PETALUMA RIVER BAYLANDS STRATEGY

APRIL 2023

IN COLLABORATION WITH

SFEI SAN FRANCISCO ESTUARY INSTITUTE

Point Blue Conservation Science

DUCKS UNLIMITED

SONOMA RESOURCE CONSERVATION DISTRICT

With funding from the CALIFORNIA WILDLIFE CONSERVATION BOARD

Authors

Ellen Plane, San Francisco Estuary Institute
Julian Meisler, Sonoma Land Trust
Jeremy Lowe, San Francisco Estuary Institute
Sam Veloz, Point Blue Conservation Science
Renee Spenst, Ducks Unlimited
Katie Robbins, Sonoma Resource Conservation District
Kendall Webster, Sonoma Land Trust

Scientific Advisory Panel

Sara Azat, National Oceanic & Atmospheric Administration
Peter Baye, Coastal Ecologist
John Bourgeois, Valley Water
Steve Carroll, Ducks Unlimited
Carlos Diaz, Sonoma Water
Roger Leventhal, Marin County Public Works
Stuart Siegel, San Francisco Bay National Estuarine Research Reserve
Karen Taylor, California Department of Fish and Wildlife
Karen Thorne, U.S. Geological Survey

Funded By

California Wildlife Conservation Board, Climate Adaptation and Resilience Program

WCB State of California Wildlife Conservation Board

Cover image credit: Robert Janover, courtesy Sonoma Land Trust

Suggested citation: Sonoma Land Trust. 2023. *Petaluma River Baylands Strategy.* Version 1. Prepared by San Francisco Estuary Institute, Sonoma Land Trust, Point Blue Conservation Science, Ducks Unlimited, and Sonoma Resource Conservation District. Funded by the Wildlife Conservation Board.

Contents

Appendices (Separate Document)

Figures

Tables

Acronyms & Abbreviations

CDFW: California Department of Fish and Wildlife

FAA: Federal Aviation Administration

MHW: Mean High Water

MHHW: Mean Higher High Water

MLW: Mean Low Water

MLLW: Mean Lower Low Water

MSL: Mean Sea Level

OLU: Operational Landscape Unit

PEL: Planning and Environmental Linkages

SMART: Sonoma-Marin Area Rail Transit

Strategy: Petaluma River Baylands Strategy

USFWS: United States Fish and Wildlife Service

Executive Summary

Historically, the Petaluma River Baylands were home to a large, complex, and biologically diverse landscape of tidal habitats, including marshes, mudflats, and open water. "Baylands" describes the area at intertidal elevation, including areas that would be flooded by the tides if not for levees or other unnatural water-control structures. Some of the historical tidal marshes of the Petaluma River Baylands remain to this day, including the largest intact tidal marsh plain in the San Francisco Estuary. However, much of the historical bayland landscape has been diked and drained for agricultural purposes and urban development. Today, the Petaluma River Baylands face increasing challenges due to climate change and rising sea levels.

The overarching goals of the *Petaluma River Baylands Strategy (*Strategy) are to:

- conserve and restore baylands and adjacent habitats;
- promote the growth and resilience of populations and habitats of native species within the study area; and
- maintain and increase the ecosystem services provided to human communities.

The Strategy was developed through a collaborative effort by Sonoma Land Trust, the San Francisco Estuary Institute, Sonoma Resource Conservation District, Point Blue Conservation Science, and Ducks Unlimited. The project team also collaborated with scientific advisors and gathered input from baylands stakeholders, tribes, and agency personnel.

With significant sea-level rise projected in San Francisco Bay by 2100 under existing emissions trajectories, both marshes and the low-lying diked baylands along the Petaluma River will be vulnerable. The project team conducted analyses of the baylands to determine existing conditions and anticipated resilience to sea-level rise. Adaptation strategies, aligned with the regional Baylands Goals Update (Goals Project, 2015), were developed to address the specific conditions found in the study area:

- **Condition 1: High marshes with high resilience.** These marshes are high in elevation today and are well-positioned to persist and continue building elevation as sea levels rise; however, at high rates of sea-level rise (projected for the late 21st century and beyond) they are likely to transition to low marsh and mudflat. Strategies focus on protection and maintenance rather than restoration or creation (e.g. native plant conservation, managing invasive species, and restoring watershed connections to deliver sediment and freshwater to the marsh).

- **Condition 2: Restoring, low-elevation, tidally-connected areas.** Several recent tidal restorations in the Petaluma River Baylands are still in the process of accreting sediment and developing into tidal marshes. According to marsh evolution modeling, these sites are expected to reach low to mid-marsh elevation by mid-century and persist through the end of the century. Strategies focus on enhancing tidal connectivity and improving sediment delivery from watersheds to baylands.

- **Condition 3: Marshes not connected to protected migration space.** Many of the high-elevation (Condition 1) and restoring (Condition 2) marshes face the same challenge: limited marsh migration space. Eventually rising seas will drown these marshes if there is not protected upland area for them to migrate into, but transportation infrastructure and diked baylands create barriers separating existing marshes from migration space. Strategies focus on removing barriers to allow bayland-upland connectivity, preserving currently unprotected migration space, and enhancing transition zone habitat.

- **Condition 4: Diked baylands disconnected from tidal action and vulnerable to flooding.** Extensive areas that were historically inundated by the tides are protected by levees and kept dry for agriculture and other purposes. Flooding in diked baylands will be exacerbated by levee overtopping during extreme tides and storm surges, rising groundwater levels, and more intense precipitation events. Depending on landowner interest, strategies can range from interim measures like promoting seasonal wetland habitat to more expansive measures like full tidal restoration.

- **Condition 5: Sedimentation necessitates regular channel dredging.** Diking and draining of tidal marshes and channelization of streams and sloughs has decreased tidal prism in the Petaluma baylands and resulted in continued sedimentation in the main Petaluma River channel. Baylands restoration could affect in-channel sedimentation, and more research is needed to determine how tidal restoration may influence channel morphology. If dredging continues, sediment should be strategically placed to benefit habitat restoration efforts.

Based on these findings and strategies, and input from stakeholders and scientific advisors, we developed a landscape vision and a series of possible alternative scenarios for the Petaluma River Baylands:

- The **Landscape Vision** prioritizes restoring estuary–watershed connections, planning for the baylands to migrate, increasing ecological complexity, and restoring diked baylands to full tidal action.

- The **No-action scenario** assumes no restoration strategies are implemented, existing levees are maintained but not raised, and pumping continues. As sea levels rise, levees are overtopped and diked baylands are flooded. Over time, existing marshes shift to low marsh, then mudflat or subtidal habitat.

- The **Public Land Only scenario** demonstrates a future where restoration is limited to properties already owned by public agencies. On private land, this scenario assumes levees are raised and lands are pumped dry for the foreseeable future.
- The **No Causeways scenario** assumes roadways and railways are maintained in their current condition or protected by levees rather than being raised on causeways. Some restoration is possible, but the level of landscape connectivity in the Landscape Vision cannot be achieved.
- The **East-West Causeway Only scenario** is a compromise between the No Causeways scenario and the Landscape Vision, assuming construction of an east-west causeway for State Route 37 and SMART rail, but no north-south SMART rail causeway.

