October 6, 2025

San Rafael Sea Level Rise Adaptation Planning Project

Community Informed Technical Feasibility Study

Project Task *2.4 Refine and analyze list of adaptation measures based on community input*
Consultant Team Scope Task *A.3 Technical Feasibility Study*

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Coastal Conservancy

This project is made possible with funding from the California State Coastal Conservancy.

The California State Coastal Conservancy is a California state agency, established in 1976, to protect and improve natural lands and waterways, to help people get to and enjoy the outdoors, and to sustain local economies along California's coast. It acts with others to protect and restore, and increase public access to, California's coast, ocean, coastal watersheds, and the San Francisco Bay Area. Its vision is of a beautiful, restored, and accessible coast for current and future generations of Californians.

The place we now call San Rafael is located on the traditional lands of the Coast Miwok people. We acknowledge the Coast Miwok People with respect and reverence. We express our gratitude for their generations of stewardship while not forgetting the colonization of this land.

Table of Contents

i. Abbreviations and Acronyms

AE Zones	The base FEMA floodplain where base flood elevations are provided.
BayWAVE	Bay Waterfront Adaptation Vulnerability Evaluation
BCDC	Bay Conservation and Development Commission
BFE	Base Flood Elevation
Caltrans	California Department of Transportation
C-CAP	Coastal Change Analysis Program
ESA	Environmental Science Associates
EIR	Environmental Impact Review
FEMA	Federal Emergency Management Agency
FFL	Finished Floor Level
FIMA	Federal Insurance and Mitigation Administration
GIS	Geographic Information Systems
HAZUS	Hazards United States
HEC-RAS	Hydrologic Engineering Center River Analysis System
H&H	Hydrologic and Hydraulic
JEC	Joint Economic Committee
MAS	Marin Audubon Society
MHHW	Mean Higher High Water
MLLW	Mean Lower Low Water
MWL	Mean Water Level
NBS	Nature Based Solutions
NSI	National Structural Inventory
NOAA	National Oceanic and Atmospheric Administration
OLU	Operational Landscape Unit
O&M	Operations and Maintenance
ROW	Right of Way
ROM	Rough Order of Magnitude
RSAP	Regional Shoreline Adaptation Plan
SFEI	San Francisco Estuary Institute
SLR	Sea Level Rise
SWL / SWEL	Still Water Level / Stillwater Elevation Level
TAC	Technical Advisory Committee
TAM	Transportation Authority of Marin
TIGER	Topologically Integrated Geographic Encoding and Referencing system
USACE	United States Army Corps of Engineers
VE Zone	"Velocity Zone" FEMA floodplain coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves

ii. Executive Summary

The primary goal of this document is to evaluate the feasibility of adaptation alternatives for sea level rise adaptation within the San Rafael Operational Landscape Unit (OLU). All alternatives strive to increase community resilience to sea level rise and flooding, increase environmental health and resilience, and minimize displacement risks and potential impacts to the community and the environment. This study does not recommend a preferred alternative but identifies potential tradeoffs and benefits of each alternative within a range of feasibility criteria.

This effort is being conducted with the understanding that disruption of natural processes and development of the historical Baylands is the root of the vulnerability, but present conditions and impending safety risks are the starting point for adaptation.

Document Organization

The Executive Summary section provides an overview of the complete sea level rise adaptation project and findings of the technical feasibility study:

a) Summary of community engagement activities, products, and feedback received over the course of the project, from the project team, partners, and City.
b) Overview of San Rafael landscape typologies used to organize adaptation strategies.
c) Descriptions of adaptation alternatives, including a baseline "No Action" scenario, Initial Actions, Nature-Based Opportunities, and three alternatives evaluated across ten criteria defined by the San Rafael Sea Level Rise Collaborative.
d) A comparative summary of feasibility across alternatives and criteria.

Next, the Adaptation Approaches section follows each alternative through all ten evaluation criteria. This structure is used to provide continuity to allow a better holistic understanding of each alternative.

All elevations refer to the NAVD88 datum unless otherwise noted.

a. Summary of Consultant's Participation in Community Engagement & Feedback

Building on a rich history of community activism and climate justice work in San Rafael, the Sea Level Rise Collaborative (Collaborative) began conducting broad and consistent outreach, engagement and education on sea level rise adaptation in 2022, with over 100 engagement activities to date. The understanding and community perspectives from this effort informed the Technical Feasibility Study and will be documented more fully in the final report.

The Technical Feasibility Study Consultant Team began contributing content for collaborative engagement efforts, as well as conducting engagement specific to the study, in the summer of 2024. Project-specific engagement by the Consultant Team included public workshops, facilitation of Technical Advisory Committee meetings, working meetings with City staff and joining several monthly Steering Committee meetings at the Multicultural Center of Marin. Content produced for these events included bilingual (English and Spanish) digital slide presentations, printed graphic display boards, interactive engagement tools, a physical model of San Rafael, and a public-facing Briefing Book that gives an overview of the flood vulnerabilities.

Figure 1. Consultant Team engagement activities and workshops for the study.

Over the course of the public engagement the Community articulated a set of guiding principles they wanted to shape the adaptation process. These principles were integrated into the planning process from the beginning of the Consultant Team's work.

- Community Leadership. Continually educate and empower residents to lead adaptation decision-making.
- Protect People. Prioritize emergency preparedness, public safety, and public health.
- Prevent Displacement. Adaptation measures should support the existing community and avoid displacing current residents.
- Connect People. Build relationships and establish resources to support community collaboration and resilience.
- Environmental Justice. Direct resources to the most vulnerable and ensure the costs of adaptation are shared fairly and equitably.
- Connect to Nature. Protect access to the waterfront and expand green space.
- Protect Ecosystems. Maximize co-benefits like habitat creation and restoration

Technical, qualitative, and experience-based feedback from a wide range of stakeholders was incorporated iteratively into materials produced by the Consultant Team. To build understanding and Community consensus, public open-house style workshops titled "Community Assemblies" were hosted on June 8 and October 21, 2024. The Consultant Team presented at three Technical Advisory Committee meetings (June 6 and September 26, 2024 and January 14, 2025) in a hybrid in-person and virtual format for feedback on the technical analysis. Additionally, the Consultant Team presented at several monthly Steering Committee meetings at the Multicultural Center of Marin to co-develop engagement materials and inform the Committee to continue advocating for a more resilient community after the project scope is complete.

Figure 2. 3D physical model of part of San Rafael illustrating topography and flood risk.

A full summary of feedback will be included in the final report, but a partial summary of the feedback provided to the Consultant Team at the events the team attended is below:

- There is general consensus that action is necessary, but concerns exist over the feasibility of the proposed adaptation measures and their impact on residents. The potential rise in costs, displacement of tenants, and the long-term impact on the affordability of housing were key concerns.
- Residents highlighted the need for tenant protections and guarantees of housing stability. Many asked about the involvement of property owners and many expressed a desire to ensure that the community as a whole (including renters) benefits from the proposed solutions and that community cohesion is maintained.
- For all the adaptation alternatives, there was a mix of support, concerns, and substantive questions about the real feasibility and efficacy of all alternative adaptation alternatives proposed. Residents recognize the importance of the project but many expressed concern about the complexity of the undertaking and time it will take to implement any alternative.
- Some stakeholders also recognized that the scale of change required for successful adaptation will require new forms of governance and finance, allowing for more transformative visioning of long-term solutions.
- A desire for clarity on the timeline of adaptation efforts. The Community consistently seeks to understand when action will be taken.
- There was an emphasis on the importance of clear communication and community involvement throughout the process.
- Opportunities for better communication to stakeholders include pairing risk reduction with multi-benefit solutions for a better, stronger San Rafael and amplifying proactive adaptation versus reactive damage repair.

b. Overview of Landscape Typologies

San Rafael can be divided into three landscape typologies: shoreline, basin, and upland. These typologies in the physical landscape are used throughout this report to organize flood risks and potential actions to address them.

Figure 3. Plan diagram describing the landscape typologies in San Rafael.

Shoreline (Bayfront and Canal)

For this report, the shoreline is defined as the strip of land along the Bay and Canal from Mean Higher High Water (MHHW) to the first public right-of-way. In San Rafael, this zone provides a starting point in the physical landscape where adaptation is likely to occur. Along the bayfront south of the Canal, the shoreline has a levee constructed as a dredge disposal cell between approximately 1950-1968 (ESA, 2020; from Siegel Environmental, 2016) and topped by the Bay Trail. Bayward land slopes gradually out into the bay as a tidal mud flat. The shoreline along the Canal is predominantly waterfront development built either directly adjacent to or over the water. At Peacock Gap, Point San Pedro Road runs along the shoreline flanked by a small rocky berm on the bayward side, and from there the land slopes gradually as a tidal flat.

At some locations on the Canal and Bayfront, the shoreline is slightly higher than the land behind it, creating a bathtub, or basin. Where the shoreline is low it overtops from high tides and the basin floods, even if structures at the shoreline itself are raised and do not flood. Most of the San Rafael Canal shoreline and some of the bayfront is private land, presenting a challenge for adaptation where collective action is required for the safety of residents in the basin.

Elsewhere, the shoreline slopes up gradually, leaving only the buildings and roads near the water potentially prone to tidal flooding.

Basin

Basins, also known as polders, are low areas with multiple flood threats that require forced drainage, or pumps, to stay dry. There are presently two basins in the study area, one south of the Canal and one near Peacock Gap. Built on reclaimed historical wetlands and tidal flats, the basins have the most acute flood risk in the study area. Over time, the weight of development on silty soils and lowered groundwater levels have caused the basins to subside below the daily high tide, and they continue to sink at varying rates. The land will never naturally rebound and therefore it will require pumps indefinitely unless the land is completely redeveloped on new fill.

A narrow strip of higher land along the shoreline keeps the basin from being inundated by high tides today. When this edge overtops, the basin floods until the tide recedes and it is drained by pumps. Sea level rise and further subsidence increase overtopping risk, eventually threatening to permanently inundate the basin in the coming decades if no action is taken.

Rainfall flooding is an additional threat to the basin. Precipitation falling directly into the basin or flowing from upland areas must be lifted out by a system of pumps. Heavy rainfall can overwhelm pump stations and cause the basin to flood.

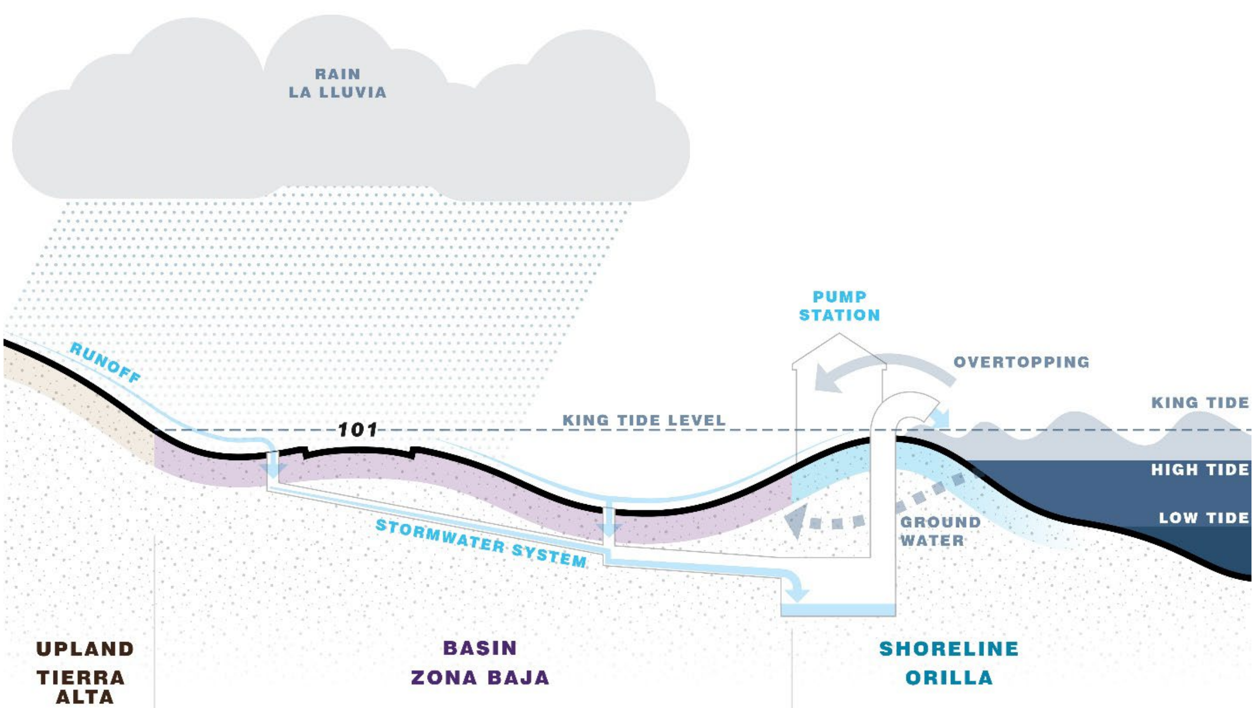


Figure 4. Section diagram describing the basin condition within the Canal District and parts of the neighborhoods along Point San Pedro Road.

Upland

The upland condition is defined as the remaining area within the OLU landward and higher than the shoreline and basin. Some areas are substantially above sea level and safe from direct tidal flood risk. As sea level rises, other areas are projected to fall below high tide and become part of the Canal basin, in particular east of the 101 Freeway to near Albert Park and around the north side of the Canal near San Rafael High School.

The level of development varies in these areas from denser downtown San Rafael to undeveloped hillsides. Upland stormwater runoff flows either into the Bay by gravity or into a basin, where it must be pumped out. Comprehensive flood risk reduction and water management must therefore involve upland areas to minimize impacts on volume and water quality downslope.

c. Summary of Adaptation Alternatives

All alternatives are conceived to protect people, existing habitat, structures, and property value; all include opportunities for habitat expansion and integration of nature-based adaptation; all contain significant tradeoffs; none are easy to achieve; and some provide more potential long-term benefits than others.

The analysis includes:

- A "No Action" Baseline Scenario as an analytical tool for comparison
- Initial Actions common to all subsequent alternatives
- Nature-Based Opportunities for incorporation into subsequent alternatives
- Three Adaptation Alternatives focused on flood hazard reduction measures that would need to be implemented throughout the study area. Every alternative requires additional phased adaptations in the future to maintain flood risk reduction levels with sea level rise and subsidence. Some of these future adaptations are common to all alternatives, such as additional bayfront levee lifts.
- Alternatives not considered due to lack of alignment with the community's Guiding Principles

Each alternative includes two sections:

1) Description of the measures and components, including integral elements common to all alternatives and that may be further adapted in the future
2) Performance & Feasibility analysis across all ten criteria.

a) "No Action" Baseline Scenario

The feasibility analysis begins by defining a baseline "No Action" scenario, where the probability of flooding along the shoreline and within the basins would increase significantly approaching mid-century if adaptation does not happen in a coordinated way. Beyond approximately 2050 the long-term viability of the most vulnerable parts of San Rafael in their current form is uncertain under this scenario. The "No Action" scenario is not a recommendation but is used only as an analytical tool to evaluate the level of tidal protection and other potential impacts for each of the evaluated alternatives.

b) Initial Actions

In this scenario initial Actions are defined for each landscape typology. They involve immediate safety measures to reduce existing flood risk in the most acutely vulnerable areas today, high-priority pilots of nature-based features to inform near term adaptation, and implementation of elements common to all subsequent alternatives. Initial Actions as defined herein provide an incremental first step to all other alternatives and would buy time to plan and implement longer-term adaptation strategies. Future adaptation measures that build on initial actions are described in subsequent alternatives.

Canal (Shoreline)

In the immediate term, raise low areas to +8 feet along the Canal edge, and replace or reinforce informal barriers, either through temporary deployable measures or more permanent interim measures depending on recommendations of a site-by-site analysis.

1) Initiate a site-by-site feasibility analysis and tidal flood response plan for shoreline at or below +8′ and areas with informal flood barriers.
2) Develop and implement pilot measures for habitat enhancement for expansion in future adaptations. Pilot measures can proceed fastest at locations where space exists on public property and in partnership with private landowners, including on piers, pilings, and docks; floating wetland prototypes in sheltered areas; and on the vertical surfaces of temporary and permanent measures, such as through subtidal textured panels or formwork.
3) Take initial steps to evaluate the implications of public acquisition of waterfront properties, structures, and/or easements along shorelines that serve a flood protection purpose for low-lying basin areas. Infrastructure that serves a public safety function is most reliably maintained when subject to public oversight in the public domain. Future FEMA certification, if pursued, may require it.

Bayfront (Shoreline)

Elevation and habitat restoration and enhancements at the bayfront are included in all alternatives and could move forward while measures in the Canal continue to be considered.

1) Begin survey, planning, and design for bayfront levee adaptation.
2) Continue to work towards implementation of Tiscornia Marsh restoration, which will serve as a demonstration project and prototype for the San Rafael and the contracting community.
3) Build on knowledge from existing habitat pilots programs to pilot and monitor additional measures that can be implemented in future alternatives. These could include an expansion of the San Francisco Bay Living Shorelines oyster reef pilot in San Rafael to different depths, geometries, and offshore distances for present and future wave attenuation.
4) Take initial steps to evaluate the public acquisition of waterfront properties and/or easements along shorelines that serve a flood protection purpose around low-lying basin areas.

Basin

For all alternatives, pump stations in some configuration will be required indefinitely to manage stormwater and groundwater in existing basins, and the extent of forced drainage area is likely to grow as seas rise and land subsides further.

1) Maintain and upgrade existing pump stations. Pump stations provide the only way to manage stormwater and tidal overtopping today, and it is critical they remain functional while adaptation measures are implemented. (Stormwater drainage performance was not evaluated as part of this study.)
2) Proactively elevate critical infrastructure, such as Fire Station 54, to ensure emergency response in the event of stormwater flooding and/or catastrophic overtopping.
3) Evaluate the feasibility of road raising at the parcel scale for critical access pathways to high ground, across the Canal, and under the interstate.

4) Evaluate the feasibility of expanding of city services to fund, maintain, and operate critical infrastructure, including levees, through the Public Works department or a new entity.
5) Incentivize, plan and construct green stormwater infrastructure on public and private property, including street bump outs, bioswales, permeable surfaces and subsurface detention to reduce flood pressure and improve water quality.

Upland

Strengthening housing options and stormwater green infrastructure upland will provide flexibility for adaptation in high flood risk areas at lower elevations.

1) Fund programs to plan and support construction of multifamily housing on higher ground outside the basin, such as downtown, and aligned with the city's General Plan that can potentially support the incremental reconstruction of low-lying and soft story dwellings within the basin. This is advisable to complement all alternatives. This will require addressing existing barriers to new housing development.
2) Incentivize, plan and construct green stormwater infrastructure on public and private property, including street bump outs, bioswales, permeable surfaces and subsurface detention to reduce downstream flood pressure and improve water quality.

c) Nature Based Opportunities

Nature-based, or 'living shorelines' solutions include habitats (e.g. coarse beaches, ecotone or 'horizontal' levees, offshore oyster reefs) that complement shoreline flood protection measures by preserving or enhancing existing habitats, recreation, and/or public access. These measures may provide some degree of flood hazard reduction in the form of wave attenuation and scour protection. They are combined with structural flood protection such as levees and floodwalls as hybrid green/grey measures where still water overtopping is the primary flood risk driver, such as in San Rafael.

These approaches have been explored at a conceptual level for the San Rafael shoreline as part of the Resilient by Design Bay Area Challenge (Bionic 2018), by the San Francisco Bay Adaptation Atlas (SFEI and SPUR 2019), by non-profit groups such as Resilient Shore, and as part of City planning efforts (City of San Rafael 2014) and county-wide planning efforts (Point Blue, SFEI, and County of Marin 2019).

There are multiple habitat opportunities within every evaluated alternative that utilize nature-based strategies to minimize wave action and erosion to support flood hazard mitigation goals, especially on the Bayfront, where these forces are most prevalent and more space exists for their implementation. There are several existing pilot projects and ongoing efforts that can be expanded and can inform other habitat opportunities creating a diversity of habitats at a variety of feasible elevations, from subtidal to upland. These opportunities can be integrated in various configurations and are subsequently presented as overlays within each alternative.

Nature Based Opportunities include:

a) Protection of existing Baylands habitats, including preservation of full tidal exchange for north Canal marshes and Tiscornia Marsh.
b) Enhancement of rocky intertidal habitat through removal of debris and derelict structures, planting of emergent native vegetation at the crown, adding donor cobbles to the slope, placement of reef balls and oyster blocks at the toe, and adding precast tide pools on

riprapped reaches from the San Rafael Bridge to Pickleweed Park, the marinas, Point San Pedro Road, and McNear Brickyard Road.

c) Enhancement and expansion of nearshore reefs and eelgrass beds that have been piloted along the bayfront. New geometries, structure configurations, and locations higher in the tide range can provide habitat, encourage sedimentation to raise the shallow bay and mudflat elevation, and provide wave attenuation benefits for the bayfront levee as sea levels rise.
d) Coarse beaches to protect marsh restoration and bayfront levees by limiting wave runup.
e) Managing and sustaining small marshes north of the Canal mouth, west of Summit Avenue, east of Sea Way, and along Beach Drive where roads cut off inland migration, possibly through thin fill placement.
f) Restoration of marsh in managed lagoons through improved tidal connection and setback levees at East Spinnaker Point Lagoon (17 acres) and East San Rafael Wetlands (14 acres).
g) Restoration of Brickyard Cove (52 acres) impounded marshes.
h) Potential sand beach creation and/or preservation of existing pocket beaches.
i) Potential restoration within the Canalways site (102 acres), although all future scenarios for the use of this property are difficult due to ongoing land subsidence and potential contamination among other challenges.
j) Enhancement of smooth vertical walls along the Canal, including introducing more natural rock surfaces with more complex grooves, shelves, ledges, holes, and surface roughness to mimic the historical rocky bluffs on islands along the north shore, adding donor seaweed on cobbles, placing reef balls and oyster blocks, adding precast tide pools, and removing debris and derelict structures.
k) Upland green stormwater infrastructure for volume and water quality management.

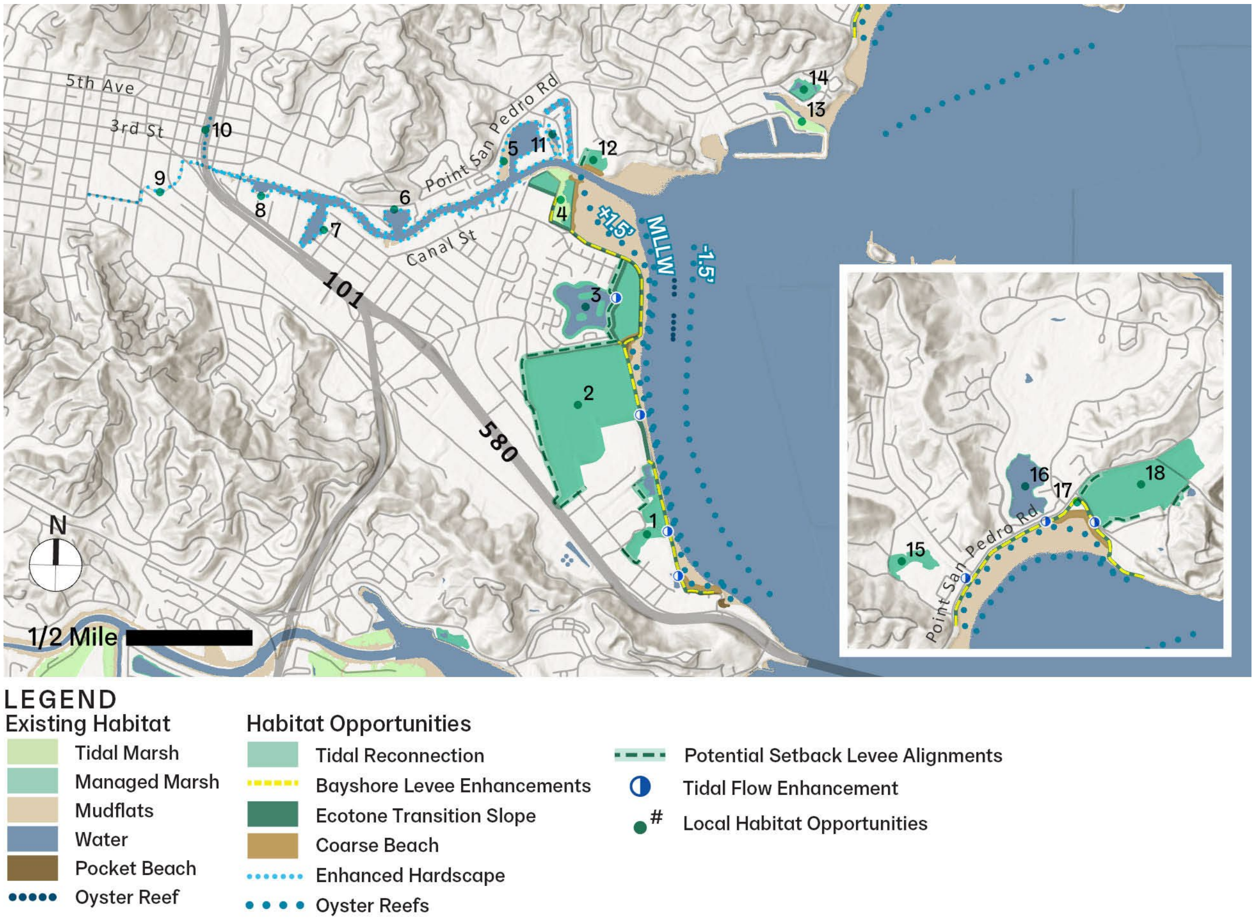


Figure 5: Nature-Based Opportunities map and key features, all alternatives.

1) *East San Rafael Wetlands*
2) *Canalways Site*
3) *Spinnaker Lagoons*
4) *Tiscornia Marsh*
5) *Marin Yacht Shoreline Enhancement*
6) *Lowrie Yacht Harbor Shoreline Enhancement*
7) *San Rafael Yacht Harbor*
8) *Municipal Yacht Harbor Shoreline Enhancement*
9) *Mahon Creek Shoreline Enhancement*
10) *Irwin Creek Vertical Habitat*
11) *Arrowhead Marsh Expansion*
12) *San Rafael Canal Mouth North*
13) *Loch Lomond Drive Wetlands*
14) *Beach Road Wetlands*
15) *Greenwood Wetlands*
16) *Peacock Gap Lagoon*
17) *Brickyard Beach Enhancement*
18) *Brickyard Cove*

a) Alternative 1: Raise Canal Edge

Alternative 1 requires raising the Canal edge to +12 feet primarily through vertical living seawalls and raising the crest of the Bayfront levee to +14 feet (BFE +1′ SLR). This alternative seeks to protect as many existing buildings and housing units in place as possible to anticipated 100-yr water levels at approximately 2050. The alternative requires the smallest physical footprint of the three evaluated, however it presents significant tradeoffs to visual character and limits future adaptation potential.

In the Canal, this would consist of three types of structures, applied in order of priority:

1) Planted berms or rip rap combined with a short stem wall where space exists on land, at or above MHHW (rare condition; primarily for properties that are/may be redeveloped)
2) Onshore seawall: vertical bulkhead with living seawall where space is limited on land, at or above MHHW
3) Offshore seawall: vertical sheet pile with cast living seawall panels and concrete cap built in water where existing structures are at or overhang the shoreline, or where space otherwise does not permit. The space between seawall and shoreline would remain hydrologically connected to the canal via sluice gates that would close only during flood events in order to balance hydrostatic pressure on both sides of the structure.

Approximately 250 docks and gangways would require demolition to implement this alternative and would need to be reconstructed canal-side of the structure, avoiding the federal navigation channel.

To prevent tidal back flooding from the Canal, the vertical seawall would continue along Irwin and Mahon Creeks under the 101 Freeway and inland to approximately Albert Park. As a sub alternative, an operable tide control gate that would close only during flooding events could be constructed between the Grand Avenue bridge and Yacht Harbor, with a new pump station to manage fluvial flow.

On the north side of the Canal and elsewhere where no basin conditions exist, individual structures and access roads would need to be raised over time. Point San Pedro Road would need to be raised in low areas, possibly including a low 3′ seawall where raising to required elevation is not possible due to space or adjacent constraints.

The bayfront levee presents the most opportunities for and benefits from nature-based adaptation in this alternative. The levee structure itself would need to be stabilized through soil mixing, widened towards land, and raised with surcharged material to anticipate compaction and subsidence. Where the existing levee is compromised or too weak for raising, full replacement with temporary shoreline protection may be required. The Bay Trail would be replaced on top. As further described in Nature Based Opportunities, the bayfront can support planted rip rap and coarse beaches to protect the bayward side of the levee and reduce wave runup; setback levees and tidal restoration allow for marsh regeneration of managed lagoons; protection and management of small marsh patches; and nearshore reef and subtidal habitat enhancements that can provide wave attenuation and reduce tidal amplification.

b) Alternative 2: Canal Gate

Alternative 2 creates a navigable flood control gate at elevation +16′ (BFE +3′ SLR) with large forward pumps, approximately 3,000cfs, at the mouth of the San Rafael Canal. Like Alternative 1, bayfront levees would initially be constructed to +14′, while the gate structure itself could be constructed higher for a design life up to 2100 conditions given the scale of investment. Combining the gate with bayfront levee adaptation as described in Alternative 1 creates a continuous line of protection for basin conditions in San Rafael and affords similar opportunities to implement nature-based opportunities throughout the bayfront.

Multiple gate locations are possible, but the analysis considers one where both the north Canal marshes and Tiscornia Marsh are bayward of the structure to remain fully tidal and Marin Yacht Club harbor entrance remains navigable. Tidal connection to the diked wetland at Pickleweed Park would be located behind the structure. The gate would remain open during normal conditions to maintain an accessible federal navigation channel and would only close during projected tidal flooding events, at a +8′ threshold, closure frequency would be approximately once annually today, 1-3 times monthly with +1′ SLR (approximately 2050) and >1 time weekly with +3′ SLR (approximately 2100).

The shorelines behind (inside) the gate would require elevation to keep pace with sea level rise and subsidence to maintain today's closure frequency over time and therefore maintain tidal function in the Canal. These measures could look like Alternative 1 and/or Alternative 3 over time. Home and road elevations described in Alternative 1 may be required on the north Canal shoreline for the same reason. Failure to adapt the shoreline behind the gate potentially compromises the ability to permit this alternative as the least environmentally damaging option.

c) Alternative 3: Incremental Elevation

This alternative would aim to incrementally elevate land and reconstruct buildings along the first block of shoreline of the San Rafael Canal to +14′, a level above the 100-year floodplain with projected SLR of +3′ through 2100. This alternative includes acquisition, demolition, fill, and redevelopment where possible, of all contiguous waterfront parcels in the Canal that protect a basin condition. This alternative is essentially localized redevelopment to make space for a levee, new public easement and trail, and vegetated shoreline beginning at or landward of the current Canal shoreline. Fill and redevelopment at this scale likely must occur at the block scale and coordinated in phases through a robust public process. If fully implemented, it may be possible to map the basin out of the FEMA floodplain. While Alternative 3 is the most expensive and potentially takes the most time to implement, it provides the greatest potential return on investment for long-term safety, quality of housing, habitat and waterfront access expansion, and real estate value to sustain the city's tax base.

Alternative 3 includes Point San Pedro Road elevation, and access road and individual structure elevations for the north side of the Canal from approximately Embarcadero Way to the mouth of the Canal. Other types of flood-adaptive housing, like houseboats or re-construction on stilts, may be used.

Housing reconstruction over time can provide better access to the water and potentially create more space to lay back the Canal edge. Rebuilding the Canal edge can also present similar opportunities for nature-based solutions as on the bayfront, including sheltered vegetated slopes and subtidal habitat where bathymetric conditions allow. Existing private docks and waterfront uses would be reimagined in this alternative.

Alternative 3 includes bayfront adaptation measures as described in Alternative 1 to form contiguous edge protection for basin conditions and neighborhoods along Point San Pedro Road, including Peacock Gap.

Solutions for tidal back flooding under the 101 Freeway and for Mahon and Irwin Creeks could look similar to Alternative 1, but where possible the waterfront edge itself would be elevated on fill and laid back with a vegetated slope.

Alternative 3 can be considered standalone or as a future phase of other alternatives, achieved over longer periods of time as landowner approval and funding become available and redevelopment is complete. While there may be benefits to raising structures and land throughout the basin, Alternative 3 focuses on adaptations that prioritize waterfront blocks to establish a protective perimeter. Elevation and full redevelopment of all land, infrastructure, and buildings in the basin are not considered within this study.

Alternatives Not Considered

Three alternatives were eliminated from consideration:

- Seawall or barrier within the first right of way (such as proposed for Canal Street in Resilience by Design)
- Managed retreat at-scale, defined as encompassing more than the first waterfront block.
- Reconstruction and elevation of all land above future high tides.

d. Summary of Feasibility Analysis Across Criteria

All alternatives, including the baseline "no action" scenario, were analyzed in terms of their multiple benefits and impacts across ten categories defined by the City of San Rafael:

i. Level of Fluvial and Tidal Flood Protection, or target elevation thresholds for flood protection.

ii. Effectiveness at Different Planning Horizons including implementation timelines and design lifespans.

iii. Spatial Requirements including footprints for adaptation measures.

iv. Permitting Requirements from local, regional, state, and federal jurisdictions.

v. Land Ownership and Access Considerations including impacts on public and private properties, open space, and public and private shoreline access.

vi. Potential Threats to the Community including catastrophic flood risks associated with infrastructure failure.

vii. Co-Benefits of Adaptation Measures including public access, ecology, neighborhood beautification, and transit network resilience.

viii. Housing Implications including for gentrification, the preservation of affordable housing, community cohesion, and displacement.

ix. Ecological Implications including for the resilience and impairment of ecological functions and ecosystem services, such as habitat provision, habitat resilience to sea level rise, water quality improvement, sediment management, and carbon sequestration.

x. Economic Implications including order-of-magnitude analysis for life cycle, losses avoided, and annual operations and maintenance costs.

i. Level of Fluvial and Tidal Flood Protection

The No Action scenario would involve no tidal protection above what is currently in place and would see flooding increase significantly over time from sea level rise. Frequency of minor overtopping events at +8′ would reach twice monthly with +1′ SLR (approximately 2050) concentrated in winter months and daily toward the end of this century. It is anticipated that monthly unmanaged overtopping events would disrupt regular function in the basin area, through regular flooding of vehicles, salt corrosion of infrastructure, business disruption, market perception of risk, and potential collapse in real estate values. Risk of catastrophic overtopping above +9′ rises to a 1-in-5 chance per year by 2050. Ongoing land subsidence will accelerate these timelines and frequencies. Based on preliminary HEC-RAS modeling in lieu of a comprehensive city stormwater model, it is projected that tidal events about +9′ without rainfall will overwhelm the existing forced drainage system. Level of fluvial protection provided by the stormwater drainage system is not evaluated in this study.

Initial Actions would elevate the lowest segments of the Canal shoreline to +8 feet and replace informal barriers with engineered structures up to this minimum threshold. This is roughly a 5-year tidal event today based on statistical probability and is an interim step intended to minimize number of parcels affected and speed implementation. Where possible, shoreline adaptations could be built higher, up to +12′, to be integrated with Alternative 1. Initial Actions includes emergency stabilization of bayfront levee where seepage is observed. Initial Actions includes upgrading pump stations throughout the basin and constructing green infrastructure to detain, store and filter stormwater. These would need to be designed to meet increased rainfall intensity and achieve a level of fluvial protection established through a dedicated stormwater evaluation, as well as be able to handle greater overtopping volumes during extreme high tides.

Alternative 1 is evaluated at the current FEMA 100-year base flood elevation +1 foot of freeboard and an additional +1 foot of sea level rise by 2050, or elevation +14 feet along the Bayfront and +12 feet in the Canal. The +12′ threshold would apply to all infrastructure and structures along the Canal, including new seawalls for basin protection and raised roads and buildings west of Embarcadero Way on the north shoreline where no basin condition exists. This 2050 level is a starting point to establish a consistent level of protection, impactful but not prohibitively high as a first step. Subsequent future elevation of +2′ or more could be designed into the foundation for relatively efficient increases to 2100 anticipated levels once the structure is in place. The Bayfront levee foundation would be planned to accommodate another incremental lift past mid-century to keep pace with sea level rise and maintain the same level of protection, approximately another +2 to +5 feet depending on updated measurements and projections (+16 to +19 feet elevation). New structures would be designed to account for subsidence to maintain their design elevation. Existing pump stations would need to be upgraded to manage stormwater in the basin and additional overtopping volumes from extreme events. Punch-outs and/or check valves would be provided through the seawall to facilitate drainage.

Alternative 2 provides the same level of protection along the bayfront at +14′, however the gate structure would be built to a higher level of projected sea level rise due to its longer design life and the difficulty of adapting the gate structure, to an elevation of +16 feet (factoring +3′ SLR, 2100 low scenario) and possibly as high as +19 feet (+6′ SLR, or 2100 high scenario). New structures would be designed to account for subsidence to maintain their design elevation. A forward pump station approximately 3,000cfs integrated with the gate structure would provide fluvial flood protection within the Canal in the event of upland rainfall when the gate is closed. Existing pump stations would be required to manage stormwater drainage in the basin.

Alternative 3 creates continuous flood protection achieved incrementally through redevelopment to anticipated 2100 water levels for the Canal basin. This alternative would be built to the current FEMA 100-year base flood elevation +1 foot of freeboard and an additional 3 to 6 feet of sea level rise, for a minimum Canal shoreline elevation of +14 feet and as high as +17 feet. This threshold is higher than other alternatives given the level of investment and disruption required to construct it. Roads and buildings on the north side of the Canal east of Embarcadero Way, where no basin exists, would be elevated to a +12′ threshold with further midcentury adaptation planned as described in Alternative 1. The bayfront levee would be raised initially to +14′ with another midcentury lift planned as described in Alternative 1. New structures would be designed to account for subsidence to maintain their design elevation. Pump stations would be required to manage stormwater drainage in the basin, and existing stations within the redevelopment footprint would be fully reconstructed.

