, also faces similar flooding challenges which need to be addressed to maintain a viable regional trail corridor.

Infrastructure Maintenance

The existing trail and bridges were constructed several decades ago and these structures are approaching the end of their design life. It is necessary to retrofit or replace many of these structures over the coming years and decades in order to provide safe continued public access.

Climate Change

The Preserve will experience many other challenges due to climate change, including changes in streamflow and watershed sediment supply (potentially exacerbated by increased risk of wildfire), altered oceanographic conditions, and changed patterns of precipitation and temperature. Some of these changes will be gradual over time, while others will be experienced as extreme events, however all of these changes will place new stresses on the Preserve and its habitats and infrastructure.

The next few pages provide a more detailed look at the existing conditions at Bothin Marsh, and the key physical processes that shape the marsh landscape.

Citations:

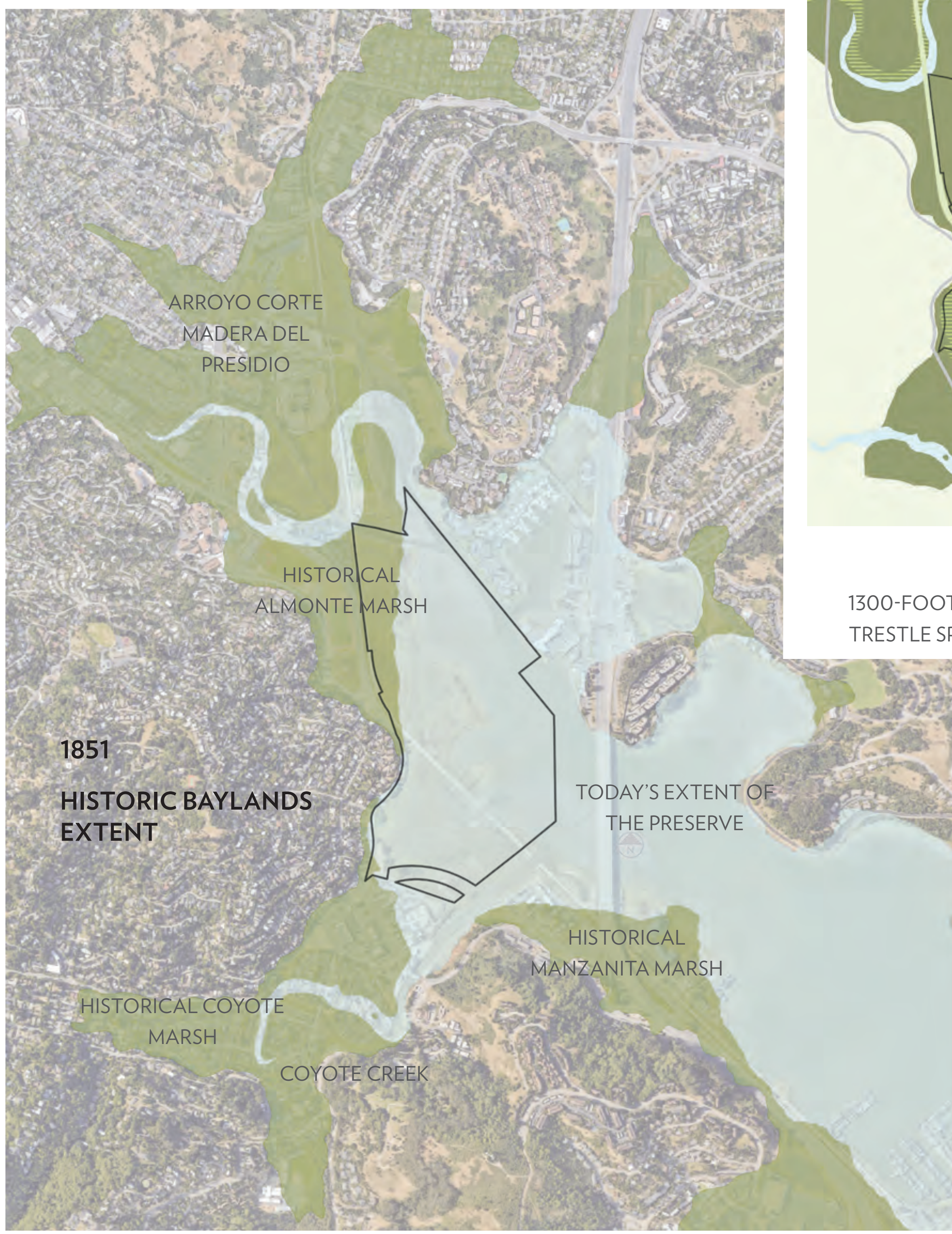
Anderson, M.K. and Moratto, M.J. 1996. Native American Land-use Practices and Ecologica Impacts. In Sierra Nevada Ecosystem Project: Final Report to Congress. Vol. 2, pp. 187-206. University of California, Centers for Water and Wildland Resources, Davis. January 1996.

Collins, L., Baye, P., and Collins, J. 2018. Bothin Marsh Geomorphology, Ecology, and Conservation Options. Prepared for the Marin County Open Space District, San Rafael CA.

Moratto, Michael J. 1984. California Archaeology. Academic Press.

Nelson, N. 1909. Shellmounds of the San Francisco Bay Region. The University Press, Berkeley. December 1909.

HISTORY OF BOTHIN MARSH



1924

1300-FOOT-LONG RAILROAD TRESTLE SPANS OPEN WATER

1946

RAILROAD BERM BUILT,

EXTENSIVE FILL, SHORT BRIDGE OVER COYOTE CREEK

1968

COYOTE CREEK CHANNELIZED,

NEW BRIDGE OVER THE CHANNEL,

OLD BRIDGE REMOVED AND TIDAL INFLUENCE BLOCKED IN SOUTH BOTHIN

TODAY (SINCE 1987)

NEW BRIDGE RESTORES TIDAL INFLUENCE IN SOUTH BOTHIN MARSH

HISTORIC BAYLANDS EXTENT 1851

NEW BAYLANDS EXTENT

Sources:

Historical maps collected by the team, including: 1851 U.S. Coast Survey, San Francisco Bay, T-00334, NOAA; 1924 (need source); 1946 Aerial Photo, Mill Valley Library History Room; 1968 San Rafael 7.5-minute Quadrangle, USGS; 1987 Aerial Pohoto, USGS via Google Earth.

LAND OWNERSHIP

EXISTING CONDITIONS: LAND OWNERSHIP

- Stakeholders near the Preserve include:
  - » Caltrans,
  - » PG&E Utility Easement,
  - » City of Mill Valley,
  - » Marin County Flood Control District,
  - » Sewer Agency of Southern Marin (SASM)
  - » Tamalpais High School
  - » in addition to local landowners, businesses and residents

Marin County Open Space District
City of Mill Valley
School
Caltrans
Marin County Flood Control District #3
Utility

INFRASTRUCTURE

EXISTING CONDITIONS: INFRASTRUCTURE

- Bay Trail is subjected to inundation during peak high tide and storm events.
- Bay Trail embankment is susceptible to erosion from waves.
- Existing asphalt trail surface suffering from mechanical / tidal weathering and base coarse upheaval due to swelling from constant water inundation.
- Portions of Bay Trail constructed on bay mud and likely still undergoing some settlement.
- Subsurface conditions along the trail embankment consist of fill, bay mud crust, bay mud, and alluvium. Bottom of bay mud depths range from 32 to 83 feet below the existing grade of the trail.
- Bay Trail, Bridges 1, 2, and 3, and connecting offsite trails, like the McGlashan Pathway, will need to be upgraded and replaced in near-term SLR scenarios.
- Bridge pile lengths are unknown, and pile capacities are unknown.
- There is no data currently available for the observed telecom manholes along the Bay Trail alignment.
- Observed culverts may be blocked - unclear drainage patterns.
- Major PG&E transmission line and associated boardwalk at risk of future inundation.
- Sanitary sewer pipelines along Almonte Blvd may be impacted by future fill placement.
- The Coyote Creek Flood Control Channel is maintained by the County.

Description

The major infrastructure in the Preserve consists of the Bay trail and its embankment, three bridges, the levees along Coyote Creek, the PG&E transmission line, the observed telecom lines potentially under the existing trail alignment, and the stormwater and sanitary sewer pipelines and drains that run along Miller Ave and Almonte Blvd. All of this infrastructure rests on layers of landfill and bay mud. The site has a history of flooding and stormwater drainage issues along Miller Ave, Hwy 1, and the Manzanita and Pohono Park and Ride locations.

Sources:

Miller Pacific Geotech Report June 6, 2017;

SF Bay Trail
Bridge
Tide Gate
Stormwater Structure
Stormwater Pump Station
Stormwater Pipeline
Sanitary Sewer Pipeline
Power Line
Transmission Line
Transmission Tower
Aboveground Telecom Line
Underground Telecom Line

INFRASTRUCTURE

EXISTING CONDITIONS: TRAIL SURFACES

The trail conditions summary below was provided in the NCE field review and short term recommendations report for the Mill Valley - Sausalito Path (2019). The County plans to move forward with trail resurfacing improvements in the immediate future which will result in a minimal elevation increase to the trail. The following information was provided in the report:

Key Issues

The trail is frequently impacted / underwater from King Tides and the surface is showing significant deterioration.

The variable and often closely spaced (< 30 ft.) thermal cracking leads to a rough surface for bicycle riders, particularly at areas of uplift and damaged/ spalled cracks.

The trail was observed to consist of at least two lifts of asphalt concrete (AC), with the top lift being approximately 1 to 1.25 inches thick. It is understood that the lower lift(s) of unknown thickness is the original paved trail and the existing surface lift was placed later.

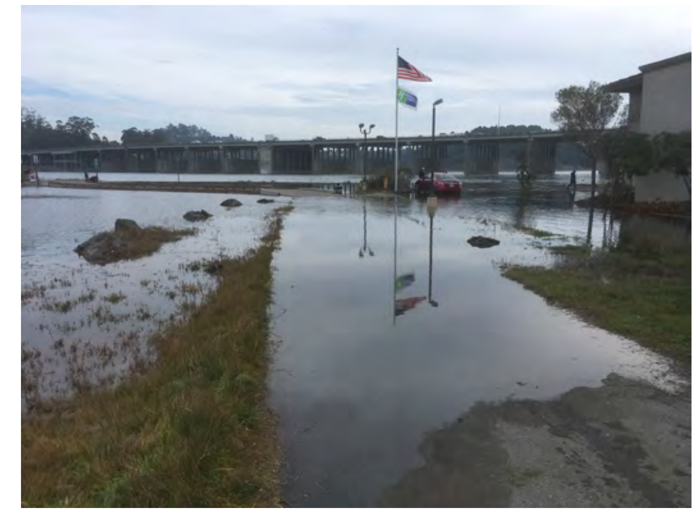
The trail appears to be performing well from a pavement structural standpoint having been built on top of a former rail bed. The distress appears to be concentrated at the trail edge and is likely in part caused by lack of proper edge confinement.

However, the trail shows significant environmental distresses, likely a result of aging, oxidation, and potential stripping of asphalt from tidal wave submersion. The trail exhibits high severity weathering over the vast majority of the trail. This weathering leaves the AC surface with a loss of much of the finer portions of the AC mix. Any further deterioration of the trail would result in aggregate raveling and rock pockets.

The trail also shows consistent thermal cracking of varying spacing and severity over much of the length of the trail. In some areas there is significant enough uplift to affect cyclist ride quality and walkers for trip hazards. The image on the right shows a typical thermal crack and also some more severe thermal cracks that have been patched.

The top lift (surface) for most of the upper AC layer from Almonte Blvd south was highly weathered and of uniform appearance and aggregate type, likely a 3/8 inch nominal maximum size AC mix as shown in the image to the right.

Source: NCE, Miller-Sausalito Trail Report, November 12, 2019



EDGE WEAR AT AREAS WITH KING TIDES

THERMAL CRACKING

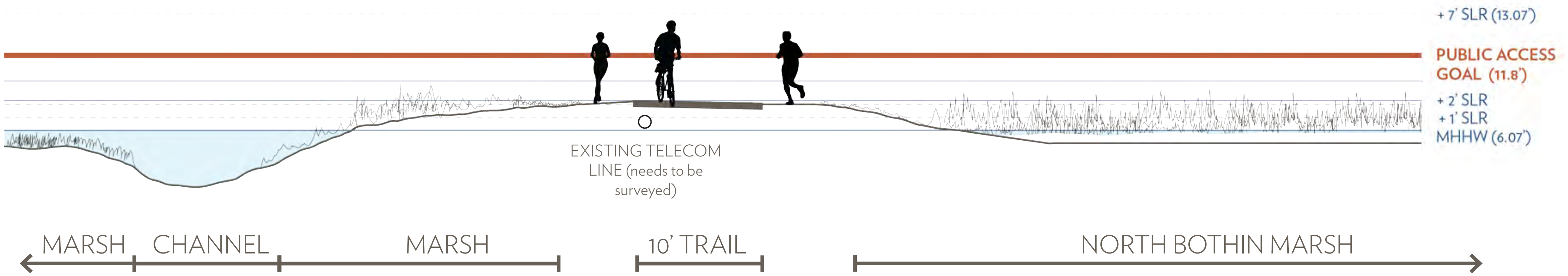
HIGH SEVERITY WEATHERING

Top photo taken by ONE TAM, middle and bottom photo taken by NCE.

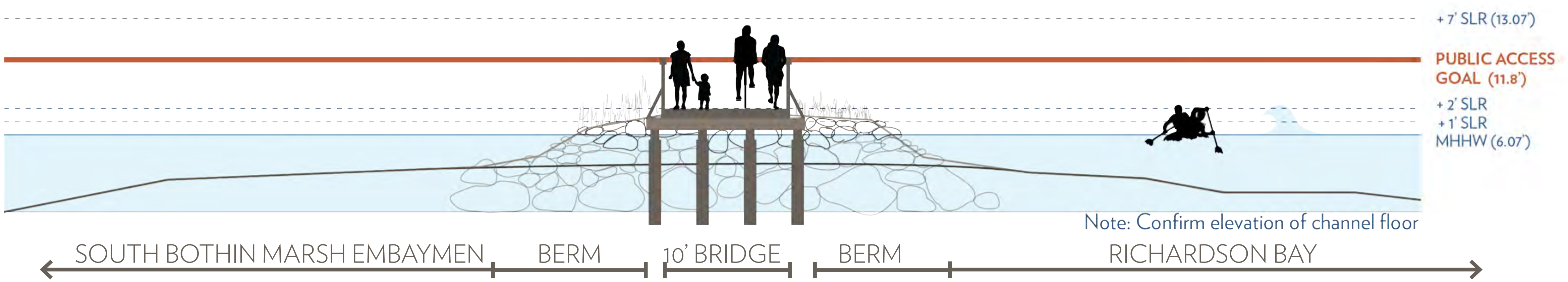
EXISTING TRAIL ALIGNMENT CROSS SECTIONS

EXISTING CONDITIONS + SLR SCENARIOS

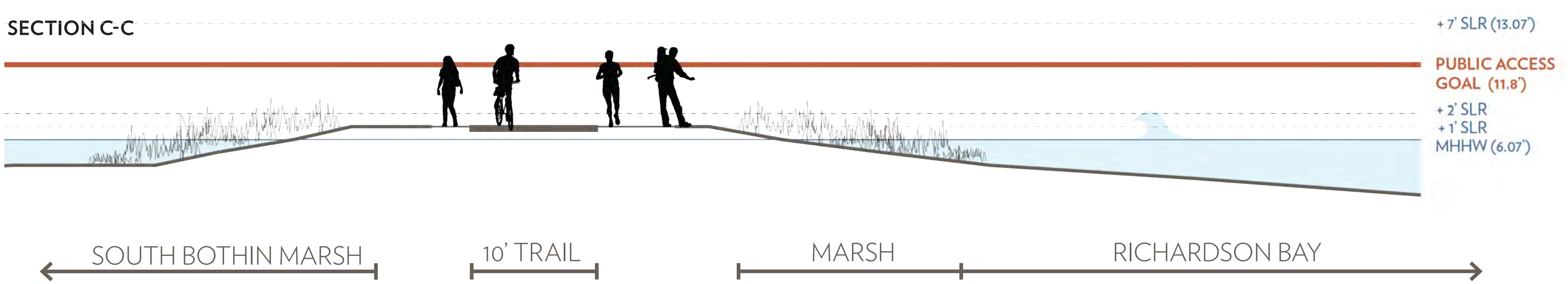
SECTION A-A



SECTION B-B



SECTION C-C

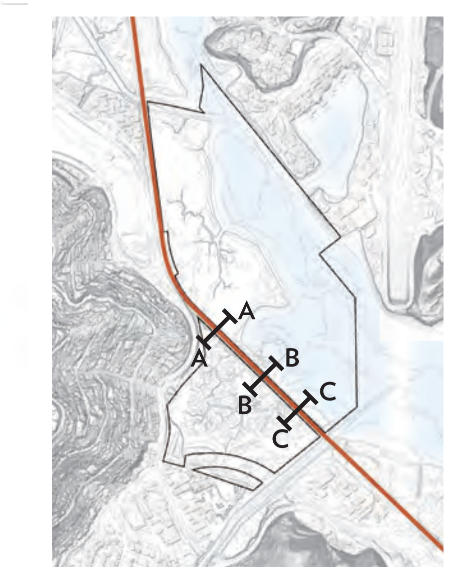


EXISTING CONDITIONS

The paved portion of the existing trail is generally ten feet across with shoulder widths that vary between two and four feet. The embankment and trail elevations generally vary approximately between 7 and 8 feet NAVD, which is just above MHHW.