Where landowners wish to continue existing land uses, restoration actions are still possible. Some near-term actions may be pursued prior to implementation of tidal restoration projects; however, the later tidal restorations are completed, the less likely they are to reach marsh elevations and persist as marsh habitat to 2100 and beyond. Near-term actions may include enhancing tidal connectivity under roads and rail lines, constructing setback levees to facilitate development of fringing marshes, and promoting seasonal wetland habitat by decreasing pumping of rainwater during winter months.

Two major considerations for implementation of the Petaluma River Baylands Strategy are coordination with private landowners and transportation corridor improvements. Landowner interest in participating in restoration projects will likely be determined by the costs of levee maintenance and pumping versus the revenue generated by current uses. The restoration community is in close coordination with transportation agencies regarding improvements of the State Route 37 corridor, and current planning processes indicate a preferred alternative of a combined road/rail causeway across the Petaluma River Baylands. With landowner participation, this would allow restoration of a wide swath of connected bayland and upland habitats.

As individual projects are considered, this document can be used as a reference to determine how they can be designed to best contribute to achieving the habitat resilience goals represented in the Landscape Vision. With large areas of open space, core areas of high-quality and biologically diverse marsh habitat, and some of the best potential opportunities for marsh migration and bayland/watershed connections, the Petaluma River is among the most important and promising locations for landscape-scale conservation and restoration in the San Francisco Estuary. However, implementation will be a puzzle, as the timing of land availability and transportation improvements are unknown, as are future rates of sea-level rise, sediment availability, and a host of other relevant factors. This Strategy lays out a vision for a resilient and connected landscape, and will serve as a touchstone as future projects add to an increasingly diverse mosaic of habitats in the Petaluma River Baylands.

Chapter 1. Introduction

1.1 Background

The Petaluma River Baylands, located in northwestern San Pablo Bay, south of the City of Petaluma (Figure 1.1), offer unparalleled opportunities to conserve, restore, and connect large blocks of tidal wetlands, transition zones, upland watersheds and the ecological processes that sustain them. Focusing on a 27,500-acre study area (Figure 1.2), this *Petaluma River Baylands Strategy* (Strategy) envisions ways to restore historical habitats and make existing habitats more resilient to climate change.

Historically, tidal marsh was the dominant habitat type in the study area, occupying about 16,150 acres along the Petaluma River, as detailed by the Coast Survey in ca. 1860 (Baumgarten et al. 2018) (Figure 1.2). Formed between 2,000 and 5,000 years ago, these physically complex tidal wetlands supported broad, stable, dendritic channel networks draining high marsh plains. Marsh ponds (pannes) were scattered across the marsh plain and natural levees lined the tidal channels. As a result of this physical complexity, the tidal wetlands were biologically diverse, and supported varied native plant and animal communities. In addition to tidal marshes, large tidal flats existed at False Bay, with smaller flats where the river met San Pablo Bay. Moist grassland, or wet meadow, was widespread northeast of the tidal marsh near Petaluma and along Lakeville Highway, and vernal pool complexes were dotted throughout the watershed.

There has been a significant loss of wetland habitat due to diking and draining from the 1850s onwards to create agricultural land. The area of tidal wetlands decreased by 58% and the area of non-tidal wetlands (wet meadows, vernal pools) decreased by 85% since 1850 (Baumgarten et al. 2018). An extensive analysis of historical bayland and wetland habitats in the watershed was undertaken for the *Petaluma Valley Historical Hydrology and Ecology Study* (Baumgarten et al. 2018). A similar analysis of historical habitats was completed for the Marin County baylands and adjacent upland areas (Collins et al. 2007). This Strategy builds on both of these efforts and analyzes where opportunities exist for habitat conservation, adaptation, and increased resilience to the effects of climate change.

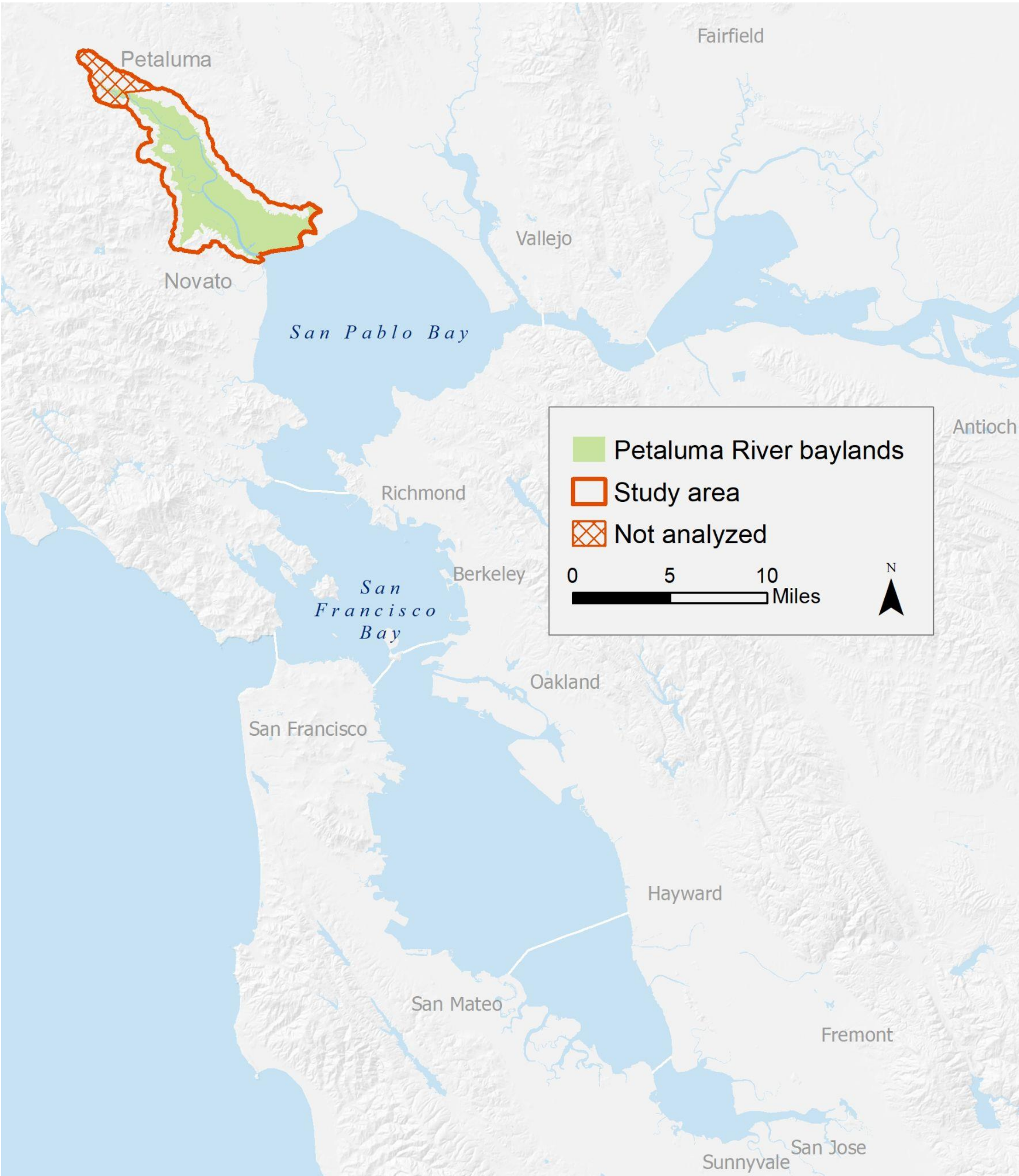

Figure 1.1. The Petaluma River Baylands Strategy study area and regional context. The urbanized portion of the study area in the City of Petaluma was not analyzed for this document.