	5-20 Years to Complete	**By 2050**	**By 2100**
No Action	Canal: <5-yr protection* Bayfront: <100-yr protection	Monthly overtopping (severe disruption, some structures likely uninhabitable)	Weekly to daily overtopping (district likely uninhabitable)
Initial Action	Canal: +8′ (5-yr protection, no freeboard or SLR) Bayfront: Emergency stabilization		
Alternative 1		100-yr BFE +1′ freeboard +1′ SLR Canal: +12′ Bayfront: +14′	Additional Canal & Bayfront lifts +2′ to 5′ for SLR or shift to Alternative 3. Canal: +14′ to 17′ Bayfront: +16′ to 19′
Alternative 2		100-yr BFE +1′ freeboard +3′ SLR Canal/+1′ SLR Bayfront Canal: +16′ gate* Bayfront: +14′	Additional Bayfront lift +2′ to 5′ for SLR Canal: +16′ gate* Bayfront: +16′ to 19′
Alternative 3		100-yr BFE +1′ freeboard +1′ SLR Canal: +12′ north bldgs. & roads; basin shoreline redev. in-progress, min. +8′ from Initial Actions Bayfront: +14′	100-yr BFE +1′ freeboard +3′ to 6′ SLR Canal: +14′ Bayfront: +16′ to 19′

*Figure 6. Table showing the level of tidal protection over time for all alternatives. *May require additional shoreline raising behind the gate for closure frequency management.*
**Protection level, including BFE, refers to statistical probability of a given water surface elevation*

ii. Effectiveness at Different Planning Horizons

For No Action, the risk of minor and catastrophic overtopping already exceeds routine safety standards and overtopping events already occur at most annual king tides.

Initial actions could be completed within the next 8.5-20 years, with varying implementation timelines driven primarily by the need for widespread community and property owner consultation and the development of political consensus. Initial Actions are intended as immediate stabilization measures and are statistically likely to be overtopped within the next 20 years. Implementation is urgent to achieve their benefits.

Alternative 1 could be completed in 8-29 years, with an averaged completion time of 18 years or by 2044, and provides for possible FEMA certification up to +1′ SLR. It would remain effective at or near its design elevation while additional adaptations are made by 2070. Future phase adaptations may need to accelerate to maintain the 100-yr level of safety depending on updated projections for sea level rise. Future levee lifts at the bayfront should occur landward to maintain the effectiveness of established offshore and at-shore habitat. Depending on observed rates of sea level rise and sediment accretion, strategies such as thin layer placement may be required to maintain ecological function of restored and protected marsh.

Alternative 2 could be completed in 8-24 years, with an averaged completion time by 2041, and would remain effective at its design elevation while additional adaptations are made by 2070, or sooner depending on sea level rise rates. If additional Canal shoreline raising is required for permitting, the timeline is more likely to follow Alternative 1.

On its own, Alternative 3 will take the longest to fully implement before contiguous flood protection is achieved, anticipated at 20-42 years, with an averaged completion time of 31 years, by 2056. The alternative is effective at managing 100-yr risks through +3′ of SLR in the Canal, potentially up to or beyond 2100, and up to +3′ of SLR along the bayfront when a future lift is included. A combination of temporary barriers and/or parts of Alternatives 1 and 2 may be required in the interim to provide effectiveness up to +1′ SLR as soon as possible.

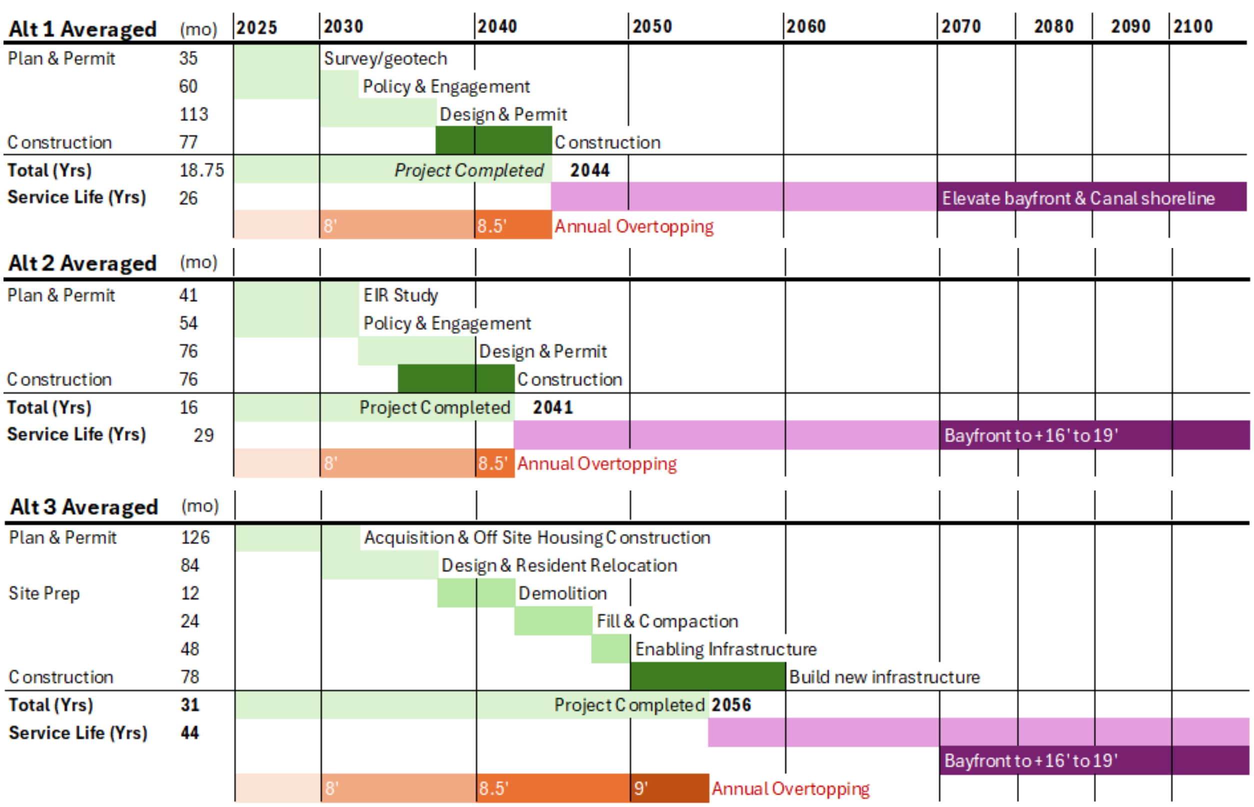


Figure 7. Estimated time to implement using averaged time estimates, with effective design lifespan.

iii. Spatial Requirements

The No Action alternative has no spatial requirements.

Initial Actions are limited in space to distributed small-scale interventions on 38 Canal waterfront parcels and within other public rights-of-way. Construction may be required from water or land. Easement acquisition should be explored but is not included in Initial Actions.

Alternative 1 onshore type requires at minimum 2′ width for steel sheet pile and concrete cap, at minimum 8′ offset from existing structures for construction, and at minimum a 10′ perpetual easement landward of the seawall for inspection and maintenance. Construction easements may be up to 25′ wide for land-based construction. On the north side of the Canal, building elevation would take place on private property, and access road raising will likely require the purchase of additional easements from adjacent owners. Road raising for Point San Pedro Road would occur within the existing public right of way. Property and/or easements and access agreements may be needed along the bayfront and would be expected to expand for future levee lifts. Easement widths may change depending on funding source and should be confirmed with potential partners such as the USACE. If USACE cost share is pursued, the city will be required to acquire property and/or easements for all land needed to implement the alternative.

Alternative 2 requires an area at least 50′ wide for the length of the structure for in-water construction access by barge. Land-side impacts would be limited to tie-in locations north of the Pickleweed Park diked wetland to the south and along the eastern edge of Sea Way to the north, potentially adjacent to two private parcels. These tie-ins would be subject to the same easement requirements as Alternative 1. Approximately 0.7-1.2 acres is estimated to be required for a 3,000cfs forward pump station, and given limited space near the Canal mouth this will likely be located partially over water and partially over marsh. Alternative 2 requires similar spatial parameters for the bayfront as described in Alternative 1.

Alternative 3 encompasses 82 acres of acquisition and redevelopment around the Canal, around a third of that land lacks the space for redevelopment and the elevated edge would likely be a berm or a raised promenade. The remaining two thirds could be elevated and redeveloped. A significant grade change from Canal levee height +14′ to 17′ would be navigated through new open space and accessible paths and/or through adjacent redevelopment. This alternative would include reconstruction of the Grand Avenue and 101 Freeway exit bridges from higher abutments. Spatial implications on the north side of the Canal and along the bayfront would resemble Alternative 1.

iv. Permitting Requirements

The permitting effort for all alternatives would need to consult with State and federal agencies, including USACE, for construction within the waters of the United States. The proposed work would also need to comply with Section 106 of the National Historic Preservation Act, requiring tribal consultation. The Regional Water Quality Control Board (RWQCB) would need to be consulted regarding potential watershed and water quality impacts. NOAA National Marine Fisheries Service (NMFS) would need to address potential impacts to fish, which would additionally require consultation with U.S. Fish and Wildlife Service (USFWS) and California Department of Fish and Wildlife (CDFW). Potential consultation with the California State Lands Commission (CSLC) will be needed if any proposed construction is on granted lands.

All alternatives would likely require an EIR as part of NEPA and CEQA requirements. The initial draft of the EIR would then be presented to government agencies and the public for comment and review. Potential review agencies include:

- U.S. Army Corps of Engineers (Corps)
- San Francisco Regional Water Quality Control Board (SFRWQCB)
- San Francisco Bay Conservation and Development Commission (BCDC)
- California Department of Fish & Wildlife (CDFW)
- US Fish & Wildlife Service
- National Marine Fisheries Service (NMFS)
- California State Lands Commission
- U.S. Coast Guard

A Mitigation and Monitoring Plan will have to be prepared as part of the environmental review process. The Section 404 Alternatives Analyses will require careful demonstration that the selected alternative could function as the Least Environmentally Damaging Practicable Alternative (LEDPA). Alternatives will require mitigation that will encompass construction practices 1:4 to 1:20 depending on the type of environmental impact.

v. Ecological Implications

The No Action scenario would result in detrimental ecological impact both through sea level rise induced "coastal squeeze" of marshes that lack migration space, and the water quality degradation caused by increasing pump discharges from developed areas.

It is unlikely that any alternative will be self-mitigating where mitigation may be required, however habitat creation should be included where possible in every alternative.

For Alternative 2, limiting gate closure frequency and duration is essential to limiting ecological impact. This likely requires incremental elevation or shoreline protection behind canal gates to raise the closure threshold in tandem with sea level rise and subsidence.

All alternatives propose to maintain full tidal exchange for Mahon and Irwin Creeks under and upstream from the 101/580 overpass.

	Potential Impacts to Waterways
Alternative 1	• 0.3 acres of alignment footprint in water • 3.3 acres of water behind alignment • Est. \$0.7m to \$3.5m mitigation cost
Alternative 2	• 0.9 acre affected by alignment footprint in water • 84 acres of waterways upstream of canal gate • Approx. 7 square mile upland watershed • Est. \$1.9m to \$9.6m mitigation cost
Alternative 3	• Potentially avoids impacting waterways • Potential to add habitat to Canal shoreline • No est. mitigation cost

Figure 7. Table showing the potential waterways impacts for all alternatives. These mitigation costs estimates are approximate and based upon the assumptions outlined in this document. The actual mitigation costs could be orders-of-magnitude higher depending on the regulatory requirements and the ultimate project design.

vi. Land Ownership and Access Considerations

The current shoreline in San Rafael is managed by hundreds of different property owners and all construction and access requirements for each property would be subject to individual negotiations where may be required for the purchase of easements or acquisition.

For Initial Actions, 38 parcels would be impacted raising the lowest portion of the edge to +8′.

The alignment used for this desktop analysis would require land easements from 132 parcels but potentially wouldn't require outright acquisitions. The alignment used for this desktop analysis would require land easements from 132 parcels but potentially would not require outright acquisitions. This includes 52 parcels affected at the bayfront and 80 in the Canal. Onshore permanent easements are estimated at 10′, subject to confirmation by federal funding authorities, and wider construction easements may be needed. Where these are not possible, the seawall would move to the offshore type. Where private property boundaries extend offshore into the Canal, negotiation with owners would be required to establish easements or sale of impacted areas. Offshore sea wall reaches in the Canal would be constructed in water from the channel side and assume public water bottom impacts at 5′ wide for their full length. It is possible that property acquisitions may be required for this alternative were it to be pursued and designed in greater detail.

Alternative 2 requires the same bayfront easements as Alternative 1 and would not require any acquisitions at the evaluated alignment. Alternative 2 would require land-side tie ins to the north and south of the Canal and potentially vehicle access for maintenance from both sides, joining from Sea Way to the north and the Pickleweed Park perimeter maintenance path to the south.

Alternative 3 requires the same bayfront easements as Alternative 1. Canal redevelopment would require the full acquisition of at least 86 parcels. The challenge of acquiring the number of parcels involved in Alternative 3 can make it potentially infeasible if contiguous protection is not achieved before routine overtopping of the Canal. Once acquired, these parcels would likely be combined at the block scale and could be sold and redeveloped privately or through a public-private partnership once shoreline protection is in place. It is not likely that a private developer will incur the expense of multiple parcel acquisitions, demolition, and construction of shoreline protection. A public process can ensure fuller public benefits and developer incentives.

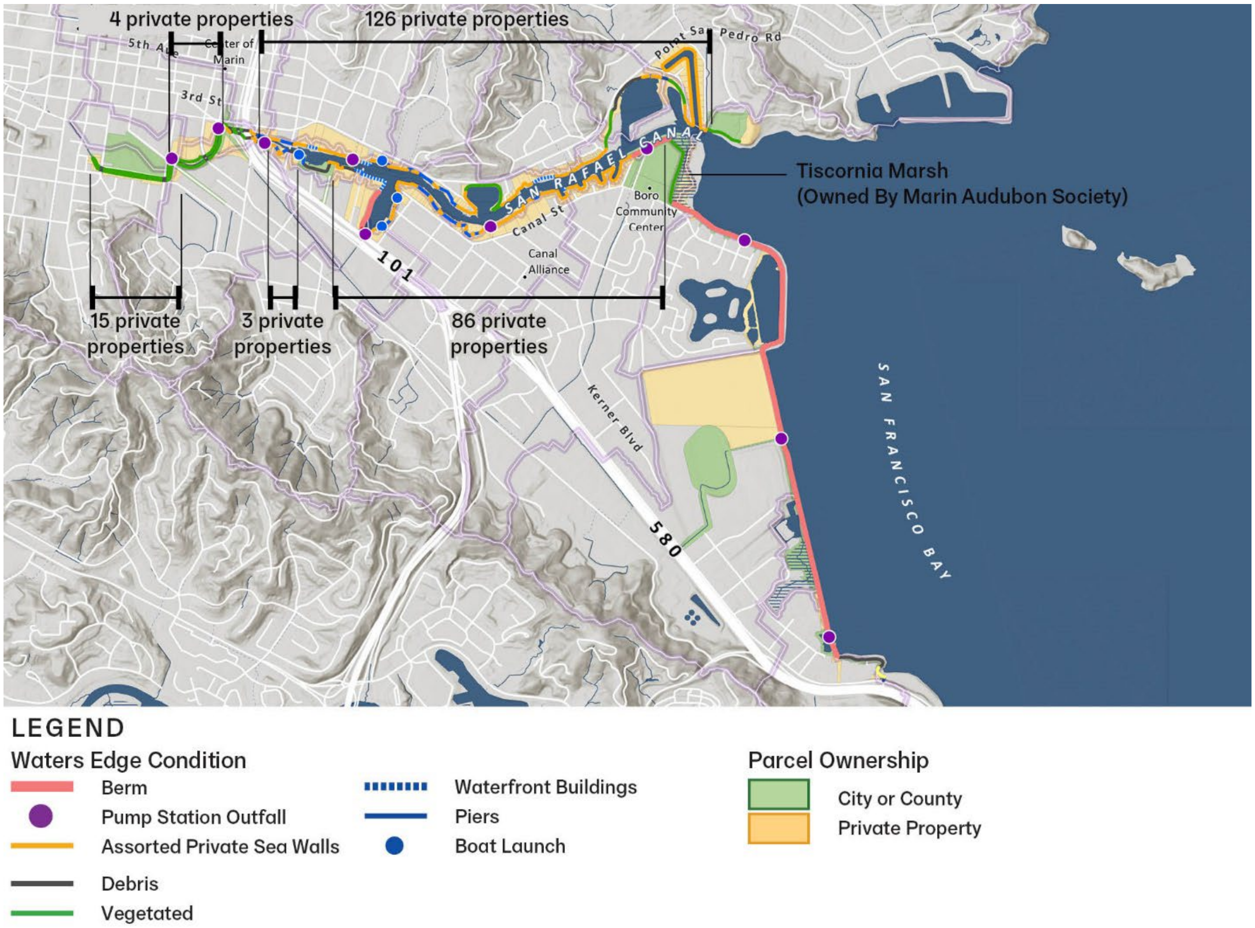


Figure 8. Property ownership and total number of parcels along the southern bayfront and Canal shoreline.

All alternatives would likely require the reconstruction of approximately 250 docks and gangways along the Canal: Alternative 1 in the base case, Alternative 2 if shoreline raising is required, and Alternative 3 as the shoreline is redeveloped incrementally. In this case, public access could be improved with new uses.

Cost for easements and acquisitions assumes existing city-assessed land and structure values. Easement costs are a small fraction of total cost of Alternatives 1 and 2, while property acquisition cost makes up about 12% of the overall cost of Alternative 3.

	Parcels Potentially Requiring Easements	**Parcels Potentially Requiring Acquisition***	**ROM Cost of Easements & Acquisitions****
Alternative 1	132	0*	$6,000,000**
Alternative 2	52	0*	$5,000,000**
Alternative 3	61	86	$211,000,000**

Figure 9. Table showing the land ownership complexity for all alternatives. Costs based on current city-assessed land and structure values.
**Alignment evaluated at the desktop level does not require acquisitions; however they may be required upon further detailed engineering if this alternative were pursued.*
***Easement acquisition cost is based on current assessed land value and does not factor any work or modifications performed within the easement.*

vii. Potential Threats to the Community

The No Action scenario would result in increased flooding impacts and subsequent displacement risk to communities in the basin and along the shoreline. By mid-century overtopping events are projected to occur monthly and the viability of continuing to live in the vulnerable areas like the basin are uncertain. Key impacts would include significant disruption and economic loss, impacts to transportation and public access, living conditions and life quality.

Without action, a seismic event could lead to multiple shoreline failures at the same time and overwhelm the capacity to close breaches before catastrophic flooding occurs, combined with potential power failures at pump stations and damage to roads and buildings.

Alternatives 1 and 2 provide safety for 100-yr flood levels but would still be at risk of overtopping from larger events. Adaptations would be designed with overtopping risk criteria to avoid catastrophic failure, and design volumes for overtopped water can be included in pump station upgrades.

Alternative 3 provides higher protection in the Canal but would still be subject to extreme tidal overtopping.

Housing Units & Population Impacts	Population	Housing Units	Multifamily Housing Units	Parcels
100-Year Event 2050 +1′ SLR (No Action)	11,300	2,720	1,280	2,580

Figure 10. Table showing the mid-century design storm used for Alternatives 1 and 2

viii. Housing Implications

All alternatives may include temporary displacement risk during construction in limited locations where equipment access or laydown areas may be needed on land; this potential could be minimized through detailed project planning and construction sequencing with the contractor. Regardless of alternative, the identification and development of new housing sites outside the basin is advised for overall housing resilience and organized support for potentially displaced residents, businesses, and organizations.

No Action leaves the entire basin and waterfront homes at risk of flooding and displacement, up to approximately 2,720 housing units and 11,300 people for a catastrophic +11′ event.

Initial Actions are intended to stabilize shoreline conditions for safety today, but displacement potential over time would be similar to No Action.

Alternative 1 and 2 would provide 100-yr protection for 2,720 housing units and 11,300 people through approximately 2050. Additional adaptation at the bayfront and/or Canal shoreline would be required beyond that point to maintain 100-yr protection.

Alternative 3 would protect 3,970 housing units and 13,400 people up to 100-yr levels in 2100. This includes a mid-century lift of bayfront measures. These figures exclude approximately 550 housing units that would be displaced to construct the Canal shoreline measures, and also does not include new housing units that may result from redevelopment of waterfront blocks where space permits. To reach replacement level for the 550 units within a smaller footprint, density (such as building height) would need to increase on affected blocks. The larger figures are a result of higher level of protection, essentially protecting more low area from future higher water.

	Protected by Alternative			**Temporary Displacement Risk** (Building Scale Adaptation)		**Permanent Displacement Risk** (Potential Acquisitions)	
	People	**Housing Units**	**Multifamily Housing Units**	**Housing Units**	**Multifamily Housing Units**	**Housing Units**	**Multifamily Housing Units**
Alternative 1	11,300	2,720	1,280	80	20	-	-
Alternative 2	11,300	2,720	1,280	-	-	-	-
Alternative 3*	13,400	3,970	1,650	160	30	390	350

Figure 11. Table showing the benefits and impacts to housing for all alternatives.
**Alternative 3 is built to lower and higher design storms respectively and subsequently have lower and higher potential levels of protection and displacement*

ix. Co-Benefits of Adaptation Measures

All alternatives involve nature-based features at the bayfront that contribute to flood risk reduction by attenuating waves and erosion and create a diverse range of habitats at a variety of feasible elevations, from subtidal to upland. Raising and stabilizing the bayfront levee included in all alternatives would create additional habitat at the bay edge and through marsh restoration as spatial constraints allow.

Raising the Canal edge as part of Alternative 1 and possibly parts of Alternative 3 would consist of a living seawall creating substrates and textured surfaces for aquatic species to grow. Alternative 3 includes laying back new planted slopes at the Canal edge as part of incremental redevelopment.

All alternatives include new construction at various points along the Canal shoreline that may affect the visual character of the neighborhood and in some places reduce visibility of the water. Alternative 3 provides the most potential for neighborhood transformation, which can be positive or negative. With a robust public process to reimagine the shoreline, it may provide improvements to streetscape such as trees, stormwater management features, open space, and neighborhood amenities. Alternative 3 would provide new access opportunities through a new Canal trail or promenade connected to the Bay Trail. Alternative 3 also may provide space and additional vertical clearance for a new pedestrian connection east of the Yacht Harbor. However with large-scale change there is also a potential for unintended negative outcomes.

Alternatives 1 and 2 do not provide additional public access opportunities, rather they seek to preserve buildings and patterns already in place.

All alternatives provide tidal flood protection for regional Caltrans assets within San Rafael, including the 101 Freeway, Interstate 580, and service facilities.

x. Economic Feasibility

External sources beyond local San Rafael funding will likely be required to offset at least some costs of all alternatives, even if phased. All alternatives regardless of funding source are likely to require at least a partial local cost share, typically 35% of federally supported projects.

Property acquisition costs, including easements, are based on the sum of current city-assessed land and structure value. These values may appreciate in the future or fall depending on market risk perception or flood damage.

The cost of habitat enhancements varies widely by measure and is captured within a 50% construction contingency value for all alternatives. Mitigation cost is assumed at $500,000 per acre.

The No Action scenario projects rapidly increasing economic losses over time as the basin begins to overtop substantially and more frequently, especially as more commercial and industrial parcels become impacted and indirect economic impacts occur. A rough order-of-magnitude cost for each alternative was calculated and compared to the "avoided economic impact," or total direct and indirect flood damages, calculated from the No Action scenario. The modeling used here was based on the best available information but given the limited scope of this project neither the flood depths nor the economic losses were calibrated against historic flood data. It is possible that loss values are only experienced long after a flood event, for example where salt water corrodes a building foundation or drainage infrastructure.

Alternative 1 is estimated to cost $718 million with a cost-to-damage-avoided ratio of 1:1.5, still positive but not especially competitive against other adaptation projects seeking federal cost share. 0.5% of construction value is assumed for additional annual operations & maintenance beyond city budget today due to the limited number of new moving parts.

Alternative 2 is estimated to cost $557 million with a cost-to-damage-avoided ratio of 1:2.0. These costs do not include the potential need to elevate the Canal shoreline behind the structure to manage closure frequency, which may make this alternative economically infeasible. 2% of construction value is estimated for annual operations & maintenance due to the complexity of gates and large pumps.

While the most expensive at over $1.8 billion, only Alternative 3 provides the potential to recoup any costs through land redevelopment. The potential returns (land sale value) for redevelopment, if pursued through private sale or public/private partnership, are not included in Alternative 3 but could be significant, potentially in the tens of millions of dollars. A special tax district such as a TIF could be established in advance to support funding and further public improvements in the redeveloped area. This value would not be achieved until after significant costs are incurred, however would effectively reduce the cost and therefore improve the cost/damages ratio, potentially above 2.0.

	Alternative 1	**Alternative 2**	**Alternative 3**

Construction	$ 533,150,000	$ 393,375,000	$ 1,258,312,000
Planning & Design	$ 178,710,000	$ 157,350,000	$ 399,750,000
Acquisition & Mitigation	$ 6,700,000	$ 6,900,000	$ 211,000,000
ROM Cost	**$ 718,560,000**	**$ 557,625,000**	**$ 1,869,062,500**
Annual Operations & Maintenance	$ 2,200,000 (0.5% of Construction)	$ 7,900,000 (2% of Construction)	$ 5,000,000 (0.5% of Construction)
Damages Avoided	**$ 1,097,000,000**	**$ 1,097,000,000**	**$ 3,127,000,000**
ROM Cost to Damages Avoided Ratio	**1 : 1.5**	**1 : 2.0**	**1 : 1.7***

Figure 12. Table showing damages avoided and rough order of magnitude cost for all alternatives.
**Does not include value of potential return from land sale or public-private redevelopment.*

Alternative Comparison Summary

	Alternative 1	**Alternative 2**	**Alternative 3**
People Protected	11,300	11,300	13,400*
Alignment Size	7 Mi	4 Mi	6.5 Mi + 82 Ac
Building Scale Adaptation	70 Buildings	Up to 70 Buildings	310 Buildings
Time to Implement	10 to 30 Years	10 to 20 Years	30+ Years
Permitting Complexity	Medium	High	Medium
Land Ownership Complexity	212 Parcels	52 Parcels	523 Parcels
Displacement Risk	Medium	Medium	High
Ecological Co-Benefit	Medium	Low	High
Cost Benefit Ratio	1 : 1.5	1 : 2.0	1 : 1.7**
Long-term Co-Benefits	Low	Low	High

Figure 13. Table summarizing key benefits and obstacles across all alternatives.
**Alternative 3 is designed to a higher design elevation up front and therefore protects more people.*
***Does not include value of potential return from land sale or public-private redevelopment.*

iii. Feasibility Analysis of Adaptation Alternatives

a) Baseline 'No Action' Scenario

Description

The most vulnerable areas in San Rafael are in a basin, where the land is lower than daily tides and water from the bay is kept out by a thin strip of land along the canal and bay edge. In the basin, every drop of rainfall must be pumped out and high tides can overtop the canal edge and cause widespread flooding. Shoreline areas across the study are often low lying and vulnerable to coastal flooding but the risk is most acute in the basin. The land is subsiding and climate change and sea level rise are projected to increase flood risk from both rainfall and tidal overtopping.

The No Action scenario is a baseline for comparison and therefore assumes no new actions are taken to address SLR. The result of this would be the continuation of the impacts experienced present day exacerbated by climate change and projected SLR as described in the following.

Coastal flooding associated with storm systems passing over the Bay Area are projected to increase with climate change. SLR plays a direct role in this regard by raising the mean sea level, occurring as a result of thermal expansion associated with global warming. Temporary bouts of SLR are already experienced today when El Niño conditions are in effect. On the California Coast and in the Bay Area, the ocean temperature rise associated with El Niño conditions manifests as a rise of the mean sea level, which can exceed 1 foot during a very strong El Niño episode. The extreme flood conditions experienced in the Bay Area in recent history on January 22-28, 1983; December 2-5, 1983, and February 2-6, 1998 were exacerbated by very strong El Niño conditions combined with extreme high winds, storm surge and high tides causing the water level in the Bay to rise by more than 3 feet. There are two contributors to storm surge, one of which is low barometric pressure which pulls up a bulge in the mean sea level. The second component is wind shear pushing water up against shoreline areas. Tides are caused by the gravitational pull of the Moon and the Sun on Earth's oceans and occur independently of storms. However, due to storm events unfolding over a number of hours to days, the tidal variation in the Bay is likely to go through one or more tide cycles over the course of a storm event. And the highest tides occurring each year, aptly named King tides, occur in December and January which are the prime months for winter storm activity. Although there is a sparsity of data upon which to base estimates, the indication may be that extreme storm events are likely to produce coincident coastal and fluvial flood hazards.

In the study area, large parts of the San Rafel community and critical infrastructure are located in the present-day floodplain. There are two significant sources of flooding that have the potential to cause impacts to City and community assets, namely fluvial flooding from San Rafael Creek and coastal flooding from the Bay. The 100-year peak discharge from San Rafael Creek, has a chance of 1 in 100 of occurring in any given year and is consequently termed the 1% annual chance flood scenario. Stormwater runoff in San Rafael Creek associated with a 1% annual chance flood event is estimated to reach 1,995 cubic feet per second at its peak, which constitutes a significant amount of floodwater having a potential to impact City and community resources in areas where the creekbanks are overtopped and flooding is routed downstream of these areas. Recent work by SFEI has established that precipitation patterns are projected to be affected by climate change in a number of ways. Precipitation intensity, duration, and frequency are projected to increase with climate change manifesting in the form of: 1) increased amounts of stormwater runoff, 2) higher levels of peak discharge, and more frequent storm events. This in effect means that what is today considered rare and infrequent storm events will be experienced more frequently, as will associated damage incurred by these storm events. The best available science also projects that climate patterns will become more irregular and extreme storm events may begin to push the boundaries of what is considered normal, seasonal precipitation patterns. Examples of such precipitation events are for example cloudburst events producing extremely intense, short-duration rainfall capable of producing flash flooding. At the other end of the scale are atmospheric rivers, which can convey a continues band of moisture to the coast producing rainfall for days. This weather pattern in well known in California and originates over the Pacific in the vicinity of Hawaii and thus termed a Pineapple Express. The historic 1955 Christmas flood was the result of a series of atmospheric rivers that produces about 20 inches of rainfall over a period of three days. Other types of storm systems that very rarely affect California, but are possible, include typhoon activity in the Pacific Basin. The indication from leading climate research is that increase sea surface temperatures will lead to more powerful storms with stronger winds and heavier rainfall.

Performance & Feasibility Analysis of "No Action" Scenario

1) Level of Fluvial and Tidal Flood Protection

If no action is taken to address SLR, the level of fluvial and tidal protection will degrade over time due to SLR and subsidence. It has been established that the San Rafael Basin is sensitive to large scale flooding at a tipping point of around +8 feet attributed to segments with low elevation, informally constructed barriers, and/or unstable geology along the Canal edge. Current King tides, reaching as high as 8.3' in 2025 are already nearing this tipping point. With a modicum of storm surge and/or El Niño conditions these tipping points could be exceeded more frequently. The flood hazard potential is significant as the lowest areas of the Canal basin are at +3 to 4 feet. Overtopping events start at around +8 feet which is currently a 5-year extreme tide. This flood would last for around 2 hours and affect around 500 people. A +10 foot event, roughly equivalent to a 100-year event, would affect around 12,000 people and could last as long as 24 hours. In addition to overtopping, there is also presently a risk of failure due to the informal nature of the existing private shoreline, which is not engineered or designed to withstand flooding above king tide levels today.

At +10', key evacuation routes are projected to be impacted or rendered inoperable, including I-580, and local evacuation routes along Anderson Drive, Bellam Boulevard, and Kerner Boulevard, portions of which are below the high tide level.

Because the flooding would be associated with tides overtopping the Canal edge, SLR will cause the number of flood events to increase significantly, which will initially be experienced as shallow nuisance flooding. With increasing SLR, the flooding will become deeper, longer in duration, and impact increasingly larger areas of the San Rafael Basin. At 1' of SLR, overtopping of the Canal bank would likely occur at least monthly, likely concentrated in winter months. The 1-foot rise in ocean level is an important threshold as this rise could be caused by high tide conditions combined with number of effects including: 1) SLR projected to occur near- to mid-term, 2) a strong to very strong El Niño episode, 3) storm surge, or 4) a combination of these. Therefore, flooding due to a 1-foot rise in ocean level could occur much more frequently than based on SLR projections alone.

On-going subsidence will mean these risks are even more likely, both in terms of reducing the height of existing protection thresholds and increasing the depth of basin inundation. Subsidence is projected to continue at varying rates throughout the developed historic Baylands area, however the subsidence rate for fill over bay mud is not linear and tends to slow over time through compaction.

2) Effectiveness at Different Planning Horizons

Under the No Action Scenario, the flood hazards identified present day will remain and gradually increase with SLR. A tipping point between minor and catastrophic tidal overtopping of the Canal shoreline is modeled between +8.5-9' today. The effects incurred by climate change are projected to increase the variability, intensity, duration, and frequency of rainfall, which will augment fluvial flood hazards. SLR will encroach on the available minimum freeboard of the Canal edge and Bayfront Levee and increase the potential for coastal flooding associated with overtopping of these structures. Rising ocean temperatures will conceivably increase the potential for larger and more impactful storm systems and potentially increase the magnitude and recurrence of El Niño episodes.

Taking no action to address SLR would be a gamble of probabilities. For each passing year, the impending probability of a large flood event would continue to build. Despite the risk of e.g. a 100-year storm event being limited to a 1% chance of occurrence each year, one can only go so many years before a major storm event could strike[1]. By this relation, the cumulative risk of experiencing a 1% annual chance storm event over a period of 100 years is a 63% chance. Other findings similarly arise from this equation. For a property located in the floodplain, the risk of facing a 100-year flood event over a 30-year mortgage term comes out to a 26% chance. During a 30-year mortgage the risk of experiencing a 10-year storm is quite high at 96%[2]. In the study area on-going subsidence further exacerbates these risks.

The precise timing of how long-term climate change and SLR will change these probabilities remains uncertain; however, over the next 30 years there is much more certainty that sea levels will continue rising, the land will continue to subside and those changes will increase the risks of flooding. One of the significant concerns of a no action scenario is the risk of a levee failure, which could result in catastrophic flood impacts within the San Rafael Basin.

Taking a No Action approach for the near-term would be playing the odds. Over the past 25 years sea levels have risen approximately 3 inches. According to the California Ocean Protection Council (OPC, 2024) there is high confidence that sea levels will rise another foot in the next 25-45 years. It should be noted that the rate of sea level rise is projected to accelerate over time. On-going subsidence in the study area will hasten the relative sea level rise felt locally—increasing the probability of overtopping shown below—and in some areas subsidence is several times faster than sea level rise.

[1] Statistically, this phenomenon is termed the encounter probability and can be described mathematically as $p=1-(1-1/R)^N$ where R is the recurrence interval of a storm event and N is the number of consecutive years.
[2] Cumulatively, the risk percentage then equals: $p=1-(1-65\%)^3$ equal to a 96% chance.

	Stillwater Level (ft NAVD88)	Modeled Recurrence Interval with Sea Level Rise (in feet)						
			2050		2100 (Low)			2100 (High)
		Present	+1’	+2’	+3’	+4’	+5’	+6’
	14	<1-in-1,000 chance	<1-in-1,000 chance	<1-in-1,000 chance	1-in-1,000 chance	**0.5% chance**	**2.5% chance**	**20% chance**
	13	<1-in-1,000 chance	<1-in-1,000 chance	1-in-1,000 chance	**0.5% chance**	**2.5% chance**	**20% chance**	**>Monthly** (21/yr)
	12	<1-in-1,000 chance	1-in-1,000 chance	**0.5% chance**	**2.5% chance**	**20% chance**	**>Monthly** (21/yr)	**>Weekly** (194/yr)
	11	1-in-1,000 chance	**0.5% chance**	**2.5% chance**	**20% chance**	**>Monthly** (21/yr)	**>Weekly** (194/yr)	**>Daily** (506/yr)
	10	**0.5% chance**	**2.5% chance**	**20% chance**	**>Monthly** (21/yr)	**>Weekly** (194/yr)	**>Daily** (506/yr)	**>Daily** (684/yr)
	9	**2.5% chance**	**20% chance**	**>Monthly** (21/yr)	**>Weekly** (194/yr)	**>Daily** (506/yr)	**>Daily** (506/yr)	**2x Daily** (706/yr)
	8	**20% chance**	**>Monthly** (21/yr)	**>Weekly** (194/yr)	**>Daily** (506/yr)	**>Daily** (684/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)
King Tide	**7.5**	**50% chance**	**>Weekly** (84/yr)	**Daily** (363/yr)	**>Daily** (612/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)
MHHW	**6.07**	**>Weekly** (167/yr)	**>Daily** (486/yr)	**>Daily** (672/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)
MHW	**5.51**	**Daily** (322/yr)	**>Daily** 592/yr)	**2x Daily** (703/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)
MSL	**3.32**	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**Submerged**
MLW	**1.13**	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**Submerged**	**Submerged**	**Submerged**
MLLW	**0.12**	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**2x Daily** (706/yr)	**Submerged**	**Submerged**	**Submerged**	**Submerged**

Figure 14. Table showing the recurrence intervals of still water levels increasing with sea level rise. Red dash indicates modeled tipping point between minor and catastrophic overtopping of the Canal shoreline. Green text indicates flood risk within FEMA 100yr standards; yellow indicates high risk of overtopping predicted; red indicates modeled overtopping prediction.

By 2050, minor overtopping events above 8’ are projected to occur approximately monthly, with higher events generally concentrated in the winter months, while the chance of catastrophic overtopping events above 9’ has doubled. For reference, FEMA certification for flood protection infrastructure typically requires a 1% annual level of protection. If no action is taken, the viability of continuing to live in the basin past 2050 is uncertain. Before the point of monthly overtopping the urbanized basin would likely no longer be inhabitable in its existing development pattern due to damage to structures, infrastructure, disruption of activity, and market perception of risk.