The trail embankment protects South Bothin Marsh from wave action and additional erosion. On the other hand, the muted tidal prism caused by the undersized openings along the embankment increases erosion and marsh submergence.

KEY PLAN



Sources:

Elevations based on 2019 LiDAR; Tidal datums based on CLE Study;

Flood Evelvations based on FEMA 2017 Flood Insurance Study

INFRASTRUCTURE

EXISTING CONDITIONS: BRIDGES

Bridge 1

Bridge 1 is a 105-ft long multi-span timber bridge, was constructed in 1960s for the flood control channel, built on the same alignment as the 1900s railway bridge. Much of the superstructure and substructure are the original construction for railroad loading and has considerably more capacity than required for the demands imposed by a pedestrian bridge. However, the steel hardware and fasteners are in need of replacement. There is a significant risk of the bridge being unseated during a seismic event or the superstructure being damaged by floating debris. The abutments for Bridges 1 are in very poor condition and in need of replacement.

Bridge 2

Bridge 2 is a 26-ft long multi-span timber bridge, built in the late 1970s to replace the tide gate that was installed as part of the flood control project in 1965. The tide gate lets freshwater flow out and prevented tides from flowing into the marsh. During flood events, the top of deck is below high-water elevation and the entire bridge can be completely submerged. The steel hardware and fasteners are severely corroded and in need of replacement. The abutments for Bridges 2 are in very poor condition and in need of replacement.

Bridge 3

Bridge 3 is a 96-ft long multi-span timber bridge that was constructed in 1981. Bridge 3 was erected much higher than Bridges 1 and 2, and there is a small freeboard between the flood water elevation and bottom of soffit, so the timber superstructure is not submerged. Thus, the timber framing is in serviceable condition, with minor to moderate corrosion at the steel hardware and fasteners that could be serviced or replaced. The abutments for Bridge 3 are above the high-water elevation and is in a serviceable condition.

BRIDGE 1 -

COYOTE CREEK

BRIDGE 2 -

SOUTH BOTHIN MARSH CHANNEL

BRIDGE 3 -
ARROYO CORTE MADERA DEL PRESIDIO

Photos taken November 2019 and January 2020.

MOBILITY

EXISTING CONDITIONS: MOBILITY

- Access to the Preserve is primarily from Almonte Blvd and Miller Ave.
- Bay trail serves as an important Safe Routes to Schools connection and provides an important carbon-free commute option for the community.
- Parking options are limited to on-street parking along Miller Ave and Almonte Blvd, in addition to the nearby Park and Ride areas and the Mill Valley Community Center.
- Bay Trail is a critical link in the active transportation network for the larger region.

MOTOR VEHICLE USE

1. Avg. # of two way, daily trips on Almonte/Miller | 2014 | **19,322**
2. Avg. # of cars, Hwy. 1, two-way peak hour | 2016 | **4,800**
3. Avg. # of cars, Hwy. 1, one way N/E peak hour | 2016 | **2,950**

Sources: 1. City of Mill Valley 2014 Traffic Counts, 2. & 3. CalTrans

TRAIL COUNTER

1. Peak # of cyclists, 8-10AM weekdays | 2017 | **99**
2. Avg. # of cyclists, weekends | 2017 | **1,796**
3. Avg. # of pedestrians, daily | 2017 | **803**

**The trail counter was located along the Mill Valley-Sausalito Path at the Sycamore Roundabout (located off the map on the north side of the Preserve).*

Description

Bothin Marsh is accessible to the region via Shoreline Highway and Highway 101. The Mill Valley - Sausalito Pathway (Bay Trail) provides major access for cyclists and pedestrians, with peak use on the weekends. The Preserve is also accessible via the McGlashan Pathway on the southwest side.

There is no parking provided on site, though parking areas can be found on nearby streets and along the trail, including the Park and Ride lots and the Mill Valley Community Center.

Marin County Transit has bus stops along Almonte Blvd. The Muir Woods Shuttle operates from the Manzanita Park and Ride lot as well.

SF Bay Trail
Multi-Use Trail
Class II Bike Route
Walking Trail
Connecting Sidewalk
Major Road
Motor Vehicle Counter
Site Access Point
Bridge
Pedestrian Crosswalks
Bus Stop
Park and Ride

USER EXPERIENCE

EXISTING CONDITIONS: USER EXPERIENCE

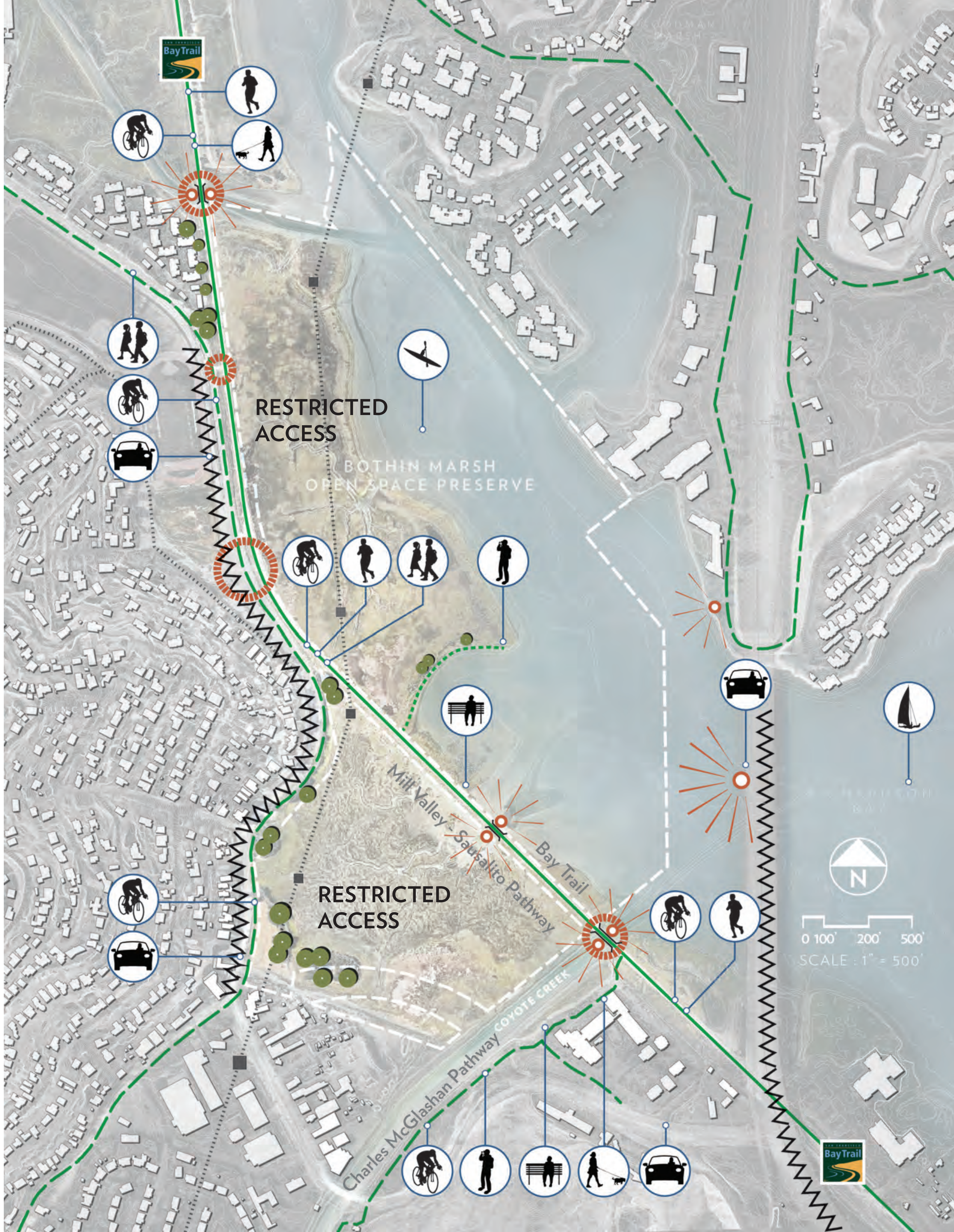
- User experience patterns highlight active vs inactive areas of the Preserve. Many users overlap along the trail, while access to the marsh areas is generally discouraged.
- Drivers experience the marsh from key vantage points along Highway 101 and Miller Avenue.
- Kayakers have access to areas in North Bothin Marsh that are otherwise unreachable by pedestrians. San Francisco Bay Water Trail Trailhead and boat launch at Bayfront Park.
- Birders and naturalists use the central trail to view more isolated habitat areas
- The Preserve is impacted by urban noise.

Description

The Preserve and its trails offer various users the ability to feel immersed in the wetland ecosystem, while also offering a direct route for students and commuters to travel between communities. The Bay Trail offers views across the marsh and the opportunity to protect diverse species and their habitats by limiting disturbance in some areas.

As sea levels rise, the experience along the trail will change as nature-based adaptation strategies are implemented, marsh habitats migrate upland, and the water experience along the trail expands.

SF Bay Trail
Off-Site Bike Trail
Walking Trail
Site Access Point
Activity on Trail
Noise Pollution
Non-Vehicular Bridge
Notable View
Tree
Power Line
Transmission Tower



TIDAL HYDROLOGY

EXISTING CONDITIONS: HYDROLOGY

FLOOD ELEVATION	ELEVATION (FT NAVD)	SOURCE
500 - YEAR STILLWATER ELEVATION	11.5	FEMA. Flood Insurance Study, Marin County, California and Incorporated Areas. 2017. FIS # 06041CV001D
100 - YEAR STILLWATER ELEVATION	9.8	
50 - YEAR STILLWATER ELEVATION	9.3	
10 - YEAR STILLWATER ELEVATION	8.3	

Measured water levels at Bothin Marsh

The Project Team installed three temporary tide gages (Solinst "Leveloggers") at the Bothin Marsh Preserve to measure water levels within the north and south marsh basins, and at the mouth of coyote Creek. A barometric pressure gage (Solinst "Barologger") was also installed at the site so that the gage measurements can be corrected to account for variations in atmospheric pressure.

The gages were installed on December 9, 2019. On January 8, 2020 the gages were serviced and one month of data was downloaded in order to allow for preliminary analysis. The gages were then reinstalled at their original locations. The gages were recovered on May 25, 2020 and more than 5 months of measured water level data was downloaded and analyzed.

- Subtidal (<MLLW)
- Mudflat (MLLW-MSL)
- Low-Mid Tidal Marsh (MSL-MHH)
- High Tidal Marsh (MHHW-HAT)
- 10-Year Stillwater Elevation
- 50-Year Stillwater Elevation
- 100-Year Stillwater Elevation
- 500-Year Stillwater Elevation
- ESA Water Level Gauges

TIDAL HYDROLOGY

TIDAL DATUMS AT BOTHIN MARSH PRESERVE

TIDAL DATUM	NORTH BOTHIN MARSH	SOUTH BOTHIN MARSH	COYOTE CREEK BRIDGE (ESA 2020)	COYOTE CREEK BRIDGE (CLE 2018)	NOAA SF GOLDEN GATE (9414290)
MHHW	5.86	5.89	5.88	6.07	5.9
MHW	5.25	5.29	5.27	5.45	5.29
MSL	3.46	3.41	3.23	-	3.18
MTL	3.71	3.6	3.37	-	3.24
MLW	2.17	1.91	1.46	1.32	1.19
MLLW	1.82	1.38	.69	1.0	.06

Note: All values are feet, NAVD88

Measured water levels at Bothin Marsh compared to NOAA SF tide gage

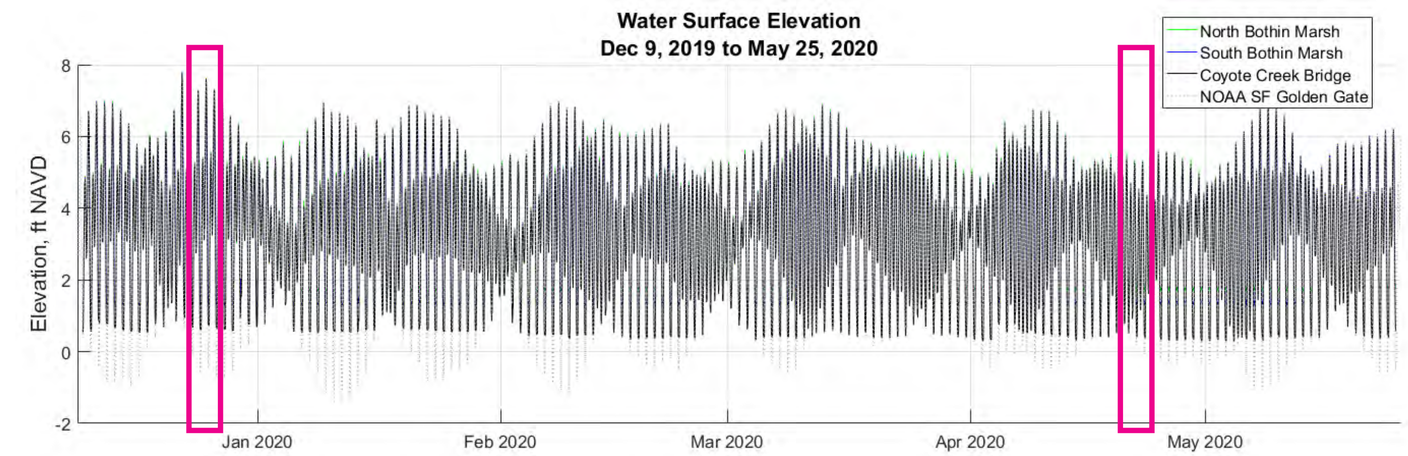
The temporary tide gages were compared to the NOAA tide gage at San Francisco (gage # 9414290). This NOAA gage is located approximately 5.9 miles south of the Bothin Marsh Preserve.

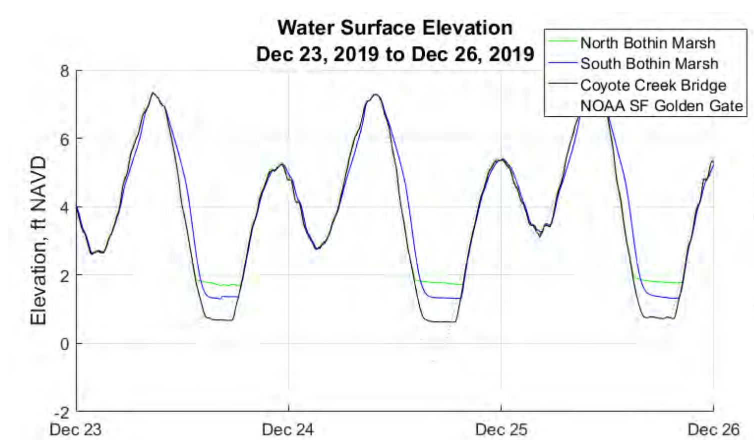
Tidal datums were calculated for all three gages, and the results were compared to tidal datums previously calculated by CLE for the mouth of Coyote Creek, and datums calculated by NOAA for the San Francisco tide gage.