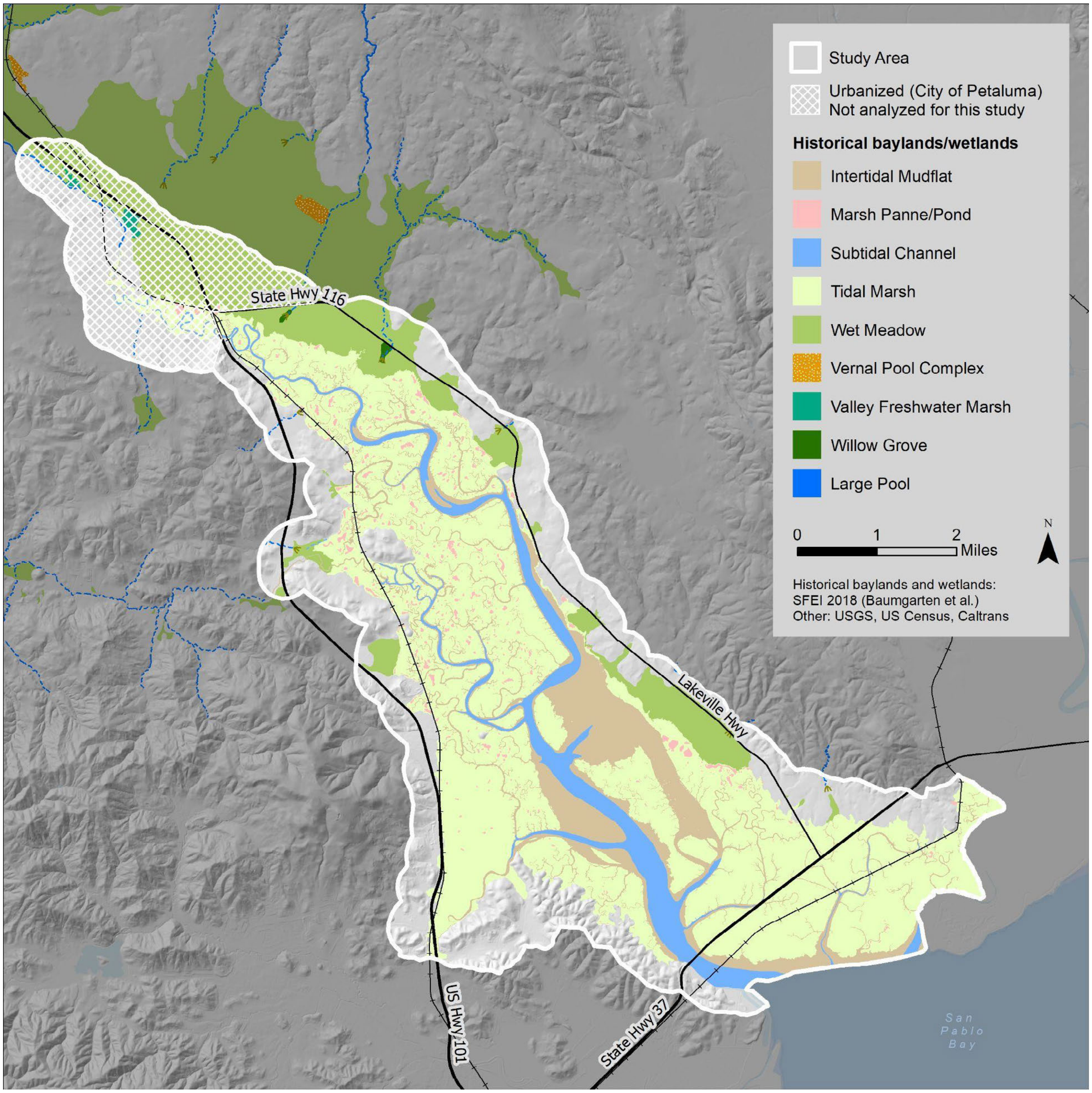

Figure 1.2. Historical habitat types (circa 1850) from the Petaluma Valley Historical Hydrology and Ecology Study (Baumgarten et al. 2018). Tidal marshes and other wetland types were historically much more widespread in the study area.

Despite extensive conservation opportunities in the lower watershed, the Petaluma River is the only major tributary in north San Francisco Bay lacking a baylands conservation strategy document. We hope this Strategy will accelerate the pace and scale of acquisition and restoration and heighten awareness of the importance of avoiding further encroachment on existing and future wetland habitats. We hope community members and stakeholders will heed this call for improved coordination to achieve the recommendations this Strategy provides. These recommendations extend to prominent transportation infrastructure managed by Caltrans (State Route 37) and the Sonoma-Marin Area Rail Transit (SMART) railroad tracks, which run both along the western edge of the Petaluma River (north-south) and parallel to State Route 37 (east-west).

This planning effort narrows the geographic focus and further builds on the foundation of the Baylands Goals (1999, 2015), which developed ambitious restoration goals for San Francisco Bay and broadly identified the ecological processes and functions that must be restored in order to rebuild ecological resilience. The 2015 Goals Update identified the urgent need over the next few decades to restore wetlands, wetland-upland transition zones, and connections to upland watersheds in advance of rapid sea-level rise. The Petaluma River Baylands Strategy is also informed by the following regional plans and studies:

- Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California (USFWS 2013)
- California State Wildlife Action Plan – 2015 Update (CDFW 2015)
- San Pablo Bay National Wildlife Refuge Comprehensive Conservation Plan (USFWS 2011)
- Natural Resource Management Plan for the San Francisco Bay National Wildlife Refuge Complex (USFWS, 2019)
- San Pablo Bay National Wildlife Refuge Climate Adaptation Plan (Veloz et al. 2016)
- San Francisco Bay Shoreline Adaptation Atlas (SFEI and SPUR 2019)
- Restoring the Estuary (SFBJV, 2022)

1.2 Vision, goals, and objectives

Vision

Through implementation of the recommendations of this Strategy, we envision the future Petaluma River Baylands landscape as an expansive suite of connected tidal wetland habitats transitioning into adjacent upland and riparian habitats, existing alongside and within low-intensity working lands. The landscape will include large swaths of connected tidal wetlands adjacent to protected uplands that improve the health of the bay, river, and watershed, provide room for wetlands to move upslope, facilitate delivery of freshwater and sediment, purify water, transform nutrients, and enable movement of wildlife between the baylands and surrounding lands. This suite of habitats will benefit native species and will improve resilience to climate change for fish and wildlife and the ecological processes they depend upon. Restored and protected habitats also provide co-benefits for neighboring landowners and communities, including flood protection and erosion control. Existing and new transportation infrastructure will be designed to accommodate rising seas and movement of water, habitats, and species.