3) Spatial Requirements

A No Action scenario would maintain status quo and would not require any additional space.

4) Permitting Requirements

A No Action scenario would maintain status quo and would not require any permitting.

5) Land Ownership and Access Considerations

Under a No Action scenario, land within the floodplain would be exposed to periodic, recurring saltwater flooding. Depending on land use, the impacts could be significant. Flood depths would range from shallow flooding to several feet of flooding of the low-lying portions of the San Rafael basin. The groundwater table may rise concurrent with SLR near the shoreline, however groundwater levels are managed (intentionally or not) by the existing stormwater drainage system past the first public right-of-way and rise would be less apparent. Below-grade utilities could be significantly impacted as would at-grade utilities and facilities if not dry flood-proofed. The corrosive nature of saltwater has the potential to damage equipment, electrical systems, and building facades and foundations.

Both regional and local evacuation routes are impacted by the No Action scenario. Some of the most vulnerable segments of both the 101 and 580 are in the basin. In major overtopping events above +9', both 101 and 580 could potentially be inundated for several hours resulting in millions in dollars of economic impact due to traffic delays. In a major overtopping event all local evacuation routes would be inundated and emergency services may need to be provided by high water vehicles or by boat.

6) Potential Threats & Benefits to the Community

Potential threats to community assets are evident with the No Action scenario and could involve immediate and gradual impacts, degradation of infrastructure and public spaces, temporary displacement associated with repetitive nuisance flooding, and potentially permanent displacement from catastrophic flooding. Key impacts would include significant disruption and economic loss, impacts to transportation and public access, reductions in property value and city tax base for public services, and loss of quality of life.

Once the flood stage in the Bay exceeds +9 feet, almost all of the Canal edge and the lowest segments of the bayfront levee would also be overtopped, extending the flood perimeter to both the Canal and the Bayfront. Because the overtopping is associated with tidal action, the period of flooding may be limited to a number of hours over the peak of the tide. However, this is assuming the edge remains intact and/or protected. Evidence from past levee breaches in the Bay and Sacramento-San Joaquin Delta has demonstrated that the failure mechanism of an overtopped levee is that a narrow cut will rapidly incise the levee down to its base, which thereafter widens in response to the surge of floodwater, ultimately reaching a breach extent that is related to the tidal prism of the flooded area. Rapid response would be required to prevent this process.

Seismic events and liquefaction potential of bay mud present another potential source of risk and grow in statistical probability over time. The USGS currently estimates a 51% probability of a 7.0 earthquake in the next 30 years. A seismic event could lead to multiple failures at the same time and overwhelm the capacity to close breaches.

7) Co-Benefits of Adaptation Measures

The No Action scenario would not incorporate any planned adaptation measures to address projected SLR. Physical displacement, temporary and permanent relocation would likely emerge as necessary measures to cope with climate change and SLR related flood impacts. Without any action for restoration or remediation, repeated flooding of the urbanized area under higher sea levels is likely to negatively impact water quality and habitat.

8) Housing Implications

Housing within the San Rafael basin has a potential to be significantly impacted by recurring nuisance flooding, from transportation disruption to car and property damage. At the 8' threshold above which the Canal edge will experience tidal overtopping, the affected areas are relatively contained to the Canal District and population affected is estimated to be about 500 people. Housing units are not significantly impacted at this level but some commercial structures may experience minor flood damage.

In the event that peak flood stage reaches 9', the Canal basin and neighborhoods along Point San Pedro Road begin to substantially overtop. An estimated 6,100 residents could be impacted. Should the peak flood stage reach 11', flooding would inundate these areas with several feet of water, and one to two feet of water in portions of Downtown near Albert Park and San Rafael High School. An estimated 11,300 residents would be affected.

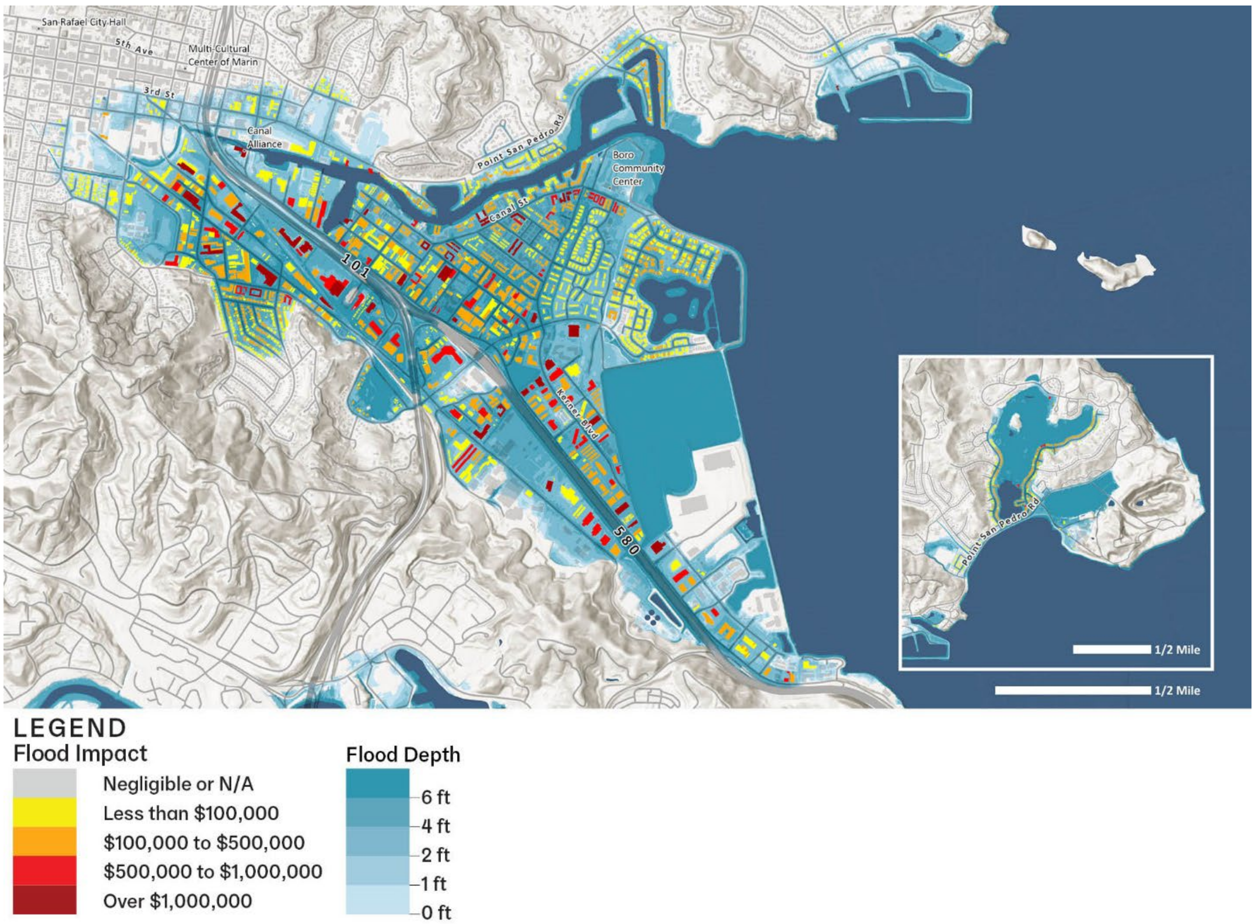


Figure 15. Impact of a +11' tidal event, used as the 2050 design storm for No Action and Alternatives 1 and 2.

9) Ecological Implications

The No-action scenario is likely to require emergency interventions which tend to be focused on short-term fixes. In the past that has included the use of large amounts of rock rather than nature-based solutions. In less developed parts of the bay, some breaches of salt pond and agricultural berms have been left unrepaired and marshes have developed. However, in San Rafael it is likely that any breaches would be rapidly repaired with gray or hardscape materials.

The No Action Scenario could incur significant impact to habitat and ecological functions. Some of the most immediate potential impacts could come from pollutants leaching from developed areas exposed to flooding and saltwater corrosion through repeated wet-dry cycles, which would then be drained and pumped to the Bay. Salt water in some respects could be considered a pollutant itself, altering nutrient availability, limiting water absorption, causing dehydration and osmotic stress to plants. It might be possible to curb egress of some toxins such as petroleum products and floating debris for which boom and capture technologies already exist. Removal of pollutants through capture, filtration and treatment would likely not be viable. Cleanup of affected areas may need to consider in-situ capping and/or groundwater cutoff and seepage barriers.

10) Economic Feasibility

The No Action scenario lacks any benefit value and so was used as a baseline for comparison. For all alternatives the economic impact was assessed as the balance between benefits and costs, where benefits encompass the value of land, facilities, properties, interior components, and elements such as housing security, stability and quality of life. Cost elements comprise flood damages, direct costs for repair and reconstruction, indirect costs, implementation of flood hazard mitigation, and operations and maintenance costs. The No Action scenario only includes costs, because without action, no benefit value is generated to measure.

Costs associated with projected flood damage were developed based on flood depths output from HEC-RAS fluvial and coastal flood modeling paired with depth-damage curves applied to city data for residential and commercial structures' parcel and assessed land values. Potential impacts to key transportation infrastructure were assessed based on the Caltrans Roadway Disruption Calculator. Indirect costs were assessed based on disruption to commercial activities, and potential for lost output, value losses, lost household earnings and employment losses, tax revenue losses, and insurance claims.

The modeling used here was based on the best available information but given the limited scope of this project neither the flood depths nor the economic losses were calibrated against historic flood data. It is possible that loss values are only experienced long after a flood event, for example where salt water corrodes a building foundation or drainage infrastructure. The economic loss assessment estimated $19 - 31M total of flood impacts for +8', increasing to $130 – 210M for still water levels reaching +9'. The large increase in economic losses between +8' and 9' water levels indicate a tipping point in the ability of the current system to manage tides in this range. At a flood stage of +10' and above, the economic loss was estimated to $340 – 560M up to $800M – 1,400M for the 11' event. The 11' event was used as the design storm for Alternatives 1 and 2 in the economic feasibility portion of the study.

Even at modest levels of overtopping the Canal edge, multiple buildings are projected to be impacted with economic losses in the $100,000 to $500,000 range, with a few facilities having the potential to incur losses exceeding $1M.

b) Initial Actions

Description

The initial actions focus on the immediate, critically needed adaptation to address present-day flood hazards. Implementation of this strategy can take multiple pathways depending on how climate change and realized SLR unfold. This approach means that SLR adaptation expenditures become more focused and streamlined and is well suited for a project-by-project approach to implementing SLR adaptation for San Rafael as opposed to embarking on one project.

There are two areas where significant weakness or low elevations create a risk of flooding for the basin. These include segments of the Canal edge and Bayfront levee that have low land surface elevations. The significant flood risk attributed to these low areas is not merely that these will serve as conduits for ingress of floodwater in a storm event, but also the risk of one or more of these low spots becoming the location of a catastrophic failure that could lead to significant flooding of the low-lying portions of the San Rafael Basin. An initial trickle of overtopping floodwater can proceed to carve a sizable channel capable of accommodating a higher rate of inflow bringing with it a vastly increased rate of erosion. Stabilizing and incorporating embankment protection along the Bayfront levee would significantly reduce the risk of a catastrophic levee failure and could mean that if the levee is overtopped in a major storm event.

Raising the crest elevation above the projected water level (freeboard) can incorporate a significant measure of resilience in that there is an inherent buffer to: 1) address a slightly higher water level, should the storm event turn out more severe than forecast, 2) as an allowance to accommodate projected SLR; 3) build resilience to withstand moderate storm events with SLR, and 4) accommodate unforeseen extreme events such as e.g. strong El Niño episodes, which can effect a rise of the mean sea level of around 1 foot. There is also an allowance for subsidence of levee structures as the Bay Mud compacts. All the San Rafael levees are constructed on Bay Mud. The Bay Mud is 80-100 feet thick by Spinnaker Lagoon and Canalways decreasing to about 40 feet by the Marin Rod and Gun Club. Along the north shore from the Canal to Brickyard Cove, it is between 20 and 40 feet thick.

Initial Actions are described according to landscape typologies:

Canal (Shoreline)

In order to balance costs versus level of protection, raising the Canal edge would be planned for incremental upgrades. The lowest portions of the canal edge, areas below +8 feet would be raised first. A key element of this strategy is to ensure that the constructed upgrades are done in such as way as to facilitate future upgrades. This functionality would be incorporated at the design stage. One option is raising the Canal edge to the design elevation of Alternative 1 as a pilot for that alternative. The other option is implementing more temporary or lower measures, either as part of the shoreline stabilization in alternative 2 or due to other constructability and or timeline restraints.

Raising the lowest portions of the edge also involves piloting and testing small-scale ecological actions in neighborhoods that can be expanded in larger future alternatives. Measures include native plantings, eelgrass and oyster test plots, nearshore reefs, enhanced pocket beaches, and planting into existing riprap/ green-grey rock slopes.

Bayfront (Shoreline)

Initial Actions on the bayfront are developed to support all future alternatives.

Every adaptation pathway includes raising the levee, and steps can be taken today to begin detailed survey, planning, and design for bayfront levee adaptation. Areas undermined by animal burrows or showing signs of seepage should be repaired immediately. Initial Actions include the evaluation of public acquisition of waterfront properties and/or easements along shorelines that serve a flood protection purpose around low-lying basin areas. Infrastructure such as levees that protect public safety are most reliably maintained when subject to public oversight in the public domain. This public ownership may be required, for example if federal funding is used or if future flood management infrastructure is built and certified to FEMA standards as a holistic system.

Continue to work towards implementation of Tiscornia Marsh restoration, which will serve as a demonstration project and prototype for San Rafael residents and the contracting community. In addition, Initial Actions can include building on knowledge from existing habitat pilots programs to pilot and monitor additional measures that can be implemented in future alternatives. These could include an expansion of the San Francisco Bay Living Shorelines oyster reef pilot in San Rafael to different depths, geometries, and offshore distances for present and future wave attenuation.

Basin

For all alternatives, pump stations in some configuration will be required indefinitely to manage stormwater and groundwater in existing basins, and the extent of forced drainage area is likely to grow as seas rise and land subsides further, which will increase reliance on the pump stations.

Initial Actions in the basins at the Canal and around Peacock Gap include maintaining and upgrading 12 existing pump stations. Pump stations provide the only way to manage stormwater and tidal overtopping today, and it is critical they remain functional while adaptation measures are implemented. (Stormwater drainage performance was not evaluated as part of this study.)

An important element of such planning would be the recent work by SFEI to gauge how future rainfall patterns may change in the Bay Area as a result of climate change (Sevier et. Al, 2025). The pertinent hydraulic engineering aspects in this regard would be the intensity of rainfall, the duration of rainfall events, the recurrence frequency of such events, potential changes in timing from a seasonal perspective, and the potential for changes in the types of atmospheric systems bringing rainfall to the area, including consideration of cloudburst events, larger low-pressure (extratropical) storm systems, atmospheric rivers (subtropical storm systems), and the potential for typhoon activity (tropical cyclones).

Initial Actions include proactive elevation of critical infrastructure, such as Fire Station 54, to ensure emergency response in the event of stormwater flooding and/or catastrophic overtopping; the evaluation of road raising at the parcel scale for critical access pathways to high ground across the Canal and under the interstate; and the evaluation of expanding of city services to fund, maintain, and operate critical infrastructure, including levees, through the Public Works department or a new entity.

Upland

Initial Actions upland include improving housing options and stormwater green infrastructure to provide flexibility for adaptation in high flood risk areas at lower elevations.

Funding programs to plan and support construction of multifamily housing on higher ground outside the basin, such as downtown, and aligned with the city's General Plan, can potentially support the incremental reconstruction of low-lying and soft story dwellings within the basin. This is advisable to complement all alternatives.

Actions include incentivizing, planning and constructing green stormwater infrastructure on public and private property, including street bump outs, bioswales, permeable surfaces and subsurface detention to reduce downstream flood pressure. Green infrastructure provides secondary benefits for urban heat island reduction. This is no-regrets and advisable for all alternatives.

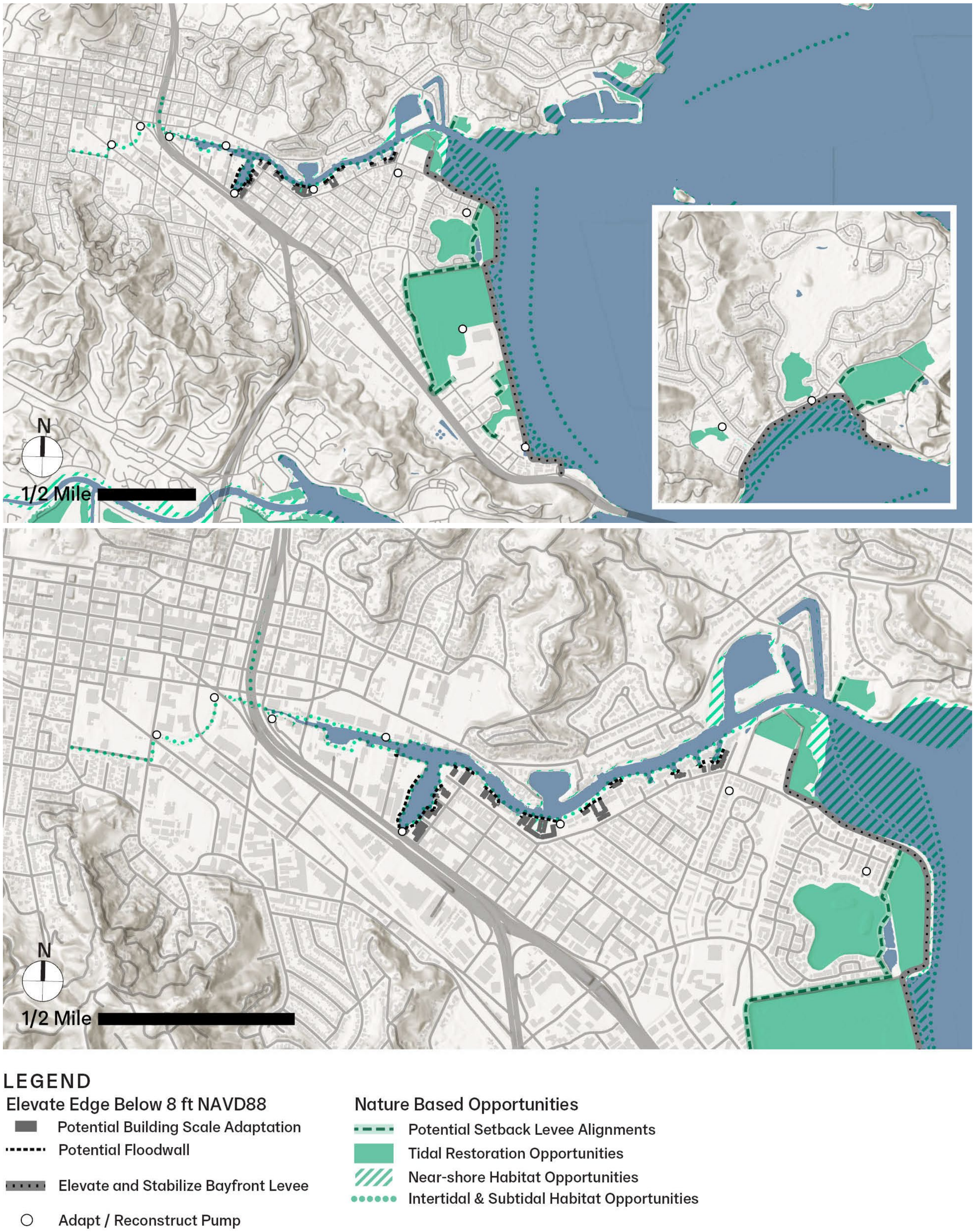


Figure 16: Initial Actions adaptation measures & alignment, full OLU (top) and Canal detail (above).

Performance & Feasibility Analysis of Initial Actions

1) Level of Fluvial and Tidal Flood Protection

Initial Actions involves elevating the lowest portions of the Canal edge, and informal edges, that protect a basin condition to at least +8 feet. That is a 5-year event currently, but the alternative would still experience overtopping during higher events. The current shoreline is a mix of conditions, some of which are very informal and could fail due to several variables. This assumption of "protection" to a 5-year event represents a best-case scenario where none of those shoreline segments fails due to another factor (like breaking, cracking, or erosion).

While the canal edge could be built to the same design elevation as Alternative 1, limiting the elevation to areas below +8 feet would limit the volume of water that could enter the area during a 5-year storm. Elevating the edge to higher elevations than +8 feet would require almost all the canal edge to be elevated to achieve a continuous line of protection. Elevating the lowest portions of the edge is an interim step to either alternative 1 where the entire edge is elevated or alternative 2 where interior edge elevation lowers the closure frequency of the tidal gates.

2) Effectiveness at Different Planning Horizons

Upon completion of construction of the initial flood risk reduction actions focused on raising the low portions of the Canal edge and stabilizing the bayfront levee, if the Canal shoreline is raised to have a minimum elevation of +8 feet or higher it would limit the volume of tidal flooding against approximately a 5-year storm event. Wave action on the bayfront could be expected at 1-2'. Subject to a 25-year event, the edge protection would be expected to hold back storm surge, but an amount of wave overtopping could be experienced at the bay and potential stillwater overtopping in the Canal. If no large storm events ensue, the perimeter upgrade to +8 ft would incorporate a measure of resilience against extreme tides and lesser storm events, El Niño episodes, and projected SLR.

Initial Actions are estimated to take from 5-20 years to implement, largely depending on public consensus and political will to take action. It is imperative these or similar measures are taken for immediate flood safety and to buy time for further adaptations.

3) Spatial Requirements

The spatial requirements of Initial Actions vary pending field investigation and confirmation of remediation need and approach. There are approximately 38 parcels along the Canal where the land is lower than +8'. Creating flood protection in these areas could take several forms including dry flood-proofing or seawalls outboard of vulnerable land and structures. It is unlikely existing buildings will be able to be modified to keep tides out, let alone out of the basin; it is more likely a semi-permanent seawall, such as pressed in with vinyl sheet pile, will be required. Construction access may require construction of temporary platforms for equipment or may be accomplished by barge in some locations. Existing docks will need to be repositioned and possibly reconstructed with ramps to maintain access. Pedestrian or vehicle gates should be avoided.

For the bayfront levee and along Point San Pedro Road, detailed survey of the entire shoreline would include over three miles in total length to inspect for seepage, animal burrows, or other weak points, followed by immediate repair with compacted fill and temporary armoring. These patches would be replaced in later alternatives. A recent levee review conducted in partnership with the US Army Corps of Engineers in June 2025 identified areas of concern along the bayfront levee. Those findings were reviewed in this study and add urgency to the need to complete a more detailed survey and conditions assessment of the levee to begin immediate repairs and temporary armoring.

Potential Building Scale Adaptation	Number / Length	Notes
Parcels	32 to 38	
Buildings	Up to 33	If adapted at building
Floodwall	Up to 3,300 ft	If adapted with seawall
Potential Shoreline Stabilization		
Bayfront levee	10,800 ft	Action to be determined; existing lengths for inspection & potential stabilization
Point San Pedro Road shoreline	6,000 ft	

Figure 17: Potential extent of spatial impacts for Initial Actions.

4) Permitting Requirements

State and federal agencies would need to be consulted with regarding permits. The US Army Corps of Engineers (USACE) would need to be consulted with for any construction considered to be within the waters of the United States. As part of the USACE permitting process, the project must comply with Section 106 of the National Historic Preservation Act, which will require tribal coordination. The Regional Water Quality Control Board (RWQCB) would need to be consulted with regarding potential watershed and water quality impacts. NOAA National Marine Fisheries Service (NMFS) would need to address potential impacts to fish, which would additionally require consultation with U.S. Fish and Wildlife Service (USFWS) and California Department of Fish and Wildlife (CDFW) at the state level. Construction within the 100-foot shoreline band along the Bay edge will require consultation and permits from the San Francisco Bay Conservation and Development Commission (BCDC). Potential consultation with the California State Lands Commission (CSLC) if any proposed construction is on granted lands, but this is not believed to apply to the project area.

5) Land Ownership and Access Considerations

Land ownership and access will play a considerable role in how SLR adaptation improvements are planned and constructed. Most areas needing initial improvement are on privately owned land, where options may including negotiation, granting rights, limiting improvements to within the right of way, or as an emergency last resort through a declaration of eminent domain for easements (not structures).

Due to the density of development, means of access, and proximity to community, facilities and city infrastructure in many areas, construction activities should be planned carefully and considered in early design phases. For any large-scale work involving large construction equipment and large quantities of material, marine construction may prove the most feasible option.

6) Potential Threats to the Community

Potential threats to the community would include impending flood risk until initial improvements are in place. Another potential impact would be visual, disruption, noise, and vibration impacts associated with construction. It is estimated that approximately 114 housing units could be affected by construction, 106 of which would be multi-family units.

7) Co-Benefits of Adaptation Measures

This alternative provides significant opportunity for aligning proposed flood mitigation measures with adjoining habitat creation, enhancement, and preservation. The objective would be to develop habitat enhancements sufficient to make the proposed improvements self-mitigating. Additionally, demonstrate that the proposed improvements reflect the Least Environmentally Damaging Practicable Alternative (LEDPA), which will necessitate evaluation of a No Action Alternative.

8) Housing Implications

Elevating the lowest portions of the canal edge would impact approximately 38 parcels. It may not be possible to maintain all existing buildings. The buildings that overhang the water and would likely be affected most by construction are predominately multi-family housing with 170 units in total. Elevating the Canal edge to +8 feet protects around 500 people in 110 housing units in total.

9) Ecological Implications

The raised Canal edge would consist of living seawall panels where possible combined with other habitat enhancing features as possible. Initial Actions along the Canal's shoreline would be shorter floodwall segments, potentially implemented as individual projects, which could be amenable to pilot-scale efforts at enhancing living seawalls. Lessons from constructing these pilots could inform the design of larger scale efforts selected for long-term adaptation.

10) Economic Feasibility

Initial Actions are intended to be implemented as fast as possible with available city resources. Site-by-site evaluation is needed to determine potential costs.

As a one reference point, the assessed value of the structure itself could indicate a range of values for building-scale adaptation. The average structure value of the 33 potentially impacted buildings, primarily multifamily residential, is $1.3M, or $42.9M.

As another reference point and upper budget bound, per-linear-foot costs for the Canal seawalls proposed in Alternative 1 are $15,000/lf for onshore construction and $23,000/lf for offshore construction. At 3,300 feet of Canal edge, these costs would range from $49.5M to $75.9M respectively.

It should be noted these values serve not only to protect the affected structures themselves, but all of the basin behind them up to the design water level.

c) Nature Based Opportunities

Description

Nature-based, or ‘living shorelines’ solutions include habitats (e.g. coarse beaches, ecotone or ‘horizontal’ levees, offshore oyster reefs) that complement shoreline flood protection measures by preserving or enhancing existing habitats, recreation, and/or public access. These measures may provide some degree of flood hazard reduction in the form of wave attenuation and scour protection. They are combined with structural flood protection such levees and floodwalls as hybrid green/grey measures where still water overtopping is the primary flood risk driver, such as in San Rafael.

These approaches have been explored at a conceptual level for the San Rafael shoreline as part of the Resilient by Design Bay Area Challenge (Bionic 2018), by the San Francisco Bay Adaptation Atlas (SFEI and SPUR 2019), by non-profit groups such as Resilient Shore, and as part of City planning efforts (City of San Rafael 2014) and county-wide planning efforts (Point Blue, SFEI, and County of Marin 2019).

There are multiple habitat opportunities within every alternative that utilize nature-based strategies to minimize wave action and erosion to support flood hazard mitigation goals, especially on the Bayfront, where these forces are most prevalent and more space exists for their implementation. There are several existing pilot projects and ongoing efforts that can be expanded and can inform other habitat opportunities creating a diversity of habitats at a variety of feasible elevations, from subtidal to upland. New pilot projects and ongoing implementation of habitat enhancements should anticipate and avoid, to the extent possible, locations of potential future construction of adaptation measures to preserve their long-term health and ecosystem value. These opportunities can be implemented in various configurations and are subsequently integrated within the analysis of each alternative.

Nearshore Habitat

San Rafael is highly suitable for the establishment of nearshore reefs and sub aquatic vegetation (SAV) with the right enhancements. The San Rafael OLU bayfront has been identified as a priority for restoration sites for native oyster restoration and eelgrass survey and restoration, and opportunities exist to advance these goals with new knowledge.

The San Rafael Living Shorelines pilot site, installed offshore of Spinnaker Point in 2012, was the first larger-scale demonstration site for restoring native oyster reefs and eelgrass beds in San Francisco Bay (Latta and Boyer 2016). Building on this pilot site and others like the Giant Marsh living shorelines projects, opportunities may exist in San Rafael to test the performance of nearshore reefs higher in the tide range working in conjunction with the pilot site already installed. For example, reef structures placed at depths up to 1.5' MHHW may provide better wave attenuation. While this elevation is less than optimal oyster habitat it could become more suitable as sea levels rise. The 0 to +1.5' band is mapped above and below the pilot site already in place. Opportunities to test novel reef geometries surrounding the existing San Rafael pilot site may also provide new insight.

Eelgrass plantings can provide physical benefits through their extensive root systems and leaf canopies, which reduce bottom velocities and promote sedimentation in the shallow subtidal and on mudflats. Increased bed elevations will help attenuate waves and ultimately reduce shoreline erosion. Eelgrass beds provide foraging habitat for fish, spawning substrate for native species such as Pacific herring, rearing habitat for species such as juvenile Dungeness crab, and habitat cover for other species of invertebrates, fish, and wildlife.

Eelgrass plantings can be conducted alone or in combination with other living shoreline approaches, such as nearshore reefs, as was done at Spinnaker Point. Pilot projects to date have collected eelgrass from donor beds and prepared planting units by bundling rhizomes. Sources of eelgrass propagules include existing natural donor beds in San Francisco Bay, such as the seven most extensive beds in the bay, including Point San Pablo, Point Molate, Keller Beach, Richardson Bay, Sausalito shoreline, Alameda Beach, and Bay Farm Island.

Coarse Beach

Coarse estuarine beaches are dynamic features that can consist of a mixture of sand, shell, gravel, and/or cobble. The beach profile starts with a supratidal berm at the top, then slopes down with its face in the intertidal range that is regularly exposed to re-working by waves. The lowest position of the beach is often characterized by low tide terrace that transitions to intertidal mudflat.

Beaches protect the shoreline from erosion while managing risks from storm surge, erosion, and wave runup. They also provide additional support for biodiversity, food supply, recreation, and public access to bay waters. Native plant species that occur along the backside of beach berms, such as California seablite, were prevalent before development encroached on these habitats. Beaches can also provide haul outs for harbor seals.

Natural beaches in San Francisco Bay are generally comprised of sand, but can consist of sand, gravel, cobbles, or shell hash. Restoration or enhancement of bay beaches requires adequate space in the cross-shore and alongshore directions, and generally a low slope in the area of material placement. Beach crest height is a function of peak wave levels from combined tides, wind setup, storm surge, and wave runup. Slope is a function of material type (with coarser material leading to a steeper equilibrium slope). Beaches in the Bay tend to exist between elevations of MLLW and 2 to 3 feet above MHHW. They generally require a minimum cross-shore distance of 50 feet and a minimum alongshore distance of at least 300 feet. To encourage beach resilience while minimizing the need for sediment augmentation to replace eroded beach sediment, new beaches should consider wave exposure, shoreline alignments, and beach sediment size.

Beaches can be augmented with sediment retention features to reduce the likelihood that wave exposure erodes beach sediments over time. Sediment retention features are natural or constructed obstructions to limit beach sediment transport. These features can be composed of a range of material types and sizes, including concrete, rock, or large woody debris. Retention features reduce beach erosion and thereby assist in providing the ecosystem benefits associated with beaches including limited erosion, high tide refugia and foraging habitat for shorebirds, and a continuum of nearshore habitat types.

Beach nourishment is an adaptation measure that provides protection against coastal storm erosion while maintaining the natural condition, beach habitat, and processes. Beach nourishment refers to placement of sand to widen a beach, which can be accomplished by placing a sediment-water slurry directly on the beach or mechanical placement of sediment with construction equipment. Impacts to beach species can occur during construction but are generally temporary.

Natural beaches within San Francisco Bay are described in in the Baylands Ecosystem Habitat Goals Project reporting (1999, 2015), San Francisco Bay Adaptation Atlas (SFEI and SPUR 2019), and recently within the New Life for Eroding Shorelines (SFEI and Baye 2021) report. Pocket beaches are present throughout San Francisco Bay, especially where a local source of sediment (typical a local creek or local bluff erosion) coincides with features such as rocky headlands that act to trap sediment. There is also a growing body of constructed beach sites with San Francisco Bay within the past decade, including at Aramburu Island in Corte Madera and Heron's Head Park in San Francisco.

Three concave insets along the San Rafael shoreline have existing pocket beaches that have naturally accumulated sand where longshore transport converges: south of Spinnaker Lagoon, south of the eastern managed wetlands, and just west of the Brickyard Marsh. Currently, the remaining portions of the Bayfront are relatively straight and could require substantial import of sand, both initially and possibly for ongoing nourishment, to sustain beaches. Future levee re-alignments inland could create similar concave insets along the shoreline that facilitate creation of and sustaining beaches. The City's planned Tiscornia Marsh Restoration and Sea Level Adaptation Project includes creating a coarse beach along the edge of Tiscornia Marsh to arrest ongoing marsh erosion.

Enhanced Hardscape

Much of the San Francisco Bay's natural shoreline has been covered with hardscape, in the form of rock armor fill (a layer of large rock or concrete chunks, known as riprap or rock slope protection) or vertical floodwalls (constructed from concrete, vinyl, or metal). This hardscape was typically selected to fortify and stabilize slopes or softer sediments from erosion while also providing flood protection. Unfortunate consequences of this hardscape have been the interruption of the natural habitat transition from water to land and corresponding reduction in foraging and breeding grounds for many species of plants, birds, benthic invertebrates, and other organisms that depend on the intertidal zone for their needs.

To increase the habitat benefits of these hardscapes, they can be enhanced with measures to make their surfaces more amenable to natural organisms, particularly those that have adapted to inhabit rocky shorelines. This includes both vegetation and invertebrates that live on rocky shorelines as well as species such as shorebirds, fish and fish, and crustacean that forage in these habitats. While not an improvement over natural marshes, beaches, and mudflats, hardscape enhancements can provide ecosystem benefits over the bare rock face of existing and proposed riprap installations. Hardscape enhancements may improve the aesthetics and increase the "natural" appearance of a shoreline relative to unenhanced hardscape but would likely have the opposite impact on existing soft shorelines.

Rocky intertidal habitat

Much of the San Rafael shoreline is armored with rip rap or with sea walls. These shorelines could be enhanced by incorporating rocky intertidal habitat elements. These can help reduce wave energy and erosion, protecting the shoreline edge. They also provide multiple habitat benefits such as substrate for seaweeds and invertebrates, and native plants that provide foraging resources for birds, fish, and wildlife, as well as niche habitats such as tide pools, that increase biodiversity in the Bay.

Rock can range in size from large boulders to cobbles and pebbles. Enhancement of rocky intertidal habitat could include planting of emergent native vegetation, adding seaweed donor cobbles to the slope, placement of reef balls and oyster blocks at the toe, and adding precast tide pools. These could be place on riprapped reaches from the San Rafael Bridge to Pickleweed Park, the marinas, Point San Pedro Road, and McNear Brickyard Road. Enhancement of smooth vertical walls along the Canal, including introducing more natural rock surfaces with more complex grooves, shelves, ledges, holes, and surface roughness to mimic the historical rocky bluffs on islands along the north shore, adding donor seaweed on cobbles, placing reef balls and oyster blocks, adding precast tide pools, and removing debris and derelict structures

These approaches would be combined with removal of debris and derelict structures (such as pilings) that are commonly found around the Bay.

Planted Rip Rap

Bare riprap slopes can be enhanced by filling interstitial spaces with finer sediments and seaweed-bearing rocks, to provide habitat, forage, and shelter options on the rock slope itself. Designing this interstitial fill depends on the wave climate and degree of sediment retention desired. Selected sediments should be responsive to the requirements of target species. Larger terrestrial species may also have preferred features, such as rocky 3-4 inch-diameter crevices for oystercatchers, as well as some larger holes or even installed artificial burrows for species like ground squirrels.

At the top of the slope, above regular inundation, soil placed over the riprap can support native plants selected for salinity tolerance and lifespan in relation to expected sea level rise. A bed of shell fragments could provide habitat for California seablite (Suaeda californica), which requires well-drained substrate to grow. Bird boxes could be installed along with native vegetation plantings to attract swallows and other cavity nesters.

Enhanced riprap has implemented in the Bay at the Point San Pablo Terminal Four Wharf, Warehouse, and Piling Removal Project by the California State Coastal Conservancy (SCC), City of Richmond (City), and Port of Richmond (ESA 2020). At Terminal Four, the efforts to enhance the habitat value of riprap shoreline consisted of a living crown of native vegetation planted at the top of the riprap slope, filling the interstitial spaces of the rock face with finer sediments and seaweed-bearing rocks, and installation of artificial oyster reefs at the toe. (Oyster reef installations at the toe of hardened shorelines help provide transitional habitat between the rock slope and Bay mudflats; these measures are discussed in more detail below).

In San Rafael, much of the shoreline, from the Richmond-San Rafael Bridge to Pickleweed Park, the marinas, Point San Pedro Road, and McNear Brickyard Road, is steep slopes armored with riprap. There are opportunities to enhance the riprap slope, such as planting native vegetation on the slope and crest with proper substrate design, as well as nearshore reefs at the toe of the slopes, to provide habitat for oysters and other sessile organisms. Coarse beaches may be suitable where there is significant wave action to reduce run-up and overtopping, particularly in areas where pocket beaches can be created.

