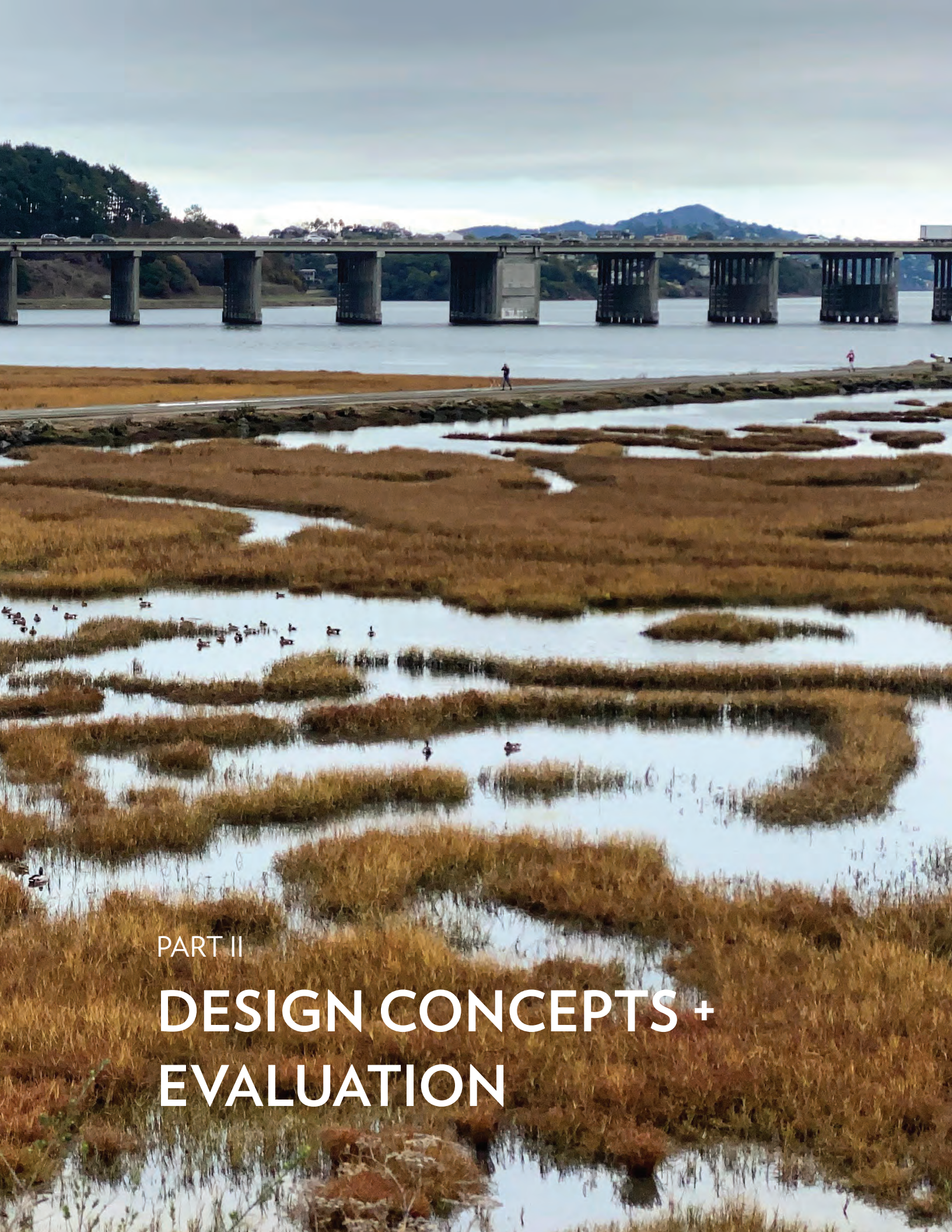
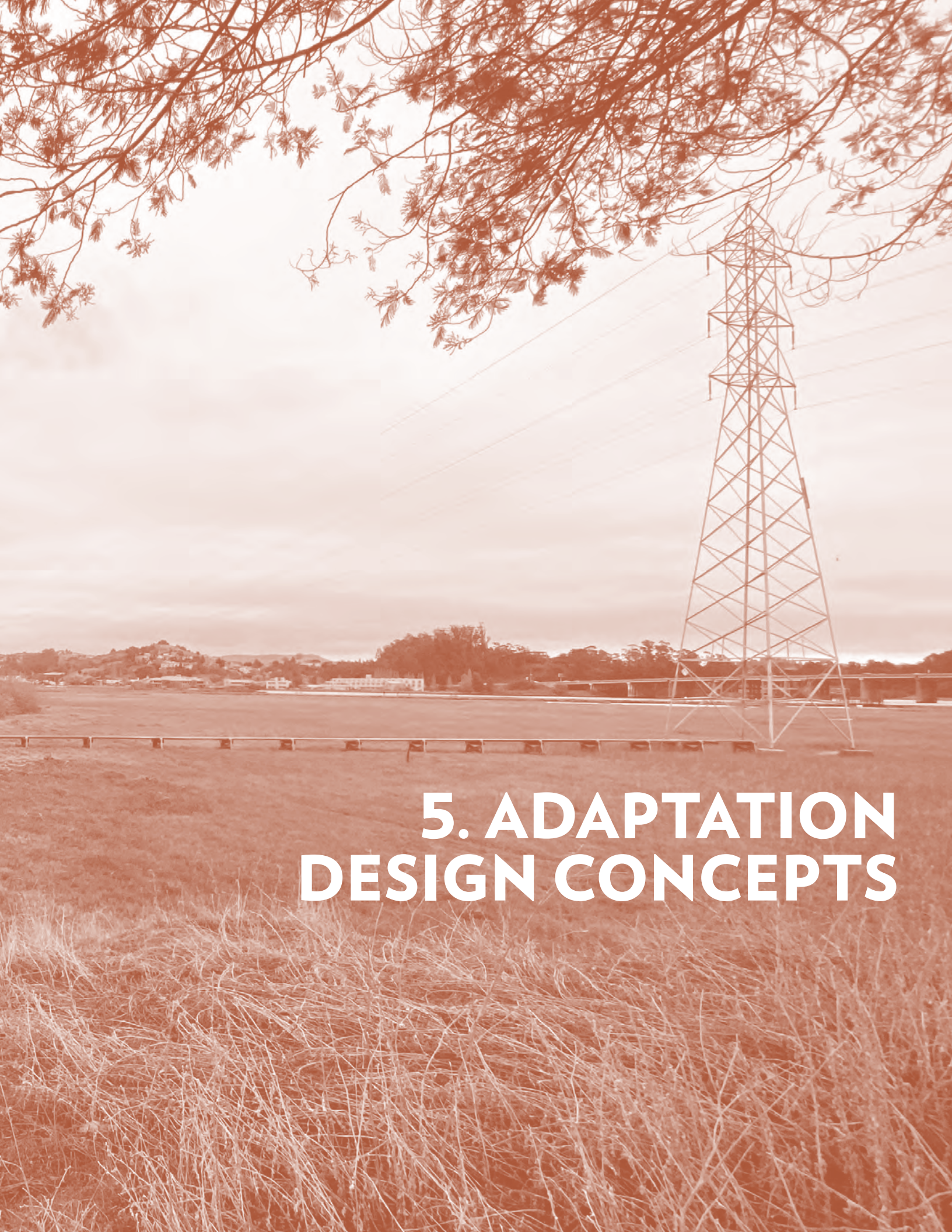


PART II

# DESIGN CONCEPTS + EVALUATION



# 5. ADAPTATION DESIGN CONCEPTS

# ADAPTATION DESIGN CONCEPTS

Three adaptation design concepts for the Bothin Marsh Open Space Preserve were developed by the design team to explore nature-based solutions that improve the ecological conditions within the Preserve while also providing resilient trail access in the near future through mid-century, and potentially beyond to end of century. To prevent continued flooding and interruptions to public access which exist in a no-action scenario, each of the concepts explore options for the alignment and elevation of the multi-use path and is designed to meet the 2050 public access resilience goals guided by the California Ocean Protection Council (OPC) state Sea-Level Rise Guidance and the Bay Conservation and Development Commission (BCDC). The design development also considers the potential adaptability of the proposed infrastructure into the future as sea levels continue to rise. (See Part 1 for more about the project planning horizons).

All three concepts include an elevated and widened multi-use path to accommodate the high volume of users and diversity including cyclists, pedestrians, dogwalkers, students, equestrians. All design concepts also explore measures to improve the health of the marsh and augment the marsh's natural processes to adapt to sea level rise, including ecotone slopes along the edges of the proposed trail embankments, and other measures described in more detail in the marsh resilience measures section of the report. The resilience of the marsh depends on a variety of measures to keep pace with sea level rise and maintain important habitat throughout the century. The marsh resilience measures are evaluated in greater detail in the Design Evaluation Chapter that follows.

This chapter describes the potential pros and cons of each of the three design concepts with an emphasis on the trail elevation and alignment and corresponding marsh resilience measures. The Community Feedback Chapter will summarize the feedback received from the community via presentations and surveys, and the Design Evaluation & Next Steps Chapter will provide more detail on the trail alignment and broader marsh resilience measures evaluation and will discuss the next steps for the project, including the preliminary design of the trail and marsh resilience measures.


*Existing conditions at the Bothin Marsh Open Space Preserve*

# ADAPTATION DESIGN CONCEPTS

## NO ACTION SCENARIO

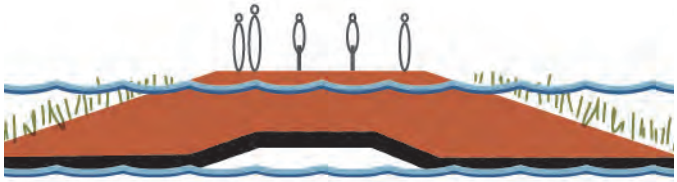
### 2100 +7' SEA LEVEL RISE

LONG-TERM

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

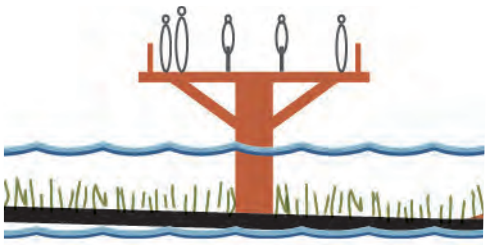
## 1 RAISE THE TRAIL IN PLACE

The trail follows the present-day alignment, but is built up on an embankment to keep pace with sea level rise.

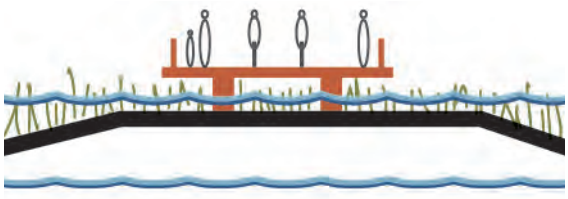
## 2 SPAN THE MARSH

The trail follows the present-day alignment, but is built up on a causeway structure to span the marsh below.

## 3 RING THE MARSH

The trail is moved to the edge of the Preserve, allowing the marsh to be reconnected to the bay.

# CONCEPT 1: RAISE THE TRAIL IN PLACE

## CONCEPT OVERVIEW

The first adaptation design concept, "Raise the Trail in Place," explores keeping the trail along the present-day alignment in South Bothin Marsh and elevating and widening it on an earthen embankment to prevent future trail flooding. Bridges would be replaced and extended to accommodate more tidal flows from South Bothin Marsh to the bay. Today, the trail bisects North and South Bothin Marsh at an elevation that already floods more than 30 times per year.

## USER EXPERIENCE

Elevating and widening the trail improves the safety and longevity of the trail for all users through mid-century sea level rise projections. The future trail would be raised between 3 to 5 feet depending on current elevations. The shoulders of the trail would be vegetated and sloped to limit erosion and to protect the marsh. The view extent to the adjacent marsh and bay would increase.

## ECOLOGY

The raised embankment would have impacts on ecological processes that support marsh habitat. Its footprint would be wider than the current trail due to the required slopes of the embankment structure and the widened path surface. In many areas, especially in North Bothin Marsh, high marsh ecotone slopes along the trail embankment would provide more uplands for the marsh to migrate in the future. However, the raised embankment through South Bothin Marsh would further separate the marsh from the bay and would create a challenging barrier for the movement of wildlife, tidal flows, and sediment.

## CONTEXT

In all three concepts, the connection between the raised Bay Trail within the Preserve, and any adjacent connections to roads and trails will need improvements. In this concept, the connection to the McGlashan Path would need to be improved to accommodate the new bridge across Coyote Creek and the associated ramp along the pathway. The trail segments along North Bothin Marsh and adjacent to Miller Avenue in Mill Valley have the potential to be coordinated with future flood control measures. Partnerships would be necessary to fund further study.