Goals

To achieve this sweeping conservation vision, the overarching goals of the Strategy are to:

- conserve and restore baylands and adjacent habitats;
- promote the growth and resilience of populations and habitats of native species within the study area; and
- maintain and increase the ecosystem services provided to human communities.

Actions

The key actions of this Strategy are:

1. To develop a strategy containing actionable projects which contribute to achieving the vision and goals laid out in this plan.
    - Produce a high-level assessment of how proposed restoration and adaptation opportunities affect species, habitats, and ecosystem services given climate change scenarios.
    - Identify subunits within the project area most suited to specific actions (e.g. restoration, protection of migration space, etc.)
    - Identify opportunities within subunits for conservation and/or restoration of upland, riparian, seasonal wetland, transition zone, and tidal habitats, especially where connections can be made between habitat types and where marsh migration space is present.
    - Identify solutions where marsh migration zones are blocked by transportation infrastructure (e.g. SMART, Caltrans).
    - Seek buy-in, if not consensus, from stakeholders, tribes and other community members on plan actions
2. To develop a shared understanding of flooding and other threats posed by climate change to habitat, infrastructure and other lands within the project area. The project team and stakeholders, tribes and other community members are better informed about nature-based actions to facilitate adaptation and increase resilience.
    - Using existing data, identify threats posed by climate change to public and private lands and associated habitat within the project area.
    - Develop a shared understanding of climate-related threats through in-person and virtual meetings.
    - As a team and with a scientific advisory panel, develop broad ideas on types of actions and projects that can reduce climate vulnerability and work with landowners to develop specific projects.

- Where projects are identified, specify where transportation infrastructure prevents adaptation and resilience efforts and what infrastructure actions will enable projects to occur.

Further guiding principles considered in the development of this document are included in Appendix A.

1.3 Community outreach

Outreach efforts to Petaluma River Baylands stakeholders consisted of one-on-one meetings, an invitation-only meeting for landowners of riverside parcels in the study area, and a larger public meeting to which stakeholders, landowners, tribes, and agency personnel were invited. For specific details regarding these outreach efforts and meetings, please see Appendix B.

Through these efforts, the project team explained actions that spurred this work, why the work is critically important and will continue to be of value in the future, how the study and its results will be used once complete, and how landowners, managers, and stakeholders can be voluntarily involved.

The responses and feedback that the project team received were essential in exploring opportunities, limitations, and feasibility of potential project actions and recommendations. The project team gained a deeper understanding of the hydrology, history, land use and management, and changing conditions of the Petaluma River Baylands landscape.

While developing the Landscape Vision, the project team reflected on discussions with Bayland stakeholders to develop a series of restoration scenarios that encompass a wide range of commitment, interest, and readiness to participate in project development efforts. Please see Chapters 7 and 8 for more information on how stakeholder feedback was incorporated into our landscape visioning process.

1.4 Native American outreach

Future conservation and restoration work will involve outreach and partnership with Native American tribal groups and organizations to ensure early involvement in planning regarding the treatment and protection of cultural and tribal resources. This work is in advance of the regulatory process; it is a matter of respect and an opportunity for the conservation community and others to learn from those who came before. See Chapter 2.11 for general information pertaining to the cultural and tribal resources study that was prepared for this document and is filed with Sonoma Land Trust. That report contains culturally sensitive information and archaeological sites, is confidential, and should not be shared with the public.

Sonoma Land Trust is currently in coordination with the Federated Indians of Graton Rancheria, who are culturally affiliated with the study area, to ensure cultural and tribal resources are addressed in this document. In addition, a search of the Sacred Lands File by the Native American Heritage Commission (NAHC) in March 2023 did not result in the identification of any sacred sites filed with the NAHC for the study area. The NAHC also provided a list of 10 other Native American individuals and groups to contact who may have information about tribal cultural resources or areas of sensitivity. Sonoma Land Trust will continue to seek input from all tribal communities listed by the NAHC.

Federated Indians of Graton Rancheria

Encroachment of European settlement culminated in a series of acts and bills removing land and political status from tribal governments. As a result, native Californians were left landless and legally powerless, often making their way as itinerant farm workers or commercial fishermen. Legal land entitlement remained out of reach until 1920, when the Bureau of Indian Affairs purchased a 15.45-acre tract of land in Graton to create a “village home” for dispersed people of Marshall, Bodega, Tomales, and Sebastopol (Federated Indians of Graton Rancheria 2023). This home consolidated neighboring, traditionally interactive groups into a single entity—Graton Rancheria—thus establishing them, temporarily, as a Federally Recognized Tribe of American Indians.

In 1958, Congress passed the California Rancheria Act, terminating all 41 Rancherias, extinguishing the recognition of their residents as American Indians, and removing the land from Federal Trust. As with many other California Tribes, federal recognition for the Coast Miwok was not restored until decades later, after tribal members raised money to travel to Washington to campaign for restoration of federal status and rights. For the Graton Rancheria, campaigning began in 1990, with recognition restored in 1997, and a tribal constitution ratified by the Bureau of Indian affairs in 2002, allowing the tribe to re-establish a land base, provide funding for cultural preservation, and establish tribally owned businesses capable of achieving self-sufficiency (Graton Rancheria 2019).

Today, the Graton Rancheria community encompasses “a federation of Coast Miwok and Southern Pomo groups recognized as a tribe by the United States Congress. The Miwok of west Marin County have, through the years, been referred to as Marshall Indians, Marin Miwok, Tomales, Tomales Bay, and Hookooeko. The Tribe opened the Graton Resort and Casino in 2013, which now funds various programs and services for its tribal membership, including environmental and cultural preservation, elder care, childcare, housing, legal support, emergency financial support, education, and employment. Graton Rancheria has developed a Tribal Heritage Preservation Office program with a designated Tribal Heritage Preservation Officer and Sacred Site Protection Committee responsible for protecting the Tribe’s tribal cultural resources.

1.5 Report structure

Chapter 2 lays out the existing conditions of the Petaluma River Baylands. In Chapter 3, sea-level rise projections and other climate stressors for the area are discussed. Chapter 4 summarizes the findings of the geomorphic and marsh evolution analyses performed as part of this study (more information in Appendices C and D). In Chapter 5, these findings are translated to overarching strategies for restoration. Chapter 6 applies these overarching strategies to develop a Landscape Vision for the Petaluma River Baylands. Chapter 7 outlines key uncertainties in implementation of the Landscape Vision and describes a range of other restoration scenarios that may arise depending on these uncertainties. Chapter 8 summarizes near-term actions that can be undertaken to improve habitat value in the baylands prior to implementation of the Landscape Vision. Chapter 9 concludes the document.