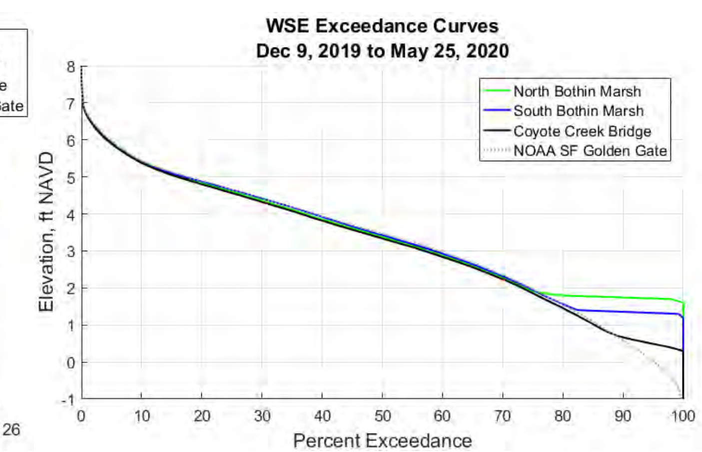
The water level data were used to calculated percent exceedance curves for the three gage locations. These curves show the percentage of time that the water level exceeded a given value for each gage location.

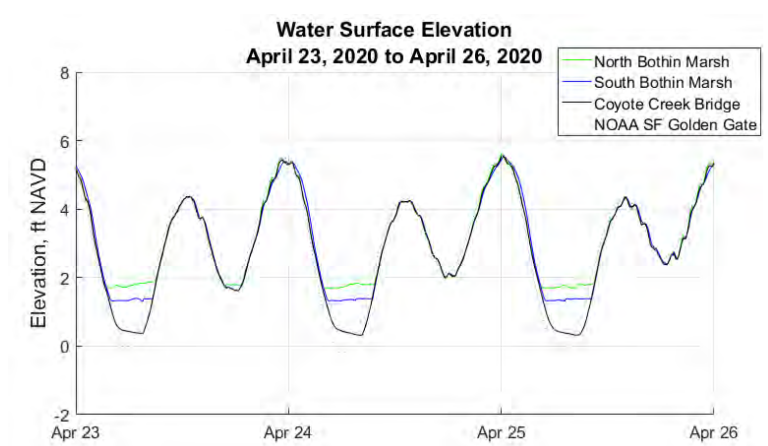
The water level data reveal the following trends:

- High tide elevations at all three gage locations are nearly identical, and are very similar to the high tide elevation at the NOAA gage.
- Low tide elevations measured in the two marsh locations are elevated relative to the low tide elevation in the open Bay or at Coyote Creek due to the higher elevation of the channel bed at the marsh gages. The channels where the two marsh gages were installed go dry during the lowest tides, and this is the reason for the higher calculated MTL, MSL, MLW and MLLW datums in the marshes (compared to Coyote Creek and Golden Gate).
- Rising and falling tides in South Bothin Marsh are delayed slightly relative to the tides at the Coyote Creek Bridge and in North Bothin Marsh. This lag is attributed to the constricted channel size at Bridge #2. The duration of the delay varies depending on the height of the tide.
- The percent exceedance curves show that areas in South Bothin Marsh that are at low to mid-marsh elevations (4 to 5 ft NAVD) are inundated more frequently (approximately 2% of a day /30 minutes per day longer on average) compared to areas of the same elevation in North Bothin Marsh or along the Richardson Bay shoreline. Tidal marsh vegetation is sensitive to inundation frequency and duration, and the longer duration of inundation in South Bothin Marsh reduces the productivity of existing tidal marsh vegetation and limits the expansion of vegetation into unvegetated areas.









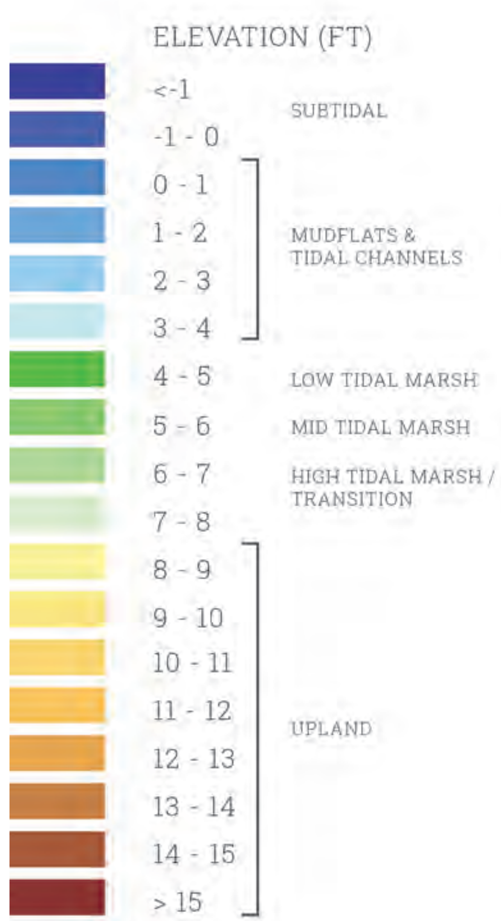
TOPOGRAPHY

EXISTING CONDITIONS

The topography at Bothin Marsh has been strongly influenced by construction and fill placement over the past 150 years.

The topography at North Bothin Marsh was largely established as the result of the construction of containment berms around the perimeter of the site, hydraulic placement of fill material within the site interior, and breaching and limited re-connection with Richardson Bay and Arroyo Corte Madera del Presidio. The North Marsh displays very little topographic relief. Elevations in the interior of North Bothin Marsh vary from 5 ft to 7 ft NAVD, and the berms around the perimeter of the marsh rise to approximately 8 ft NAVD. The Bay Trail embankment runs along the east boundary of the North Marsh, ranging in elevation between 8 and 10 ft NAVD. A small area of remnant historic Almonte Marsh exists along the bayward toe of the Bay Trail embankment, identifiable as a band of high marsh at slightly higher elevations than the majority of the marsh interior.

The topography at South Bothin Marsh has been influenced by the railroad/Bay Trail embankment and the several phases of re-alignment and diversions of the Coyote Creek channel. Typical elevation of marshes within the interior of South Bothin Marsh is 4.5 to 6ft NAVD. Deep scour pools exist on both sides of the Bridge 2 tidal channel due to the high velocity flows under the bridge during rising and falling tides. The Bay Trail embankment separates South Bothin Marsh from Richardson Bay, ranging in elevation between 7-8 feet NAVD. Higher elevation upland/transition areas exist along the west perimeter of South Bothin Marsh, adjacent to Almonte Blvd and Tam Junction. Several debris mounds are found in the southwest corner of the Preserve. These mounds are remnants of various mid-20th century fills related to channel dredging, bridge construction, and bay filling before modern Bay fill regulation. The mounds contain a mix of soil as well as concrete, rebar and other debris.



Source: 2018 Marin County LiDAR

SEDIMENT AND EROSION

EXISTING CONDITIONS

Sediment is an essential resource for the formation and sustenance of tidal marshes and mudflats. These landforms exist where there is an equilibrium between sediment deposition from creeks and the estuary, and erosion due to waves and currents. If the amount of sediment available increases, new marshes and mudflats are formed. However, areas of marsh and mudflat may be lost if the sediment supply decreases, or if hydrologic conditions change leading to increased erosion. It will be important to understand the balance of sediment and erosion at Bothin Marsh under existing and future conditions, and to understand how proposed project measures might increase the resilience of tidal marsh habitats by increasing sediment delivery, sediment capture, and reducing erosion. Outcomes and findings from prior studies evaluating these processes are summarized below.

Bothin Marsh receives very low amounts of estuarine sediment. The geology and hydrologic conditions in Richardson Bay are such that only a small amount of sediment from the San Francisco Bay and Delta reach north Richardson Bay and Bothin Marsh (Collin, L. et al., 2018).

Creeks may provide a significant additional source of fine sediment (silt, clay) in north Richardson Bay during wet years. Depositional channel bars consisting of mixed coarser sediment (sand, gravel) and fine sediment are evident in upstream reaches of Coyote Creek and Arroyo Corte Madera del Presidio below the head of tide. Coarser sediment is not recently evident in lower reaches of the creeks near the Bothin Preserve.

The average annual total sediment yields from nearby creek watersheds have been estimated based on regional regressions:

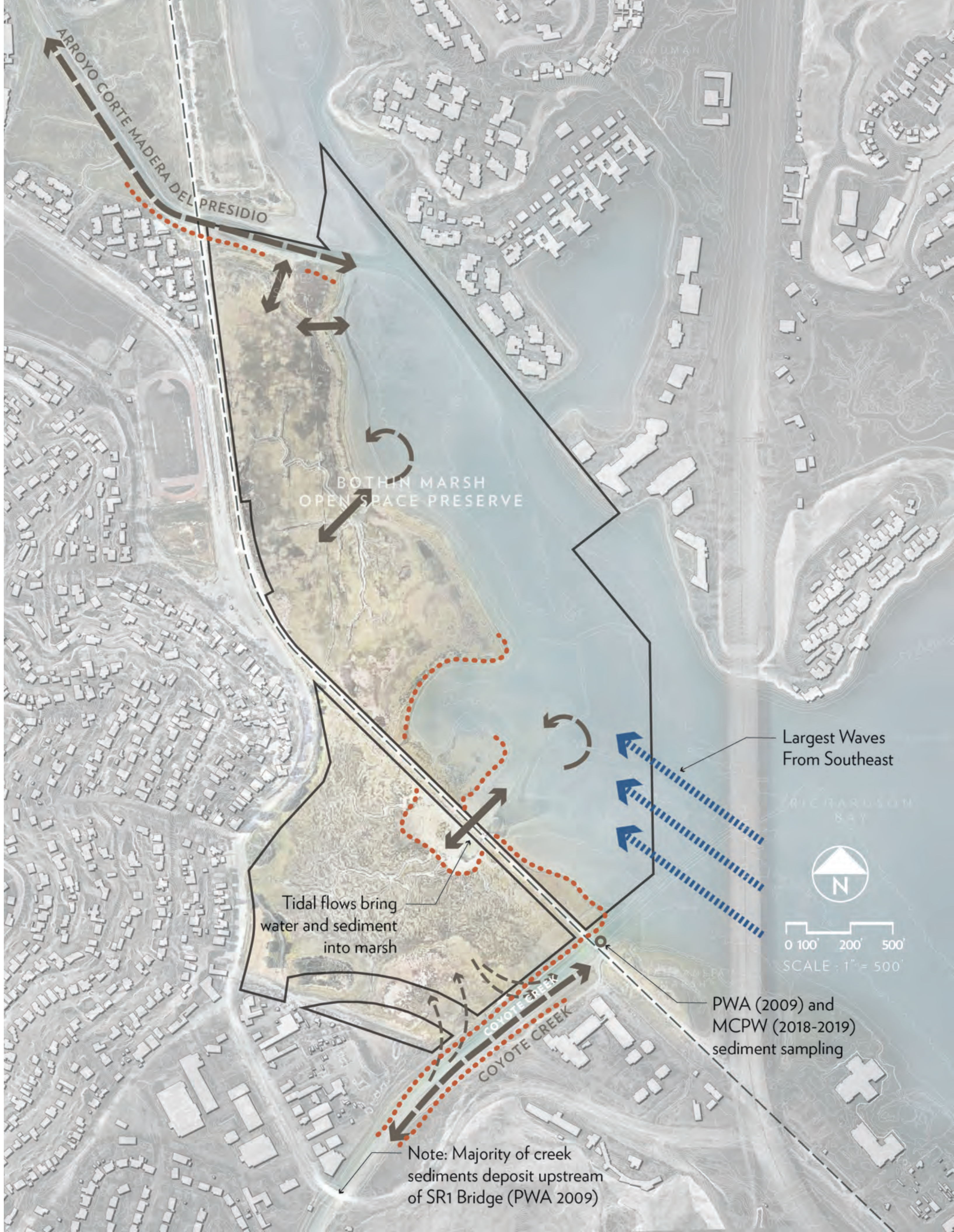
- Coyote Creek: 1854 tons/year (from SFEI 2017)
- Arroyo Corte Madera del Presidio: 5900 tons/year (based on SFEI 2017 estimates for Coyote Creek, scaled to match ACMdP drainage area)
- The amount of sediment that is delivered from the creek mouths to nearby tidal marshes and mudflats will be less than the total watershed yield because some of the watershed sediment yield is trapped in upstream depositional channel segments, and some of the sediment yield is flushed out to deep water areas of the Bay. The fraction of total watershed sediment yield that deposits on the marshes and mudflats is a topic of ongoing analysis.

Direction of largest wind waves approaching site

Hydraulic connections conveying suspended sediment into (and out of) marsh areas

Eroding scarps along marsh edge of channel bank

Sources: SFEI 2017; PWA 2009; Stralberg, et al. 2011



SEDIMENT AND EROSION

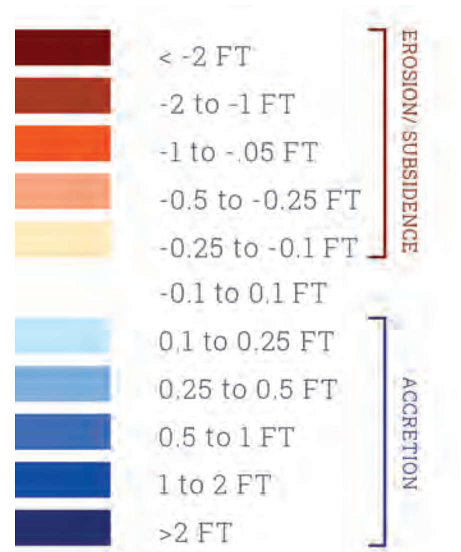
- Landforms that separate the marshes from nearby creek mouths, such as artificial levees and embankments, reduce the amount of sediment from the creeks that deposits on the marshes. The North Bothin Marsh tidal channel network is reasonably well-connected to the mouth of ACMdP , however the South Bothin Marsh tidal channel network is disconnected from the mouth of Coyote Creek by a remnant berm along the north bank of the creek and the Bay Trail embankment.

Comparison of LiDAR surveys in 2009 (CA Coastal Conservancy) and 2019 (Marin County) do not show signs of progradation of deltaic tidal marsh or mudflat at the Coyote Creek canal or Arroyo Corte Madera del Presidio mouth. Both creek channels express across the mudflats and connect with the main Richardson Bay thalweg. The LiDAR datasets show signs of deposition in the former dredged channels near North Bothin marsh, slight erosion/subsidence on the shallow wave-exposed mudflats, and show evidence of shoreline erosion along the bay-facing edge of the berms around the perimeter of North Bothin Marsh. The LiDAR data shows a mix of accretion and erosion/subsidence within the tidal marshes. The trail and perimeter berms show evidence of slight subsidence, but are within the margin of error of the surveys.

LiDAR surveys have less accuracy in vegetated areas, and the observed elevation changes in the vegetated tidal marsh areas are within the margin of error of the LiDAR datasets.

Re-suspension of sediments from mudflats during large wave conditions can cause temporary increases in suspended sediment concentrations and may cause episodic pulses of sediment delivery to marshes. PWA (2009) observed visible areas of higher turbidity offshore in Richardson Bay relative to outflow of Coyote Creek during windy conditions while monitoring sediment at Coyote Creek.

TOPOGRAPHIC CHANGE 2009-2019



This map shows the observed change in ground elevation between 2009 and 2019 based on available LiDAR datasets (CA Coastal Conservancy 2009; Marin County 2019). The mapped elevation changes are subject to the limitations and uncertainties inherent in LiDAR-based topographic surveys, and may exhibit errors and distortions due to vegetation, standing water, and built infrastructure.

SEDIMENT AND EROSION

Typical suspended sediment concentrations in Richardson Bay are around 20-40mg/L on average (PWA 2009). The average rate of deposition in dredged channels near Sausalito significantly exceeds the deposition rate expected under typical conditions; observed accretion rates in dredged channels near Sausalito indicate that the deep-water portions of Richardson Bay experience an average suspended sediment concentration of 120mg/L (PWA 1983). This suggests that rare events that cause temporary periods of high suspended sediment concentrations, such as periods of high streamflow and large wave conditions, play an outsized role in sediment transport processes in Richardson Bay.

The magnitude of sediment delivered to marshes during large wave and large streamflow events has not been well quantified and is a topic of ongoing research. Streamflow and wave events might not deliver sediment to marshes as frequently as to the deep-water areas, because marshes are only inundated during high tides.

Order of magnitude estimates based on regional average vegetation growth rates suggest that organic productivity can have a significant contribution to marsh accretion. In areas with low estuarine sediment supplies, organic productivity can outpace mineral sediment deposition in vegetated marsh areas (Stralberg, et al. 2011). Vegetation productivity and organic accretion rates have not been directly measured at Bothin Marsh and should be studied further.