TRAIL & USER EXPERIENCE

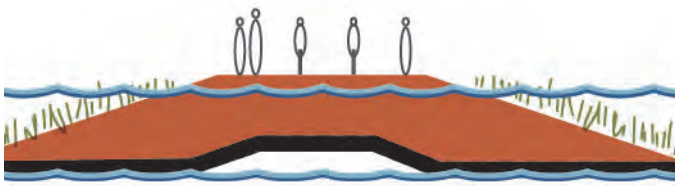
ECOTONE SLOPE & MARSH IMPROVEMENTS


MILL VALLEY
GOODMAN MARSH
ALTO MARSH
ARROYO CORTE MADERA DEL PRESIDIO
ALMONTE MARSH
SHELTER BAY
NORTH BOTHIN MARSH IMPROVEMENTS
STRAWBERRY MANOR
BOTHIN MARSH OPEN SPACE PRESERVE
IMPLEMENT ECOTONE SLOPE IN NORTH BOTHIN MARSH
ELEVATE PATHWAY ALIGNMENT
NORTH BOTHIN MARSH
EXISTING ON-STREET BIKE LANES
BUILD UP THE EMBANKMENT ALONG SOUTH BOTHIN MARSH
ALMONTE
SOUTH BOTHIN MARSH IMPROVEMENTS
WIDER BRIDGE SPAN IMPROVES MARSH DRAINAGE
Mill Valley - Sausalito Pathway
Bay Trail
RICHARDSON BAY
SOUTH BOTHIN
NEW CONNECTIONS ALONG COYOTE CREEK
0 100' 200' 500'
MANZANITA MARSH
COYOTE CREEK
Charles McGlashan Pathway
MCGLASHAN PATH SLOPES UP TO MEET NEW TRAIL ELEVATION
TAM JUNCTION
MANZANITA
MARIN CITY
Bay Trail

# CONCEPT 1: RAISE THE TRAIL IN PLACE

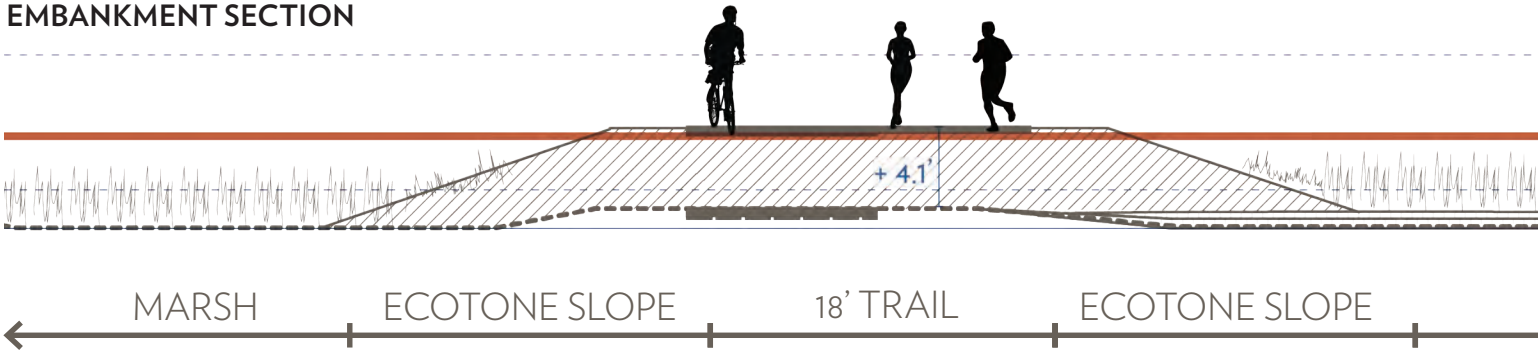
## 1 RAISE THE TRAIL IN PLACE

The trail follows the present-day alignment, but is built up on an embankment to keep pace with sea level rise.

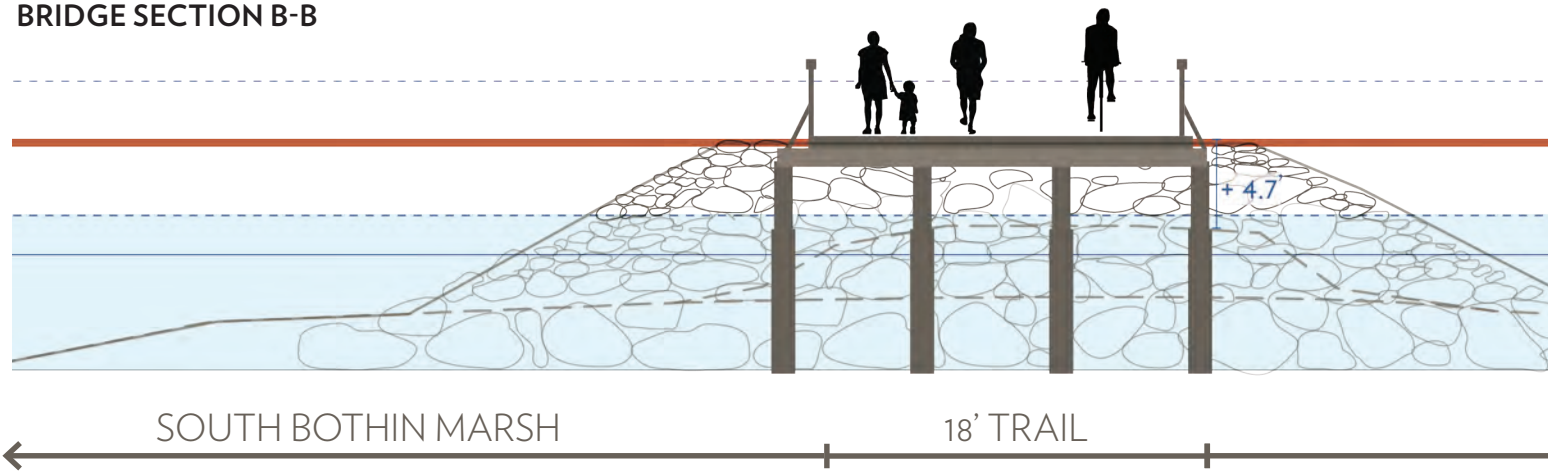



# CONCEPT 1: RAISE THE TRAIL IN PLACE

**EMBANKMENT SECTION**



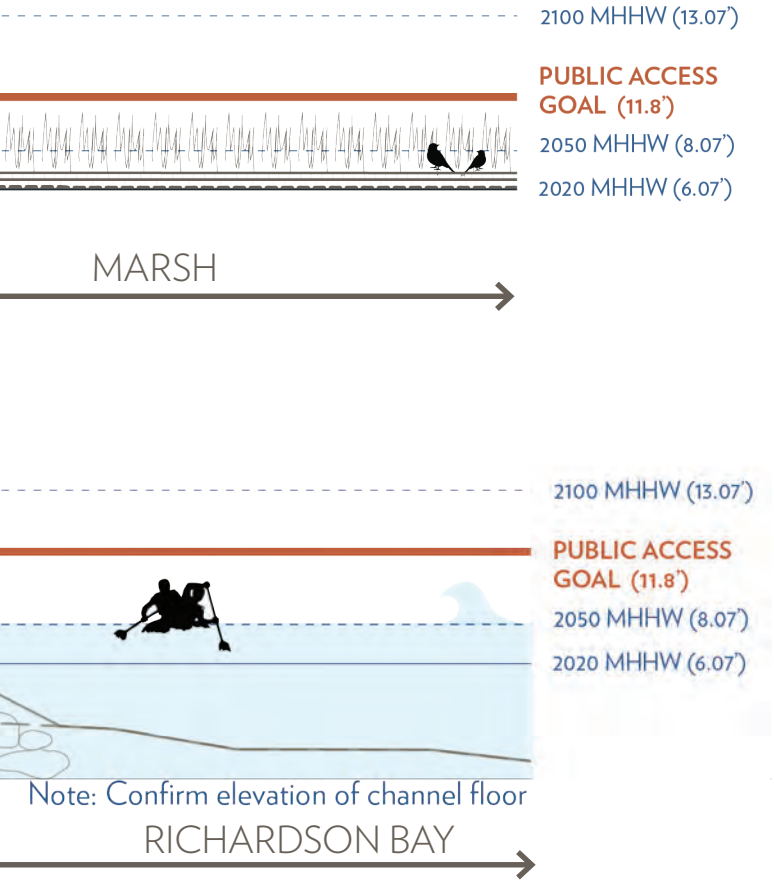

**BRIDGE SECTION B-B**





**KEY PLAN**

*Trail on embankment through marsh habitat. Shown: Spanish Moss Trail, Beaufort, SC. Image credit: Friends of the Spanish Moss Trail*




- In this design concept, the trail would be raised along the existing alignment to an elevation that would provide resilient public access through mid-century (as recommended by BCDC).
- Raised embankment would require significant quantities of fill placement but would allow for new high marsh habitat along ecotone slopes along the trail.
- The trail embankment would require new bridges to convey creek and tidal flows. These bridges would need to be longer in length than the existing structures to prevent trail flooding and adverse ecological impacts.
- Raised embankment would protect marsh interior from high wave energy and erosion but would also limit flows of wildlife, water, and sediment between the marsh and the bay.

*Raised trail with rip rap and bridge. Shown: Colchester Causeway, Colchester, VT.. Image credit: VT Fish and Wildlife Department*

*Trail with room for ecotone slope to water. Shown: D&R Canal Trail, New Brunswick, NJ. Image credit: East Coast Greenway*

# CONCEPT 2: SPAN THE MARSH

## CONCEPT OVERVIEW

The second adaptation concept, "Span the Marsh," proposes keeping the existing trail along the present-day alignment but in this case the southern segment of the trail would be raised on a causeway structure. Instead of using fill material to raise the trail on an embankment through South Bothin Marsh, a causeway structure would span across and above the marsh area.

## USER EXPERIENCE

Similar to the first concept, the trail widening improves the safety and longevity of the trail for all users through mid-century sea level rise projections and potentially beyond. The future trail would be raised between 3 to 5 feet depending on local conditions across the Preserve. At this elevation, the extent of the views to the adjacent marsh and bay would increase with minor visual obstructions caused by railings. Special attention would be necessary to ensure comfortable passage for all types of trail users over the causeway structure constrained by railings on both sides. Overlooks could be created to accommodate seating and viewing.

## ECOLOGY

The footprint of the trail structures through South Bothin Marsh would be greatly reduced compared to existing conditions and Concept 1, allowing greater flexibility for the implementation of measures designed to increase marsh resilience. Same as with the other trail concepts, new high marsh ecotone slopes along the trail embankment would be created to provide more uplands for the marsh to migrate in the future. However, construction of the causeway would likely require heavy equipment that may impact the marsh.

## CONTEXT

In all the design concepts, the connection between the raised trail within the Preserve, and any adjacent roads, trail connections, and open space areas will need improvements. In this design, the connection to the McGlashan Path would need to be improved to accommodate the new causeway across South Bothin Marsh and the associated ramp along the pathway. The trail segments along North Bothin Marsh and adjacent to Miller Avenue in Mill Valley have the potential to be coordinated with future flood control measures. Partnerships would be necessary to fund further study.

TRAIL & USER EXPERIENCE

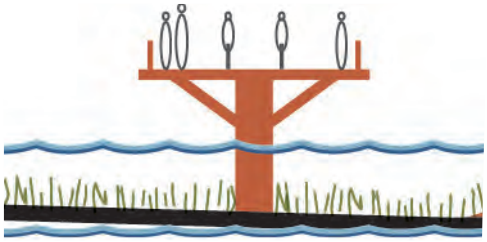
ECOTONE SLOPE & MARSH IMPROVEMENTS


MILL VALLEY
GOODMAN MARSH
ALTO MARSH
ARROYO CORTE MADERA DEL PRESIDIO
ALMONTE MARSH
SHELTER BAY
NORTH BOTHIN MARSH IMPROVEMENTS
STRAWBERRY MANOR
BOTHIN MARSH OPEN SPACE PRESERVE
IMPLEMENT ECOTONE SLOPE IN NORTH BOTHIN MARSH
ELEVATE PATHWAY ALIGNMENT
NORTH BOTHIN MARSH
CAUSEWAY SPANS ABOVE THE EXISTING ALIGNMENT
EXISTING ON-STREET BIKE LANES
ALMONTE
CAUSEWAY ALLOWS MARSH DRAINAGE IMPROVEMENTS
SOUTH BOTHIN MARSH IMPROVEMENTS
SMALL CAUSEWAY FOOTPRINT
RICHARDSON BAY
SOUTH BOTHIN MARSH
0 100' 200' 500'
MANZANITA MARSH
MCGLASHAN PATH SLOPES UP TO MEET NEW TRAIL ELEVATION
TAM JUNCTION
COYOTE CREEK
MANZANITA
MARIN CITY

# CONCEPT 2: SPAN THE MARSH

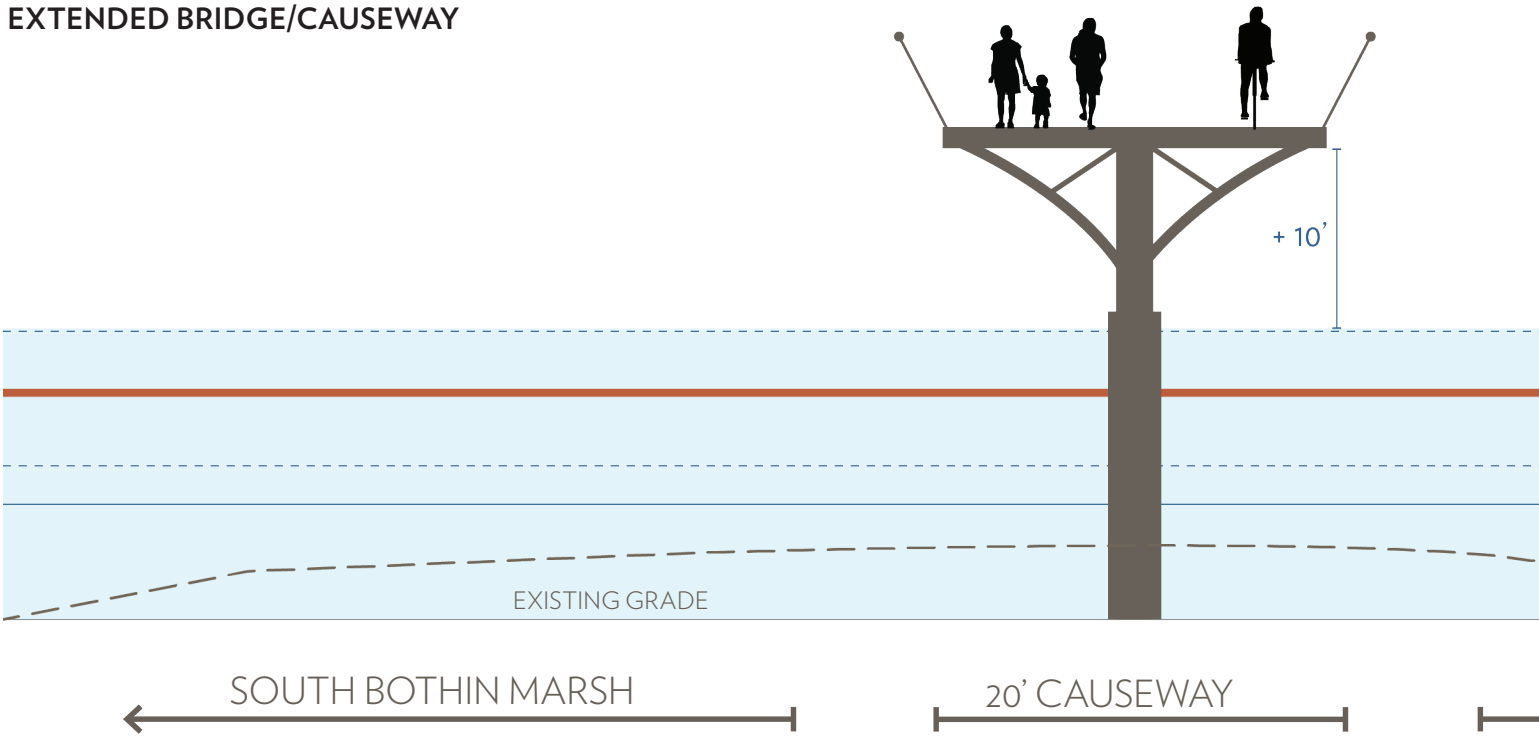
## 2 SPAN THE MARSH

The trail follows the present-day alignment, but is built up on a causeway structure to span the marsh below.

