WHERE CREEKS MEET BAYLANDS:

Opportunities to re-establish freshwater and sediment delivery to the baylands of San Francisco Bay

SFEI | AQUATIC SCIENCE CENTER

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Front cover, left to right: Creek in Briones Regional Park (photo by Shira Bezalel); Alameda Creek, Coyote Hills Regional Park (photo by Shira Bezalel).

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GLOSSARY

Baylands: The area between the maximum and minimum extent of the tides including tidal and diked habitats (i.e. areas that would be subject to tidal influence if not for unnatural obstructions like levees and berms). The focus of this report is on baylands that are fully or partially connected to the tides and sustained, in part, by fine-grained sediment (i.e. tidal marshes and mudflats). Common baylands habitats referenced in this report are defined below, based on definitions from the Goals Project (1999, 2015), SFEI and SPUR (2019), and WRMP (2022):

- **Tidal marsh:** Vegetated wetland subject to tidal action located at elevations where vascular vegetation grows within San Francisco Bay, typically ranging from Mean Low Water (MLW) to Mean Higher High Water (MHHW).

- **Mudflat:** Broadly used to encompass all tidal areas within San Francisco Bay that exist from below the local Mean Lower Low Water (MLLW) to Mean Tide Level (MTL), which may vary in dominant grain size and thus terminology (e.g., sandflat, shellflat).

- **Beach:** Coarse or composite features that can consist of a mixture of sand, shell, gravel, or cobble and are typically located at the mouths of creeks, along the bayward edge of marshes, or between headlands in San Francisco Bay. Estuarine beaches include a supratidal beach berm and a beach face, and the lowest portion is often characterized by a low tide terrace and transitions to tidal flat. While beaches are an integral part of baylands, this first version of a conceptualized understanding of sediment transport focuses on fine-grained sediment with the hopes of including coarse-grained sediment (e.g. beaches) in a next iteration.

- **Shallows:** Tidal areas within San Francisco Bay ranging from MLLW to 12 feet below MLLW.

- **Deep Bay/channels:** Tidal areas within San Francisco Bay exceeding 12 ft below MLLW.

Operational Landscape Unit (OLU): Connected geographic areas sharing certain physical characteristics that would benefit from being managed as a unit to provide particular desired ecosystem functions and services. For more information, see SFEI and SPUR (2019).

Polders: Low-lying areas of land that would normally be inundated by regular tides if they were not protected by dikes. Polders are the diked, ditched, and drained historical tidal marshes and mudflats that are locally known in San Francisco Bay as “diked baylands.”

Resilience: The ability of a system to maintain function after being perturbed by a disturbance: either a long-term trend (e.g., rising sea levels) or a specific event (e.g., storm)

San Francisco Bay (Bay): Includes the subembayments of Suisun Bay, San Pablo Bay, Central Bay, South Bay, Lower South Bay.

Shoreline: Broadly used to encompass all elements of the “shore,” including natural features like marshes, beaches, and mudflats, as well as the “shoreline”, or the “line of defense” from coastal flooding.

EXECUTIVE SUMMARY

Overview

As baylands restoration and climate change alter the ecosystems of the San Francisco Bay (Bay), novel restoration approaches are needed to meet growing challenges. Paramount among these challenges for the baylands is a projected lack of sufficient inorganic sediment to help marsh elevations keep pace with sea-level rise over the coming decades. One restoration approach that may address this challenge is to diversify the way that creeks are connected to baylands, returning those connections to the adaptive, resilient nodes of habitat complexity that they were historically. In this way, the templates of landscape connectivity from the past can guide how our present landscapes adapt to the pressures of climate change.

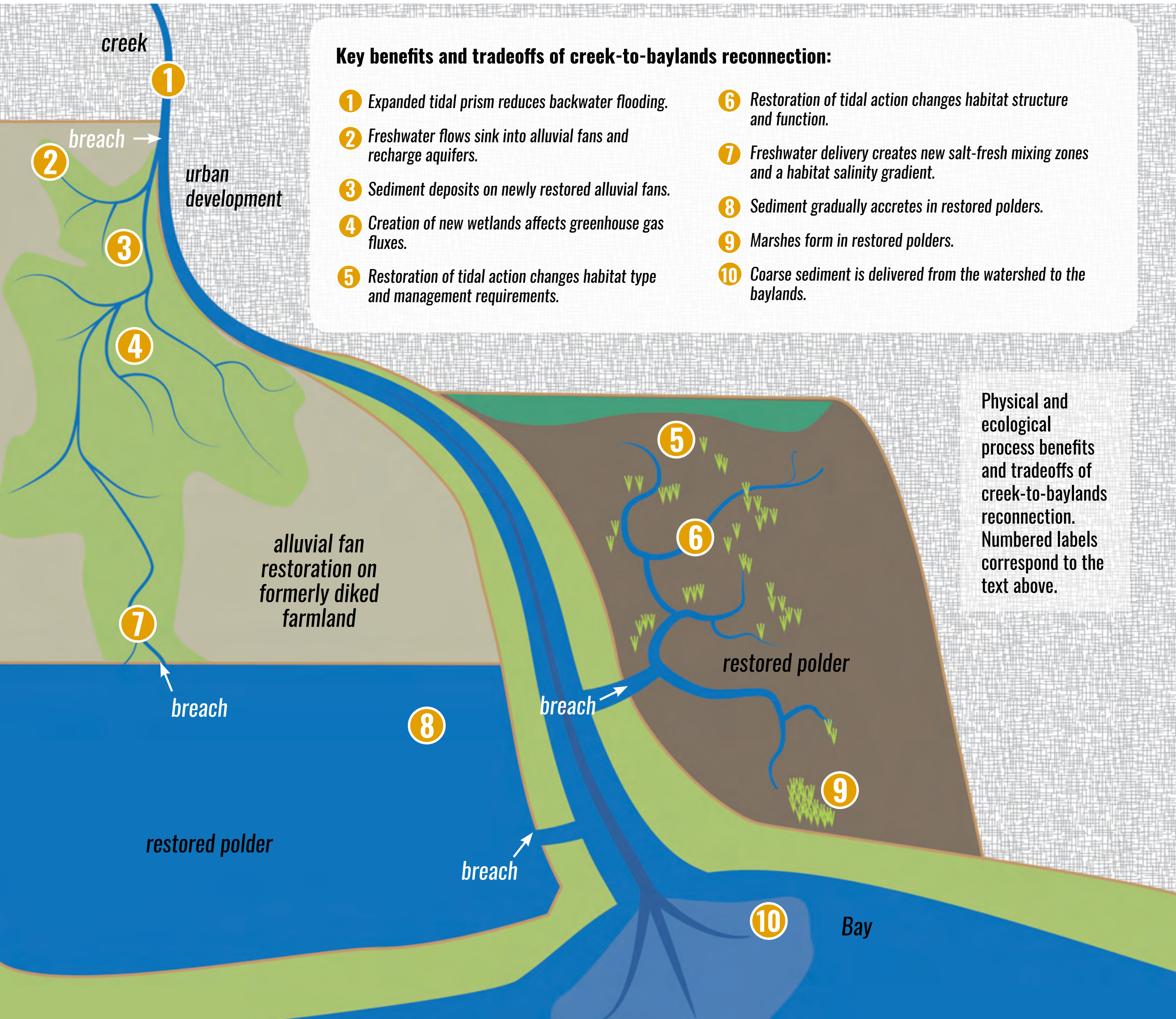
The intended outcome of this effort is to aid in the long-term resilience of baylands as sea level rises by working with natural processes to deliver sediment while providing additional benefits, like flood risk management, to nearby communities and other vital ecosystem services. Restoration practitioners, flood risk managers, regulatory agency representatives, and others can use this report to help identify and pursue more opportunities in the Bay to connect fluvial channels to baylands.

This report:

- Explains potential benefits, risks, and tradeoffs of reconnecting creeks to baylands
- Maps and classifies a range of watershed channels around the region into reconnection opportunity types where channels meet baylands
- Characterizes those channels by taking into account six aspects of physical and ecological processes: local sediment supply, tidal marsh suitability, marsh migration space suitability, polder suitability, vertical accretion potential, and steelhead habitat
- Develops high-level reconnection concepts at a case study site (Suisun Creek), which we chose based on its suitability for alluvial fan restoration to demonstrate a lesser known opportunity type and its high rankings for five out of the six categories considered above
- Offers guidance and next steps for restoration practitioners, flood risk managers, regulators, funders, and others focused on implementing multi-benefit management actions where rivers meet the Bay

Benefits

Historically, uninhibited delivery of freshwater and sediment from watersheds to baylands created complex marsh habitat mosaics. Restoring some of those historical creek-to-baylands connections can re-establish freshwater and sediment delivery from watersheds, changing physical and ecological conditions at the site scale and contributing to regional habitat goals (e.g. Goals Project 2015). Careful consideration of benefits and tradeoffs of reconnection projects is critical for engaging partners, securing funding and permits, developing implementable and effective design concepts, and achieving restoration goals. Several physical and ecological process benefits and tradeoffs are illustrated below, with more in-depth discussion offered in Chapter 2.



Physical and ecological process benefits and tradeoffs of creek-to-baylands reconnection. Numbered labels correspond to the text above.

The benefits to adjacent communities are also an important motivation for reconnecting creeks to baylands. These benefits include:

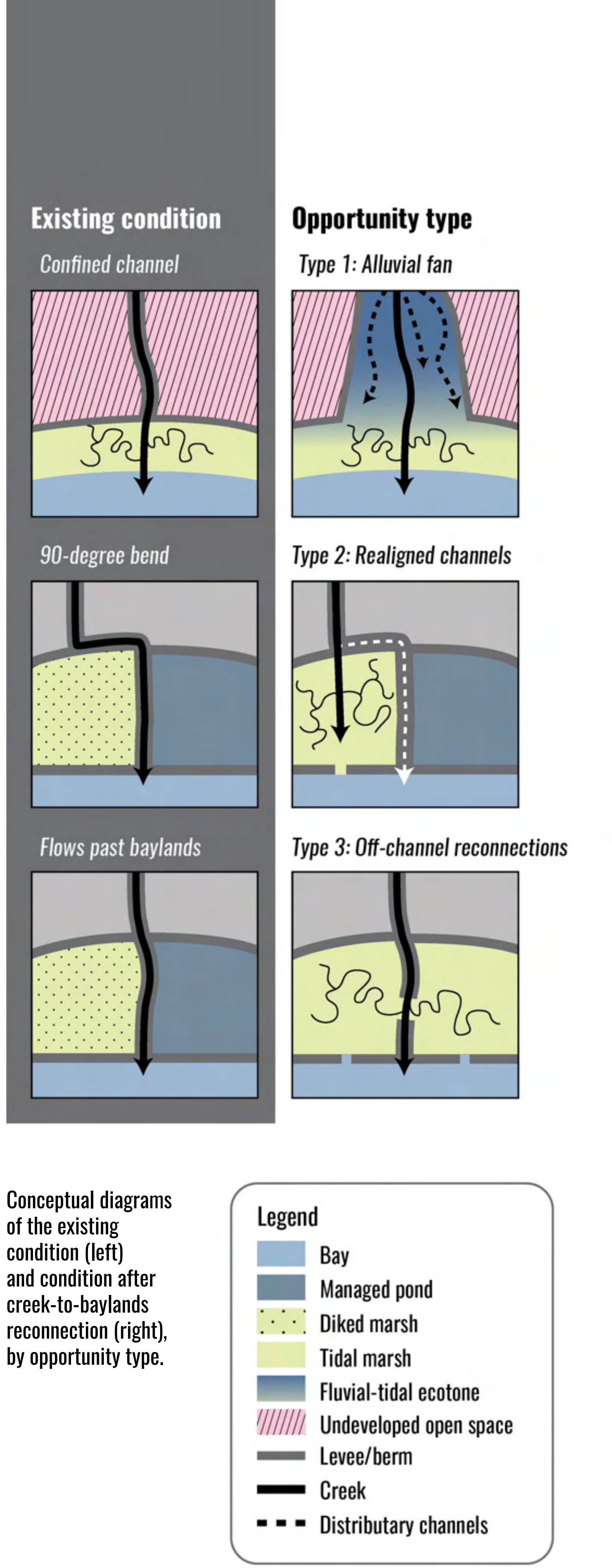
- **Recreational access**, including trails, recreational facilities, educational, and cultural elements.
- **Health and wellbeing benefits** from spending time outdoors and near the water.
- **More productive food web for fishers** due to improved ecosystem function and health of fisheries.
- **Creation of jobs** for project planning, construction, monitoring, and maintenance.
- **Flood-risk reduction** for adjacent communities, if projects are designed to reduce upstream flooding.
- **Public cost savings** due to reduced maintenance costs for long levees around diked baylands and narrow creek channels that require dredging.

Recreational trail at the Don Edwards Wildlife Refuge (photo by Shira Bezalel, SFEI)

Opportunity types

A major innovation of this report is creating categories for creek-baylands reconnection opportunity types and identifying where they occur around the region. The opportunity types include:

- **Alluvial fans ("Fan out")**: Opportunities to give a creek space to allow distributary channels to form, migrate over time, abandon and form new channels, and transport sediment downstream.
- **Realigned channels ("Realign")**: Opportunities at the creek mouth to realign, establish, or reestablish flow directly into an existing marsh or diked baylands slated for restoration.
- **Off-channel reconnections ("Connect to the side")**: Opportunities to connect an area adjacent to the channel that is currently protected by berms, levees or other infrastructure that restricts tidal and fluvial flows, opening it to full fluvial-tidal action.
- **Channels with limited floodable space**: Little to no opportunities are present due to limited available floodable space. Ecological enhancements that do not require a lot of floodable space (e.g., improving the creek's ecological corridor, reuse of dredged sediment to support accretion in local baylands) are recommended. This opportunity type is not visualized, since it will vary greatly depending on the site.



Conceptual diagrams of the existing condition (left) and condition after creek-to-baylands reconnection (right), by opportunity type.

Needs and actions

To accelerate the implementation of creek-baylands reconnections, several actions could be taken by scientists, restoration practitioners, planners, agency staff, community and Tribal leaders, and other stakeholders that would address current needs.

Need: Assessment of all Bay Area watersheds for opportunities and more in-depth analysis of benefits, risks, and tradeoffs to help drive decision making.

Action: Refine opportunity mapping and benefit analysis at the regional and OLU scales.

Need: A blueprint for how to restore fluvial-tidal habitats with climate change in mind.

Action: Create design and engineering guidelines and best practices for reconnection concepts that are less studied or have yet to be implemented in the Bay.

Need: Coordination at subregional scales to drive holistic solutions and maximize resources.

Action: Plan at the OLU scale in a way that integrates across ecosystems and brings together Tribes, communities, and other project partners.

Tidal marsh at Hamilton Wetlands in Novato (photo by Shira Bezalel, SFEI)

1. Introduction

Overview

Indigenous communities have lived around San Francisco Bay (Bay) for thousands of years, historically shaping the baylands through land management practices honed through observation and generational teachings that resulted in land stewardship and symbiosis between humans and the landscape (POST 2021). The arrival of colonists to the Bay Area in the 1700s brought intensive and destructive land management practices that began to change the landscape. Over the last two centuries, European-American colonization heavily modified San Francisco Bay's (henceforth "the Bay") local watersheds and baylands to accommodate urban development, salt production, duck hunting, agriculture, and other uses (Dusterhoff et al. 2017). These modifications have led to the reconfiguration of local rivers and creeks through actions like realigning, lengthening, straightening, and leveeing. Rivers and creeks once provided essential sediment, nutrients, and freshwater directly to diverse and endemic marsh and riparian habitats around the Bay—sycamore alluvial woodlands, seasonal wet meadows and other freshwater wetlands, tidal marshes and mudflats (Figure 1). Many of the historical marshes that covered the rich transitional space between creeks and the Bay have been drained and reclaimed to support current land uses. Today, most tributaries flow through leveed channels out to the Bay, bypassing the intertidal and transition-zone elevations of the baylands that were historically connected and would benefit from the diverted freshwater and sediment (Figure 2).

Levees along Alameda Creek channel (Courtesy of Dan Rademacher, CC BY 2.0)

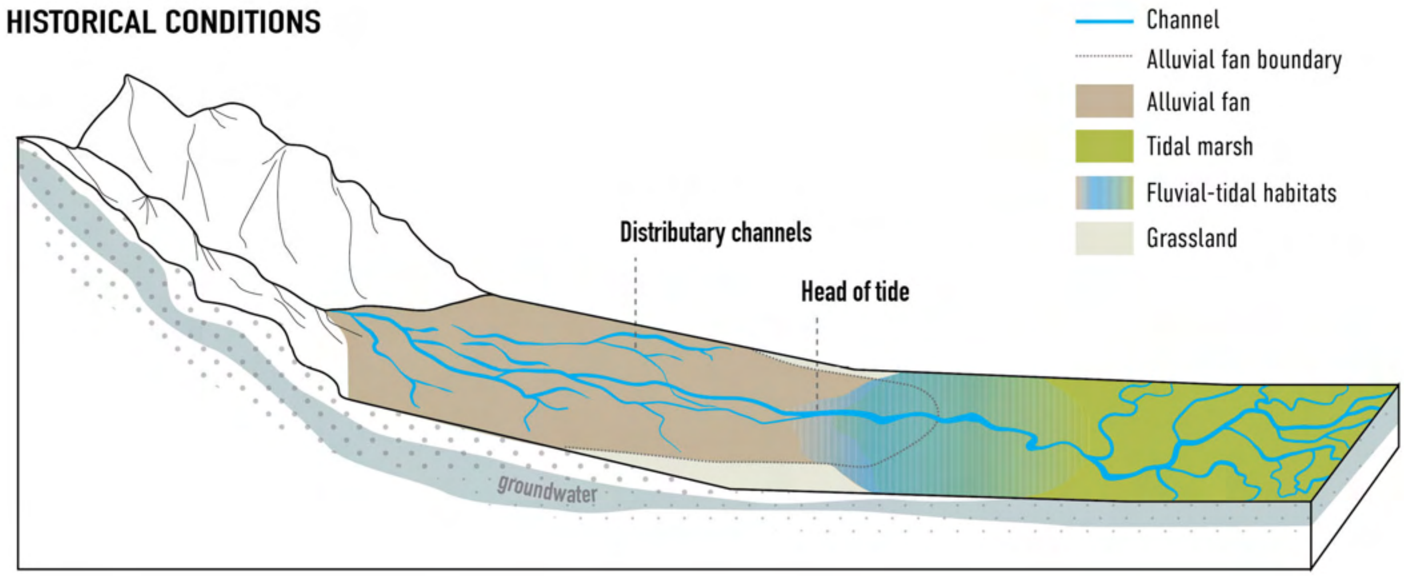


Figure 1. Many fluvial channels historically flowed into an alluvial fan where distributary channels—stream channels that branch off from the mainstem channel—allowed water to spread out and deposit sediment in a gently sloping gradient. In many cases, these alluvial fans drained into the back of extensive tidal marsh complexes.

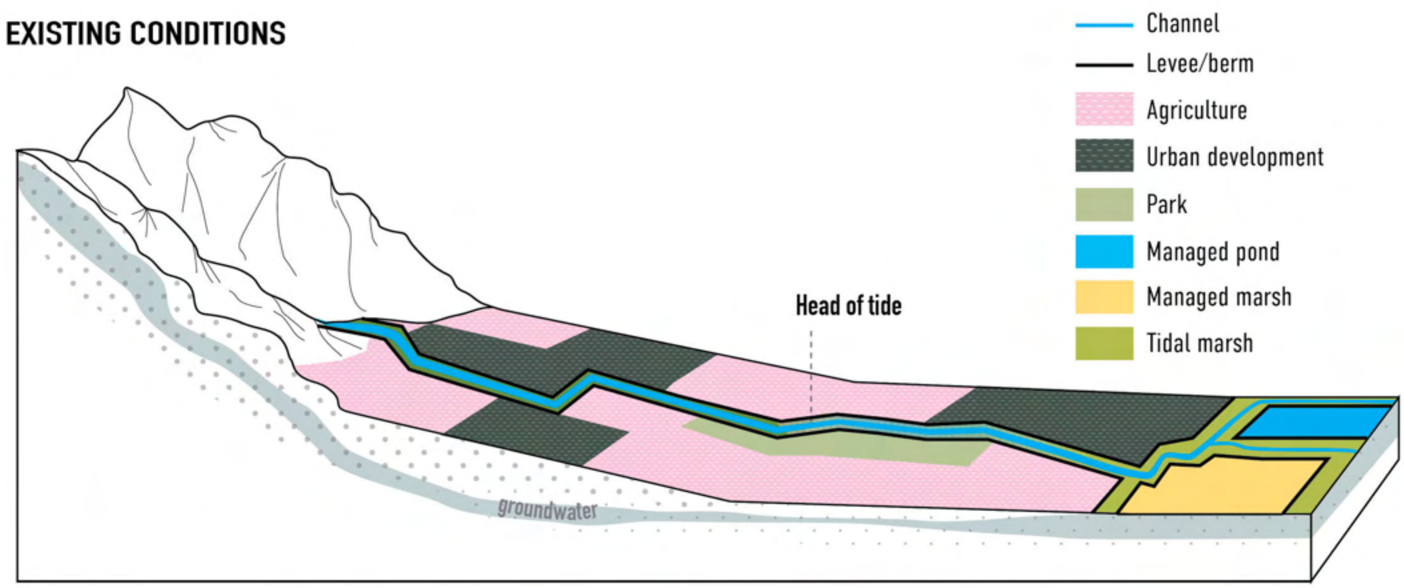


Figure 2. Today, the alluvial fans and their downstream baylands have been highly modified through a mix of urban development, agriculture, salt ponds, parks and open space, leaving little room between levees and the channel to accommodate flood flows and deliver sediment and freshwater to surrounding landscapes. Undeveloped areas (e.g., agricultural land, parks/open space, diked marshes/ponds) adjacent to the channel and immediately above and below head of tide are ideal locations for creek-to-baylands reconnections and can help to reduce flood risks and replenish groundwater supplies near the channel.

In addition to restoring historical transitional habitat types, there is growing urgency to re-establish freshwater and sediment delivery to build baylands elevation. This report defines baylands as lands open to full tidal action that range across the maximum extent of the tides (mean higher high water to mean lower low water), which includes tidal marshes, mudflats, and beaches. Tidal marshes and mudflats around the Bay will likely not be able to gain elevation at pace with sea-level rise unless action is taken to increase the amount of local mineral sediment supply available for deposition (Dusterhoff et al. 2021). Perhaps a sustainable and cost-effective way to get more sediment onto existing and planned tidal restoration projects is to direct creek flows onto marshes and mudflats. Indeed, these efforts—known as creek-to-baylands reconnection projects—are gaining attention as a way to move sediment out of flood control channels to reduce local flooding while increasing delivery of sediment to downstream baylands.

There are several areas with visioning efforts underway around the region to reconnect creeks to their downstream baylands, including Walnut Creek, Novato Creek, Calabazas and San Tomas Aquino creeks, Sonoma Creek, and the Petaluma River. These reconnection plans have the potential to achieve multiple benefits for people and wildlife while reducing long-term costs for repeat dredging and frequent channel maintenance requirements. Most of these projects are still in the planning stages and have yet to be implemented, highlighting a need for more comprehensive guidance to make these types of projects come to fruition across the Bay.

Reconnecting channels to baylands was noted as one of the five most critical overarching ideas to come out of the ***Baylands Ecosystem Habitat Goals Project*** (Goals Project) (2015) to build baylands that are resilient to climate change and was one of ten nature-based adaptation measures mapped and discussed in the ***San Francisco Bay Shoreline Adaptation Atlas*** (Adaptation Atlas) (SFEI and SPUR 2019). Since the completion of these efforts, there has been a concerted regional effort to identify reconnection opportunities around the Bay. Through the Flood Control 2.0 initiative, 25 major flood control channels were identified as having the potential for creek-to-baylands reconnection, primarily due to the presence of undeveloped land adjacent to the channels that could be restored to tidal marsh and related estuarine habitats (Figure 3; Dusterhoff et al. 2017). The study also revealed that there are more than 200 channels that currently wind through reclaimed or diked baylands, highlighting the need for additional study to determine which channels beyond the 25 analyzed may be reconnection candidates (Dusterhoff et al. 2017).

While creek-to-baylands reconnection is gaining momentum as a restoration technique, flood risk management tool, and shoreline adaptation strategy, more information is needed to understand where and how channels can be reconnected to baylands. A better understanding of how reconnection opportunities differ by landscape setting, expected benefits and tradeoffs, and permitting considerations are needed in order for restoration practitioners and stakeholders to achieve more widespread implementation across the region.

Figure 3. Channels assessed as having considerable undeveloped adjacent land and the potential for creek-baylands reconnection in SFEI's Changing Channels report (Dusterhoff et al. 2017).

Report overview

This report is a step toward developing a regional toolkit to support creek-to-baylands reconnection projects in the Bay. To date, restoration efforts in the Bay have focused on one type of reconnection: off-channel reconnections, or breaching levees to connect adjacent subsided diked lands for tidal marsh restoration. This report explores two additional types of reconnection opportunities--distributary channels and realigned channels--to expand the creek-to-baylands restoration planning toolkit in the Bay. The intended outcome of this effort is to aid in the long-term resilience of baylands as sea-level rises by working with natural processes to deliver sediment while providing additional benefits and ecosystem services. Restoration practitioners, flood risk managers, regulators, and others can use this report to help identify and pursue more opportunities in the Bay to connect fluvial channels to baylands. The questions that this work aimed to address include:

- Where are opportunities to increase baylands resilience by working with natural processes to deliver sediment onto marshes and mudflats?
- Where have reconnection opportunities already been identified? Where are actions already in development? Where are the opportunities to connect creeks that have not yet been studied?
- How do creek reconnection opportunities differ around the Bay and within an OLU, and what drives those differences?
- How could reconnection opportunities be prioritized to increase regional resilience of the baylands to sea-level rise?

Undeveloped marsh migration space along Tolay Creek in the Napa-Sonoma OLU (photo by Julie Beagle, SFEI)

Specifically, the report:

- **Explains the possible benefits, risks, and tradeoffs** of reconnecting creeks to baylands (Chapter 2)
- **Explains how creeks with reconnection opportunity were filtered and categorized** at the regional scale (Chapter 3)
- **Categorizes creeks into reconnection opportunity types (Figure 4) and characterizes six aspects of physical and ecological processes** (local sediment supply, tidal marsh suitability, marsh migration space suitability, polder suitability, vertical accretion potential, and steelhead habitat) for each creek, organized by OLU (Chapter 4)
- **Develops high-level reconnection examples** for one of the types to demonstrate how the information in this report can be applied (Chapter 5)
- **Highlights key considerations** for implementing creek-to-baylands reconnection projects (Chapter 6)
- **Concludes with next steps** to refine our approach and to achieve more widespread implementation of these types of projects (Chapter 7)

Restoration of creeks and marshes has been occurring for over five decades in the region, yet great potential exists to implement more projects that restore the important nodes where fluvial creeks meet tidal marshes and mudflats (known as fluvial-tidal interfaces and fluvial-estuarine transition zones). While creek and marsh restoration concepts are not new to practitioners and planners, the challenge of adapting to sea-level rise introduces opportunity for new restoration models. This new era underscores the need to restore, enhance, or emulate the physical and biological processes that allow baylands to weather change. This can be done by integrating creek restoration knowledge with tidal marsh restoration knowledge and piloting novel approaches to help tidal marshes and mudflats keep pace with sea-level rise into the future.