Based on regional average marsh accretion rates, the tidal marshes in North Richardson Bay are not expected to keep pace with sea-level rise through the end of century (2100) and will convert to mudflats or open water unless the sediment supply to the marshes is increased (Stralberg, et al. 2011).

Edge erosion has been observed along southeast-facing shorelines and along the banks of the creeks. Episodic bank erosion can occur during large storm events, and may also be an indication of a long-term sediment deficit resulting in sustained shoreline erosion. Continued monitoring and observations are recommended.

Eroding vegetation and mudflats in South Bothin Marsh, 2019.

Estimated Average Annual Sediment Delivery Required to Keep Pace with SLR

SCENARIO	SEA-LEVEL RISE RATE		SOUTH MARSH (24 ACRES)	NORTH MARSH (26.4 ACRES)
HISTORIC SLR	0.0064 ft/ yr	(2mm/ yr)	248 CY/ yr	273
IMMEDIATE FUTURE	0.02 ft/ yr	(6mm/ yr)	774	852
NEAR TERM (MID-CENTURY)	0.04 ft/ yr	(12mm/ yr)	1549	1704
MID TERM	0.08 ft/ yr	(24mm/ yr)	3098	3407
LONG TERM (END OF CENTURY)	0.12 ft/ yr	(36mm/ yr)	4646	5111

EXISTING ECOLOGICAL RESOURCES

KNOWN SPECIAL STATUS SPECIES

The following is a short list of special status species known to occupy Bothin Marsh. There are numerous additional species with the potential to occupy the marsh or that may be affected by changes to the marsh, see Collins et al. (2018) for complete list.

CALIFORNIA RIDGEWAY'S RAIL (*Rallus obsoletus*). FE, SE

- Critical Habitat Features: Small tidal channels and adjacent berms

CALIFORNIA BLACK RAIL (*Laterallus jamaicensis coturniculus*). FSOC, ST

- Critical Habitat Features: Secluded high marsh and transition zones (away from trail)

NORTH COAST OR POINT REYES BIRD'S-BEAK (*Chloropyron maritimum subsp. palustre* also listed as *Cordylanthus maritimus ssp. palustris*) FSOC, CNPSR

- Critical Habitat Features: High marsh and transition-zone habitats with high soil salinity

NOTE ON SALT MARSH HARVEST MOUSE:

- Past identification of salt marsh harvest mouse (*Reithrodontomys raviventris*; FE,SE) occurrence at Bothin Marsh has been corrected as tidal marsh populations of western harvest mouse (*Reithodontomys megalotis*) based on new genetic analysis (V. Pearson, pers. Comm. 2017). No salt marsh harvest mice are known to occur at Bothin Marsh and vicinity.

ECOGEOMORPHIC UNITS

The Bothin Marsh Preserve contains a diverse range of habitats that are influenced by specific geomorphic, hydrologic, and ecologic processes affecting different areas of the Preserve. Collins et al. (2018) applied an "ecogeomorphic unit"-based framework to account for the interactions between these processes in shaping the extents and functions of existing habitats within the Preserve. Detailed mapping of existing ecogeomorphic units present within the Preserve can be found in Chapter 4 of the Collins et al. (2018) report and a brief annotated summary of that mapping is provided in the Appendix of this document.

The basic ecogeomorphic units of Bothin Marsh are dynamic landforms associated with major distinct vegetation and habitat types. The units include variable forms of high salt marsh (flooded only during higher spring tides), playa-like high salt marsh pans, terrestrial transition zones (gradients between above-tide lands and high salt marsh), salt marsh plains, low intertidal salt marsh, tidal channels and banks, and various types of saline pools within the marsh. Marsh wildlife utilize interconnected combinations of these features, and plant distributions correspond with them in different positions within the Bothin Marsh landscape.

Sources: SFEI 2017; PWA 2009; Stralberg, et al. 2011

CALIFORNIA RIDGEWAY RAIL

Image Credit : Peter Baye

POINT REYES BIRD'S-BEAK

Image Credit : Peter Baye

CALIFORNIA BLACK RAIL

Image Credit : UC Division of Agriculture and Natural Resources, photo taken by Laurie Hal

ABBREVIATIONS

PAST IDENTIFICATION OF SALT MARSH HARVEST MOUSE (REITHRODONTOMYS RAVIVENTRIS; FE,SE) OCCURRENCE AT BOTHIN MARSH

PREDICTED SEA-LEVEL RISE IMPACTS ON BOTHIN MARSH

TODAY (SINCE 2019)

- Subtidal (<MLLW)
- Mudflat (MLLW-MSL)
- Low-Mid Tidal Marsh (MSL-MHHW)
- High Tidal Marsh (MHHW-HAT)
- 10-Year Coastal Flood
- 100-Year Coastal Flood

2030 +1' SEA LEVEL RISE

IMMEDIATE

The inundation extents shown provide only a rough estimate of the inundation extents that may occur during the indicated flood events. These maps have been developed to inform project planning and may contain errors or inaccuracies. Key processes affecting actual inundation extents have been neglected in this simplified mapping.

2050 +2' SEA LEVEL RISE

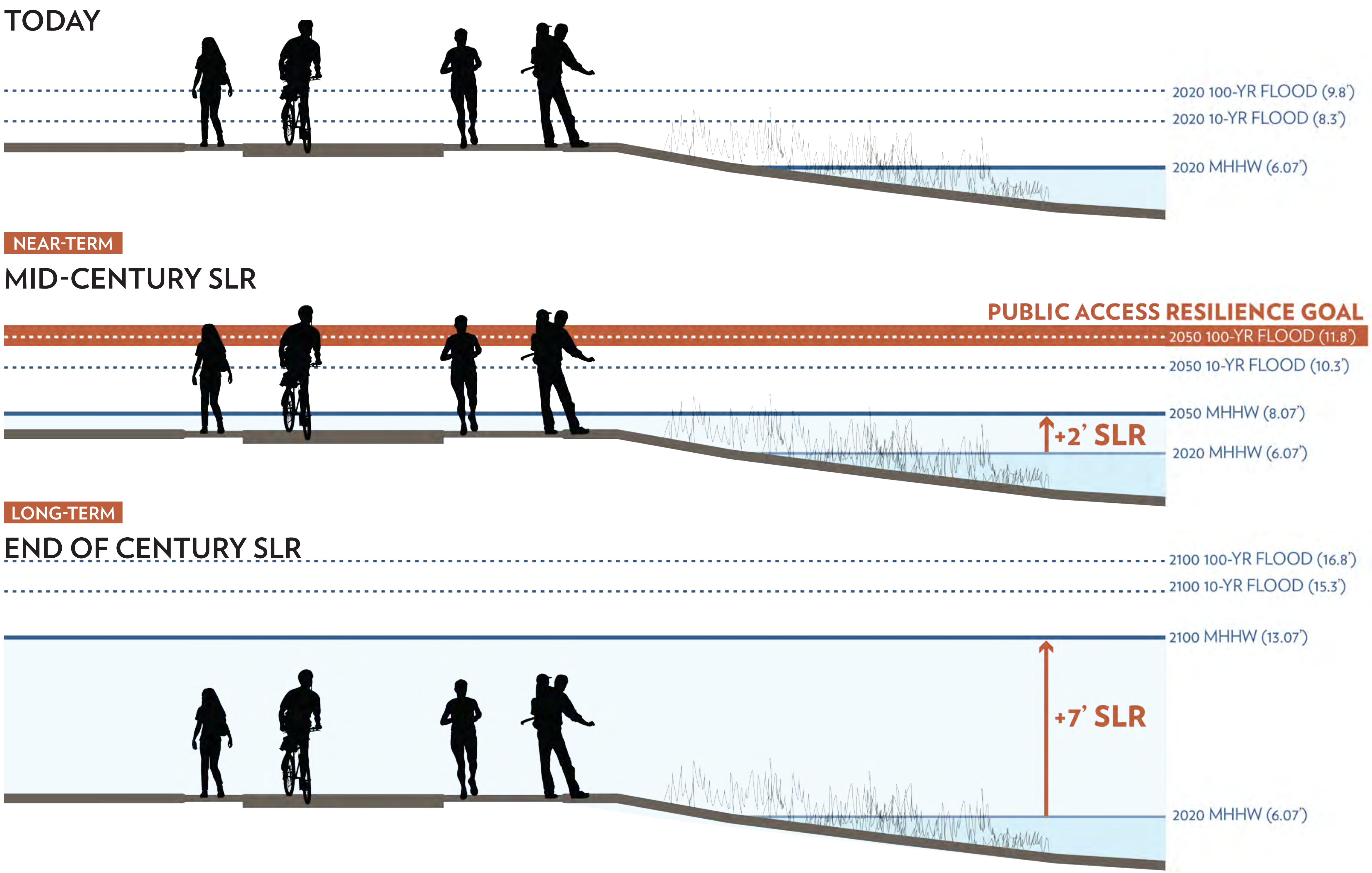
NEAR-TERM

2100 +7' SEA LEVEL RISE

LONG-TERM

Sources:
Elevations based on 2019 LiDAR; Tidal daturms based on CLE Study; Flood elevations based on FEMA 2017 Flood Insurance Study;
SLR Scenarios based on OPC's State of California Sea-Level Rise Guidance, 2018, Table 1: Projected Sea-Level Rise (in feet) for San Francisco, assuming Medium-High Risk Aversion in the High Emissions scenario for 2030, 2050, and 2100.

PREDICTED SEA-LEVEL RISE IMPACTS
EXISTING TRAIL CONDITIONS + SLR SCENARIOS



EXISTING TRAIL CONDITIONS & SLR SCENARIOS

The existing trail ranges from approximately 7 to 8 feet NAVD in elevation, just above MHHW and below 10-year flood levels. The poor trail surface conditions are a result of frequent trail overtopping throughout the year.

The "near-term" planning horizon for this project assumes the mid-century sea level to be about 2 feet above today's conditions. As is indicated in the sections to the left, BCDC recommends that public access to the shoreline be resilient to the mid-century sea-level rise and 100-year flood levels. To achieve this resilience goal the elevation of the trail ought to exceed 11.8 feet NAVD.

The "long-term" planning horizon for this project assumes end-of-century sea level to be about 7 feet above today's condition. This scenario is shown here for reference, but the proposed conceptual design of this project will not address this condition because it will require land use and policy changes well beyond the Preserves boundaries.

KEY PLAN

Sources:
Elevations based on 2019 LiDAR; Tidal datums based on CLE Study; Flood Evelvations based on FEMA 2017 Flood Insurance Study; SLR Scenarios based on OPC's State of California Sea-Level Rise Guidance, 2018

3. POTENTIAL DESIGN ELEMENTS

POTENTIAL DESIGN ELEMENTS

INTRODUCTION: MENU OF POTENTIAL DESIGN ELEMENTS

This section presents a “menu” of potential design elements that have been identified for improving public access, ecological functions and sea-level rise resilience at Bothin Marsh. The collection of potential elements includes elements identified in prior planning studies and community workshops (CC&B; Leventhal and Baye, Evolving Shorelines), regional planning efforts, and workshops between the project team and the STAC. More detailed information regarding the Science and Technical Advisory Committee (STAC), including membership, meeting notes and presentation slides, can be found in the Appendix.

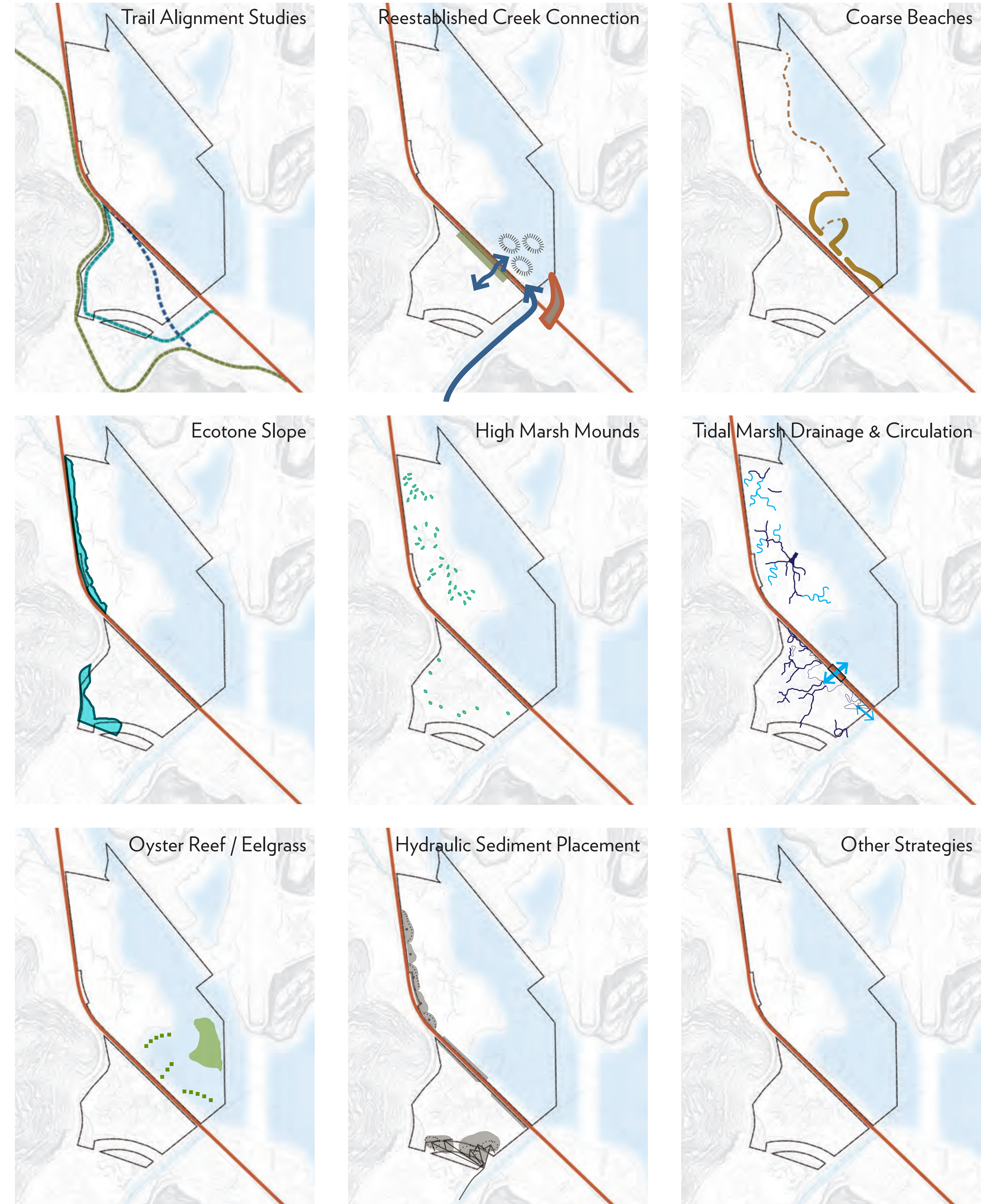
The pages that follow provide brief descriptions of the potential design elements and summaries of the opportunities, constraints, and uncertainties associated with each. The project has also developed preliminary recommendations for how each potential element might be incorporated into potential design alternatives. Each of the potential design elements aligns with one or more of the project planning horizons (Immediate, Near-term, Mid-term, and Long-term) as defined on pages 16-17 of this report and is identified with a label in the upper left-hand corner of the page.

During future planning phases, these design elements will be assembled and combined into project alternatives for more detailed evaluation and comparison. The project alternatives will represent a range of potential approaches and prioritizations of the multiple project goals and objectives.

These alternatives will be evaluated and a preferred alternative will be selected, establishing the design approach that will be advanced to a detailed conceptual level of design and subsequent design phases.