# CONCEPT 2: SPAN THE MARSH

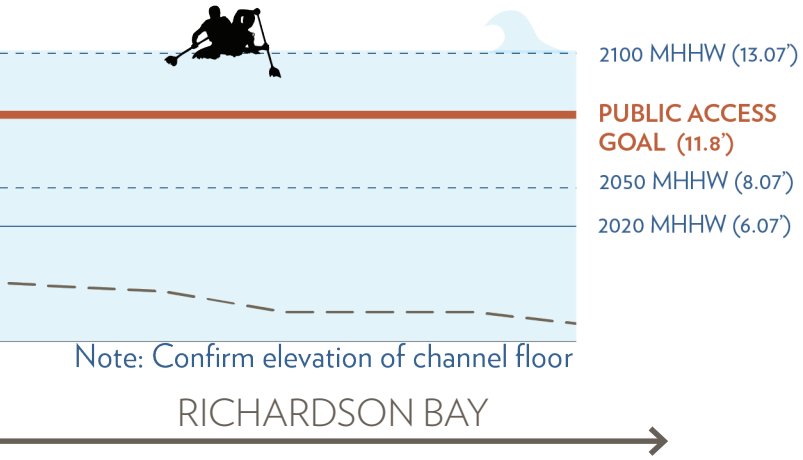
## EXTENDED BRIDGE/CAUSEWAY





## KEY PLAN

*Elevated trail over marsh. Shown: Jack Markell Trail, Wilmington, DE. Image credit: East Coast Greenway*




- In this design concept, the trail would be raised along the existing alignment to an elevation that would provide resilient public access through mid-century (as recommended by BCDC).
- The design would require a new long-span bridge or causeway over South Bothin Marsh and Coyote Creek. The embankment along North Bothin Marsh would require a significant quantities of fill placement and would allow for new high marsh habitat along an ecotone slope.
- An elevated bridge/trail along this alignment would connect high elevation areas through mid-century sea level rise scenarios and beyond.
- In this concept, in South Bothin Marsh portions of the concrete on the existing Bay Trail would be removed and an opening created to enhance ecological and hydrologic connectivity between Richardson Bay and South Bothin Marsh.


*Elevated trail over open water at high tide. Shown: Shem Creek Park, Mt. Pleasant, SC. Image credit: Donnie Whitaker*

*Trail with room for ecotone slope. Shown: Charles River Bike Trail, Boston, MA. Image credit: East Coast Greenway*

# CONCEPT 3: RING THE MARSH

## CONCEPT OVERVIEW

The third trail adaptation concept, "Ring the Marsh," relocates the trail to the upland edge of South Bothin Marsh and creates a new connection from the Tam Junction community to the Preserve. The trail would be elevated along an earthen embankment in most areas, similar to the ecotone slope approach proposed for the North Bothin Marsh segment. One low-lying area near Almonte may require a bridge or boardwalk structure. Where Almonte is high, the trail would be built on a cantilever structure between the road and marsh. A new bridge is required to cross Coyote Creek near the Dipsea Café.

## USER EXPERIENCE

Similar to the first two concepts, the trail widening improves the safety and longevity of the trail for all users through mid-century sea level rise projections and potentially beyond. The future trail would be raised between 3 to 5 feet depending on local conditions across the Preserve. At this elevation and new location, the extent of the views to the adjacent marsh and bay would increase with a new vantage point along South Bothin Marsh. The new location also offers better trail connections to adjacent commercial and residential areas in Tam Junction. Special attention to the design of the multi-use path will ensure for enhanced safety and comfort completely separated away from car traffic, and the existing on-street bike lanes on Almonte Blvd. would remain in place.

## ECOLOGY

Relocating the trail to the outer edge of South Bothin Marsh would improve the potential for measures designed to increase marsh resilience. The former trail embankment would be lowered and regraded to create a landscape consisting of a mix of high marsh, beach and marsh channels. These new habitat areas will allow wildlife, water and sediment to move more freely and unimpeded between Richardson Bay and South Bothin Marsh. Most of the former trail embankment will be kept at elevations suitable for high marsh and transition-zone vegetation. These areas of higher ground will provide a buffer against wave erosion and create refuge for species that need high marsh habitat. The large rock in the existing trail embankment may be salvaged and re-used. New high marsh ecotone slopes along the new trail embankment would be created to provide more upland elevations for the marsh to migrate in the future  The new trail location behind the existing Tam Junction properties allow for restoration opportunities.

## CONTEXT

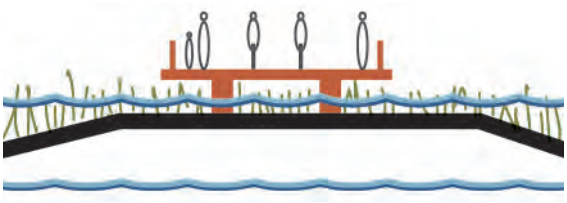
In all the design concepts, the connection between the raised trail within the Preserve, and any adjacent roads, trails, and open space areas will need improvements. In this design, the connection to the McGlashan Path would need to be improved to accommodate the new bridge across South Bothin Marsh. This concept offers the most flexibility and potential for future coordination and integration with local flood control improvements, for example, the trail segment along South Bothin Marsh could be integrated with future Coyote Creek levee improvements. The trail segments along North Bothin Marsh and adjacent to Miller Avenue in Mill Valley also have the potential to be coordinated with future flood control measures. Partnerships would be necessary to fund further study.


TRAIL & USER EXPERIENCE
ECOTONE SLOPE & MARSH IMPROVEMENTS
NORTH BOTHIN MARSH IMPROVEMENTS
IMPLEMENT ECOTONE SLOPE IN NORTH BOTHIN MARSH
ELEVATE PATHWAY ALIGNMENT
EXISTING ON-STREET BIKE LANES
REMOVE EXISTING TRAIL ELEMENTS & RESTORE MARSH
BRIDGE SPAN ACROSS LOW AREAS
SOUTH BOTHIN MARSH DRAINAGE IMPROVEMENTS
NEW CONNECTION TO TAM JUNCTION
CONTINUE ECOTONE SLOPE IN SOUTH BOTHIN
ALIGN PATHWAY ALONG MARSH PERIMETER
NEW BRIDGE
REALIGN AND ELEVATE MCGLASHAN PATHWAY
MILL VALLEY
GOODMAN MARSH
ALTO MARSH
ARROYO CORTE MADERA DEL PRESIDIO
ALMONTE MARSH
SHELTER BAY
BOTHIN MARSH OPEN SPACE PRESERVE
NORTH BOTHIN MARSH
STRAWBERRY MANOR
ALMONTE
TAM JUNCTION
SOUTH BOTHIN MARSH
MANZANITA MARSH
RICHARDSON BAY
COYOTE CREEK
MARIN CITY
MANZANITA
0 100' 200' 500'
Bay Trail

# CONCEPT 3: RING THE MARSH

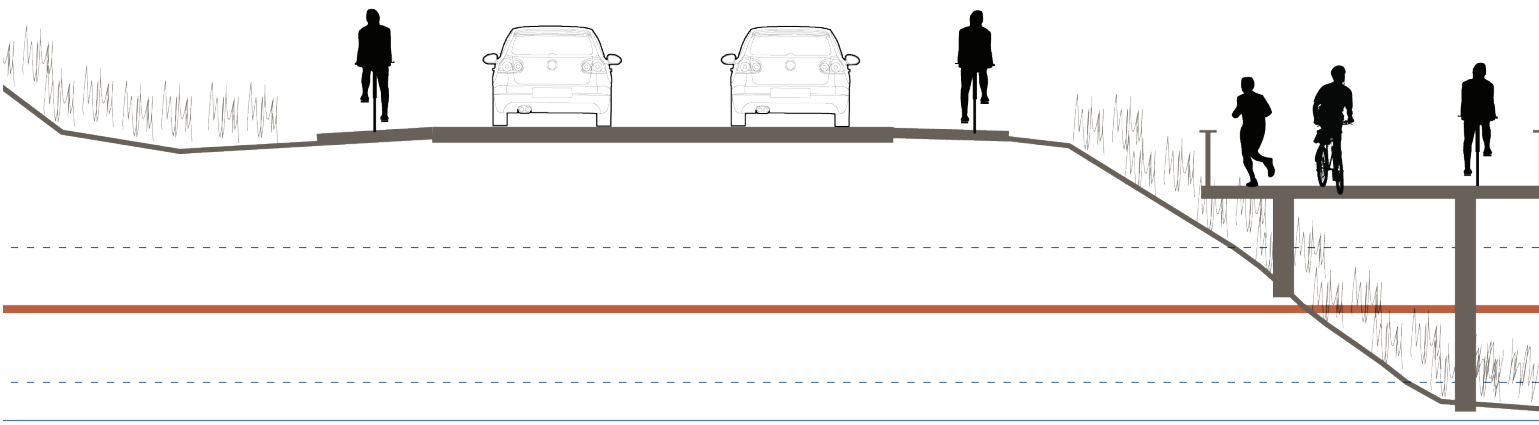
## 3 RING THE MARSH

The trail is moved to the edge of the preserve, allowing the marsh to be reconnected to the bay.

# CONCEPT 3: RING THE MARSH

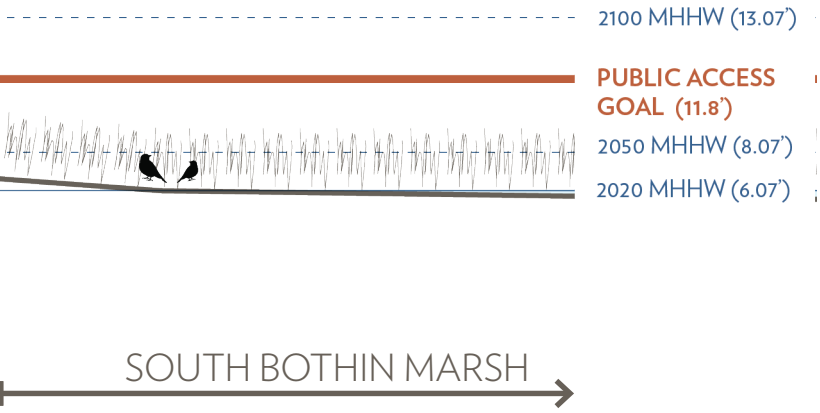
## WITHIN PRESERVE NEAR ALMONTE BLVD.



ALMONTE | ALMONTE BLVD. WITH EXISTING BIKE LANES | ECOTONE SLOPE | 18' TRAIL IN PRESERVE


KEY PLAN

*Trail at perimeter of marsh. Shown: Shining Sea Bikeway, Cape Cod, MA. Image credit: East Coast Greenway*




- In this design concept, the pathway is routed along the higher elevations of the Preserve primarily along a raised embankment with some segments requiring a bridge structure as shown. All segments would provide resilient public access through mid-century (as recommended by BCDC).
- Raised embankment would require significant quantities of fill placement, but less fill compared to Concept 1 because of higher existing elevations.
- In this concept, the infrastructure along the existing trail alignment in South Bothin Marsh would be removed and high marsh mounds would be designed to enhance ecologic and hydrologic connectivity between Richardson Bay and South Bothin Marsh.
- The location of the raised embankment in this concept could be integrated into flood protection strategies in the future.

*Trail delineating transition from urban environment to natural habitat. Shown: Hudson River Greenway, NY, NY. Image credit: East Coast Greenway*

*Trail at edge of wildlife refuge with viewing opportunities. Shown: John Heinz Wildlife Refuge, Philadelphia, PA. Image credit: East Coast Greenway*

# 6. COMMUNITY FEEDBACK

# COMMUNITY FEEDBACK

*Happy hour engagement event.*

*Scavenger hunt in the marsh*

**TOP PRIORITIES:**

- Improve pathway safety for a wide range of users (width, surfacing, line-of-site, etc).
- Reduce trail flooding.
- Maximize the ecological benefits of the project.

**KEY CONSIDERATIONS:**

- Maintain views of open space and wildlife.
- Protect the trail experience from roads and pollution.
- Enhance trail connectivity to the community.
- Minimize impacts to public access and habitat during construction.
- Responsibly manage costs and align with funding sources.

Community engagement continues to be integral to the project design process. Beginning in early 2018, the community was engaged in conversations and events to help craft the project vision. Throughout this planning phase, the design team has continued to present findings and collect feedback from the community. Three key meetings most recently helped inform this study: an Initial Planning Community Presentation on July 16, 2020; a Design Concepts Community Presentation on October 15, 2020; and a Design Concepts Evaluation Community Presentation on June 8, 2021.

After the design concepts were presented to the community on October 15, 2020, a community survey was shared and circulated to several thousand people through email and social media which resulted in 815 survey participants. The following pages summarize the results from the survey and various workshops and meetings with stakeholders across the community.