Chapter 2. Existing conditions

The Petaluma River Baylands region is largely rural, and comprises large expanses of undeveloped and lightly developed agricultural lands where wetlands historically fringed the Petaluma River, its neighboring uplands, and its confluence with San Pablo Bay.

2.1 Study area

The study area is adapted from the Petaluma Operational Landscape Unit (Figure 2.1), as defined in the San Francisco Bay Shoreline Adaptation Atlas (SFEI and SPUR 2019). Operational Landscape Units (OLUs) are geographically connected areas sharing similar physical characteristics. These coherent units provide a useful scale for climate change planning, as management actions that affect processes in one part of the unit are likely to also affect other areas within the unit. The OLU upland boundaries are defined by the area that will potentially be inundated at high tide with 5m of sea-level rise (CoSMos2.0; Barnard et al 2014), plus 500m horizontally inland to capture transitional areas upslope of the sea-level rise zone (Robinson et al. 2017).

To help analyze and describe variation in environmental conditions across this broad and diverse landscape, we have divided the study area into nine subunits, as shown in Figure 2.2 The City of Petaluma - North subunit was not analyzed in this study because of its urban character. The City of Petaluma will need its own adaptation and resilience plan, which will consider many factors outside the scope of this document. The subunits are generally defined by physical differences in baylands characteristics, as described in Table 2.1. More details on individual subunits are provided in the Habitats and Species sections of Chapter 2.

Parcels owned and managed by the California Department of Fish and Wildlife (CDFW) have their own unit names, some of which vary slightly from the colloquial names used herein to describe Petaluma River marshes. Given the extensive area of the Petaluma baylands managed by CDFW, the CDFW Petaluma Marsh Wildlife Area map is included for reference in Supplemental Figure F-1. The broader subunit names are used for this Strategy (Table 2.1, Figure 2.1).

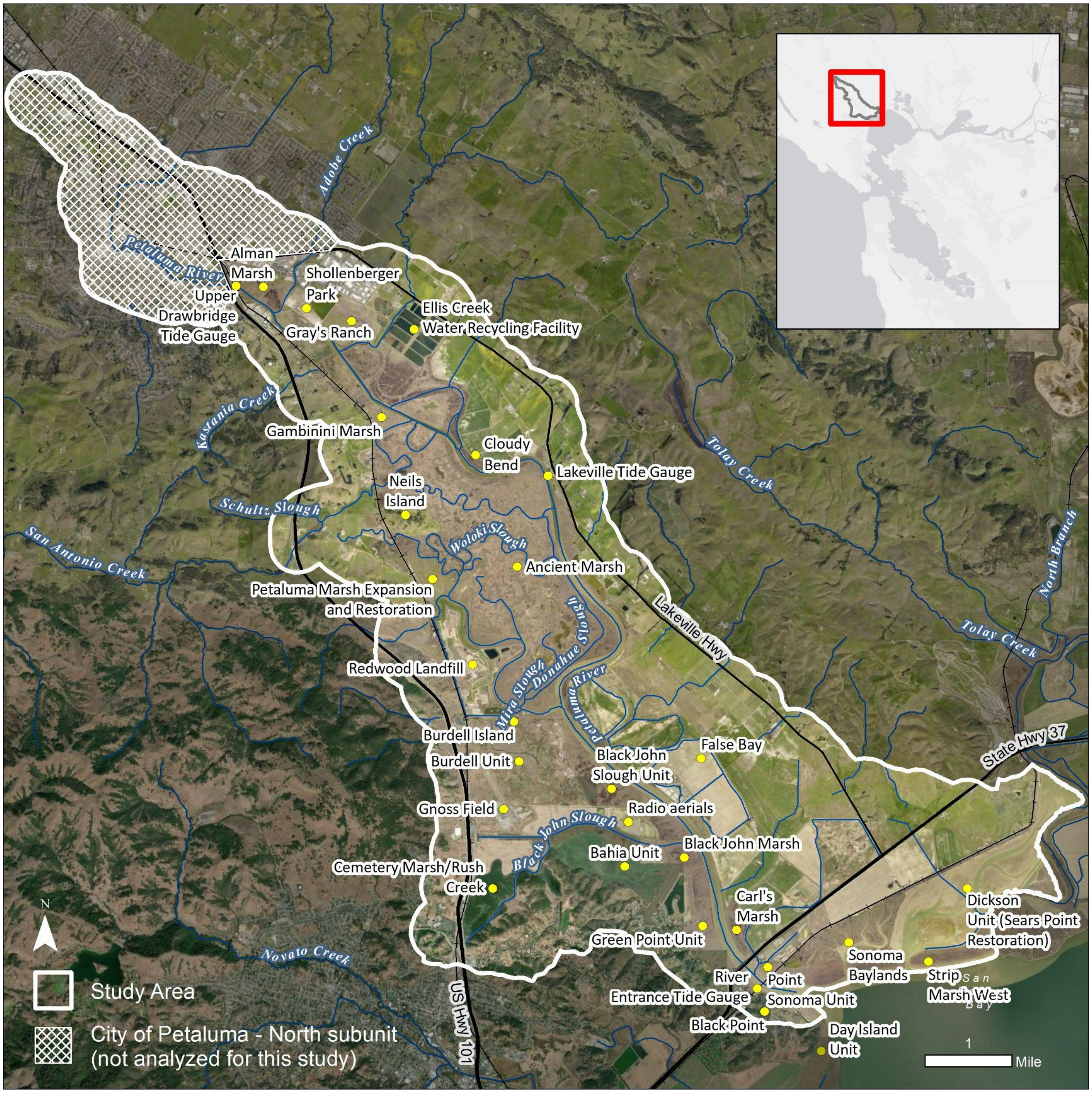

Figure 2.1. Study area boundary and key locations and features of the Petaluma River Baylands. "Units" labeled here (e.g. Green Point Unit, Bahia Unit) are the official names of CDFW and USFWS management units.