Managed Wetlands & Tidal Marsh Restoration

Tidal marshes are vegetated coastal wetlands subject to tidal inundation. These marshes comprised much of the historic San Rafael shoreline before fill was placed within these marshes for development and to construct levees along the outboard marsh edge. While most of the historic marshes have been completely buried with fill, portions of these marshes remain along the Bayfront as managed wetlands, in sizes varying from about an acre to about one hundred acres. These areas are managed in the sense that inundation from the Bay is obstructed by levees, at most only allowing for some groundwater seepage and, in some cases, allowing for muted tidal exchange via tide gates. Many of these wetlands still host tidal marsh vegetation and brackish or saline water and soils. However, the ground surface in these managed wetlands may be subsided relative to natural tidal marsh.

Tidal marshes provide flood benefits by reducing wave runup on and erosion of landward shorelines. This can reduce the potential for wave overtopping, possibly enabling lower landward levees and reducing levee maintenance. Because marshes naturally build up elevation through biomass and sediment accumulation, these flood benefits can be sustained with sea level rise.

Tidal marshes provide important habitat for sensitive and special status native species. Tidal marshes may have freshwater inputs that establish estuarine, brackish marsh gradients. Historic tidal marshes often transitioned from to unvegetated tidal flats at lower elevations and to dune scrub or willow sausal habitat at higher elevations. Tidal marshes sustain a diverse array of specialized and often rare species. They serve as critical habitat for endangered wildlife such as the salt marsh harvest mouse (Reithrodontomys raviventris) and Ridgway's rail (Rallus obsoletus). Marshes also support a wide range of waterbirds—including ducks, geese, herons, egrets, and shorebirds. Marshes play a crucial role in aquatic ecosystems by supporting food webs and serving as nursery grounds for fish and open-water species like Dungeness crab (Cancer magister). They also support resident fish species such as the longjaw mudsucker (Gillichthys mirabilis), which spend their entire lives within the marsh environment.

The few existing marshes along the City shoreline or restored marshes could face increased inundation and potential drowning of marsh vegetation if sea level rise accelerates beyond these areas' natural capacity to build elevation with biomass and sediment accumulation. If sea level rise causes this marsh degradation, the marshes could be sustained for longer with thin layer sediment placement to help maintain marsh elevation with sea level rise.

Ecotones are vegetated, gradually sloped area between high marsh and upland areas that can provide unique transitional habitat value. Ecotones can provide high tide refugia for marsh wildlife and create a wildlife buffer between the marsh and adjacent developed areas. When located on the outboard side of flood protection levees, ecotones can also dissipate wave energy by inducing wave breaking, and by resistance from vegetation. Relatively wide ecotones could also create transgression space for tidal marsh habitats, whereby upland transitional habitats would gradually convert to tidal marsh as sea level rises. The actual width of a constructed ecotone slope varies significantly, and depends on functional objectives, available space, ability for long term maintenance, and other factors.

Along the San Rafael Shoreline, ecotone slopes maybe incorporated along the waterside of new or existing levees for ecological and flood protection benefits.

As part of ongoing SLR planning, the city should evaluate the potential for re-aligning the Bayfront levee landward to restore diked former wetlands to tidal marsh. For managed wetlands on public lands, the city would ideally consider restoring marsh and levee realignment in conjunction with Bayfront levee improvements. For privately-owned wetlands, the potential for future marsh restoration will depend on landowner cooperation, and the timing of which could likely not align with Bayfront levee improvements.

Key considerations for tidal marsh potential and restoration feasibility include land ownership, site topography and degree of subsidence, parcel size and constructability of the proposed setback levee alignment. Besides constructing new setback levee to restore tidal connectivity, marsh restoration may also include placing sediment to raise any subsided areas, planting to accelerate vegetation establishment, and creating ecotone transition slopes between the marsh edges and any setback levee.

Opportunities for tidal marsh restoration and/or enhancements as the Bayfront shoreline is improved for flood protection include:

- Tiscornia Marsh Restoration and Sea Level Adaptation Project
- Point San Pedro Road shoreline , including east of Sea Way, east of Loch Lomond Drive, and inboard of Beach Drive
- Spinnaker Lagoon
- Canalways
- East San Rafael Wetlands
- Brickyard Marsh

At Tiscornia Marsh (adjacent to the Al Boro Community Center), a planned restoration project to addressing ongoing marsh erosion will showcase three nature-based approaches, coarse beach, and levee ecotone slope and tidal marsh restoration (in conjunction with a shoreline setback levee) (ESA 2018). The Tiscornia Marsh project would demonstrate the value of comprehensive flood protection planning for the city. This project has been planned with state funding in partnership with the city and will be ready to begin construction next year as a first step in the city's coastal flood protection. The project will increase the area of fully tidal marsh at the mouth of the Canal and includes the lowering of the outboard levee and the construction of a new setback levee.

There are also small marshes north of the Canal mouth, west of Summit Avenue, east of Sea Way, and along Beach Drive. There is little opportunity for expansion or migration of these marshes given the present road layout, and the focus should be on managing and sustaining these marshes. For all alternatives, both the north Canal marshes and Tiscornia Marsh should be allowed to remain fully tidal.

Other recent conceptual designs have proposed ecotone levees fronting the Bayfront South area, restoration of the Canalways and Spinnaker marsh areas, and coarse beaches fronting raised levees in front of the Bayfront South and Point San Pedro Road and Loch Lomond areas. There are two managed lagoons/wetlands along the shoreline - East Spinnaker Point Lagoon and East San Rafael Wetlands. These are both landward of the shoreline levee and have limited to no tidal connection. The East Spinnaker Point Lagoon Conceptual Enhancement and Management Alternatives Report proposed modifying the shoreline levee to increase tidal flow. East Spinnaker Point Lagoon could be breached, and a shorter setback levee could be constructed between the east and west lagoons. A marsh could naturally accrete, or fill be placed to accelerate marsh development. The marsh could help reduce wave runup on the levee. Building a setback levee behind East San Rafael Wetlands could allow for increased tidal connection without increasing flood risk.

The undeveloped historical baylands of Brickyard Cove are surrounded by uplands. Creating tidal connection has the potential to restore 52 acres of a relatively complete marsh complex, which is not too subsided (mudflat and low marsh elevations) and adjacent to an undeveloped transition zone. However, a setback levee is required to protect some low-lying areas in the quarry to the south; Point San Pedro Road, east of McNear Brickyard Road; and some access roads hugging the former marshlands. Opportunities will depend on choices made for Point San Pedro Road and McNear Brickyard Road in long-term alternatives.

Canalways is another impounded wetland condition although it is somewhat different from Brickyard Cove. While it is twice as large, it is more deeply subsided—and may continue to subside 2-4 feet in the next 30-70 years—and is mainly below Mean Lower Low Water (MLLW). Portions of the bayfront levee along the property remain privately owned and appear to be low and/or in poor condition. Two former landfill sites are immediately adjacent to the property, so restoration would also require investigation and likely mitigation measures to limit the groundwater interaction with potential contamination. One site has a leachate system and is actively monitored, but the other may or may not have a leachate collection system. Both landfill sites are in a location where the groundwater is artificially depressed, approximately +0′, due to the levee and the leachate collection system. Stormwater outfalls for the surrounding area flow through open ditches to the recently replaced San Quentin pump station and out to the Bay. All future options for Canalways, whether reconnected to the Bay or filled and developed, are constrained.

If reconnected to the Bay, the property would require a long time to naturally accrete sediment before marsh vegetation could establish or would require the placement of large volumes of fill to accelerate marsh development. Creating a setback levee could allow the initial restoration of mudflat, much of which was lost historically with the diking of the Baylands and later allow the establishment of marsh. This would help create an almost continuous natural shoreline of marsh and mudflat between Tiscornia Marsh, East Spinnaker Point Lagoon, Canalways, and East San Rafael Wetlands. There are also opportunities to place fill to create an ecotone slope transition zone along the setback levee to compensate for the lack of naturally rising ground. If developed, the property may still sustain some area of open space for potential restoration and reconnection to the Bay.

The East San Rafael wetlands were initially implemented as a mitigation project and are required to be maintained. Tide gate replacement for flow control improvement as well as setback levees for SLR management on the lowest inland edges will be required.

Enhanced Seawalls

Incorporating ecological features into seawalls — like niches that support aquatic plants and small marine organisms — can provide ecosystem benefits. Seawall enhancement can take the form of attaching textured tiles to an existing seawall (retrofit) or incorporating ecological features into new designs. The texturing provides purchase and shelter and should be placed at appropriate elevations relative to tidal inundation. Seawall enhancements are applicable in intertidal and subtidal parts of the wall, not in areas above the tides. Seawall retrofit is being tested at the Port of San Francisco's Embarcadero seawall with plans for integrated seawall panels for new seawall construction.

As part of raising the Canal edge as part of the initial actions and a selected alternative, seawalls are likely measures to provide flood protection within the limited space along the Canal's shoreline. Initial actions along the Canal's shoreline would be shorter floodwall segments, potentially implemented as individual projects, which would be amenable to pilot-scale efforts at enhancing living seawall enhancements. Lessons from constructing these pilot efforts could inform design of larger scale efforts selected for long-term adaptation.

Similarly, as the Bayfront levees are improved both initially and over the long term, areas with riprap could be enhanced with native plantings along the top and seaweed along the face. As part of selecting the alignment for these Bayfront levee improvements, opportunities to create additional nature-based solutions, such as those described below, should be considered to expand the diversity of shoreline habitats beyond just enhanced hardscape.

Mudflat Habitats

Continuing nature-based solutions to offshore onto the fronting mudflat offers enhanced ecological function of diverse habitats in close proximity to shoreline marshes and beaches and improves overall resilience to changing environmental conditions.

The California State Coastal Conservancy installed the San Rafael Living Shorelines pilot site offshore of Spinnaker Point in 2012 (Latta and Boyer 2016). Oyster reef and eelgrass pilot plots were deployed on the mudflat approximately 750 feet offshore from Spinnaker Lagoon. Various configurations of oyster reef and eelgrass were deployed, as well as testing of different oyster reef substrates (large reef balls, small reef ball stacks, layer cakes and oyster blocks).

Populations of both species were dynamic, with substantial interannual fluctuations. Early monitoring results indicate that long-term oyster reef success could be limited by variable recruitment, space competition, and low salinity events. Eelgrass shoots could be difficult to establish and were re-planted several times. In addition to the two treatment species, other species of invertebrates, fish, and birds were observed to use the sites with greater intensity than at nearby untreated sites. Co-locating eelgrass and oyster reefs may maximize overall habitat value by compounding diversity of other species, since eelgrass and oysters appeared to draw different species.

Wave energy was reduced in the lee of the plots, but the reduction is not likely to be substantial further inshore at the flood protection elements when bay water levels are at flood stage. Planting eelgrass shoreward of oyster reefs appeared to improve conditions for eelgrass density, perhaps due to wave attenuation.

The pilot eelgrass and oyster reefs project along the San Rafael mudflats, along with additional understanding from other pilot sites suggest that integrated beds of these two species could complement nature-based solutions further inland by enhancing the mudflat habitat.

Upland Green Infrastructure

Upland throughout the OLU, green stormwater infrastructure could be distributed in the uplands where space exists on public land, in parks, and along street rights-of-way; and incentivized on private property through policy and fee programs to reduce fluvial flood volume and improve water quality in the developed valleys and basins below.

Intentional management of fresh stormwater within the basin may help prevent salinization of soil and related habitat impacts from SLR-induced groundwater rise. Infiltration zones and the establishment of shallow lenses may help mitigate saline groundwater intrusion.

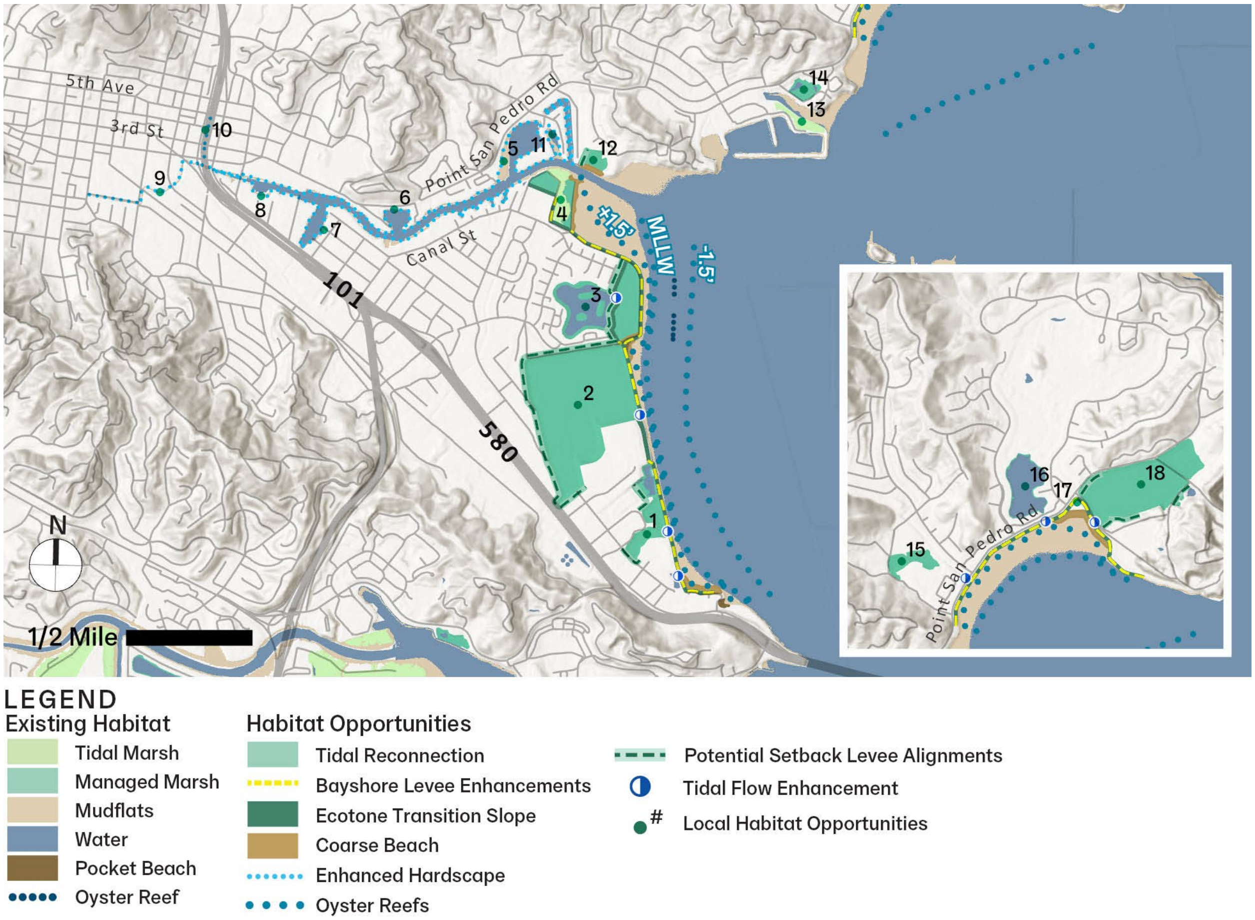


Figure 18: Nature-Based Opportunities map and key features, all alternatives.

Contractor Considerations

There are many contractors who can build levees and control structures; there are fewer who have experience with living shorelines. Lack of competition among qualified bidders can result in higher bids as firms build in a margin for risk and uncertainty associated with less familiar project types. The Regionally Advancing Living Shorelines (RALS) project is working to address this problem by writing guidance for designers and contractors and is currently advancing ten projects, which should broaden opportunities for contractors to gain more experience.

At a program and project scale, workforce training opportunities could be included in the planning stage on both the planning and design and contracting side, from new construction to routine operation and maintenance. If consistent funding sources can be found to support implementation over several decades, there may be opportunity to invest in and grow contractors, workers, and the knowledge base for a regional restoration economy.

d) Alternative 1: Raise Canal Edges

Description

Alternative 1 requires raising the Canal edge to +12 feet primarily through vertical living seawalls on land and in the Canal and raising the crest of the bayfront levee to +14 feet. The alternative selected for study here was created with the intention to protect as many existing buildings and housing units in place as possible. While many details are not known at this time, for the purposes of this study it was assumed that this goal could be achieved. There may be physical constraints, ownership issues, or design requirements that come to light later in the process that mean it is not possible to construct this alternative without some impact to existing buildings. This alternative requires the smallest physical footprint but presents significant tradeoffs to visual character and future adaptation potential.

In the Canal, this would consist of three types of structures, applied in order of priority: 1) where space exists on land, planted berms or rip rap combined with a short stem wall at or above MHHW (least common type); 2) where space is limited on land, vertical bulkhead with living seawall at or above MHHW; and 3) where existing structures are at or overhang the shoreline, or where space otherwise does not permit, vertical sheet pile with cast living seawall panels and concrete cap built in water.

Structure types for Alternative 1 at the Canal shoreline include:

1) Berm and stem wall. Where there is sufficient setback distance between the shoreline and any landward structure, raise the existing shoreline embankment or build a combination of a berm and a short stem wall (such as in Foster City). This type provides the most habitat value and future adaptability but is the least common type due to space constraints; it may be viable for small lengths on only a handful of parcels. The concept is to continue the type of existing shoreline protection higher to required elevations and vegetate the slope with native plantings. A permanent maintenance easement along the shoreline would be required (at minimum 10 feet landward of the structure). Construction would be from land where possible. Where offshore embankment slopes are steep, geotechnical conditions may require a flatter slope for stability.
2) Onshore seawall. Where space for a berm does not exist, install a vertical bulkhead near the top of slope. The bulkhead would be steel, concrete or composite (fiberglass) and may need tiebacks (landside) or counterforts (canal side) for stability. Construction would be a combination of marine (from canal side) and land-based (if tiebacks required). There would need to be a permanent maintenance easement along the shoreline (width depends on structure type).
3) Offshore seawall. Where structures are right at the edge of the canal (existing bulkhead) or overhang the water (pile supported) and space is unavailable to construct on land, install a vertical cantilevered (free-standing without tie backs) sheet pile wall at least 8-ft offshore of building facades and overhanging elements. The seawall would have returns to the shore to create a managed basin landward of the structure and would stay outside the federal navigation channel. The wall would likely be constructed of steel sheets because of their weight (lighter than concrete), ability to vibrate them into place (as opposed to pile drive), and desire for the wall to be cantilevered. A concrete pile cap would tie the individual steel sheets together. Steel sheet piles would be in the 60-ft to 80-ft range. Assuming the channel begins at about -5′, and elevation is initially set at +12′, the embedment would be in the 40 to 60-ft range.

The structure would be detached from shore except where the ends return. The structure is not anticipated to be publicly accessible (such as a promenade) to keep it lightweight and avoid safety-related design issues (plumb, guardrails, decking, seismic, etc.). Initial loading design could factor a future lift to +14' through sheet pile or pile cap extension.

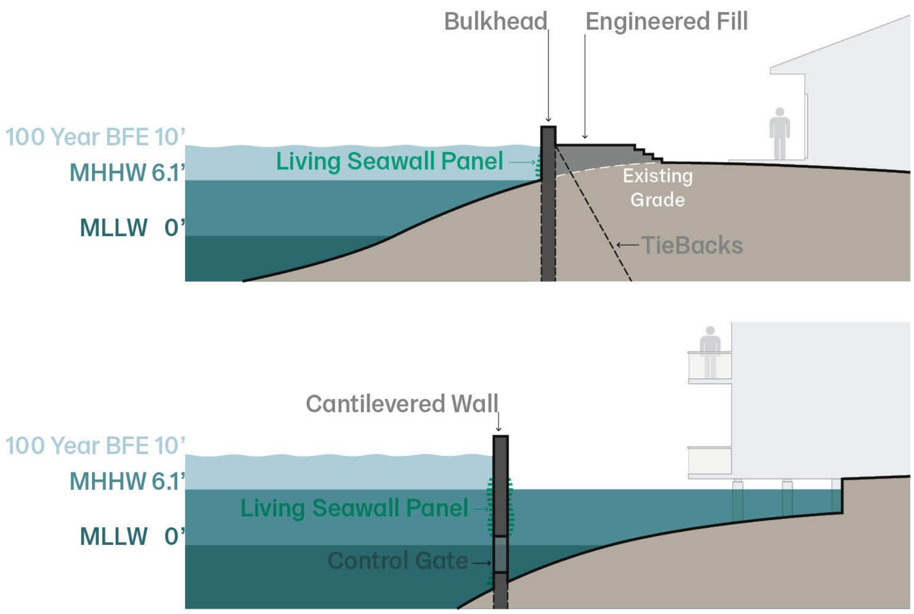


Figure 19. Conceptual onshore and offshore seawall structure types.

Water levels in the area between the wall and existing shoreline would be managed via sluice gates that would be part of the wall, effectively keeping it part of the Bay (not Bay fill). This design allows hydraulic pressure to equalize on both sides of the seawall for all but the highest water levels, when the sluice gates would need to be closed. For the majority of tidal fluctuations there would be free exchange of water up to approximately MHHW today to limit water quality degradation. It is assumed that overhanging structures have a seawall/bulkhead behind the first few rows of piles with rock buttress fronting the seawall which would remain in place.

Ecological enhancements within the controlled area, such as fringe marshes along the shoreline or disconnected tidal marsh islands, could be considered as part of this concept, however most areas below overhanging buildings lack adequate sunlight and shoreline at most structures built to the edge is too steep for marsh propagation.

On the north side of the Canal in places where no basin condition exists, individual structures and access roads would need to be raised over time if this alternative were to be pursued. Point San Pedro Road would need to be raised in low areas, possibly including a low 3' seawall where raising is not possible due to space or tie-in constraints.

West of the interstate canal crossing along Mahon Creek, stem walls similar to structure type two would need to be constructed to prevent tidal back flooding. This would include the addition of floodwalls or panels to Francisco Blvd, Lincoln Ave, Lindaro Street, and Andersen Drive, and the rail bridges. Similar structures would be built under the interstate where Irwin Creek is daylit.

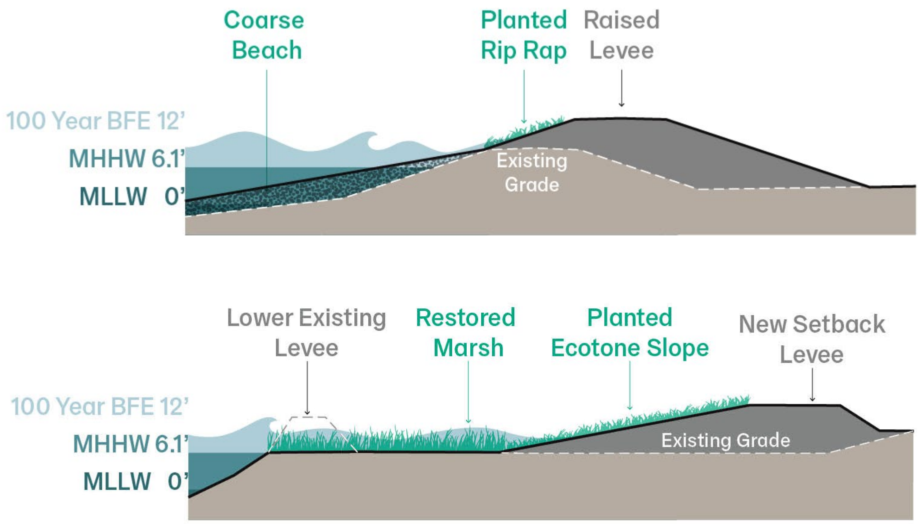
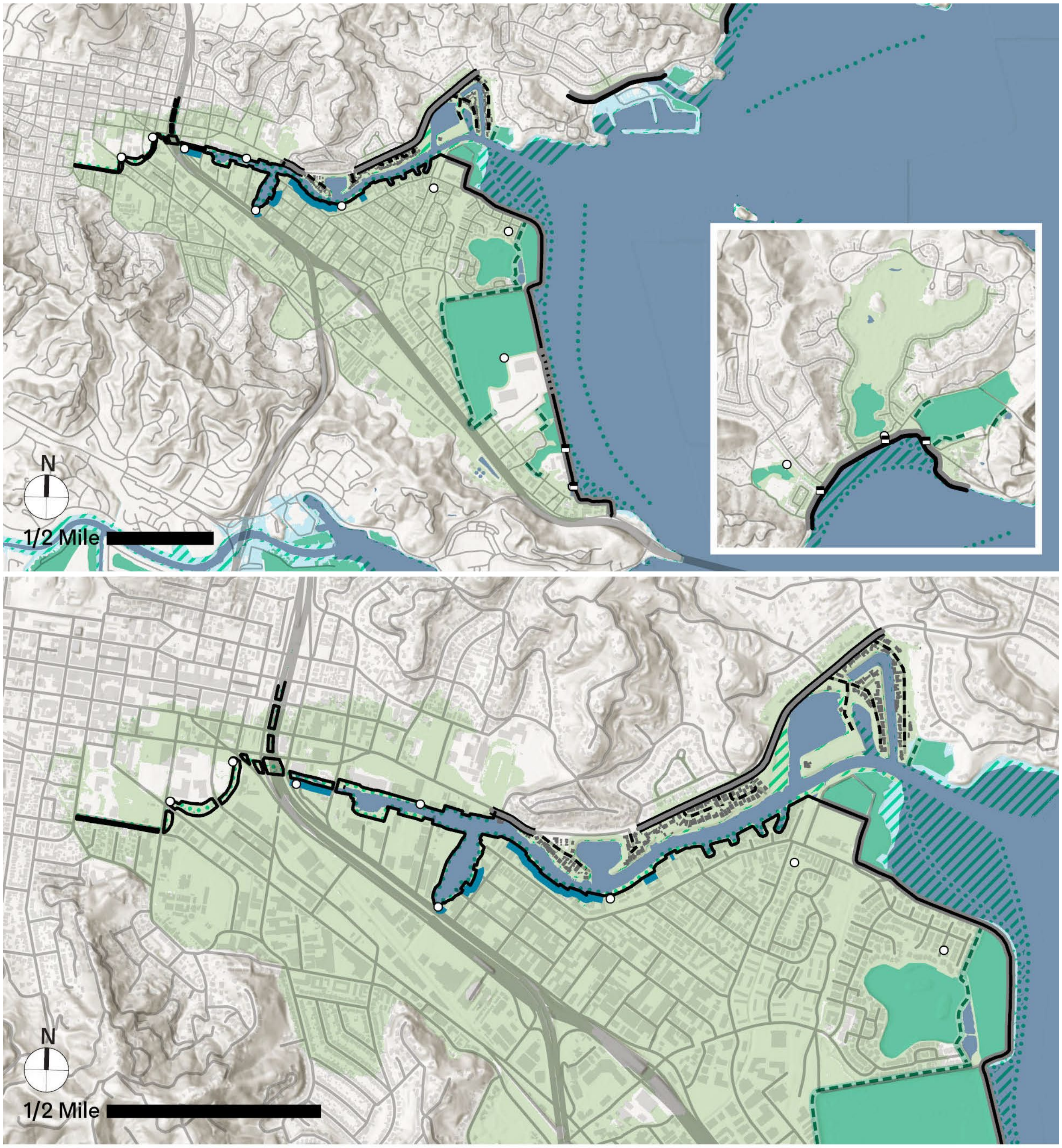


Figure 20. Conceptual cross sections for enhanced bayfront levee and setback levee with restored marsh.

The bayfront levee presents the most opportunities for, and benefits from, nature-based adaptation in this alternative. The levee structure itself would be stabilized through soil mixing, widened towards land, and raised with surcharged material to anticipate compaction and subsidence. Where the existing levee is compromised or too weak for raising, full replacement with temporary shoreline protection may be required. The Bay Trail would be replaced on top. Erosion-resistant elements could still be incorporated, but these would be embedded at sufficient depth to accommodate native plantings atop. As further described in Nature Based Opportunities, the bayfront can support planted rip rap and coarse beaches to protect the bayward side of the levee and reduce wave runup; setback levees and tidal restoration allow for marsh regeneration of managed lagoons; protection and management of small marsh patches; and nearshore reef and subtidal habitat enhancements that can provide wave attenuation and reduce tidal amplification.



LEGEND

- Levee
- Minor Adjustments to Existing Grade
- Onshore Floodwall
- Offshore Floodwall
- Raised Road
- Raised Road with Wall
- Alternative Alignment
- Adjust Existing Pump
- Adapt / Reconstruct Closure Structure

Building Scale Adaptation

- Building Scale Adaptation
- Raised Access Road

2050 100 Year Event

- Tidal Inundation
- Protected Land

Nature Based Opportunities

- Potential Setback Levee Alignments
- Tidal Restoration Opportunities
- Near-shore Habitat Opportunities
- Intertidal & Subtidal Habitat Opportunities

Figure 21: Alternative 1 adaptation measures & alignment, full OLU and Canal detail. See Appendix for detailed maps of conceptual alignment.

Feasibility & Performance Analysis of Alternative 1

1) Level of Fluvial and Tidal Flood Protection

With the Canal edge upgraded to a stable surface elevation at +12′, and the bayfront levee crest and Point San Pedro Road raised to +14′, the alternative would address a 100-year storm event with up to +1′ of SLR and +1′ of freeboard, conditions that are expected at approximately 2050. Past mid-century, the structure would need to be modified higher and may require significant reconstruction.

The +1′ SLR level of protection is used as a planning horizon as a reasonable first step toward longer term adaptation. Higher levels of protection require larger and taller structures, higher upfront costs and impacts. Although the elevation would be constructed to +12′, the structure would be designed to accommodate a +14′ elevation in terms of ground improvements and structural loads. The 2-ft raising could either be in the form of a hybrid element (sheet pile over a berm, like the Foster City seawall) or a future extension of the sheet piles. A structural sheet pile extension may require the addition of soldier piles or counterforts that would not adversely affect the built structure. Where the flood protection element is an offshore seawall, the elevation could be set initially at +14′ rather than +12′, unless there are segments where visual or boating access concerns do not allow it. In either case, the design of the structural system would use a future elevation +14′ for load cases (both geotechnical and structural). The 2-ft raising would involve reconstruction of the concrete pile cap.

A new, higher structure would need to be in place by at least 2070, depending on sea level rise rates, to maintain a 100-yr level of protection. For a range of 3-6 feet of sea level rise at 2100, the design elevation for this phased reconstruction would be to +14 to +17 feet along the Canal and +16 to +19 feet along the bayfront.

Until a contiguous line of defense is completed, the level of protection is not reached.

The basin condition would persist San Rafael, and pumps would still be required to manage stormwater and groundwater levels. The pumping system could be upgraded over time to handle overtopping from more extreme tidal events beyond the 2100 100-yr level, however this would be for emergency management scenarios only.

2) Effectiveness at Different Planning Horizons

Alternative 1 has a design elevation set to the100-year water level in 2050. Past mid-century, sea level rise projections will need to be re-evaluated and additional adaptations adjusted accordingly. For planning purposes a range of 3 to 6 feet has been used for 2100. If realized SLR turns out to be more modest than projected, Alternative 1 could remain effective perhaps until 2070, however based on recent acceleration trends this is unlikely. If SLR veers towards the higher-end projections, action may be required sooner, and potentially while the alternative is still under construction.

Aiming for around mid-century to further upgrade the bayfront levee protection, raising the protection elevation to +14 ft, there could be about a 75% chance of experiencing a storm event in the intervening time that could produce some level of wave action overtopping the edge. However, after upgrading the protected elevation to +14 ft the risk of the edge being overtopped in a storm event would decrease to around 35%. Wave action alone would be expected in the 1-2′ range, would not alone be expected to cause catastrophic overtopping, and could be managed by the basin stormwater drainage system.

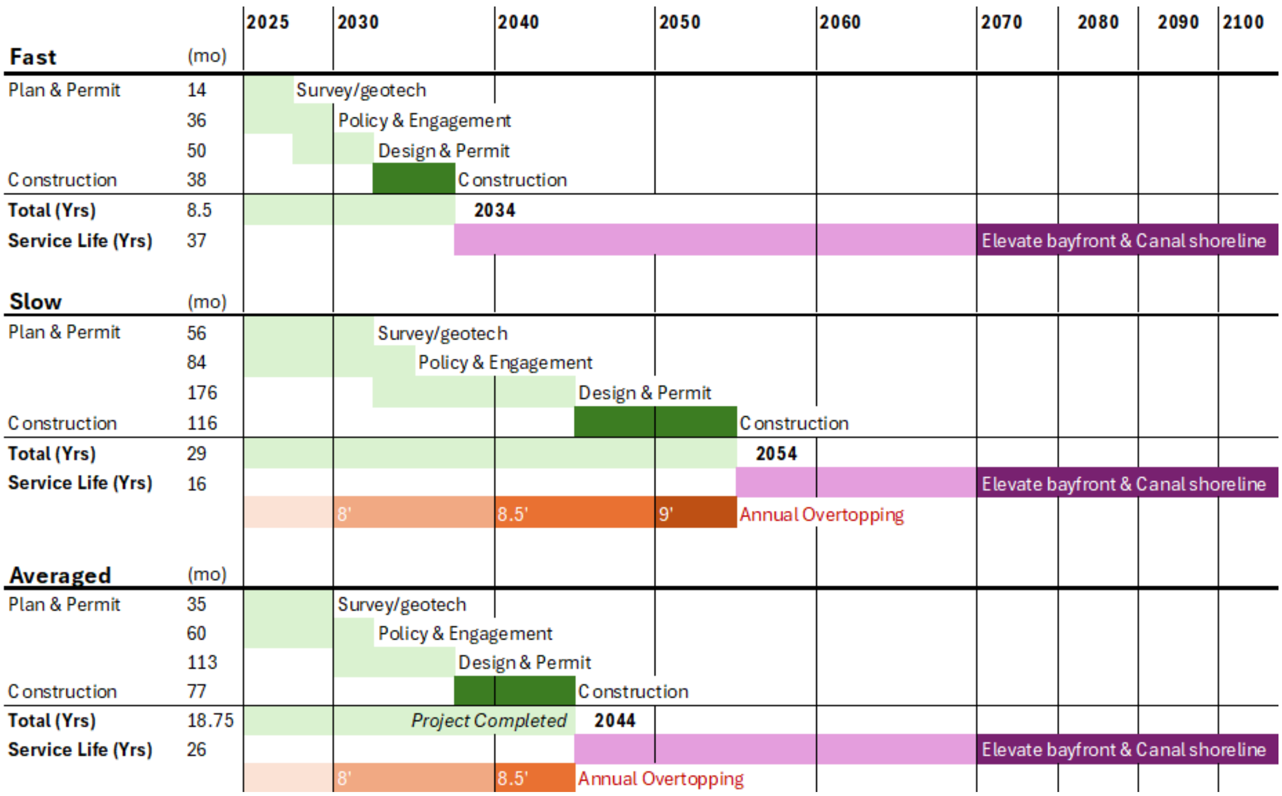


Figure 22. Detailed Timeline of the slowest and fastest projected schedules for Alternative 1

3) Spatial Requirements

Alternative 1 provides flood protection in-place for existing structures. Three types of structures would be used where space permits.

In the Canal, there is effectively no space for structure type one, a planted berm with stem wall, and it is not mapped for this alternative. If redevelopment of a parcel or shoreline occurs within the design phase of Alternative 1, it is recommended this type be explored for accessibility and habitat improvement potential.

Structure type two, an onshore sheet pile seawall with concrete cap, would be located at or above MHHW. The structure itself would require approximately 2′ of width and a 10′ minimum landside easement. Subgrade tie-backs would be installed around existing building foundations. Piles would be vibrated into place to limit impacts to nearby structures. It is estimated that 1.8 miles of required protection would use this concept. It is likely that segments of type two would shift offshore to type three in some instances when site-scale survey, access and geotechnical evaluation are conducted.

Type three, an offshore steel sheet pile seawall with concrete cap, would be used where others are space constrained, approximately 0.6 miles of the required total length. This structure would be a minimum of 8’ away from existing structures and would be vertically cantilevered (no tie-backs required). The existing shoreline behind this type would remain in its current form.

If a tide gate is required upstream in lieu of raising the edge under the interstate and beyond, it would likely be located between the Yacht Harbor and Grand Ave Bridge. This area limits decommissioning extent of the federal navigation channel and affords potential pump station locations on land to the south of the Canal currently used for parking lots, which would require acquisition. A pump station approximately 3,000cfs and 0.7 to 1.2ac footprint would be required to manage fluvial outflow when the tide control structure is closed. Similar to Alternative 2, if the gate must be closed more frequently over time due to sea level rise, mitigation of the entire tidal area upstream from the structure may be required, and/or raising upstream banks to maintain current tidal flows may be required for permitting.

Bayfront levee adaptation is anticipated to require an easement of approximately 10’ additional land-side width for the length of the levee expansion, approximately 2 miles. This easement would require negotiation and compensation for private property owners along the bayfront and would be intended to allow land-based construction without in-water impacts. The bay trail would be temporarily rerouted during levee construction and replaced on top. Habitat improvement opportunities integrated within the levee raising would be as described in Nature Based Opportunities and include offshore, nearshore, and at shore features.

Road raising and/or seawall for the length of Point San Pedro Road is estimated to occur within an 80’ wide ROW. All raised roads are assumed to have a 3:1 side slope. Intersections and crossings would need further design and shallower slopes, therefore requiring potentially more space.

Alternative 1 Spatial Summary	Length (mi)	Width	Easement Width	Notes
Levee	2.0	50-100 ft	10 ft	Bayfront
Minor Grade Adjustments	0.2	10 ft		Bayfront Shopping Center
Onshore Seawall	1.8	2 ft	10 ft	Min. easement; actual dimension to be confirmed by funding & permitting authorities
Offshore Seawall	0.6	2 ft	8 ft	Assumes 5’ wide impacts to water bottom for mitigation
Raised Road	0.9	80 ft		
Raised Road with Seawall	1.6	80 ft		Wall elevation to BFE + freeboard + SLR, max 3’ above grade for pedestrian and vehicle visibility; raised road to meet the difference
Total	**7.0**			

Figure 23: Alternative 1 dimensions for shoreline features protecting basin areas and/or critical access routes.

Pumps & Gates	#	Size	Notes
Adapt/Reconstruct Pump	9	Existing Footprint	Integration with seawall incl. punch out; stormwater upgrade if req'd.
Adapt/Reconstruct Tide Gate	5	Existing Footprint	Extension and/or reconstruction of operable gates depending on survey inverts and condition

Figure 24: Alternative 1 drainage pump station and existing tide gate modifications.