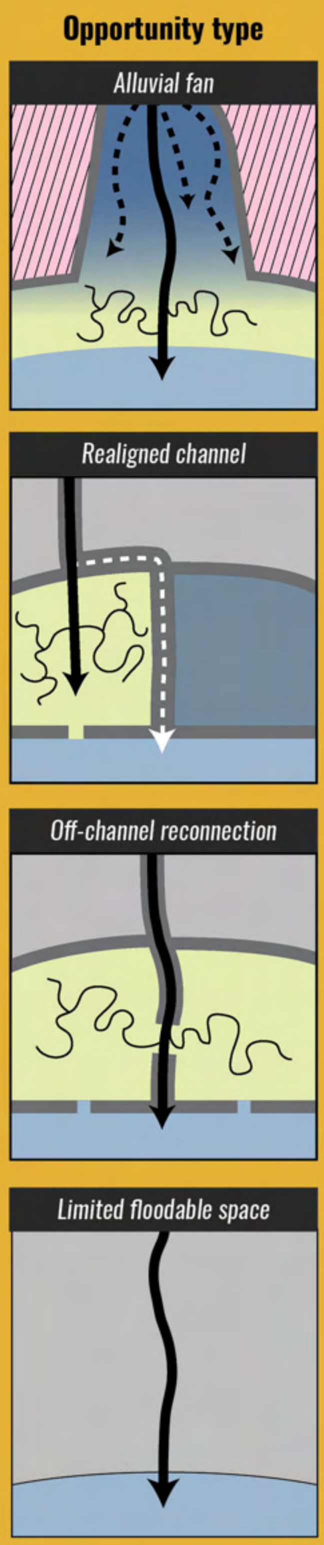
Disclaimer: *This report is a first attempt at categorizing creek-to-baylands reconnection opportunities into types to identify promising sites in pursuit of specific restoration goals. The findings detailed in this report do not replace the need for discussions with local and regional partners, engineering design, feasibility assessments, flood risk modeling, and other analyses.*

TYPES OVERVIEW

Creek-to-baylands reconnection opportunity types described in this report include (1) Alluvial fans, (2) Realigned channels, (3) Off-channel connections, and (4) Channels with limited floodable space. To read more about each type, see Chapter 4 on pg. 27.

- ***Alluvial fans ("Fan out"):*** Opportunities to give a creek space to allow distributary channels to form, migrate over time, abandon and form new channels, and transport sediment downstream.
- ***Realigned channels ("Realign"):*** Opportunities at the creek mouth to realign, establish, or reestablish flow directly into an existing marsh or diked baylands slated for restoration.
- ***Off-channel reconnections ("Connect to the side")***: Opportunities to connect an area adjacent to the channel that is currently protected by berms, levees or other infrastructure that restricts tidal and fluvial flows, opening it to full fluvial-tidal action.
- ***Channels with limited floodable space:*** Little to no opportunities are present due to limited available floodable space. Ecological enhancements that do not require a lot of floodable space (e.g., improving the creek's ecological corridor, mechanical reuse of dredged sediment to support local baylands) are recommended. This opportunity type is not visualized, since it will vary greatly depending on the site.

Figure 4. Conceptual diagrams of the existing condition (left) and condition after creek-to-baylands reconnection (right), by opportunity type.



About the Operational Landscape Unit (OLU) approach

The San Francisco Bay Shoreline Adaptation Atlas (henceforth the “Adaptation Atlas”; SFEI and SPUR, 2019) identified science-based shoreline planning units and mapped suitable sites for nature-based sea-level rise adaptation measures. The planning units, called Operational Landscape Units (OLUs), are a practical way to manage the physical and jurisdictional complexity of the Bay shoreline (Figure 5). The Adaptation Atlas divides the Bay shoreline into 30 OLUs—connected geographic areas that share common physical characteristics and would benefit from being managed holistically. OLUs cross traditional jurisdictional boundaries of cities and counties but adhere to the boundaries of natural processes like tides, waves, and sediment movement. Taken as a whole, OLUs include areas potentially vulnerable to future sea-level rise where science-based shoreline adaptation strategies that are appropriate for the particular geographic setting can be developed.

For each OLU, the Adaptation Atlas mapped opportunities for nature-based shoreline adaptation primarily based on the physical suitability of the shoreline for various types of nature-based measures. While the general concepts behind creek-to-baylands reconnection were discussed in the Adaptation Atlas, future research is needed to refine the mapping and understand potential benefits, trade-offs, and implementation considerations in more detail.

In this technical update to the Adaptation Atlas, we focus on expanding our understanding of creek-to-baylands reconnections in the Bay and how opportunities may differ based on landscape setting and development. This report augments the Adaptation Atlas by summarizing our findings by OLU to encourage cross-jurisdictional collaborations for future reconnection projects. For a crosswalk of jurisdictional boundaries to OLUs, see pg. 186 of the Adaptation Atlas (SFEI and SPUR 2019).

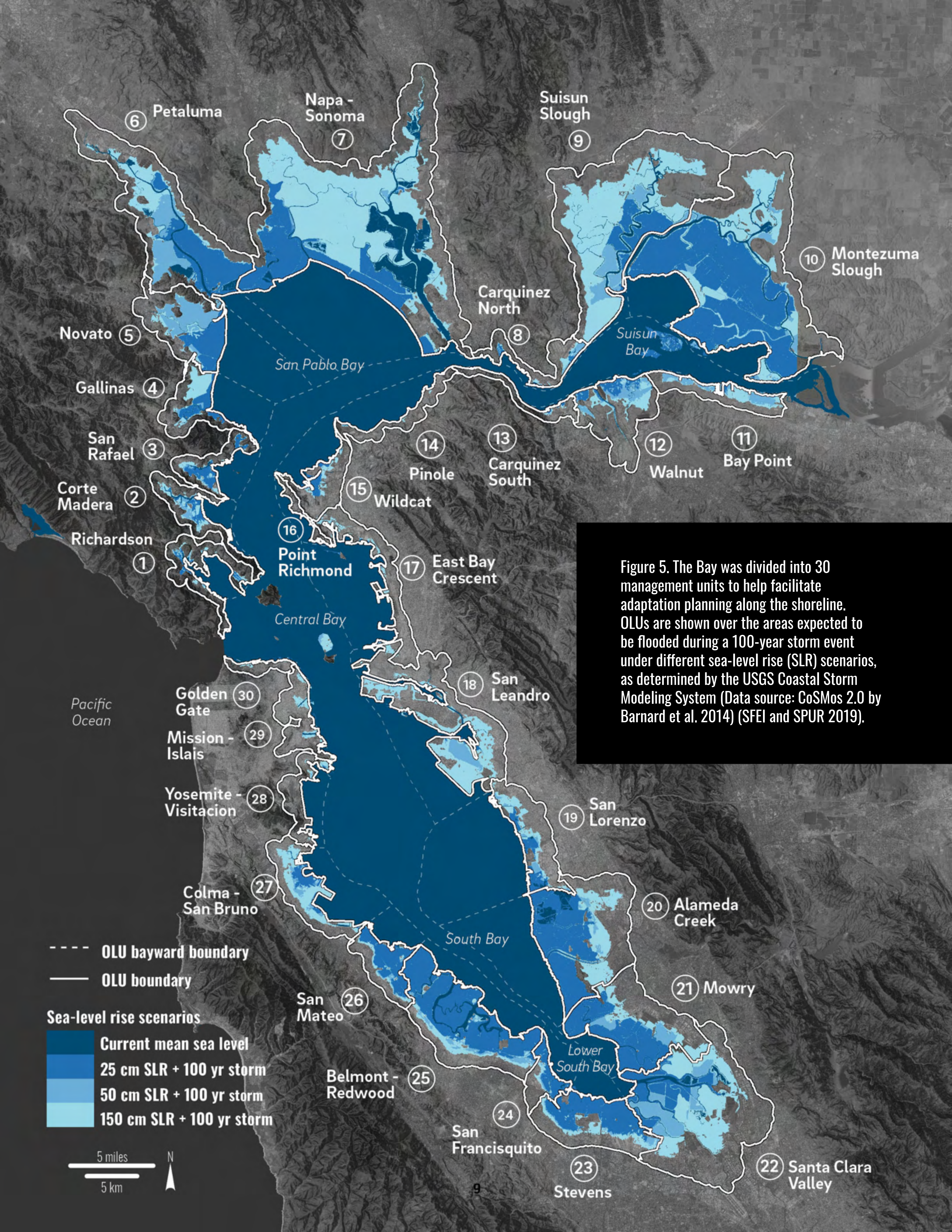


Figure 5. The Bay was divided into 30 management units to help facilitate adaptation planning along the shoreline. OLUs are shown over the areas expected to be flooded during a 100-year storm event under different sea-level rise (SLR) scenarios, as determined by the USGS Coastal Storm Modeling System (Data source: CoSMos 2.0 by Barnard et al. 2014) (SFEI and SPUR 2019).

2. Benefits and tradeoffs

When creeks are connected to downstream baylands, essential watershed resources—sediment and freshwater—are delivered to marshes and mudflats. Delivery of sediment is essential for baylands to gain elevation over time and, if enough sediment is available, keep pace with sea-level rise (Dusterhoff et al. 2021). Freshwater delivery increases marsh diversity, helps wildlife persist during drought years, and increases rates of peat building, thereby increasing rates of elevation gain and carbon sequestration (Goals Project 2015). The form of historical watershed-baylands connections varied depending on local topography, geology, and other physical conditions. Some creeks flowed over and across alluvial fans and others flowed through densely wooded willow thickets before emerging out into tidal channels (SFEI 1998). Many of the freshwater connections to the baylands created complex habitat mosaics with high biodiversity (Goals Project 2015). Restoring some of those historical creek-to-baylands connections can renew freshwater and sediment delivery from watersheds, with a range of associated benefits.

Physical and ecological process benefits

There are a wide array of potential benefits from creek-to-baylands reconnection. Understanding these benefits is a key step in developing partnerships, acquiring funding, designing projects,and securing permits. In many cases, creek-to-baylands reconnection efforts may be designed with a specific benefit in mind (e.g. upstream flood reduction); however, there may be a broad suite of co-benefits to consider that can expand the range of interested stakeholders and potential funding sources. In all cases, project design will influence the degree to which various benefits can be realized, and tradeoffs may be inherent, requiring careful consideration. For example, a reconnection project prioritizing marsh resilience may include sinuous channels to enhance sediment delivery and wildlife habitat; however, this design may not be beneficial in reducing upstream flooding.

In some cases, the tradeoffs may be between short-term and long-term impacts. These tradeoffs require weighing short-term disturbance or conversion of existing habitat versus the long-term benefits of reestablishing natural geomorphic processes that will sustain the restored habitat. Short-term disturbances may include construction impacts, and longer-term disturbances include conversion of existing non-tidal habitats (e.g., seasonal wetlands, diked ponds) to tidal habitats, and physical impacts to existing tidal marshes and channels (e.g. conversion of saline marshes to brackish marshes by adding freshwater inputs, scouring/erosion due to increased flow, or conversion of marshes to open water channels or alluvial fans). Weighing such short and long-term disturbances against long-term benefits, like greater landform resilience, will be critical for habitat types vulnerable to climate change. For example, a project site may initially be subject to increased scour and loss of existing tidal marsh habitat following a creek reconnection; however, it will ultimately be able to persist longer due to increased sediment delivery from the creek allowing marsh elevation to keep pace with sea-level rise. Permitting agencies that require expensive monitoring and mitigation for any loss of existing habitat are perhaps unwittingly preventing these types of projects from happening as the risks are all on the applicant's side and thus often not worth taking. Other long-term benefits include improved connections and gradients between riparian and estuarine habitats, increased delivery of freshwater to the back of tidal marshes (which promotes habitat diversity and greater peat production), and increased potential for dynamic evolution of baylands habitats in response to climate change (Figure 6).

Figure 6 summarizes key benefits and tradeoffs of creek-to-baylands reconnection. Many of these benefits and tradeoffs are not unique to creek-to-baylands reconnection and are shared by tidal marsh restoration projects more broadly. This figure is not meant to provide an exhaustive list of benefits. In particular, it does not delve into species-specific benefits of creek-to-baylands reconnection.

1. **Expanded tidal prism reduces backwater flooding.** Where baylands have been diked, drained, and disconnected from watersheds, sediment tends to build up in the remaining confined channels, causing backwater flood impacts when heavy precipitation events coincide with a high tide in the Bay. Restoring downstream baylands can reduce backwater flooding through two mechanisms: (1) increased tidal prism in the lower watershed increases in-channel scour and deepens the channel; and (2) restored marshes can absorb floodwaters from the watershed. Increased in-channel scour may reduce dredging requirements, reserving public funds for other critical uses. Reduced backwater flooding can also reduce siltation above head of tide, which may provide habitat benefits for fish, particularly salmonids, whose rearing habitat can be impacted by silt. Changing tidal prism and channel morphology may also affect the head of tide location. Effects on upstream flood risk from creek-to-baylands reconnection projects need to be determined on a project-by-project basis. In some cases, a sediment bar can build up just upstream of the breach where water velocities are lower; this could increase upstream water surface elevations. Many factors affect water surface elevations, including changes in the overall channel profile, downstream boundary conditions, and channel geometry. See the "Flood-risk reduction" section on page 18 for more context on this topic.

Key benefits and tradeoffs of creek-to-baylands reconnection:

1. *Expanded tidal prism reduces backwater flooding.*
2. *Freshwater flows sink into alluvial fans and recharge aquifers.*
3. *Sediment deposits on newly restored alluvial fans.*
4. *Creation of new wetlands affects greenhouse gas fluxes.*
5. *Restoration of tidal action changes habitat type and management requirements.*
6. *Restoration of tidal action changes habitat structure and function.*
7. *Freshwater delivery creates new salt-fresh mixing zones and a habitat salinity gradient.*
8. *Sediment gradually accretes in restored polders.*
9. *Marshes form in restored polders.*
10. *Coarse sediment is delivered from the watershed to the baylands.*

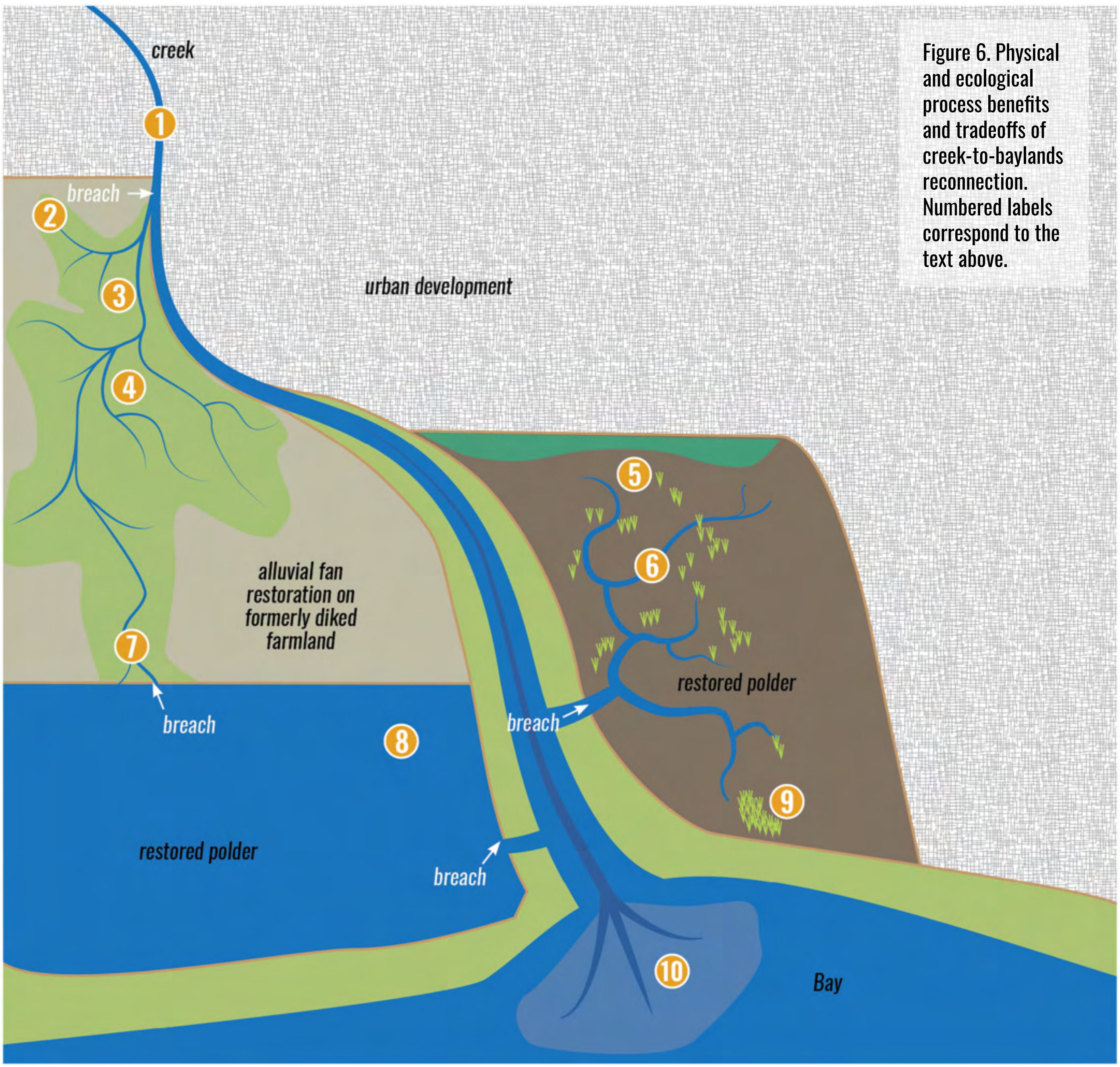


Figure 6. Physical and ecological process benefits and tradeoffs of creek-to-baylands reconnection. Numbered labels correspond to the text above.

2. **Freshwater flows sink into alluvial fans and recharge aquifers.** Expanding areas along the channel for floodwaters to spread out and sink in can increase groundwater elevation and decrease saltwater intrusion into aquifers pumped for water-supply purposes (where the soils and geology are appropriate). This is particularly relevant given how sea-level rise can increase nearshore groundwater elevations. Additionally, recharging local groundwater can help support rearing habitat for salmonids. Groundwater, particularly from deeper aquifers, tends to be cooler than surface water in warm weather so when groundwater seeps into a creek, it can help to lower the water temperature. This cooling effect can benefit salmonids, particularly during hot summer months.

3. **Sediment deposits on newly restored alluvial fans.** Restoration of distributary channels allows channels to spread out naturally, depositing sediment and creating new habitat within and along the estuarine-terrestrial transition zone. Alluvial fans create topographic and substrate heterogeneity; the range of elevation bands and sediment grain sizes present on an alluvial fan support different species and increase biodiversity at the creek mouth. In addition, alluvial fans can benefit marsh wildlife by providing high-water refugia. Alluvial fans also increase marsh resilience to sea-level rise as they create new space for marshes to migrate upland and inland.

4. **Creation of new tidal marshes affects greenhouse gas fluxes.** Net greenhouse gas (carbon sequestration) benefits will depend on previous land elevation, land use, and water salinity levels. Salt marshes in the Bay have lower methane emissions than freshwater wetlands and brackish tidal marshes; however, they also have lower soil carbon accumulation rates (Vaughn et al. 2022). Historical baylands that are kept dry for agriculture release more greenhouse gasses due to oxidation of organic soils than wet historical baylands (such as managed ponds or seasonal wetlands), where oxidation rates are lower. Therefore, restoring historical baylands currently used for agriculture to marshes is likely to have a larger greenhouse gas reduction benefit than restoring currently wet habitats.

5. **Restoration of tidal action changes habitat type and management requirements.** A necessary tradeoff of tidal marsh restoration is a reduction in the extent of any non-tidal habitats that existed before levees were breached. In many cases, managing habitat in tidal marshes, a dynamic and self-sustaining system, may be less costly than management of diked baylands. Even if this is the case, public agencies responsible for managing tidal areas after restoration have limited capacity and funding for maintenance. Often, restoration of tidal marshes requires setback levees and pumps, which can be expensive to operate and maintain (as are levees and pumps in existing diked baylands). Operations, monitoring, and maintenance costs should be carefully considered as part of the planning

Aerial image from 2019 of tidal marsh restoration in Sonoma Baylands (courtesy of Robert Janover, Sonoma Land Trust)

and design process. Invasive and special status species may require specific maintenance considerations. Diked baylands are often colonized by invasive species, and restoring tidal flows can help with management by flooding them out. However, restoring tidal flows does not solve all invasive species issues; care should be taken to ensure invasive ***Spartina*** (***S. alterniflora*** and hybrids) does not establish in newly restored areas. Likely, creek-to-baylands restorations that create new tidal marshes in diked baylands will increase habitat for threatened and endangered species, such as Ridgway's rail (***Rallus obsoletus obsoletus***). However, tradeoffs may need to be considered depending on pre-restoration conditions; for instance, if snowy plover (***Charadrius nivosus alexandrinus***) nesting areas are restored to tidal marsh, the short-term losses need to be assessed against the long-term gains for tidal marsh species. A valuable resource for considering and evaluating tradeoffs between habitat types is the Aquatic Resource Type Conversion Evaluation Framework (Stein et al. 2022).

6. **Restoration of tidal action changes habitat structure and function.** Restored tidal marshes are likely to have increased habitat complexity relative to pre-restoration conditions, in terms of salinity, flow velocities, vegetation, and physical structure. Increased habitat complexity and redundancy introduced by restoration projects increases the resilience of wildlife to disturbance. Over time, complex channel networks develop in restored sites; these networks influence energy dissipation, structural complexity, land-water exchange and residence time. These factors in turn affect food web dynamics. Restoring marshes can also increase habitat connectivity between wetland patches and diversify food web resources for Bay, marsh, and terrestrial species.

7. **Freshwater delivery creates new mixing zones and a habitat salinity gradient.** This area tends to have higher productivity at the freshwater-saltwater interface, which benefits fish and other wildlife. For some species, freshwater delivery can open up new habitat essential for specific life stages; for instance, floodplain rearing habitat for juvenile salmonids. Adding freshwater inputs to tidal marshes affects plant species composition and diversity (Dusterhoff et al. 2014). The plants that grow in lower salinity marshes tend to have higher productivity and can build up organic matter more quickly than higher salinity marshes, increasing elevation capital and resilience to sea-level rise. Brackish marsh habitat gradients support especially diverse vegetation communities, including populations of unique plant ecotypes (e.g. salt-tolerant yarrow, ***Achillea millefolium***) and culturally important species (e.g. basket sedge, ***Carex barbarae***). Creation of salt-to-freshwater marsh salinity gradients can allow for genetic differentiation and potentially even ecological speciation.

8. **Sediment gradually accretes in restored polders.** Many tidal marsh restorations in the Bay are planned in polders—low-lying areas of land that would normally be inundated by regular tides if they were not protected by dikes. Not all restored polders may reach tidal marsh elevation; some may be too deep to fill by natural sediment accretion. However, many of these polders provide habitat and increased productivity for nesting and migratory waterbirds, estuarine fish, and invertebrates. Conversion of open water to mudflat habitat (e.g. for shorebirds) in restoring polders can offset conversion of mudflat to open water driven by sea-level rise in the Bay.

9. **Marshes form in restored polders.** In order for marsh vegetation to establish, polders need to be raised to about mean tide elevation. As sediment builds up in restored polders, mudflats can establish in formerly subtidal areas and tidal marshes can establish in former mudflats. Marshes and mudflats can attenuate waves before they reach levees, reducing erosion and likelihood of overtopping. This may provide flood risk reduction and sea-level rise resilience benefits for communities and infrastructure behind levees.

10. **Coarse sediment is delivered from the watershed to the baylands.** This can increase habitat heterogeneity; for example, coarse beaches, fans, and deltas may develop in some locations. Many rare/uncommon tidal marsh plants in the estuary (e.g. salt marsh bird's beak, *Chloropyron maritimum*) are dependent upon coarse sediment to germinate and grow. Dominant salt marsh plants like gumplant (*Gridnelia stricta*), saltgrass (*Distichlis spicata*), and pickleweed (*Salicornia pacifica*) also tolerate burial by coarse sediment and provide sand-trapping roughness (SFEI and Baye 2020). Increased tidal prism can allow an ebb delta (deposited coarse sediment at the mouth of the creek) to expand. This ebb delta can provide protection from wave energy for the adjacent shoreline, reducing erosion rates. More broadly, a functional tidal delta has a range of benefits, including increased habitat patch sizes and cascading positive impacts on the food web.

Community benefits

Creek-to-baylands reconnection projects present opportunities to incorporate benefits for people, especially when designs are tailored to meet the needs of Tribes and local communities. Climate change impacts are not equally distributed across communities and socially vulnerable populations (according to income, race, age, and educational attainment) are often disproportionately exposed to climate risks (EPA 2021). In the Bay Area, many underserved communities are located in coastal floodplains. An analysis of household income and coastal flooding in the Bay Area suggests that lower income census block groups in San Mateo and Marin Counties face disproportionate flood risk, as average household income is lower in floodplains than the county average (Bick et al. 2021).

According to the UCLA-UC Berkeley Toxic Tides project, “Climate resilience strategies must address the disproportionate impacts of sea-level rise and associated flooding threats faced by environmental justice communities” (Toxic Tides 2022). The researchers found that contaminated and hazardous sites in the coastal floodplain are disproportionately located in poor communities and communities of color (Cushing et al. 2023). This disparity is partly due to historical injustices in the housing market that restricted where people of color could live. Redlining and other racist housing policies ensured that white residents could buy homes with government-backed mortgages in the suburbs, while residents of color were restricted to less desirable areas in coastal floodplains and near contaminated industrial areas. These inequities have persisted: today, historically redlined areas in California have higher environmental contamination burdens, higher population vulnerability to pollution, and over-representation of people of color (CalEPA 2021). Though the Bay Area is diverse as a region, most cities remain deeply segregated at the neighborhood scale (Menendian and Gambhir 2018).

The San Francisco Bay Conservation and Development Commission (BCDC) has identified community vulnerability based on social factors and contamination exposure in the Bay Area. Creek-to-baylands reconnection efforts that are undertaken in these areas can take advantage of opportunities to collaborate with community-based organizations (a list has been compiled in BCDC’s Community Vulnerability + CBO Directory webmap (BDCD 2021)) to ensure that restoration projects target community benefits. BCDC’s Environmental Justice policy provides resources on how to meaningfully involve communities in shoreline projects (BCDC 2023). Restoration practitioners and planners interested in creek-to-baylands reconnections should partner with Tribes and local community based organizations early in the process to prioritize local needs and goals into restoration designs.

Community benefits of creek-to-baylands reconnection may include:

- **Recreational access.** Reconnection projects can include trails and other recreational facilities to increase community access to riparian and shoreline areas. Projects can be designed to include educational elements (e.g., signage, programming) and wildlife viewing opportunities in addition to trails. Cultural elements can be included in project design: for example, projects might create signage to acknowledge places and landmarks significant to local Tribes and/or integrate plants with cultural value into restoration designs.

- **Wellness benefits.** Studies have shown that spending time outdoors and in nature can improve public health and wellness (APHA 2013, SFEI 2023a). Access to open space on the water has also been shown to be associated with improved health outcomes (Smith et al. 2021).

- **More productive food web for fishers.** Reconnection projects can increase habitat area and improve ecosystem function, improving the health of fisheries and benefiting fishers.

- **Job creation.** A NOAA study found that on average, habitat restoration projects can support approximately 17 jobs per $1 million spent (Samonte et al. 2017).

- **Flood-risk reduction.** In some places reconnection projects may be designed to reduce flooding upstream, with associated benefits in terms of avoided damages to life, infrastructure, and property. There may also be potential for reduced insurance costs.

- **Public cost savings.** Creek reconnection projects may be designed to reduce taxpayer-funded maintenance costs, particularly in comparison to alternative gray infrastructure adaptation projects. For example, reconnection projects may reduce costs for maintaining long levees around diked baylands and dredging narrow channels subject to siltation due to low tidal prism. Reconnections may also reduce vegetation maintenance requirements upstream in channels due to reduced need to remove obstructions.