## Q8. What about the concepts for the pathway excites you most? What is concerning?

Answered: 586 Skipped: 229

| ANSWERS | Exciting | Concerning | Net |
|---|---|---|---|
| Concept 3 (Ring the South Marsh) | 103.5 | 16 | 87.5 |
| Concept 2 (Span the South Marsh) | 84.5 | 17 | 67.5 |
| Concept 1 (Raise Trail in Place) | 28 | 16 | 12 |

## Q9. Tell us more about your vision for the adaptation of the Bothin Marsh Open Space Preserve. What would you like to see? What did we miss? Are there ways you would like to be involved?

Answered: 339 Skipped: 464

| ANSWERS | Positive | Negative | Net |
|---|---|---|---|
| Concept 3 (Ring the South Marsh) | 94 | 19 | 75 |
| Concept 2 (Span the South Marsh) | 66 | 22 | 44 |
| Concept 1 (Raise Trail in Place) | 26 | 13 | 13 |

*These open-ended questions generated written responses which expressed positive and negative comments on the three concepts. These charts reflect an interpretation of those comments and the net results.*

# COMMUNITY FEEDBACK


*One Tam engagement on site at Bothin Marsh*

Throughout the development of the initial planning memo and adaptation concepts for the trail, the design team looked to the community for their thoughts and opinions.

While drafting the Planning Memo, meetings and presentations were held with stakeholder groups and the community to identify opportunities and constraints across the site. After refining concepts and receiving feedback from the STAC, the concepts were presented to the community for feedback in survey form.

815 people from the community responded to the survey, including locals, Marin County residents, and others from across the Bay Area. It represented a wide swath of user groups that frequently went through the site including 87% of respondents having experienced flooding on the Mill Valley-Sausalito Pathway.

Cyclists were the most represented group, with safety for bicyclists and pedestrians being a top priority. Concerns such as adding length to the trail, were of minimal concern with most respondents being comfortable with additional trail length. A resounding majority of survey respondents were supportive of relocating the trail for increased ecological benefits, keeping in mind, this must be done with design elements that provide physical separation from roads and maintain an inviting experience of the marsh.

For those that answered a question regarding increased impacts from sea level rise, 100%

acknowledged that this is a threat. These respondents already experience frequent flooding, though the actual impacts of sea level rise are not as widely recognized in day-to-day life.

Along with multiple choice answers, people responding to the survey had the opportunity to describe their considerations, values, and priorities in their own words. Many expressed an interest in wildlife overlooks, volunteer opportunities, interpretive elements, and ongoing trail adaptability.

**"I don't mind a longer trail, but would prefer the path wasn't exposed to traffic noise and pollution while exercising by putting it next to car traffic."**

*Community engagement event at the marsh*

**"I would favor whichever solution has the least impact on the ecosystem."**

**"Concept 3 seems to be the best tradeoff between ecosystem restoration, cost, and trail improvements so that one seems great! Biggest concern is that nothing will happen and it gets flooded permanently in a decade or two."**

**"I love the experience my children have with the wildlife. As a cyclist, I also want this to be a safe path for groups passing through, children learning to ride and people walking. So please give consideration to all these trail user types."**

*Quotes from the Community Survey*

# 7. DESIGN EVALUATION & NEXT STEPS

# DESIGN EVALUATION

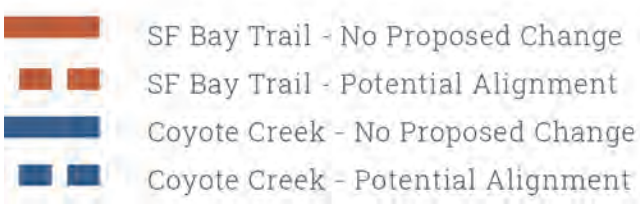
Based on the preliminary nature of these concepts and the best available data, our evaluation was intended to help select a conceptual approach to further design and refine. In order to evaluate the tradeoffs associated with each design concept at a high level, the design team with support from the STAC developed an evaluation method that distinguishes the trail alignment decision from the marsh resilience elements decision. Although the overall project will be designed as one cohesive vision, by separating the evaluation of the trail alignment from the marsh resilience measures, the benefits and challenges associated with each approach can be more clearly articulated. The STAC was consulted throughout this evaluation process to ensure early collaboration and consistency across agencies and special advisors.

### TRAIL ALIGNMENT EVALUATION

- To address existing trail flooding and provide for long-term public access and recreation opportunities, and maintain and enhance the carbon free/active transportation network.

### MARSH RESILIENCE EVALUATION

- To protect and enhance the tidal marsh habitats, which will become increasingly stressed by rising sea-levels.




MILL VALLEY
GOODMAN MARSH
ARROYO CORTE MADERA DEL PRESIDIO
SASM
ALTO MARSH
Bayfront Park
ALMONTE MARSH
SHELTER BAY
Tamalpais High School
STRAWBERRY MANOR
BOTHIN MARSH OPEN SPACE PRESERVE
ALMONTE MARSH
NORTH BOTHIN MARSH
TRAIL ALIGNMENT DECISION
ALMONTE
Mill Valley - Sausalito Pathway
Bay Trail
MARSH RESILIENCE DECISION
RICHARDSON BAY
SOUTH BOTHIN MARSH
0 100 200 500
MANZANITA MARSH
COYOTE CREEK
TAM JUNCTION
Charles McGlashan Pathway
MANZANITA
MARIN CITY

# RESULTS BY CATEGORIES OF EVALUATION

## PUBLIC ACCESS & TRAIL CONNECTIVITY

If no action is taken, public access and trail connectivity through the Preserve and along a critical segment of the regional San Francisco Bay Trail will continue to diminish because of increasing sea levels. All three adaptation design concepts would widen and raise the trail to meet public access guidance through mid-century sea level rise projections.

Although all three concepts are technically feasible, Concepts 1 and 2 would be more challenging to construct as these concepts require extensive construction over soft bay mud subsoils. The softer subsoils introduce greater structural/geotechnical complexity, adding challenges during construction and requiring more costly engineering measures and a larger physical footprint in order to avoid or mitigate for potentially high rates of subsidence. The subsoils on the Concept 3 trail alignment likely have thinner layers of soft bay mud and will be less susceptible to subsidence compared to the alignments for Concept 1 and 2, allowing for the use of simpler embankment designs and less complex construction methods.

In terms of providing long-term trail access from a construction and adaptability perspective, Concept 3 is considered the most feasible because the trail alignment is relocated to the upland edge of the Preserve away from geotechnical conditions that are more likely to be unstable. Concept 3 will offer more flexibility to develop a design that can be implemented incrementally and in conjunction with potential future flood protection strategies in the area, especially along Coyote Creek.

Unlike Concept 1 and 2, the Concept 3 trail alignment provides new a community access point from Tam Junction to the trail, providing a new connection for residents and businesses along the trail.

Concept 3 would cause less disruption to public access during the construction period because the existing trail could remain accessible for the majority of the construction period. In contrast, Concepts 1 and 2 would cause several months of trail closures during construction.

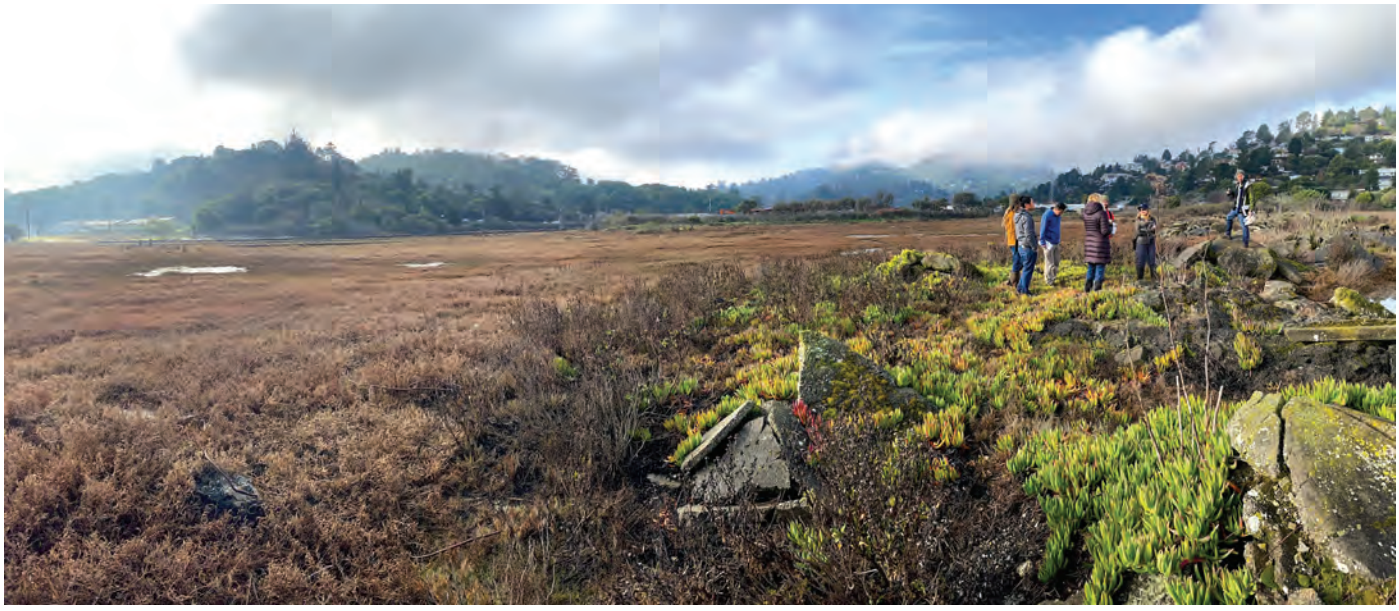
## ECOLOGICAL FUNCTION

Ecological function considers the impact that trail development has on the surrounding marsh through all phases of implementation. The evaluation of ecological function is based on a qualitative assessment of the expected outcomes related to habitat extents, quality and resilience, and effects on protected species.  This ranking has been developed in consultation with the project's STAC.

Concept 1 would exacerbate the problems associated with the existing trail alignment, in particular how the trail embankment creates a barrier for wildlife migration and tidal flows between the Bay and the marsh. The expanded footprint of the trail within the Preserve would enlarge and reinforce this physical barrier.

Concepts 2 and 3 both remove the physical barrier between South Bothin Marsh and the Bay, but have different footprints. Concept 2 would have the smallest footprint within the marsh, whereas

*Different types of trail users near the northern access point. Image: WRT*



*The design team observes existing ecological functions and discusses opportunities and constraints. Image: WRT*

# RESULTS BY CATEGORIES OF EVALUATION

Concept 3 would rely on areas of fill. However, Concept 3 would create transition-zone habitats along the bayward edge of the new embankment that will provide high-tide refuge and support a more diverse range of plant species. The Concept 3 embankment would also provide a platform for future beneficial reuse of sediment (through thin lift placement) in order to improve the resilience of the marsh habitats to rising sea levels.

The locations most affected by the visual and noise impacts associated with recreational use of the trail are different for Concepts 2 and 3. Under Concept 2 the trail structure would remain at the interface between South Bothin Marsh and the Bay, however the elevated structure would be highly visible from all locations in the marsh and would potentially obstruct views from Almonte Boulevard to the Bay. While the elevated causeway would not present a physical barrier for wildlife, noise, and visual impacts from the trail could still discourage movement of wildlife between the Bay and South Bothin Marsh. The California Black Rail and Ridgways Rail, two endangered bird species with a known presence at the Preserve, are particularly sensitive to noise and visual impacts, especially during their breeding and nesting season. Under Concept 3 the trail embankment would be located along the western, upland edge of the marsh, adjacent to existing built infrastructure including Almonte Boulevard and the east side of the Tam Junction commercial area. The raised embankment would be similar in elevation to the existing road and existing fencing blocks views from the Tam Junction area, therefore the new embankment is not expected to cause new obstructions to views. The embankment location also re-locates the noise and visual impacts associated with the recreational uses of the trail to coincide with the noise and visual impacts of the road and Tam Junction commercial activities. This will reduce disturbance to wildlife within the South Marsh, in particular in the eastern areas of the marsh. There may be some new disturbance to wildlife that occupy the western marsh, and care should be taken during the design process to develop a trail layout that creates appropriate barriers between the trail activities and wildlife areas to minimize noise, visual, and physical impacts to them. Concept 3 will disrupt majority of the existing transition zone and upland habitat within South Bothin Marsh, however these existing habitats are already highly disturbed and degraded. The design for this concept should aim to offset losses of existing habitats to the extent possible by creating new transition zone and upland habitat within the footprint of the former trail embankment and along the bayward edge of the new trail embankment and by enhancing exist habitats elsewhere in the Preserver

Ultimately, Concept 3 does the most to reconnect South Bothin Marsh to the bay and makes room for various marsh improvements to take place over time.

## COST – DIRECT & RECURRING

Each of the concepts has a similar rough order of magnitude cost, and there is a high level of uncertainty in the cost estimates at this stage of conceptual design.

Major cost uncertainties include:

- Required depth of pilings for bridges and other structures.
- Sources of embankment fill and associated costs for purchase and haul.

The potential for funding the project relies on the ability to meet multiple design objectives including but not limited to marsh resilience and associated pilot projects that might help inform future sea level rise adaptations around the Bay Area, active transportation, and compatibility with future flood protection measures.

## REGIONAL GUIDANCE & REGULATIONS

Concept 3 is consistent with regional priorities for restoring natural shorelines by relocating a portion of the multi-use path to the westernmost edge of the Preserve within adjacent uplands, and enhancing natural processes supporting the tidal marsh habitats. The Concept 3 trail embankment would be consistent with regionally recognize strategies for sea-level rise adaptation along natural shorelines, such as incorporating ecotone habitat slopes and allowing space to raise and widen the embankment over time as sea-levels rise. These strategies are identified and encouraged by regional planning efforts including the San Francisco Baylands Habitat Goals Project, San Francisco Bay Shoreline Adaptation Atlas, and BCDC's "Bay Fill for Habitat Restoration, Enhancement, and Creation in a Changing Bay" policies.