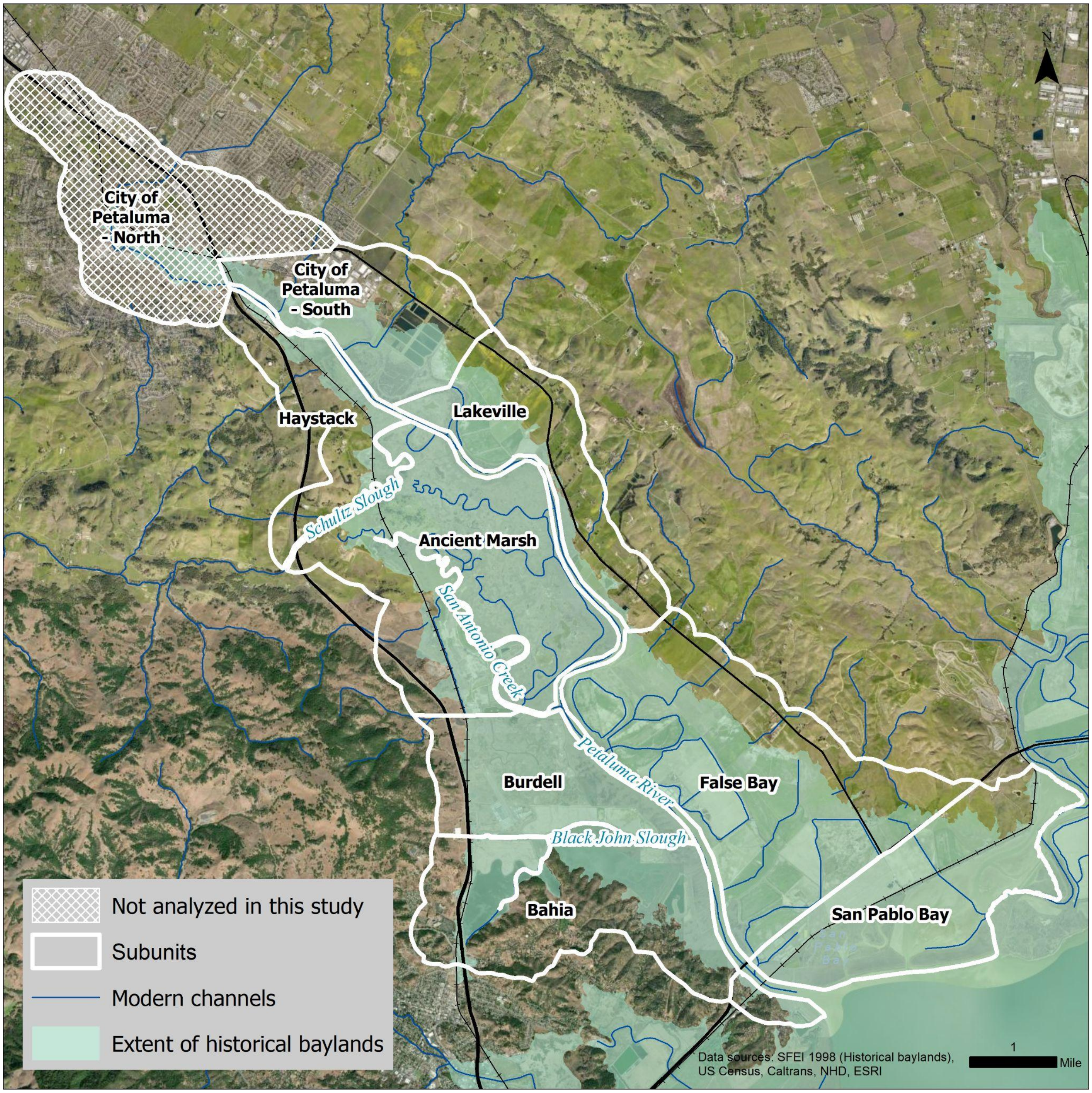

Figure 2.2. Subunits used to describe various locations within the study area. The City of Petaluma - North area was not analyzed for this study.

Table 2.1. Subunits with acreage and brief description.

Subunit	Acres	Brief Description
Ancient Marsh	4,510	Fully tidal (brackish), mature high marsh and adjacent upland
Bahia	3,220	Tidally connected but low-elevation and newly restored, upland
Burdell	1,940	Fringe marsh, diked non-tidal and seasonal wetlands, upland
City of Petaluma - South	2,060	Industrialized baylands and treatment wetlands, seasonal wetlands, mature tidal (brackish) marsh
False Bay	5,040	Subsided diked baylands, fringe marsh
Haystack	1,500	Mature high marsh and diked baylands
Lakeville	2,080	Historical fringing marsh, diked baylands
San Pablo Bay	3,210	Centennial (recently accreted) strip marsh, restored tidal marsh, subsided diked baylands

2.2 Geomorphology

The topography of the study area is highly varied, with mountainous and hilly upland areas on either side of the broad Petaluma River valley. Prior to the Holocene rise in sea level (12,000-7,000 years ago), alluvium consisting of sand, gravel and clay filled the Petaluma Valley. This sedimentation occurred by multiple processes including stream deposition, landslides, soil creep, and sheetwash. The tidelands developed through the combination of tidally reworked sediments from the Petaluma terrestrial uplands and other watersheds that make up the bay sediments. Alluvial deposits in the upper Petaluma Valley are generally fairly thin, but thicken to over 300 ft near the bay. The rise in sea level during the last 11,000 years, and the subsequent encroachment of the waters of San Pablo Bay, resulted in filling of the lower valley with silts and clays, extending inland as far as the City of Petaluma.

The Petaluma River area is generally subject to low wave energy and high sediment availability: conditions conducive to marsh formation. Prior to diking and draining in the 1940s, False Bay, a mudflat referred to by surveyors as a “high water lagoon”, accreted to marsh elevation by the early 1900s (Baumgarten et al. 2018). Hydraulic mining operations in the Sierras contributed additional sediment via the Sacramento-San Joaquin Delta, and sediment accumulated in the main channel and prograded at the Petaluma River mouth in the early 1900s. In the period before 1940, tideland elevations ranged from mean sea level (MSL) to three feet above MSL. Today, diked lands behind constructed levees have subsided due to the removal of tidal action, the subsequent loss of sediment supply, and oxidation of peat. Elevations of diked baylands now range from 2 feet below mean lower low water (MLLW) to MSL.

Sediment accumulation in the watershed continues today. Progradation (bayward expansion) of the marsh edge at the river's mouth averaged 3.3-6.6 ft between 1993 and 2010, though this expansion slowed between 2010 and 2018 (SFEI and Baye 2020). Due to reduced tidal prism (volume of water entering and exiting the baylands between MLLW and MHHW) and increased sedimentation, the channel width (subtidal and mudflat) in the lower reach of the river has decreased by up to 2,000 feet over approximately the last 150 years (Baumgarten et al. 2018).

The Petaluma River was used so intensely for commerce during the late 1800s and early 1900s that repeated dredging operations were undertaken. These efforts both deepened and widened the river channel and changed its course by constructing cut-offs at meander bends to facilitate navigation. During the process of dredging, many river meanders were filled with dredged material (Baumgarten et al. 2018). Dredging of the river and straightening of channels to manage sediment buildup and allow continuous navigation in the channel continues today, with the most recent dredging occurring in late 2020 and the next dredging event scheduled for 2024. Sediment from recent dredging events is deposited in the City of Petaluma's dredge placement ponds in Shollenberger Park.

2.3 Hydrology

The Petaluma River watershed covers 146 square miles in Marin and Sonoma counties (Supplemental Figure F-2). Major tributaries to the Petaluma River in the eastern portion of the watershed include Lichau Creek, Willow Brook Creek, Lynch Creek, Adobe Creek, and Ellis Creek. The largest drainage on the western side is San Antonio Creek, which flows into the Ancient Marsh. The historical pathway of San Antonio Creek defines the Sonoma/Marin county boundary. During the late 1800s and early 1900s, the lower tidal reaches of San Antonio Creek were diverted from San Antonio Slough into the smaller, more northerly Schultz Slough. The rerouting of San Antonio Creek to Schultz Slough resulted in sediment deposition from the creek being more concentrated than it was when the alluvial fan spread over Petaluma Marsh in the original San Antonio alignment (L. Collins, pers. comm., February 2020).