Special consideration must be given to designing creek-to-baylands reconnection efforts in collaboration with communities near contaminated sites to ensure projects do not increase exposure of people or ecosystems to harmful contaminants. Coordination with the project manager at the agency responsible for regulating the site cleanup (e.g., CA State Water Resources Control Board, CA Department of Toxic Substances Control, US Environmental Protection Agency) will be an essential early step. In some cases a creek-to-baylands project could be designed to improve water quality. In all cases appropriate steps should be taken to ensure that restoration projects do not increase community exposure to harmful contaminants.

Flood-risk reduction

Several recent projects have employed hydrodynamic models to explore the impact of restoring downstream baylands on upstream in-channel flood frequency, depth, and duration. These studies demonstrate two key considerations:

- Projects restoring downstream baylands have the potential to reduce upstream flooding.
- Restoration projects must be carefully designed to ensure that projects do not inadvertently increase upstream flooding.

Modeling of water surface elevations on Novato Creek demonstrate how baylands restoration reduces upstream flooding (KHE 2016) (Figure 7). The “some baylands restoration” alternative (a.k.a. “Medium term” alternative) included restoration of some parcels bayward of Highway 37, and the “extensive baylands restoration” scenario (i.e. “Long term” scenario) included restoration of these parcels and the Deer Island Basin. Modeling results demonstrated that water surface elevations upstream can be reduced by up to 4 feet in some locations as a result of these baylands restorations.

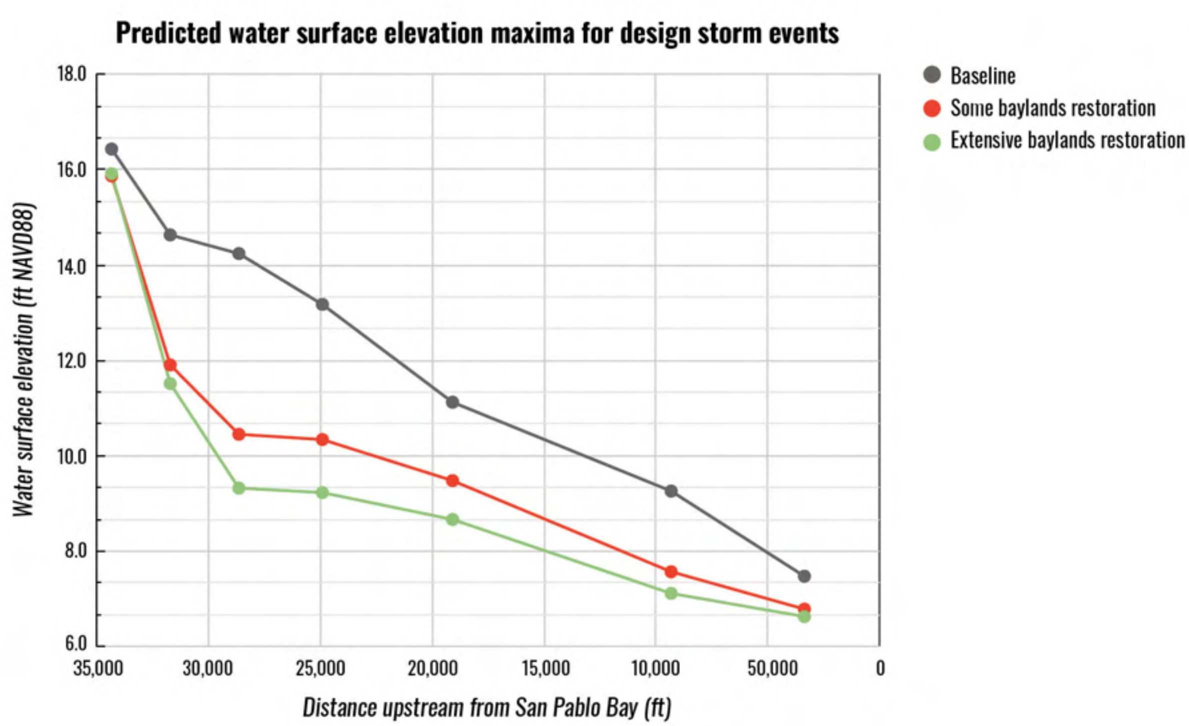


Figure 7. Water surface elevations are reduced by up to four feet when comparing the “baseline” alternative to the extensive baylands restoration (long-term) alternative in the Novato Creek baylands (Figure adapted from KHE 2016).

Similarly, hydrodynamic modeling of Schell and Sonoma Creeks completed for the Sonoma Creek Baylands Strategy (SLT and partners 2020) predicted upstream reductions in water surface elevations when creeks are reconnected to downstream baylands (Figure 8). All restoration alternatives decreased upstream water levels on Sonoma and Schell Creeks during an approximately 1% annual chance storm event. The restoration alternative that was identified as best achieving the project goals (Alternative 3, which restored the maximum practicable acreage of tidal baylands) had a significantly lower peak water surface elevation at a flooding hotspot, the junction of State Route (SR) 121 and SR 12, compared to baseline conditions.

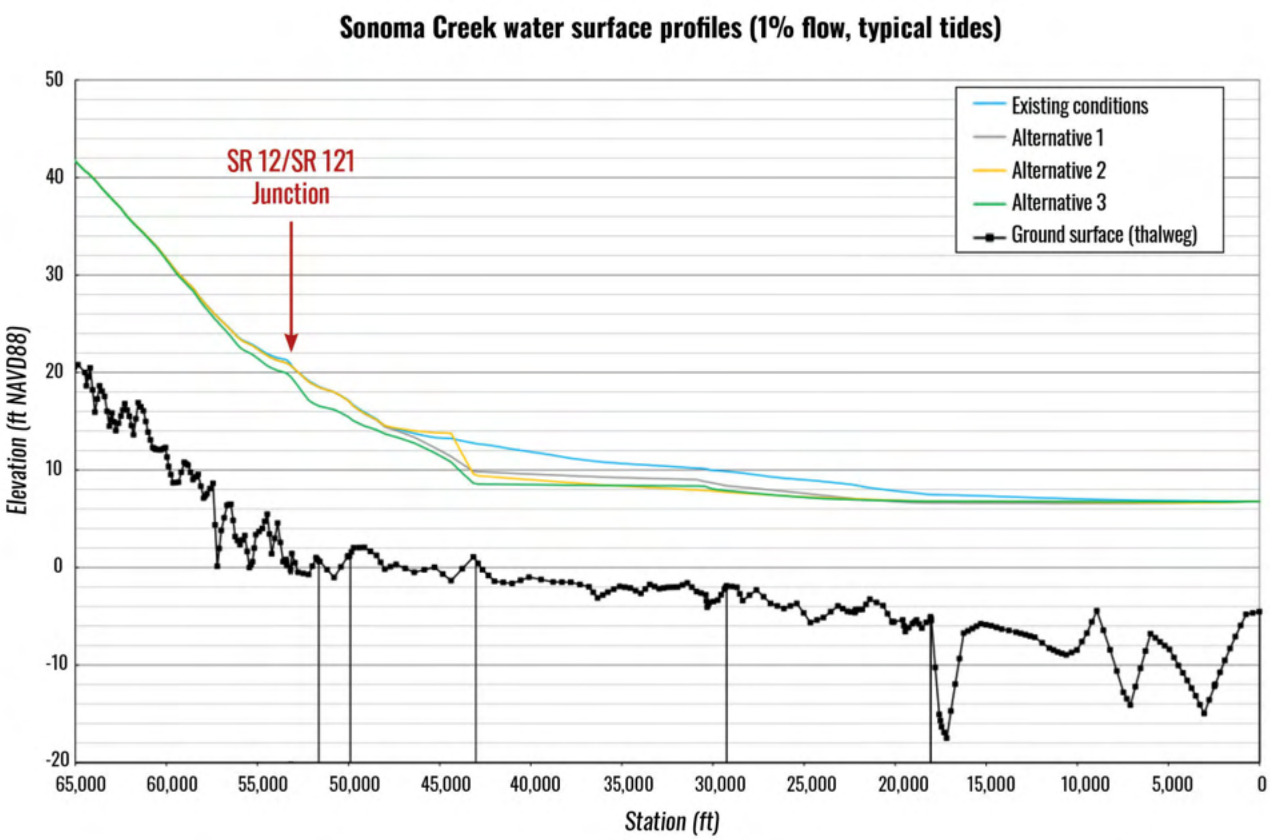


Figure 8. All creek-to-baylands reconnection alternatives reduced water surface elevations relative to existing conditions. Alternative 3 reduced water surface elevations most at the key flooding hotspot at the SR 12/SR 121 junction (near the Highway 121 bridge) (courtesy of ESA 2020).

Hydrodynamic modeling at Coyote Creek (Bothin Marsh, Richardson Bay) demonstrates the caveat that creek-to-baylands reconnection projects must be carefully designed to avoid increasing upstream water levels (Figure 9). In this case, the project objective was to deliver sediment from Coyote Creek to Bothin Marsh. Sediment in this system is particularly coarse relative to other areas of the Bay, and that may impact the dynamics of this restoration. The first two alternatives tested by the hydrodynamic model were both sinuous channels with the same alignment and depth but different side-slope assumptions. Both increased upstream water levels. Alternative 3 was developed in response to this result. In this alternative, channel width was increased and sinuosity decreased to allow for better conveyance of flood flows. The hydrodynamic modeling predicted that Alternative 3 would allow sediment delivery to the marsh without increasing upstream water levels (Anchor QEA 2021).

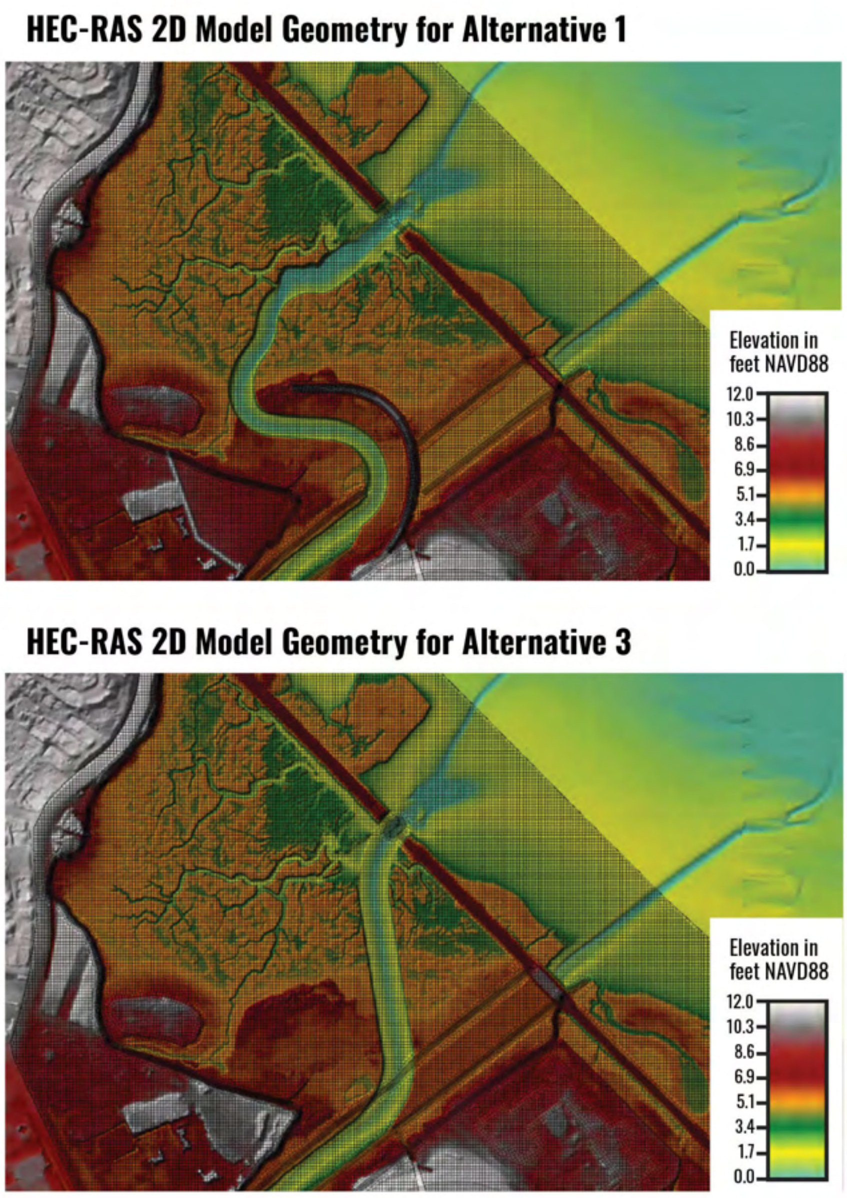


Figure 9. The narrow and sinuous channel first modeled for creek reconnection from Coyote Creek to Bothin Marsh increased upstream flooding (left, top). Alternative 3 was developed in response to this finding (left, bottom) (Courtesy of Anchor QEA 2021).

3. Methods

The study area includes the 30 OLUs and their contributing watersheds extending east of the Golden Gate to the downstream end of the Sacramento-San Joaquin Delta, west of Browns Island (SFEI and SPUR 2019). Information on physical setting, vertical and lateral resilience, and wildlife support was developed for a subset of the 353 channels that historically drained the Bay. The analysis followed four steps: (1) filtering for creeks of interest, (2) categorizing creeks into opportunity types, (3) synthesizing creeks into a criteria matrix, and (4) creating reconnection concepts of lesser-known opportunity types.

Data and concepts from ***Changing Channels*** (Dusterhoff et al. 2017) and the ***Adaptation Atlas*** (SFEI and SPUR 2019) were used to support this report and are detailed below.

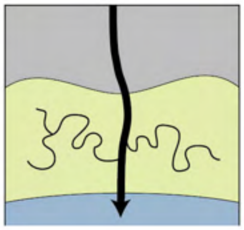
Filtering for creeks of interest

To identify the creeks of interest for this study, a two-step filtering process was conducted based on creek watershed size and contemporary fluvial-tidal interface type.

A minimum watershed size threshold of 3,600 acres was established to filter for creeks with a medium to high supply of sediment and freshwater, resulting in 57 focus creeks for this study. This threshold was chosen using a histogram of watershed size for all 353 Bay tributary watersheds and, in combination with best professional judgment, selecting a cutoff that expands upon the 33 channels analyzed in SFEI's Changing Channels report (Dusterhoff et al. 2017) while keeping the number to a reasonable size for the purpose of this study. It is important to note that watersheds excluded from this analysis (<3,600 acres in size) may also be good candidates for creek-to-baylands reconnection. Additional study is needed to assess excluded channels as reconnection candidates, since watersheds of all sizes may have a high relative supply of sediment or freshwater in relation to their downstream baylands and could be an important local source of these inputs.

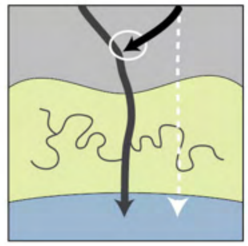
Next, creeks were filtered based on contemporary fluvial-tidal interface types shown in Dusterhoff et al. (2017). Included fluvial-tidal interface types range from those that already have a direct connection to tidal marsh to those that lack a direct connection to their baylands but still flow through or near diked or tidal baylands (Figure 10). Creeks that already merge into a tidal channel network and maintain a direct connection to tidal marsh (e.g. Petaluma River) were included since there may be instances where existing connections could be improved to better convey sediment and freshwater more directly onto marsh. Creeks that are no longer present in the landscape, such as those that have been completely culverted underground (e.g. Yosemite Creek), were excluded. Additionally, creeks that drain directly to the Bay (e.g. Hilarita Drainage) were also excluded.

Contemporary Fluvial-Tidal Interface Types Included in Analysis



Connected to a tidal marsh channel

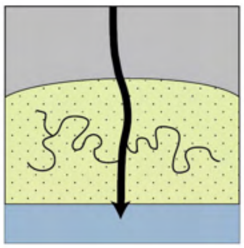
Channels reach the baylands and merge into a tidal channel network. ***Example:*** Petaluma River (Sonoma County)



Channel has become a tributary channel

Channels that historically reached the baylands but have been re-routed inland to flow into another channel.

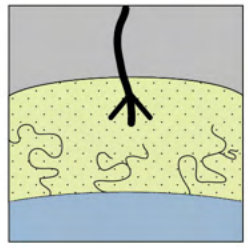
Example: Laurel Creek (Solano County)



Connected to a tidal channel through diked baylands

Channels enter areas where baylands have been diked (i.e., isolated from the tides by dikes or levees) and flow into a tidal channel.

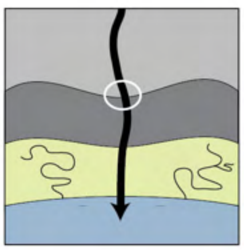
Example: Novato Creek (Marin County)



Drains onto diked baylands

Channels enter baylands that are now diked (e.g. salt ponds, managed marsh) but dissipate without connecting to a tidal channel.

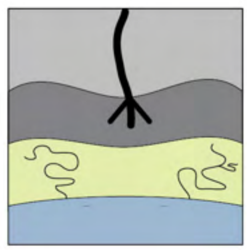
Example: Willow Creek (Contra Costa County)



Connected to a tidal channel through bay fill

Channels flow through bay fill (i.e., fine sediment placed on baylands to increase elevation and allow for development) before reaching the Bay.

Example: Wildcat Creek (Contra Costa County)

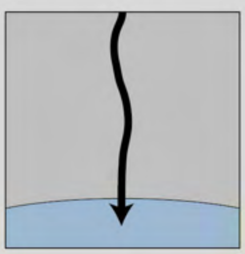


Drains onto bay fill

Channels enter baylands that are now covered in bay fill but dissipate without connecting to a tidal channel.

Example: Unnamed drainage to Scottsdale Pond (Novato Creek watershed, Marin County)

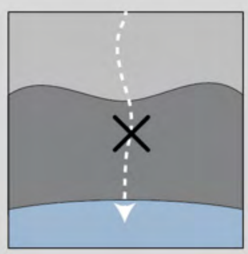
Contemporary Fluvial-Tidal Interface Types Excluded from Analysis



Connected to the Bay

Channels entered directly into the Bay without passing through baylands (i.e., mudflats, tidal marshes, tidal-terrestrial transition zones).

Example: Hilarita Drainage (Marin County)



Channel no longer present on the landscape

Channels have been routed into underground culverts or have been filled in completely.

Example: Yosemite Creek (San Francisco County)

Figure 10. (top) Included fluvial-tidal interface types range from those that already have a direct connection to tidal marsh to those that lack a direct connection to their baylands but still flow through or near diked or tidal baylands. (bottom) Excluded fluvial-tidal interface types include creeks that are no longer present in the landscape and creeks that drain directly to the Bay without passing through baylands (Dusterhoff et al. 2017).

Categorizing creeks into opportunity types

We identified and mapped four types of reconnection opportunities (***see Chapter 4 for reconnection opportunity type definitions***) through a qualitative assessment of extent and configuration of available "floodable space", geomorphic setting, and other creek-specific considerations, in combination with our professional knowledge of fluvial-estuarine systems in the Bay and feedback from the project's Technical Advisory Team (TAC). Opportunity types include: (1) alluvial fans; (2) realigned channels; (3) off-channel reconnections; and (4) channels with limited floodable space (see pg. 7 and pgs. 27-48 (Chapter 4) for definitions of each type).

The type categorization aims to differentiate creek reconnection opportunities based on landscape setting and current development constraints. While the types of reconnection opportunities discussed here share many benefits, it is difficult to know whether or to what extent benefits separate out among each type. A better understanding of this will be possible when more creek-to-baylands reconnection projects have broken ground in the Bay. When more implementation progress is made, an assessment of near- and long-term anticipated and measured outcomes should be conducted to understand the varying degrees of benefits, trade-offs, and permitting requirements for each type, which will be useful to plan for and increase the likelihood of achieving project goals.

We created a decision tree to qualitatively evaluate the degree of floodable space and the geomorphic setting for each creek to map where each reconnection opportunity type may be suitable (Figure 11). Extents of potential "floodable space" were qualitatively assessed using aerial imagery (e.g. Google Earth Pro) and land cover maps (e.g. SFEI-ASC 2017). We define available "floodable space" as undeveloped lands adjacent to the channel that have the potential to be inundated by fluvial and tidal flows if a reconnection between the channel and baylands is established (adapted from Dusterhoff et al. 2017). We did not consider land ownership nor current land use in our evaluation of potential floodable space, and so it is worth noting that some areas considered may fall on private property (e.g., agricultural lands, duck clubs) public open space (e.g., parks, managed ponds). Additionally, we did not consider contaminated sites or site-scale infrastructure (e.g. utility lines), which may reduce the extent of potential floodable space for each channel and warrants further site-scale analysis.

Following the assessment of potential floodable space, we qualitatively classified the channels into two bins: "floodable space exists" and "floodable space is limited." Channels classified as "floodable space exists" have varying extents of undeveloped low-lying upland, tidal marsh, diked marsh, or subsided areas immediately adjacent to the creek channel near head of tide or along the downstream tidal reach, ranging from small pockets (e.g. Corte Madera Creek) to vast amounts of undeveloped space (e.g. Suisun Creek). Channels classified into “floodable space is limited” have developed areas up to the channel and are too constrained for reconnection (e.g., San Mateo Creek, Temescal Creek). As mentioned above, creeks categorized as “channels with limited floodable space” were not investigated further for the purposes of this study, but it is worth noting that such creeks may be candidates for other types of enhancement measures that require less space such as local beneficial sediment re-use, wildlife corridor enhancements, and recreational access.

Each creek that fell into the “floodable space exists” category was classified by geomorphic unit type, based on mapping by SFEI and SPUR (2019), which includes: (1) headlands and small valleys, (2) alluvial fans and alluvial plains, and (3) wide alluvial valleys. These units are distinguished by different underlying geology and resulting landscape morphometrics, such as width of the baylands, slope of the shoreline, and watershed size. We limited the ***alluvial fans*** opportunity type to be mapped only within alluvial fans and plains and wide alluvial valleys as these settings are where historical distributary channels and alluvial fan deposits were generally located and thus have the appropriate landscape setting to theoretically support such channels. We applied the decision tree to each creek, asking questions about floodable space that reflect each opportunity type’s requirements, and answered with a “yes” or “no.” When the answer was “yes,” we continued down the decision tree to see if additional opportunities may be possible, which led to the potential for multiple opportunities to be suitable at one site, especially sites with ample available floodable space.

Birdseye view of Temescal Creek draining from the East Bay Crescent OLU into the Bay (courtesy of Jay Huang Photography, CC BY 2.0)

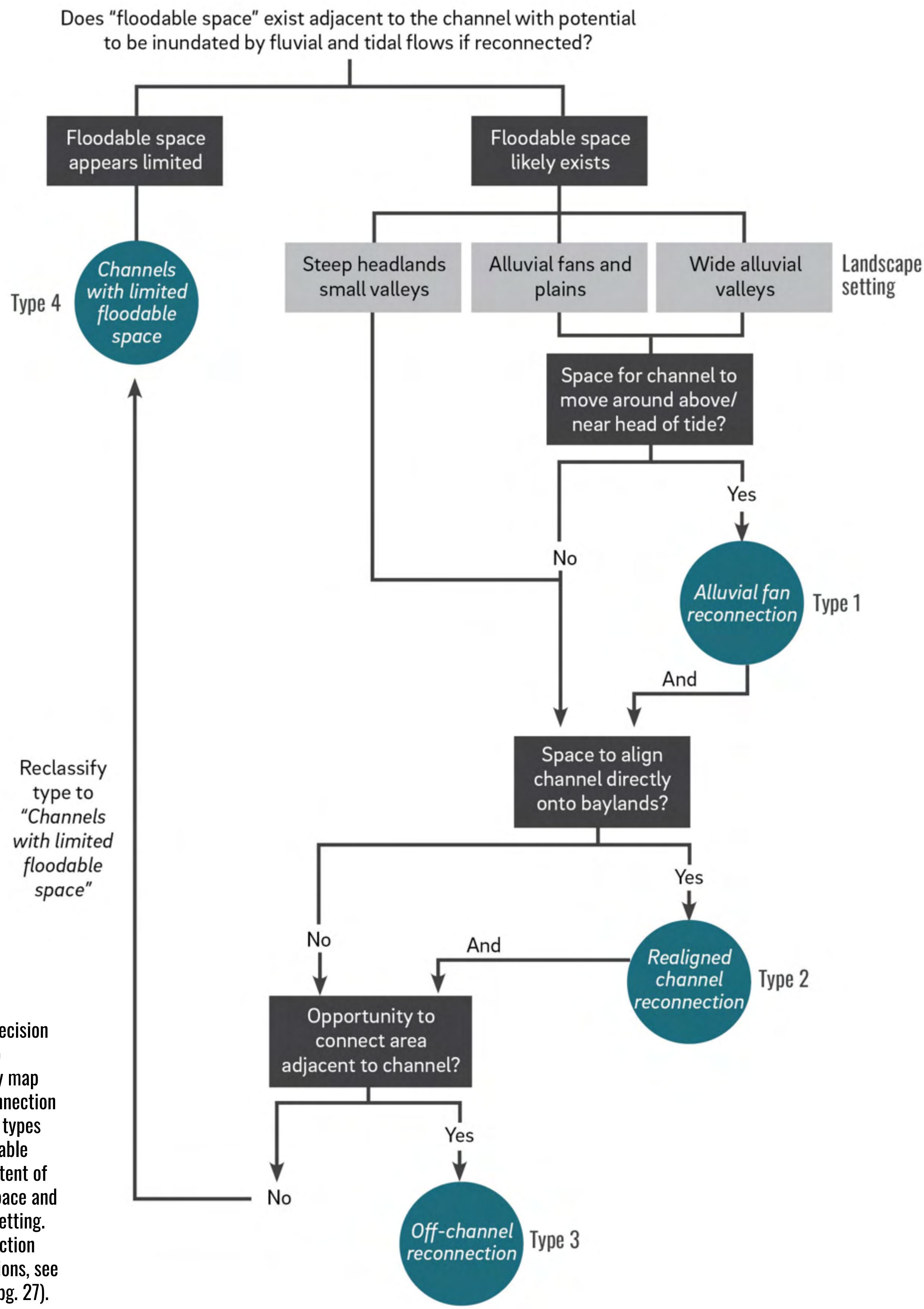


Figure 11. Decision tree used to qualitatively map where reconnection opportunity types may be suitable based on extent of floodable space and landscape setting. For reconnection type definitions, see Chapter 4 (pg. 27).

Development of assessment criteria

Creeks were assessed based on guiding principles that identify which creeks may have high potential to yield long-term benefits if reconnected to downstream baylands. The guiding principles are:

- Restoring physical processes in creek-baylands systems yields the highest resilience to sea-level rise and other climate impacts over time.
- Building complete tidal marsh systems that include subtidal, intertidal, and upland connections to offer better physical and ecological benefits are the goal (Goals Project 2015).
- Creek-to-baylands reconnections are important opportunities to support vulnerable aquatic and terrestrial wildlife populations.

Assessment criteria associated with the three guiding principles were created by compiling the best available science at the time of this report. A matrix was then developed, organized by OLU, that summarizes the reconnection opportunity type assessed above (i.e. alluvial fans, realigned channel, off-channel connection). The matrix provides a qualitative description of the space available for reconnection and details values for the criteria associated with the guiding principles for each channel. The opportunity map and matrix are described in Chapter 4 (Figure 12 on pg. 30 and Table 1 on pgs. 58–60).