Concept 3 also provides the greatest potential compatibility with future flood protection strategies in the area. The new trail embankment is located on an alignment that could support a future flood protection levee to protect portions of Tam Junction (if combined with flood protection improvements along Coyote Creek), and the new trail embankment could potentially be readily raised and improved to provide a flood protection function as part of a larger comprehensive community adaptation planning effort. This is an ideal location for a flood protection levee as the adjacent tidal marsh would help dissipate wave energy affecting the levee.  At the same time, the embankment provides a physical platform that could support the equipment required to deliver beneficially re-used sediment to the marsh (eg. through thin lift sediment placements), which would in turn increase the resilience of the marsh habitats. This concept could also be compatible with an integrated regional coastal flood protection system if integrated with future flood protection improvements along Coyote Creek and Arroyo Corte Madera del Presidio.

# EVALUATION SUMMARY

## OVERVIEW OF CONCEPT EVALUATION

The concept evaluation was organized around the community's values and the defined goals and objectives established in the Vision Document. Across all four categories, "Concept 3: Ring the Marsh" had the greatest potential for public and ecological benefit.


**NO ACTION**

| | |
|---|---|
| **PUBLIC ACCESS** | + |
| **ECOLOGICAL FUNCTION** | ++ |
| **COST - DIRECT & RECURRING** | n/a |
| **REGIONAL GUIDANCE & REGULATIONS** | + |

Ranking:

"+" = more benefits

"?" = uncertainty




| | CONCEPT 1: RAISE THE TRAIL IN PLACE | CONCEPT 2: SPAN THE MARSH | CONCEPT 3: RING THE MARSH |
|---|---|---|---|
| | ++ | ++++ | +++++ |
| | + | +++ ? | +++ ? |
| | ++ | ++ | ++ |
| | ++ | +++ | ++++ |

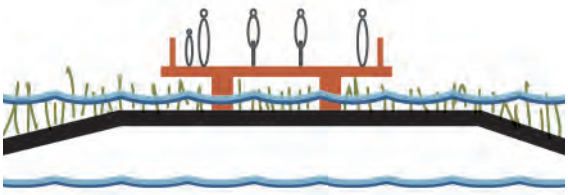
# FAVORED CONCEPT: RING THE MARSH

## 3 RING THE MARSH

The trail is moved to the edge of the Preserve, allowing the marsh to be reconnected to the bay.

After evaluating the design concepts, "Concept 3: Ring the Marsh" emerged as the highest ranking and community favored concept.

By realigning the trail along the upland areas of the Preserve, the "Ring the Marsh" concept builds on the assets found naturally on the site and is compatible with anticipated future strategies for flood protection and sea-level rise adaptation. This concept would provide ecological benefits by removing a major barrier between the marsh and bay. The design of the new pathway will provide safe access for multiple types of users and will keep the pathway separated from the road while also providing a new access point to Tam Junction. Finally, the new trail corridor establishes a potential location for future coastal flood protection that would have a synergy with the existing ecological resources.




MILL VALLEY
ALMONTE MARSH
ARROYO CORTE MADERA DEL PRESIDIO
MILLER AVE
ALMONTE BLVD
NORTH BOTHIN MARSH
SHELTER BAY
RICHARDSON BAY
HIGHWAY 101
STRAWBERRY MANOR

# MARSH RESILIENCE EVALUATION

## INTRODUCTION TO MARSH RESILIENCE MEASURES

This section presents a collection of recommended measures to improve the resilience, habitat quality and ecologic function of the Preserve's tidal marsh habitats. This section also identifies three large-scale measures to improve the resilience of the marsh habitats and are recommended for additional study and potential implementation.

The recommended measures include improving the tidal channel network, creating new high marsh habitat areas, managing invasive vegetation, promoting populations of desirable native plant communities, and addressing shoreline erosion. The location and design of these enhancement measures will vary depending on which combination of large-scale resilience measures is selected for implementation.

Three potentially feasible large-scale measures to increase the resilience of the marsh habitat have been identified:

- Coyote Creek Re-Alignment
- Thin Lift Sediment Placements
- Mudflat Sediment Augmentation

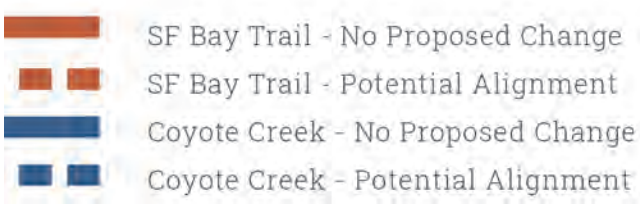
These three measures are recommended for additional study to confirm feasibility and, if found to be feasible, for refinement and integration with the future potential trail alignment. The preliminary evaluation and projected outcomes for each of these measures are described below, along with questions for additional study and recommendations for next steps. Importantly, these measures could be combined with one another in order to achieve greater benefits, and so they are presented as a "menu" of options, rather than a set of ranked alternatives.

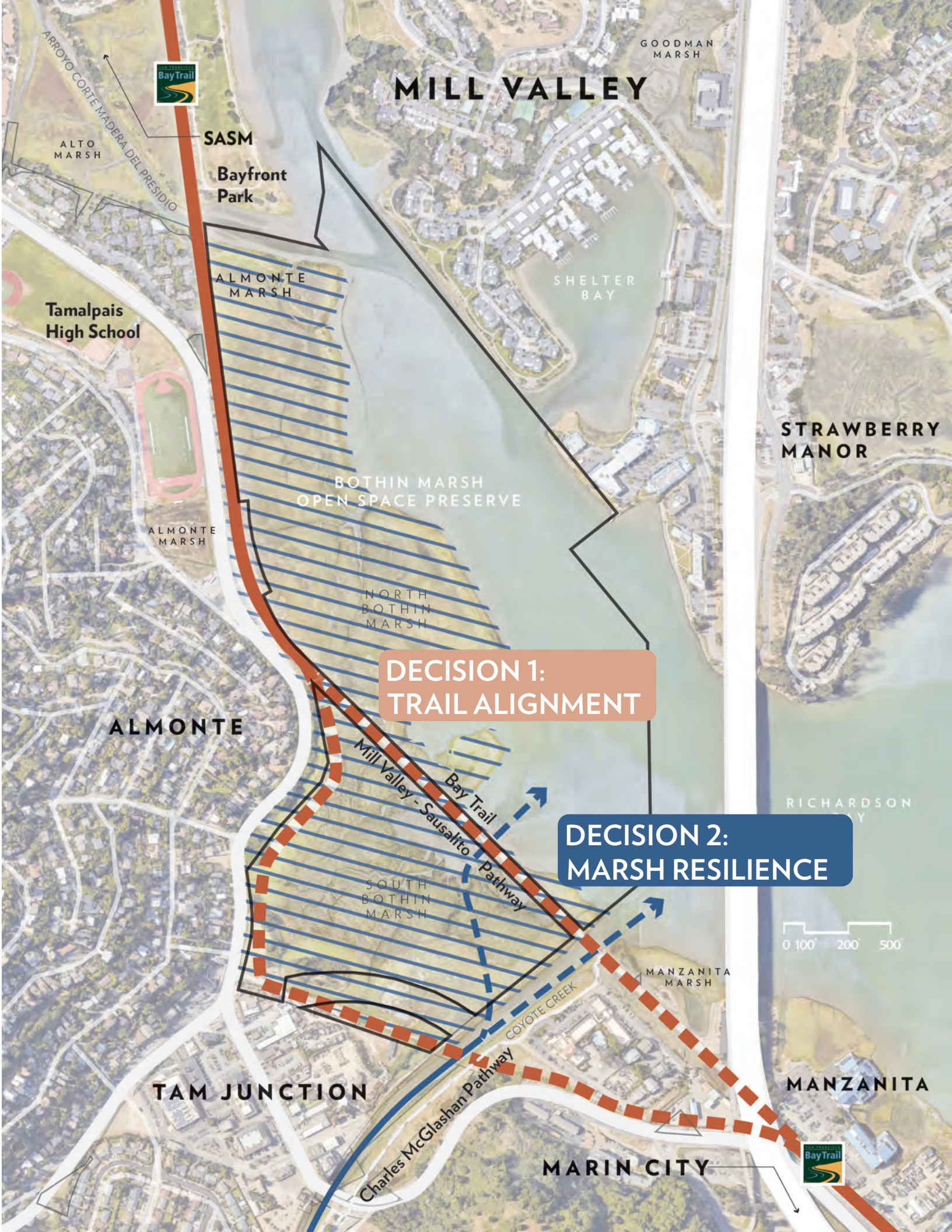
### TRAIL ALIGNMENT EVALUATION:

- To address existing trail flooding and provide for long-term public access and recreation opportunities.

### MARSH RESILIENCE EVALUATION:

- To protect and enhance the tidal marsh habitats, which will become increasingly stressed by rising sea-levels.




MILL VALLEY
GOODMAN MARSH
ARROYO CORTE MADERA DEL PRESIDIO
SASM
ALTO MARSH
Bayfront Park
ALMONTE MARSH
SHELTER BAY
Tamalpais High School
STRAWBERRY MANOR
BOTHIN MARSH OPEN SPACE PRESERVE
ALMONTE MARSH
NORTH BOTHIN MARSH
DECISION 1: TRAIL ALIGNMENT
ALMONTE
Mill Valley - Sausalito Pathway
Bay Trail
DECISION 2: MARSH RESILIENCE
RICHARDSON BAY
SOUTH BOTHIN MARSH
0 100 200 500
MANZANITA MARSH
COYOTE CREEK
TAM JUNCTION
Charles McGlashan Pathway
MANZANITA
MARIN CITY

# PROBLEM STATEMENT

The tidal marshes at the Preserve are vulnerable to rising sea-levels due to their low elevation (a result of historic placement of dredged material), past and existing physical barriers which disconnect the marshes from the bay and neighboring creeks, and the low regional sediment supply. The Preserve's marshes already show signs of stress due to historic sea-level rise over the past century, and will become increasingly impacted as sea-level rise accelerates over coming decades. The tidal marsh habitats at the Preserve offer a preview of the impacts that accelerating sea-level rise will have on tidal marsh habitats throughout San Francisco Bay over the coming century. This Project aims to improve the resilience of marshes at the Preserve and to develop and refine tools that will allow land managers around San Francisco Bay to adapt and respond to rising sea-levels and preserve valuable tidal marsh ecosystems.

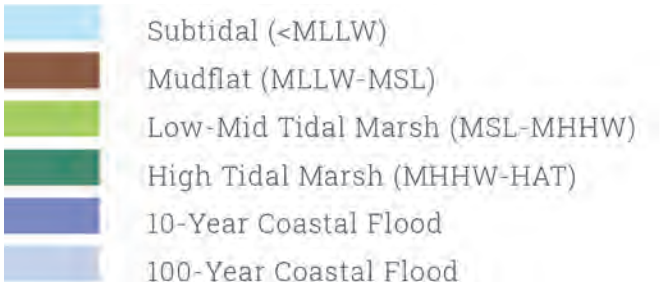
The primary focus of the tidal marsh resilience measures is to rely on natural processes to increase the rate of sediment delivery to the tidal marsh habitats. Natural processes deliver and distribute sediment to marshes with tidal action, and the project team has evaluated measures to improve sediment delivery by removing barriers between the marshes and the adjacent creeks and bay. However, natural processes alone may not provide enough sediment to preserve and maintain these habitats under the accelerated rates of sea-level rise projected for the second half of this century, and so the Project has also begun to consider importing and beneficially re-using sediment from nearby sources. Lastly, the project evaluated a variety of measures aimed at improving the quality of the existing tidal marsh habitats. These measures could offset temporary ecological impacts associated with the other project measures, and could support specific marsh habitats that are at greatest risk of being lost as sea-levels rise.

The following pages present a "menu" of potential resilience measures, the findings of the preliminary evaluation, and a comparison of measures. The evaluation shows that all of these measures have the potential to provide important benefits to the Preserve's tidal marsh habitats, and that these measures can create greater benefits when applied in combination. The Design Team recommends consideration of all of these measures as the project moves forward into the next phase of planning and design.

The next phase of planning and design should include:

- Technical studies to better understand and balance the costs, benefits and impacts associated with each measure.
- Building partnerships to secure project funding and identify cost-effective sources of imported sediment for beneficial re-use.
- Continued coordination with the scientific community to plan and implement pilot studies that will test innovative techniques for sediment placement and habitat enhancement.
- Planning and design refinements that integrate the resilience measures with the trail enhancements presented in the prior section of this document.