MENU OF POTENTIAL DESIGN ELEMENTS

- Trail Alignment Studies
- Reestablished Creek Connection
- Tidal Marsh Drainage & Circulation
- High Marsh Mounds
- Oyster Reef / Eelgrass
- Hydraulic “Thin-lift” Sediment Placement
- Ecotone Slope
- Coarse Beaches
- Other Strategies



NEAR-TERM
LONG-TERM

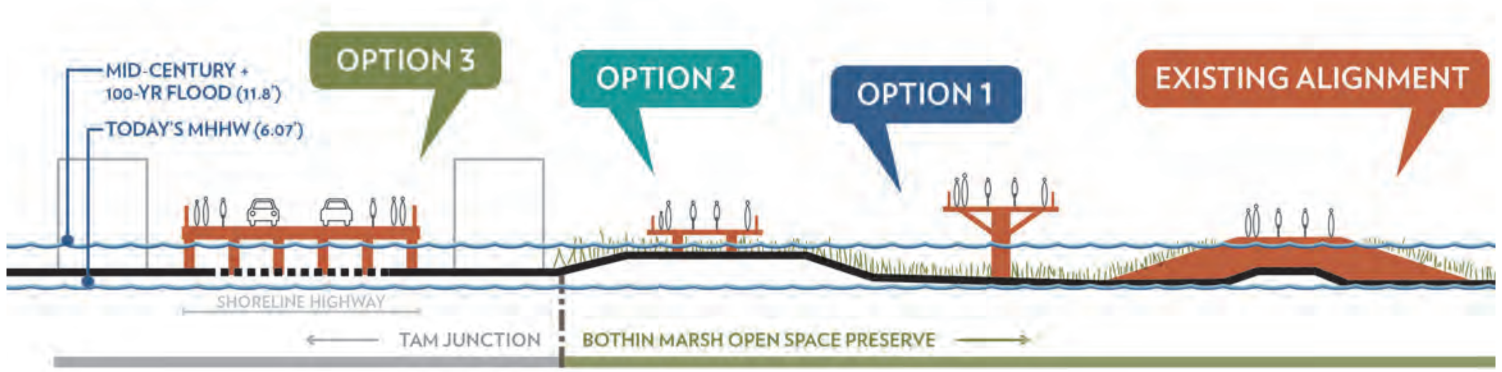
TRAIL ALIGNMENT STUDIES

ALIGNMENT STUDIES

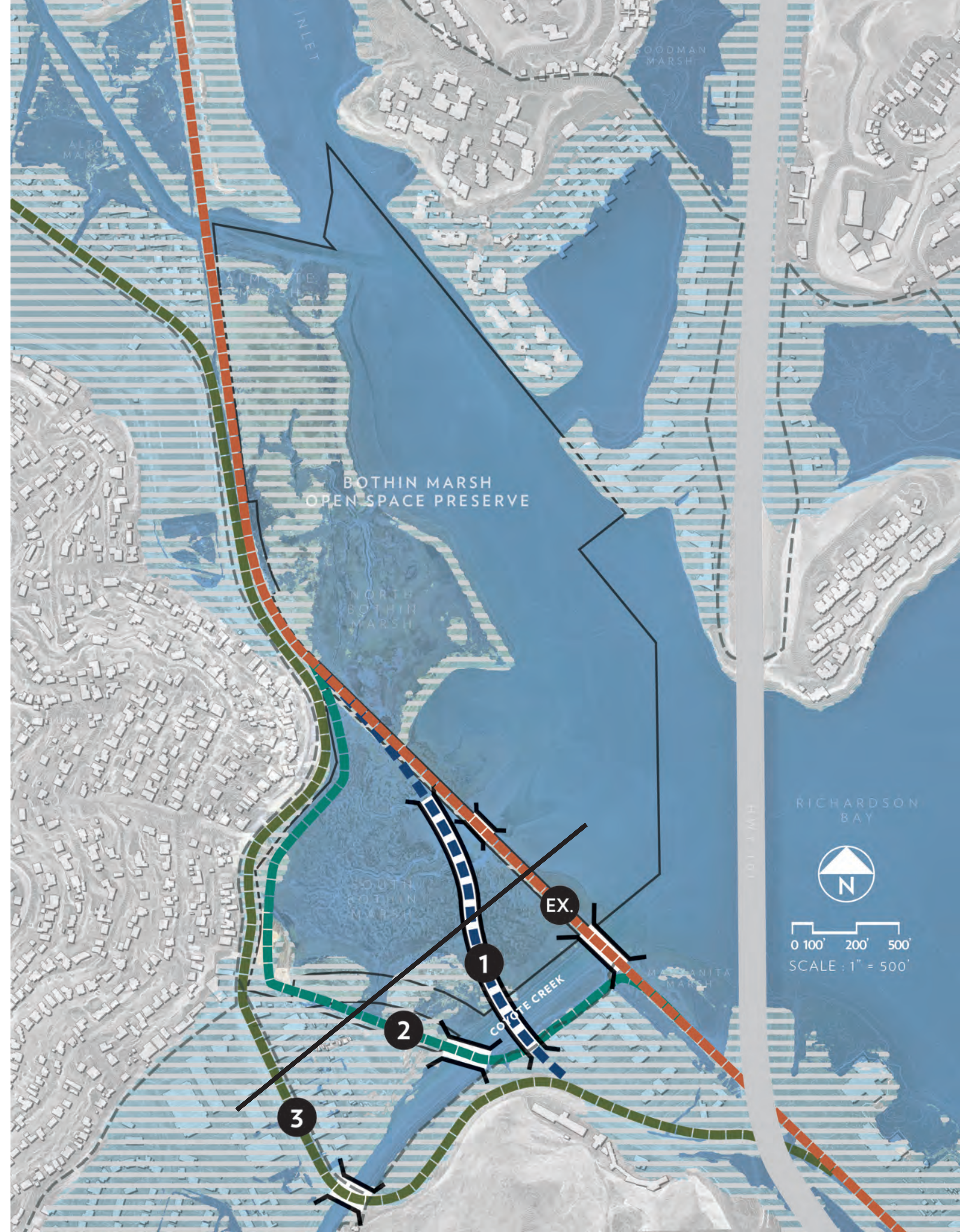
- There are several limitations to keeping the existing Mill Valley-Sausalito Pathway alignment through the Bothin Marsh Open Space Preserve. In order to address concerns related to present-day flooding, trail user conflicts, ecological concerns, and the future impacts of sea-level rise across the shoreline, the following potential trail alignments are being explored and represent high-level conceptual alternatives. The existing alignment, Option 1, and Option 2 are shown in greater detail on the following pages.
- The trail alignment along Option 3 is not shown in detail in this study because the alignment is outside of the preserve, but it is likely that sea-level rise impacts will require a complete street redesign of Almonte Blvd and Highway 1/Shoreline Highway. The project team recommends that this alignment remain in consideration as a long-term trail alignment as the region begins planning for mid-century and end-of-century sea-level rise adaptations.

TRAIL WIDTH STUDIES

- The existing trail width is understood to be inadequate based on the high number of users and number of collisions recorded over time. This study illustrates options that follow Bay Trail Guidelines for shared-use trails, and also explores separated-use trail alternatives.



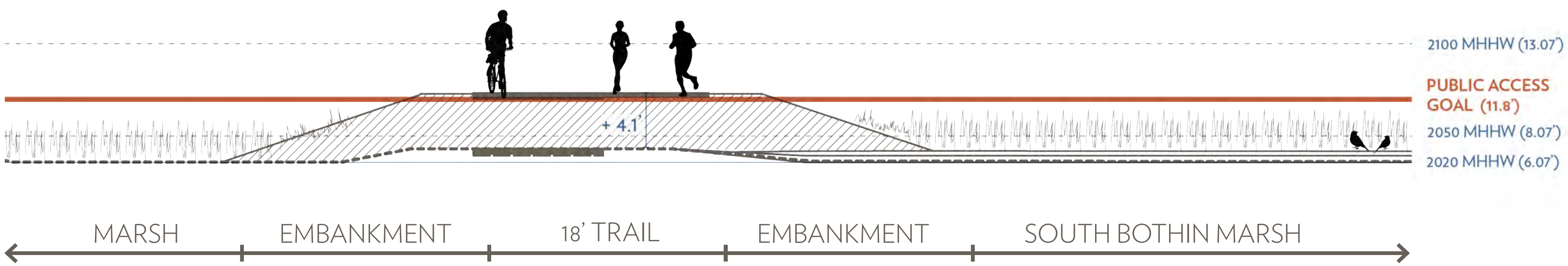
2020 MHHW (6.07')
2050 SLR + 100-YR Flood (11.8')
Bridge or Causeway



TRAIL ALIGNMENT: EXISTING
ENLARGED EMBANKMENT AND BRIDGES

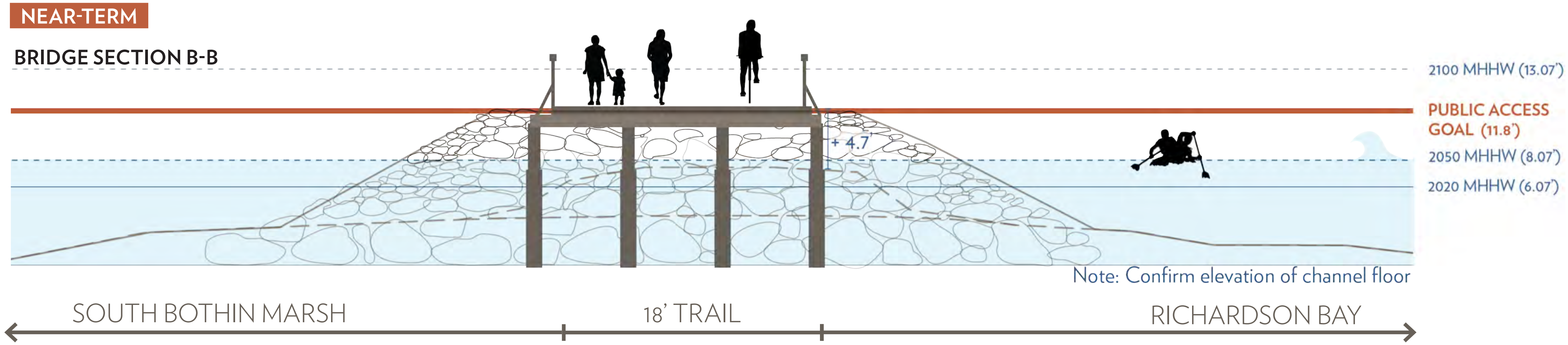
NEAR-TERM

EMBANKMENT SECTION C-C



NEAR-TERM

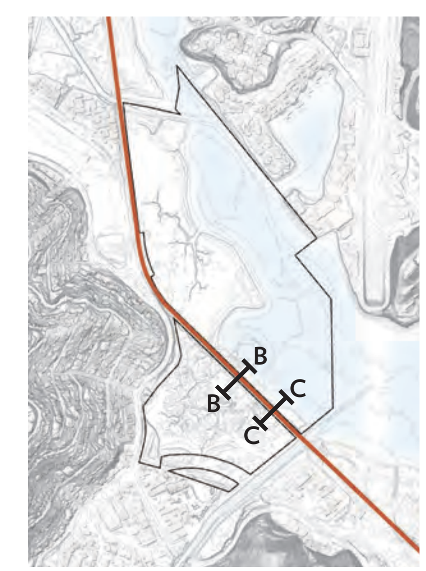
BRIDGE SECTION B-B



EXISTING TRAIL ALIGNMENT

- Trail redesign could build upon the existing foundation as sea levels rise, or elevate it on a causeway
- Existing embankment would continue to protect habitat from high wave energy
- The trail embankment would require 1 or more bridges to convey creek and tidal flows. These bridges would likely need to be longer in length than the existing structures to avoid adverse flooding and ecological impacts
- Raising the trail on a larger embankment would require significant fill and would impact tidal drainage
- Fill placement could impact existing telecom line
- An elevated trail along this alignment should be planned in coordination with the regional approach to active transportation improvements.

KEY PLAN



Sources:

Elevations based on 2019 LiDAR; Tidal datums based on CLE Study; Flood Evelvations based on FEMA 2017 Flood Insurance Study

TRAIL ALIGNMENT: OPTION 1

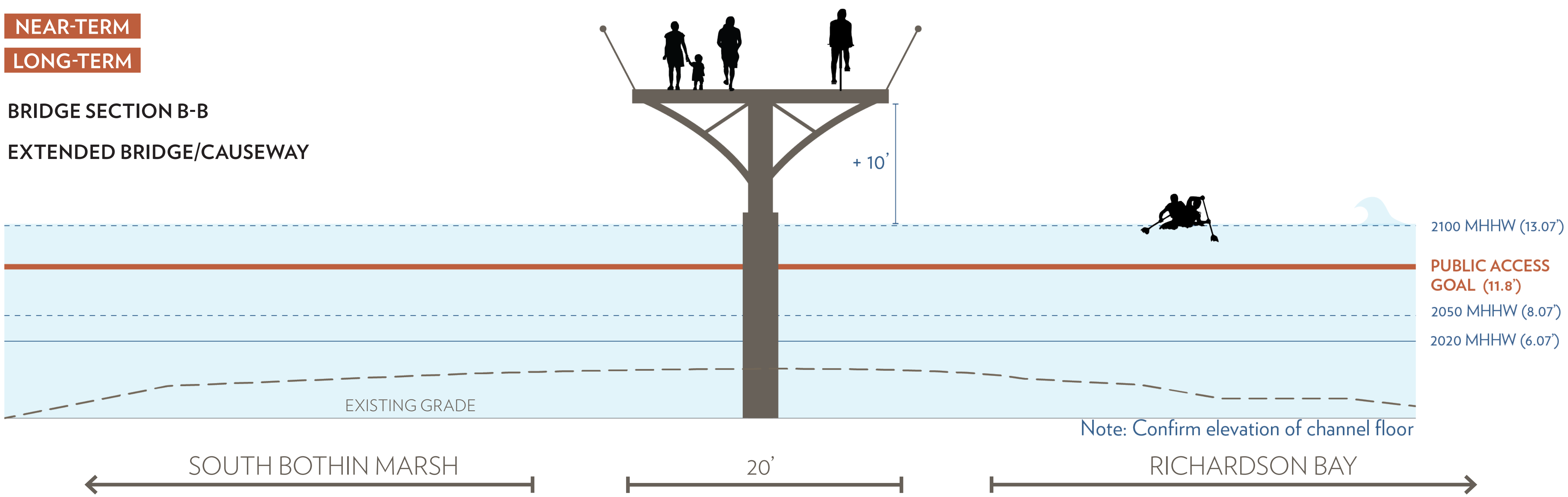
CAUSEWAY CONNECTING HIGH ELEVATIONS

NEAR-TERM

LONG-TERM

BRIDGE SECTION B-B

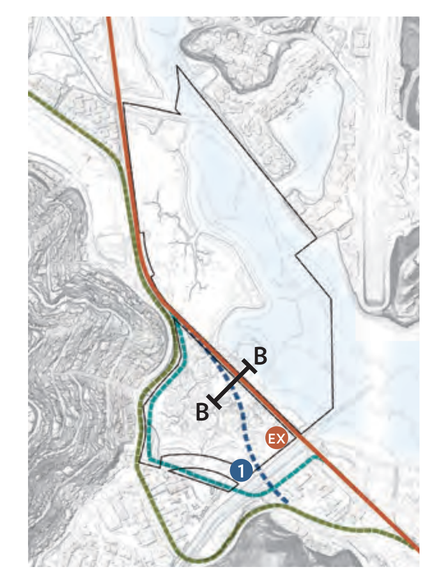
EXTENDED BRIDGE/CAUSEWAY



OPTION 1 - CAUSEWAY

- Would require a new long-span bridge or causeway over South Bothin Marsh and Coyote Creek
- An elevated bridge/trail along this alignment would connect high elevation areas through long-term sea level rise scenarios
- The specific footprint and alignment of this option would need further study in the alternatives phase.
- In this option, the trail along the existing alignment could be abandoned and the embankment could be modfied to enhance ecological and hydrologic connectivity between Richardson Bay and South Bothin Marsh.