Building Scale Adaptation	# / Length	
Multifamily Residential	9	Full reconstruction likely
Single Family Residential	58	Raise and/or reconstruct depending on foundation type
Commercial	7	Dry flood-proof and/or reconstruct
Industrial	0	
Total Buildings	**74**	
Raised Access Road	1.1	Access to Point San Pedro Road from raised buildings

Figure 25: Alternative 1 building and road adaptations for non-basin shorelines.

4) Permitting Requirements

Alternative 1 has the most potential for subaquatic impacts of all alternatives. There are approximately 50 buildings that overhang MHHW along the canal. Moving the alignment to the bayward side of these buildings and either filling in or leaving the impounded water open would require mitigation. Opportunities for self-mitigation may exist depending on the design of structural tie-ins, such as development of ecotone levees and supporting marsh habitats if space for slopes permit. Moving the alignment of the bayfront levee further inland could also create mitigation opportunities. Moving the alignment to the right of way could also reduce impact and mitigation but would leave buildings on the outside of the alignment. Depending on how much of the alignment ends up in the water the potential impact could outweigh alternative 2. This requires further development in detailed engineering and subsequent EIR process.

5) Land Ownership and Access Considerations

While Alternative 1 could theoretically avoid physically impacting existing buildings, at +12' there would be significant viewshed impacts and all private waterfront docks and gangways would require reconstruction. Land ownership patterns overall would remain as today, however Alternative 1 would require easements from approximately 130 parcels, including the 40-50 parcels required for elevating the bayfront levee. Additionally 70-80 buildings north of the Canal require building scale adaptation and raising of public access roads to these properties. Construction would require cooperation from property owners, and it could be a challenge to acquire the necessary easements and parcels needed for the implementation of the upgrades.

In this alternative, approximately 250 private docks and gangways would need to be demolished, realigned if needed, and reconstructed for continued boating use. Docks would need to move channel-side of the seawall without encroaching the federal channel, which may require changes to geometry, area, and number or size of slips. Where space does not exist between the structure and channel, some docks may not be able to be replaced and would require compensation to the owners. Floating gangways and ramps over the seawall would be used to avoid operable gates within the structure to the extent possible.

Where access is required for boat launches, such as the Yacht Harbor and Waterway Marine storage facility, the seawall structure would turn landward and the upper part of boat ramps would either be regraded or provided with a swing gate.

For construction of stem walls along Irwin Creek under the interstate, a micro pile technique could be used in areas with low clearance where short segments of steel sheet pile are driven and welded sequentially. Geotech and survey evaluation would be needed, as well as Caltrans approval and coordination, for construction so close to overpass foundations.

6) Potential Threats to the Community

Potential threats to the Community may include temporary disruption associated with construction activities from noise, equipment access, and vibration, and detrimental impacts to viewshed. However, expedited completion of construction would provide an immediate benefit to the community by significantly lowering flood risk.

For reaches constructed offshore, tidal or sluice gates within the structure to balance hydrostatic pressure create potential failure points if they fail to close during high water, whether from mechanical or human error. This alternative potentially creates additional operational burdens on Public Works staff and budget to test, maintain, and manage the sluice gate network and the wider system.

Under Alternative 1 (and all alternatives), basin residents would rely on drainage pumps indefinitely to manage stormwater and groundwater and may be subject to flooding from mechanical or human error at pump stations. For this and all alternatives, there is an inherent risk of failure that comes with living below the Bay.

7) Co-Benefits of Adaptation Measures

Alternative 1 is located on private property along most of the Canal edge, with limited additional opportunities for access to water, connectivity, or transportation improvements. Its primary purpose is to provide a level of flood safety while protecting existing structures and patterns in place.

8) Housing Implications

The goal of Alternative 1 would be to preserve as many housing units in place as possible. It is estimated that 360 housing units could be affected by construction of Alternative 1, 320 of these in multifamily buildings. Due to the proximity of the alignment to buildings along the shoreline, temporary displacement during construction may be possible. New housing construction is not included in Alternative 1, however phased redevelopment over time may be possible, and potentially at higher density if desired by the community and permitted by the city, once a reliable flood safety threshold has been established.

For Alternative 1, it is estimated that 2,720 housing units would benefit from reduced flood risk. Of these, 1,280 of these are in multifamily buildings.

Alternative 1 does not address other housing risks such as remediation of soft story seismic risks, code violations, or other housing quality issues, and it does not provide a mechanism or impetus for redevelopment beyond natural market forces.

9) Ecological Implications

The bayfront levee presents the most opportunities for and benefits from nature-based adaptation in this alternative. As further described in Nature Based Opportunities, the bayfront can support planted rip rap to protect the bayward side of the levee; coarse beach in places to protect pocket beaches and marsh terraces, such as is planned for the Tiscornia restoration, and reduce wave runup; setback levees with ecotone slopes and tidal flow restoration allow for marsh regeneration of managed lagoons; protection and management of small marsh patches; and nearshore reef and subtidal habitat enhancements that can provide wave attenuation and reduce tidal amplification.

Within the Canal, seawall enhancements that may be able to support marine ecosystems could include panel mounts with crenulations, features and surfacing amenable to attachment of marine life mounted within the tidal range. These features would also play a role in improving water quality and potentially reducing turbulence and localized wakes through their roughness.

10) Economic Feasibility

Measured in terms of capital improvement cost versus flood damage potential, Alternative 1 would maintain a ratio of ROM cost to flood damage reduction of 1:1.5. The current evaluation for Alternative 1 considers a seawall for all shoreline segments along the Canal fronting a basin condition and raising the bayfront levee and measures along the Point San Pedro Road shoreline. Including ecological and community benefits, the expected benefit to cost ratio of Alternative 1 would likely be at or greater than 1, a prerequisite for federal cost sharing but not highly competitive against other projects around the country.

Onshore seawall is estimated at $15,000/lf and offshore at $23,000/lf including sluice gates. Tidal closure structure adaptation is estimated at $250,000 per structure. Within construction costs, approximately 250 private boat slips are impacted in Alternative 1 with reconstruction cost assumed at $56,250 per slip (average size estimated at 750sf at $75/sf for materials and labor). Docks and appurtenances could be reconstructed and may not be allowable for federal cost sharing. Without adequate compensation for these private property features and functions, the alternative is potentially subject to takings suits.

Pump station retrofits are estimated at $22,000 per 1 cfs. This was based on the San Quentin Pump Station upgrades which cost $6.6 million to upgrade a 300 cfs pump station. That cost may include check values and punch outs through new seawalls but excludes pump upgrades based on stormwater criteria.

Overall construction contingency is estimated at 50% given the early-stage uncertainties at a feasibility level. This contingency is also intended to capture the array of nature-based measures integrated into the alternative.

Building scale adaptation on the north Canal shoreline is estimated at 100% of city-assessed structure plus land value, assuming that most structures have slab foundations and will need to be fully reconstructed.

Easement costs are estimated based on assumed average of 80' for adapted bayfront levee footprint, resulting in $4M of compensation for bayfront easements using city-assessed land values. The remaining $2M of easements are required within the Canal. Easement values are subject to change with detailed design: they will rise if more of the seawall is able to be constructed on land, or if a funding or permitting agency requires more land-side access.

Approximately 0.3 acres of water bottom impacts for the offshore seawall are anticipated in the Canal and would require mitigation.

Alternative 1 is estimated to include additional annual operations and maintenance costs of approximately 0.5% of initial construction cost, or approximately $2 million. This cost is expected to include Public Works staff and equipment to routinely test, maintain, and operate sluice gates, and inspect and repair seawalls and levees. These costs are not typically covered by state or federal grants and would require a local recurring revenue source.

Rough Order of Magnitude Cost				
Construction				
Levee		2. Mi	$	14,000,000
Raised Roads		2.5 Mi	$	106,000,000
Floodwall		2.4 Mi	$	148,000,000
Adapt Existing Pump Stations		9	$	28,600,000
Adapt Existing Closure Structure		5	$	1,250,000
Contingency	50%		$	148,925,000
Total			**$**	**446,775,000**
Building Scale Adaptation			$	86,375,000
Planning				
Professional Services	20%		$	89,355,000
Compliance & Permitting	20%		$	89,355,000
Property & Mitigation				
Easement Cost			$	6,000,000
Wetlands Mitigation	0.3 ac		$	700,000
Total			**$**	**718,560,000**
ROM Cost to Damages Avoided				**1 : 1.5**
Annual O&M	0.5%		$	2,200,000

Figure 26. Rough order-of-magnitude cost summary for Alternative 2

e) Alternative 2: Canal Gate

Description

Alternative 2 creates a navigable flood control gate at elevation +16′ (BFE +3′ SLR) with large forward pumps, approximately 3,000cfs, near the mouth of the San Rafael Canal. Like Alternative 1, bayfront levees would initially be constructed to +14′, while the gate structure itself would be constructed higher for a design life up to 2100 conditions given the scale of investment. Combining the gate with bayfront levee and Point San Pedro Road adaptation as described in Alternative 1 creates a continuous line of protection for basin conditions in San Rafael and affords similar opportunities to implement nature-based opportunities throughout the bayfront.

The shorelines behind (inside) the gate would require elevation to keep pace with sea level rise and subsidence to maintain today's closure frequency over time and therefore maintain tidal function in the Canal. These measures could look like Alternative 1 and/or Alternative 3 over time. Home and road elevations described in Alternative 1 may be required on the north Canal shoreline for the same reason. Failure to adapt the shoreline behind the gate potentially compromises the ability to permit this alternative as the least environmentally damaging option.

Alternative 2 consists of the following measures:

1) An operable Tide Control structure (gate) near the mouth of San Rafael Creek with tie-in to the Bayfront levee at the south and natural high ground at the north, in a configuration that preserves the Tiscornia Marsh restoration features and navigation access to the federal channel in the Canal.
2) Forward pumps that would convey fluvial flows coming down the Creek.
3) Elevating the Canal edge to a minimum elevation of +8′ (Initial Action), coupled with an adaptation strategy to progressively raise the Canal edge to limit the number of closure events to what would be feasible from a hydraulic, environmental permitting and operations perspective (estimated at 5 to 10 events per year).

Alternative 2 may require the following future measures:

1) Implementation of the strategy to progressively raise the Canal edge, or:
2) Potential mitigation for an area up to the surface area of tidal tributary impounded by the structure (84 acres), if allowed at all, if the Canal edge is not raised and the number of closure events increases beyond a threshold determined by regulators to maintain tidal exchange.

If these measures are not implemented, Alternative 2's ability to navigate the EIS evaluation of least impact alternatives may be compromised.

The gate would remain open for almost all tidal conditions except extreme high tides (today's seasonal king tides and higher) to maintain fluvial flows, allow navigation access, and to avoid adverse environmental effects stemming from impacts to fish passage and water quality degradation.

Multiple locations for a point of closure we gathered based on previous proposals by different agencies and organizations. The USACE (two inner-most) and outer-most alignments may be technically feasible but were not considered in detail in this evaluation process due to potential impacts to existing wetlands, navigational challenges, and number of roads and buildings left outboard of the alignment. The systemic and operational implications related to ecological and private property impacts will differ across these discreet placements.

A gate alternative maintains existing polder conditions, with interior ground elevations remaining unchanged; however, it would require improvements to the city's stormwater system to address potentially higher amounts of stormwater associated with climate change within the basin, as well as rise in groundwater levels over time. Although a gate alternative avoids the significant hurdles associated with acquiring or building on private properties and buys the city a substantial amount of time to plan and build resiliency for the community, it would have adverse impacts to natural hydrologic functions, especially during winter high tide conditions when fluvial flows could be significant; therefore, pumps to pass the flows across a closed gate would be part of the alternative.

Nature-based strategies such as ecotone levees, planted rip-rap and rock slopes, and subtidal habitat could potentially be created on the bay-facing side of the gate tie-ins as bathymetric and geologic conditions allow, as well as living shoreline elements along the Canal shoreline where feasible.

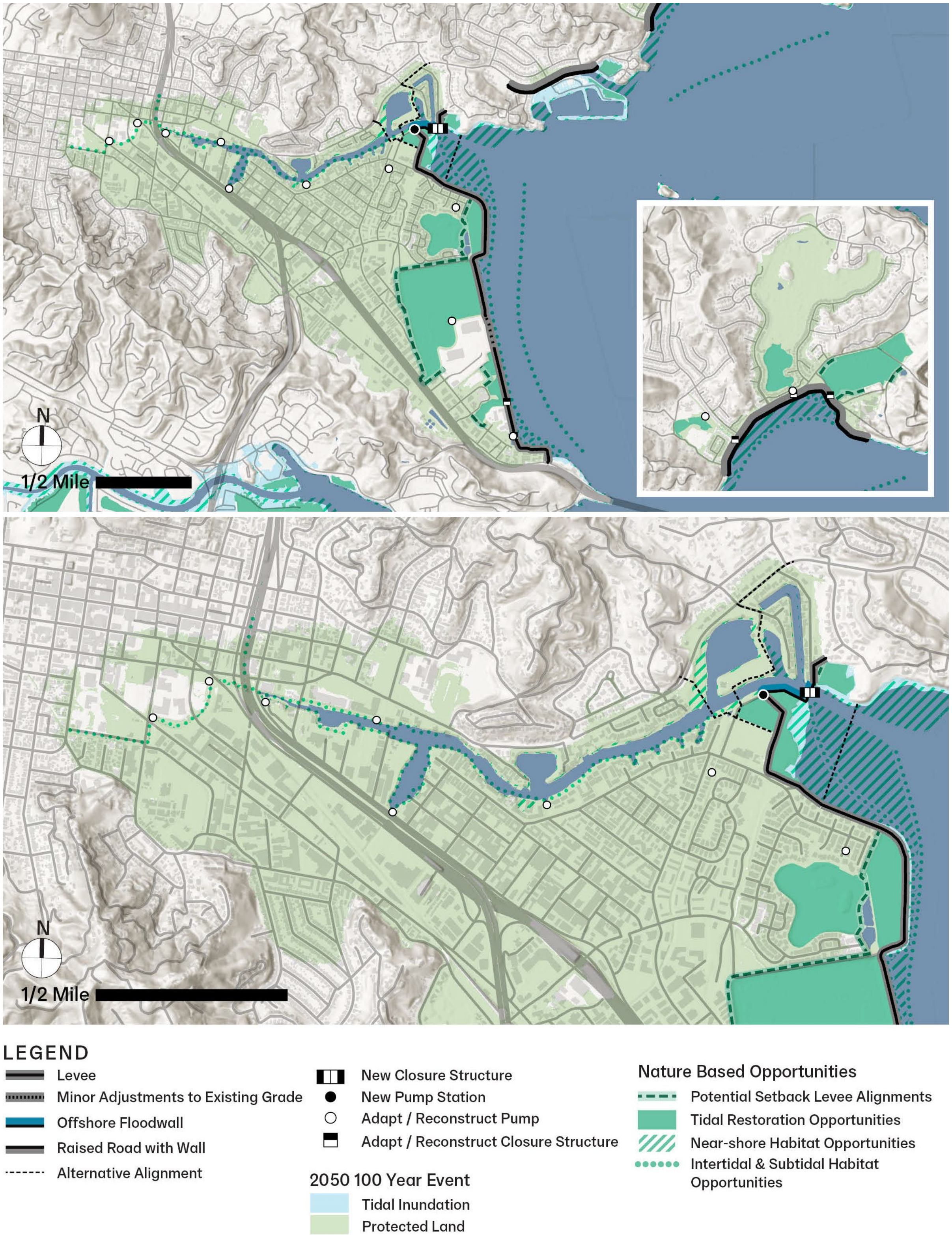


Figure 27: Alternative 2 adaptation measures & alignment, including potential gate alignments noted but not evaluated; full OLU (top) and Canal detail (above).

Performance & Feasibility Analysis of Alternative 2

1) Level of Fluvial and Tidal Protection

A Canal Gate would be built to at least +16’ to meet anticipated 100-yr water levels in 2100 including +3’ SLR and +2’ freeboard. With the bayfront levee crest raised to +14 feet, the perimeter protection would address a 100-year storm event with up to +1’ SLR (2050), maintaining 1 foot of freeboard as a buffer. The bayfront levee would need to be raised again to 2100 levels as described in Alternative 1 to match the level of protection offered by the gate.

The gate would remain open during normal conditions to maintain an accessible federal navigation channel and would only close during projected tidal flooding events. At a +8’ threshold, closure frequency would be approximately once annually today, 1-3 times monthly with +1’ SLR (approximately 2050) and >1 time weekly with +3’ SLR (approximately 2100). There may be practical operational limits to how often a gate can be opened and closed each day depending on its specific design (sector, flap, swing, etc).

Over time the number of closure events will increase depending on two factors: sea level rise outside the gate and subsidence behind it. If the interior Canal edge is not raised, the gate would have to operate (close) more frequently, up to the point where it may have to remain closed most of the time when daily tides would overtop the Canal banks. The gate structure itself would be founded on piles to prevent subsidence and maintain its vertical position.

Until a contiguous line of defense is completed, the level of protection is not reached. Given the environmental and hydrologic impacts associated with frequent closures, a potential, albeit expensive, strategy could be that a gate alternative is planned and constructed as an interim solution. The gate construction timeline could potentially achieve contiguous basin protection faster than other alternatives, buying time for implementation of a long-term solution through Alternative 1 or 3. In this case, it would be designed to operate until a specific amount of SLR occurs (for example a 50-year service life which is standard engineering practice) and then it could either remain open or be dismantled.

The persistence of the basin condition and requirements for pump upgrades would be as described in Alternative 1.

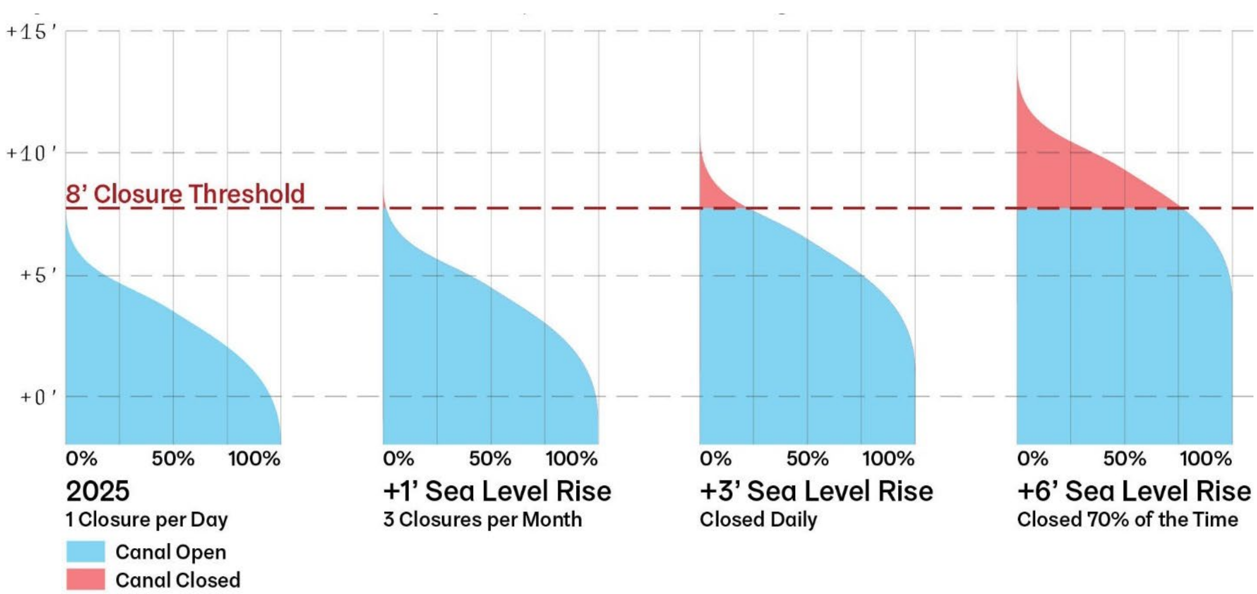


Figure 28: Alternative 2 closure frequency analysis at +8' Canal shoreline elevation under various SLR scenarios.

2) Effectiveness at Different Planning Horizons

It was assumed that the Canal gate would be designed to accommodate SLR-related hazards projected by the end of the century with an initial design elevation of at least +16'. Combined with phased bayfront improvements, Alternative 2 provides potentially the highest level of flood protection in the shortest averaged implementation timeframe. In the near term, this effectively means a level of protection above the 100-yr event for within the Canal until SLR reaches +3' above today's levels.

Tide gate effectiveness depends on regular maintenance and upkeep, and the staff to operate it when needed. While frequency of operation is to be minimized, trained staff (primary and backup teams) should be available at all times starting at completion date. Gate structure type was not evaluated as part of this study and specific staffing requirements are not estimated.

The effective planning horizon for the bayfront shoreline would follow Alternative 1, including an initial levee lift and road raising to meet expected 100-yr water levels by 2050, with an additional lift and road raising implemented before 2100 to provide the same effective protection as sea level rises.

If Canal shoreline adaptations are required, their planning horizon would be similar to Alternative 1.

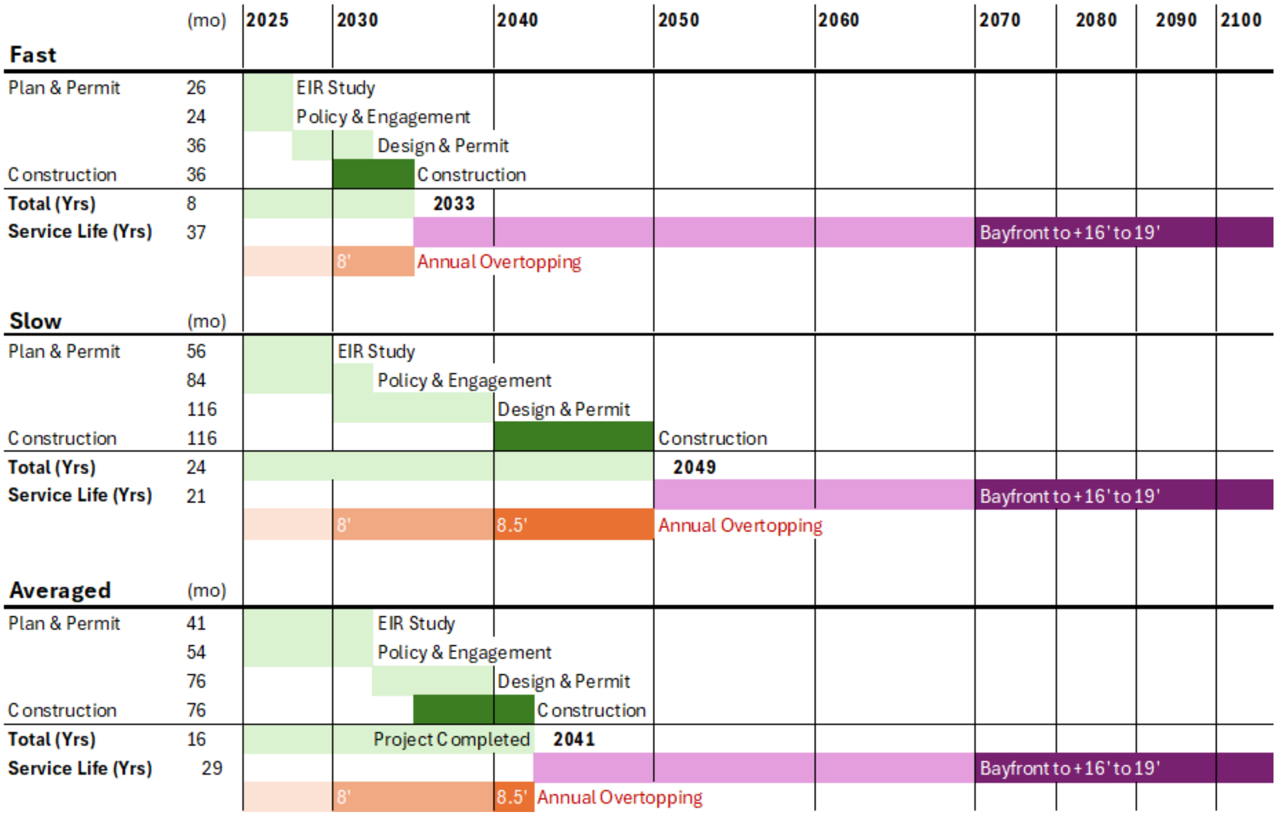


Figure 29. Detailed Timeline of the slowest and fastest projected schedules for Alternative 2. These timelines do not include raising the interior shoreline.

3) Spatial Considerations

Multiple gate locations are possible, but the analysis considers one where Tiscornia Marsh and the north Canal marsh east of Sea Way are bayward of the structure to remain fully tidal and Marin Yacht Club harbor entrance remains navigable. Arrowhead marsh and the tidal reconnection of Pickelweed diked wetland would be located behind the gate. If this alignment is possible, it would mean that potentially no acquisitions would be needed for the construction of the gate structure. The evaluated alignment would run beneath existing high voltage electrical lines crossing the Canal. Overall feasibility of the alternative is not expected to be impacted by the lines due to their height, but a contractor would need to account for them for crane clearance, etc.

Forward pump at 3,000cfs requires approximately 0.7 to 1.2 ac footprint and would require a robust foundation. Given the limited available sites near the mouth of the Canal, the pump station in the analyzed alignment could potentially need to be integrated with the gate structure and be sited over water. Depending on configuration of the pump station, its footprint may impact marsh in the vicinity of the structure. For the purpose of this study, impacted area is captured within an estimated easement zone around the structure. Over-water or marsh locations would both require mitigation likely at a multiple of the impacted area, which would be determined during an environmental review. Water bottom impacts for mitigation purposes are estimated at 50’ wide for the length of the structure.

For areas inside the gate alignment, if additional shoreline adaptation is required, the spatial considerations would reflect Alternative 1, 3, or a hybrid approach.

Spatial requirements along the bayfront and Point San Pedro Road would be as described in Alternative 1.

Alternative 2 Spatial Summary	Length / #	Width	Easement	Notes
Levee	2.1 mi	50-100 ft	10 ft	
Minor Grade Adjustments	0.2 mi	10 ft		Bayfront Shopping Center
Offshore Floodwall	0.2 mi	50 ft	10 ft	Gate structure tie-in
Raised Road	-	80 ft		
Raised Road with Wall	1.6	80 ft		Wall elevation BFE + freeboard + SLR, road elevated to maintain visibility over wall for pedestrians and vehicles
Total Length	**4.0**			
Adapt / Reconstruct Pump	2	Existing Footprint		Integration with raised edge
Adjust Existing Closure Structure	5	Existing Footprint		Tide control gates
New Pump	1	0.7 to 1.2 acres		Footprint size based on similar sized pumps stations elsewhere in U.S.
Building Scale Adaptation				
Single Family Residential	Up to 26			Left outside gate alignment in western-most sub alternative (not evaluated). Building adaptation varies depending on where the alignment crosses the Canal.
Commercial	Up to 3			
Raised Access Road	Up to 0.6 mi			Raised road length varies depending on where the alignment crosses the Canal

Figure 30. Summary of spatial requirements for Alternative 2, excluding potential Canal shoreline adaptions.

4) Permitting Requirements

Alternative 2 crosses the Canal and its footprint in the water would require mitigation. Additional mitigation is determined by the frequency and duration of gate closures. Setting the closure threshold at +8′, the gate would close approximately once a year for less than hour on average in the immediate future. Leaving the closure threshold at +8′ would result in the gate being closed daily by the end of century in both the +3′ and the +6′ SLR scenario. This would have significant impacts on the water behind the gate and would likely result in the alternative requiring mitigation for the entire canal and/or not meeting the Least Environmentally Damaging Practicable Alternative.

To maintain minimal gate closures, the Canal edge on the inside of the alignment would need to be incrementally elevated to raise the closure threshold in tandem with sea level rise. Without interior incremental elevation this alternative is likely a non-starter from a permitting perspective. Remediating and stabilizing the shoreline would require additional permitting impacts to be incorporated into the alternative analysis.

Opportunities for self-mitigation may exist such as development of ecotone setback levee slopes and supporting marsh habitats if space for slopes permit and depending on the selected alignment. Moving the alignment of the bayfront levee further inland could also create mitigation opportunities. This requires further development in detailed engineering and subsequent EIR process.

Approvals from several Federal, State and Local Agencies will be required to implement this alternative. Given the significant amount of fill and construction within jurisdictional waters, the anticipated impacts to water quality, air quality, sensitive species, sensitive resources, and navigation, review and approvals would take a substantial amount of time and effort.

One of the biggest challenges will be to demonstrate that this alternative is the Least Environmentally Damaging Practicable Alternative (LEDPA) as compared to other alternatives. A permanent, operable gate that would increase its closure frequency to the point that it closes daily is likely infeasible and should not be considered. A gate that operates only to keep out highest annual (King) tides and higher storm tides, with a minimal increase in operational frequency over time could be considered. This would provide the city valuable time to raise and/or redevelop vulnerable areas, which is an integral part of this alternative.

5) Land Ownership and Access Considerations

Construction of the majority of the canal gate structure could be done from the waterside by barge with marine construction equipment. In deep enough water, construction may proceed through most tidal cycles. Landside tie-ins would require construction and perpetual easements, though the evaluated alignment makes use of existing public rights-of-way and may not impact private land.

Alternative 2 would require land-side tie ins to the north and south of the Canal. In the evaluated alignment, the northern tie-in runs along the east side of Sea Way until it meets sufficient grade and is potentially adjacent to two private parcels. Vehicle access for maintenance may be preferred, if not required, atop the structure, and would likely join Sea Way from the north and an extension of the maintenance route around Pickleweed Park to the south.

6) Potential Threats to the Community

Alternative 2 would significantly disrupt the Canal boating and water recreation community during construction and may close access to the federal channel for long periods, potentially years at a time through phased construction. It is anticipated the gate structure itself would be constructed first and left open to maintain tidal flow, followed by landside tie-ins.

Catastrophic failure of the gate and pump structure is possible, but a greater risk may be human error in the event of a fluvial or tidal high water emergency. Alternative 2 is the most complex from an operational standpoint, and therefore the most likely to fail operationally.

Viewshed impacts for waterfront properties in the vicinity of Marin Yacht Club would be significant for the evaluated alignment, nearly one full story at +16’ level of protection plus any railings or superstructure required for operator safety or gate function. In addition, a large forward pump station would likely be highly visible near the mouth of the Canal. Global examples exist of inspiring design for pumps and gates, such as the Thames Barrier in London or the Marina Barrage in Singapore, however the degree to which design may mitigate the visual presence of the pump station and structure is uncertain.

Under Alternative 2 (and all alternatives), basin residents would rely on drainage pumps indefinitely to manage stormwater and groundwater, and may be subject to flooding from mechanical or human error at pump stations.

Potential threats and benefits of bayfront adaptations are the same as described in Alternative 1. For this and all alternatives, there is an inherent risk of failure that comes with living below the Bay.

7) Co-Benefits of Adaptation Measures

Co-benefits of Alternative 2 are potentially limited, as one of its primary purposes is to protect existing structures and patterns in place. This alignment could potentially add an additional pedestrian water crossing at the mouth of the Canal. This would connect in the vicinity of Pickleweed Park with the Marin Yacht Club.

The majority of proposed construction for Alternative 2, excepting potential Canal shoreline adaptation, is along the fringe of developed areas and therefore won't incur as significant of an impact on Community and City resources and assets.

The primary nature-based opportunities for Alternative 2 are along the bayfront. Ecotone levees and other subtidal habitat could potentially be created on the bayward side of the canal gate as bathymetric and geologic conditions allow. It is possible that vertical subtidal and intertidal habitat could be incorporated into the abutments and tie-ins of the gate structure.

8) Housing Implications

It is estimated that 2,720 housing units would benefit from reduced flood risk with this alternative. Of these, 1,280 of these are in multifamily buildings. An estimated 11,300 people would be protected in this alternative.

The analyzed and costed alignment was selected because it may minimize the need for building-scale adaptation and could potentially protect all existing housing units; however, if the shoreline needs to be raised with sea level rise to limit gate closures than there would be significant impacts to existing buildings. If the alignment closure has to shift upstream for feasibility and environmental impact concerns, around 30 buildings could potentially be left outside of the line of protection on the north side of the Canal along Summit Ave and Sea Way. Access to these sites would not be impaired by the alignment but they would require individual raising, and a raised access road, in the future.

As a sub alternative, the inner-most alignment requires 26 single family residential and 3 commercial structure adaptations for uniform level of protection for +12' level of protection (2050 100yr).

Alternative 2 does not address other housing risks such as remediation of soft story seismic risks, code violations, or other housing quality issues.

9) Ecological Implications

<u>Construction:</u> Due to construction activities associated with the gate, the pump station, raising the Bay and Canal edges, and making stormwater system improvements, impacts to fisheries,

air quality, water quality, wetlands, mudflats, visual, sensitive species, noise receptors, sediments, and navigation are anticipated. Construction may require the construction of coffer dams and temporarily draining parts of the bay. Vibrations associated with piling can affect marine life.

Planted rip-rap and subtidal habitat enhancements could potentially be created in limited areas on the bayward side of the gate abutments near the Canal mouth as bathymetric and geologic conditions allow. Low vegetated slopes may be possible in limited areas bayward of the gate abutment tie-ins only where mudflat and marsh already exist.

Operations: Due to operations of the gate and pump and modifications to the shoreline at the Bay and Canal edges, impacts to fisheries, air quality, wetlands, mudflats, visual, sensitive species, noise receptors, sediments, and navigation are anticipated. Gates increase local flow velocities as they reduce the cross-sectional area of the channel. This can affect fish passage and the movement of sediment on the bed and in suspension. In other estuaries, gates have been linked to erosion of wetlands and mudflats. Local scour holes and shoals may develop in the channel adjacent to the gates affecting navigation and stability of structures.

Because the gate structure could have the potential to significantly impact water quality, ecology, and habitat within San Rafael Canal relying on tidal exchange, it would have to be carefully demonstrated to regulatory agencies that this alternative could function as the Least Environmentally Damaging Practicable Alternative (LEDPA). In this regard, it should be noted that SLR would tend to result in more frequent and longer gate closures. These factors could to some extent possibly be mitigated by pumping and/or by incorporation of a flap gate array that would convey flow to the Bay whenever the water level in the Bay drops below the water level in the canal.

The evaluated alignment avoids impacts to Marin Yacht Club and ongoing and planned Tiscornia Marsh restoration. Tidal connection to the diked wetland at Pickleweed Park would be located behind the structure and would be subject to interruption when the gate is closed, however future additional tidal inlets from the bay may be explored (not evaluated in this study).

A potential concern would be impacts to water quality and fish passage associated with frequent gate operation. However, such impacts could be deferred by only closing the gate during storm events, which would leave the canal open to tidal exchange at all other times. Gate opening should be sized to maintain approximately the same tidal flow through cross sectional area of the narrowest point of the canal channel to preserve tidal flow regime. Tide gate operation in the Bay Area, in some places operating since the sixties, has demonstrated that these structures do not preclude habitat from developing upstream of the gate structures, however the long-term habitat impacts of gates are untested under the SLR conditions anticipated in coming decades.

While unlikely, it may be possible to decommission and remove the gate by the end of the century. This would require the entire Canal edge to be incrementally elevated to 2100 design elevation.

Ecological impacts for bayfront and Point San Pedro Road adaptations would be as described in Alternative 1.

10) Economic Feasibility

Measured in terms of capital improvement cost versus flood damage potential, this alternative would maintain a ROM cost to flood damage ratio of approximately 1:2. With consideration to ecological and community benefits, the expected benefit to cost ratio would likely be greater than 1:2.

The new gate complex with forward pumps is estimated to cost approximately $50,000 per cubic foot per second capacity based on precedent structures including the New Orleans Hurricane Storm Damage and Risk Reduction System (HSDRRS). At 3,000cfs this facility requires approximately $152M. A contingency factor of 50% is applied given the complexity of the site, cost of regional construction market, and the many unknowns at feasibility level.

Bayfront easement costs of $4M would be as defined in Alternative 1, with the remaining easement values incurred around the gate structure.

Approximately 1 acre of water bottom impacts for the closure gate are anticipated at the mouth of the Canal and would require mitigation.

Alternative 2 is estimated to include additional annual operations and maintenance costs of approximately 2% of initial construction cost, or approximately $8 million. This cost is expected to include Public Works staff and equipment to routinely test, maintain, and operate sluice gates, and inspect and repair seawalls and levees. These costs are not typically covered by state or federal grants and would require a local recurring revenue source.

Potential economic impacts to Canal businesses and uses are not calculated for Alternative 2 construction

Rough Order of Magnitude Cost

Construction	Percent	Amount	Value	
Levees		2.1 Mi	$	15,000,000
Raised Roads		1.6 Mi	$	79,000,000
Floodwall Tie-Ins		0.2 Mi	$	13,000,000
Gate & Pump Station Complex		1	$	152,000,000
Adapt Existing Pump Stations		2	$	2,000,000
Adapt Existing Closure Structure		5	$	1,250,000
Contingency	50%		$	131,125,000
Total			$	393,375,000
Planning				
Professional Services	20%		$	78,675,000
Compliance & Permitting	20%		$	78,675,000
Property & Mitigation				
Easement Cost			$	5,000,000
Wetlands Mitigation	1 ac		$	1,900,000
Total			**$**	**557,625,000**
ROM Cost to Damages Avoided				**1 : 2**
Annual O&M	2%		$	7,900,000

Figure 31. Rough order-of-magnitude cost summary for Alternative 2

f) Alternative 3: Incremental Elevation

Description

This alternative would aim to incrementally elevate land and reconstruct buildings along the first block of the south and portions of north shoreline of the San Rafael Canal to +14′, a level at the 100-year BFE with +1′ freeboard and projected SLR of +3′ through 2100. This alternative includes acquisition, demolition, fill, and redevelopment where possible, of all contiguous waterfront parcels in the Canal that protect a basin condition. This alternative is essentially localized redevelopment to make space for a levee, new public easement and trail, and vegetated shoreline beginning at or landward of the current Canal shoreline. Fill and redevelopment at this scale likely must occur at the block scale and coordinated in phases through a robust public process. Incremental elevation could occur in phases over longer periods of time as land-owner approval and funding becomes available. Alternative 3 provides the greatest margin of safety and most potential co-benefits but has the highest first cost and takes the longest to implement.