### "BATH-TUB MODEL" HABITAT EXTENTS PROJECTIONS WITH SLR



TODAY (SINCE 2019)

2030 +1' SEA LEVEL RISE

IMMEDIATE

2050 +2' SEA LEVEL RISE

NEAR-TERM

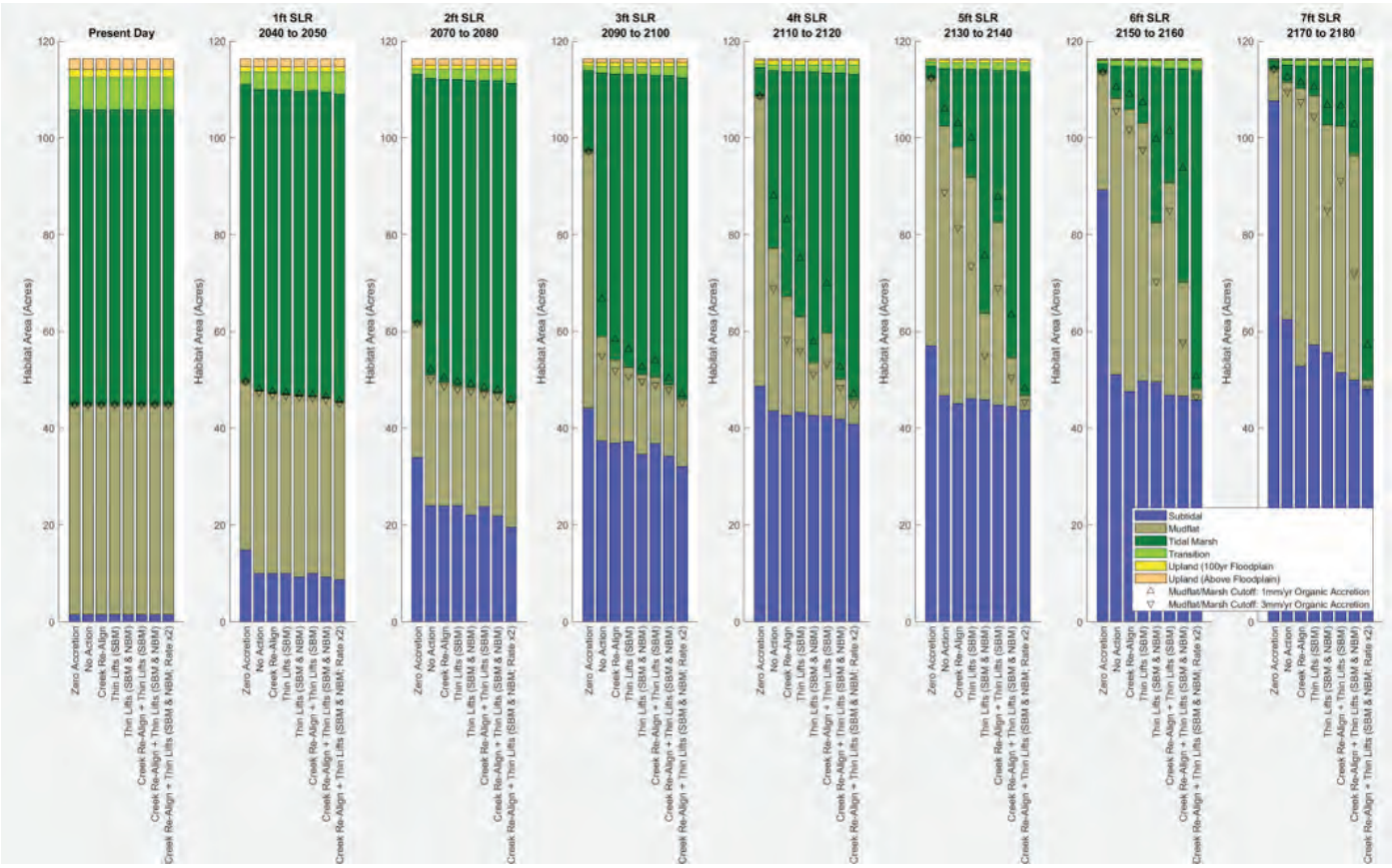
2100 +7' SEA LEVEL RISE

LONG-TERM

# EVALUATION OF MARSH RESILIENCE MEASURES

During the Planning Phase the feasibility of the potential measures for improving marsh resilience were investigated with several technical studies that have informed the evaluation of the potential measures

- **Preliminary Flood Impact Analysis [Anchor 2021]:** This study confirmed that it would be possible to re-align Coyote Creek without adversely increasing flooding upstream in Tam Valley. Three potential channel geometries were evaluated and one of these geometries provided satisfactory flood performance and is potentially feasible. The potentially feasible channel design has a large cross section and footprint and its construction would cause considerable impacts to the existing marsh habitats that would likely outweigh the benefits to marsh resilience. Additional study is needed to refine the location and geometry of the proposed re-aligned channel design in order to maximize sediment delivery to the marsh and minimize ecological impacts.
- **Coyote Creek Sediment Transport Analysis [Anchor 2021]:** This study, evaluated the potential increase in sediment delivery from Coyote Creek to South Bothin Marsh under the re-aligned Coyote Creek scenario. The re-aligned creek channel results in an approximately 60% increase in sediment delivery from the creek to the marsh.
- **Habitat Resilience Modeling [ESA 2021]:** This study estimated the potential benefits to tidal marsh habitat resilience for different combinations of channel re-alignment and beneficial re-use measures and for several sea-level rise scenarios. This study found that the resilience benefits from the project measures are strongly dependent on the future rate of sea-level rise: under a mildly conservative sea-level rise projection (eg. OPC's "Low Risk Aversion" projection) the project measures could extend the lifespan of the marsh by many decades. Under very rapid sea-level rise (e.g. OPC's "Medium-High Risk Aversion" projection), the effect of the project measures would be greatly reduced. See "Projected Change in Tidal Marsh Habitat Area for Different SLR Scenarios" Chart. This study also confirmed that the beneficial re-use measures like thin lift sediment placements can result in the highest rate of sediment delivery to the marsh and provide the greatest long-term benefits, and that combining measures like creek re-alignment and thin lift sediment placements would result in greater resilience compared to either of those measures on their own.
- **Science and Technical Advisory Committee [STAC 2020 and 2021]:** The project team consulted with a committee of expert ecologists and physical scientists to understand likely ecological and geomorphic outcomes from each of the proposed measures. Over the course of several meetings, the committee helped the design team understand the potential benefits and impacts of the proposed measures on key species and habitats. The committee also helped the team identify situations where the ecological impacts are not well understood or unpredictable and may require monitoring and adaptive management.
- **Preliminary Cost Estimates [WRT and ESA, 2020]:** The project team has developed preliminary rough order of magnitude cost estimates based on the conceptual designs.

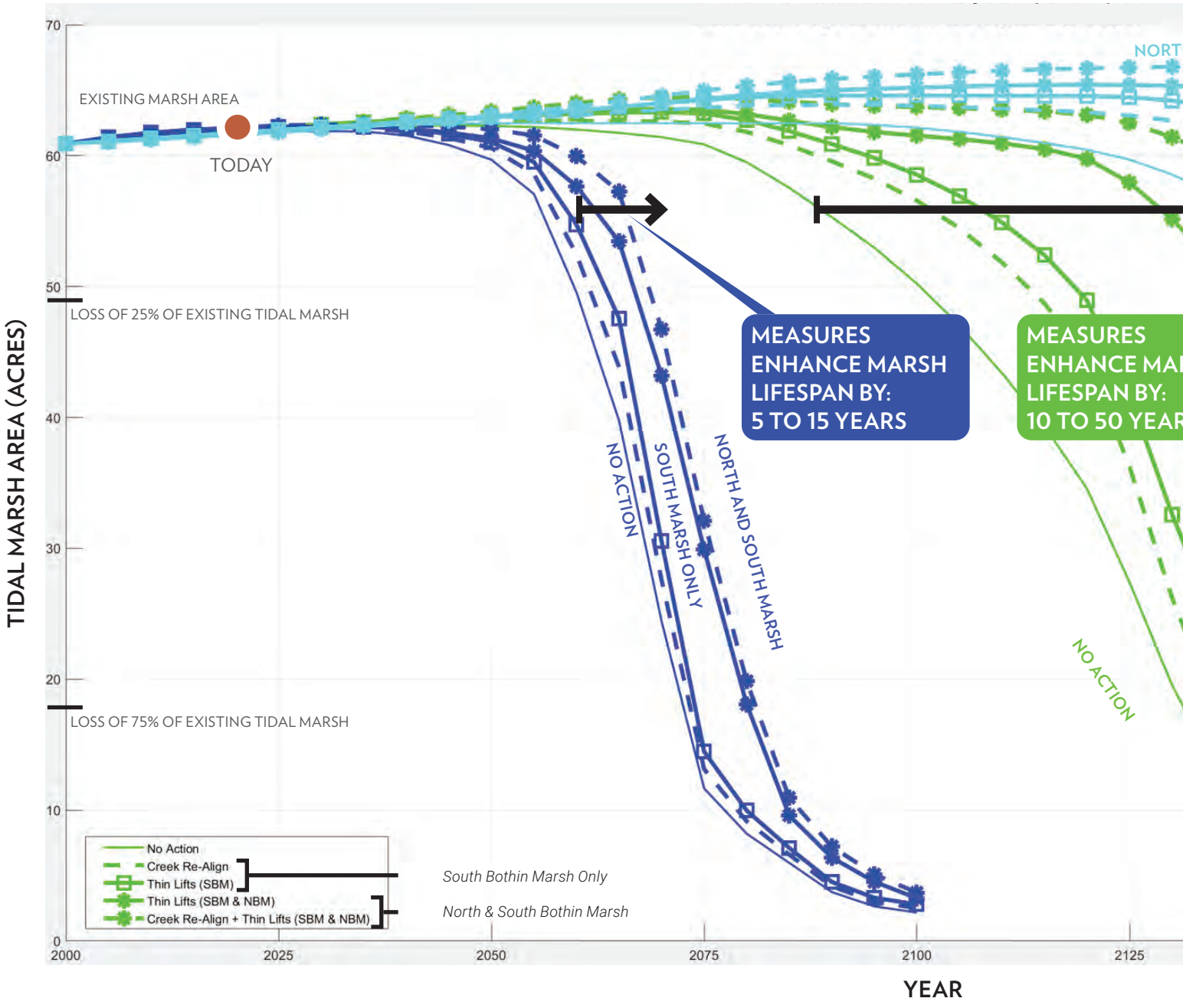



*Sediment strategies analysis from Habitat Resilience Modeling Report, ESA 2021*

These studies represent a preliminary feasibility analysis for the proposed measures in order to screen and rank the potential project measures. The measures presented in the next several pages are all potentially feasible. However some of the measures have notable challenges or uncertainties that will need to be resolved before they could be incorporated into the Project, including:

- High level of sensitivity to assumed rate of future sea-level rise. This uncertainty is not likely to be resolved during the planning process, and consequently a risk-based decision process is recommended.
- Reliance on a small number of sediment concentration measurements to estimate sediment delivery from Coyote Creek. Additional sediment sampling is recommended.
- Source of imported sediment for beneficial re-use. Outreach and coordination with nearby dredging projects and other potential sediment suppliers is recommended.
- The feasibility analysis will be updated as the potential measures are studied and refined over the course of the next phases of planning and design.

# PROJECTED CHANGE IN TIDAL MARSH HABITAT AREA FOR DIFFERENT SLR SCENARIOS

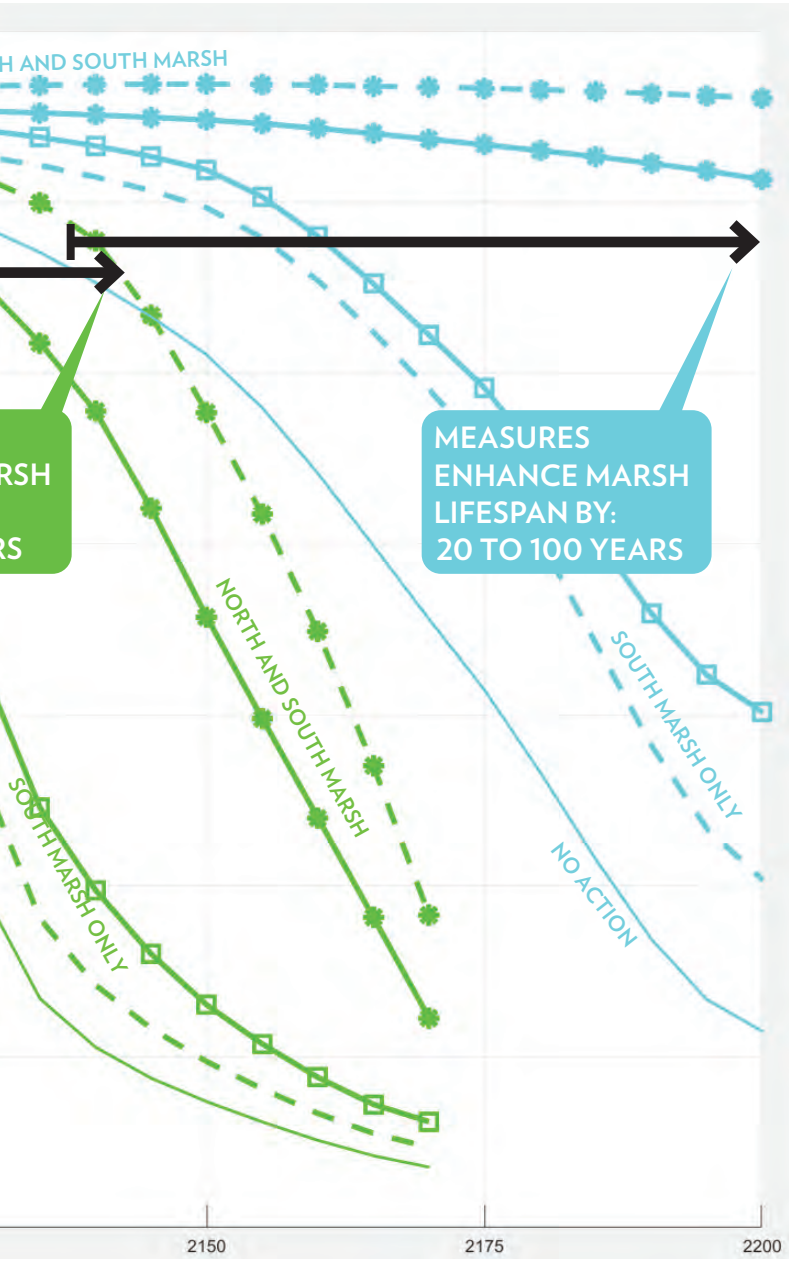



MEDIUM-HIGH RISK AVERSION SLR PROJECTIONS (OPC 2018)

50TH-PERCENTILE SLR PROJECTIONS (OPC 2018)

LOW RISK AVERSION SLR PROJECTIONS (OPC 2018)

ENHANCED MARSH LIFESPAN




*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.*

## MARSH RESILIENCE RESULTS

This figure shows the projected change in the area of tidal marsh habitat at the Preserve over time for different rates of sea-level rise and for different combinations of management actions. See the Planning Horizons and Conceptual Phasing graphic in Part I for more details on the different rates of sea level rise considered for this analysis. Key findings from this analysis include:

- The lifespan of the tidal marsh habitats at Bothin Marsh will depend on the future rate of sea-level rise (SLR) and the level of investment in measures to enhance and preserve the marsh.
- The rate of future SLR is uncertain due to limitations in the understanding of the relevant geophysical processes and due to the potential for current and new policies to reduce future GHG emissions, slowing SLR. This figure shows potential outcomes for three different SLR scenarios, represented by different colored lines.
- The marsh resilience study evaluates several combinations of project actions. This graphic presents potential trajectories for a representative range of project actions, represented with different line styles.
- The greatest resilience is provided by Thin Lift Placement on North and South Bothin Marsh (SBM & NBM), while Thin Lift Placement on South Marsh Only (SBM) provides less benefit and re-aligning Coyote Creek (Creek Re-Align) provides the lease benefit.