Developing example concepts for a lesser-known opportunity type

In an exercise aimed at envisioning future creek-to-baylands reconnection projects in the Bay, and to build on the analyses described above, an example site was chosen to develop high-level reconnection concepts for the alluvial fan type. The example site serves as a reference to inspire and inform future action at these or similar suitable locations in the Bay. We refer to this example as a “pre-vision” to represent concepts in the idea-generation stage that could be taken further and turned into a full multi-benefit resilient landscape vision through collaborations with science advisors and project partners (e.g., communities, Tribal governments, agency staff, municipalities, local NGOs).

4. Types

Baylands protect billions of dollars of bay-front housing and infrastructure (including neighborhoods, business parks, highways, sewage treatment plants, and landfills), making the resilience of these habitats critical to all who live in the Bay Area. Creek-to-baylands reconnections have the potential to protect and support baylands in the face of sea-level rise, helping to ensure that the ecosystem services and human benefits that baylands provide persist over time. As already limited resources like funding and sediment grow scarcer with climate change, identifying reconnection projects that restore physical processes, build complete tidal marsh systems, and support vulnerable aquatic and terrestrial wildlife populations will be important considerations to maximize long-term benefits.

In this chapter, we describe three types of creek-to-baylands reconnection opportunities that exist around the Bay (Alluvial Fans, Realigned Channels, and Off-channel Connections), offering examples when possible to further contextualize each reconnection opportunity types. Opportunity types are summarized in a regional opportunity map (see pg. 30). We also present a matrix of creek-to-baylands reconnection opportunities by OLU (see pgs. 58–60) that can be used in combination with the regional opportunity map to assess the potential benefits associated with new reconnection projects to help evaluate where a project may be most suitable based on the guiding principles associated with supporting the resilience of tidal marshes and mudflats and the habitat needs of threatened species.

Looking downstream at the mouth of Lower Adobe Creek, a tributary to the Petaluma River (photo by Kyle Stark, SFEI)

HOW WILL SEDIMENT TRANSPORT AND OTHER FACTORS AFFECTING BAYLANDS RESILIENCE SHIFT AS THE CLIMATE CHANGES?

As creek-to-baylands reconnection projects gain attention as a way to move sediment out of flood control channels to reduce local flooding while increasing delivery of sediment to downstream baylands, an important question arises: How will sediment transport and other factors affecting baylands shift with climate change? Climate change adds a layer of complexity to understanding future sediment needs within the baylands and how these habitats will evolve over time. Major uncertainties exist regarding how sediment pathways from the upper watersheds to the baylands and greater Bay will evolve in the future as climate changes and sea level rises. SFEI's Conceptual Understanding of Fine Sediment Transport in San Francisco Bay report (McKnight et al. 2023) highlights several factors and processes that are expected to change in the coming decades, some of which have implications for the future of sediment in the baylands. Considerations that will affect both future baylands sediment supply and demand include changes in sea level, precipitation patterns and runoff, wildfires, and salinity levels (McKnight et al. 2023). The creek-to-baylands reconnection opportunity matrix, presented in this chapter, should be considered in combination with these future uncertainties. For more information on these considerations, see pg. 47 of the Conceptual Understanding of Fine Sediment Transport in San Francisco Bay report (McKnight et al. 2023).

Tidal marsh at the mouth of Codornices Creek (photo by Ellen Plane, SFEI)

Regional reconnection opportunities

In this section, we describe the three types of creek-to-baylands reconnection opportunities with floodable space (Figures 12 and 13). We also mention a fourth type that does not have sufficient space, which is included in mapping of the types but not investigated in further detail. For each of the three reconnection types, we provide a definition, mapped locations, background information of the reconnection concept, and on-the-ground examples (if they exist, either built or planned).

Opportunity types include:

- **Alluvial fans (*"Fan out"*):** Opportunities to give a creek space to allow distributary channels to form, migrate over time, abandon and form new channels, and transport sediment downstream.
- **Realigned channels (*"Realign"*)**: Opportunities at the creek mouth to realign, establish, or reestablish flow directly into an existing marsh or diked baylands slated for restoration.
- **Off-channel reconnections (*"Connect to the side"*)**: Opportunities to connect an area adjacent to the channel that is currently protected by berms, levees or other infrastructure that restricts tidal and fluvial flows, opening it to full fluvial-tidal action.
- **Channels with limited floodable space**: Little to no opportunities are present due to limited available floodable space. Ecological enhancements that do not require a lot of floodable space (e.g., improving the creek's ecological corridor, mechanical reuse of dredged sediment to support local baylands) are recommended. This opportunity type is not visualized, since it will vary greatly depending on the site.

OLU	ID #	Creek Name
Corte Madera	1	Corte Madera Creek
Gallinas	2	Miller Creek
Novato	3	Novato Creek
Petaluma	4	San Antonio Creek
	5	Petaluma River
	6	Adobe Creek
	7	Unnamed Sonoma County Creek
Napa - Sonoma	8	Tolay Creek
	9	Sonoma Creek
	10	Schell Creek
	11	Huichica Creek
	12	Carneros Creek
	13	Napa River
	14	Fagan Creek
	15	American Canyon Creek
	16	Chabot Creek
Carquinez North	17	Sulphur Springs Creek
Suisun Slough	18	Unnamed Napa County Creek
	19	Green Valley Creek
	20	Suisun Creek
	21	Ledgewood Creek
	22	Laural Creek
	23	Union Creek
Montezuma Slough	24	Denverton Creek
	25	Unnamed Solano County Creek
Walnut	26	Mount Diablo Creek
	27	Walnut Creek
Carquinez South	28	Alhambra Creek
Pinole	29	Rodeo Creek
	30	Pinole Creek
Wildcat	31	San Pablo Creek
	32	Wildcat Creek
East Bay Crescent	33	Temescal Creek
San Leandro	34	Peralta Creek
	35	Unnamed Alameda County Creek
	36	San Leandro Creek
	37	Estudillo Canal
	38	San Lorenzo Creek
Alameda	39	Alameda Creek
Mowry	40	Unnamed Alameda County Creek
Santa Clara Valley	41	Laguna Creek
	42	Agua Fria Creek
	43	Coyote Creek
	44	Guadalupe River
	45	Saratoga Creek
	46	Calabazas Creek
	47	Sunnyvale East
Stevens	48	Sunnyvale West
	49	Stevens Creek
	50	Permanente Creek
	51	Adobe Creek
	52	Matadero Canal
San Francisquito	53	San Francisquito Creek
Belmont - Redwood	54	Atherton Creek
	55	Redwood Creek
San Mateo	56	San Mateo Creek
Colma - San Bruno	57	Colma Creek

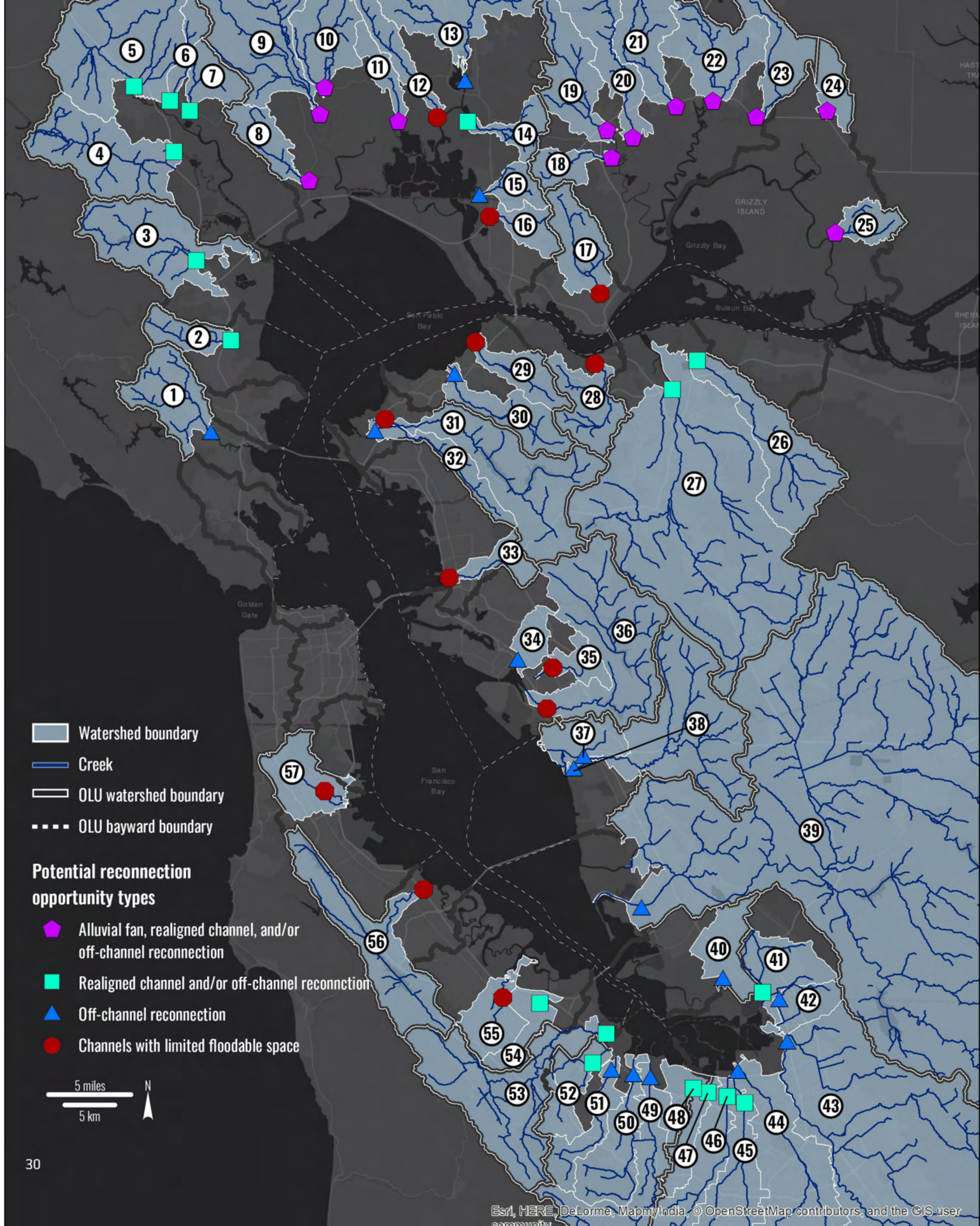


Figure 12. Channels mapped by opportunity type for the 57 creeks of interest based on amount of floodable space and configuration of the floodable space to the channel. Alluvial fan reconnection opportunities generally occur in areas with less urbanization and where creeks historically flowed into an alluvial valley. Conversely, direct alignment and off-channel connections tend to occur in areas with higher urbanization, where the channel is more constrained (Note: Head of tide locations were adapted from Dusterhoff et al. (2017) and adjusted to reflect modern locations based on high confidence MHHW levels as mapped by OCM (2023).

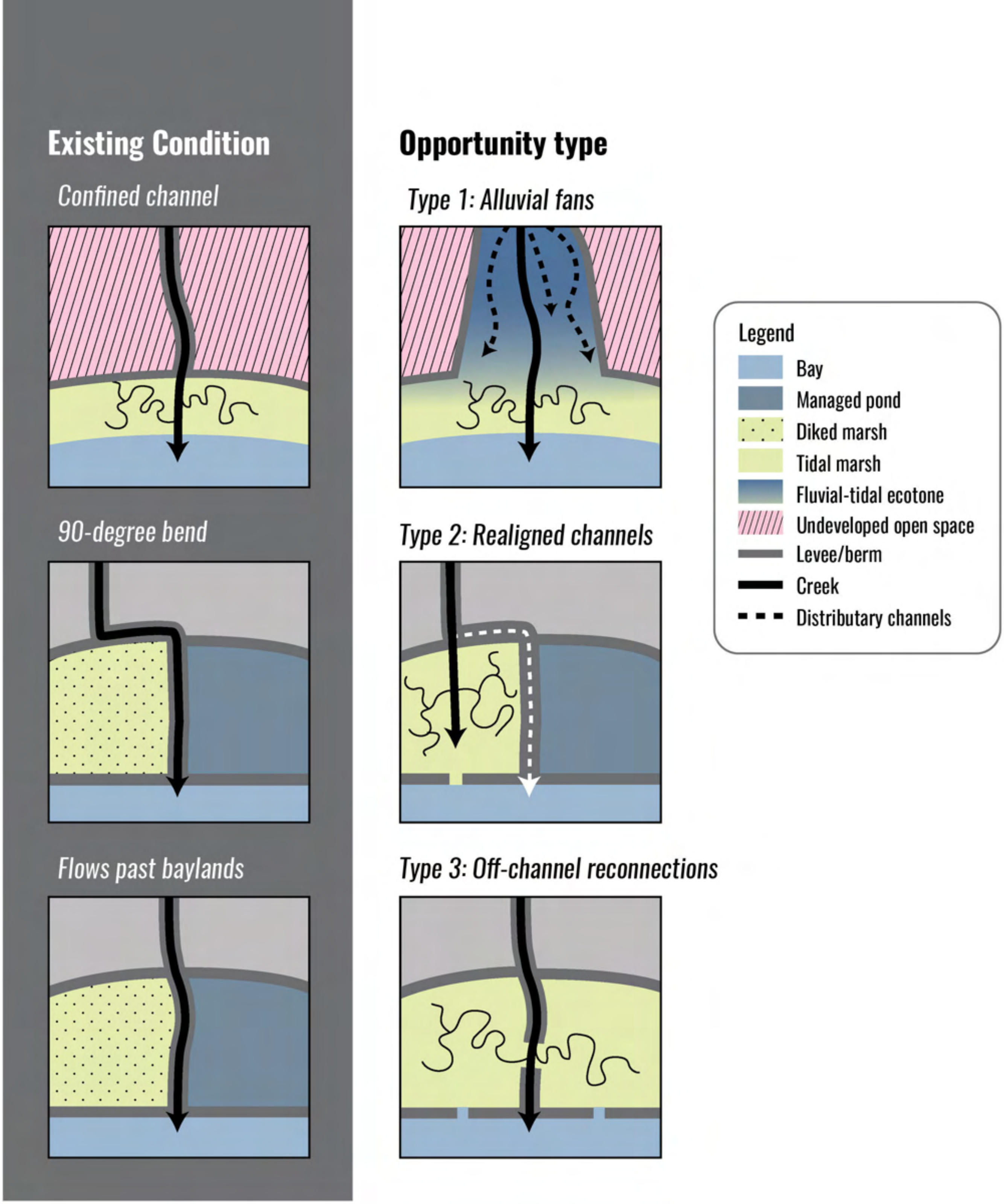


Figure 13. Conceptual diagrams of the existing condition (left) and condition after creek-to-baylands reconnection (right), by opportunity type. These diagrams represent the main type of reconnection and do not represent all conditions where each type might be applied in the landscape.

Alluvial fan: "Fan out"

BACKGROUND

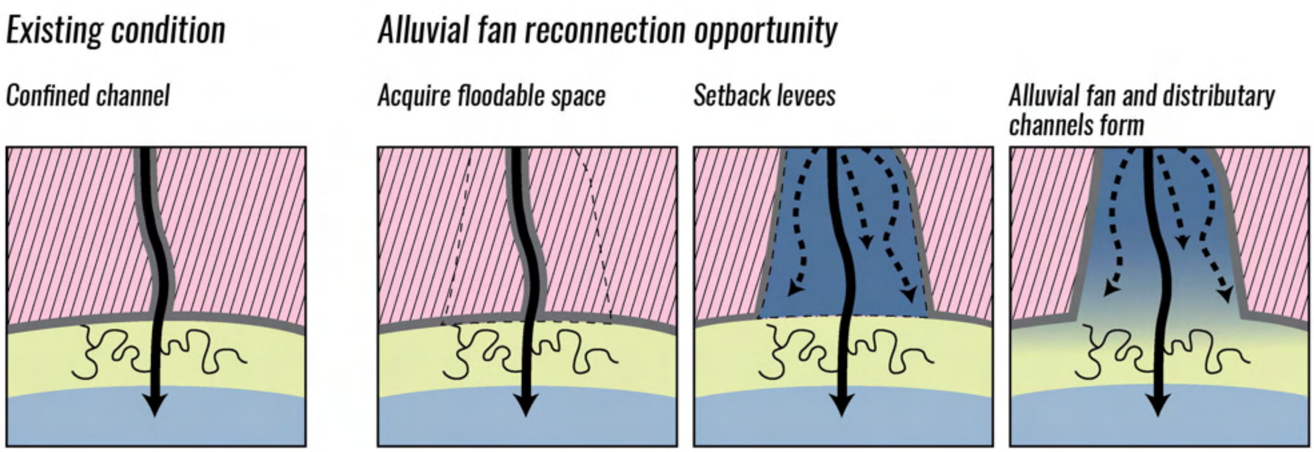
Alluvial fans form at the mouths of streams as sediment erodes out of steep, hilly areas and is carried downstream. As the channel enters a flatter, unconfined plain (i.e., alluvial plain), the velocity of the water slows and stream power decreases, allowing sediment to deposit and build up (NRC 1996). Over time, deposited sediment, debris, and/or vegetation growth blocks the flow of the channel causing the channel to shift position and possibly abandon the existing channel and form a new channel (i.e., avulsion). These migrating and avulsing channel alignments are known as distributary channels and result in fan-shaped patterns that characterize alluvial fans (NRC 1996). Tectonic activity, geology, slope, watershed sediment supply, storm frequency and intensity, deposition and erosion processes, and other factors influence whether and to what extent an alluvial fan forms on the landscape. In the Bay Area, alluvial fans historically provided important habitat zones like sycamore alluvial woodlands (Stanford et al. 2013), riparian grasses, and wet meadows (Beller et al. 2018; Baumgarten et al 2018; SLT and partners 2020) that transitioned into baylands. In most cases, though, these channels have been confined by levees and berms and no longer have the space needed to function as alluvial fans and distributaries.

Alluvial fans can vary in size, ranging from small, localized features to extensive formations that cover large areas. In the Bay Area, there are watersheds where alluvial fan deposits adjacent to the baylands influence the extent and shape of the baylands. This occurs mostly along the southern San Francisco peninsula, the East Bay shoreline, and at the foot of the Diablo Range plain near Bay Point OLU (see "alluvial fans and plains" in Figure 15) (SFEI and SPUR 2019). In other areas, alluvial fans exist much farther back from the baylands in large valleys. These valleys are at the northern and southern axes of the Bay Area (see "wide alluvial valleys" in Figure 15) (SFEI and SPUR 2019). In other settings, rocky headlands intersect the shoreline, leaving little space for alluvial fans to form. These headlands are found along the northern San Francisco peninsula, the Marin shoreline, and around Carquinez Strait (see "headlands and small valleys", Figure 15) (SFEI and SPUR 2019). Today, alluvial fans are often the site of extensive agriculture and development, due to their tendency to build fertile soils with good drainage.

Restoring a functioning alluvial fan can bring numerous physical and ecological benefits, reduce the chance of flooding, and decrease the need for repeated, costly dredging and channel maintenance. Alluvial fans convey water and sediment delivery to downstream landscapes, replenish groundwater through infiltration, create important and unique terrestrial and aquatic habitats, and support tidal marshes and channels at their downstream ends (NRC 1996). One of the most significant benefits is that it allows the channels to deposit sediment above tidal elevations, building elevation capital adjacent to the tidal marshes and creating migration space in preparation for sea-level rise. Conversely, when development occurs on an alluvial fan and inhibits the physical processes of sediment and freshwater onto the landscape, it can lead to undesirable outcomes. For example, development of an alluvial fan can lead to lower groundwater recharge rates that adversely affect aquatic species that rely on cool groundwater-fed flows during hot summer months. In addition, creeks on alluvial fans that have been artificially confined to a mainstem channel to convey floodwaters around development often require active management to reduce flood risk to nearby areas, including repeat dredging and continued channel maintenance. If channels are not maintained, they are at risk of channel aggradation and avulsion due to berm/levee failure, leading to flooding. Thus, acquiring open space adjacent to a channel to reconnect the alluvial fan and distributary formations can provide natural flood-risk reduction while decreasing maintenance costs.

Alluvial fans that intersect baylands are unique opportunities to reroute creeks directly into evolving or established tidal marsh. There, sediment can deposit at the back of the marsh where it would have deposited historically. This type of reconnection could help increase the resilience of the marsh by focusing sediment deposition in fans to build elevations. These fans can then provide space for marsh migration upland. Under rapid rates of sea-level rise, this strategy may be more successful in ensuring marsh persistence than trying to supply sediment to the whole marsh plain, which may or may not keep pace. If the marsh plain is able to keep pace with sea-level rise, the alluvial fan can continue to provide essential tidal-terrestrial transition zone habitat. This type of creek-to-baylands reconnection provides strategic places for sediment deposition and has the potential to decrease backwater flooding impacts due to sediment buildup in channels.

Aerial image of Alameda Creek (photo by Micha Salomon, SFEI)



OPPORTUNITY

Alluvial fan reconnection projects are suitable at higher elevations compared to the other types, starting upstream above head of tide and merging into the tidal reach (Figure 14). This type is best suited to areas with evidence of geologic alluvial fan deposits, indicating that the slope, sediment supply, landscape setting and other factors would likely support the processes that form distributary channels (e.g., sediment transport and deposition, elevational gradient). This opportunity is also best suited to areas with available undeveloped open space. These opportunities are mainly in the North Bay where the former marshes in front of the historical alluvial fans are agricultural fields. In the East Bay there are less opportunities because the former marshes in front of the alluvial fans are now urban areas (see “alluvial fans and plains” in Figure 15). Actions that may occur to facilitate this type of reconnection include setting back or removing levees, acquiring and reclaiming land, eliminating flow barriers, and grading the site to optimize distributary channel formation. Example objectives include reconnecting the alluvial fan, expanding/connecting the floodplain, and restoring outflow from braided channels, where they would naturally exist, into tidal marsh.

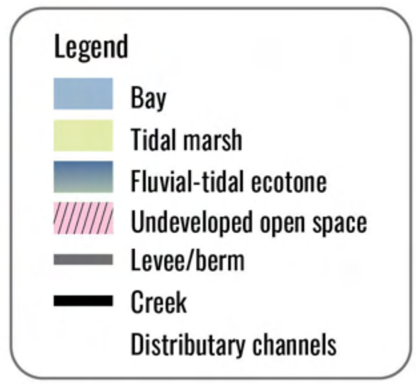


Figure 14. Conceptual illustration of a time sequence of alluvial fan reconnection, showing conditions before (left) and after (right) reconnection. Existing conditions reflect a confined channel flowing through levees past undeveloped open space (pink) into tidal marsh. By acquiring adjacent undeveloped space and opening up the channel, the creek has room to form distributary channels above head of tide. These distributary channels merge directly into tidal marsh, allowing a robust fluvial-estuarine ecotone to form.

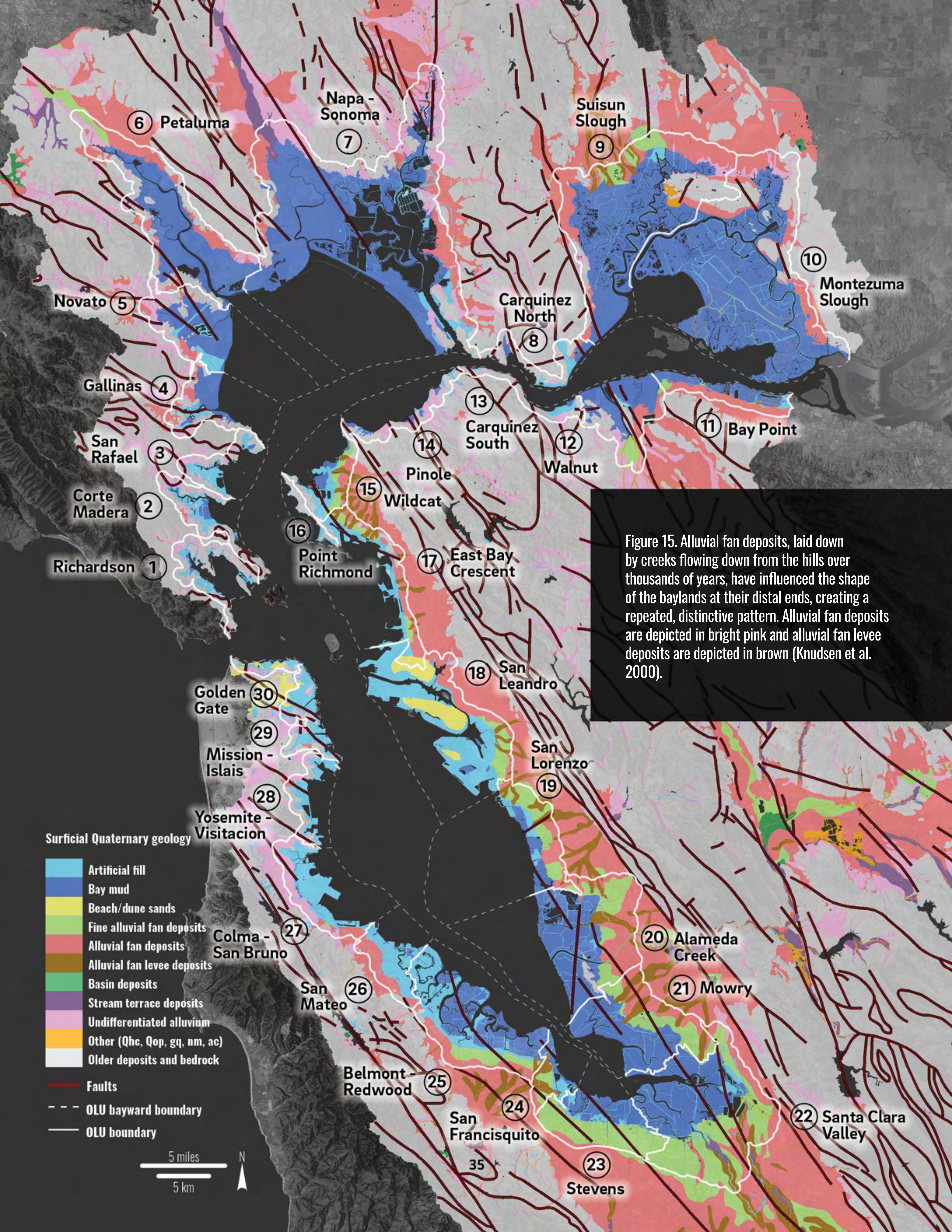


Figure 15. Alluvial fan deposits, laid down by creeks flowing down from the hills over thousands of years, have influenced the shape of the baylands at their distal ends, creating a repeated, distinctive pattern. Alluvial fan deposits are depicted in bright pink and alluvial fan levee deposits are depicted in brown (Knudsen et al. 2000).

EXAMPLE

Reconnecting Sonoma, Schell, and Tolay creeks to the San Pablo baylands (Napa-Sonoma OLU; Planning stage): The Sonoma Creek Baylands Strategy (Strategy) outlines plans for landscape-scale restoration, flood protection, and public access in the tidal Lower Sonoma Creek portion of the San Pablo Baylands (SLT and partners 2020). SFEI worked with Sonoma Land Trust (SLT) and other project partners to analyze existing site conditions, develop restoration alternatives, evaluate geomorphic and habitat evolution, and assess the feasibility and cost of alternatives.

According to the study, under historical conditions, sediment from Sonoma Creek was deposited between State Route 121 and Railroad Slough in the form of an alluvial fan across a series of distributary channels, which were perched higher than the surrounding marshes (ESA 2012, SLT and partners 2020). A smaller alluvial fan is located on Tolay Creek where there is a similar gradient change from uplands to baylands. A key element of the Strategy is to reconnect the channels to their alluvial fans. More specifically, Alternative 3 (Enhanced Maximum Tidal, the alternative that best met project goals) calls for restoring Sonoma Creek's alluvial fan by removing and selectively lowering levees to allow distributary channels to form (Figure 16). This would connect marshes to higher-elevation areas at the back of the baylands and allow marsh migration with sea-level rise. Alternative 3 also calls for a realignment of Schell Creek to flow directly into reclaimed areas adjacent to the confluence of Sonoma and Schell creeks, supporting tidal marsh development in this area more broadly. Finally, Alternative 3 also envisions alluvial fan restoration at the mouth of Tolay Creek, before it reaches Tubbs Island, to reconnect the alluvial fan to the baylands.