Anticipated construction activities include:

- Acquire and demolish all structures and utilities within the proposed footprint of work.
- Construct ground improvements to stabilize the proposed fill for liquefaction and settlement mitigation. This would likely be a combination of excavating unsuitable materials and a surcharging and wicking program to consolidate soft bay mud and to increase shear strength. (See Bel Marin Keys levee for precedent.)
- Elevate using compacted construction fill, including laying back the Canal edge and vegetating the slope. This could include planted rip rap or ecotone slopes where space permits.
- Construct a public promenade connected to the Bay Trail.
- Redevelop open space, housing, and/or new uses through a community process where space for redevelopment exists landward of the promenade.

Alternative 3 would be a significant waterfront redevelopment driven by policies with precedent in the Bay Area. The recently formed OneShoreline agency (former San Mateo County Flood Control District) is advocating through zoning ordinances for buildings in new development around the bay to have a Finish Floor Elevation (FFE) of the BFE plus 3 feet and requiring shoreline structures to maintain a crest elevation at the BFE +6′. The 6-ft elevation is to address SLR plus wave runup, which can vary depending on the profile and composition of the fronting shoreline. Because of the sizable footprint required for a levee having a crest elevation 6 feet above the BFE, many developers opt to raise the entire grade of the proposed development to the required BFE +6′. Stillwater levels, rather than wave runup, is the flood risk driver in for the Canal shoreline, but with the right policy incentives and public support a similar redevelopment outcome may be achieved. For basin protection, it is critical that an incrementally raised edge be developed to consistent standards, and not left up to individual developers.

Redevelopment on fill would bring benefits such as:

1) open views of the Canal and Bay
2) ability to incorporate the Bay Trail along the crest
3) ability to provide the public with access to recreational water activities
4) integration of living shoreline and nature-based approaches
5) reducing flood hazards
6) potentially reducing the need for flood insurance.

West of the interstate canal crossing, berms and stem walls along Mahon Creek are required for back flooding prevention similar to Alternative 1. As a sub alternative, additional block-scale fill and redevelopment could occur around the creek. This would include reconstruction of Francisco Blvd, Lincoln Ave, Lindaro Street, and Andersen Drive bridges. The rail bridge would likely remain in place with floodwalls due to the difficulty of rail grade changes.

Alternative 3 includes individual building elevation, Point San Pedro Road elevation, and access road elevations for the north side of the Canal from approximately Embarcadero Way to the mouth of the Canal.

Alternative 3 includes bayfront adaptation measures as described in Alternative 1 to form contiguous edge protection for basin conditions and along Point San Pedro Road.

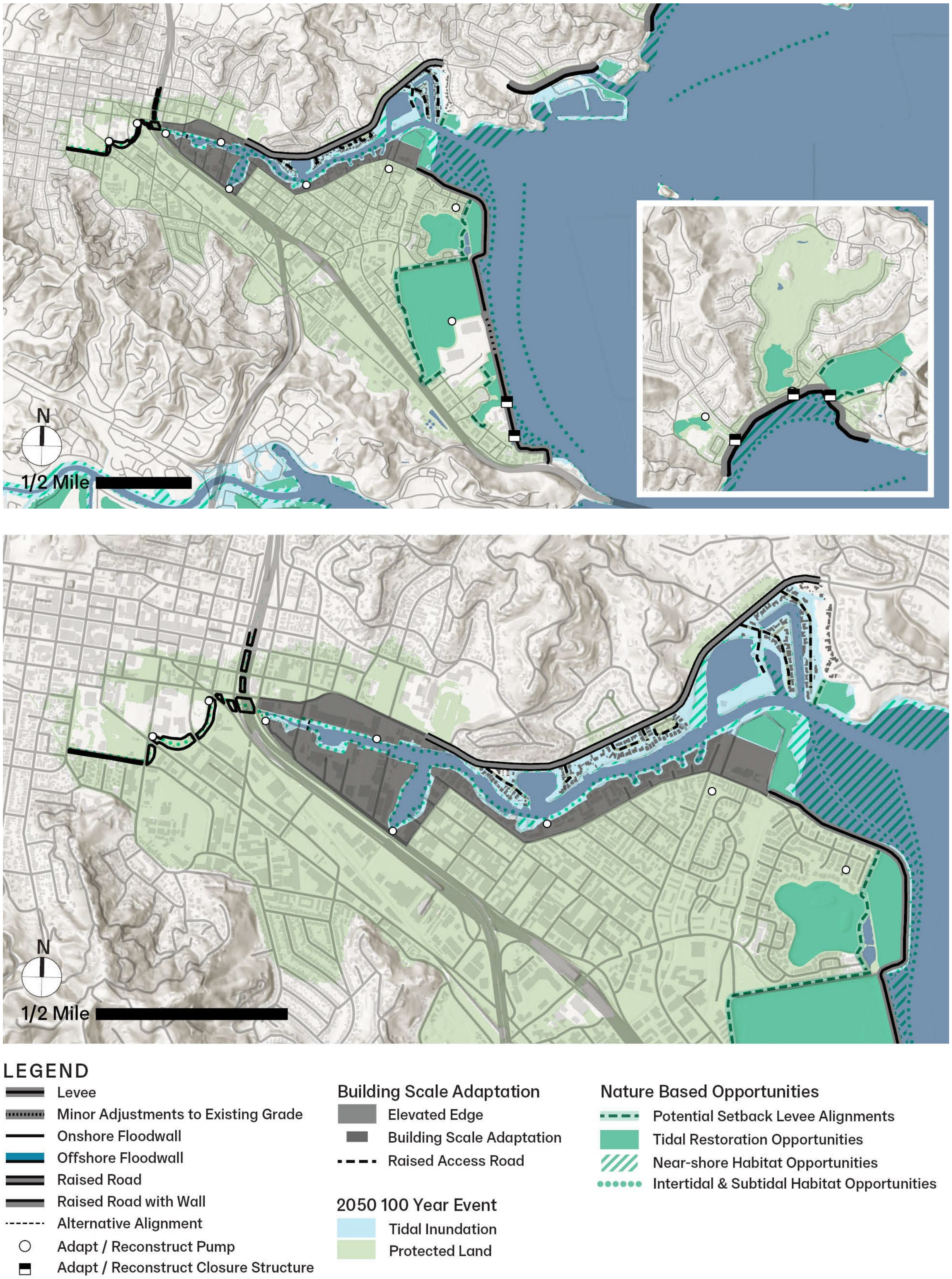


Figure 32: Alternative 3 adaptation measures & alignment, full OLU (top) and Canal detail (above).

Performance & Feasibility Analysis of Alternative 3

1) Level of Fluvial and Tidal Protection

This alternative would provide 100-year level of protection with projected SLR up to 2100 in the Canal, and up to the same level with a midcentury levee lift on the bayfront and road lift along Point San Pedro Road.

If the basin is able to meet at least 100-yr level of protection as certified by FEMA, it may be able to be mapped out of the floodplain, meaning BFE would not apply for redevelopment. Or, if the extent of filled land is wide enough, it may no longer be considered a levee and it may be possible to remap without certification.

Until a contiguous line of defense is completed, the level of protection is not reached

The persistence of the basin condition and requirements for pump upgrades would be as described in Alternative 1.

2) Effectiveness at Different Planning Horizons

Elevation of land along the basin shoreline would provide benefits through to the end of the century and potentially beyond. While it would likely take the longest to fully construct, the alternative provides the highest level of protection in the Canal of all the alternatives considered. With the right planning, it would allow space for future adaptations if needed by creating a wide public easement along the water.

Effectiveness of this alternative depends on complete contiguous implementation, or the integration of other alternatives as redevelopment progresses incrementally. The land acquisition process would be complex and costly. An estimated “fast” timeline would see the alternative completed in 20 years; a “slow” timeline of over 40 years; and an averaged timeline of about 30 years. This would be a generational project for San Rafael.

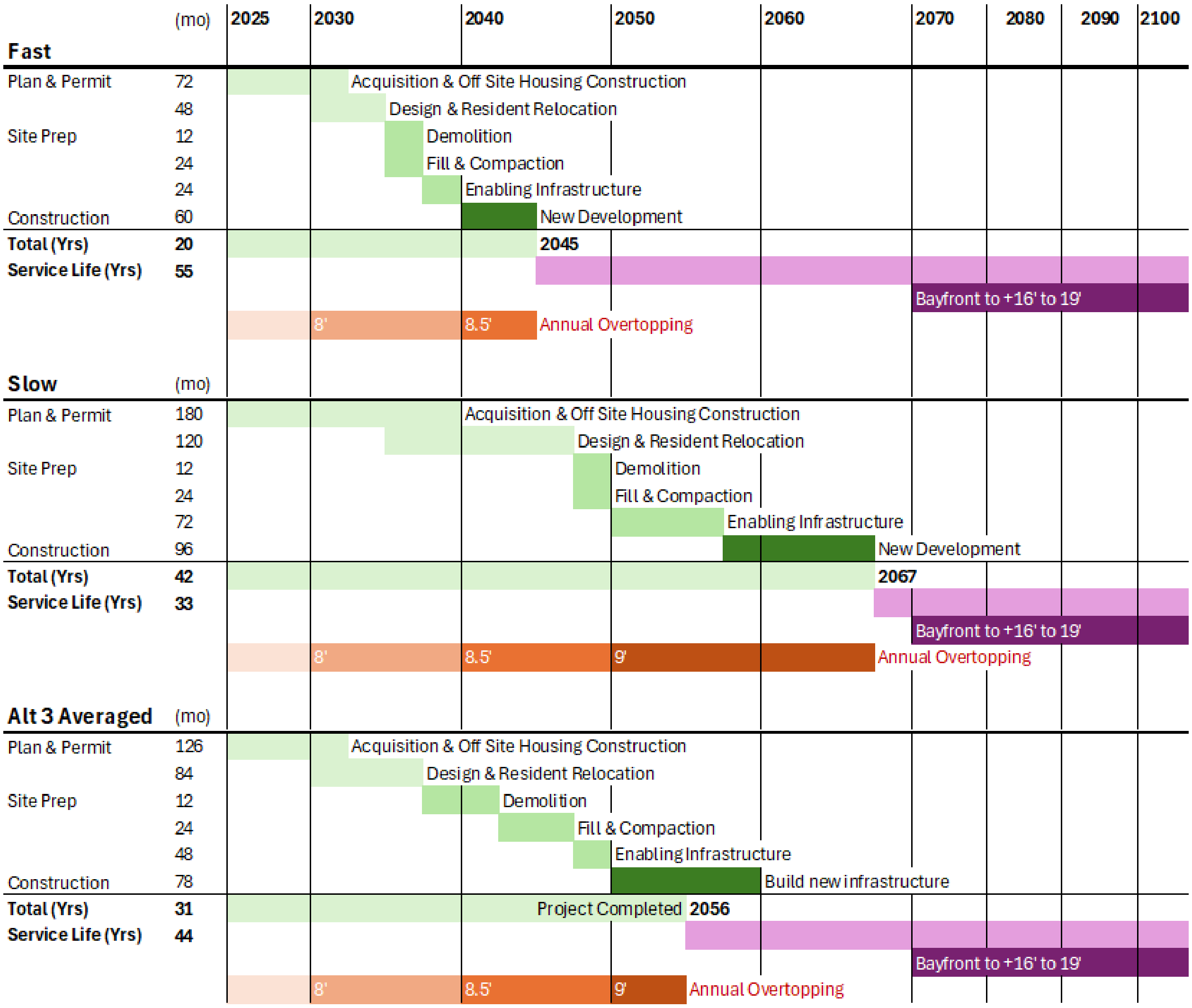


Figure 33. Fast, slow and average conceptual implementation timelines for Alternative 3

3) Spatial Considerations

For a target elevation of +14 feet, the footprint of the levee fill would be about 50 to 100 feet in width, assuming approximately 5’ average elevation of the landward property line and 9’ average elevation at the shoreline. This would accommodate a low slope canal edge (4 or 5:1 slope), 20 feet for publicly accessible trail/promenade, and a 3:1 slope down on the landward side. Where the distance between the shoreline and landward property line is approximately 150’ or greater, the opportunity to redevelop may exist, depending upon discussions with FEMA for levee-adjacent construction and possibly with USACE for permanent easement requirements. Where lots are narrower, options such as a vertical bulkhead could be considered along the canal edge to provide an additional approximately 30 ft for redevelopment, or the elevated land could be converted to open space.

In total approximately 82 acres along the Canal would be impacted by this alternative. In the aggregate, the approximate footprint for levee fill over this shoreline reach assumes 100’ toe-to-toe, slopes between 3:1 and 5:1, and 1.8 miles in length for estimation. This results in approximately two thirds remaining outside the levee footprint for redevelopment, either at existing grade or on fill.

At the scale of reconstruction required for Alternative 3, it is likely that parcels would be acquired and combined to define a new public waterfront and subdivide new, larger parcels inboard and/or on top of newly filled areas for sale redevelopment.

At a crest height of +14' to 17' there would be a considerable elevation change to reach existing grade around +5' in many places, almost a full building story. If the basin is able to be mapped out of the FEMA floodplain, it may be possible to develop at-grade mixed uses; otherwise, all new development and redevelopment will have to be elevated above BFE. Where redevelopment is not possible, this grade change could be accomplished through new open space and accessible paths. Where redevelopment may fit, the space could be used for parking and grade could be made up through elements integrated with new buildings, providing access to the new Canal trail from the first occupied floor. In all cases it may be advisable to elevate existing grade to some degree as protection from stormwater or extreme overtopping flooding, and potentially to help manage stormwater runoff in subsurface storage within the raised area.

This alternative would include reconstruction at higher landing elevations of Grand Ave bridge and the Irwin Street off ramp.

For areas under the 101 Freeway, along Mahon and Irwin Creeks, on the north Canal shoreline east of Embarcadero Way, along the bayfront levee and Point San Pedro Road to Peacock Gap, the spatial implications of this alternative would be similar to Alternative 1.

Alternative 3 Spatial Summary	Length / #	Structure Width	Easement Width	Notes
Levee	1.8 mi	50-100 ft	10 ft	Along reconstructed Canal waterfront
Minor Grade Adjustments	0.2 mi	10 ft		Bayfront Shopping Center
Onshore Floodwall	1.6 mi	2 ft	10 ft	Mahon & Irwin Creek Banks
Raised Road	1.2 mi	80 ft		Pt San Pedro Rd Embarcadero to Sea Way
Raised Road with Wall	1.6 mi	80 ft		Wall elevation BFE + freeboard + SLR, road elevated to maintain visibility over wall for pedestrians and vehicles
Total Length	**6.5 mi**			
Elevated Edge	82 ac	50 – 100 ft		
Adapt / Reconstruct Pump	10	Existing Footprint		Integration with raised edge
Adjust Existing Closure Structure	5	Existing Footprint		East San Rafael Wetlands and Brickyard Cove
Building Scale Adaptation				

Multifamily Residential	35			
Single Family Residential	176			
Commercial	93			
Industrial	3			
Total Buildings	**307**			Building scale adaptation includes both the north and south sides of the canal
Raised Access Road	2.1 mi			Access to Point San Pedro Road from raised buildings length varies depending on where the alignment crosses the Canal

Figure 34. Summary of spatial requirements for Alternative 3

4) Permitting Requirements

As a baseline, city building permits would be required. Updated city codes for higher finished floor elevations for structures and buildings may help advance this alternative, however the small scale of waterfront parcels in the target area do not lend themselves to individual redevelopment requiring investment and coordination of this magnitude. One possibility is that a new public program would lead the acquisition of required parcels. These could then be re-subdivided and sold to developers after shoreline protection is installed or co-developed through a public-private partnership.

Development in proximity to shoreline areas and within the BCDC 100-ft shoreline band and tidal tributaries could require the full gamut of permitting needed for development along the Bay and Canal shoreline and waters of the U.S. In this case, consultation and permitting could involve USACE for construction within the waters of the United States, tribal consultation, Regional Water Quality Control Board (RWQCB), NOAA National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), California Department of Fish and Wildlife (CDFW), and the San Francisco Bay Conservation and Development Commission (BCDC). Potential consultation with the California State Lands Commission (CSLC) would be needed if any proposed construction is on granted lands, but this is not believed to apply to the project area.

5) Land Ownership and Access Considerations

For this alternative, all 86 Canal shoreline parcels protecting the basin condition would be acquired, combined, potentially re-subdivided, and redeveloped after the levee is in place. The number of private land owners would pose a significant hurdle to this process as acquisition would be voluntary and tidal protection depends on 100% participation. If the city were to pursue non-voluntary acquisition, through eminent domain, declaration of a hazard district, or other mechanism, legal processes could delay implementation nearly indefinitely. As such, acquisition of the required parcels may come at a premium despite their flood risk.

Alternative 3 provides opportunity for full public access to the Canal shoreline on a new accessible trail connected to the Bay Trail, at least for elevated and redeveloped blocks. Public docks, get downs, small craft launches, and overlooks for fishing and viewing could be incorporated into the naturalized and redeveloped edge.

Reconstruction of the Irwin Street off ramp would require coordination with Caltrans. Additional bridge reconstructions may be required over Mahon Creek to maintain cohesive urban connectivity.

Ownership and access implications for the north Canal shoreline without a basin condition, Mahon and Irwin Creeks, and the bayfront would be as described in Alternative 1.

6) Potential Threats to the Community

Alternative 3 provides the greatest long-term safety from tidal flooding for the San Rafael basins, however it is also likely to take the longest to complete. The threat of increasingly catastrophic overtopping will rise similar to the No Action scenario if contiguous edge protection is not completed in some form, even temporarily, while block-scale acquisition and redevelopment occur.

Alternative 3 provides a levee structure within Canal redevelopment that would be designed to resist seismic forces, similar but smaller in scale to examples such as Bel Marin Keys.

Alternative 3 reduces slightly, but does not fundamentally alter, the basin condition where development and infrastructure exist below tide levels. Under this alternative (and all alternatives), basin residents would rely on drainage pumps indefinitely to manage stormwater and groundwater and may be subject to flooding from mechanical or human error at pump stations. For this and all alternatives, there is an inherent risk of failure that comes with living below the Bay.

Potential threats of bayfront adaptations are the same as described in Alternative 1.

7) Co-Benefits of Adaptation Measures

A primary co-benefit of this alternative is the establishment of continuous public space along the Canal's basin edge, approximately from Pickleweed Park to the 101 Freeway on the south shoreline and along the north shoreline from the Freeway to Embarcadero Way, just past San Rafael High School. This feature could essentially extend the Bay Trail almost into downtown as a recreational and multimodal route.

A new pedestrian bridge across the Canal may also become more feasible through this scale of change. This would improve connectivity to downtown and San Rafael High School and may serve as an evacuation route for emergencies. Space for bridge landings and approaches could be reserved within the redeveloped area. Depending on the extent of fill on waterfront blocks, road and pedestrian networks may also be raised to provide access and egress corridors safe from flooding.

At the scale of redevelopment proposed over time in this alternative, there could be opportunity to significantly reimagine the waterfront and adjacent urban streetscapes around the Canal, including making more space for stormwater green infrastructure, street trees, and other amenities.

Co-benefits of bayfront adaptations are the same as described in Alternative 1.

8) Housing Implications

Up to 550 housing units could be displaced as part of construction activities for incremental elevation in this alternative. It is estimated that approximately 390 housing units could be impacted by construction of the basin protection measures out of which 350 are in multifamily buildings. Additionally there are 160 housing units north of the canal that would require building scale adaptation to achieve flood protection. Considering this option involves completely rebuilding waterfront blocks, it is likely that all 390 units would be displaced. The complexity of this alternative would likely require permanent relocation, if possible in a coordinated fashion led by the city and within city limits. It is possible that entities other than the city could coordinate such an effort, such as at the county or regional level, however in the consultant team's experience most jurisdictions prefer to maintain local control of housing decisions and maintain their existing tax base to the extent possible. This requires the identification and development of designated receiver sites outside of the basin for displaced residents, businesses, and organizations.

It is estimated that 3,970 housing units would benefit from reduced flood risk with this alternative. Of these, 1,650 are in multifamily buildings. An estimated 13,400 people would be protected in this alternative. These numbers do not include residents displaced by construction; it is assumed that even if they relocate elsewhere in San Rafael, it will be to higher ground and they are no longer technically protected by the alternative. Also not counted are potential new residents if/when waterfront parcels are reconstructed on or adjacent to filled areas where space allows, which may be at or above current densities, and would likely include a percentage of affordable units.

At present, parcel acquisitions would need to be made on a voluntary basis, and over time all waterfront parcels would need to be acquired and filled to a consistent elevation for contiguous protection. A geologic or other hazard abatement district, if implemented by the City, could potentially be a tool for eminent domain of parcels required for basin-wide safety. Public acquisition may not signal immediate demolition and affected housing units could become part of a new program of housing construction and temporary relocation elsewhere in the city.

9) Ecological Implications

This alternative would provide opportunity to master plan and align incremental elevation of land with habitat creation, enhancement, and preservation. While no mitigation need is anticipated in this alternative, it may be possible to create habitat enhancements sufficient to establish mitigation credit value, such as through the development of fringe marsh within the Canal. Additionally, these features may support a determination of the Least Environmentally Damaging Practicable Alternative (LEDPA).

Water quality in the Canal would be expected to improve under this alternative. The waterway would remain fully tidal with expanded vegetated slopes.

While no previous heavy industrial uses are known within the alternative's footprint, it may be possible that light industrial uses have resulted in some degree of contamination on land or at the Canal bottom. If discovered, and depending on specific chemicals, groundwater migration potential and soil characteristics, it may be possible to integrate a remediation strategy into the alternative. None is considered at this time.

Ecological implications for the bayfront and inland would be as described in Alternative 1.

10) Economic Feasibility

A key differentiator of this alternative is the long-term 2100-level effectiveness for flood protection. With this long-term benefit comes high upfront cost over $1.8 billion for the acquisition and shoreline adaptation measures only and in today's dollars, not counting additional investment to rebuild new housing or structures. While this type of alternative is inherently incremental, outside funding is likely required for first costs.

Property acquisition costs include the sum of land value and structure value. Measured in terms of capital improvement cost versus flood damage potential, this alternative would maintain a ROM cost to a ratio of approximately to flood damage ratio 1:1.7 without factoring potential real estate return on investment.

The potential need for remediation is not included in cost estimates and would depend on soil sampling and analysis.

Professional services for this alternative may include a program management firm to support the city through project management and logistics for everything from new housing construction to a relocation process to property negotiations to owner's representative during design and construction. If an entity other than the city were to lead this process, it would be advisable for the city to develop a decision-making structure to localize project decisions and control of project priorities to the extent possible.

Only Alternative 3 provides the potential to recoup costs through land redevelopment. The potential returns (land sale value) for redevelopment, if pursued through private sale or developed through public/private partnership, are not included in Alternative 3 but could be significant, approaching the property acquisition cost. Additional tools such as tax increment financing (TIF) districts and transfer of development rights (TDR) may be explored to raise revenue and facilitate value transfer.

Construction	Percent	Amount	Value	
Levee		1.8 mi	$	12,000,000
Raised Roads		2.8 mi	$	102,000,000
Floodwall		1.7 mi	$	90,000,000
Elevated Land		82 ac	$	429,000,000
Rebuild Existing Pump Stations		10	$	32,000,000
Adapt Existing Closure Structure		5	$	1,250,000
Contingency	50%		$	333,125,000
Total			**$**	**999,375,000**
Building Scale Adaptation			$	159,000,000
Utility Upgrade & Reconnections	10%		$	99,935,500
Planning				

Professional Services	10%		$	199,875,000
Compliance & Permitting	20%		$	199,875,000
Property & Mitigation				
Easement Cost			$	5,000,000
Property Acquisition		86	$	206,000,000
Wetlands Mitigation		-	-	
Total			**$**	**1,869,062,000**
ROM Cost to Damages Avoided				**1 : 1.7**
Annual O&M	0.5%		$	5,000,000

Figure 35. Rough order-of-magnitude cost summary for Alternative 3

g) Alternatives Not Considered

Seawall or Barrier Within First Right-of-Way

This alternative was proposed during Resilient by Design and would focus on the first designated right-of-way (road) inland from the Canal shoreline as a corridor within which to build flood protection. Incorporation of a continuous crest elevation at +12 feet could be achieved through a combination of raised roads, promenades and wall sections. Wall sections would either be included along the median of Canal Street or along the north edge of the right-of-way. Gates would be incorporated where pedestrian and vehicular connectivity is needed. Gates could either be mechanically operated or flip up structures embedded within existing grade that would passively raise themselves in flooding scenarios. The alignment for this alternative avoids conflict with existing buildings and can largely be constructed on public property. Relocation and realignment of utilities in the right-of-way would need to be considered as part of the upgrades.

This alternative was ultimately not considered due to the complexity of managing walls and gates for a multitude of private properties in constrained public rights-of-way, and the near certainty of litigation by property owners left outboard of the structure.

Managed Retreat At-Scale

While site specific retreat may be unavoidable for some properties to protect human life and safety or as a temporary measure during construction, managed retreat as a standalone alternative was not considered, most importantly because it is not aligned with residents' priorities and vision for their community. Additionally, the scale and cost of moving potentially several thousand people makes this infeasible as a standalone strategy. Currently there are neither programs nor funding streams that would facilitate this kind of change at this scale in a fair and predictable manner. The costs of redeveloping the public infrastructure alone and remediation of the landscape would likely require several billion dollars in outside resources. For this and other reasons it was not considered.

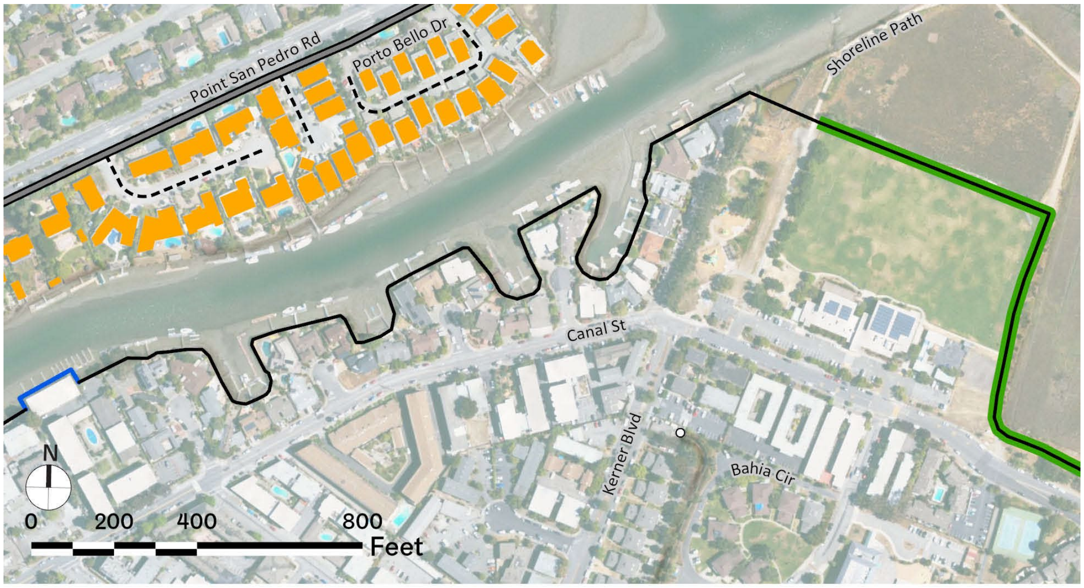
Reconstruct & Elevate All Land Above Future High Tides

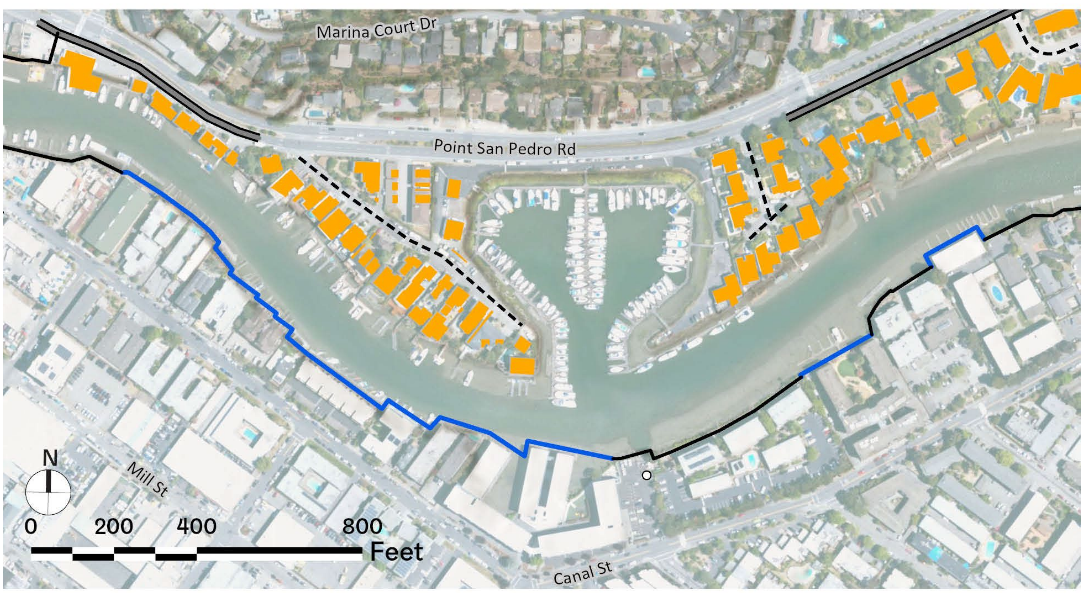
This alternative would include acquisition, demolition, fill, and reconstruction of all structures and infrastructure in basin areas above land elevation +16', the 2100 BFE +3 feet of SLR. This alternative would encompass low-lying portions of Interstate 580, tens of thousands of residents, and potentially hundreds of square blocks. In practice, this alternative could look like the recent filling and redevelopment of Treasure Island.

While this is the only alternative that would elevate all land in San Rafael above high tide levels anticipated at the end of the century, it was not evaluated due to the extreme disruption and costs involved, and because other alternatives can provide comparable levels of safety. Only in the event of a catastrophic disaster would such a drastic reshaping of the city potentially be considered.

iv. Appendices

Alternative 1 Conceptual Alignment Detail Maps





LEGEND

- Levee
- Onshore Floodwall
- Offshore Floodwall
- Raised Road
- Alternative Alignment
- Adjust Existing Pump

Building Scale Adaptation

- Building Scale Adaptation
- Raised Access Road

Figure 36. Zoom in map of Alternative 1

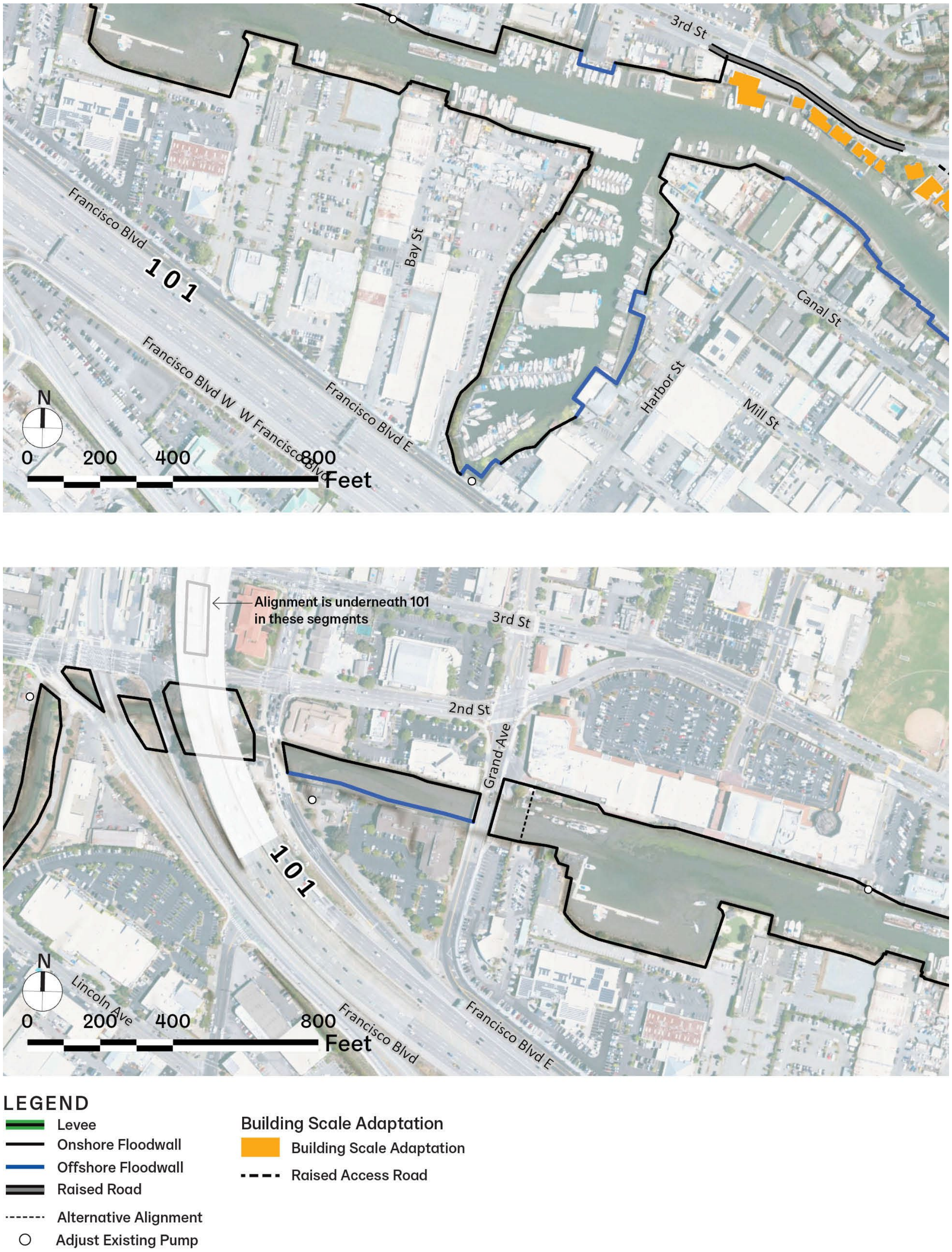


Figure 37. Zoom in map of Alternative 1

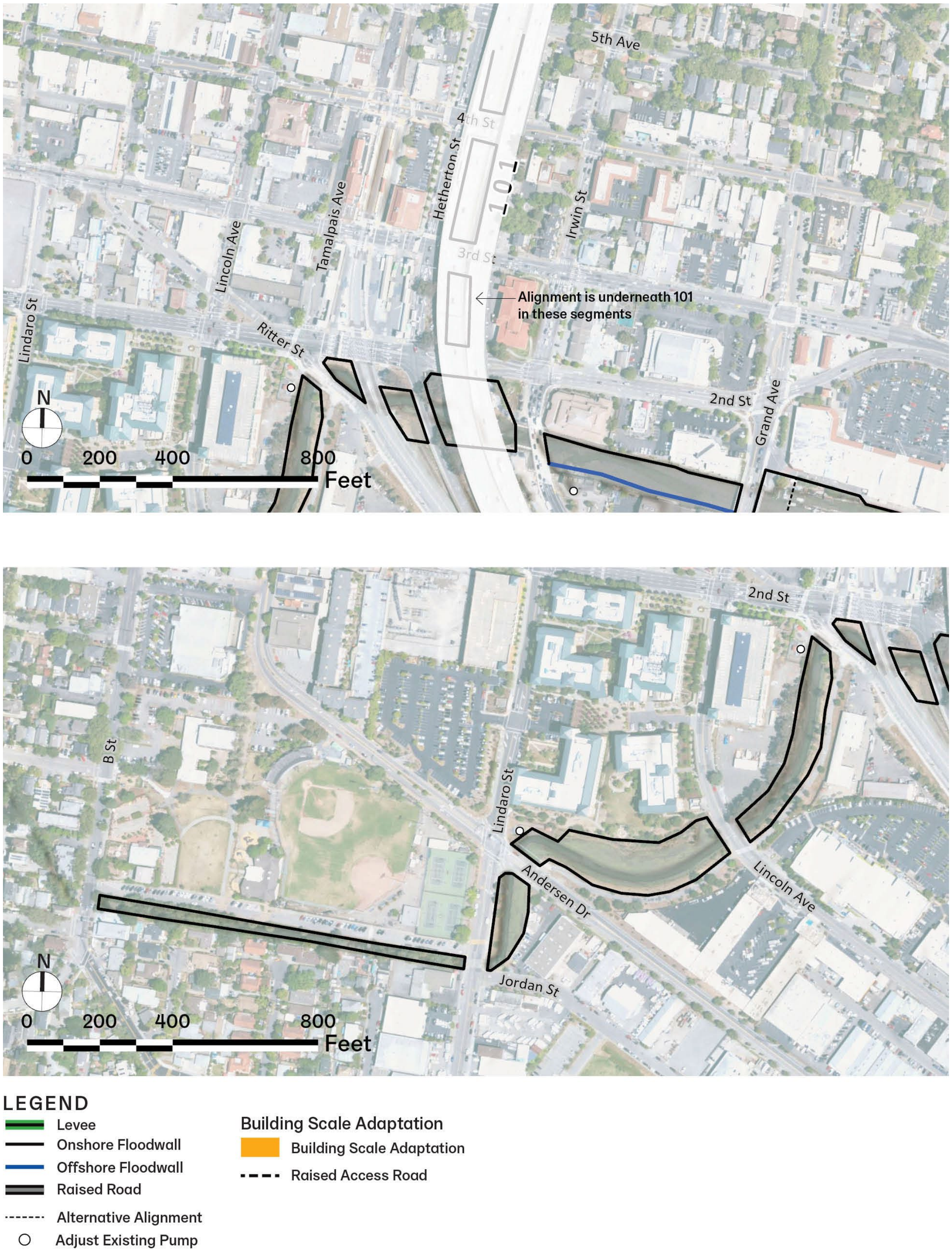


Figure 38. Zoom in map of Alternative 1

Resumen Ejecutivo

El objetivo principal de este documento es evaluar la viabilidad de las alternativas de adaptación al aumento del nivel del mar en la Unidad Operativa de Paisaje (OLU en sus siglas en inglés) de San Rafael. Todas las alternativas buscan aumentar la resiliencia de la comunidad ante el aumento del nivel del mar y las inundaciones, mejorar la salud y la resiliencia ambiental, y minimizar los riesgos de desplazamiento y los posibles impactos en la comunidad y el medio ambiente. Este estudio no recomienda una alternativa preferida, sino que identifica las posibles desventajas y beneficios de cada una dentro de una serie de criterios de viabilidad.