The study also finds that the benefit of measures to enhance the lifespan of the marsh will be much higher if the marsh experiences slower rates of SLR, while the benefit is much lower under rapid sea-level rise.

# MENU OF MARSH ENHANCEMENT MEASURES

Several marsh resilience measures have been evaluated and are recommended for inclusion in the next phase of project planning and design. The design and scale of these measures will be adjusted to be compatible with the new trail alignment. All marsh enhancement measures final locations are subject to further study and design.

**RECOMMENDED MEASURES FOR ECOLOGICAL ENHANCEMENT:**

- Widen the tidal inlet to South Bothin Marsh
- Vegetation Management
- Small Tidal Channels and Marsh Mounds
- Erosion Management
- Small Scale Habitat Features

**ADDITIONAL MEASURES TO IMPROVE MARSH RESILIENCE:**

- Coyote Creek Realignment
- Thin-lift Sediment Placement
- Mudflat Augmentation

CREEK CONNECTIONS

THIN LIFT SEDIMENT PLACEMENTS


MUDFLAT AUGMENTATION

INVASIVE PLANT REMOVAL

MARSH MOUNDS AND SMALL CHANNELS

COARSE BEACH

HIGH MARSH/ TRANSITION ZONE PLANTING

# WIDEN THE TIDAL INLET TO SOUTH BOTHIN MARSH

The existing inlet to South Bothin Marsh is too shallow and narrow to allow unrestricted tidal flow between the marsh and Richardson Bay. The resulting muted tidal conditions in the South Marsh adversely affects vegetation in the marsh and slows the delivery of sediment to the marsh. The project should increase the size of the South Marsh inlet channel to allow for unrestricted tidal exchange between South Bothin Marsh and Richardson Bay. Estimated design dimensions of the widened inlet channel using hydraulic geometry equations (Williams et al 2002) are presented in the table.

| DIMENSION | NEAR-TERM EQUILIBRIUM DIMENSION (BASED ON PRESENT-DAY TIDAL PRISM) | LONG-TERM EQUILIBRIUM DIMENSION (BASED ON MARSH AREA) |
|---|---|---|
| Input Value | Tidal Prism: 15 acre-ft | Marsh Area: 35 acres |
| Top Width | 45 ft | 49 ft |
| Depth | 7.2 ft | 7.3 ft |
| Bottom Elevation | -1.4 ft NAVD | -1.5 ft NAVD |

These inlet channel dimensions should be refined during future design phases to account for potential project measures which may change the tidal prism (such as Coyote Creek channel re-alignment) and/or marsh area (such as the trail re-alignment and embankment construction).

*Existing tidal inlet between South Bothin Marsh and RIchardson Bay. Image: WRT*

# VEGETATION MANAGEMENT

There are several recommended management actions which aim to encourage healthy and diverse populations of native plants within the Preserve. There are two recommended immediate-term actions which are already performed by Marin County Parks and should continue during the years leading up to and following construction. These include removal or minimization of the extent of non-native invasive plants within the Preserve. Invasive plant species can rapidly colonize areas that are disturbed by construction activities. The County should continue to remove and limit the population of non-native invasive plants. This action is particularly important during the years immediately prior to construction as it can greatly reduce the risk of these undesired species colonizing areas impacted during construction. We also recommend continued observation and monitoring of populations of Point Reyes bird's-beak, a rare plant present in the Preserve. The population and range of this rare plant species can vary from year to year in response to the amount of winter rainfall. The County performs periodic surveys to map the extent and population of birds-beak in the Preserve, and continued observation and evaluation of the survey results will help to identify conditions and landforms where this plant is most successful, which will help inform the design of new habitat areas for this plant.

The project design should incorporate planting of desired native species in upland and transition zone areas that are disturbed by temporary construction impacts to reduce the risk of colonization by non-native invasive plants. These planting efforts should include focused plantings to propagate Point Reyes bird's-beak, to reduce adverse impacts to existing populations due to construction.

Upland areas, including the upland portions of the of the new trail embankments, should also be planted with native species, with attention given to the selection of species that are tolerant of the anticipated hydrology and soil conditions on the trail embankment. The trail embankment will likely be constructed from silty or clayey soils that may have high salinities and high organic content. These soils may include material sourced from excavation within the Preserve to widen the south marsh inlet, lower the former trail embankment, and to construct new tidal channels. Groundwater and soil moisture will likely be limited along most of the embankment during much of the year, however there may be opportunities to direct stormwater from adjacent upland areas onto portions of the embankment slope to create conditions that support native upland vegetation.

# SMALL TIDAL CHANNELS AND MARSH MOUNDS

There are areas in both the South and North Bothin Marsh that experience limited tidal circulation due to the lack of nearby tidal channels. These areas pond water during low tides, and accumulate salts during the summer months, stressing the marsh vegetation. During drier years the marsh vegetation may die off completely resulting in unvegetated scalds. To promote diverse and healthy marsh vegetation, we recommend the construction of small tidal channels to increase tidal circulation to areas that show indications of scald formation, in particular in the western portion of the South Bothin Marsh, and the southern portion of North Bothin Marsh. The size of the channels will vary depending on the tributary area, but should be relatively small (bottom elevation 2 feet below marsh grade with 3 to 5 foot top widths). If feasible, these channels should be excavated using hand tools to avoid the need to construct temporary construction access roads across the marsh. Material excavated from these channels should be placed on the adjacent marsh plain to create mounds that rise 0.5 to 1 foot above MHHW (approximately elevation 6.5 to 7ft NAVD). These marsh mounds will support high marsh vegetation and will provide high tide refuge areas. If possible, these marsh mounds should be planted with native plants to prevent colonization by invasive non-native species.

*Marsh Mounds, Low Tide, Muzzi Marsh, Corte Madera*

*Aramburu shoreline coarse beach demonstration project*

# EROSION MANAGEMENT

Concerning rates of shoreline erosion have been observed in several areas along the Preserve's shoreline. The existing marshes at the Preserve formed as the result of historic placement of dredge material within basins bordered by engineered containment berms. These containment berms are eroding in several areas, in particular along the south facing shorelines of the North Bothin Marsh. While these berms likely were not designed to resist long-term wave exposure, they likely were compacted, resulting in soils that are more erosion resistant that typical marsh soils, but still susceptible to erosion and degradation over time. If the perimeter berms were to erode completely, much softer soils in the marsh interior would be exposed to waves, resulting in potentially rapid erosion of the marsh habitats.

To avoid this outcome, we recommend a coastal engineering study to evaluate wave conditions causing shoreline erosion and to identify nature-based solutions to reduce or halt the shoreline erosion. Nature-based solutions can provide shoreline protection as well as ecological benefits. The study should consider the installation of features such as offshore reefs and mudflat augmentation to reduce wave energy striking the shoreline and coarse beaches, reinforced plantings, large wood sills and groins, and nearshore reefs to stabilize portions of the shoreline that are most vulnerable to erosion.

Rock armor and other shoreline protection features which offer limited or no ecological value should only be placed in to limited areas where no nature-based alternatives can provide acceptable performance.

# SMALL-SCALE HABITAT FEATURES

The project should include the opportunistic installation of small-scale habitat features through the salvage and reuse of woody debris and natural rocks encountered during construction. Salvaged rocks and wood should be opportunistically re-used to create habitat features such as brush piles, wood snags, trellises, and artificial burrows. These habitat features can be constructed at little cost (assuming salvaged materials are available) and can provide a diverse array of benefits for plants and wildlife by increasing the structural complexity of the landscape.

If salvaged materials are not available in suitable quantities, it may be beneficial to import wood debris from offsite if cost-effective suppliers can be identified. The project team should coordinate with local agencies conducting tree maintenance and fire abatement efforts to identify potential sources of woody debris.

# COYOTE CREEK RE-ALIGNMENT

Coyote Creek currently flows through an engineered channel along the south side of South Bothin Marsh. Under the current alignment the creek is connected to the tidal marsh only during very high tides, and for the majority of the time stream flows and suspended sediment from the Coyote Creek watershed bypass the marsh and flow directly to Richardson Bay. This measure proposes to re-align the creek through South Bothin Marsh to increase the amount of watershed sediment that is delivered to the marsh.

## PROS:

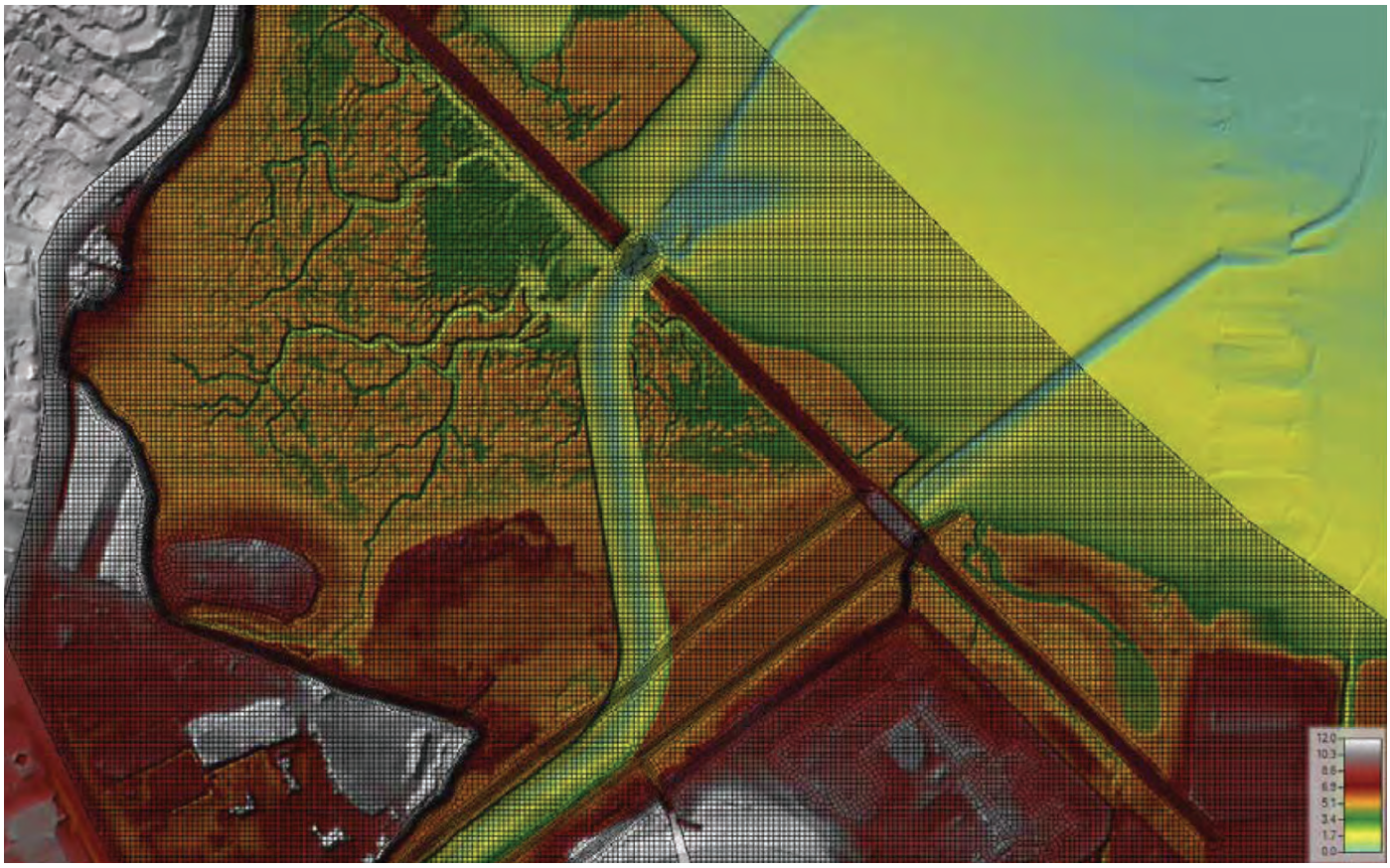
- **One-Time Expense, Long-term Benefits:** Re-aligning Coyote Creek would provide modest long-term benefits to the resilience of the tidal marsh habitats in South Bothin Marsh. Once the channel is re-aligned, the creek would continue to deliver sediment to the marsh for many decades, resulting in potential long-term resilience benefits.

## CONS:

- **Temporary Impacts to South Bothin Marsh**: Re-aligning the creek channel would require extensive excavation within the interior of South Bothin Marsh, directly impacting approximately 2 acres of marsh and tidal channel habitat used by special status species like Ridgway's Rail, California Black Rail, and Point Reyes bird's-beak. The noise and visual impacts associated with the work would also affect a wider area of the marsh.
- **Limited Benefits**: The maximum achievable benefits from creek re-alignment are limited by the total supply of sediment from the watershed. While the watershed may supply enough sediment to extend the life of South Bothin Marsh by a few decades, there is not enough watershed sediment to support the marsh habitats under the accelerated rates of sea-level rise projected for the end of this century. In addition, the creek re-alignment only provides resilience benefits to South Bothin Marsh, the tidal marshes in North Bothin Marsh would not receive any benefit.

## UNCERTAINTIES:

- **Coyote Creek Sediment Supply**: The conveyance of sediment by the Coyote Creek is driven primarily by large rain events, and consequently there can be large year-to-year variations in sediment delivery from the watershed. Current estimates of the watershed sediment yield are based on a small number of suspended sediment measurements taken during a single winter. These measurements likely do not capture the full range of variability of the watershed sediment yield. The collection of additional suspended sediment measurements during high streamflow events would reduce the uncertainty in the estimated watershed sediment yield, which in turn would increase confidence in the estimated benefits to marsh resilience from the creek re-alignment.
- **Refine Channel Geometry**: The 2021 Anchor hydraulic modeling study confirmed the feasibility of the modeled channel geometry from a flood risk and sediment transport perspective, however the channel geometry evaluated in that study had very large near-term ecological impacts. Additional modeling and analysis is required to evaluate the potential benefits of an optimized channel geometry and evaluate the long-term stability and sustainability of the re-aligned channel. It is possible that a smaller, more sinuous channel could provide more efficient sediment delivery to the tidal marsh and would cause fewer near-term impacts, however as the channel becomes smaller the potential for upstream flood impacts may increase.
- **Ecological Outcomes for Special Status Species**: The creek re-alignment would alter the internal landscape of South Bothin Marsh, resulting in changes in patterns of sediment deposition that would alter the distribution of tidal channels, unvegetated tidal pannes and vegetated high marsh. Additional study and review of reference sites is needed to better understand how these changes would affect special status species like Ridgway's rail, CA black rail and Point Reyes bird's-beak.