The watershed provides both surface and subsurface freshwater inputs to the baylands (Goals Project 2015). Therefore, the Petaluma River estuary is a zone of transition from the more saline tidal waters of the Bay to freshwater inputs from the Petaluma watershed. Vegetation composition in particular can affect the evolution of the marshes and their ability to respond to sea-level rise. Plants that grow in brackish environments tend to be more productive, create more organic material, and grow at lower elevations than plants growing in more saline conditions (Schile et al. 2014). For the Petaluma River, the head of tide is upstream of the river's confluence with Lynch Creek, about 2 miles upstream of the Highway 101 crossing, as indicated by tidal influence on water surface elevations (SRCD 2022). However, freshwater influences can be seen in the marshes closer to the Bay as local creeks join the Petaluma River (supplemental figure F-3).

Historically, alluvial fans were connected more gradually over broader areas, and transitions between tributary and estuarine inputs resulted in gradual shifts in fresh to saline conditions and the resulting vegetation community structure. However, there has been considerable modification of the natural hydrology, which has changed both the variation in salinity and the pattern of sediment delivery. Many of the historical creek channels were artificially channelized in the late 19th and early 20th centuries by lengthening through ditching to improve drainage and reduce flooding in diked baylands. This has reduced the ability of the Petaluma River’s tributary streams to spread sediment in alluvial fans and has greatly reduced the area of non-tidal wetlands within the watershed. Sediment historically replenished non-tidal wetlands and alluvial fans, but now bypasses these areas and is routed further downstream within the channels (Baumgarten et al. 2018). Sediment within these channels now tends to be deposited at the break of slope between the uplands and the historical baylands where the gradient of slope and the flow velocity decreases.

Changes in the natural hydrology of the channels and drainages have left a system lacking natural transitions in salinity and vegetation. Alluvial fans are disconnected and there is inefficient sediment transport from watersheds to baylands. This has affected overall habitat composition (discussed further in Section 2.5).

2.4 Elevation

Tidal elevations vary along the complex San Francisco Bay shoreline, and tidal elevations and ranges are important determinants of ecological conditions in the Petaluma River Baylands (Figure 2.3). Therefore, local tidal datums (standard elevations defined by a tidal phase and used as reference points) are essential to understanding current environmental conditions and provide important baseline information for analyzing impacts of sea-level rise. Tidal datums for the Petaluma River are shown in Supplemental Table F-1.

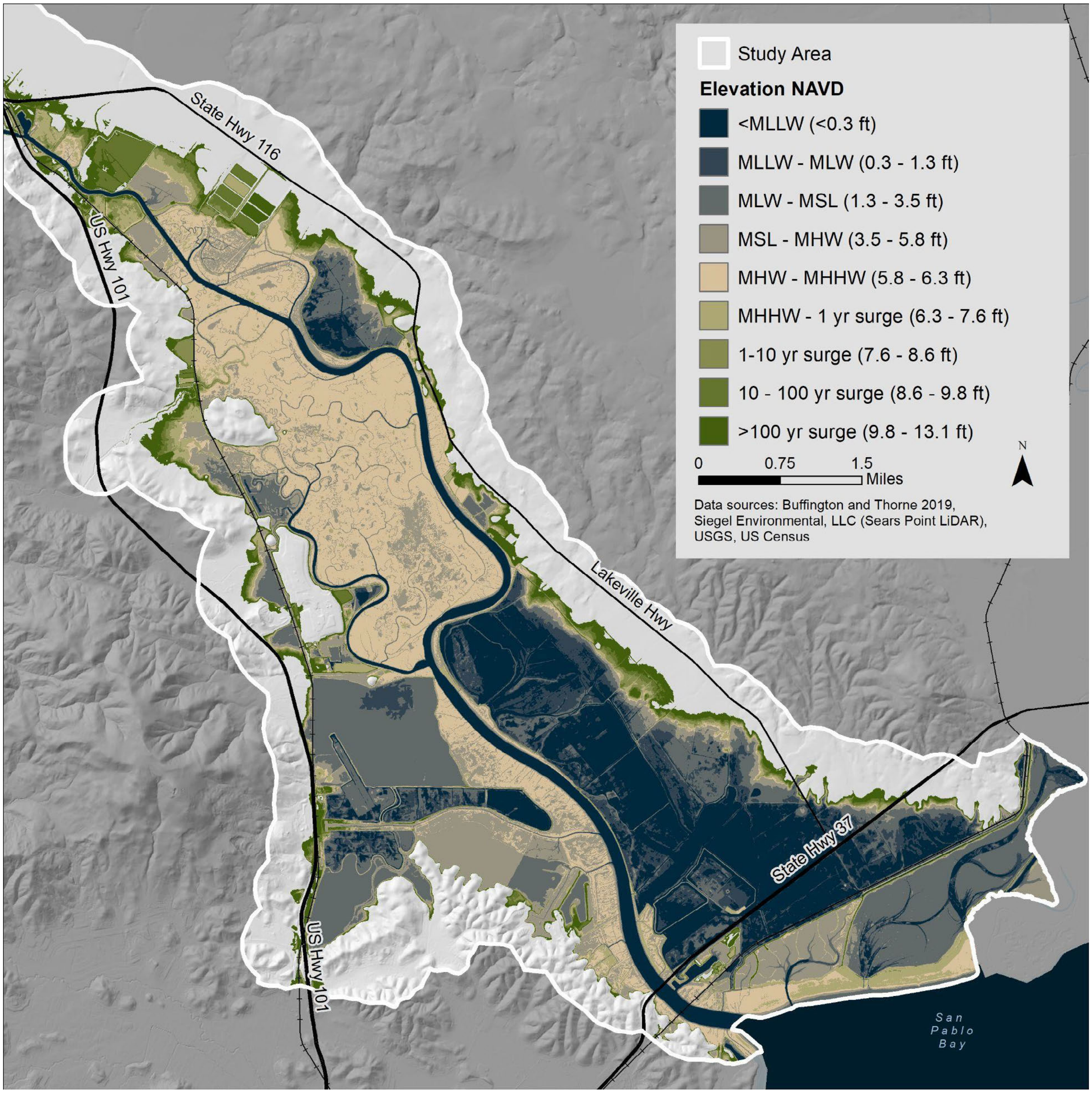

Figure 2.3. Tidally-referenced elevation of Petaluma River Baylands (tidal datums from Petaluma River Entrance gauge). The average elevation of the higher of the two daily tides is Mean Higher High Water (MHHW); the average elevation of the lower of the two daily tides is Mean Lower Low Water (MLLW). Mean High Water (MHW) is the average of all the high water heights and Mean Low Water (MLW) the average of low water heights. Mean Sea Level (MSL) is the mean of observed water levels.

Tidal marsh plant communities can be grouped based on their observed elevation distributions, as zonation in bayland plant communities is closely related to inundation tolerance and soil salinity. Using local tidal datums, this information can be translated to estimate elevations of plant communities in the Petaluma River Baylands. Bayland vegetation community categories (elevations relative to MHHW from Stralberg et al. 2011) are listed in reference to local tidal datums at the Petaluma River in Table 2.2.