Este esfuerzo se lleva a cabo con el entendimiento de que la alteración de los procesos naturales y el desarrollo de las Baylands históricas son la raíz de la vulnerabilidad. Sin embargo, las condiciones actuales y los riesgos inminentes a la seguridad son el punto de partida para la adaptación.

Organización del Documento

La sección del Resumen Ejecutivo ofrece una visión general del proyecto completo de adaptación al aumento del nivel del mar y las conclusiones del estudio de viabilidad técnica:

a) Un resumen de las actividades de participación comunitaria, los productos y la retroalimentación a lo largo del proyecto recibidas del equipo del proyecto, los colaboradores y la Ciudad.
b) Una descripción general de las tipologías de paisaje utilizadas para organizar las estrategias de adaptación en San Rafael. c) Descripciones de las alternativas de adaptación, incluyendo un escenario base de "No Acción", Acciones Iniciales, Oportunidades Naturales y tres alternativas las cuales fueron evaluadas según diez criterios definidos por la Ciudad de San Rafael.
c) Un resumen comparativo de la viabilidad de las alternativas y sus criterios.

Todas las elevaciones se refieren al dato NAVD88 a menos que se indique lo contrario.

a. Resumen de la Participación Comunitaria

En 2022, fundamentada en una larga trayectoria de activismo comunitario y trabajo por la justicia climática en San Rafael, la Colaborativa para el Aumento del Nivel del Mar (Colaborativa) comenzó a realizar amplias y constantes actividades de divulgación, participación y educación sobre la adaptación al aumento del nivel del mar, con más de 100 actividades de participación hasta la fecha. La comprensión y las perspectivas de la comunidad derivadas de este esfuerzo informaron el Estudio de Viabilidad Técnica y se documentarán en mayor detalle en el informe final.

En el verano de 2024, el Equipo Consultor del Estudio de Viabilidad Técnica comenzó a contribuir contenido a las iniciativas colaborativas de participación, así como a realizar actividades específicas de participación para el estudio. Las actividades de participación del proyecto realizados por Equipo Consultor incluyeron talleres públicos, la facilitación de reuniones del Comité Asesor Técnico, reuniones de trabajo con el personal de la Ciudad y la participación en varias reuniones mensuales del Comité Directivo en el Centro Multicultural de Marin. El contenido producido para estos eventos incluyó presentaciones digitales bilingües (inglés y español), paneles gráficos impresos, herramientas interactivas de participación, una maqueta de San Rafael y un Libro Informativo público que ofrece un repaso general de las vulnerabilidades de inundación.

Figura 1. Actividades de participación del equipo consultor y talleres para el estudio.

Durante estas oportunidades de participación pública, la comunidad articuló un conjunto de principios rectores que buscan definir el proceso de adaptación. Estos principios se integraron en el proceso de planificación del Equipo Consultor desde el inicio del trabajo.

- Liderazgo Comunitario: Educar y empoderar continuamente a los residentes de Canal para que lideren la toma de decisiones sobre medidas de adaptación.
- Proteger a las Personas: Priorizar la preparación para emergencias, la seguridad pública y la salud pública.
- Prevenir el Desplazamiento: Las medidas de adaptación deben apoyar a la comunidad y evitar el desplazamiento de sus residentes.
- Conectar a las Personas: Construir relaciones y establecer recursos para apoyar la colaboración y la resiliencia de la comunidad.
- Justicia Ambiental: Dirigir recursos técnicos y económicos a los más vulnerables y garantizar que los costos de la adaptación se compartan de manera justa y equitativa.
- Conectar con la Naturaleza: Proteger el acceso a la costa y ampliar los espacios verdes.
- Proteger los Ecosistemas: Maximizar los beneficios medioambientales, como la restauración de hábitats naturales.

El Equipo Consultor incorporó iterativamente en sus materiales la retroalimentación pública de una amplia gama de grupos interesados, la cual fue técnica, cualitativa y basada en la experiencia local. . Para incrementar la comprensión y el consenso comunitario, se organizaron talleres públicos denominados "Asambleas Comunitarias" el 8 de junio y el 21 de octubre de 2024. El Equipo Consultor participó en tres reuniones del Comité Asesor Técnico (el 6 de junio y el 26 de septiembre de 2024, y el 14 de enero de 2025) en un formato híbrido, presencial y virtual, para recibir comentarios sobre el análisis técnico. Además, el Equipo Consultor participó en varias reuniones mensuales del Comité

Directivo del Centro Multicultural de Marin para desarrollar materiales de participación en conjunto y empoderar al Comité para que continúe abogando por la resiliencia de la comunidad una vez finalizado el alcance de este proyecto.

Los comentarios proporcionados al Equipo Consultor incluyen:

- Existe el consenso general de que es necesario actuar, pero también existe preocupación sobre la viabilidad de las medidas de adaptación propuestas y su impacto en los residentes. El posible aumento de los costos, el desplazamiento de inquilinos y el impacto a largo plazo en la vivienda asequible fueron preocupaciones clave.
- Los residentes destacaron la necesidad de protección a los inquilinos y las garantías de estabilidad habitacional. Muchos preguntaron sobre la participación de los propietarios y expresaron el deseo de garantizar que toda la comunidad (incluidos los inquilinos) beneficien de las soluciones propuestas.
- En todas las alternativas de adaptación, se observó una combinación de apoyo, inquietudes y preguntas sustanciales sobre la viabilidad y la eficacia real de cada una de ellas. Los residentes reconocen la importancia del proyecto, pero muchos expresaron preocupación por la complejidad del proyecto y el tiempo que tomará implementar cualquier alternativa.
- Algunos profesionales también reconocieron que la magnitud del cambio necesario para una adaptación exitosa requerirá nuevas formas de gobernanza y financiación, lo que permitirá una visión más transformadora en las soluciones a largo plazo.
- Se buscó claridad en el cronograma de las iniciativas de adaptación. La comunidad busca constantemente entender cuándo se tomarán las medidas.
- Se hizo hincapié en la importancia de la comunicación clara y la participación comunitaria durante todo el proceso.
- Otras oportunidades clave para una mejor comunicación con las partes interesadas incluyen la combinación de la reducción de riesgos con soluciones de beneficios múltiples para un mejor y más fuerte San Rafael y la intensificación de la adaptación proactiva versus la reparación reactiva de daños.

b. Resumen de las Tipologías de Paisaje

San Rafael se puede dividir en tres tipologías de paisaje: tierras altas, costa y las zonas bajas. Existen dos zonas bajas en el área de estudio, una al sur del Canal y otra en Peacock Gap. La condición de la costa varía a lo largo del área de estudio. En algunas zonas, la costa desciende formando una zona baja y, en otras, asciende formando tierras altas. La condición de tierras altas se define por el resto de la OLU por encima de la costa y la zona baja.

Figura 3. Diagrama en plano que describe las tipologías de paisaje en San Rafael.

Costa

La costa se define como el borde del terreno a lo largo de la Bahía y el Canal, dentro del alcance de las mareas. A lo largo del frente sur de la bahía, la costa cuenta con un dique construido aproximadamente entre 1950 y 1968 (Siegel Environmental, 2016), y en el lado de la bahía, el terreno se inclina gradualmente hacia la bahía formando una planicie de humedales. La costa a lo largo del Canal está compuesta principalmente por desarrollos costeros construidos directamente adyacentes al agua o sobre el agua. En Peacock Gap, la carretera Point San Pedro recorre la costa, colindado por una pequeña barrera rocosa del lado de la bahía. Desde allí, el terreno desciende gradualmente formando una planicie de humedal.

Al interior, la línea costera asciende gradualmente, dejando expuestos a los edificios y carreteras cerca del agua a las inundaciones causadas por las mareas. Donde la línea costera se encuentra con la condición de cuenca, se encuentra la primera línea de defensa contra las inundaciones por mareas. La línea costera es ligeramente más alta que las zonas bajas, dándole al terreno la forma de una bañera, con la costa y las zonas altas actuando como los lados y la las zonas bajas como el fondo. Cuando la línea costera se inunda, las zonas bajas se inundan también.

La zonas bajas

Construidas sobre humedales históricos y planicies mareales, las zonas bajas presentan el mayor riesgo de inundación de todas las tipologías de paisaje del área de estudio. Con el tiempo, el peso del desarrollo sobre suelos limosos y la disminución de los niveles de agua subterráneos han provocado que las zonas bajasse hundan más bajo que la marea alta diaria. Solo una franja de tierra estrecha a lo largo de la costa impide que la las zonas bajas se inunden. Cuando el agua sobrepasa este borde, las zonas bajas se inundan hasta que la marea retrocede o hasta que se bombee el agua de la inundación. El aumento del nivel del mar y un mayor hundimiento de la tierra aumentan el riesgo de rebose, amenazando con inundar las zonas bajas permanentemente si no se toman medidas en las próximas décadas.

Las inundaciones causadas por la lluvia son una amenaza adicional para las zonas bajas. Dado que el terreno se encuentra por debajo del nivel de las mareas durante gran parte del día, el drenaje por gravedad de aguas pluviales es imposible. En cambio, la precipitación que cae directamente dentro de las zonas bajas o que fluye desde las zonas altas debe ser extraída mediante un sistema de bombeo. Las lluvias fuertes pueden saturar las estaciones de bombeo y provocar la inundación de la zona baja.

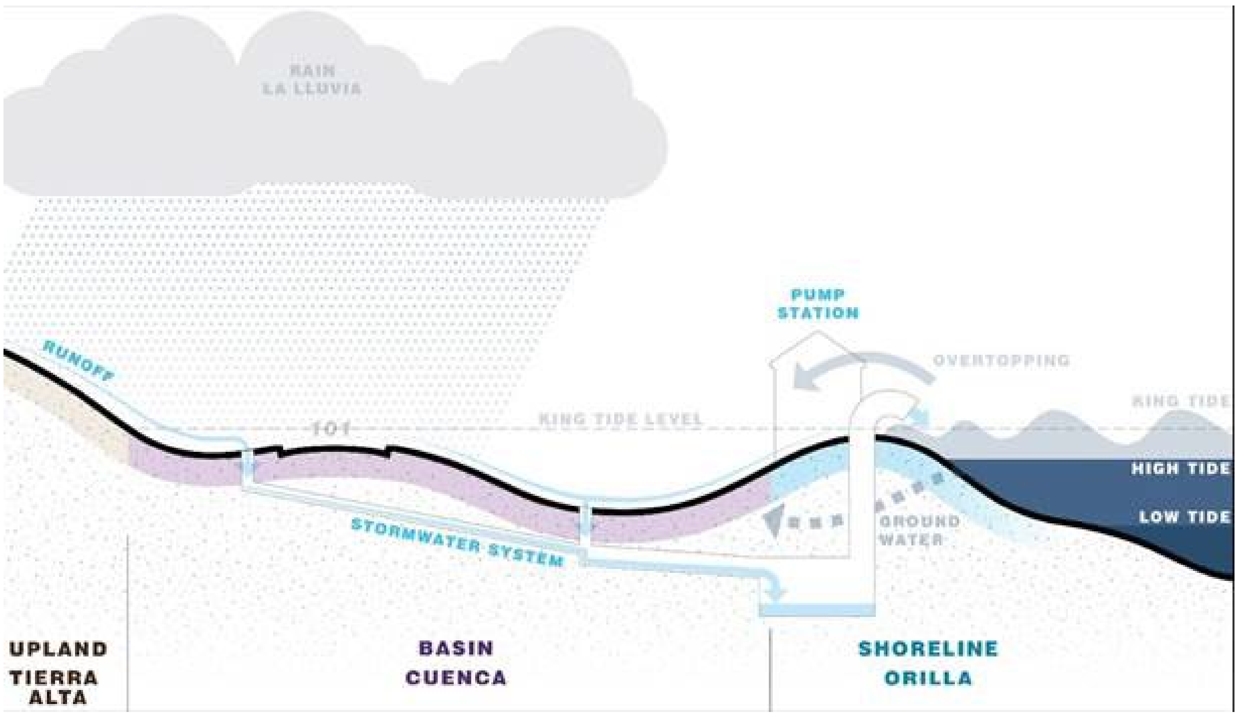


Figura 4. Diagrama de sección que describe el estado de la zona baja a en el Distrito del Canal y partes de Peacock Gap en San Rafael.

Tierras altas

El resto del área de estudio es más montañoso, con algunas zonas situadas sustancialmente por encima del nivel del mar y protegidas del riesgo directo de inundaciones por mareas. El nivel de desarrollo varía en estas zonas, desde el centro de San Rafael, con mayor densidad, hasta colinas sin urbanizar. Las tierras altas, la costa y las zonas bajas se encuentran dentro de zonas hidrográficas comunes. La escorrentía de las zonas altas puede causar inundaciones en las zonas bajas a lo largo de la costa. Por lo tanto, la reducción integral del riesgo de inundaciones debe incluir las zonas altas para minimizar los impactos aguas abajo.

c. Resumen de las Alternativas de Adaptación

El análisis incluye un escenario base de “No Acción” como herramienta analítica de comparación; la definición de Acciones Iniciales comunes a todas las alternativas subsiguientes; la identificación de Oportunidades Naturales para su incorporación en alternativas subsiguientes; y la definición de tres alternativas centradas en medidas de reducción del riesgo de inundaciones que se implementarán en toda el área de estudio. Cada alternativa requiere adaptaciones adicionales en el futuro por fases para mantener los niveles de reducción del riesgo de inundaciones con el aumento del nivel del mar y el hundimiento del agua. Algunas de estas adaptaciones futuras podrían ser comunes a todas las alternativas, como la elevación adicional de los diques frente a la bahía.

Cada alternativa incluye dos secciones: 1) Descripción de las medidas y sus componentes, incluyendo elementos integrales y comunes en todas las alternativas y que podrían adaptarse en el futuro; y 2) Análisis de desempeño y viabilidad según los diez criterios.

Línea Base de “No Acción”

El análisis de viabilidad comienza con la definición de un escenario base de “No Acción”, donde la probabilidad de inundaciones a lo largo de la costa y dentro de las zonas bajas aumentaría significativamente hacia mediados de siglo si medidas de adaptación no se realizan de manera coordinada. Después de aproximadamente 2050, la viabilidad a largo plazo de las zonas más vulnerables de San Rafael en su estado actual es incierta dentro de este escenario. El escenario de "No Acción" no es una recomendación, sino que se utiliza únicamente como herramienta analítica para evaluar y comparar el nivel de protección y otros impactos potenciales en cada una de las alternativas evaluadas.

Acciones Iniciales

Las Acciones Iniciales son medidas urgentes para reducir el riesgo de inundación existente en las zonas más vulnerables, implementar estrategias naturales piloto e implementar elementos que son comunes dentro de todas las alternativas siguientes. Las Acciones Iniciales, tal como se definen aquí, constituyen un primer paso gradual hacia todas las demás alternativas y permiten ganar tiempo para planificar e implementar estrategias de adaptación a largo plazo. Las futuras medidas de adaptación que se basan en las acciones iniciales se describen en las alternativas siguientes.

Las acciones iniciales incluyen:

Canal

A corto plazo, elevar las zonas bajas a +2,4 metros NAVD88 a lo largo del borde del Canal y reemplazar o reforzar las barreras informales, ya sea mediante medidas temporales desplegables o medidas provisionales , según las recomendaciones de un análisis individualizado del sitio.

1) Iniciar un análisis de viabilidad sitio por sitio y un plan de respuesta ante inundaciones por mareas a lo largo de la línea costera por debajo de +8’ NAVD88 y en áreas con barreras informales contra inundaciones.
2) Desarrollar e implementar medidas piloto para la mejora del hábitat y su expansión en futuras adaptaciones. Las medidas piloto pueden avanzar más rápidamente en lugares donde existe el espacio en propiedad pública y en colaboración con propietarios privados e incluyen muelles, pilotes y embarcaderos; prototipos de humedales flotantes en áreas protegidas; y en la superficie de estructuras verticales bajo el agua, como texturas superficiales.
3) Tomar medidas iniciales para evaluar las implicaciones de la adquisición pública de propiedades, estructuras y/o servidumbres costeras a lo largo de la costa que sirvan como protección contra inundaciones para las zonas bajas.

La zona baja

En todas las alternativas, se requerirán estaciones de bombeo, por el momento en configuración indefinida, para manajer las aguas pluviales y subterráneas en las zonas bajas existentes, y es probable que la extensión del área de drenaje tendrá que aumentar a medida que suba el nivel del mar y se hunda aún más el terreno.

1) Mantener y modernizar las estaciones de bombeo existentes. Actualmente, las estaciones de bombeo son la única manera de manejar las aguas pluviales y los desbordamientos de la marea, y es fundamental que permanezcan funcionales mientras se implementan las medidas de adaptación. (El rendimiento del drenaje de aguas pluviales no se evaluó en este estudio).
2) Elevar proactivamente la infraestructura crítica, como la Estación de Bomberos 54, para garantizar la respuesta de emergencia en caso de inundaciones por aguas pluviales o desbordamientos catastróficos.
3) Evaluar la viabilidad de la elevación de carreteras a escala de cada parcela para vías de acceso críticas a terrenos elevados, a través del Canal y debajo de la interestatal.
4) Evaluar la viabilidad de ampliar los servicios municipales para financiar, mantener y operar la infraestructura crítica, incluyendo los diques, a través del Departamento de Obras Públicas o una nueva entidad.

Tierras altas

Fortalecer las opciones de vivienda y la infraestructura verde para las aguas pluviales en tierras altas brindará más flexibilidad para la adaptación en zonas de alto riesgo de inundación en las zonas bajas.

1) Financiar programas para planificar y apoyar la construcción de viviendas multifamiliares en terrenos más altos fuera de la cuenca, como el centro de la ciudad, alineados con el Plan General de la ciudad, que potencialmente puedan apoyar la reconstrucción gradual de viviendas de baja altura y de planta baja dentro de las zonas bajas. Esto es recomendable para complementar todas las alternativas.
2) Incentivar, planificar y construir infraestructura verde para las aguas pluviales en propiedades públicas y privadas, incluyendo resaltes en calles, biofiltros, superficies permeables y detención subterránea para reducir la presión de las inundaciones aguas abajo.

a) Oportunidades basadas en la naturaleza

Las soluciones basadas en la naturaleza, o "costas vivas", incluyen hábitats (p. ej., playas de arena gruesa, ecotonos o diques horizontales, arrecifes de ostras costa afuera) que complementan las medidas de protección contra inundaciones costeras al preservar o mejorar los hábitats existentes, la recreación y/o el acceso público. Estas medidas pueden reducir en cierta medida el riesgo de inundación mediante la atenuación de las olas y la protección contra la erosión. Se combinan con la protección estructural contra inundaciones, como diques y muros de contención, como medidas híbridas verdes/grises donde el desbordamiento de aguas estancadas es el principal factor de riesgo de inundación, como lo es en San Rafael. Estos enfoques se han explorado a nivel conceptual a lo largo de la costa de San Rafael como parte del Desafío del Área de la Bahía Resiliente por Diseño (Bionic 2018), por el Atlas de Adaptación de la Bahía de San Francisco (SFEI y SPUR 2019), por organizaciones sin fines de lucro como Resilient Shore, y como parte de las iniciativas de planificación urbana (Ciudad de San Rafael 2014) y a nivel de condado (Point Blue, SFEI y Condado de Marin 2019).

Existen múltiples oportunidades de hábitat dentro de cada alternativa evaluada que utilizan estrategias basadas en la naturaleza para minimizar la acción de las olas y la erosión, apoyando así los objetivos de mitigación de riesgos de inundación, especialmente en la zona costera, donde estas fuerzas son más prevalentes y existe mayor espacio para su implementación. Existen varios proyectos piloto y esfuerzos en encaminados que pueden ampliarse e inspirar otras oportunidades de hábitat, creando una diversidad de hábitats en diversas elevaciones factibles, desde zonas submareales hasta las tierras altas. Estas oportunidades pueden integrarse en diversas configuraciones y posteriormente se pueden presentar como superposiciones dentro de cada alternativa.

Las oportunidades basadas en la naturaleza incluyen:

a) Protección de los hábitats existentes en la bahía, incluyendo la preservación del intercambio completo de las mareas para los humedales del norte del Canal y el humedal de Tiscornia.
b) Mejora y ampliación de la zona de transición mediante la construcción de escollera con vegetación nativa desde el Puente de San Rafael hasta el Parque Pickleweed, los puertos deportivos, la carretera Point San Pedro y la carretera McNear Brickyard.
c) Estudio y expansión de la batimetría submareal para la expansión del hábitat, incluyendo en zosteras marinas y arrecifes costeros. Las nuevas geometrías, configuraciones estructurales y ubicaciones más altas en la amplitud de la marea pueden potencialmente proporcionar beneficios de atenuación de olas con el aumento del nivel del mar a largo plazo.
d) Playas de arena gruesa para proteger la restauración de los humedales y los diques frente a la bahía, así limitando la subida de las olas.
e) Gestión y mantenimiento de pequeños humedales al norte de la desembocadura del Canal, al oeste de Summit Avenue, al este de Sea Way y a lo largo de Beach Drive, donde las carreteras impiden la migración tierra adentro, posiblemente mediante la colocación de relleno delgado. Restauración de humedales en lagunas gestionadas mediante la mejora de la conexión mareal y diques de contención en la Laguna East Spinnaker Point (7 hectáreas) y los Humedales East San Rafael (6 hectáreas).
f) Restauración de los humedalesde Brickyard Cove (20 hectáreas).
g) Posible creación de playas de arena y/o preservación de las playas de bolsillo existentes.
h) Posible restauración dentro del sitio Canalways (41 hectáreas), aunque todos los escenarios futuros para el uso de esta propiedad son difíciles debido al continuo hundimiento del terreno y la posible contaminación, entre otros desafíos.
i) Mejora del hábitat vertical, incluyendo paneles de malecón viviente y pilotes vivientes dentro del Canal.
j) Infraestructura verde para las aguas pluviales en tierras altas para el manejo del volumen y la calidad del agua.

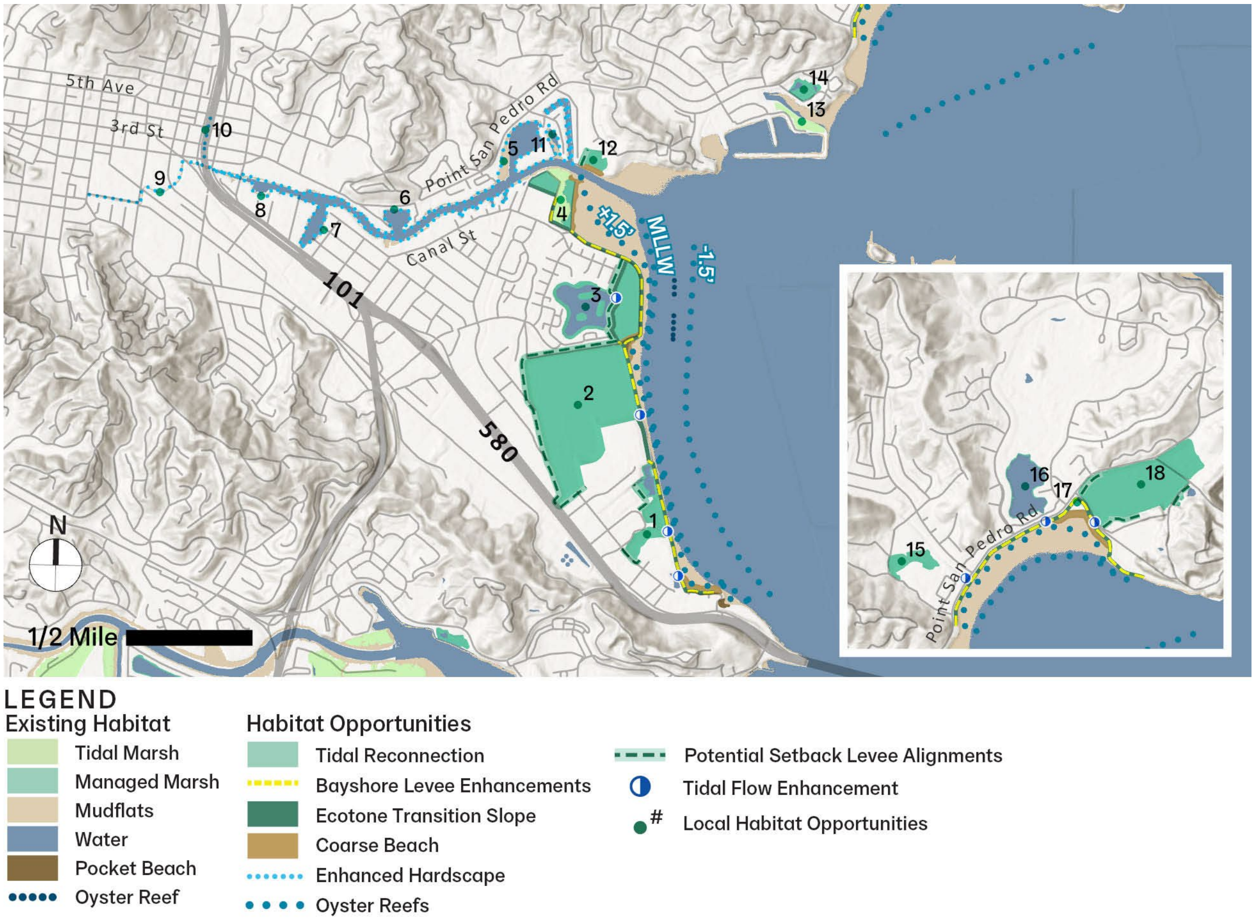


Figura 5: Mapa de oportunidades basadas en la naturaleza y características clave, todas las alternativas.

1) *East San Rafael Wetlands*
2) *Canalways Site*
3) *Spinnaker Lagoons*
4) *Tiscornia Marsh*
5) *Marin Yacht Shoreline Enhancement*
6) *Lowrie Yacht Harbor Shoreline Enhancement*
7) *San Rafael Yacht Harbor*
8) *Municipal Yacht Harbor Shoreline Enhancement*
9) *Mahon Creek Shoreline Enhancement*
10) *Irwin Creek Vertical Habitat*
11) *Arrowhead Marsh Expansion*
12) *San Rafael Canal Mouth North*
13) *Loch Lomond Drive Wetlands*
14) *Beach Road Wetlands*
15) *Greenwood Wetlands*
16) *Peacock Gap Lagoon*
17) *Brickyard Beach Enhancement*
18) *Brickyard Cove*

b) Alternativa 1: Elevación del Borde del Canal

La Alternativa 1 requiere elevar el borde del Canal a +3,6 metros, principalmente mediante diques vivos verticales, y elevar la cresta del dique frente a la bahía a +4,3 metros (BFE +30 cm de nivel del mar). Esta alternativa protege todos los edificios y viviendas existentes según las normas de FEMA hasta aproximadamente 2050 y requiere la menor huella física posible. Sin embargo, presenta desventajas significativas para el carácter visual y limita el potencial de adaptación futura. En el Canal, esto consistiría en tres tipos de estructuras, aplicadas en orden de prioridad:

1) Bermas plantadas o escollera combinada con un muro de fuste corto donde exista espacio en la tierra, a la altura o por encima de la MHHW (condición poco común; principalmente para propiedades que se están reurbanizando o podrían reurbanizarse).
2) Malecón terrestre: mamparo vertical con malecón viviente donde el espacio en la tierra es limitado, a la altura o por encima de la MHHW.
3) Malecón marino: tablestacas verticales con paneles de malecón viviente y cubierta de hormigón, construida en el agua donde las estructuras existentes se encuentran a la altura o sobresalen de la costa, o donde el espacio no lo permite. El espacio entre el malecón y la costa permanecería conectado hidrológicamente al canal mediante compuertas que se cerrarían solo durante inundaciones para equilibrar la presión hidrostática a ambos lados de la estructura.

Aproximadamente 250 muelles y pasarelas tendrán que ser demolidos para implementar esta alternativa y se reconstruirían a lo largo del canal, evitando el canal de navegación federal. Para evitar inundaciones a causa de las mareas provenientes del Canal, el malecón vertical continuaría a lo largo de los arroyos Irwin y Mahon, bajo la autopista 101, y tierra adentro hasta aproximadamente Albert Park. Como alternativa, se podría construir una compuerta de control de mareas operable que se cerraría solo durante inundaciones entre el puente de Grand Avenue y Yacht Harbor, con una nueva estación de bombeo para gestionar el flujo fluvial.

En el lado norte del Canal y en otras zonas donde no existen condiciones de zona baja, las estructuras individuales y los caminos de acceso se elevarían gradualmente. Point San Pedro Road se elevaría en zonas bajas, posiblemente incluyendo un malecón bajo de 90 cm donde no sea posible elevarlo a la altura requerida debido a limitaciones de espacio o adyacentes.

El dique frente a la bahía presenta las mayores oportunidades y beneficios para la adaptación basada en la naturaleza en esta alternativa. La estructura del dique se estabilizaría mediante la mezcla de tierra, se ensancharía hacia la tierra y se elevaría con material sobrecargado para anticipar la compactación y el hundimiento. Donde el dique existente esté comprometido o sea demasiado débil como para elevarlo, podría ser necesario reemplazarlo por completo con protección temporal de la costa. El sendero de la bahía se reemplazaría en la parte superior. Como se describe más detalladamente en Oportunidades basadas en la naturaleza, la zona frente a la bahía puede soportar rip rap plantado y playas de arena gruesa para proteger el lado de la bahía del dique y reducir la acumulación de olas; los diques de retroceso y la restauración de las mareas permiten la regeneración de pantanos de lagunas gestionadas; la protección y gestión de pequeños parches de pantanos; y mejoras en los arrecifes costeros y el hábitat submareal que pueden proporcionar atenuación de olas y reducir la amplificación de las mareas.

c) Alternativa 2: Compuerta del Canal

La Alternativa 2 crea una compuerta navegable de control de inundaciones a una cota de +16’ (BFE +3’ SLR) con grandes bombas de avance, de aproximadamente 3000 pies cúbicos por segundo (3000 pies cúbicos por segundo), en la desembocadura del Canal de San Rafael. Al igual que en la Alternativa 1, los diques frente a la bahía se construirían inicialmente a +14’, mientras que la estructura de la compuerta se construiría a mayor altura para una vida útil de diseño de hasta 2100, dada la magnitud de la inversión. La combinación de la compuerta con la adaptación del dique frente a la bahía, como se describe en la Alternativa 1, crea una línea de protección continua para las condiciones de la zona baja de San Rafael y ofrece oportunidades similares para implementar oportunidades basadas en la naturaleza en toda la zona frente a la bahía.

Son posibles varias ubicaciones de compuertas, pero el análisis considera una donde tanto las marismas del norte del Canal como la marisma de Tiscornia se encuentren hacia la bahía de la estructura para que permanezcan completamente permeables a las mareas y la entrada al puerto del Club Náutico de Marin permanezca navegable. La conexión con el humedal diqueado del Parque Pickleweed se ubicaría detrás de la estructura. La compuerta permanecería abierta en condiciones normales para mantener un canal de navegación federal accesible y solo se cerraría durante las inundaciones proyectadas por mareas. Con un umbral de +8 pies, la frecuencia de cierre sería aproximadamente una vez al año en la actualidad, de 1 a 3 veces al mes con un aumento del nivel del mar de +1 pie (aproximadamente en 2050) y más de una vez a la semana con un aumento del nivel del mar de +3 pies (aproximadamente en 2100).

Las costas detrás (dentro) de la compuerta requerirían elevación para mantener el ritmo del aumento del nivel del mar y la subsidencia para mantener la frecuencia de cierre actual a lo largo del tiempo y, por lo tanto, mantener la función de las mareas en el Canal. Estas medidas podrían asemejarse a la Alternativa 1 o la Alternativa 3 con el tiempo. Las elevaciones de viviendas y carreteras descritas en la Alternativa 1 podrían ser necesarias en la costa norte del Canal por la misma razón. La falta de adaptación de la costa detrás de la compuerta podría comprometer la posibilidad de permitir esta alternativa como la opción menos perjudicial para el medio ambiente.

d) Alternativa 3: Elevación Incremental

Esta alternativa buscaría elevar gradualmente el terreno y reconstruir los edificios a lo largo del primer bloque de la costa del Canal de San Rafael a +14 pies, un nivel por encima de la llanura aluvial de 100 años, con un nivel del mar proyectado de +3 pies hasta el año 2100. Esta alternativa incluye la adquisición, demolición, relleno y reurbanización, cuando sea posible, de todas las parcelas costeras contiguas del Canal que protegen una condición de zona baja. Esta alternativa consiste esencialmente en una retirada controlada localizada para crear espacio para un dique, una nueva servidumbre pública y un sendero, y una costa con vegetación que comience en la costa actual del Canal o tierra adentro. El relleno y la reurbanización a esta escala probablemente deban realizarse a escala de bloque y coordinarse en fases mediante un sólido proceso público. De implementarse en su totalidad, podría ser posible mapear la zona baja fuera de la llanura aluvial de FEMA. Si bien la Alternativa 3 es la más costosa y potencialmente la que requiere más tiempo para implementarse, ofrece el mayor retorno de la inversión en seguridad a largo plazo, calidad de vivienda, expansión del hábitat y del acceso a la costa, y valor inmobiliario para sustentar la base impositiva de la ciudad.

La Alternativa 3 incluye la elevación de Point San Pedro Road, así como la elevación de la carretera de acceso y de las estructuras individuales para el lado norte del Canal, desde aproximadamente Embarcadero Way hasta la desembocadura del Canal. Se podrían utilizar otros tipos de viviendas adaptadas a inundaciones, como casas flotantes o reconstrucción sobre pilotes.

La reconstrucción de viviendas a lo largo del tiempo puede proporcionar un mejor acceso al agua y potencialmente crear más espacio para extender el borde del Canal. La reconstrucción del borde del Canal también puede presentar oportunidades similares para soluciones basadas en la naturaleza, como en la bahía, incluyendo laderas con vegetación protegida y hábitat submareal donde las condiciones batimétricas lo permitan. Los muelles privados existentes y los usos de la costa se reimaginarían en esta alternativa.

La Alternativa 3 incluye medidas de adaptación a la bahía, como se describe en la Alternativa 1, para formar una protección de borde contiguo para las condiciones de la zona baja en el Canal y alrededor de Peacock Gap. Las soluciones para las inundaciones por reflujo de marea bajo la autopista 101 y para los arroyos Mahon e Irwin podrían ser similares a la Alternativa 1, pero, siempre que sea posible, el borde costero se elevaría sobre relleno y se aplanaría con una pendiente con vegetación.

La Alternativa 3 puede considerarse independiente o como una fase futura de otras alternativas, que se logrará a lo largo de períodos más largos, a medida que se obtenga la aprobación y la financiación de los propietarios de los terrenos y se complete la reurbanización. Si bien la elevación de estructuras y terrenos en toda la zona baja puede ser beneficiosa, la Alternativa 3 se centra en adaptaciones que priorizan los bloques costeros para establecer un perímetro de protección. Este estudio no considera la elevación ni la reurbanización completa de todos los terrenos, infraestructuras y edificios de la zona baja.

e) Alternativas no consideradas

Tres alternativas se descartaron:

- Malecón o barrera dentro del primer derecho de paso (como el propuesto para Canal Street en Resilience by Design).
- Retirada controlada a escala, definida como la que abarca más allá del primer bloque costero.
- Reconstrucción y elevación de todo el terreno por encima de futuras mareas altas.

d. Resumen del Análisis de Viabilidad según Criterios

Todas las alternativas, incluyendo el escenario base de "no acción", se analizaron en términos de sus múltiples beneficios e impactos en diez categorías definidas por la Ciudad de San Rafael:

i. Nivel de Protección contra Inundaciones Fluviales y Mareomotrices, o umbrales de elevación objetivo para la protección contra inundaciones.
ii. Efectividad en Diferentes Horizontes de Planificación, incluyendo plazos de implementación y vida útil del diseño.
iii. Requisitos Espaciales, incluyendo la huella para las medidas de adaptación.
iv. Requisitos de Permisos de las jurisdicciones locales, regionales, estatales y federales.
v. Consideraciones sobre Propiedad y Acceso a la Tierra, incluyendo impactos en propiedades públicas y privadas, espacios abiertos y acceso público y privado a la costa.
vi. Amenazas Potenciales para la Comunidad, incluyendo riesgos de inundaciones catastróficas asociados con fallas de infraestructura.
vii. Cobeneficios de las Medidas de Adaptación, incluyendo acceso público, ecología, embellecimiento de vecindarios y resiliencia de la red de transporte.
viii. Implicaciones en materia de vivienda, incluyendo la gentrificación, la preservación de viviendas asequibles, la cohesión comunitaria y el desplazamiento.
ix. Implicaciones ecológicas, incluyendo la resiliencia y el deterioro de las funciones ecológicas y los servicios ecosistémicos, como la provisión de hábitat, la resiliencia del

hábitat al aumento del nivel del mar, la mejora de la calidad del agua, la gestión de sedimentos y el secuestro de carbono.

x. Implicaciones económicas, incluyendo el análisis de orden de magnitud para el ciclo de vida, las pérdidas evitadas y los costos anuales de operación y mantenimiento.

i. Nivel de protección contra inundaciones fluviales y mareales

El escenario de no acción implicaría una protección contra las mareas superior a la actual y las inundaciones aumentarían significativamente con el tiempo debido al aumento del nivel del mar. La frecuencia de desbordamientos menores a +8′ alcanzaría dos veces al mes con un nivel del mar de +1′ (aproximadamente en 2050), concentrándose en los meses de invierno y diariamente hacia finales de este siglo. Se prevé que los desbordamientos mensuales sin control perturbarían el funcionamiento normal de la zona baja, debido a la inundación regular de vehículos, la corrosión salina de la infraestructura, la interrupción de las actividades comerciales, la percepción de riesgo del mercado y el posible desplome del valor inmobiliario. El riesgo de desbordamientos catastróficos por encima de +9′ aumenta a una probabilidad de 1 en 5 por año para 2050. El continuo hundimiento del terreno acelerará estos plazos y frecuencias. Con base en el modelo preliminar HEC-RAS, en lugar de un modelo integral de aguas pluviales de la ciudad, se proyecta que los desbordamientos de mareas de alrededor de +9′ sin lluvia saturarán el sistema de drenaje forzado existente. El nivel de protección fluvial que proporciona el sistema de drenaje pluvial no se evalúa en este estudio.