In total, Alternative 3 calls for the protection, acquisition, restoration, and enhancement of a mix of public and private land adjacent to and downstream of Sonoma, Schell, and Tolay creeks. To our knowledge, this is the first plan in the Bay Area to reconnect alluvial fans above head of tide to baylands downstream. If implemented, this project would be an important blueprint for how to plan and permit alluvial fan restoration and distributary channels at the fluvial-tidal interface.

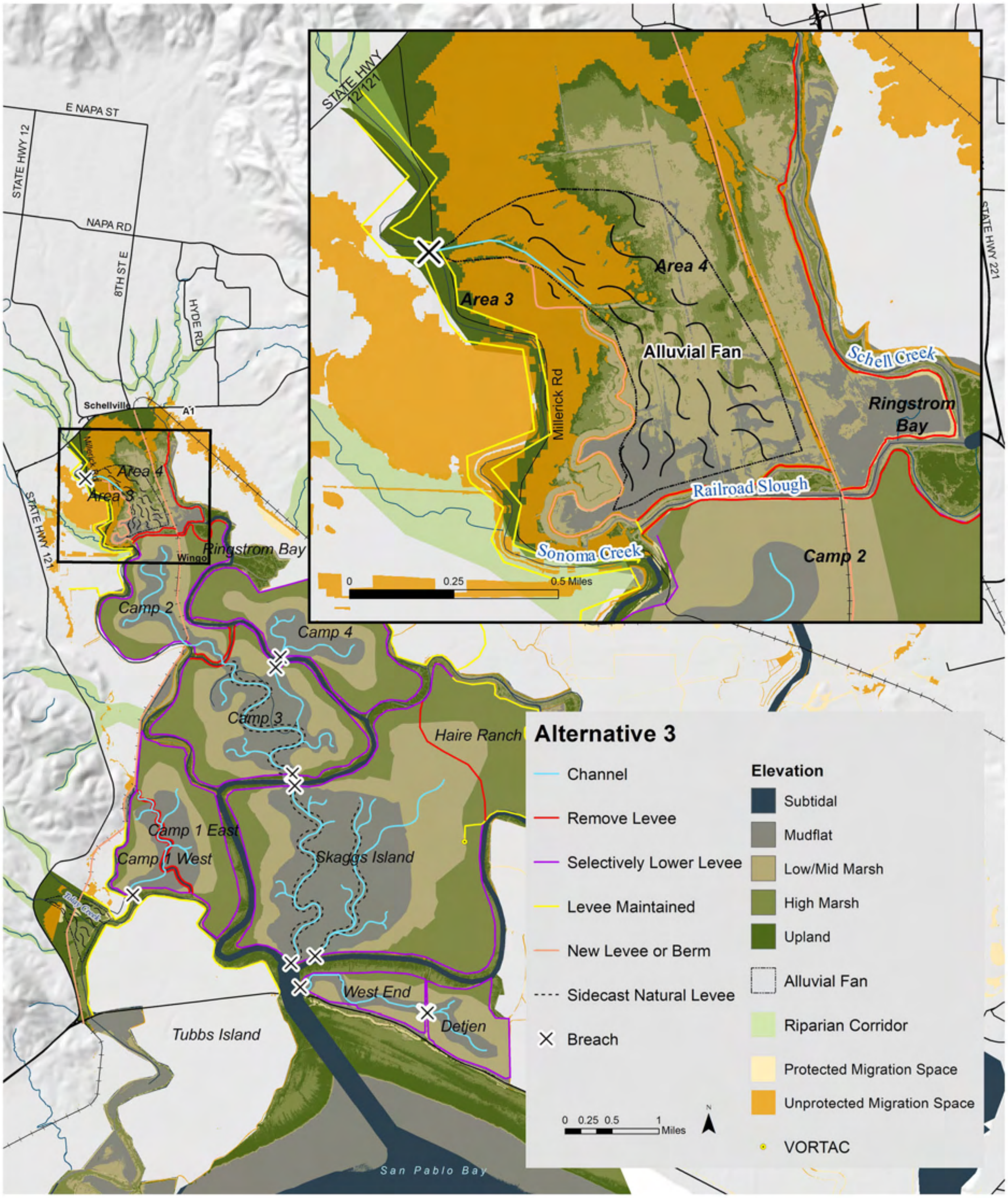


Figure 16. Alternative 3 from the Sonoma Creek Baylands Strategy includes an alluvial fan restoration on Sonoma Creek. An existing weak point in the levee where flooding occurs today would become a connection to a protected alluvial fan where distributary channels could form. This would connect marshes to higher-elevation areas at the back of the baylands and allow marsh migration with sea-level rise. Adapted from Sonoma Creek Baylands Strategy (courtesy of SLT and partners, 2020)

Realigned channels: "Realign"

BACKGROUND

Starting in the mid-1800s, the flatter, lower elevations in watersheds at the Bay edge were diked and drained for agriculture and development. With urban development, the construction of salt ponds, and the diking of land for agriculture, the edge of the Bay shifted farther and farther out. Channels were realigned and leveed to convey floodwaters from the developed baylands out to the Bay. This has resulted in low-gradient, confined, depositional channels, many of which have dramatically altered alignments. Often, channels flow through sharp angles around properties to expand arable land, prevent discharge into salt ponds, or contain flood flows (e.g., San Francisquito Creek, Calabazas Creek, San Tomas Aquino Creek, Sulpher Creek) (Figure 17). In the 20th century, the increased need to protect development adjacent to these creeks from flooding led to the extension, straightening, and widening of channels, as well as the construction of engineered flood control levees. These channel modifications have caused the lower portions of many creeks to accumulate sediment upstream of sharp-angle channel realignments, requiring regular sediment removal to maintain effective flood conveyance. These channel modifications have also, in many cases, caused channels to flow past or away from areas at appropriate elevations for tidal marsh restoration.

Throughout the Bay Area, there are dozens if not hundreds of examples of channel reaches with these problematic sharp-angle channel alignments near and below head of tide. Restoring more natural alignments for those channels with excess sediment accumulation has the potential to increase sediment transport capacity, thereby improving flood conveyance and facilitating more sediment delivery to downstream baylands. Additionally, there are numerous examples of channels that have been rerouted away or conveyed around their downstream baylands below head of tide. Realigning those channels to drain directly into the baylands offer an important opportunity to improve the delivery of sediment to areas that need it.

Figure 17. Examples of channels that flow through sharp angles before reaching the Bay include Lagunitas Creek (left), Miller Creek (center), and San Francisquito Creek (right) (courtesy of Google Earth).

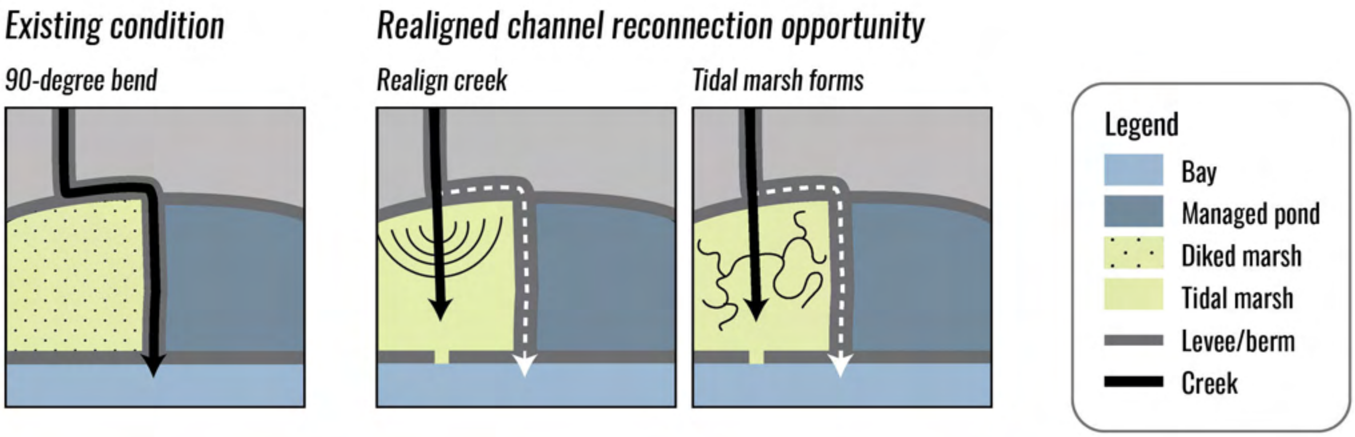


Figure 18. Conceptual illustration of a time sequence of a realigned channel reconnection, with conditions of before (left) and after (right) reconnection. Existing conditions reflect a confined channel flowing through levees past a diked marsh and a managed pond before draining to the Bay. By breaching the levee at the back of the diked marsh, the channel is realigned to flow directly into the diked marsh and breached to full tidal action.

OPPORTUNITY

Realigned channels are opportunities at or below head of tide to align and establish (or realign and reestablish) flow directly onto an existing marsh or undeveloped area slated for baylands restoration (Figure 18). While the opportunity type described here focuses on the interface with the baylands below the head of tide, it is worth noting that channel realignment could occur anywhere in the watershed to improve the delivery of sediment. Historical channel alignment (where known) should be used as a guide to inform redesign, acknowledging local constraints and landscape changes upstream and downstream that would necessitate a modified alignment. Realigned channels require enough floodable open space to redirect the full flow of sediment and water downstream, making this type most suitable to less developed landscapes. Actions that may facilitate this type of reconnection include levee breach, removal, or realignment (either partial or full), elimination and/or creation of flow barriers, and acquisition, reclamation, and grading of adjacent land to be opened to fluvial and tidal flows. Example objectives include increasing sediment transport capacity and improving flow conveyance in a manner that reduces local flood risk and supports local aquatic habitat and marsh establishment/persistence.

In the North Bay there are large areas of diked baylands separated by historical channels which now contain some of the few remaining fringing marshes. These fringing marshes may be the only high-quality marsh in the area and so, in these instances, such areas may need to be protected. Restoring tidal marsh upstream and putting more flow into the historical channels will erode these marshes. Realigning channels could be an opportunity to avoid erosion of the existing marsh habitats by routing flow through the adjacent diked baylands. This approach has been suggested for the marsh restoration projects occurring along Sonoma Creek (SLT and partners 2020) and for Deer Island in Novato Creek.

EXAMPLES

Calabazas and San Tomas Aquino Creeks into Pond A8 (Santa Clara Valley OLU; Planning stage): As part of the EPA-funded Healthy Watershed Resilient Baylands project, SFEI worked with partners at Valley Water and the South Bay Salt Pond Restoration Project, along with a team of technical advisors and regulatory agency representatives, to move forward a recommendation from Flood Control 2.0 by developing a conceptual design for a first-of-its-kind channel-baylands reconnection along the Lower South Bay shoreline (McKnight et al. 2018). When implemented, Calabazas and San Tomas Aquino Creeks will be realigned to flow directly into Pond A8, to allow a subsided former salt pond to accrete to tidal marsh elevations (Figures 19 and 20). Pond A8 would benefit from an additional local supply of sediment. Valley Water is conducting feasibility studies and additional designs of the proposed realignment, with the potential to break ground between 2027 and 2029 (Valley Water 2023).

Figure 19. Existing conditions showing Calabazas and San Tomas Aquino creeks flowing around Pond A8 (McKnight et al. 2018).

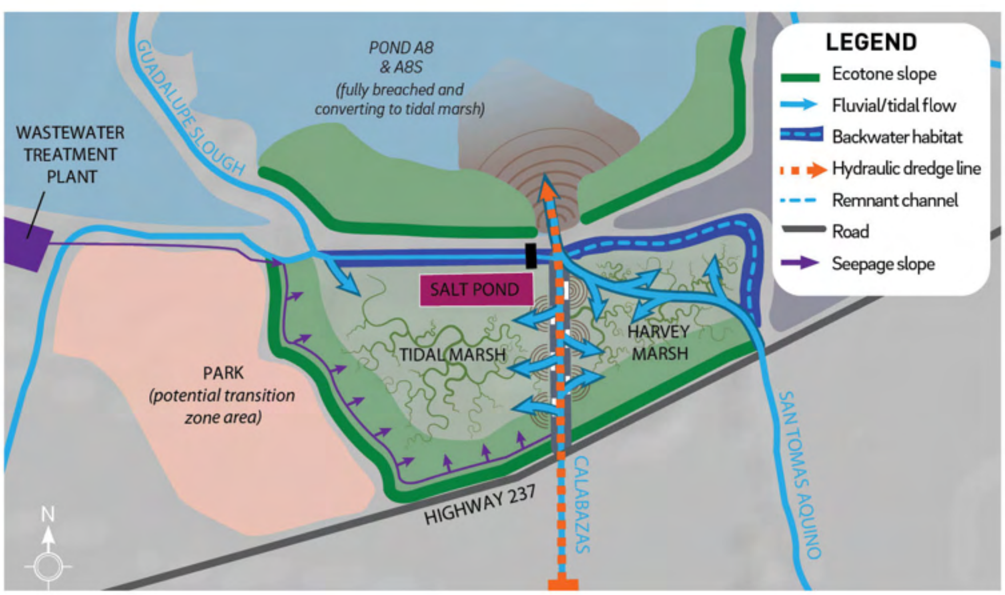


Figure 20. Planning documents envision Calabazas and San Tomas Aquino Creeks to flow directly into Pond A8 by realigning the creeks via a breach through the existing levee and creating off-channel reconnections, which will be discussed in the next section, between Calabazas Creek and Harvey Marsh (McKnight et al. 2018).

Figure 21. Proposed realignment of Miller Creek to flow into Gallinas Creek at McInnis Marsh (adapted from KHE 2016). This provides a high-level concept view only; actual design would include more tidal channels.

Miller Creek to McInnis Marsh in Gallinas Baylands (Gallinas OLU; Planning stage): The proposed 180-acre McInnis Marsh Restoration Project aims to redirect flows from Miller Creek to Gallinas Creek through McInnis Marsh, opening McInnis Marsh to full tidal action. Reintroducing these diked baylands to tidal action would expand tidal marsh habitat area and increase tidal prism to Gallinas Creek, resulting in a potential reduction in downstream dredging. The project would also establish an ecological corridor between Miller and Gallinas creeks (KHE 2016) (Figure 21). Historically, Miller and Gallinas creeks were intermittently connected: during periods of large flows and high tide, Miller Creek spread out into a fluvial-estuarine transition zone and, when this area was flooded, drained south to Gallinas Creek. The two creeks supported a connected tidal marsh complex in the Gallinas Baylands (KHE 2016). This reconnection project would restore this connection and reclaim a portion of the Gallinas Baylands complex. The feasibility study for the project details five alternatives with varying opportunities and constraints, and involves breaching levees, constructing channels, and removing existing levees. If implemented, this project would enhance the marshes' ability to keep pace with sea-level rise and enhance foraging and passage options for Splittail and Steelhead fish species (KHE 2016). Marin County Parks is managing this project which is currently in the planning stage.

Bothin Marsh in Mill Valley, Marin (courtesy of Joe Passe, CC BY-SA 2.0)

Coyote and Nyhan creeks to Bothin Marsh (Corte Madera OLU) (planning stages): Another example of realigned channels in the planning stages is the proposed realignment of Lower Coyote Creek into Bothin Marsh in Marin County. Anchor QEA and ESA are investigating potential alignments and have modeled several configurations, two of which fall into the realigned channels type and two of which fall into the off-channel reconnection type (Anchor QEA 2022, ESA 2021, ESA 2022). Nyhan Creek drains into Coyote Creek, forming Lower Coyote Creek, which then proceeds to flow adjacent to South Bothin Marsh in its current alignment. The main objective behind this project is to increase sediment deposition rates from Lower Coyote Creek onto South Bothin Marsh to help the marsh have a better chance of keeping pace with sea-level rise through vertical accretion.

Out of the four alignments assessed, Alternatives 3 and 5 fit our definition of the realigned channel type (Figure 22), whereas Alternatives 4 and 6 fit our definition of the off-channel type. In these alternatives, the current channel alignment is either fully filled in (Alternative 3) or blocked to a certain flood stage (Alternative 5) to redirect low flows from Coyote Creek into a new channel alignment that goes more directly into Bothin Marsh while extreme discharges would go through the existing channel alignment.

The modeling predicts different rates of sediment deposition for each configuration, with the realigned types yielding a higher anticipated direct sediment deposition benefit compared to the off-channel types. A 60% and 77% increase in sediment deposition in the marsh from fluvial sources was modeled for Alternatives 3 and 5 respectively, compared to baseline conditions. Fluvial sediment deposition in the realignment scenarios is 1.5 to 2 times higher than the deposition achieved with the off-channel scenarios. This study is one of the first to assess the difference in sediment deposition across reconnection types and demonstrates that multiple reconnection options are possible at one site.

As of August 2023, this project is in the early design phase and the team is leaning towards Alternative 6 due to concerns over potential loss of existing marsh habitat and impacts to upstream flooding. Alternative 6 (Figure 22) only establishes a high-flow overbank connection (off-channel type), resulting in the least impacts to marsh habitat and upstream flooding but also the least sediment deposition compared to the other alternatives.

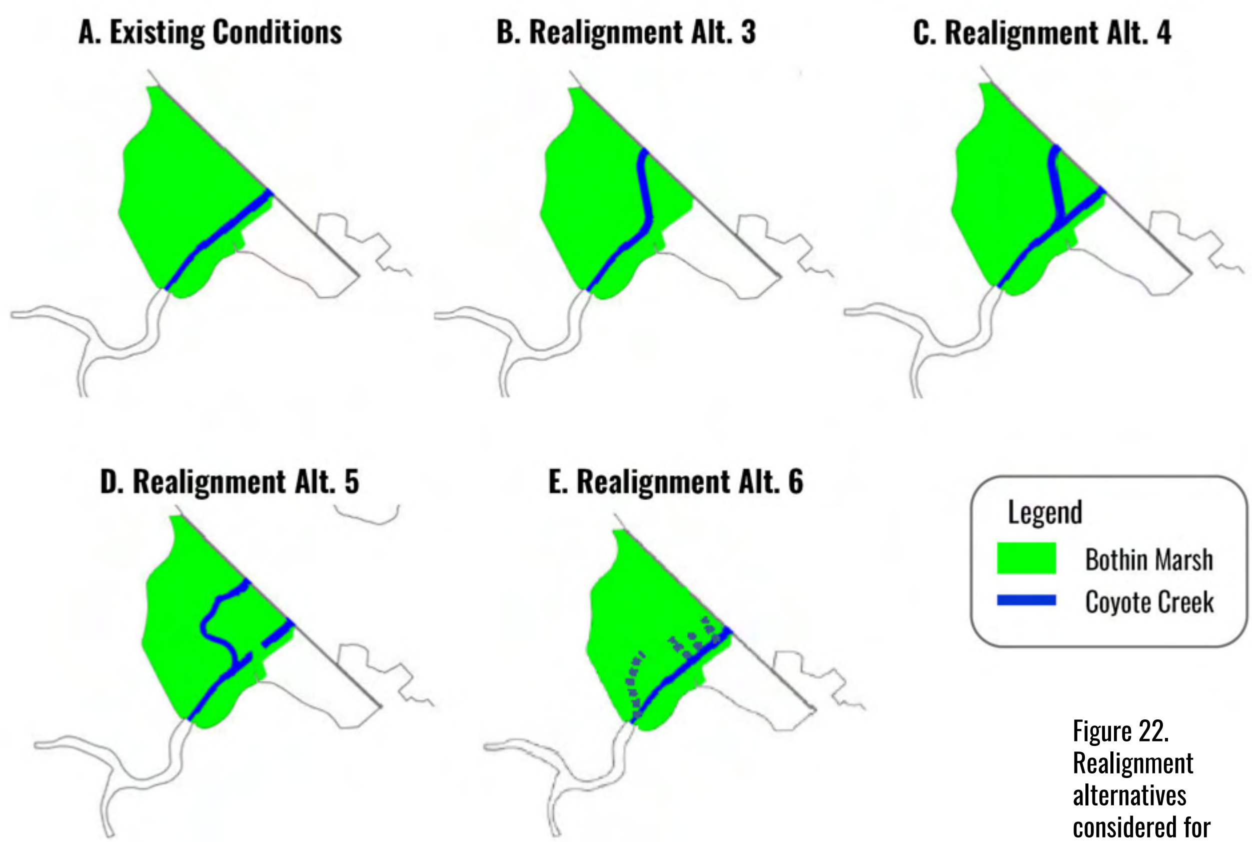


Figure 22. Realignment alternatives considered for Coyote Creek in Marin County (courtesy of Anchor QEA 2022 and ESA 2022).

Off-channel: “Connect to the side”

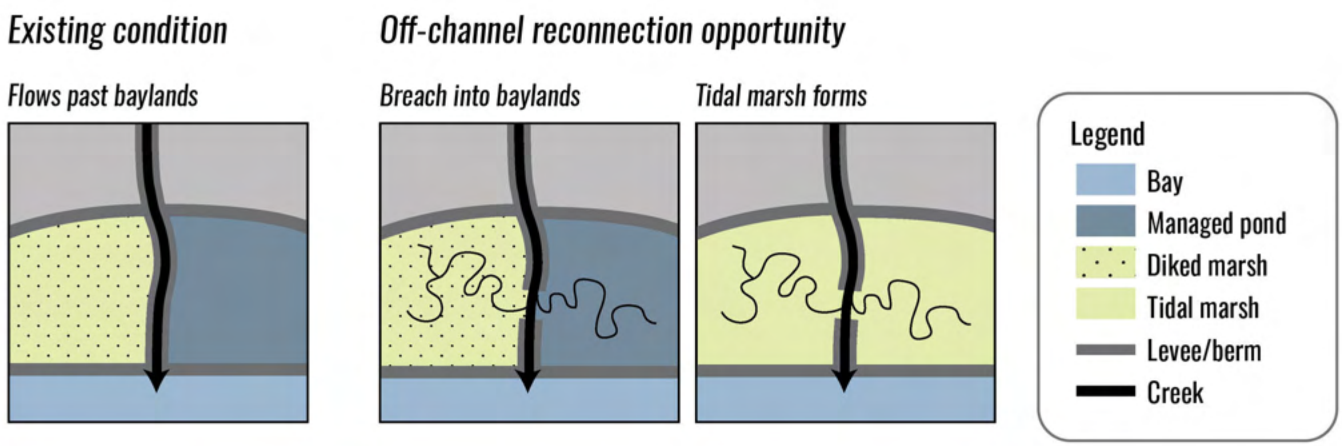
BACKGROUND

As baylands were diked and drained for development, agriculture and other uses, confinement and reconfiguration of channels led to two significant and common issues: (1) a reduction in a channel’s tidal prism and capacity, reducing the scouring power from tidal flows and increasing in-channel sediment deposition, (2) a reduction in extent and connectivity of baylands habitats.

Among the various creek-to-baylands reconnection types identified in the Bay, the most commonly implemented approach to date is off-channel reconnections, often through breaching diked baylands to tidal and fluvial action. Efforts to restore tidal marshes commenced in the 1970s (Williams and Faber 2001) and gained substantial momentum through initiatives like the Baylands Goals Project in 1999 and its subsequent update in 2015 (Goals Project 1999, 2015; SFBRA n.d.), the former of which included a regional goal to restore tidal marsh to achieve a total of 100,000 acres.

Many levees have been breached to restore diked baylands to full tidal action. The first documented tidal marsh restoration in the Bay was the 79-acre Faber Tract project in 1972 (Williams and Faber 2001), located in the San Francisquito OLU in the Lower South Bay. Since then, numerous tidal marsh restorations have occurred in various contexts, including at dredged material reuse sites, salt ponds, and agricultural fields (Williams and Faber 2001; Orr 2018). Many of these projects have Bay-facing breaches that are near but indirectly connected to fluvial channels. Some have fluvial-facing breaches directly connected to a fluvial channel: the off-channel reconnection type addressed in this section. Examples of some of the first off-channel fluvial-facing breaches include the 1994 Carl’s Marsh restoration (which connected to the tidal reach of the Petaluma River) and the 1999 Tolay Creek Restoration Project (which connected to the tidal reach of Tolay Creek) (Takekawa et al. 2005; Williams and Faber 2001).

The 1990s brought increases in the size of individual restoration projects, enabling more complex sites to take shape by building on lessons learned and successes from earlier restoration projects (Orr 2018). Notable projects with off-channel reconnections include the 1994 purchase of the 10,000-acre Napa-Sonoma Marsh Restoration (which connected to the tidal reach of the Napa River) and the 2003 purchase of the 15,100-acre South Bay Salt Ponds Restoration Project (comprising a mix of fluvial-facing and Bay-facing breaches) (USFWS and CDFG 2007, SCC 2023). These larger projects also began recognizing flood-risk reduction benefits and identifying opportunities for public access by nearby communities (Orr 2018).



OPPORTUNITY

Off-channel reconnections are opportunities below head of tide to connect diked baylands adjacent to the channel that is currently protected by berms, levees, or other infrastructure to full fluvial-tidal action (Figure 23). In contrast to the distributary channel and realigned channel types discussed above, the off-channel reconnection type occurs when flows from the channel branch off into adjacent baylands, capturing only a portion of the water and sediment from the channel rather than the full flow of water and sediment. Actions that may occur to facilitate this type of reconnection include levee breach or removal, acquisition and restoration of adjacent land to be opened to fluvial and tidal flows, and grading of pilot channels.

Example objectives include decreasing local flood risk and improving the conveyance of freshwater and sediment onto a marsh by increasing tidal prism while minimizing large changes in channel length and/or position. The ability of an off-channel connection project to provide flood storage depends on the location along the channel, size of the area, and form of connectivity with the channel (e.g., number, width, size, sill elevation of culverts, weirs, breaches). Flood storage projects are commonly located along the upper parts of channels rather than near the Bay. The sill elevation will also affect the timing of flooding and the amount of sediment that can be captured. A high sill will only allow high, infrequent flows into the restoration site and may only allow fine sediment from higher up in the water column to enter, leaving the coarser sediment, including the bedload, in the channel.

Figure 23. Conceptual illustration of a time sequence of an off-channel reconnection, with conditions of before (left) and after (right) reconnection. Existing conditions reflect a confined channel flowing through levees past diked marsh and managed pond habitats before draining to the Bay. By creating an off-channel breach, both the diked marsh and managed pond are connected to the channel, allowing fluvial and tidal waters to flow into the adjacent habitats. Both habitats are reconnected to full tidal action with the goal of tidal marsh restoration.

EXAMPLE

Walnut Creek to Pacheco Marsh (Walnut OLU; Implemented): The North Reach of Lower Walnut Creek, known as Pacheco Marsh, is an example of an off-channel reconnection project. A 122-acre parcel of land adjacent to the mouth of Lower Walnut Creek that was historically tidal marsh was diked, drained, and partially filled with sediment generated from nearby dredging activities in the 1950s (CCPW 2022). In 2021, the John Muir Land Trust, Contra Costa County Flood Control District, East Bay Regional Park District and partners completed a tidal marsh restoration project that reconnected these diked areas back to full tidal action with breaches to Suisun Bay and Walnut Creek (JMLT 2023a, 2023b). Pacheco Marsh now totals 232 acres of restored tidal marsh (CCPW 2022). The eastern portion of the project (~50 acres) was directly reconnected to Walnut Creek in a manner consistent with the off-channel reconnection type. While only one portion of the site can be classified as an off-channel reconnection, the Pacheco Marsh restoration project at large resulted in the creation of tidal marsh habitat that supports ten special-status plants and animals including the salt marsh harvest mouse (***Reithrodontomys raviventris***) and the black rail (***Laterallus jamaicensis coturniculus***), recreational opportunities like trails and water access, marsh-upland transition zones for marsh to move upslope with sea-level rise, and flood protection benefits (JMLT 2023a).