KEY PLAN



Sources:

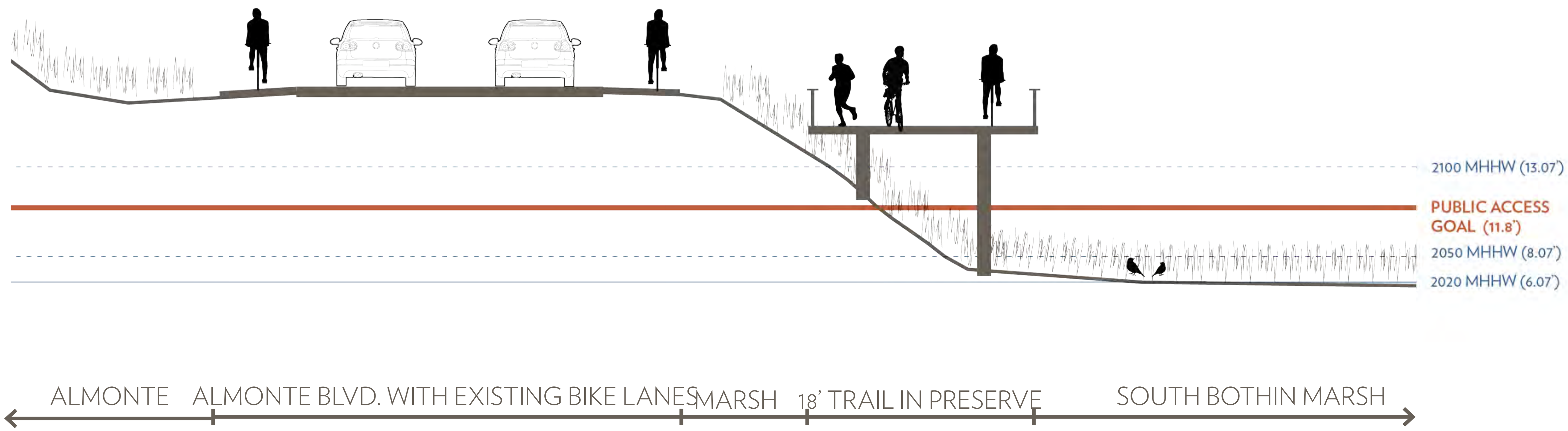
Elevations based on 2019 LiDAR; Tidal datums based on CLE Study; Flood Evelvations based on FEMA 2017 Flood Insurance Study

TRAIL ALIGNMENT: OPTION 2
ALONG THE EDGE OF THE PRESERVE

NEAR-TERM

WITHIN PRESERVE NEAR ALMONTE BLVD.

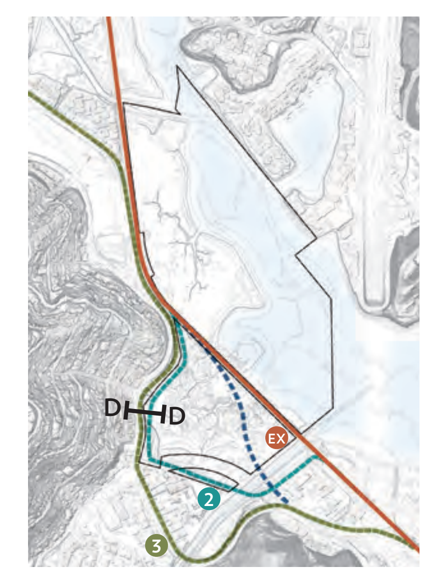
SECTION D-D



OPTION 2 - WITHIN THE PRESERVE

- Trail stays within the Preserve, along an embankment on the high elevation perimeter through long-term sea level rise scenarios
- Could be integrated into an ecotone levee strategy and provide some flood protection to adjacent land uses.
- Would require significant fill and would affect drainage conditions
- Could impact PG&E transmission towers
- Would require a new bridge over Coyote Creek connecting down to the McGlashen Trail
- In this option, the trail along the existing alignment could be abandoned and the embankment could be modfied to enhance ecological and hydrologic connectivity between Richardson Bay and South Bothin Marsh.

KEY PLAN



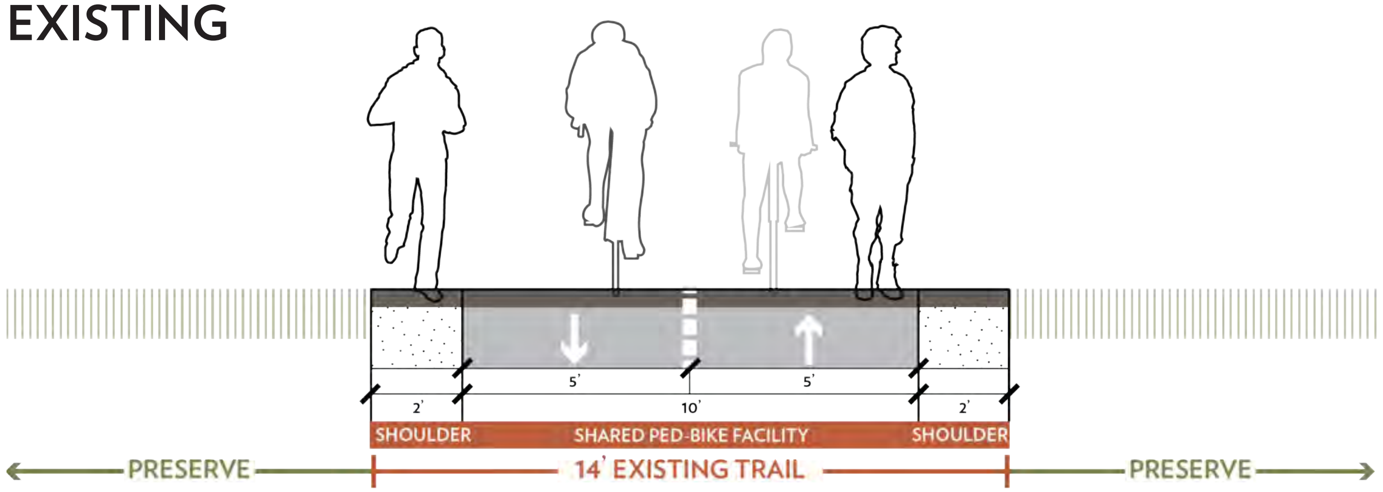
Sources:

Elevations based on 2019 LiDAR; Tidal datums based on CLE Study;

Flood Eevlations based on FEMA 2017 Flood Insurance Study

TRAIL WIDTH OPTIONS

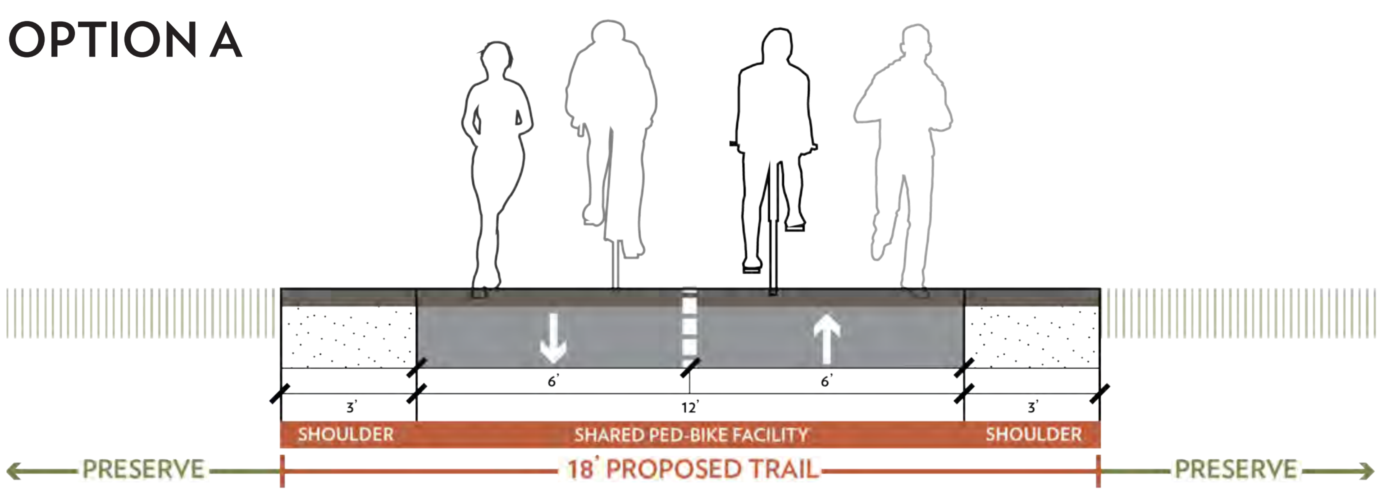
EXISTING



EXISTING TRAIL WIDTHS

The existing trail consists of a 10-foot wide paved path with 2-foot shoulders providing 14' of clearance overall. The existing trail is heavily used and has a history of dangerous collisions.

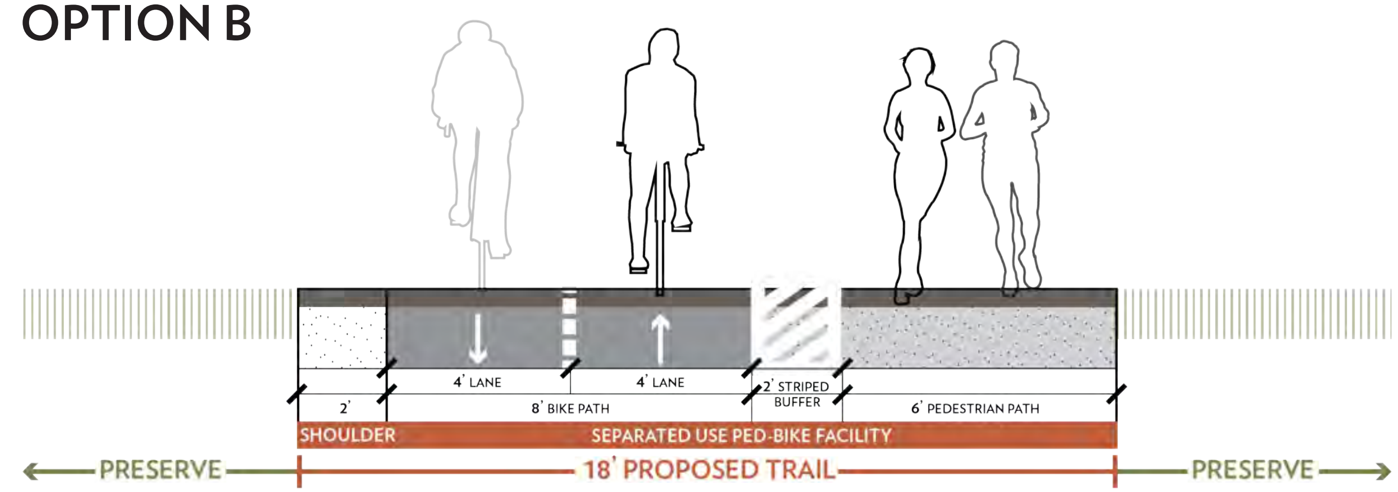
OPTION A



OPTION A : BAY TRAIL DESIGN STANDARD

The 2016 Bay Trail Design Guidelines and Toolkit recommends that typical trail segments provide a minimum of 18' of clearance overall, with at least 12' of paved surface for a shared-use facility. In this case, the shoulders are 3' wide.

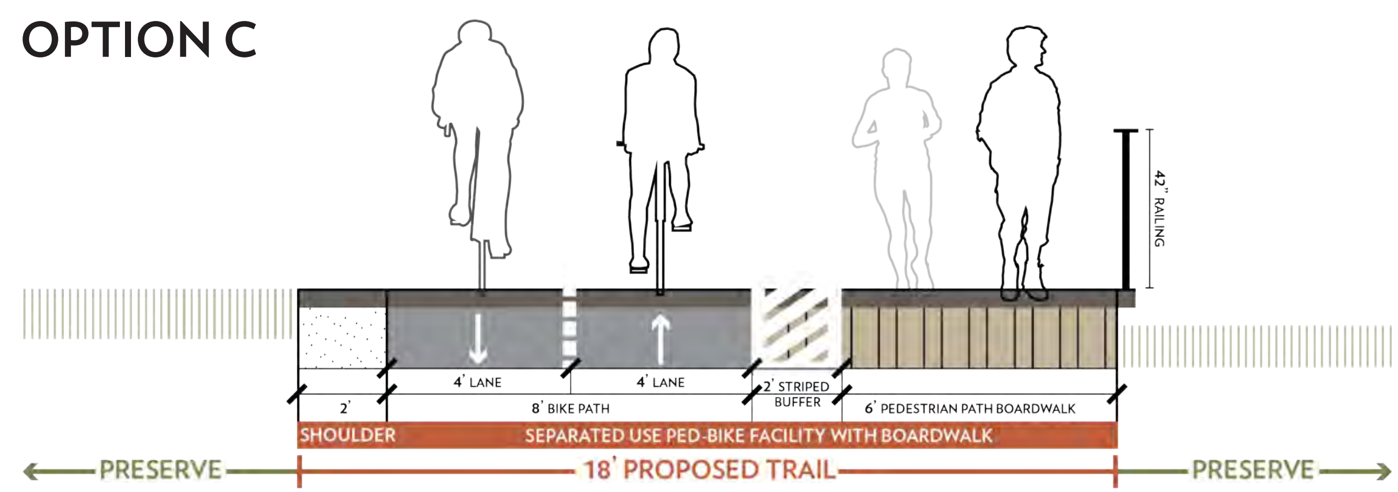
OPTION B



OPTION B: SEPARATED USE

Another option for the trail is a separated-use facility. Within the same 18'-wide clearance recommended by the Bay Trail Guidelines, this option provides a two-way 8' bike path with 2' shoulders and a 6' dedicated pedestrian path. The 2' striped shoulder provides a safe, curbless buffer that provides separation, but still encourages bikers to maintain safe speeds.

OPTION C



OPTION C: SEPARATED USE WITH BOARDWALK

Option 3 provides the same widths for the separated-use facility but includes a boardwalk and railing component for the areas of the trail where there may be an opportunity to elevate the structure above the marsh.

NEAR-TERM

MID-TERM

REESTABLISHED CREEK CONNECTION

NO ACTION

1. WIDEN BRIDGE

2. REDIRECT CREEK MOUTH TO OFFSHORE MUDFLATS

3. LOWER BERM ALONG NORTH COYOTE CREEK

4. SMALL TIDAL CHANNELS BETWEEN CREEK AND MARSH

5. BIFURCATED COYOTE CREEK CHANNEL

6. FULLY DIVERT CREEK THROUGH SOUTH BOTHIN MARSH

OTHER?

REESTABLISHED CREEK CONNECTION

Two creeks border the Bothin Marsh Preserve, Coyote Creek and Arroyo Corte Madera del Presidio. The creeks convey sediment from their upland watersheds into the Bay. Under historic conditions the sediment from creeks deposited in alluvial fans along the upland edge of the bay-fringing tidal marshes, helping to help build and sustain mudflats and tidal marsh habitats. Prior flood protection and reclamation projects have altered the alignments of both creek channels, and now these channels bypass the marshes along the Bay's edge and convey the majority of their stream flow and sediment load directly into Richardson Bay.

Prior studies at Bothin Marsh have identified the potential for benefits to the Preserve's tidal marsh habitats by improving the connection between Coyote Creek and the tidal marshes in South Bothin Marsh (Collins et al., 2018). There are a wide range of potential measures that aim to improve the connection between the creek and marsh and enhance sediment delivery to the tidal marsh habitats, improving the resilience of those habitats to sea level rise. These measures cover a wide range of potential scales ranging from the excavation of small connecting channels to the complete re-alignment of the creek channel. The relative benefits and impacts anticipated for these different measures will need to be carefully evaluated and considered. The long-term evolution of a stream delta in a confined, small tidal marsh may be similar to other examples from the Central Coast region, such as Pine Gulch Creek in Bolinas Lagoon, and Los Osos Creek in Morro Bay, and others. These have generated tidal marsh landforms and dynamics that do not correspond with ecological objectives for Bothin Marsh (relatively planar high salt marsh with no significant development of tidal channels or channel banks, frequent flood disturbance, poor high tide cover), not associated with maintenance or enhancement of rail or bird's-beak habitats. Marsh areas near new creek connections would be periodically disturbed due to sediment deposition during flood events. These periodic deposition events may be detrimental to existing birds beak populations and may fill existing tidal channels that provide rail habitat. Fluvial sediment deposits on former marsh plain can create foraging habitat for shore birds, and over the long term can increase marsh resilience to sea-level rise.

Potential options for re-establishing connections between Coyote Creek and South Bothin Marsh include:

Widening Bridge #2 to increase connection between offshore mudflats and South Bothin Marsh. Potentially modify offshore mudflats and shallows with flow diversion features (e.g. tidal marsh islands or peninsulas) to encourage deltaic deposition on nearby shallow mudflats rather than in the deeper parts of Richardson Bay. Sediments deposited on the mudflats would be available as a source of sediment to the tidal marsh, reducing export of sediment from North Richardson Bay. Wave break features (e.g. reefs) could be incorporated to increase sediment trapping. (Option 1 & 2)

Excavating small channels connecting between the creek and the marsh interior. The size and location of the connecting channels could vary, and the channels may enlarge on their own over time. (Option 3 & 4)

Creating a second creek channel - a distributary channel - through the marsh interior. The current Coyote Creek channel would remain in place. A new bridge would be constructed across the second creek channel. (Option 5)

Fully diverting the creek into a new channel through the marsh interior. Fill would be placed to block the existing creek outlet, and a new channel would be excavated through the existing marsh habitats and discharging to Richardson Bay at Bridge #2. This option has the potential to increase sediment delivery and trapping in the tidal marsh, but also would have extensive impacts to existing marsh habitats. (Option 6)

The outlet of Arroyo Corte Madera del Presidio is relatively well connected to North Bothin Marsh via existing tidal channels, and no significant opportunities to improve connections between that creek and North Bothin Marsh have been identified.