Las Acciones Iniciales elevarían los segmentos más bajos de la costa del Canal a +2.4 metros y reemplazarían las barreras informales con estructuras de ingeniería hasta este umbral mínimo. Este fenómeno representa aproximadamente un evento de marea cada 5 años y es una medida provisional destinada a minimizar el número de parcelas afectadas y acelerar la implementación. Siempre que sea posible, se podrían construir adaptaciones en la costa a una mayor altura, hasta +3.6 metros, para integrarlas con la Alternativa 1. Las Acciones Iniciales incluyen la estabilización de emergencia del dique frente a la bahía donde se observan filtraciones. Las Acciones Iniciales incluyen la modernización de las estaciones de bombeo en toda la zona baja y la construcción de infraestructura verde para retener, almacenar y filtrar las aguas pluviales. Estas se diseñarían para hacer frente al aumento de la intensidad de las precipitaciones y lograr un nivel de protección fluvial establecido mediante una evaluación específica de aguas pluviales, además de ser capaces de gestionar mayores volúmenes de desbordamiento durante mareas altas extremas. La Alternativa 1 se evalúa con la elevación base de inundación de 100 años de FEMA, más 30 cm de francobordo y 30 cm adicionales de aumento del nivel del mar para 2050, o una elevación de 4.2 m a lo largo de la Bahía y 3.6 m en el Canal. El umbral de 3.6 m se aplicaría a toda la infraestructura y estructuras a lo largo del Canal, incluyendo nuevos diques para la protección de la zona baja y carreteras y edificios elevados al oeste de Embarcadero Way en la costa norte, donde no existe una condición de zona baja. Este nivel para 2050 es un punto de partida para establecer un nivel de protección consistente, impactante pero no prohibitivamente alto como primer paso, y a un nivel para la posible certificación de FEMA si se desea. El dique de la Bahía se planificaría para permitir otra elevación incremental después de mediados de siglo para seguir el ritmo del aumento del nivel del mar y mantener el mismo nivel de protección, aproximadamente de 60 a 150 cm adicionales, dependiendo de las mediciones y proyecciones actualizadas (de 4.8 a 6.8 m de elevación). Las nuevas estructuras se diseñarían considerando el hundimiento para mantener su elevación de diseño. Las estaciones de bombeo existentes se modernizarían para gestionar las aguas pluviales en la zona baja y los volúmenes adicionales de desbordamiento debido a eventos extremos. Se instalarían perforaciones o válvulas de retención a través del malecón para facilitar el drenaje.

La Alternativa 2 ofrece el mismo nivel de protección a lo largo del frente de la bahía a +4,35 m; sin embargo, la estructura de la compuerta se construiría a un nivel mayor del aumento proyectado del nivel del mar debido a su mayor vida útil y a la dificultad de adaptarla, a una elevación de +5,8 m (considerando +1 m de nivel del mar, escenario bajo de 2100 grados Celsius) y posiblemente hasta +6,8 m (+1,8 m de nivel del mar, escenario alto de 2100 grados Celsius). Las nuevas estructuras se diseñarían considerando el hundimiento para mantener su elevación de diseño. Una estación de bombeo frontal de aproximadamente 113,6 m^3/s, integrada con la estructura de la compuerta, proporcionaría protección contra inundaciones fluviales dentro del Canal en caso de lluvias en tierras altas cuando la compuerta esté cerrada. Se requerirían estaciones de bombeo existentes para gestionar el drenaje de aguas pluviales en la zona baja. La Alternativa 3 crea una protección continua contra inundaciones que se logra de forma incremental mediante la reurbanización hasta los niveles de agua previstos para el año 2100 en la zona baja del Canal. Esta alternativa se construiría según la elevación base de inundación de 100 años de FEMA, más 30 cm de francobordo y un aumento adicional del nivel del mar de 90 cm a 180 cm, para una elevación mínima de la costa del Canal de 4,35 m y hasta 5,25 m. Este umbral es más alto que otras alternativas, dado el nivel de inversión y las interrupciones requeridas para su construcción. Las carreteras y los edificios en el lado norte del Canal, al este de Embarcadero Way, donde no existe zona baja, se elevarían a un umbral de 3,65 m con una adaptación adicional planificada para mediados de siglo, como se describe en la Alternativa 1. El dique frente a la bahía se elevaría inicialmente a 4,35 m con otra elevación planificada para mediados de siglo, como se describe en la Alternativa 1. Las nuevas estructuras se diseñarían teniendo en cuenta el hundimiento para mantener su elevación de diseño. Las estaciones de bombeo serían requiridas gestionar el drenaje de aguas pluviales en la zona baja, y las estaciones existentes dentro del área de reurbanización se reconstruirían por completo.

	5-20 años para completar	**Para 2050**	**Para 2100**
No acción	Canal: <5-yr protección Bayfront: <100-yr protección	Desbordamiento mensual (interrupción grave)	Sobrecarga semanal a diario (inhabitable)
Acciones Initiales	Canal: +8′ (5-yr protección, no freeboard or SLR) Bayfront: Emergency stabilization		
Alternativa 1		100-yr BFE +1′ freeboard +1′ SLR Canal: +12′ Bayfront: +14′	Additional Canal & Bayfront lifts +2′ to 5′ for SLR or shift to Alternative 3. Canal: +14′ to 17′ Bayfront: +16′ to 19′
Alternativa 2		100-yr BFE +1′ freeboard +3′ SLR Canal/+1′ SLR Bayfront Canal: +16′ gate* Bayfront: +14′	Additional Bayfront lift +2′ to 5′ for SLR Canal: +16′ gate* Bayfront: +16′ to 19′
Alternativa 3		100-yr BFE +1′ freeboard +1′ SLR Canal: +12′ north 101ldgs.. & roads; basin shoreline redev. in-	100-yr BFE +1′ freeboard +3′ to 6′ SLR Canal: +14′ Bayfront: +16′ to 19′

		progress, min. +8' from Initial Actions Bayfront: +14'	

*Figura 6. Tabla que muestra el nivel de protección contra las mareas a lo largo del tiempo para todas las alternativas. *Podría requerirse una elevación adicional de la línea de costa detrás de la compuerta para gestionar la frecuencia de cierre.*

ii. Eficacia en diferentes horizontes de planificación

Si no se toman medidas, el riesgo de desbordamientos leves y catastróficos ya supera los estándares de seguridad habituales, y los desbordamientos ya ocurren durante la mayoría de las mareas altas anuales.

Las acciones iniciales podrían completarse en los próximos 8,5 a 20 años, con plazos de implementación variables, impulsados principalmente por la necesidad de una amplia consulta con la comunidad y los propietarios, así como por el desarrollo de un consenso político. Las acciones iniciales están concebidas como medidas de estabilización inmediatas y, estadísticamente, es probable que se desborden en los próximos 20 años. Su implementación es urgente para obtener sus beneficios.

La Alternativa 1 podría completarse en un plazo de 8 a 29 años, con un plazo promedio de finalización de 18 años o para 2044, y contempla la posible certificación de FEMA hasta un nivel del mar de +1'. Seguiría siendo eficaz en o cerca de su nivel de diseño, mientras se realizan adaptaciones adicionales para 2070. Es posible que sea necesario acelerar las adaptaciones de las fases futuras para mantener el nivel de seguridad de 100 años, dependiendo de las proyecciones actualizadas sobre el aumento del nivel del mar. Las futuras elevaciones de diques en la bahía deberían realizarse tierra adentro para mantener la eficacia del hábitat establecido, tanto en alta mar como en tierra. Dependiendo de las tasas observadas de aumento del nivel del mar y de la acumulación de sedimentos, podrían requerirse estrategias como la colocación de capas delgadas para mantener la función ecológica de la marisma restaurada y protegida.

La Alternativa 2 podría completarse en un plazo de 8 a 24 años, con un plazo promedio de finalización para 2041, y mantendría su eficacia a la altura de diseño mientras se realizan adaptaciones adicionales para 2070, o antes, dependiendo de las tasas de aumento del nivel del mar. Si se requiere una elevación adicional de la costa del Canal para obtener los permisos, es más probable que el cronograma se ajuste a la Alternativa 1.

Por sí sola, la Alternativa 3 será la que más tardará en implementarse por completo antes de lograr la protección contra inundaciones contiguas, prevista entre 20 y 42 años, con un plazo promedio de finalización de 31 años, para 2056. Esta alternativa es eficaz para gestionar los riesgos a 100 años con un aumento de 90 cm del nivel del mar en el Canal, potencialmente hasta 2100 o más allá, y hasta un aumento de 90 cm del nivel del mar a lo largo de la bahía cuando se incluya una elevación futura. Mientras tanto, podría requerirse una combinación de barreras temporales o partes de las Alternativas 1 y 2 para alcanzar un nivel del mar de 30 cm lo antes posible.

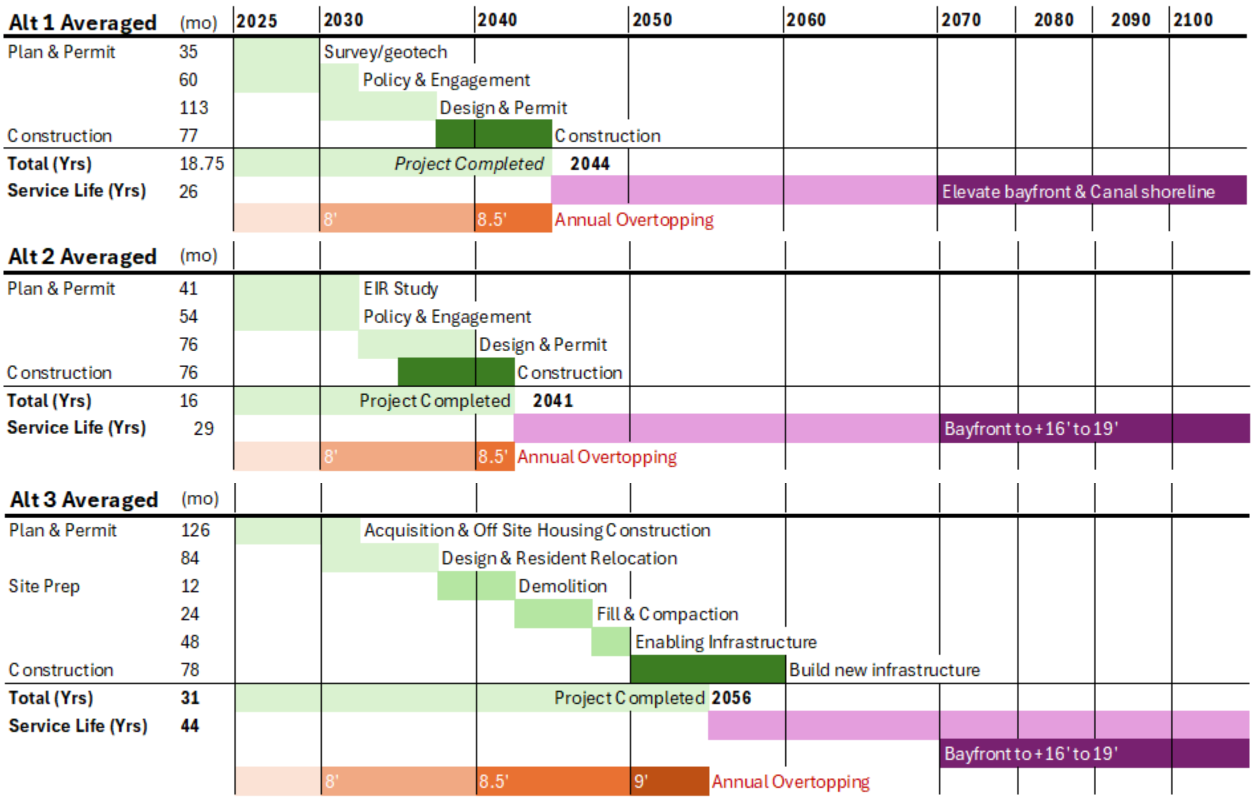


Figura 7. Tiempo estimado de implementación utilizando estimaciones de tiempo promedio, con vida útil de diseño efectiva.

iii. Requisitos Espaciales

La alternativa de No Acción no tiene requisitos espaciales.

Las Acciones Iniciales se limitan a intervenciones distribuidas a pequeña escala en 38 parcelas costeras del Canal y dentro de otras servidumbres de paso públicas. Podría requerirse construcción desde agua o tierra. Se debe explorar la adquisición de servidumbres, pero no está incluida en las Acciones Iniciales.

La Alternativa 1, tipo terrestre, requiere un mínimo de 60 cm de ancho para tablestacas de acero y tapa de hormigón, una separación mínima de 2,4 m con respecto a las estructuras existentes para la construcción y una servidumbre perpetua mínima de 3 m tierra adentro del malecón para inspección y mantenimiento. Las servidumbres de construcción pueden tener hasta 7,6 m de ancho para la construcción en tierra. En el lado norte del Canal, la elevación de los edificios se realizaría en propiedad privada, y la elevación de la vía de acceso probablemente requerirá la compra de servidumbres adicionales a los propietarios adyacentes. La elevación de la vía para Point San Pedro Road se realizaría dentro de la servidumbre de paso pública existente. Podrían necesitarse propiedades y/o servidumbres, así como acuerdos de acceso a lo largo de la bahía, y se espera que se amplíen para futuras elevaciones de diques. El ancho de las servidumbres puede variar según la fuente de financiamiento y debe confirmarse con posibles socios, como el Cuerpo de Ingenieros del Ejército de Estados Unidos (USACE). Si se solicita la participación en los costos del USACE, la ciudad deberá adquirir propiedades o servidumbres para todos los terrenos necesarios para implementar la alternativa.

La Alternativa 2 requiere un área de al menos 15 metros de ancho a lo largo de la estructura para el acceso de la construcción en el agua mediante barcaza. Los impactos en tierra se limitarían a las ubicaciones de conexión al norte del humedal diqueado del Parque Pickleweed al sur y a lo largo del borde este de Sea Way al norte, posiblemente adyacentes a dos parcelas privadas. Estas conexiones estarían sujetas a los mismos requisitos de servidumbre que la Alternativa 1. Se estima que se requerirán aproximadamente entre 0,7 y 1,2 acres para una estación de bombeo de proa de 3000 pies cúbicos por segundo (3000 pies cúbicos por segundo), y dado el espacio limitado cerca de la desembocadura del Canal, es probable que esta se ubique parcialmente sobre el agua y parcialmente sobre la marisma. La Alternativa 2 requiere parámetros espaciales similares para la zona de la bahía a los descritos en la Alternativa 1.

La Alternativa 3 abarca 82 acres de adquisición y reurbanización alrededor del Canal. Aproximadamente un tercio de ese terreno carece de espacio para la reurbanización, y el borde elevado probablemente sería una berma o un paseo elevado. Los dos tercios restantes podrían elevarse y reurbanizarse. Un cambio de rasante significativo, desde la corona del dique del Canal de +14 pies a 17 pies, se gestionaría mediante nuevos espacios abiertos y senderos accesibles, o mediante la reurbanización adyacente. Esta alternativa incluiría la reconstrucción de los puentes de salida de Grand Avenue y la Autopista 101 desde estribos más altos. Las implicaciones espaciales en el lado norte del Canal y a lo largo de la zona de la bahía serían similares a las de la Alternativa 1.

iv. Requisitos de Permisos

La tramitación de permisos para todas las alternativas requeriría consultar con agencias estatales y federales, incluyendo el Cuerpo de Ingenieros del Ejército de Estados Unidos (USACE), para la construcción dentro de aguas de Estados Unidos. La obra propuesta también debería cumplir con la Sección 106 de la Ley Nacional de Preservación Histórica, que exige la consulta tribal. Se debería consultar a la Junta Regional de Control de Calidad del Agua (RWQCB) sobre los posibles impactos en las zona baja s hidrográficas y la calidad del agua. El Servicio Nacional de Pesca Marina (NMFS) de la NOAA debería abordar los posibles impactos en los peces, lo que también requeriría consultar con el Servicio de Pesca y Vida Silvestre de Estados Unidos (USFWS) y el Departamento de Pesca y Vida Silvestre de California (CDFW). Será necesario consultar con la Comisión de Tierras Estatales de California (CSLC) si alguna construcción propuesta se realiza en terrenos concesionados.

Es probable que todas las alternativas requieran un Informe de Impacto Ambiental (EIR) como parte de los requisitos de la NEPA y la CEQA. El borrador inicial del EIR se presentaría a las agencias gubernamentales y al público para su revisión y comentarios. Las posibles agencias de revisión incluyen:

- Cuerpo de Ingenieros del Ejército de los EE. UU. (Cuerpo)
- Junta Regional de Control de Calidad del Agua de San Francisco (SFRWQCB)
- Comisión de Conservación y Desarrollo de la Bahía de San Francisco (BCDC)
- Departamento de Pesca y Vida Silvestre de California (CDFW)
- Servicio de Pesca y Vida Silvestre de los EE. UU.
- Servicio Nacional de Pesca Marina (NMFS)
- Comisión de Tierras Estatales de California
- Guardia Costera de los EE. UU.

Se deberá elaborar un Plan de Mitigación y Monitoreo como parte del proceso de revisión ambiental. Los Análisis de Alternativas de la Sección 404 requerirán una demostración rigurosa de que la alternativa seleccionada podría funcionar como la Alternativa Practicable Menos Dañina para el Medio Ambiente (LEDPA). Las alternativas requerirán una mitigación que abarcará prácticas de construcción de 1:4 a 1:20, dependiendo del tipo de impacto ambiental.

v. Implicaciones Ecológicas

El escenario de No Acción resultaría en un impacto ecológico perjudicial tanto por la "compresión costera" de las marismas, que carecen de espacio para la migración, inducida por el aumento del nivel del mar, como por la degradación de la calidad del agua causada por el aumento de las descargas de bombeo de las zonas urbanizadas.

Es poco probable que alguna alternativa sea automitigable cuando se requiera mitigación; sin embargo, la creación de hábitat debería incluirse siempre que sea posible en todas las alternativas.

Para la Alternativa 2, limitar la frecuencia y la duración del cierre de las compuertas es esencial para limitar el impacto ecológico. Esto probablemente requiera una elevación incremental o la protección de la costa detrás de las compuertas del canal para elevar el umbral de cierre junto con el aumento del nivel del mar y la subsidencia.

Todas las alternativas proponen mantener el intercambio de mareas completo para los arroyos Mahon e Irwin, aguas abajo y aguas arriba del paso elevado 101/580.

	Potential Impacts to Waterways
Alternative 1	• 0.3 acres of alignment footprint in water • 3.3 acres of water behind alignment • Est. $170,000 mitigation cost
Alternative 2	• 0.9 acre affected by alignment footprint in water • 84 acres of waterways upstream of canal gate • Approx. 7 square mile upland watershed • Est. $480,00 mitigation cost
Alternative 3	• Potentially avoids impacting waterways • Potential to add habitat to Canal shoreline • No est. mitigation cost

Figura 7. Tabla que muestra los posibles impactos en las vías fluviales para todas las alternativas.

vi. Consideraciones sobre la propiedad y el acceso a la tierra

La costa actual de San Rafael está administrada por cientos de propietarios, y todos los requisitos de construcción y acceso para cada propiedad estarían sujetos a negociaciones individuales, cuando fuera necesario, para la compra o adquisición de servidumbres.

Para las Acciones Iniciales, 38 parcelas se verían afectadas, elevando la parte inferior del borde a +8 pies.

La Alternativa 1 requiere servidumbres de 132 parcelas, pero no adquisiciones, incluyendo 52 en la bahía y 80 en el Canal, para elevar el dique de la bahía y construir el malecón costero. Se estima que las servidumbres permanentes en tierra firme son de 10 pies, sujetas a la confirmación de las autoridades federales de financiación, y podrían requerirse servidumbres de construcción más amplias. De no ser posible, el malecón se convertiría en mar abierto y no se requeriría servidumbre.

Los tramos del malecón costero en el Canal se construirían en el agua desde el lado del canal y asumirían impactos en el fondo del agua pública de 5 pies de ancho en toda su longitud. La Alternativa 2 requiere las mismas servidumbres frente a la bahía que la Alternativa 1 y no requeriría adquisiciones en el trazado evaluado. La Alternativa 2 requeriría conexiones terrestres al norte y al sur del Canal y, potencialmente, acceso vehicular para mantenimiento desde ambos lados, conectando Sea Way al norte y el sendero de mantenimiento perimetral del Parque Pickleweed al sur.

La Alternativa 3 requiere las mismas servidumbres frente a la bahía que la Alternativa 1. La reurbanización del Canal requeriría la adquisición de 86 parcelas. El desafío de adquirir la cantidad de parcelas involucradas en la Alternativa 3 puede hacerla potencialmente inviable si no se logra una protección contigua antes del desbordamiento rutinario del Canal. Una vez adquiridas, estas parcelas probablemente se combinarían a escala de bloque y podrían venderse y reurbanizarse de forma privada o mediante una asociación público-privada una vez que se implemente la protección costera. Es improbable que un promotor privado incurra en los gastos de múltiples adquisiciones de parcelas, demolición y construcción de protección costera. Un proceso público puede garantizar mayores beneficios públicos e incentivos para los promotores.

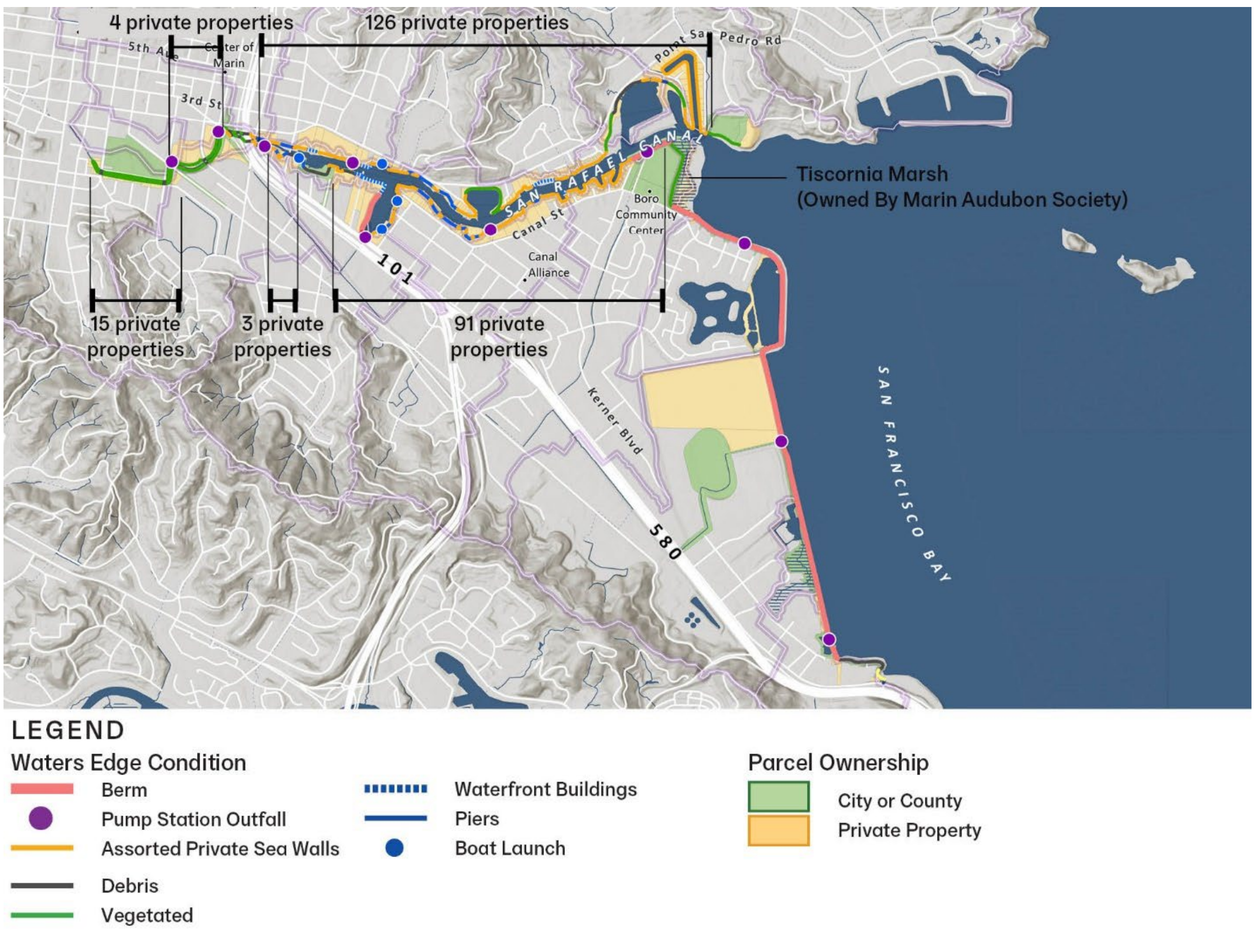


Figura 8. Propiedad y número de parcelas a lo largo de la costa sur de la bahía y la costa del Canal.

Todas las alternativas probablemente requerirían la reconstrucción de aproximadamente 250 muelles y pasarelas a lo largo del Canal: la Alternativa 1 en el caso base, la Alternativa 2 si se requiere la elevación de la línea costera, y la Alternativa 3 a medida que la línea costera se reurbaniza gradualmente. En este caso, el acceso público podría mejorarse con nuevos usos.

El costo de las servidumbres y adquisiciones asume los valores actuales de los terrenos y las estructuras tasados por la ciudad. Los costos de las servidumbres representan una pequeña fracción del costo total de las Alternativas 1 y 2, mientras que el costo de adquisición de propiedades representa aproximadamente el 12% del costo total de la Alternativa 3.

	Parcels Potentially Requiring Easements	Parcels Potentially Requiring Acquisition	ROM Cost of Easements & Acquisitions*
Alternative 1	132		$6,000,000
Alternative 2	52		$5,000,000
Alternative 3	61	86	$211,000,000

Figure 9. Table showing the land ownership complexity for all alternatives. Costs based on current city-assessed land and structure values.

vii. Posibles Amenazas para la Comunidad

El escenario de No Acción resultaría en un aumento en el impacto de las inundaciones y el consiguiente riesgo de desplazamiento para las comunidades de la zona baja y a lo largo de la costa. Para mediados de siglo, se proyecta que se produzcan desbordamientos mensuales, y la viabilidad de seguir viviendo en zonas vulnerables como la zona baja es incierta. Los principales impactos incluirían importantes perturbaciones y pérdidas económicas, impactos en el transporte y el acceso público, así como en las condiciones y calidad de vida.

Sin acción, un evento sísmico podría provocar múltiples fallas en la costa simultáneamente y desbordar la capacidad de cerrar las brechas antes de que se produzcan inundaciones catastróficas, además de posibles cortes de energía en las estaciones de bombeo y daños a carreteras y edificios.

Las alternativas 1 y 2 ofrecen seguridad para los niveles de inundación de 100 años, pero aún presentarían riesgo de desbordamiento debido a eventos mayores. Se diseñarían adaptaciones con criterios de riesgo de desbordamiento para evitar fallas catastróficas, y los volúmenes de diseño para el agua desbordada podrían incluirse en las mejoras de las estaciones de bombeo. La alternativa 3 ofrece mayor protección al Canal pero aún estaría sujeta a desbordamientos extremos por mareas.

Housing Units & Population Impacts	Population	Housing Units	Multifamily Housing Units	Parcels
100-Year Event 2050 +1’ SLR (No Action)	11,300	2,720	1,280	2,580

Figura 10. Tabla que muestra la tormenta de diseño de mediados de siglo utilizada para las alternativas 1 y 2

viii. Implicaciones para la Vivienda

Todas las alternativas pueden incluir el riesgo de desplazamiento temporal durante la construcción en ubicaciones limitadas donde se requiera acceso a equipos o áreas de almacenamiento en tierra. Este riesgo podría minimizarse mediante una planificación detallada del proyecto y la secuenciación de la construcción con el contratista. Independientemente de la alternativa, se recomienda la identificación y el desarrollo de nuevos sitios de vivienda fuera de la zona baja para la resiliencia general de la vivienda y el apoyo organizado para residentes, negocios y organizaciones potencialmente desplazados.

La no acción deja toda la zona baja y las viviendas costeras en riesgo de inundación y desplazamiento, hasta aproximadamente 2720 unidades de vivienda y 11 300 personas en caso de un evento catastrófico de +11 pies.

Las acciones iniciales tienen como objetivo estabilizar las condiciones de la costa para garantizar la seguridad actual, pero el potencial de desplazamiento a lo largo del tiempo sería similar a la no acción.

Las alternativas 1 y 2 proporcionarían una protección de 100 años para 2720 unidades de vivienda y 11 300 personas hasta aproximadamente 2050. Se requerirían adaptaciones adicionales en la bahía y/o la costa del Canal más allá de ese punto para mantener la protección de 100 años. La Alternativa 3 protegería 3970 viviendas y 13 400 personas hasta los niveles de 100 años en 2100. Esto incluye una suspensión a mediados de siglo de las medidas de la zona costera. Estas cifras excluyen aproximadamente 550 viviendas que se desplazarían para construir las medidas de la costa del Canal, y tampoco incluyen las nuevas viviendas que podrían resultar de la reurbanización de las manzanas costeras donde el espacio lo permita. Para alcanzar el nivel de reemplazo para las 550 viviendas en un área más pequeña, sería necesario aumentar la densidad (como la altura de los edificios) en las manzanas afectadas. Las cifras más altas se deben a un mayor nivel de protección, que esencialmente protege una mayor superficie baja de futuras crecidas del agua.

	Protected by Alternative			**Temporary Displacement Risk** (Building Scale Adaptation)		**Permanent Displacement Risk** (Potential Acquisitions)	
	People	**Housing Units**	**Multifamily Housing Units**	**Housing Units**	**Multifamily Housing Units**	**Housing Units**	**Multifamily Housing Units**
Alternative 1	11,300	2,720	1,280	80	20	-	-
Alternative 2	11,300	2,720	1,280	-	-	-	-
Alternative 3*	13,400	3,970	1,650	160	30	390	350

*Figura 11. Tabla que muestra los beneficios e impactos en la vivienda para todas las alternativas. *La alternativa 3 está diseñada para tormentas de diseño más bajas y más altas, respectivamente, y, por consiguiente, presenta niveles potenciales de protección y desplazamiento más bajos y más altos.*

ix. Cobeneficios de las Medidas de Adaptación

Todas las alternativas incorporan elementos naturales en la ribera de la bahía que contribuyen a la reducción del riesgo de inundaciones al atenuar las olas y la erosión, y crean una amplia gama de hábitats a diferentes elevaciones, desde submareales hasta tierras altas. La elevación y estabilización del dique de la ribera, incluida en todas las alternativas, crearía hábitat adicional en el borde de la bahía y mediante la restauración de marismas, según lo permitan las limitaciones de espacio.

La elevación del borde del Canal, como parte de la Alternativa 1 y posiblemente parte de la Alternativa 3, consistiría en un malecón viviente que crearía sustratos y superficies texturizadas para el crecimiento de especies acuáticas. La Alternativa 3 incluye la reubicación de nuevas laderas plantadas en la ribera del Canal como parte de una reurbanización gradual.

Todas las alternativas incluyen nuevas construcciones en varios puntos a lo largo de la ribera del Canal que podrían afectar el carácter visual del barrio y, en algunos lugares, reducir la visibilidad del agua. La

Alternativa 3 ofrece el mayor potencial de transformación del barrio, que puede ser positivo o negativo. Un sólido proceso público para reimaginar la costa podría mejorar el paisaje urbano, como la incorporación de árboles, elementos de gestión de aguas pluviales, espacios abiertos y servicios del vecindario. La Alternativa 3 ofrecería nuevas oportunidades de acceso a través de un nuevo sendero o paseo marítimo junto al Canal conectado al Sendero de la Bahía. La Alternativa 3 también podría proporcionar espacio y mayor altura libre para una nueva conexión peatonal al este del Puerto Deportivo. Sin embargo, con un cambio a gran escala, también existe la posibilidad de consecuencias negativas imprevistas.

Las Alternativas 1 y 2 no ofrecen oportunidades adicionales de acceso público, sino que buscan preservar los edificios y los patrones existentes.

Todas las alternativas ofrecen protección contra inundaciones por mareas para los activos regionales de Caltrans dentro de San Rafael, incluyendo la Autopista 101, la Interestatal 580 y las instalaciones de servicio.

x. Viabilidad Económica

Probablemente se requerirán fuentes externas, además del financiamiento local de San Rafael, para compensar al menos algunos costos de todas las alternativas, incluso si se implementan por etapas. Es probable que todas las alternativas, independientemente de la fuente de financiamiento, requieran al menos una participación local parcial en los costos, típicamente el 35% de los proyectos con apoyo federal.

Los costos de adquisición de propiedades, incluyendo las servidumbres, se basan en la suma del valor actual del terreno y la estructura tasados por la ciudad. Estos valores podrían apreciarse o disminuir en el futuro dependiendo de la percepción del riesgo del mercado o de los daños por inundaciones.

El costo de las mejoras del hábitat varía ampliamente según la medida y se incluye dentro de un valor de contingencia de construcción del 50% para todas las alternativas. El costo de mitigación se asume en $500,000 por acre.

El escenario de No Acción proyecta pérdidas económicas que aumentan rápidamente con el tiempo a medida que la zona baja comienza a desbordarse sustancialmente y con mayor frecuencia, especialmente a medida que más parcelas comerciales e industriales se ven afectadas y se producen impactos económicos indirectos. Se calculó un costo aproximado de orden de magnitud para cada alternativa y se comparó con el impacto económico evitado, o los daños totales directos e indirectos por inundación, calculados a partir del escenario de no acción.

Se estima que la Alternativa 1 costará $718 millones, con una relación costo-daños evitados de 1:1.5, aún positiva, pero no especialmente competitiva frente a otros proyectos de adaptación que buscan participación federal en los costos. Se asume un 0.5% del valor de construcción para operaciones y mantenimiento anuales adicionales que superan el presupuesto actual de la ciudad, debido al número limitado de nuevas piezas móviles.

Se estima que la Alternativa 2 costará $557 millones, con una relación costo-daños evitados de 1:2.0. Estos costos no incluyen la posible necesidad de elevar la orilla del Canal detrás de la estructura para gestionar la frecuencia de cierre, lo que podría hacer que esta alternativa sea económicamente inviable. Se estima un 2% del valor de construcción para operaciones y mantenimiento anuales debido a la complejidad de las compuertas y las bombas de gran tamaño. Si bien es la más costosa, con un costo superior a los $1.8 mil millones, solo la Alternativa 3 ofrece el potencial de recuperar los costos mediante la reurbanización de terrenos. La rentabilidad potencial (valor de venta del terreno) para la reurbanización, si se logra mediante venta privada o asociación público-privada, no se incluye en la Alternativa 3, pero podría ser significativa, potencialmente de decenas de millones de dólares. Se podría establecer con antelación un distrito fiscal especial, como un TIF, para financiar y realizar mejoras públicas adicionales en la zona reurbanizada. Este valor no se alcanzaría hasta después de incurrir en costos significativos; sin embargo, reduciría efectivamente el costo y, por lo tanto, mejoraría la relación costo/daños, potencialmente por encima de 2.0.

	Alternativa 1	**Alternativa 2**	**Alternativa 3**
Construction	$ 533,150,000	$ 393,375,000	$ 1,258,312,000
Planning & Design	$ 178,710,000	$ 157,350,000	$ 399,750,000
Acquisition & Mitigation	$ 6,700,000	$ 6,900,000	$ 211,000,000
ROM Cost	**$ 718,560,000**	**$ 557,625,000**	**$ 1,869,062,500**
Annual Operations & Maintenance	$ 2,200,000 (0.5% of Construction)	$ 7,900,000 (2% of Construction)	$ 5,000,000 (0.5% of Construction)
Damages Avoided	**$ 1,097,000,000**	**$ 1,097,000,000**	**$ 3,127,000,000**
ROM Cost to Damages Avoided Ratio	**1 : 1.5**	**1 : 2.0**	**1 : 1.7***

Figura 12. Tabla que muestra los daños evitados y el orden aproximado de magnitud del costo para todas las alternativas.
**No incluye el valor de la rentabilidad potencial de la venta de terrenos ni de la reurbanización público-privada.*

Resumen de comparación de alternativas

	Alternativa 1	**Alternativa 2**	**Alternativa 3**
People Protected	11,300	11,300	13,400*
Alignment Size	7 Mi	4 Mi	6.5 Mi + 82 Ac
Building Scale Adaptation	70 Buildings	Up to 70 Buildings	310 Buildings
Time to Implement	10 to 30 Years	10 to 20 Years	30+ Years
Permitting Complexity	Medium	High	Medium
Land Ownership Complexity	212 Parcels	52 Parcels	523 Parcels
Displacement Risk	Medium	Medium	High
Ecological Co-Benefit	Medium	Low	High
Cost Benefit Ratio	1 : 1.5	1 : 2.0	1 : 1.7**
Long-term Co-Benefits	Low	Low	High

Figura 13. Tabla que resume los principales beneficios y obstáculos de todas las alternativas.
**La alternativa 3 está diseñada con una elevación inicial mayor y, por lo tanto, protege a más personas.*
***No incluye el valor de la rentabilidad potencial de la venta de terrenos ni de la reurbanización público-privada.*

Briefing Book