Union Pacific Railroad Bridge over lower Walnut Creek (photo by Carolyn Doehring, SFEI)

CHANNELS WITH LIMITED FLOODABLE SPACE

Figure 24. The Colma Creek Restoration and Adaptation Project in South San Francisco is reimagining the tidal reaches of Colma Creek to restore and expand habitat for riparian and baylands species, as well as expanding recreational opportunities along a highly urbanized shoreline (Image courtesy of Hassell).

Channels identified as having low opportunity for distributary, realigned, or off-channel type reconnections may still have value as potential restoration opportunities. Channels in highly urbanized areas are often channelized, flow through contaminated lands, and are inaccessible to the public. While this limits reconnection options, there are often opportunities to improve the landscape in other ways and increase community value. For example, the San Leandro (Lisjan) Creek Urban Greenway project will create a community asset for East Oakland residents, including green space and bike/pedestrian trails connecting from residential areas to San Leandro Bay. The effort, led by the Brower Dellums Institute, has been guided by the desires of the local community. Signage and programming will feature local voices and East Oakland residents will be hired to build and maintain the future Greenway. This project does not involve any changes to the creek channel itself, but is an example of increasing community benefits of a creek corridor in an area with limited floodable space. More information at: https://www.browerdellumsinstitute.org/san-leandro-creek-greenway-trail.

Another project at the creek-baylands interface with limited available space is underway at Colma Creek in South San Francisco (Figure 24). The project emerged from the 2018 Resilient By Design competition. A project team led by Hassell has continued work on the effort, with designs evolving over the years based on community input, research, and collaboration with local stakeholders. A number of physical constraints (e.g., pump stations, jet fuel lines, contaminated parcels) have limited the scope of the originally planned effort in this industrial corridor. Despite these challenges, the planned design will enhance public access to the shoreline through the inclusion of trails and parks and add green stormwater infrastructure, floodable parks, and enhanced tidal-terrestrial transition zone habitats.

Matrix of reconnection opportunities by OLU

In this section, we present a matrix of creek-to-baylands reconnection opportunities around the Bay that can be used in combination with the opportunity map presented on page 30 in the previous section. The matrix is organized by OLU and divided into three categories: lateral resilience, vertical resilience, and steelhead support. The matrix can also be used in combination with data outlined in the San Francisco Bay Shoreline Adaptation Atlas (SFEI and SPUR 2019), such as jurisdictional boundaries within an OLU or other site-specific considerations, to help guide the prioritization process.

Principles that guide the opportunity matrix:

- Restoring physical processes in creek-baylands systems yields the highest resilience to sea-level rise and other climate impacts over time.
- Building complete tidal marsh systems that include subtidal, intertidal, and upland connections to offer better physical and ecological benefits are the goal (Goals Project 2015).
- Creek-to-baylands reconnections are important opportunities to support vulnerable aquatic and terrestrial wildlife populations.

Additional criteria could be added to the matrix based on specific goals and priorities established by project proponents, which could change where reconnection opportunities are prioritized and the types of benefits anticipated. For example, this matrix identifies steelhead to represent aquatic wildlife reconnection opportunities using a species of special concern in the Bay. Future iterations could include additional aquatic or terrestrial species (e.g. salt marsh harvest mouse) or other considerations, like direct or indirect benefits to people, that project proponents may be interested in prioritizing as part of creek-to-baylands reconnection projects. Read on for a brief description and corresponding map of each criterion used to inform the matrix.

Lateral resilience: *How much space and elevation capital does a given channel's baylands have to move upland with sea-level rise?*

TIDAL MARSH

Existing and potential tidal marsh are areas at appropriate elevations in which marsh vegetation currently grows or could grow (i.e. between mean sea level and the highest astronomical tides), based on mapping by SFEI and SPUR (2019) (Figure 25). Suitability ratings correspond to the specific channel of interest, not the entire OLU, and reflect areas immediately adjacent to the channel either at or along the tidal reach downstream where reconnection may be possible. Suitability ratings are based on a qualitative interpretation of existing and potential marsh: ***limited suitability*** = little to no undeveloped land exists at suitable elevations for existing/ potential tidal marsh near the channel; ***some suitability*** = some suitable land exists near the channel; and ***high suitability*** = ample suitable land exists near the channel.

MARSH MIGRATION SPACE

Potential marsh migration space are areas that are undeveloped and above today's highest astronomical tide and within the area expected to be inundated with 2.0 m of sea-level rise (as predicted by the Coastal Storm Modeling System (CoSMoS)) based on updated mapping in 2021 for the San Francisco Bay Shoreline Adaptation Atlas (Plane and Iknayan 2021) (Figure 26). Suitability ratings correspond to the specific channel, not the entire OLU. Suitability ratings are based on a qualitative interpretation of potential marsh migration space: ***limited suitability*** = little to no undeveloped land exists at suitable elevations for marsh migration space near the channel; ***some suitability*** = some suitable land exists near the channel; and ***high suitability*** = ample suitable land exists near the channel.

POLDER MANAGEMENT

Polders are subsided areas below mean sea level and disconnected from tidal inundation by dikes (as mapped by SFEI and SPUR 2019) (Figure 27). Creek-to-baylands reconnection opportunities have the potential to benefit polders by directing sediment into these areas to raise them to higher elevations. Suitability ratings correspond to the specific channel of interest, not the entire OLU. Suitability ratings are based on a qualitative interpretation of existing polder extents: ***limited suitability*** = little to no undeveloped land exists at suitable elevations for polders near the channel; ***some suitability*** = some suitable land exists at polder elevations near the channel; and ***high suitability*** = ample suitable land exists near the channel at polder elevations.

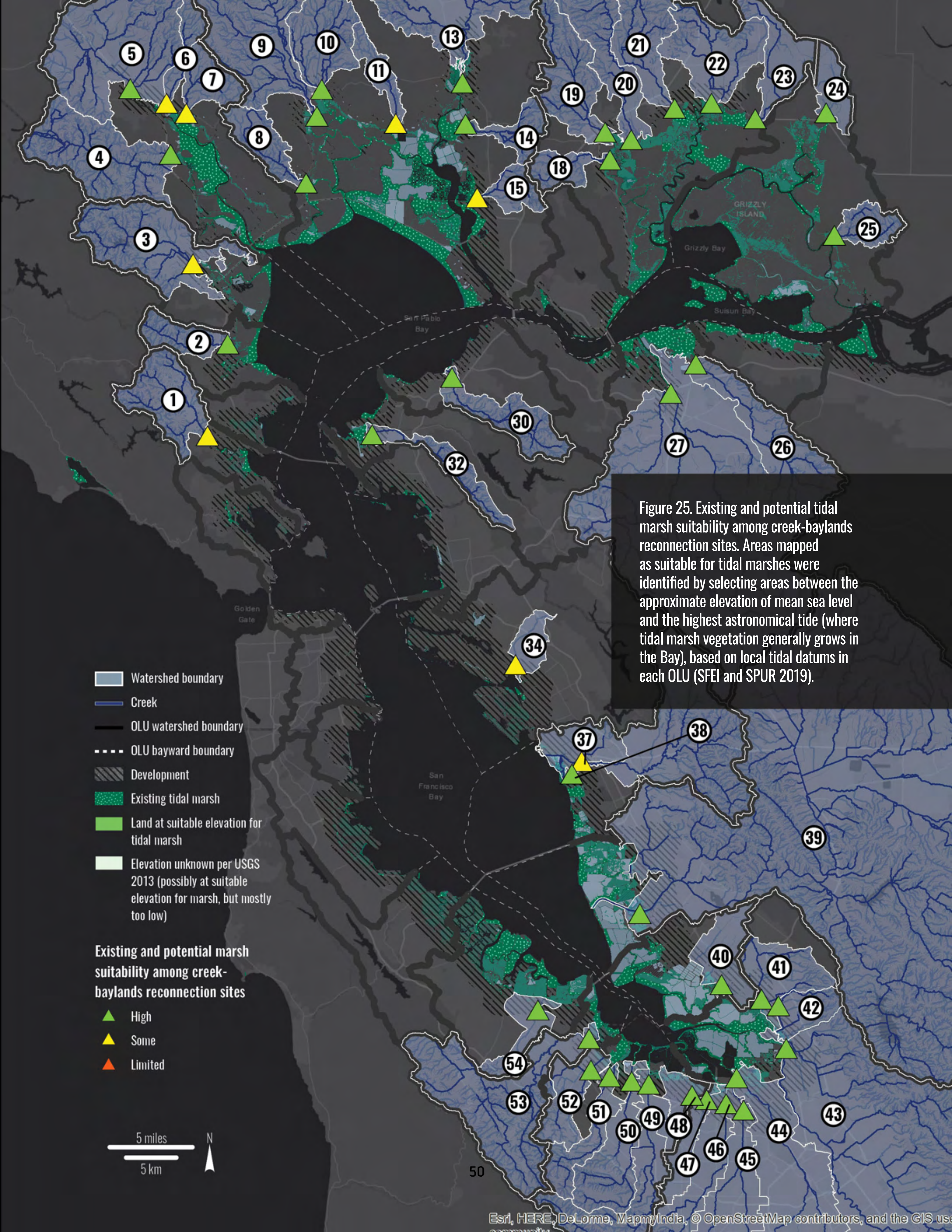


Figure 25. Existing and potential tidal marsh suitability among creek-baylands reconnection sites. Areas mapped as suitable for tidal marshes were identified by selecting areas between the approximate elevation of mean sea level and the highest astronomical tide (where tidal marsh vegetation generally grows in the Bay), based on local tidal datums in each OLU (SFEI and SPUR 2019).

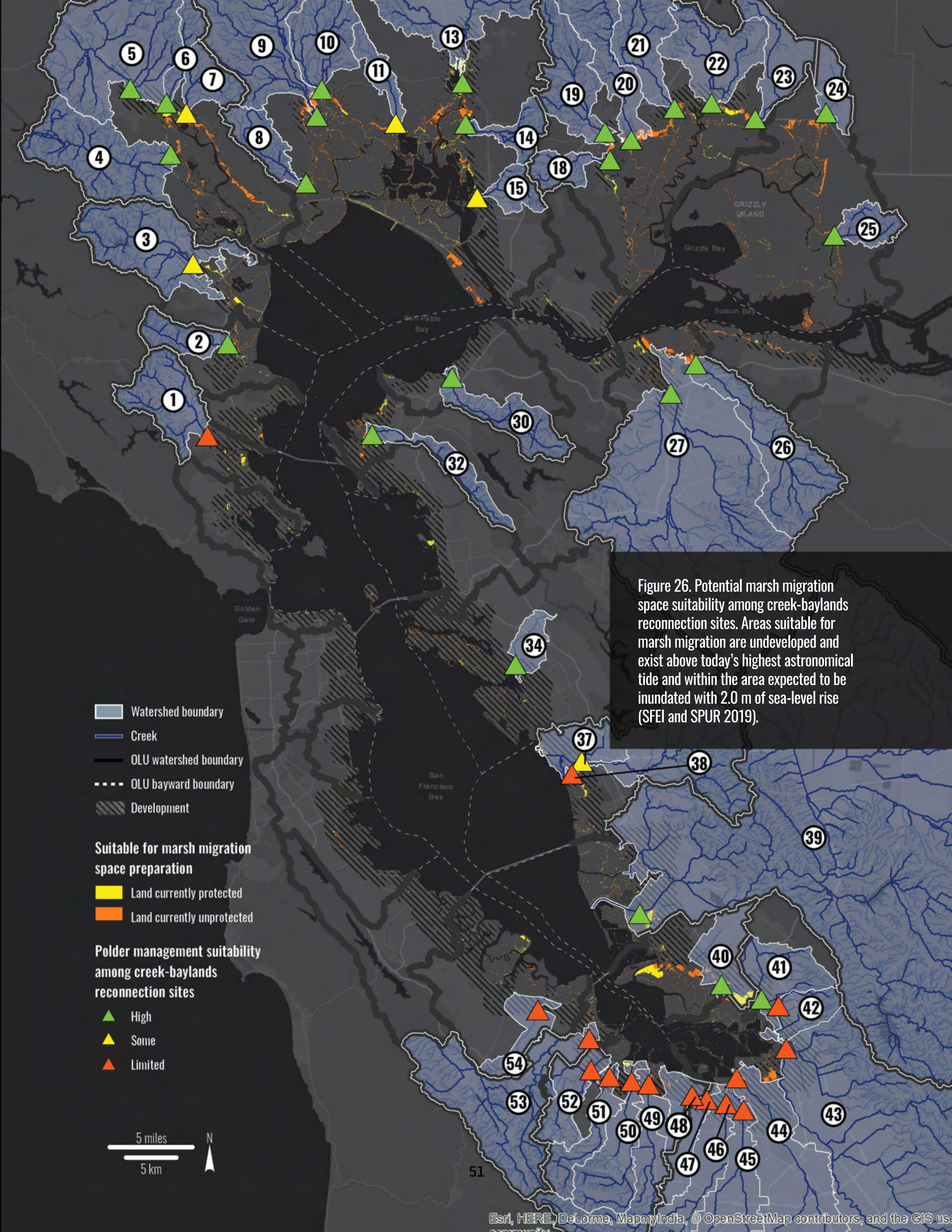


Figure 26. Potential marsh migration space suitability among creek-baylands reconnection sites. Areas suitable for marsh migration are undeveloped and exist above today's highest astronomical tide and within the area expected to be inundated with 2.0 m of sea-level rise (SFEI and SPUR 2019).

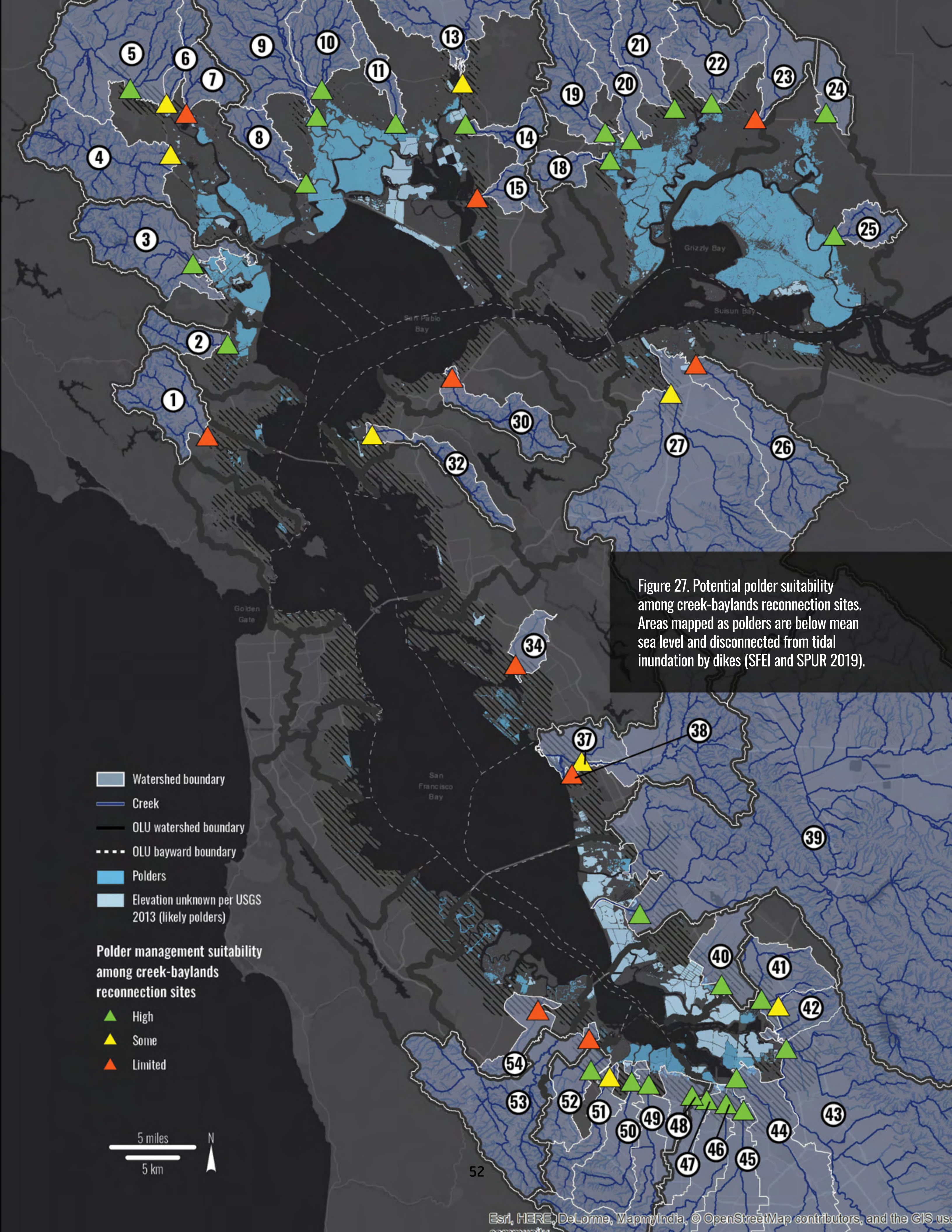


Figure 27. Potential polder suitability among creek-baylands reconnection sites. Areas mapped as polders are below mean sea level and disconnected from tidal inundation by dikes (SFEI and SPUR 2019).

Vertical resilience: *What is the magnitude of local sediment supply? How much sediment is available or may be available in the future for a given channel's baylands to accrete vertically at pace with sea-level rise?*

SEDIMENT SUPPLY

The Bay Area's watersheds provide essential sediment, nutrients, and freshwater to the baylands ecosystem. Watershed sizes and sediment loads differ around the Bay Area, resulting in varying opportunities by creek reconnections to sustain created or restored baylands (Figure 28). Average annual total sediment load was calculated for Bay Area subwatersheds based on water years 1995 through 2016 by Schoellhamer et al. (2018). Sediment yield was classified into ***high*** (greater than 50,000 metric tonnes), ***medium*** (5,000 to 50,000 metric tonnes), and ***low*** (less than 5,000 metric tonnes) categories.

VERTICAL ACCRETION

Potential to accrete vertically is based on mapping by Dusterhoff et al. (2021), which qualitatively combines findings comparing future projected baylands sediment demand to local sediment supply from watersheds and the Delta, and also qualitatively takes into account an assessment of organic matter accumulation rates (Figure 29). Unlike the other criteria considered, this criterion is based on the entire OLU, not individual creeks and their nearby baylands. Creek-to-baylands reconnection opportunities with a suitability of ***highest*** corresponds to the highest potential for long-term baylands resilience with respect to vertical accretion: local supply of inorganic sediment and organic matter combined with Bay inorganic sediment supply could go a long way towards meeting demand for existing and restored baylands under wetter and drier futures (to year 2100). Creek-to-baylands reconnection opportunities with a suitability rating of ***higher*** corresponds to a higher potential for long-term baylands resilience with respect to vertical accretion with polder filling: local inorganic sediment supply combined with Bay inorganic sediment supply could go a long way toward meeting demand for existing and restored baylands for wetter and drier future out to 2100 if polders filled mechanically before restoring tidal connection. Creek-to-baylands reconnection opportunities without a rating (noted on the map as "***other***") are assumed to have a lower vertical resilience than the higher and highest categories based on the evaluation by Dusterhoff et al. (2021).

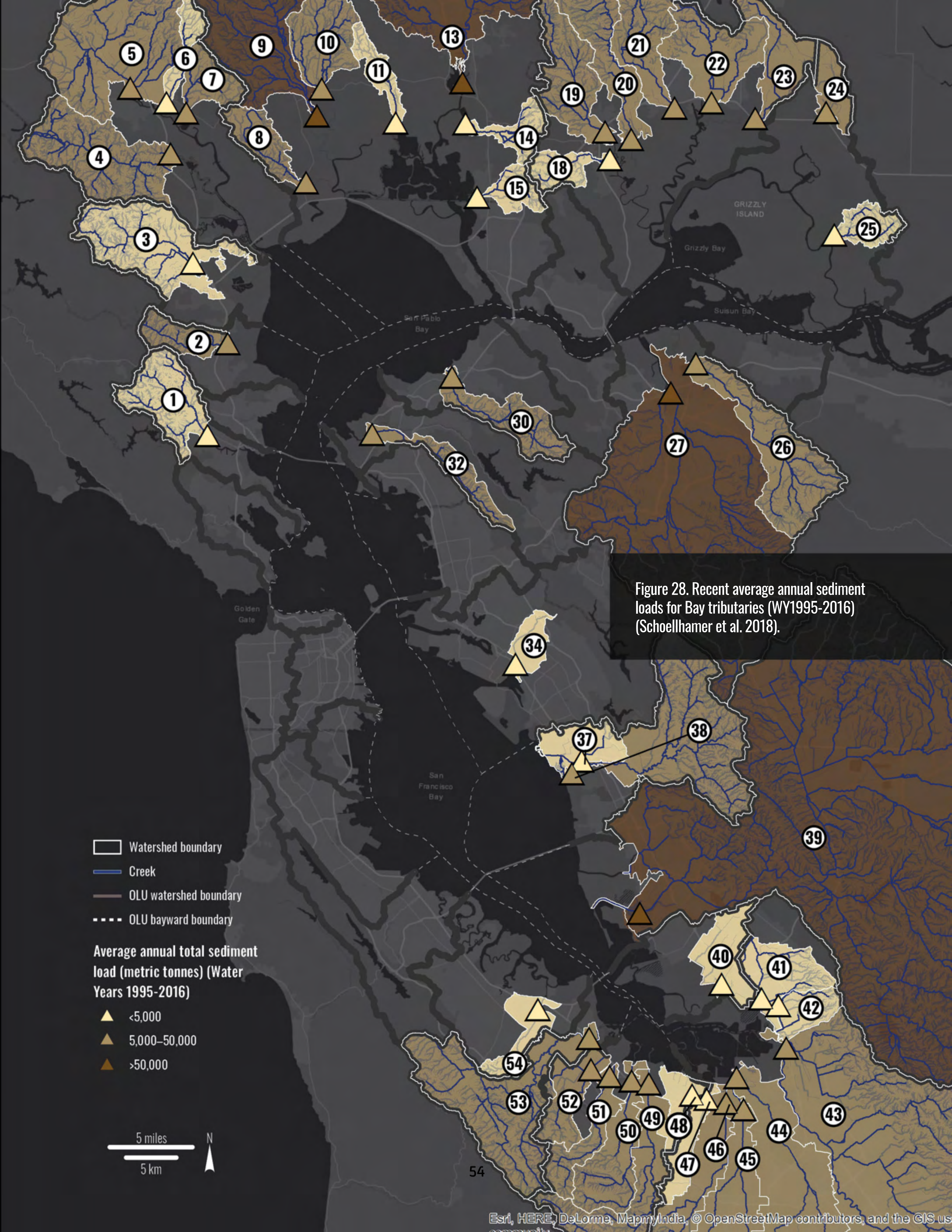


Figure 28. Recent average annual sediment loads for Bay tributaries (WY1995-2016) (Schoellhamer et al. 2018).

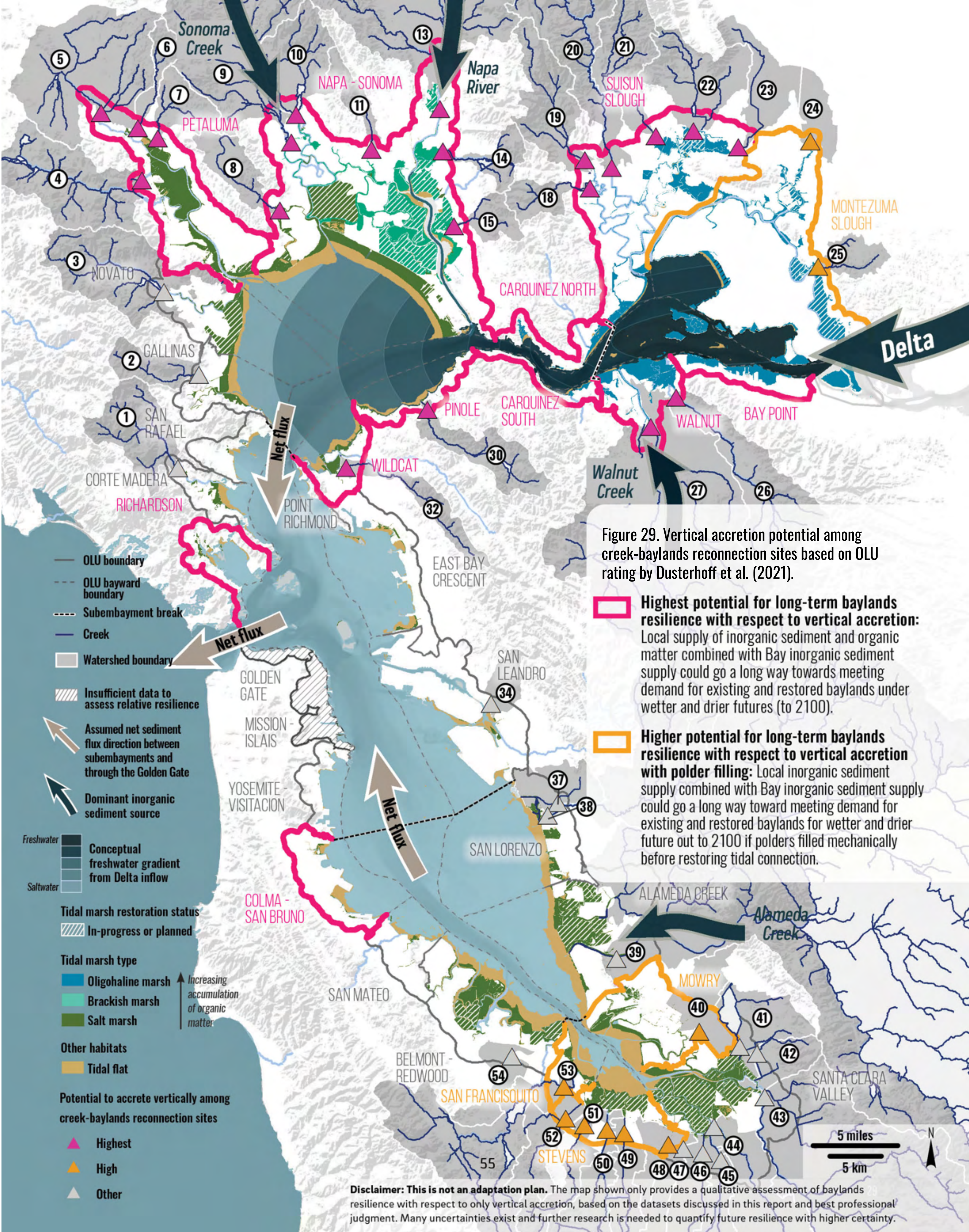


Figure 29. Vertical accretion potential among creek-baylands reconnection sites based on OLU rating by Dusterhoff et al. (2021).

Disclaimer: This is not an adaptation plan. The map shown only provides a qualitative assessment of baylands resilience with respect to only vertical accretion, based on the datasets discussed in this report and best professional judgment. Many uncertainties exist and further research is needed to quantify future resilience with higher certainty.