Options 1 and 2 promote indirect sediment delivery from creek to mudflats to marsh whereas Options 3 through 6 promote direct sediment delivery from creek to marsh.

OPPORTUNITIES

- Increase delivery of fluvial sediments to North and South Bothin Marsh.
- Improve tidal drainage in South Bothin Marsh via lower Coyote Creek to support more robust vegetation growth (see also Tidal Marsh Drainage and Circulation below).
- Increase ecological connections and opportunities for wildlife movement between creek channels and tidal marshes.

CONSTRAINTS AND CONSIDERATIONS

- Creek re-connection would require earthwork in sensitive existing habitats, including habitats occupied by rare/special status species, and result in long-term conversion from one habitat type (e.g., high marsh) to another (e.g., shallow open water channel). Temporary and permanent impacts to habitats must be considered.
- The design measures must cause no adverse flood impacts to upstream infrastructure or communities
- Any configuration would need to consider the need for ongoing maintenance dredging in the Coyote Creek channel to maintain flood capacity. Reconfiguration of the creek mouth could potentially increase the environmental impacts or cost of dredging. The lower reaches of Coyote Creek have not historically required frequent maintenance dredging; however, the upper reaches of the creek are periodically dredged to maintain flood conveyance capacity. The project should consider opportunities for beneficial re-use of dredged sediments, and should avoid creek configurations that would increase need for future maintenance dredging.

UNCERTAINTIES

- The extent to which creek reconnection will result in increased marsh sedimentation and resilience. This uncertainty makes it difficult to weigh the potential benefits of reconnection with the readily-quantified drawbacks of direct marsh loss with channel excavation.
- The average sediment yield of the adjacent creeks and the fraction of that sediment that is likely to deposit on the tidal marshes (rather than deposit in upstream channels or flush to the Bay) is challenging to measure or estimate with great certainty. Diversion of sediment

REESTABLISHED CREEK CONNECTION

from existing creek channel into South Bothin Marsh may alter the sediment budget for offshore mudflats and marshes along the Bay edge, potentially aggravating ongoing shoreline erosion.

- The fraction of creeks sediment yield that is likely to travel as suspended load (and could potentially deposit on tidal marshes), or as bed load (and would be unlikley to deposit on tidal marshes).
- The effects of creek connections on the morphological evolution and ecological functions of the tidal marsh habitats in South Bothin Marsh are uncertain. While some increased deposition at South Bothin Marsh would be beneficial, significant sediment deposition could transform the channel-adjacent marsh to a higher, poorly drained and relatively unvegetated deltaic plain. This type of deltaic plain can be seen at the mouth of Wildcat Creek in Richmond and in other systems. Deltaic plain, if it were to occur, would provide high tide shorebird roosting habitat, but would result in a loss of the small tidal channels critical for rails. Large seasonal sediment pulses would create conditions too disturbed for Point Reyes birds beak to persist. Processes that shape the long term habitat outcome are complex and difficult to predict with certainty.

ADDITIONAL STUDIES

- Marin County and Anchor QEA are conducting a parallel project to evaluate potential impacts to flooding and sediment transport processes from reconnecting Coyote Creek to South Bothin Marsh. The outcomes of this study will be informative for the Evolving Shorelines Project.
- Any creek re-connection must be carefully evaluated for flood performance, potential ecological benefits associated with increased sediment supply, and potential ecological impacts associated with habitat type conversions.

LINKAGES WITH OTHER DESIGN ELEMENTS

- The creek connection measures will need to be developed in coordination with any changes to the Bay Trail, with particular attention to the bridges.

PHASING CONSIDERATIONS

- It is likely that many of the uncertainties related to the Creek Connection measures will not be fully resolved in the course of this phase of the project. The STAC suggested that simplified analyses can still be informative and useful to guide prioritization and decision making.

Existing conditions along Coyote Creek, photos taken by project team in 2019.

IMMEDIATE

NEAR-TERM

TIDAL MARSH DRAINAGE AND CIRCULATION

Tidal marshes are strongly influenced by the patterns of drainage and circulation with the rising and falling tides. Increased tide range and improved low tidal drainage provides benefits for salt marsh vegetation productivity, which in turn benefits species living and foraging in the marsh, and increases marsh accretion rates and SLR resilience. Good low tide drainage is important to avoid stressing emergent vegetation and inhibiting plant growth. Tidal circulation is important for exchange of sediment, nutrients and biota in and out of the marsh.

Some areas of the Bothin Marsh Preserve experience poor drainage and circulation compared to healthy tidal marshes. North Bothin Marsh has fewer tidal channels compared to natural tidal marshes, and demonstrates habitat changes indicative of poor drainage of and circulation to the marsh interior, including vegetation die-offs and conversion of vegetated marsh to tidal ponds during recent drought years (ca. 2011-2016). South Bothin Marsh experiences delayed and incomplete low tide drainage due to the small size of the channel at Bridge #2, which is the primary connection between South Bothin Marsh and Richardson Bay. While channel excavation would cause near-term habitat impacts and longterm conversions, it seems likely that drainage improvements can be implemented at select appropriate locations and at appropriate scales to achieve a more balanced distribution of marsh micro-habitats, to increase abundance of specific micro-habitats, and to achieve net habitat diversity benefits.

OPPORTUNITIES

- Establish full low tide drainage in South Bothin Marsh by increasing the depth and width of the Bridge #2 channel and/or by creating new tidal connection channels between the marsh and the Coyote Creek channel.
- Improve interior tidal drainage and circulation in North Bothin Marsh by excavating new tidal marsh channels connecting to poorly drained areas. In addition to providing tidal circulation and drainage benefits, small tidal channels provide foraging areas and movement corridors for fish, birds and other marsh species (including Ridgway's rail).

IMMEDIATE

NEAR-TERM

TIDAL MARSH DRAINAGE AND CIRCULATION

CONSTRAINTS AND CONSIDERATIONS

- Temporary impacts associated with construction access and excavation within existing tidal marsh areas (expected to be limited in extent and duration).
- Permanent, small-scale impacts associated with habitat conversions (eg. conversion from vegetated tidal marsh to tidal channel/open water).
- Certain species benefit from poor marsh drainage, for example certain bird species forage in tidal ponds that form in poorly drained marsh areas. These species could be adversely impacted by drainage improvements.
- Drainage and circulation patterns may change with future sediment deposition or erosion, with sea level rise, due to changes in the tidal prism and due to increased erosion and/or overtopping of the perimeter berms. The project design should anticipate and be compatible with such changes, to extent feasible.
- The new tidal channels would likely be constructed in the interior of the tidal marsh, in close proximity to portions of the site used by Ridgway's rail and California black rail. There is a need to evaluate tradeoffs between habitat type conversions and outcomes for wildlife (eg. marsh pool to marsh plain conversion). Elements should be located to avoid or minimize conflicts with sensitive habitats and rare/special status species.

UNCERTAINTIES

- Some benefits of new channels may be temporary and relative project benefits may be reduced over time as sea-levels rise, for example, the benefits associated with increases in tidal flushing of the marsh plain and reduction in salt concentration (Watson and Byrne 2009).

LINKAGES BETWEEN DESIGN ELEMENTS

- Consider synergies been tidal channel excavation and marsh mound construction. Tidal channels can be constructed with adjacent high tide habitats (marsh mounds) to create adjacent forage and refuge habitats for rails and small mammals.
- Creek connections and Thin-lift sediment placement project elements could alter tidal drainage and circulation patterns. These design elements will need to be coordinated.

Salt pans have formed in North Bothin Marsh in recent years due to poor tidal drainage. Vegetation die-back occurs in poorly drained areas subject to extended periods of inundation, and die back can be exacerbated by elevated salinities that occur during periods of drought. Image Credit: P. Baye

IMMEDIATE

NEAR-TERM

HIGH MARSH MOUNDS

The Bothin Marsh Preserve currently has very little high-tide refuge habitat. These areas are locations where animals living in the marsh can find shelter during higher tides when the majority of the marsh is underwater. Currently, many of the existing refuge areas are near trails and roads, leading to wildlife-recreation conflicts.

High marsh mounds are constructed features that mimic naturally occurring channel-adjacent mounds. High marsh mounds are relatively low-relief mounds constructed on the tidal marsh plain that support plant species with canopies that rise above the high tides. The ground elevation of a marsh mound is slightly above the surrounding marshplain and below the highest tides. Keeping the ground elevation below the highest tides reduces the potential for colonization by undesirable upland vegetation and avoids conversion of jurisdictional wetlands to uplands. Mounds just need to be high enough to support taller high-marsh vegetation (I.e. gumplant).

These features have been implemented and have shown benefits for enhancing habitat diversity in other parts of San Francisco Bay (M. Latta pers. Comm). Marsh mounds can be co-located with new tidal channel creation, reusing excavated channel material to construct adjacent mounds. Other potential sources of fill are the adjacent marshplain and imported fill.

Marsh mounds can be constructed using manual labor to minimize construction-related impacts.

Marsh mounds are likely to provide significant near-term ecological benefits, but like all tidal marsh habitats, marsh mounds are vulnerable to drowning and submergence with rising sea-levels.

The scale of marsh mounds (size of individual mounds, and number and density of mounds) can be adjusted to balance benefits from increased habitat diversity versus the impacts to existing habitats.

IMMEDIATE
NEAR-TERM

HIGH MARSH MOUNDS

OPPORTUNITIES

- Marsh mounds provide high-tide refuge areas for birds and terrestrial marsh species. Mounds could increase habitat diversity and heterogeneity by supporting a greater variety of plant species in the marsh interior.

CONSTRAINTS AND CONSIDERATIONS

- Requires fill placement in existing sensitive habitats, causing short-term impacts to these habitats.

INTEGRATION OF ELEMENTS

- Identified synergies with tidal channel excavation. Channel excavation can be source of fill material for mound construction.
- Marsh mounds require relatively small lead time and investment to construct and could provide immediate ecological enhancements. Mounds could be installed as a permanent enhancement feature, or could be temporary features providing interim benefits before measures requiring longer lead time such as thin-lift sediment placement and creek connections can be constructed.

Low Tide, Muzzi Marsh, Corte Madera

High Tide, Muzzi Marsh, Corte Madera

IMMEDIATE

NEAR-TERM

OYSTER REEF / EELGRASS

Artificial oyster reefs and eelgrass plantings are potential elements that aim to increase the ecological diversity of the shallow subtidal habitats offshore of a tidal marsh. The extents of oyster and eelgrass habitat in San Francisco Bay has significantly decreased over the past centuries due to artificial fill and increased turbidity and sediment deposition resulting from hydraulic mining operations and other upland land use changes.

There have been several recent demonstration projects in San Francisco Bay testing approaches for creating new native oyster habitats and eel grass beds. These demonstration projects are also testing the effectiveness of these habitats for dissipating wave energy and reducing coastal erosion.

These habitats are sensitive to coastal conditions, and only are appropriate within a limited range of depths, salinities, and wave exposure.

OPPORTUNITIES

- These features could increase diversity of nearshore aquatic habitats.
- Native Olympia oysters occur on rip-rap (at existing bridge abutments) at lower intertidal elevation ranges, suggesting potential habitat suitability for this species.
- Potential to provide wave energy dissipation and increase sediment trapping on mudflat.

CONSTRAINTS

- Native oyster survival is best at the lowest inter-tidal elevations. Mudflats off shore of Bothin Marsh may be too high to support productive oyster reefs. Offshore areas at suitable elevations may be too far from the shoreline to provide wave attenuation benefits. Near-shore reefs would provide greater wave attenuation benefits. Such reefs would not support native oysters, but could provide benefits for other marine organisms.
- Oyster reefs and eelgrass beds are most productive under conditions with relatively low turbidity, but most objectives for marsh resilience favor higher turbidity conditions to encourage sediment deposition.

IMMEDIATE

NEAR-TERM

OYSTER REEF / EELGRASS

- Native oysters can experience high mortality during periods of freshwater or brackish conditions. Freshwater flows from Coyote Creek and Arroyo Corte Madera del Presidio can cause low-salinity conditions in the local embayment during periods of prolonged high discharges.
- Marine-based access for construction/installation may be challenging due to shallow bathymetry in north Richardson Bay.

UNCERTAINTIES

- Unclear how to resolve conflicting sediment needs for these aquatic habitat features compared to healthy tidal marshes.
- There have been no studies of native oyster recruitment/survival in this part of Richardson Bay. Conditions in the Bothin Preserve may be different from conditions at prior oyster reef projects in San Francisco Bay. The non-native Atlantic oyster drills may impact any pilot project to establish native oysters.
- The non-native Atlantic oyster drills may impact any pilot project to establish native oysters.

INTEGRATION OF ELEMENTS

- Bridge abutments and other engineered rock slope protection may provide persistent local sub-habitats for native oysters. These hard substrate features should be designed with attention to suitability for oysters and other desired benthic species.

Giant Marsh Living Shoreline Project

IMMEDIATE MID-TERM
NEAR-TERM LONG-TERM

HYDRAULIC "THIN-LIFT" SEDIMENT PLACEMENT

Hydraulic sediment placement uses pumps and hoses to deliver sediment to a tidal marsh or mudflat more rapidly than would occur under natural conditions. A sediment-rich slurry is pumped and discharged onto the marsh or mudflat, and water-to-sediment ratio of the slurry can be controlled to allow the sediment to flow and deposit in a manner similar to natural deposition during a large streamflow event. Hydraulic sediment placement can create landforms that mimic natural alluvial depositional fans.

"Thin-lift" sediment placement refers to the use of hydraulic placement methods to deposit sediment on an existing vegetated tidal marsh in a controlled manner that avoids burying the existing vegetation. Under a "thin-lift" approach, the depth of sediment placement during a given year is limited to a few inches, so that the existing vegetation can grow through and above the newly placed sediment. In this way, sediment can be placed on an existing marsh while avoiding the creation of large unvegetated areas and subsequent temporary habitat loss.

The San Francisco Bay NERR is testing thin-lift sediment placement on small-scale test plots at the neighboring Manzanita Marsh, (located ¼ mile southeast of the Preserve) as part of a nation-wide study. Outcomes from the NERR study could inform future pilot projects.

OPPORTUNITIES

- Engineered sediment placement can raise ground elevations and improve sea-level rise resilience in both inter-tidal and adjacent transitional and upland areas.
- Proposed hydraulic dredging on Coyote Creek could provide a local source to supply hydraulic slurry sediment placement at Bothin Marsh.
- Hydraulic sediment placement can mimic natural sediment deposition processes, resulting in landforms that are suitable for native tidal marsh vegetation communities.
- Hydraulic sediment placement can be performed gradually in "thin-lifts" that avoids burial of existing marsh vegetation (burial depth can be limited to below the canopy height of perennial salt marsh vegetation). This allows the existing habitats to recover faster for thin-lift projects compared to traditional, thicker fill placement methods that burry and kill the majority of the existing vegetation in the fill placement area.