*The HEC-RAS hydraulic model was used to evaluate flood impacts and sediment transport for the re-aligned Coyote Creek channel.*

## RECOMMENDATIONS

- **Coyote Creek Sediment Sampling**: Measure suspended sediment concentrations in Coyote Creek during moderate and high stream flow events to improve confidence in the estimates of watershed sediment yield.
- **Design Refinements**: Refine the geometry of the new channel to balance benefits of sediment delivery, ecological impacts in the excavation footprint, while avoiding adverse flood impacts.

# THIN LIFT SEDIMENT PLACEMENTS

The Project evaluated options for importing and re-using sediments from nearby maintenance dredging. Thin Lift Sediment Placement is a method for delivering dredged sediments to enhance the resilience of tidal marsh habitats that involves pumping a thin layer of sediment-rich slurry onto the marsh plain in a process that mimics natural patterns of sediment deposition. This method can be used to increase the long-term resilience of a marsh through a management program that includes periodic placement of thin layers of sediment followed by recovery periods to allow the marsh vegetation to grown and adjust to the new bed elevation. The timing and location of slurry placement and the thickness of the sediment layer placed during each event are important parameters for the design of a thin lift project.

The Project proposes to partner with the Marin County Flood Control District to conduct a pilot study to test and monitor the outcomes of thin lift placements and develop best practices that balance the near-term ecological impacts with the long-term benefits to marsh resilience. In addition, work could be coordinated with research efforts by the National Estuarine Research Reserve, who is currently conducting a small-scale thin lift pilot study at the nearby Manzanita Marsh.

## PROS:

- **Flexible/Scalable**: There is the potential to scale the Thin Lift Sediment Placement as needed to achieve the desired resilience benefits for the tidal marsh habitats. The benefits of thin lift placement could be increased or decreased in response to the actual future rates of sea-level rise to balance resilience vs. temporary ecological impacts. The flexibility of thin lift creates an appealing tool for adaptive management, however there are some limits – the maximum rate of placement is limited by the tolerance of the vegetation to thicker/more frequent sediment placements, and placement may also be limited by availability of imported sediment.
- **Benefits for Desired Plant Species**: Several desired native plant species, including Point Reyes bird's-beak and California sea-lavender, can thrive on recently deposited sediments in the high inter-tidal zone. These species may greatly benefit from the periodic creation of these depositional features provided that the placed sediments contain a suitable seedbank or if sediment placement occurs near existing plant populations to allow for natural dispersal. The Project Team should consider whether to conduct seed collection and planting after each thin lift placement to further support these species.
- **High Value Pilot Study**: There are several factors that make Bothin Marsh particularly well suited as a pilot study site. 1) The marshes at the Preserve exhibit a wide range of existing elevations, allowing for potential experiment designs that test the effectiveness of thin lifts to reverse subsidence in marshes that are already showing signs of drowning from rising sea levels (eg. South Bothin Marsh), as well as testing the methods on marshes that are at higher elevations (eg. North Bothin Marsh). 2) The presence of salt marsh harvest mouse has not been confirmed by the United States Fish and Wildlife Service in recent studies at Bothin Marsh. The potential presumed absence of this fully protected species may simplify the regulatory process for approving a pilot study. 3) Potential to build off current studies being conducted by the Marin County Flood Control District by designing the pilot study to re-use sediment generated from maintenance dredging on Coyote Creek.

## CONS:

- **Repeated Ecological Impacts**: In order to realize long-term benefits from thin lift sediment placements, it would be necessary to place lifts of sediment at regular intervals (eg. every 5 to 10 years). The vegetation and wildlife within

*Seal Beach Thin Lift Pilot Study (Orange County, CA)*
*Image: SWIA*

the marsh should be reasonably well adapted to the periodic disturbance conditions that would be created by thin lift placements. Nonetheless, each lift of sediment has the potential to disturb existing habitats and wildlife, both due to the sediment itself, as well as noise, visual and other impacts related to the installation of piping and pumping the sediment rich slurry. The pilot study would include monitoring and adaptive management to better understand the level of disturbance and to develop best practices to limit adverse impacts.

- **Repeated Project Costs**: This measure would incur periodic costs to the County to fund the import and placement of each thin lift of sediment. The vast majority of funding sources that support habitat restoration and enhancement projects are one-time grants or allocations. Ideally the Project would identify a long-term funding stream that could support these ongoing costs. There could be potential cost savings through cost-sharing partnerships with nearby dredging projects. Thin lift sediment placement may be a more cost-effective option for handling dredged material compared to traditional disposal methods.

## UNCERTAINTIES:

- **Sediment Sources**: This project measure is reliant on the availability of sediment that can be cost-effectively imported to the Preserve. The Project does not have control over when imported sediments may become available, and in what quantity. There are several potential sources of sediment that might meet the project's needs, including maintenance dredging on Coyote, maintenance dredging on Arroyo Corte Madera del Presidio, and navigation dredging elsewhere in Richardson Bay. One of the main objectives of the next Project phase will be to build partnerships with agencies that manage these dredging operations and to coordinate to align dredging events with the thin lift placements. In addition, there may be logistical constraints affecting feasibility of different methods of sediment import, for example the shallow waters in north Richardson Bay will limit the size/draft of barges that can approach Bothin Marsh to delivery sediment.

## RECOMMENDATIONS:

- **Develop Pilot Study**: Consider partnerships with research institutions (STAC members and other science-oriented agencies and non-profits)
- **Identify Potential Sediment Sources**
- **Coordinate with Funding Agencies**: Advocate for long-term funding streams to support ongoing future sediment placement efforts.

# MUDFLAT SEDIMENT AUGMENTATION

An alternate approach to increasing sediment supply to the tidal marshes is to import and place sediments on the mudflats offshore of the Preserve and allow waves and tidal circulation to bring these sediments onto the tidal marshes. This experimental method is logistically similar to thin lift sediment placement in that it requires coordination with nearby dredging projects or other projects that generate excess sediments, however the sediment would be placed offshore rather than directly on the tidal marsh, resulting in different benefits and impacts.

## PROS:

- **Minimal Disturbance to Marsh Habitats**: Mudflat sediment placement does not directly impact the existing tidal marsh habitats, and so would avoid direct impacts to special status marsh species .
- **Flexible/Scalable**: There are fewer limitations on the thickness and volume of sediment that could be placed on mudflats during a single placement event compared to thin lift sediment placement on a tidal marsh. For this reason, mudflat sediment placement might be preferred if a large volume of dredged sediment becomes available and needs to be placed within a short period of time.
- **Increase Resilience of Mudflats**: Inter-tidal mudflats are also a valuable element of the marsh and Bay ecosystem, providing a home to benthic organisms and foraging habitat for shorebirds and fish. Like tidal marshes, mudflat habitats will also be impacted and lost due to rising sea-levels, and mudflat sediment augmentation is a very effective method to improve the resilience of these habitats.

## CONS:

- **Repeated Ecological Impacts & Repeated Project Costs**: Similar to thin lift sediment placements, mudflat sediment augmentation would require repeated sediment placements in order to achieve long-term resilience benefits, resulting in recurring ecological impacts and periodic costs.
- **Less Efficient Sediment Delivery to Marsh**: Mudflat sediment placement is a less efficient method of increasing the resilience of tidal marshes compared to placement of thin lifts directly on the marsh. While additional study is needed to understand the expected patterns of sediment transport following the placement of sediment on the mudflats, it is likely that a larger portion of the placed sediment will remain on the mudflats or move to deeper waters farther offshore and a smaller portion of the sediment will move onto the tidal marshes.
- **Impacts to Aquatic Resources**: Mudflat sediment augmentation mimics natural sediment deposition processes, however sediment deposition would occur at a more rapid rate than is typical for offshore habitats, and so the sediment placement would potentially disturb offshore aquatic habitats, including mudflats and subtidal areas, with potential impacts to fish, benthic wildlife, and aquatic vegetation. Eelgrass, a protected aquatic plant, is known to be present in north Richardson Bay and may be particularly sensitive to this measure. The level of disturbance to these habitats would depend on the methods, locations and volume of sediment placed, and future project phases should include analysis and design to minimize adverse effects on aquatic resources.

## UNCERTAINTIES:

- **Sediment Sources**: Similar to thin lift sediment placements, this project measure is reliant on the availability of sediment that can be cost-effectively imported to the Preserve. The Project does not have control over when imported sediments may become available, and in what quantity.
- **Efficiency of Sediment Delivery**: Waves and tidal circulation will cause some of the sediment that is placed on the mudflat to circulate and deposit within the tidal marsh. Additional study is needed to understand how waves and currents with move the sediment, and what fraction of

*Existing mudflat areas in South Bothin Marsh: Potential location of mudflats where beneficially reused sediment could be placed. Image: ESA*

the placed sediment can be expected to reach the marsh and what fraction remains on the mudflat or is flushed into deeper portions of Richardson Bay. If future studies show that a large fraction of the sediment placed on the mudflat will likely reach the marsh, then this measure may be a very effective means of supporting marsh resilience.

## RECOMMENDATIONS:

- **Sediment Transport Modeling**: Hydraulic and sediment transport modeling is recommended to estimate the efficiency of sediment delivery from the mudflats to the nearby tidal marshes. This analysis will inform estimates of the scale of potential benefits for marsh resilience.
- **Develop Pilot Study Objectives and Methods**: Continued coordination with the Science and Technical Advisory Committee is recommended in order to develop an experimental approach that will yield results that can inform the design of future mudflat sediment augmentation projects across the San Francisco Bay Region.

# SUMMARY OF RECOMMENDATIONS FOR PLANNING & DESIGN

This Adaptation Concepts report has identified a recommended approach for re-aligning and improving the Bay Trail segment at the Preserve and potential measures for improving the resilience and quality of the Preserve's tidal marsh habitats. These findings set the stage to begin detailed engineering and design on the trail. The following is a summary of the recommended design measures.


## CONCEPT 3 TRAIL ALIGNMENT

- Re-align trail along south marsh using alignment shown in "Concept 3: Ring the Marsh"
- Evaluate options for integrating new trail embankment with potential future off-site flood protection infrastructure in order to improve regional sea-level rise resilience.

## MARSH ENHANCEMENT MEASURES

- Implement measures to improve resilience, habitat quality and ecologic function of the Preserve's high marsh habitats.
- Excavate small tidal channels to improve tidal circulation in areas of the marsh that exhibit signs of scald formation or excessive stress of marsh vegetation due to prolonged ponding.
- Side-cast material from this channel excavation to create high-marsh mounds. Plant mounds with native vegetation.
- Continue to manage non-native invasive species, with specific emphasis on treating populations near earthwork areas in order to reduce spread of non-native weeds to areas that are disturbed during construction.
- Plant desired native high marsh and transition zone plant species, including salt-marsh bird's beak, along bayward toe of new trail embankment and on restored former trail footprint.
- Conduct costal study to identify appropriate measures to reduce rates of shoreline erosion along marsh edges. To the extent feasible, apply natural infrastructure methods such as coarse beaches, nearshore reefs, wood debris, and plantings in order to enhance habitat diversity and provide ecological functions in addition to shoreline protection.
- Study additional geometries for channel connections between Coyote Creek and South Bothin Marsh with the aim of identifying a geometry that increases sediment delivery to the marsh while causing acceptable levels of near-

term impact to the marsh habitats compared to the geometries evaluated to date.

- Develop a pilot study to test methods and outcomes from thin lift sediment placement and mudflat augmentation. Continue to build partnerships with researchers and regulatory agencies in order to define scientific objectives and monitoring protocols. Coordinate with the Marin County Department of Public Works, US Army Corps of Engineers and other land managers in order to identify potential sources of sediment for both the pilot studies and potential long-term beneficial sediment re-use.

### CONSTRUCTION SEQUENCING/ ADAPTATION PATHWAY PLANNING

- Advance the development of adaptation pathway planning with potential project phasing and construction sequencing.

### MONITORING AND ADAPTIVE LANDSCAPE MANAGEMENT

- Continue to build partnerships with local community.
- Consider incorporating citizen science programs to assist with long-term monitoring of project.
- Consider opportunities for local community organizations to participate in project implementation
- Continue to conduct educational programing related to ecology, coastal processes and sea-level rise adaptation planning.
- Develop adaptive management plan for long-term maintenance and management of marsh habitats in coordination with the adaptation pathway planning identified above. Recognize that habitats within the Preserve will change over time as sea-levels rise. Apply adaptive management to balance near-term and long-term outcomes.

# NEXT STEPS

The next phase of the project should involve preparation of preliminary design plans for the new Bay Trail, and coordination with regulatory agencies. Studies should include preliminary geotechnical studies to inform the design of the raised trail embankment and preliminary engineering of utilities and structures.

In parallel with the trail design effort, the next project phase should include work to further develop the approach for improving the resilience of the tidal marsh habitats. This should include a technical study to quantify the amount of sediment that is delivered by the Coyote Creek watershed, and outreach to identify potential sources of imported sediment for beneficial re-use as thin lift placements and/or mudflat augmentation.

The ongoing work is focused on public access via the trail and restoration of the marsh. The project does not provide resilience measures to properties outside the marsh. The study has identified the potential for broader flood protection benefits if partnerships between agencies and cities are formed. Next step actions include continued efforts by County staff and GGNPC to coordination climate change and sea level rise adaptation planning with agencies and stakeholders that own and manage properties and infrastructure adjacent to the Preserve.

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