***Steelhead support -** Where are there opportunities to support steelhead?*

STEELHEAD HABITAT

Steelhead habitat is based on mapping from the BAOSC et al. (2011) (Figure 30). Channels classified as suitable winter steelhead habitat reflect observation-based, stream-level geographic distribution of anadromous steelhead trout (***Oncorhynchus mykiss irideus***) during winter months as evaluated for the nine county Bay Area. Creek-to-baylands reconnection sites ranked as "***steelhead observed***" are areas known or believed to be used by steelhead based on steelhead observations and therefore only contains positive occurrences of steelhead. Creek-baylands reconnection sites ranked as "***steelhead not observed***" does not necessarily rule out the possibility that steelheads use the channel (BAOSC et al. 2011).

Steelhead during a summer run in the Eel River (courtesy of John Heil, USFWS, PDM 1.0 DEED)

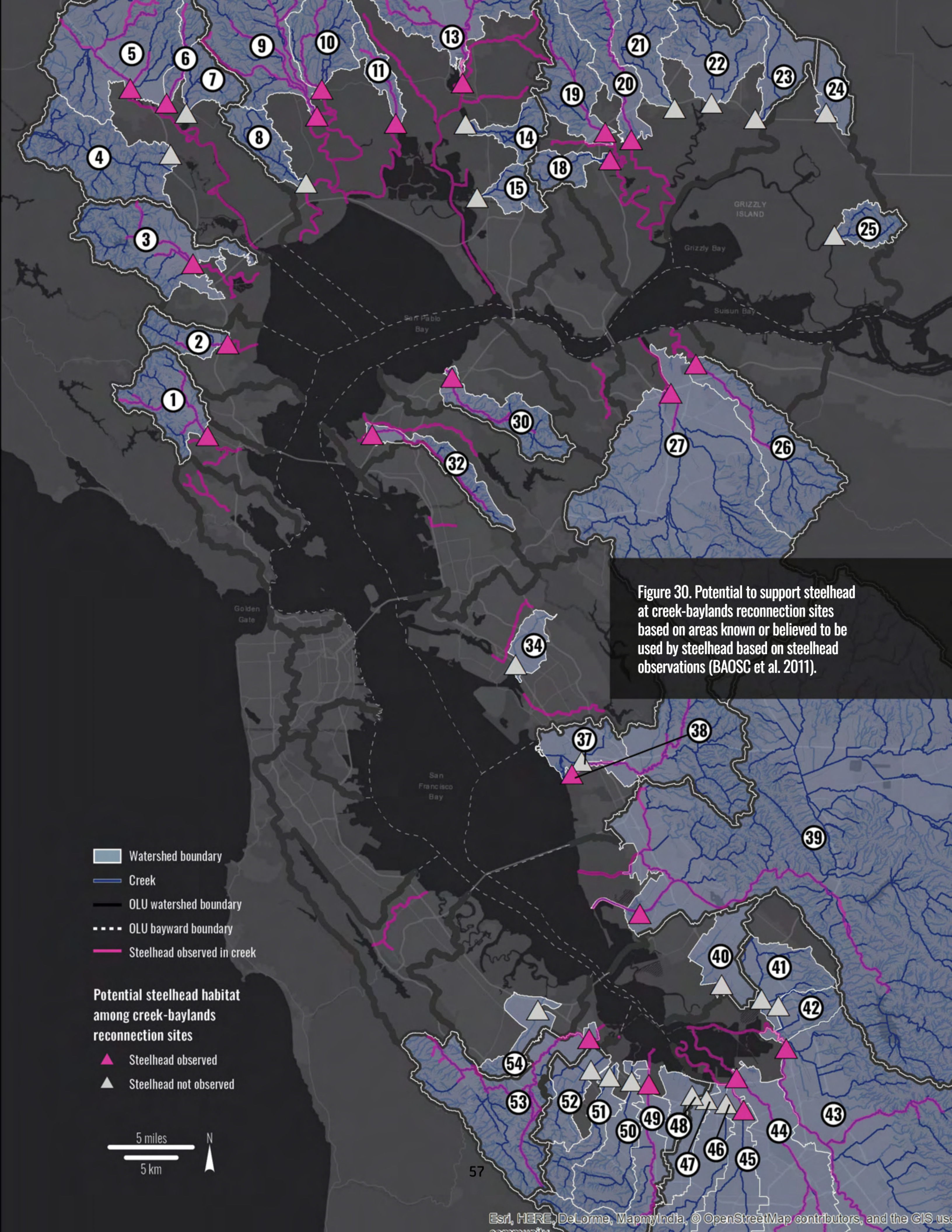


Figure 30. Potential to support steelhead at creek-baylands reconnection sites based on areas known or believed to be used by steelhead based on steelhead observations (BAOSC et al. 2011).

Table 1. Matrix of creek-to-baylands reconnection opportunities by OLU for selected creeks that drain to the Bay. Suitability ratings for each category are visualized using the circles below: a white circle indicates the lowest rating, a half gray circle indicates a medium rating, and a full circle indicates the highest rating. For more details on suitability ratings for each category, see pgs. 48–57. Note: Channels categorized as "channels with limited floodable space", as mapped on pg. 30, are not included in this matrix.

OLU Name	ID #	Creek Name	Opportunity type	Lateral resilience			Vertical resilience		Steelhead support
				Tidal marsh suitability (existing and potential)	**Marsh migration space suitability**	**Polder management suitability**	**Sediment supply** (average annual yield, metric tonnes)	**Vertical accretion** (potential ability to accrete vertically)	**Steelhead habitat** (Status of ***O. mykiss irideus***)
Corte Madera	1	Corte Madera Creek	Off-channel	Some ◐	Limited ○	Limited ○	2,800 ●	Other ○	Observed ●
Gallinas	2	Miller Creek	Realigned channel, Off-channel	High ●	High ●	High ●	5,800 ●	Other ○	Observed ●
Novato	3	Novato Creek	Realigned channel, Off-channel	Some ◐	Some ◐	High ●	4,100 ●	Other ○	Observed ●
Petaluma	4	San Antonio Creek	Realigned channel, Off-channel	High ●	High ●	Some ◐	28,800 ●	Highest ●	Not observed ○
	5	Petaluma River	Realigned channel, Off-channel	High ●	High ●	High ●	46,300 ●	Highest ●	Observed ●
	6	Adobe Creek	Realigned channel, Off-channel	Some ◐	High ●	Some ◐	3,600 ●	Highest ●	Observed ●
	7	Unnamed Sonoma County Creek	Realigned channel, Off-channel	Some ◐	Some ◐	Limited ○	6,400 ●	Highest ●	Not observed ○
Napa - Sonoma	8	Tolay Creek	Alluvial fan, Realigned channel, Off-channel	High ●	High ●	High ●	7,300 ●	Highest ●	Not observed ○
	9	Sonoma Creek	Alluvial fan, Realigned channel, Off-channel	High ●	High ●	High ●	143,600 ●	Highest ●	Observed ●
	10	Schell Creek	Alluvial fan, Realigned channel, Off-channel	High ●	High ●	High ●	12,900 ●	Highest ●	Observed ●
	11	Huichica Creek	Alluvial fan, Realigned channel, Off-channel	Some ◐	Some ◐	High ●	4,200 ●	Highest ●	Observed ●
	13	Napa River	Off-channel	High ●	High ●	Some ◐	168,000 ●	Highest ●	Observed ●
	14	Fagan Creek	Realigned channel, Off-channel	High ●	High ●	High ●	4,800 ●	Highest ●	Not observed ○
	15	American Canyon Creek	Off-channel	Some ◐	Some ◐	Limited ○	3,600 ●	Highest ●	Not observed ○

[Table 1 continued from previous page]

OLU Name	ID #	Creek Name	Opportunity type	Lateral resilience			Vertical resilience		Steelhead support
				Tidal marsh suitability (existing and potential)	**Marsh migration space suitability**	**Polder management suitability**	**Sediment supply** (average annual yield, metric tonnes)	**Vertical accretion** (potential ability to accrete vertically)	**Steelhead habitat** (Status of ***O. mykiss irideus***)
Suisun Slough	18	Unnamed Napa County Creek	Alluvial fan, Realigned channel, Off-channel	High ●	High ●	High ●	4,800 ●	Highest ●	Observed ●
	19	Green Valley Creek	Alluvial fan, Realigned channel, Off-channel	High ●	High ●	High ●	14,300 ●	Highest ●	Observed ●
	20	Suisun Creek	Alluvial fan, Realigned channel, Off-channel	High ●	High ●	High ●	34,800 ●	Highest ●	Observed ●
	21	Ledgewood Creek	Alluvial fan, Realigned channel, Off-channel	High ●	High ●	High ●	13,400 ●	Highest ●	Not observed ○
	22	Laural Creek	Alluvial fan, Realigned channel, Off-channel	High ●	High ●	High ●	13,100 ●	Highest ●	Not observed ○
	23	Union Creek	Alluvial fan, Realigned channel, Off-channel	High ●	High ●	Limited ○	6,700 ●	Highest ●	Not observed ○
Montezuma Slough	24	Denverton Creek	Alluvial fan, Realigned channel, Off-channel	High ●	High ●	High ●	5,600 ●	High ◐	Not observed ○
	25	Unnamed Solano County Creek	Alluvial fan, Realigned channel, Off-channel	High ●	High ●	High ●	4,900 ●	High ◐	Not observed ○
Walnut	26	Mount Diablo Creek	Realigned channel, Off-channel	High ●	High ●	Limited ○	8,600 ●	Highest ●	Observed ●
	27	Walnut Creek	Realigned channel, Off-channel	High ●	High ●	Some ◐	136,600 ●	Highest ●	Observed ●
Pinole	30	Pinole Creek	Off-channel	High ●	High ●	Limited ○	5,400 ●	Highest ●	Observed ●
Wildcat	32	Wildcat Creek	Off-channel	High ●	High ●	Some ◐	20,000 ●	Highest ●	Observed ●
San Leandro	34	Peralta Creek	Off-channel	Some ◐	High ●	Limited ○	1,500 ●	Other ○	Not observed ○
	37	Estudillo Canal	Off-channel	Some ◐	Some ◐	Some ◐	2,700 ●	Other ○	Not observed ○
	38	San Lorenzo Creek	Off-channel	High ●	Limited ○	Limited ○	18,900 ●	Other ○	Observed ●

[Table 1 continued from previous page]

OLU Name	ID #	Creek Name	Opportunity type	Lateral resilience			Vertical resilience		Steelhead support
				Tidal marsh suitability (existing and potential)	**Marsh migration space suitability**	**Polder management suitability**	**Sediment supply** (average annual yield, metric tonnes)	**Vertical accretion** (potential ability to accrete vertically)	**Steelhead habitat** (Status of ***O. mykiss irideus***)
Alameda	39	Alameda Creek	Off-channel	High ●	High ●	High ●	118,200 ●	Other ○	Observed ●
Mowry	40	Unnamed Alameda County Creek	Off-channel	High ●	High ●	High ●	2,300 ●	High ◐	Not observed ○
Santa Clara Valley	41	Laguna Creek	Realigned channel, Off-channel	High ●	High ●	High ●	3,800 ●	Other ○	Not observed ○
	42	Agua Fria Creek	Off-channel	High ●	Limited ○	Some ◐	2,400 ●	Other ○	Not observed ○
	43	Coyote Creek	Off-channel	High ●	Limited ○	High ●	10,800 ●	Other ○	Observed ●
	44	Guadalupe River	Off-channel	High ●	Limited ○	High ●	13,300 ●	Other ○	Observed ●
	45	San Tomas Aquino Creek	Realigned channel, Off-channel	High ●	Limited ○	High ●	29,500 ●	Other ○	Observed ●
	46	Calabazas Creek	Realigned channel, Off-channel	High ●	Limited ○	High ●	14,800 ●	Other ○	Not observed ○
	47	Sunnyvale East	Realigned channel, Off-channel	High ●	Limited ○	High ●	500 ●	Other ○	Not observed ○
Stevens	48	Sunnyvale West	Realigned channel, Off-channel	High ●	Limited ○	High ●	200 ●	High ◐	Not observed ○
	49	Stevens Creek	Off-channel	High ●	Limited ○	High ●	25,900 ●	High ◐	Observed ●
	50	Permanente Creek	Off-channel	High ●	Limited ○	High ●	19,000 ●	High ◐	Not observed ○
	51	Adobe Creek	Off-channel	High ●	Limited ○	Some ◐	11,700 ●	High ◐	Not observed ○
	52	Matadero Creek	Realigned channel, Off-channel	High ●	Limited ○	High ●	11,700 ●	High ◐	Not observed ○
San Francisquito	53	San Francisquito Creek	Realigned channel, Off-channel	High ●	Limited ○	Limited ○	24,500 ●	High ◐	Observed ●
Belmont - Redwood	54	Atherton Creek	Realigned channel, Off-channel	High ●	Limited ○	Limited ○	1,000 ●	Other ○	Not observed ○

5. Example Concept

To further advance the concepts described earlier, Suisun Creek was selected to develop high-level reconnection concepts suitable for the alluvial fan type because it is a lesser implemented type with high potential to yield multiple benefits. Suisun Creek has a vast amount of undeveloped floodable space that exists above and below head of tide, making it well suited for the alluvial fan type. In addition, Suisun Creek and its baylands have high potential for lateral baylands resilience, vertical baylands resilience, and steelhead support (see Table 1, pg. 59). This example serves as a reference to inspire and inform future action that combines multiple nature-based adaptation measures and creek-to-baylands reconnection types into a strategy to meet specific objectives, which could occur at this or similar suitable locations in the Bay Area.

Suisun Creek

Suisun Creek drains approximately 53 square miles of largely undeveloped land in Napa and Solano Counties within the Suisun Slough OLU (NCRCD 2008, SFEI and SPUR 2019, USGS 2023). The watershed has no incorporated cities and is largely open space and privately owned agricultural land used for cattle grazing and irrigated agriculture (i.e. vineyards, nut and fruit orchards, and row crops) (LMA 2004, 2010; Levy and Post 2010). Urban land uses comprise less than 5% of the watershed and impervious surfaces total less than 1% (USGS 2023). Suisun Creek flows into Suisun Slough and from there into Suisun Marsh and greater Suisun Bay. Suisun Marsh is the largest brackish-water marsh in California (Moyle et al. 2014), totaling roughly 100,000 acres (USBR et al. 2011). Its size and fresh-to-brackish salinity gradient makes Suisun Marsh an important habitat area of open space, tidal sloughs, and marshlands for many species of wildlife, including several federally listed, sensitive species (e.g., Delta smelt (***Hypomesus transpacificus***), salt marsh harvest mouse, Suisun shrew (***Sorex ornatus sinuousis***) (Moyle et al. 2014).

Historical setting

The gently sloping downstream reach of Suisun Creek probably had much more adjacent floodplain historically than it does today (Figure 31), before reaches were confined by levees and berms, likely with pools and riffles forming where floodwaters slowed and spread out (LMA 2004). Surficial quaternary geology shows alluvial fan deposits and natural levee deposits adjacent to the channel, indicating that the mouth of Suisun Creek spread out and deposited sediment before draining into the baylands (Knudsen et al. 2000). Grassland and wet meadow/

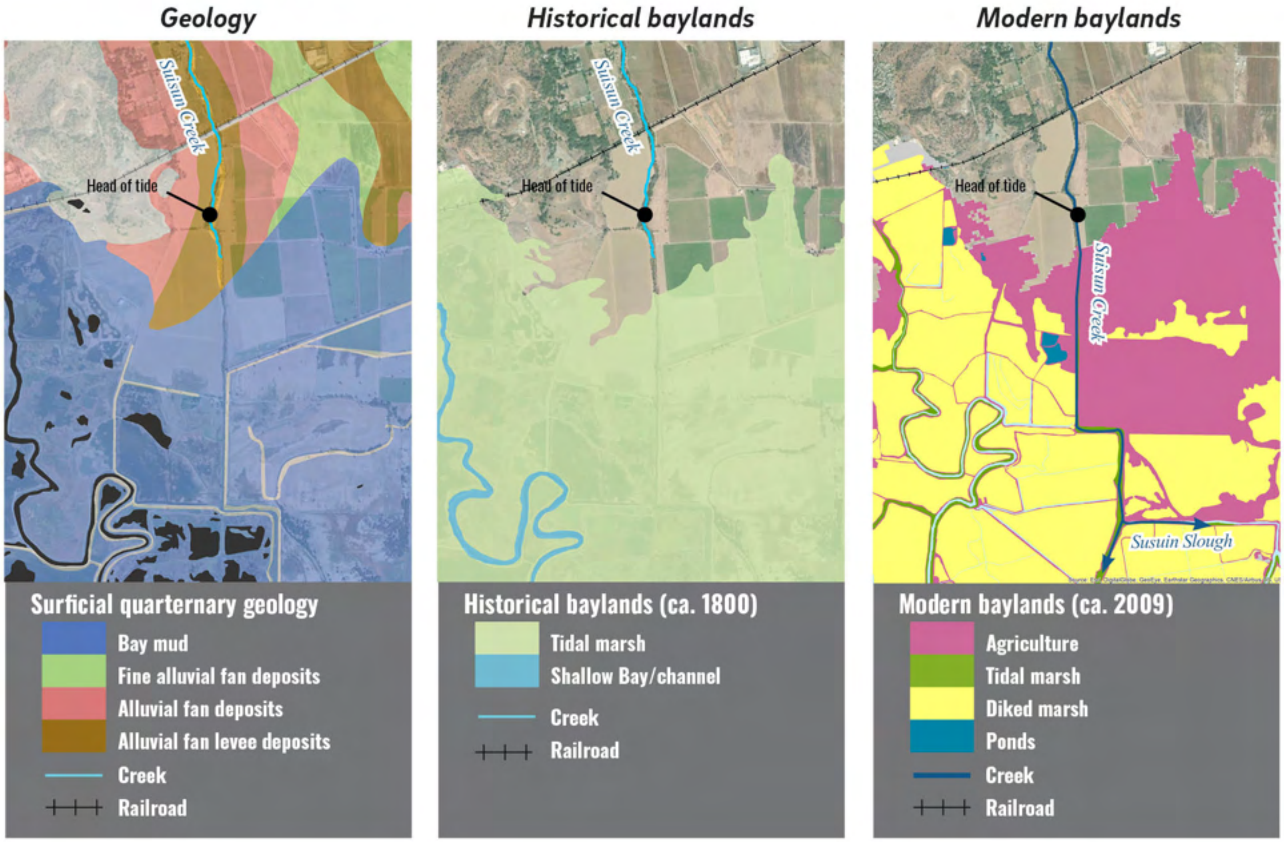


Figure 31. Suisun Creek generated alluvial fan and natural levee deposits, as mapped using surficial quaternary geology (Knudsen et al. 2000), over thousands of years, creating a repeated, distinctive pattern (left). Before the baylands were significantly altered by humans (ca. 1800), Suisun Creek fed an expansive tidal marsh complex (middle; SFEI 1998). Today, the baylands in this area are largely diked marsh and agriculture (Dusterhoff et al. 2017) with Suisun Creek conveyed around these areas by berms.

seasonal wetland habitats were found on Suisun Creek's alluvial fan adjacent to the extensive tidal marsh network of greater Suisun Marsh (Baumgarten et al. in prep). The brackish mixing zone between the creek mouth and the tidal marsh likely provided valuable ecosystem functions for wildlife (e.g. feeding and breeding). The higher elevation alluvial fan allowed wildlife to seek refuge during high tides and storm events. Suisun Creek probably also supported significant riparian habitat. The creek may have been an important rearing area for salmonids as well, depending on the availability and timing of cooler groundwater to the creek in the summertime (LMA 2004).

Modern setting

While the Suisun Creek watershed remains largely undeveloped, the land adjacent to the channel and the physical and ecological processes present have undergone notable changes (FIgure 31). Suisun Creek has one major dam which forms 377-acre Lake Curry, where the watershed's steep upper headwaters drain (NCRCD 2008, LMA 2004). The dam at Lake Curry affects the frequency and magnitude of flooding on Suisun Creek, reducing the frequency of flood flows and impacting stream morphology and sediment flows and delivery downstream (LMA 2004, NCRCD 2008). Downstream of Lake Curry, Suisun Creek flows for about 11.5 miles before draining through a series of levees and berms into a patchwork of diked marshes and managed ponds in western Suisun Marsh (LMA 2004; SFEI 2023b). Much of the tidal marsh that Suisun Creek historically drained into was either diked for use as duck hunting clubs (diked marshes and managed ponds) or diked and drained to support irrigated agriculture (Moyle et al. 2014).

Opportunities for reconnection

Contrary to most urban creeks and watersheds that drain to the Bay, the baylands downstream of Suisun Creek have high potential for both vertical sediment accretion and landward marsh migration. Both of these processes are curtailed by the restricted tidal flows to the marshes and ponds, and the unprotected open space at suitable elevations for marsh migration is vulnerable to land-use conversion. The land uses in Suisun Creek's downstream reach currently support agriculture and recreation (e.g. managed duck clubs), but climate change and sea-level rise may make these land uses less tenable over time. With a sediment supply of about 35,000 metric tonnes per year, opportunity exists to reconnect Suisun Creek to its alluvial fan and give the creek room to form distributary channels. Distributary channels could also be redirected to flow onto the diked marshes and managed ponds downstream, and over time these diked areas could be opened to full tidal action. This would create a node of fluvial-estuarine ecotone at the back end of the marsh and increase freshwater and mineral sediment supply to the baylands of Suisun Marsh. Additionally, contrary to most urban creeks and watersheds that drain to the Bay, the rural nature of the Suisun Creek watershed creates ideal conditions to improve and enhance aquatic and riparian habitats that, in turn, could support steelhead (***O. mykiss***) and other endemic species (LMA 2004; BAOSC et al. 2011). All in all, there is strong potential to create an area of high-value, resilient riparian, floodplain, transition zone, and tidal marsh habitat in this area.

Other considerations

Suisun Creek has benefited from numerous research efforts including a watershed enhancement plan (LMA 2004), a channel study (Jackson and LMA 2007), and a Riparian Habitat Enhancement Plan (CRP 2007). Coordination is needed to determine whether connecting Suisun Creek to its former alluvial fan and opening up the downstream diked marshes/ponds would align with near- and long-term plans underway in this area. Collaboration with local Tribes, landowners, and other partners would be needed early on to ensure reconnection concepts work with local priorities and other long-term adaptation plans that may exist.

The concepts described above would require purchasing adjacent agricultural lands and managed baylands or partnering with landowners to incorporate more space for Suisun Creek to spread out. Additionally, California Northern Railroad operates across Suisun Creek, just north of the proposed reconnection site. Flood modeling would need to ensure that changes in the creek alignment would not cause a backwatering effect on the creek or other creek-adjacent properties or properties upstream. Additional investigation of site-scale conditions such as legacy contamination and additional nearby infrastructure would also be needed.

Suisun Marsh (courtesy of California Department of Fish and Wildlife, CC BY 2.0)

EXAMPLE MEASURES FOR SUISUN CREEK

Numerous opportunities exist at the mouth of Suisun Creek to reimagine a landscape that allows the creek's natural physical and ecological processes to support the baylands (Figures 32 and 33). This example explores the types of nature-based adaptation measures that may be suitable to this area and, when combined, could offer a multifaceted approach to fostering more resilience within the baylands as the climate changes.

Matrix criteria	Suitability
Sediment	◐ 35,000 mt
Tidal marshes	● High
Migration space	● High
Polder management	● High
Vertical accretion	● Highest
Steelhead support	● Observed

Figure 32. Suisun Creek ranks high in lateral resilience, vertical resilience and steelhead support, making it a prime candidate for supporting baylands and wildlife into the future as sea level rises. For more information on suitability ratings, see pgs. 48–57.

Ⓐ **Alluvial fan reach:** Allow the creek to "fan out" by opening up space along the creek channel above head of tide where distributary channels could form. These channels could feed the back end of undeveloped land at suitable elevations for marsh migration as sea level rises.

Ⓑ **Marsh migration space reach:** This reach contains land adjacent to the channel that currently exists at suitable elevations to accommodate landward marsh migration as sea level rises. Opportunity exists to prepare these areas to accommodate tidal marsh in the future. The marsh migration space reach is identified by isolating undeveloped areas above the approximate elevation of today's highest astronomical tides and within the area expected to be inundated with 2.0 m of sea-level rise (SFEI and SPUR 2019).

Ⓒ **Tidal marsh restoration and polder management reach:** Some areas adjacent to the channel along this reach are at elevations suitable for tidal marsh vegetation to establish, but that are currently diked. Opportunity exists to return these areas to full tidal action and fluvial flows. Some areas in this reach are too low for tidal marsh vegetation to establish and could either be restored to tidal ponds, host floating wetlands, or filled with sediment before breaching. Creating a zone of tidal marsh, tidal ponds, and floating wetlands would create a full suite of habitat types that connect to greater Suisun Marsh.

Ⓓ **Ecotone levee area:** While not located along the channel, opportunity exists to incorporate an ecotone levee into a creek-to-baylands reconnection design at lower Suisun Creek. This area exists at proper elevation for tidal marsh and is both adjacent to urban development and wide enough to support a levee with a 1:30 slope (SFEI and SPUR 2019). An ecotone slope has potential to protect the berm fronting the railroad and provide high-water refuge for wildlife.

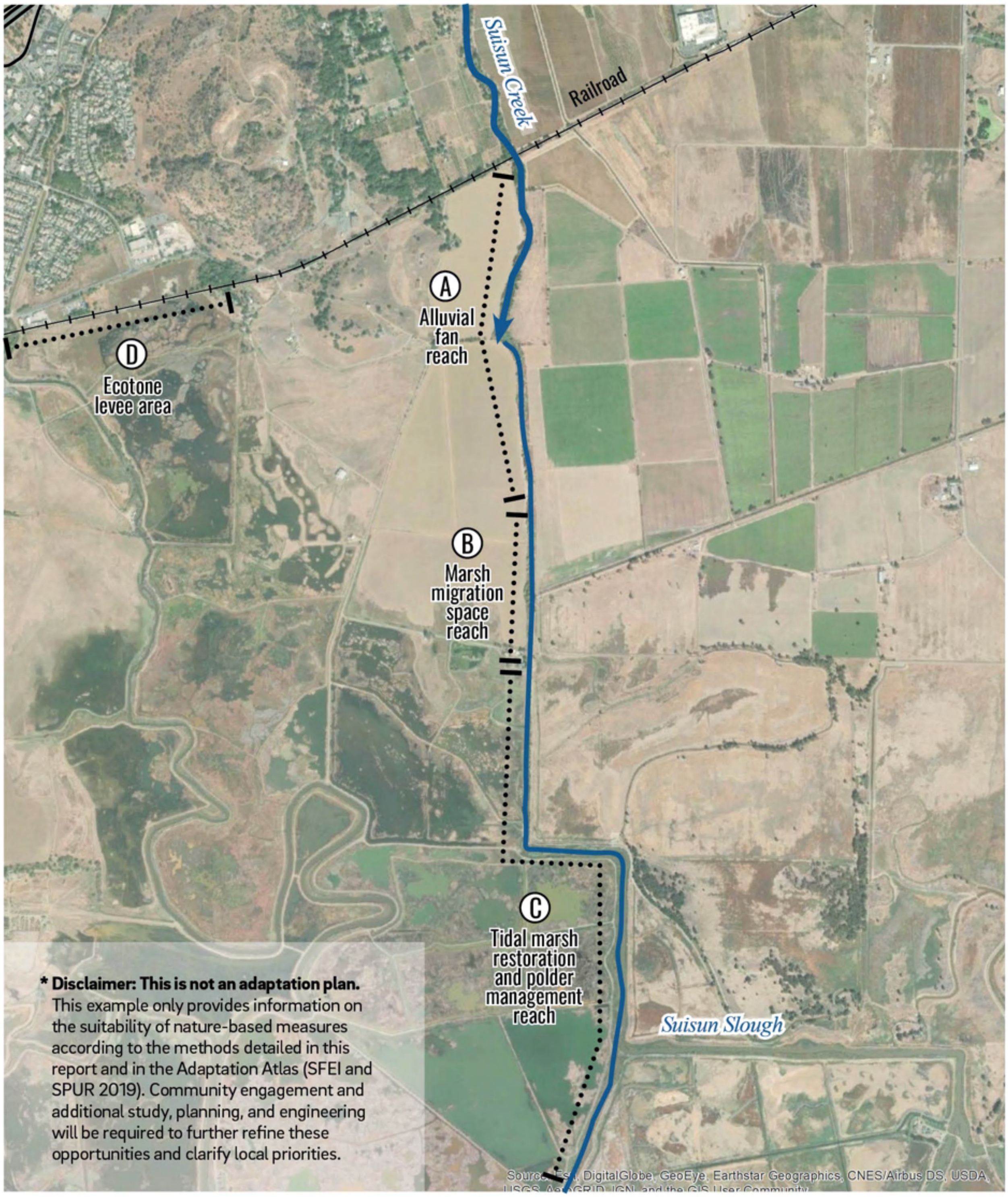


Figure 33. Example concept of alluvial fan reconnection along the lower reach of Suisun Creek. This concept entails reconnecting the channel's alluvial fan to the downstream baylands and restoring the fluvial-tidal transition zone. The concept would open up space along the creek channel above head of tide where distributary channels could form that feed the back end of undeveloped land at suitable elevations for marsh migration as sea level rises. The concept would also convert areas at elevations suitable for tidal marsh vegetation to establish, but that are currently diked, to tidal marsh. Areas that are below tidal marsh elevations could be restored to tidal ponds to create a full suite of habitat types that connect to greater Suisun Marsh. Additionally, an ecotone slope could be sited bayward of the railroad alignment to protect the railroad levee while also providing high-water refuge for wildlife.