IMMEDIATE MID-TERM NEAR-TERM LONG-TERM

THIN-LIFT SEDIMENT PLACEMENT

CONSTRAINTS AND CONSIDERATIONS

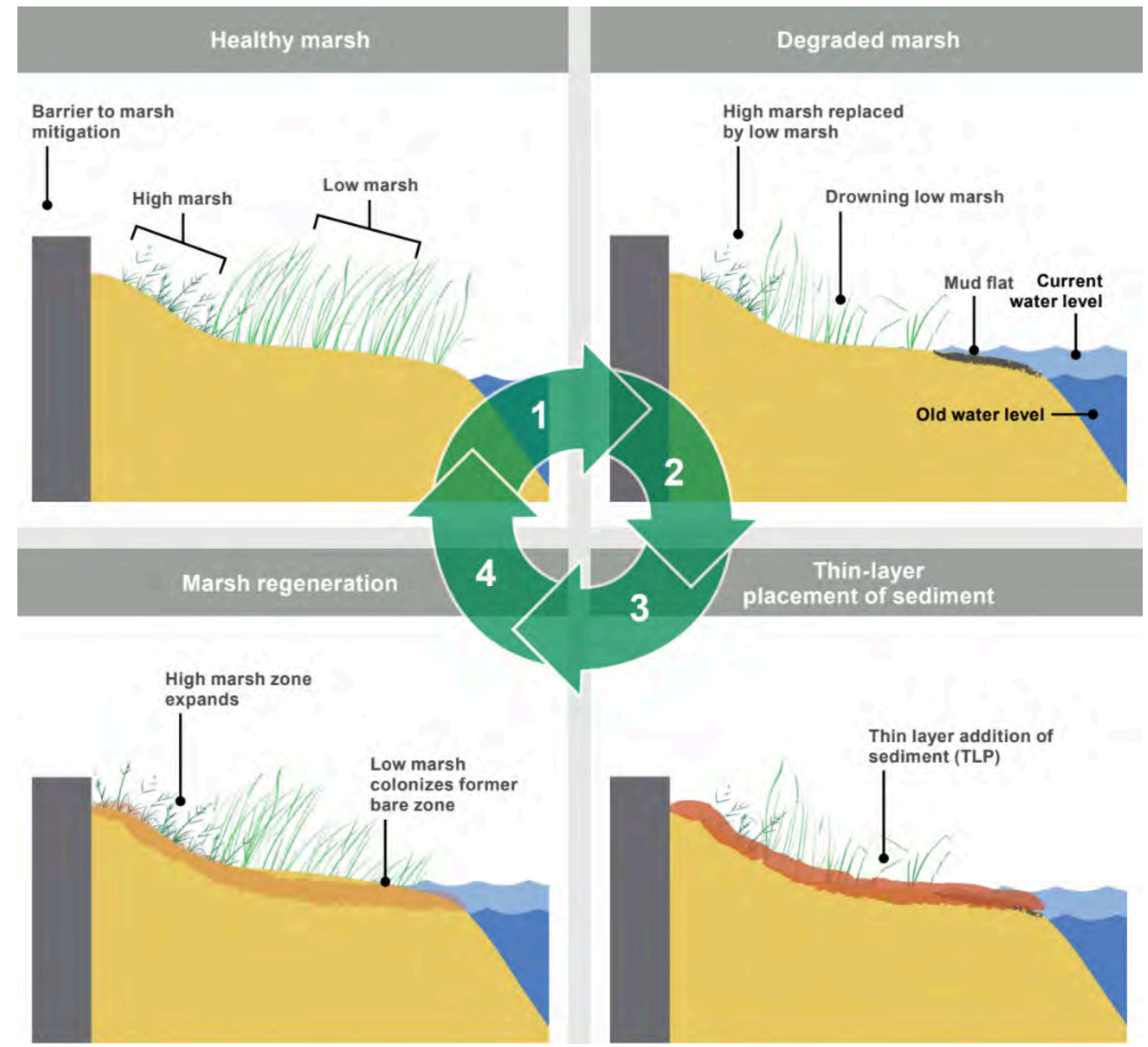
- Sediment placement can be staggered in both time and space to minimize near-term impacts to habitats. Application of sediment in staggered patches (alternating placement and preserved areas) may facilitate recovery and recolonization of sediment-disturbed patches and can preserve non-impacted habitats near impacted areas in order to maintain stable populations of sensitive species.
- There are no examples of thin-lift placement on a large scale in an existing tidal marsh in San Francisco Bay. The project would likely be considered a “Pilot Project” and would require extensive monitoring and adaptive management.

UNCERTAINTIES

- There is limited information on methods and best practices for thin-lift sediment placement to minimize impacts/maximize long-term benefits.
- Need to identify reliable, long term sediment supply and funding sources to allow for repeated lifts over several years or decades.
- Need to better understand risk of placed material eroding/washing to Bay. What trapping efficiency would be acceptable? Are there potential impacts (or benefits) to downstream/offshore areas?

INTEGRATION OF ELEMENTS

- Design elements that restore natural sediment delivery processes, such as creek re-connection, should be considered first. If natural-processes approaches are found to be unable to provide sufficient benefits to marsh resilience, then engineered sediment placement options, including thin-lift placement, should be considered. Thin-lift placement is particularly valuable as this method can increase the resilience of high marsh and marsh to upland ecotone transition habitat types that are more difficult or impossible to support via natural estuarine or fluvial deposition.



Source: National Estuarine Research Reserve Association

IMMEDIATE MID-TERM
NEAR-TERM LONG-TERM

ECOTONE SLOPE

An "ecotone" refers to a transition between two habitat types or biological communities. Ecotones are found around the edges of tidal marshes where the landscape transitions from marsh habitats to upland habitats. Tidal marsh ecotones provide essential services for rails and terrestrial animals by providing safe refuges during high tides when the tidal marshes are submerged. An ecotone slope can be constructed along the Bay-facing side of an engineered levee or embankment in order to create a wider band of transition zone and high marsh habitat than would be provided by a typical engineered fill slope.

Ecotone slopes can support valuable marsh to upland transition-zone habitats in the near term, and provide space for tidal marshes to transgress with rising sea-levels. There are few existing ecotone slopes at the Preserve and little terrestrial space to create them, since most of the higher perimeter of the marsh has been developed. To avoid impacts to existing high-value habitats, ecotone slopes are best constructed where poor-quality transition zones exist (weed uplands, rubble).

Low-value, weedy lowland terrestrial fills suitable for grading into wide ecotone slopes exist at the west end of South Bothin Marsh. Ecotone slopes can be created here with minimal impacts to existing high-value habitats. Some of these areas are outside of the County-owned Preserve, and so are not included in the current planning study.

In North Bothin Marsh, much of the available area for ecotone slope creation is high-value, high-diversity high salt marsh occupied by special-status plants (bird's-beak). The project will want to avoid extensive fill over these areas, yet without any fill these high-value habitats are vulnerable to loss with sea-level rise. Ecotone slope creation at North Bothin could be phased as a series of smaller thin-lift sediment fans. This would avoid extensive fill and allow vegetation and wildlife recruitment to the fill areas from adjacent undisturbed areas. Fans could continue to be created in a phased approach, over time, improving overall marsh resilience.

Constructed ecotone slopes can be designed to incorporate subsurface application of treated wastewater as a source of irrigation water to support native brackish wetland vegetation. Filtering of treated wastewater through an ecotone slope also provides water quality treatment benefits. Water quality treatment wetlands could incorporate lessons learned from the Oro Loma "Horizontal Levee" pilot project.

IMMEDIATE MID-TERM
NEAR-TERM LONG-TERM

ECOTONE SLOPE

OPPORTUNITIES

- Create ecotone slopes in low-value, weedy terrestrial fills or, in higher-value salt marsh areas, use a phased approach to add resilience while minimizing impacts.
- Opportunities for ecotone slope creation exist in areas where new upland fill placement may be otherwise unavoidable; for example, adjacent to potential new trail embankments.
- Integration of treated wastewater into an ecotone slope could be explored in coordination with nearby wastewater treatment facilities in Mill Valley.

CONSTRAINTS AND CONSIDERATIONS

- There is little terrestrial space for ecotone slope creation at most of the Bothin Marsh Preserve.
- Ecotone slopes require more fill and have a larger footprint compared to traditional steep-sloped embankments. Several regulatory policies for fill placement in tidal wetlands and waters encourage projects to minimize fill volume and footprint to the extent feasible.
- Single-event construction of ecotone slopes in existing high tidal marsh would likely have excessive near-term adverse ecological impacts unless located in existing upland or degraded areas. Create ecotone slopes opportunistically in areas where impacts are already unavoidable (e.g., for trail improvements) or where fill can be justified given anticipated long-term benefits.

UNCERTAINTIES

- The nearby Mill Valley Sewage Treatment Plant is a potential source of treated wastewater, but the feasibility of treated wastewater delivery to North Bothin Marsh across Arroyo Corte Madera del Presidio is currently unknown.

PROJECT PHASING

- Consider use of methods like gradual construction by staggered/phased thin-lift sediment deposition in pace with sea-level rise, and to minimize ecological impacts.

China Camp valley grassland ecotone with prehistoric tidal salt marsh. Species include Pickleweed in the tidal marsh, Baltic rush and creeping wildrye in the moist transition zone, with scattered coyote brush, poison oak, California rose. Peter Baye, 2008.

Horizontal Levee Project at Oro Loma Sanitary District, ESA, 2019.

IMMEDIATE

NEAR-TERM

COARSE BEACHES

The fine-grained estuarine sediments (clays and silts) present at the site offer very little resistance against wave-induced erosion on wave-exposed shorelines, such as those along the southeast-facing shorelines of Bothin Marsh. Coarse sediment beaches, made of materials such as shell, sand, or gravel, can provide protection against marsh edge erosion. Coarse sediment beaches can adjust to a cross section geometry that is stable under higher estuarine wave energy. The highest elevation portions of the beach can support tidal marsh vegetation, and these salt marsh beach berms can provide valuable habitat and wave attenuation benefits.

Coarse sand and gravel beaches are usually depositional during periods of high, steep waves that otherwise erode marshes and fine sand, allowing them to migrate landward and build to higher elevations with rising sea-levels where their sediment supply is sustained. While not present within the immediate project area, pocket beaches historically occurred in west-facing Richardson Bay shorelines near the location of Bothin Marsh.

Aramburu Island and Sanctuary Beach provide local reference sites, and ongoing monitoring at these locations could help resolve uncertainties.

The rate of sediment loss can be reduced by using appropriate sediment sizes and by incorporating structural features like rock headlands, and rock or wood groyne structures. Periodic maintenance and nourishment may be advisable to replace beach material that is transported to offshore or downdrift areas.

OPPORTUNITIES

- Some bay-edge salt marsh and levee scarps that exhibit long-term indicators of net erosion could be converted to beach-edged marshes that develop high salt marsh berms like natural levees, with associated habitat benefits.
- While not at risk of erosion, the rocky, compacted fill of the Bay Trail (old railroad) embankment is a potentially receptive shore for coarse beaches like those that historically occurred in the vicinity. The old railroad embankment is likely to be retained even if the trail is relocated, its large boulders are difficult to remove and the embankment provides wave attenuation and sediment trapping benefits for South Bothin Marsh. Creation of a coarse beach along the eastern slope of the embankment would provide beach berm habitat. This would be particularly valuable if the trail is realigned, as the created habitat would be more secluded from human disturbance.
- Coarse sand and gravel beaches rise with sea level if supplied with sufficient sediment.

IMMEDIATE

NEAR-TERM

COARSE BEACHES

CONSTRAINTS

- Depending on the shoreline geometry and wave climate, beaches may gradually lose coarse sediment due to longshore or offshore transport.

UNCERTAINTIES

- Still learning about the ecological function of constructed beaches.
- Need to identify suitable source of coarse sediment.
- Period maintenance is likely to be required and ability to source material and maintenance costs are unknown.
- Future funding source for maintenance.
- Need to better understand coastal erosion rates and offshore/nearshore wave conditions. The NERR's Richardson Bay sonde data might be useful if wind, wave, or turbidity data is measured. Otherwise it is not apparent whether wind speed/direction data exists in the vicinity (Crissy Field is closest known long-term wind gage).

ADDITIONAL STUDIES

- Evaluate shoreline erosion rates along the Preserve coastline, and identify areas of greatest concern where ongoing erosion is most likely to cause loss of marsh habitats (e.g. rapid erosion of exposed tidal marsh, or erosion leading to imminent loss of high marsh providing high tide refuge habitats).

INTEGRATION OF ELEMENTS

- If the Bay Trail is relocated from its present alignment, the existing trail embankment could be reconfigured to support a new coarse beach.

Coarse beach at Aramburu Island, ESA, 2013.

OTHER STRATEGIES

This section describes additional potential strategies that were identified in collaboration with the STAC to be considered for incorporation into the project alternatives.

POTENTIAL STRATEGIES

- Vegetation management should be considered as an integral component of all measures, since all measures involve actions that result in bare disturbed substrate subject to new colonization by estuarine marsh plants. Passive, spontaneous colonization of disturbed, bare sediment by the local estuarine flora is influenced by high "seed rain" by only a few dominant native species and non-native weeds, which by itself may not maintain the characteristic high native species diversity of Bothin Marsh that has accrued over decades. The seed rain at Bothin Marsh is loaded with wetland weeds from outside the Preserve, but only small loads of seed from the some of the less prevalent native species. Vegetation management can vary in scope and scale. A minimal approach might be limited to repairing areas affected by construction. A larger scale approach could include targeted or broad removal of invasive weeds, and landscape-scale seeding or planting of uncommon, rare and/or high value native plants.
- Consider planned trail flooding for the Bay Trail. One option might be to establish an alternate trail alignment at higher elevation, but leave the existing trail in place. Acknowledge that the existing trail won't always be accessible, but will still provide value during lower tides. This is similar to seasonal trail restrictions used at other Bay trails. Meanwhile, the new alignment would be accessible at all tide levels. Plan for eventual abandonment of the existing trail at the end of its useful life.

4. REFERENCES

LIST OF REFERENCES

Anderson, M., and Michael Moratto. "Native American Land-Use Practices and Ecological Impacts." *University of California, Davis, Centers for Water and Wildland Resources 2* (January 1, 1996): 187–206.

SFEI & SPUR. *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. 2019.

Collins, Laurel, Peter Baye, and Joshua Collins. "Bothin Marsh Geomorphology, Ecology, And Conservation Options," 2018. https://www.onetam.org/sites/default/files/pdfs/BothinMarshGeomorphologyEcologyandConservationOptions.pdf.

Latta, Marilyn. "RE: Bothin STAC Meeting #1" Email, 2020.

Leventhal, R. and Baye, P. "Coyote Creek to Bothin Marsh Dredge Sediment Reuse Feasibility Study". January 30, 2017.

Miller Pacific Engineering Group. "Foundation Report Mill Valley-Sausalito Path Bridge Planning Project. Federal Project No. 5927(051) Caltrans District 4, Mill Valley, CA." Project 1665.031. Report prepared for California Infrastructure Consultancy. June 6, 2017.

Moratto, Michael J., and David Allen Fredrickson. *California Archaeology.* Academic Press, 1984.

NCE. "Mill Valley-Sausalito Trail Maintenance Recommendations." November 12, 2019.

Nelson, Nels C. *Shellmounds of the San Francisco Bay Region*. Berkeley: The University press, 1909. https://catalog.hathitrust.org/Record/100170034.

One Tam. "Evolving Shorelines: Vision For The Future." Accessed June 18, 2020. https://www.onetam.org/sites/default/files/pdfs/Evolving%20Shorelines_VisionForTheFuture_BothinMarsh_FINAL_WEB.pdf.

Philip Williams & Associates (PWA). "Reassessment of Coyote Creek Channel Management Requirements". Report prepared for Marin County Flood Control and Water Conservation District. January 10, 2005.

PWA. "Feasibility Study: Lower Coyote Creek Flood Management and Marsh Enhancement Project". Report prepared for Marin County Flood Control and Water Conservation District. September 1, 2009.

San Francisco Estuary Institute-Aquatic Science Center. "Changing Channels: Regional Information for Developing Multi-benefit Flood Control Channels at the Bay Interface". A SFEI-ASC Resilient Landscape Program report developed in cooperation with the Flood Control 2.0 Regional Science Advisors, Publication #801, San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA. 2017.

Stralberg, Diana, Matthew Brennan, John C. Callaway, Julian K. Wood, Lisa M. Schile, Dennis Jongsomjit, Maggi Kelly, V. Thomas Parker, and Stephen Crooks. "Evaluating Tidal Marsh Sustainability in the Face of Sea-Level Rise: A Hybrid Modeling Approach Applied to San Francisco Bay." *PLOS ONE* 6, no. 11 (November 16, 2011): e27388. https://doi.org/10.1371/journal.pone.0027388.

Watson, Elizabeth Burke, and Roger Byrne. "Abundance and Diversity of Tidal Marsh Plants along the Salinity Gradient of the San Francisco Estuary: Implications for Global Change Ecology." *Plant Ecology* 205, no. 1 (2009): 113–28.

Watson, Elizabeth, and Roger Byrne. "Recent (1975-2004) Vegetation Change in the San Francisco Estuary, California, Tidal Marshes." *Journal of Coastal Research* 28 (January 1, 2012): 51–63. https://doi.org/10.2307/41331989.