6. Guidance

Creek-to-baylands reconnection efforts are essential for increasing the resilience of communities, infrastructure, and ecosystems to flooding, especially in the context of rising sea levels and increasingly intense storms. As shown in the example above, this strategy may be most effective when used in combination with other measures. Many challenges to implementation of creek-to-baylands reconnection projects exist and, without clear guidance, these projects may continue to move slowly. Here we outline some of the key considerations for creek-to-baylands reconnection projects, some of which have been extensively studied (e.g. permitting) but most of which are in need of additional study.

Permitting

Many of the permitting considerations relevant to creek-to-baylands reconnection projects overlap with considerations for tidal marsh restoration and broader ecological restoration projects. Most baylands habitat restoration and multi-benefit climate adaptation projects in the region must obtain permits from six different agencies: US Army Corps of Engineers, US Fish and Wildlife Service, National Marine Fisheries Service, California Dept. of Fish and Wildlife, San Francisco Bay Regional Water Quality Control Board, and San Francisco Bay Conservation and Development Commission. Each agency has its own statutory authority over different (and occasionally overlapping) environmental resources (e.g. fill in wetlands and waters, water quality, habitats, vegetation, fish and wildlife), and broadly speaking, their permitting processes aim to avoid, minimize, and if necessary compensate for adverse impacts to these resources. “Impacts” can be direct, indirect, and/or cumulative in nature, as described in SF Bay Regional Water Board, 2019:

> *“Direct impacts to wetlands generally include instances in which a wetland is impacted by an activity at the same time and location as the activity, whereas indirect or secondary impacts are instances where a wetland is impacted on a different spatial and/or temporal scale as the activity. For example, building a levee around a tidal wetland not only results in direct impacts to the wetland underneath the footprint of levee fill; it also results in indirect/secondary impacts to the non-filled wetland inside the levee by isolating it from the tidal processes (tidal flows, sediment deposition, etc.) that sustain the wetland. Cumulative impacts are the incremental (direct and/or indirect) impacts of an activity considered together with the impacts of other past, present, and reasonably foreseeable future activities implemented by a discharger and other entities. Cumulative impacts can result from individually minor but collectively significant activities that take place over a period of*

time. For example, the impact from a small shoreline hardening project may be minor, but the cumulative impacts of multiple shoreline hardening projects within a region over time are likely to be significant."

When assessing the potential adverse impacts of projects on environmental resources, regulatory agencies usually consider the likely spatial and temporal scales of impact, as well as the likelihood that impacts will be offset by benefits to resources. The dynamic nature of coupled creek-baylands habitats, and the variable ways in which they can respond to climate change, can introduce considerable uncertainty into these assessments. It is difficult if not impossible for most creek-to-baylands projects to avoid at least near-term, site-scale impacts to environmental resources (for example, temporary impacts to vegetation communities as they shift from diked baylands species assemblages to tidal marsh assemblages). However, using the guidance in this report and related resources, project advocates can develop designs that work with natural processes and the influence of climate change. These designs can offset near-term impacts by supporting long-term, landscape-scale benefits to those same resources.

Birdseye view of the Petaluma River (courtesy of Phliar, CC BY-SA 2.0)

Chapter 2 of this document lists many of the benefits that might be described (and possibly quantified) as part of the project development and permitting process. Emphasizing the long-term resilience benefits of restoring watershed-tidal marsh connections is critical. Cumulative elevation gains from freshwater and sediment inputs over the years increase the likelihood of tidal marsh persistence in the context of sea-level rise. Regional studies and collaborative planning efforts have made it clear that restoring connections to natural sediment sources early this century is key to achieving regional tidal marsh restoration targets (Goals Project 2015, Dusterhoff et al. 2021). Providing as much information as possible about project benefits and tradeoffs during the permitting phase can help regulators in the decision-making process. There are multiple resources that can help project proponents demonstrate these benefits in their permit applications, including:

- Wetland Fill Policy Challenges and Future Regulatory Options: Findings and Recommendations (Water Board 2019)
- Bay Fill for Habitat Restoration, Enhancement, and Creation in a Changing Climate: Staff Report (BCDC 2019)
- Aquatic Resource Type Conversion Framework Version 2.0 (Stein et al. 2022)
- Advancing Ecosystem Restoration with Smarter Permitting: Case Studies from California (Grenier et al. 2021)
- Regulatory Pathways for Nature-Based Solutions (SFEP in prep): https://www.sfestuary.org/regulatory-pathways-for-nbs/

The addition of new freshwater inputs may affect wildlife in salt or brackish marshes, diked marshes, or other habitats where creeks have been redirected. In many cases, these freshwater inputs will likely enhance habitat complexity, recreating freshwater to saltwater marsh gradients that historically existed along the estuary's margins and providing productive brackish mixing zones. However, the addition of freshwater to salt marshes may have adverse impacts to some salt marsh species, including the endangered California Ridgway's rail, which prefer saline marsh habitat to brackish marsh. Near- and long-term benefits and tradeoffs need to be assessed on a site-by-site basis and within the landscape context. For example, in some areas vegetation shifts driven by creek-baylands reconnection may be offset by the development of more "complete" marsh habitats that are more diverse and resilient to climate change, benefitting species like Ridgway's rail in the longer term.

Flooding impacts

Hydrodynamic modeling of alternatives to determine potential flooding impacts and benefits is essential. Tidal restoration projects need to consider the communities or infrastructure at the back of the marsh that may need to be protected from flooding from the Bay. Often, setback levees are constructed to facilitate restoration projects. Creek-to-baylands reconnection projects also need to consider how changing the route or floodplain of creek channels may affect upstream flooding. Rerouting creeks has the potential to reduce upstream flooding, but may also increase upstream flooding if not carefully designed to avoid this outcome. The Coyote Creek-Bothin Marsh project described in Chapter 2 is an illustrative example. Hydrodynamic modeling should be done early in the project planning process and designs adjusted if necessary to ensure there are no adverse flooding impacts. As in the Coyote Creek example, designs can be adjusted to ensure this outcome; however, this may result in tradeoffs for other project objectives. For Coyote Creek, this required compromises on the desired channel sinuosity and sediment delivery.

Erosion impacts

Erosion is another concern when developing creek-to-baylands reconnection projects. Increasing tidal prism may cause erosion, or scour, of downstream fringing marshes within creek channels. In some watersheds, these fringing marshes are all that remains of once-extensive historical marsh complexes. Scour of these marshes would be detrimental not only to wildlife but also to the restoration process as a whole, because they provide important source populations for recolonization. In the development of the Sonoma Creek Baylands Strategy, the erosion challenge was addressed by suggesting that creek reconnections be routed through new channels in existing diked baylands rather than through existing channels.

Design specifications

There are also a number of physical considerations in the design of creek-to-baylands restorations that can help increase or maximize desired fluvial to tidal marsh channel development and ecosystem and human benefits. For example, for projects aiming to maximize sediment delivery to baylands, appropriately sizing channels is a key consideration. Tidal channels should be of sufficient size and density to convey suspended and coarse sediment to landward portions of the marsh. Trapping efficiency of sediment can be increased using plantings, sedimentation fences, and by ensuring waters remain on the surface for a sufficient period of time (Goals Project 2015). Special consideration should be given in the design phase to ensure protection of public and ecosystem health in locations where adding or moving channels may impact contaminated sites or infrastructure. For example, if a channel is located close to infrastructure or contaminants, green or gray armoring may be necessary to reduce the likelihood of erosion, unless the infrastructure or contaminants are adequately buried below the deepest point of the channel or far enough from the erosive outer bends of channels.

Monitoring and reporting

Many off-channel creek-to-baylands reconnection projects have been successfully implemented in the Bay Area (Williams and Orr 2002, PWA and Phyllis M. Faber 2004). However, the first distributary channel and realigned channel restorations are in the planning stage. In-depth monitoring and reporting on lessons learned from the permitting and implementation processes of these and future projects will be essential, especially as novel reconnection strategies are tested. Advance planning is needed to ensure sufficient monitoring coverage beyond the required permit conditions, which often end five or ten years after restoration. This will require early coordination with the Wetlands Regional Monitoring Program (WRMP) to facilitate a smooth handoff of monitoring responsibilities from the project to the regional program. The WRMP will facilitate integration of lessons learned into a regionwide wetland monitoring and restoration framework. Lessons learned from both successful and unsuccessful cases are useful. As regulations shift over time to accommodate rapid changes in the baylands due to sea-level rise, it may be worth revisiting infeasible or low-priority projects to determine if they now may be more desirable given shifts in priorities.

Monitoring bird activity at China Camp Marsh (photo by Sarah Pearce, SFEI)

Participatory planning

Creek-to-baylands reconnections need to solve local problems and achieve local priorities. Creating an inclusive participatory process with Tribes, communities, land owners, flood-risk managers, restoration practitioners, and other project partners early on and throughout the planning process is paramount. What are the local priorities at each creek-to-baylands reconnection site, which priorities are essential to achieve, and which can be adjusted as tradeoffs are better understood? How can these types of restorations meet local and regional goals and deliver multiple benefits with respect to flooding, habitat, recreation, and more? Development of an OLU-scale working group is needed to ensure the voices of all stakeholders are heard, particularly those of local landowners and community members, and stakeholders from state, regional, tribal, and local agencies. A few useful resources to guide participatory planning include the National Association of Climate Resilience Planner's Community-Driven Climate Resilience Planning framework and BCDC's Environmental Justice policies and practices website.

Early coordination with permitting agencies

To accelerate project implementation, partnering with regulators early on and throughout the planning process is critical, so that all concerns and options are understood and accounted for. Regulators want to adapt the Bay Area to climate change in a way that supports our valued and protected ecosystems and upholds current regulations. Engaging regulatory staff early and often as partners on the project gives them chances to weigh in and refine the approach in ways that may expedite the permitting process later in a project. Such alignment avoids costly efforts to redo proposed construction designs or other planning documents. A successful example of this process is the work conducted in 2019 on Butano Creek and Pescadero Marsh (see an overview of this case study below as well as the Appendix (pg. 83) for a more detailed description). Additionally, efforts like Cutting the Green Tape and the Bay Restoration Regulatory Integration Team (BRRIT) are also focused on improving permitting and may have additional resources to help inform the permitting process for creek-to-baylands reconnections.

Drone photo of Butano Channel as restoration activities begin (courtesy of San Mateo RCD)

Drone photo of Butano Channel as restoration activites near completion in the fall of 2019 (courtesy of San Mateo RCD)

OVERVIEW OF THE BUTANO CHANNEL RESTORATION AND RESILIENCY PROJECT

Written by Kellyx Nelson and Jim Robins (San Mateo Resource Conservation District)

Pescadero Marsh in southern coastal San Mateo County is bar-built estuary with a 275-acre coastal wetland formed at the confluence of Pescadero and Butano creeks with a history of land disturbance that has caused considerable problems. Historical logging, creek channelization, road construction, agriculture, and development dramatically increased the volume of sediment entering and depositing within the channel network. These disturbances resulted in excess flooding during the wet season, anoxic water conditions in the tidal marsh during the dry season, and decreased access for steelhead trout and coho salmon (***Oncorhynchus kisutch***) to critical spawning and rearing habitat. For decades, there were opposing perspectives on the best way to address the problems caused by increased sedimentation, with the overall thought that flood mitigation and environmental protection were mutually exclusive.

After years of working to build trust and a shared vision across a diverse array of stakeholder, the San Mateo Resource Conservation District, California State Parks, scientists, local residents, and regulatory agency representatives were able to develop a multi-benefit restoration approach for lower Butano Creek that restored fish passage between the lagoon and the watershed, provided an escape route for fish during poor water quality conditions, reduced anoxia by enhancing freshwater circulation, and reduced flooding of the road and adjacent properties. The Butano Channel Restoration and Resiliency Project resulted in the removal of 45,000 cubic yards of sediment to re-establish 8,000 feet of the historic creek channel and beneficial reuse of that sediment to restore 28 acres of degraded freshwater and tidal marshes. The process was facilitated explicitly to ensure that all voices were heard—from residents to agency staff—and that all methods, findings, and recommendations were written for a broad audience. Finding common ground across diverse stakeholders led to a superior and more widely accepted project design. This resulted in the Project completing all California Environmental Quality Act (CEQA) requirements and permitting in eight months in an area known to support protected species including coho salmon, steelhead trout, tidewater goby (***Eucyclogobius newberryi***), California red-legged frog (***Rana draytonii***), and San Francisco garter snake (***Thamnophis sirtalis tetrataenia***). The Project rapidly secured nearly 7 million dollars in local, state, and federal funds. The project broke ground in October 2018 and was completed within a year. Not only did the project accomplish its goals regarding fisheries and flooding, it fostered collaboration among diverse stakeholders, community confidence in government, and helped people shift to a belief that wins for the community can be wins for the environment. This partnership and sense of collaboration is still going strong with local landowners, resource agency staff, and State Parks continuing to work on projects throughout the watershed that will increase the longevity and value of this Project and create lasting benefits for the watershed and all of its inhabitants. For more information on the Butano Channel Restoration and Resilience Project, see Appendix (pg. 83).

Kellyx Nelson, Executive Director of San Mateo RCD, speaking at the community kickoff celebration for the Butano Channel Restoration and Resiliency Project in 2019 (photo courtesy of San Mateo RCD)

Financial pathways

As with any type of restoration, adequate funding to plan, implement, manage, and monitor creek-to-baylands reconnection projects is essential. Thus, an understanding of financial pathways to implement and accelerate efforts for more resilient baylands is needed. A list of targeted funding opportunities that crosswalks how a creek-to-baylands reconnection project meets funder criteria would help catalyze more momentum among practitioners. A list that outlines local, regional, and federal funding opportunities would help make these types of projects more surmountable.

Aerial view of Sonoma Baylands near Highway 37 (photo by Micha Salomon, SFEI)

7. Next steps

While great strides have been made with tidal marsh restoration and channel enhancements in the Bay Area, there are still few examples of implemented creek-to-baylands reconnection projects. More effort is needed to establish best practices and create implementation pathways that increase baylands resilience to climate change while benefiting people and wildlife. Here we outline next steps that would result in more creek-to-baylands reconnections and tangible gains for the Bay's ecosystems and communities.

***NEED:* Assessment of all Bay Area watersheds and more in-depth analysis of benefits, risks, and tradeoffs to help drive decision making.**

***ACTION:* Refine opportunity mapping and benefit analysis at the regional and OLU scales.** This analysis examined 47 creeks, a fraction of the creeks that drain into the Bay. Watersheds of all sizes offer potential to support baylands, so opportunity mapping should extend to all watersheds that drain to the Bay. Matrix criteria should include additional considerations to evaluate more benefits, risks, and tradeoffs, including: (1) the role and magnitude of freshwater in building organic matter and restoring brackish ecotones and corridors; (2) a flood-risk metric based on channel profile; (3) the magnitude and frequency of sediment removal in flood-control channels to identify projects that might result in long-term cost-savings and flood-risk reductions; and (4) more aquatic and terrestrial native species to plan for a broader suite of wildlife. In addition, more work can be done for creeks identified as "channels with little floodable space" to refine the suite of possible enhancement actions for these highly urbanized channels.

***NEED:* A blueprint for how to restore fluvial-tidal habitats with climate change in mind.**

***ACTION:* Create design and engineering guidelines and best practices for reconnection concepts that are less studied or have yet to be implemented in the Bay.** More specific implementation guidance is needed to catalyze distributary channel and realigned channel reconnection projects in the Bay. For example, what design/engineering strategies would support alluvial fans and distributary channels at the mouths of Bay channels where adequate open space exists? What are appropriate design/engineering strategies to realign creek mouths to deliver more sediment directly onto baylands, and what factors could influence the timing and duration of delivery (e.g. blocking channels to certain flood stages, the building of ebb deltas over time)? Lessons learned should be collected from reconnections in similar estuaries through literature review, interviews, and other means. In addition, design strategies should be developed based on how reconnection design influences sediment inflows from newly connected creeks to maximize tidal marsh accretion. For example, design strategies may explore reconnecting creeks in a way that directs sediment to the landward edge of a site versus directing sediment across the full site, or a design strategy might consider adding roughness (e.g., baffles, low points) to site designs to effectively decant flows, leaving behind sediment at specific locations. A meta-analysis of flood models created for creek-to-baylands reconnection projects could inform the identification and design of future projects by analyzing how landscape conditions affect flood reduction outcomes. For example, projects in watersheds with steep headlands and narrow valleys may have different flood reduction outcomes than projects in wide alluvial valleys. Further study is needed to determine how the wide array of design parameters interacts with landscape conditions to drive changes in upstream water surface elevations.

***NEED:* Coordination at subregional scales to drive holistic solutions and maximize resources.**

***ACTION:* Plan at the OLU scale in a way that integrates across ecosystems and brings together Tribes, communities, and other project partners, planning across the entire OLU—from ridge line to shallow Bay—and between reconnection opportunities.** A new effort funded by the San Francisco Bay Regional Water Quality Control Board moves planning at the OLU scale into watersheds, focusing on watershed management actions that support long-term riparian area resilience with input from stakeholders. Planning at the OLU watershed scale will lead to a cohesive long-term strategy that follows nature's boundaries while maximizing resources. For example, urban creek restoration projects often require sediment excavation to create floodplains which expands riparian habitat, adds complexity to the channel-floodplain corridor, and maintains or reduces flood risks. Excavating adjacent to a channel generates earthen material that could be matched with creek-to-baylands reconnection projects downstream in need of fill to raise subsided baylands to intertidal elevations. Strategic resource sharing would solve a sediment surplus and sediment deficit in the same channel or within the OLU, reducing storage and transport costs. There should be a focus on regular coordination between flood control agency staff and regulatory agency staff to discuss ways to increase these types of projects. The meetings of the Bay Area Flood Protection Agency Association could be a good venue for such conversations.

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9. Appendix

NARRATIVE OF THE BUTANO CHANNEL RESTORATION AND RESILIENCY PROJECT

Written by Kellyx Nelson and Jim Robins (San Mateo Resource Conservation District)

Pescadero Marsh in southern coastal San Mateo County is renowned for its beauty and biodiversity, notorious for its high-profile challenges in terms of frequent flooding and mass fish mortality events, and celebrated for recent successes and innovations overcoming decades of acrimony regarding its management.

Pescadero is Spanish for fishmonger, an indication of the historic abundance of coho salmon and steelhead trout that not only made it a key fishing location for native peoples, but led to its destination status for San Francisco fishermen in the late 19th century. It is the largest tidal marsh between Elkhorn Slough and San Francisco Bay, and home to many rare, threatened, and endangered species. Pescadero and Butano Creeks flow through 8,000 acres of publicly and privately owned lands from their headwaters in the mountain redwood forests to their convergence in the 235-acre Pescadero Marsh Natural Reserve. Much of the habitat was degraded or eliminated due to land use changes and water management practices in the last 150 years

Watershed management has direct implications for the community that was built in the Pescadero Creek and Butano Creek floodplain in the early 1800s. Historical logging, channelizing creeks, road construction, agriculture, and development dramatically increased the volume of sediment entering the channel system. By the early 1990s Butano Creek had largely filled with sediment where the creek entered the marsh. Large portions of the channel literally ceased to exist and transitioned from creek to forest. It was nearly impassable for fish, including steelhead trout and coho salmon that could no longer complete their ancestral migration to critically needed habitat for spawning, rearing, and refuge. Butano Creek flows seeped under the marsh surface, flowing through oxygen-depleted marsh soils, and stagnated in deep borrow pits with little or no oxygen. The resulting anoxic water caused devastating mortality events when lagoon mouth breached in late fall or early winter in which large numbers of steelhead trout suffocated nearly annually. The creek's inability to carry water also caused chronic flooding, even in very small rain events. The flooding of the road into town disconnected the community from its main access route as well as emergency services, while damaging farm fields, homes, and businesses. Regular road closures severely impacted the tourism-fueled community, where even the perception that the road may be closed can harm commercial activity.

The flooding and fish kills garnered significant media attention. Community members formed a non-profit organization to sue agencies over the fish kills. The National Marine Fisheries Service (NMFS) described the Pescadero estuary as "impaired and nonfunctional" in its recovery plan for Central Coast coho salmon (NMFS 2012). The watershed was listed under the Clean Water Act as impaired by sediment, enraging some locals who perceived the focus to be on regulating them rather than addressing their concerns. Some called for a return to the routine dredging and levee construction that local farmers conducted in the decades before State of California acquired the property that is now the Natural Preserve- also before the passage of the Endangered Species Act, Clean Water Act, and California Coastal Act. Some local residents conducted guerilla activities to change the hydrology in and around the marsh, including on State property. Highly polarized positions were taken, demanding a choice be made between community and species protection.

For decades, these issues were documented, discussed and debated. There were contentious community meetings, facilitated workshops with scientific presenters, and technical working groups of agency staff with limited tangible results. The prevailing wisdom was that flood mitigation and environmental protection were mutually exclusive, perpetuating a perception among local residents, State Parks, resource agencies, and elected officials that common ground could not be found. "It can't be done," or "they won't let us do it" were common refrains about dredging Butano Creek through a natural preserve inhabited by multiple protected species. With seemingly intractable problems, polarized perspectives, and a history of litigation, high-profile funders said restoration was hopeless and that they would "not invest another nickel."

There was a clear need to take meaningful action grounded in shared purpose and shared understanding to overcome three decades of conflict and paralysis. It would require a high level of collaboration and trust-building rooted in honesty, authenticity, and transparency. It would require good science and also knowing when to overcome "analysis paralysis" and proceed with action. It would involve vulnerable conversations about risks and tradeoffs. And, ultimately, it would result in the 2019 Butano Channel Restoration and Resiliency Project that removed 500 riparian trees and 45,000 cubic yards of sediment to re-establish 8,000 feet of the historical creek channel and beneficially reuse the sediment to restore 28 acres of marsh. The project restored fish passage between the lagoon and the watershed, provided an escape route for fish during poor water quality conditions, reduced anoxia by enhancing freshwater circulation, and reduced flooding of the road and properties (https://www.sanmateorcd.org/project/butano-creek-reconnection-project/).

In 2013, the San Mateo Resource Conservation District (RCD) initiated an effort to identify integrated solutions to flooding and habitat restoration with funding from the California Department of Water Resources, County of San Mateo, and US Fish and Wildlife Service. The RCD created a stakeholder process that involved deep listening, town hall meetings that lasted as late as they needed to hear every voice, meeting people in their homes, and creating an advisory group that included local residents, scientists from academia, and technical staff from state and federal resource agencies. The process was facilitated explicitly to ensure that everyone was heard and that all methods, findings, and recommendations were available in layperson language. The inclusive effort resulted in a broadly supported report prepared by in 2014 (cbec eco engineering and Stillwater Sciences 2014) that recommended four solutions: upland sediment control, upstream floodplain restoration, addressing flow capacity at the road, and restoring a channel in the marsh.

In a parallel process, the Pescadero Lagoon Science (PLS) Panel was commissioned by the California Department of Parks and Recreation (Parks) and California Department of Fish and Wildlife (CDFW) to help inform understanding of the fish kills. Their 2015 (Largier et al. 2015) report contained the first comprehensive assessment and conceptual model for key physical processes. At the same time, the San Francisco Bay Regional Water Quality Control Board was developing its Total Max Daily Load (TMDL) and published the first comprehensive accounting of erosion sources and sediment movement in the watershed (BalanceGeo 2015). This work provided an eye-opening historic perspective on watershed change and help create a shared understanding of how land use practices and sediment directly impact the health of the marsh.

Building on all these efforts, the RCD formed the Pescadero Technical Roundtable in 2015 and brought together decision makers and technical experts from the agencies and the scientist who led the State's PLS Panel. The Roundtable leveraged partnerships that had been forged in the Integrated Watershed Restoration Program, a decades-long, trust-based, highly collaborative conservation planning effort funded by the Coastal Conservancy and convened by three Resource Conservation Districts. The Roundtable brought in new energy and voices that were less entrenched in disagreements of the past, a sense of urgency for taking action, and catalyzed culture change in decision-making regarding Pescadero marsh. The RCD worked to ensure that the Roundtable's studies and project development were both transparent and iterative – regularly bringing information to public meetings and sharing with the Roundtable, that grew from six members to nearly twenty by 2017. Data from these various efforts coupled with keen observations from local residents, and a multi-benefit project started to come into focus.

As the saying goes, "Never let a crisis go to waste." A massive fish kill in November 2016 was followed two months later with town flooding. Politicians took notice and local residents were at their wits' ends. Fortunately, the Roundtable and community were coalescing on a series of project alternatives. As the pressure for solutions hit an all-time high, the shared vision, understanding and trust that had been nurtured parlayed into action. The idea of dredging Butano Creek had become feasible.

Out of these twin crises, strong relationships, and shared technical understanding arose the sentiment that doing nothing was substantially riskier than doing something. With support from technical consultants, local residents, and the Roundtable, the RCD and State Parks developed a dredge project that spanned State, County and three private properties and would to improve fish passage, water quality, and reduce flooding of Pescadero Creek Road. But what to do with all of that sediment that a dredging project would generate? In a eureka moment, the team realized that it could be beneficially reused onsite to reverse and repair some of the altered hydrology contributing to the fish kills, in particular filling old borrow pits and relic drainage channels.

Finding common ground across diverse stakeholders led to a superior project design that was broadly supported. This resulted in the project completing CEQA and all permitting in eight months, despite the fact that the area supported protected species including coho salmon, steelhead trout, tidewater goby, California red-legged frog, and San Francisco garter snake. The project rapidly secured seven million dollars from diverse sources including County general fund dollars, a state funding earmark, and grant funding from the NOAA Restoration Center. Four years later, we can state that not only did the project accomplish its goals regarding fisheries, water quality, and flooding, it also built collaborative capacity among diverse stakeholders, restored community confidence in government, and helped people shift to a belief that wins for the community can also be wins for the environment. The non-profit that had formed to litigate dissolved and its leader donated to the RCD for results-oriented collaboration. The RCD, together with State Parks, residents and resource agency that helped make this project happen, continue to partner today are continuing to advance floodplain restoration and address upland sediment sources at a watershed scale.

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