Table 2.2. Petaluma River bayland habitat thresholds by elevation. Habitat elevation thresholds are from Stralberg et al (2011), referenced to the tide gauge data listed in Table F-1.

Habitat Threshold	ft NAVD	m NAVD	ft MHHW	m MHHW
High Marsh/ Upland	7.2	2.2	1.0	0.3
Mid/High Marsh	6.9	2.1	0.7	0.2
Low/Mid Marsh	5.2	1.6	-1.0	-0.3
Mudflat/Low Marsh	4.3	1.3	-2.0	-0.6
Mudflat/Subtidal	0.3	0.1	-5.9	-1.8

The habitat ranges are characterized by key plant species: upland transition by coyote bush (*Baccharis pilularis*); high marsh by alkali heath (*Frankenia salina*) and jaumea (*Jaumea carnosa*); mid marsh by pickleweed (*Salicornia pacifica*); low marsh by cordgrass (*Spartina* spp.) or, in brackish areas, by bulrush (*Schoenoplectus* spp.); mudflat habitat is unvegetated or sparsely covered with cordgrass (Takekawa et al 2013).

Average elevations for the baylands in each subunit are shown in Figure 2.4. The upper boundary of the baylands was drawn at the lower end of the upland transition zone, as defined in this report: highest astronomical tide (estimated as Mean Higher High Water (MHHW) plus 1 ft). There is a wide range in mean elevation across the subunits. The City of Petaluma South and Haystack units are relatively high in elevation, with mean elevations of 5.6 ft (1.7 m) and 5.9 ft (1.8 m) respectively. The Ancient Marsh unit, much of which has been accreting sediment over the centuries and left undeveloped, is also at an elevation of 5.6 ft (1.7 m), just below MHHW. The Lakeville and Bahia subunits fall between Mean Sea Level (MSL) and Mean High Water (MHW) elevations, and have a mix of low-lying diked areas below MSL and fringing marsh above MHW elevation. The Burdell and San Pablo Bay subunits are lower: between Mean Low Water (MLW) and MSL. This is due to diked and subsided areas in the Burdell subunit and subtidal areas in the San Pablo Bay subunit[1]. Lowest in elevation, below MLW at 0.8 ft (0.2 m), is False Bay. This former mudflat lagoon has undergone significant subsidence since being converted to agricultural use in the mid-20th century.

---

[1] Diked baylands with restored tidal action, such as Sears Point (now known as Dickson Unit, San Pablo Bay National Wildlife Refuge), are in the process of restoring and today have higher elevations than those indicated in the digital elevation model used for this analysis (Buffington and Thorne 2018).

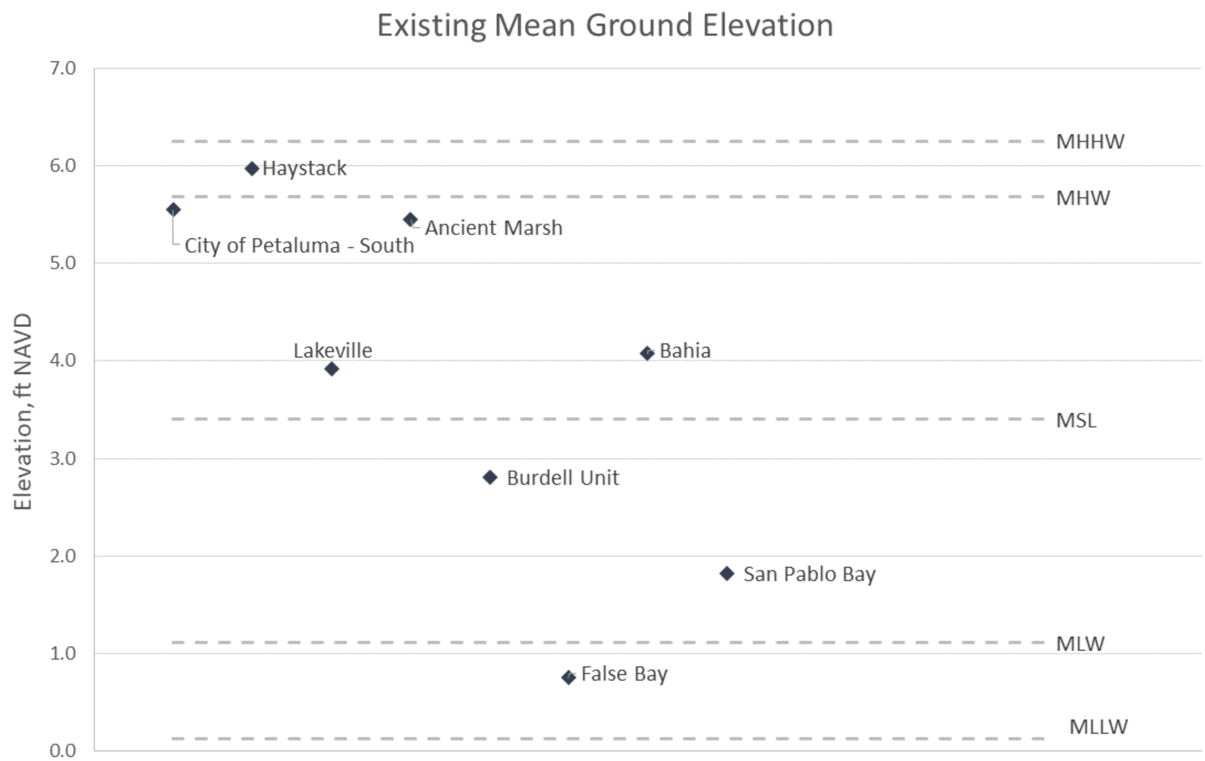

Figure 2.4. Existing mean ground elevations for Petaluma baylands subunits (only the baylands area – the area below highest astronomical tide elevation). A visualization of the baylands area of each subunit used to calculate these mean elevations is provided in Supplemental Figure F-4.

2.5 Habitats

The Petaluma baylands currently support 4,930 acres of tidal marsh, 90 acres of wet meadow, and 20 acres of vernal pools (Baumgarten et al. 2018). The ancient Petaluma Marsh (called the Ancient Marsh in this report) is the largest intact tidal marsh plain in the San Francisco Estuary at over 2,500 acres, and estimated to be 2,000-4,000 years old (Goals Project 2015, SRCD 2022) (Figure 2.5). The Ancient Marsh supports high native plant and animal species diversity, including rare, threatened and endangered species. Though there are some natural transition zones in the Ancient Marsh (e.g. at Neils Island), connections to the adjacent watershed are hindered by the SMART rail line that runs along the back of the marsh. There is limited connectivity to lowland valleys through culverts and trestle bridges under the rail line. In addition to the Ancient Marsh, more recently formed fringing marshes border the Petaluma River in the study area. Large areas of former baylands (historically inundated by the tides) exist today as subsided, diked agricultural fields. More recently, restoration efforts have returned tidal exchange to some of these former salt and brackish marsh areas that have been cut off from flows for the last 100 years or more.

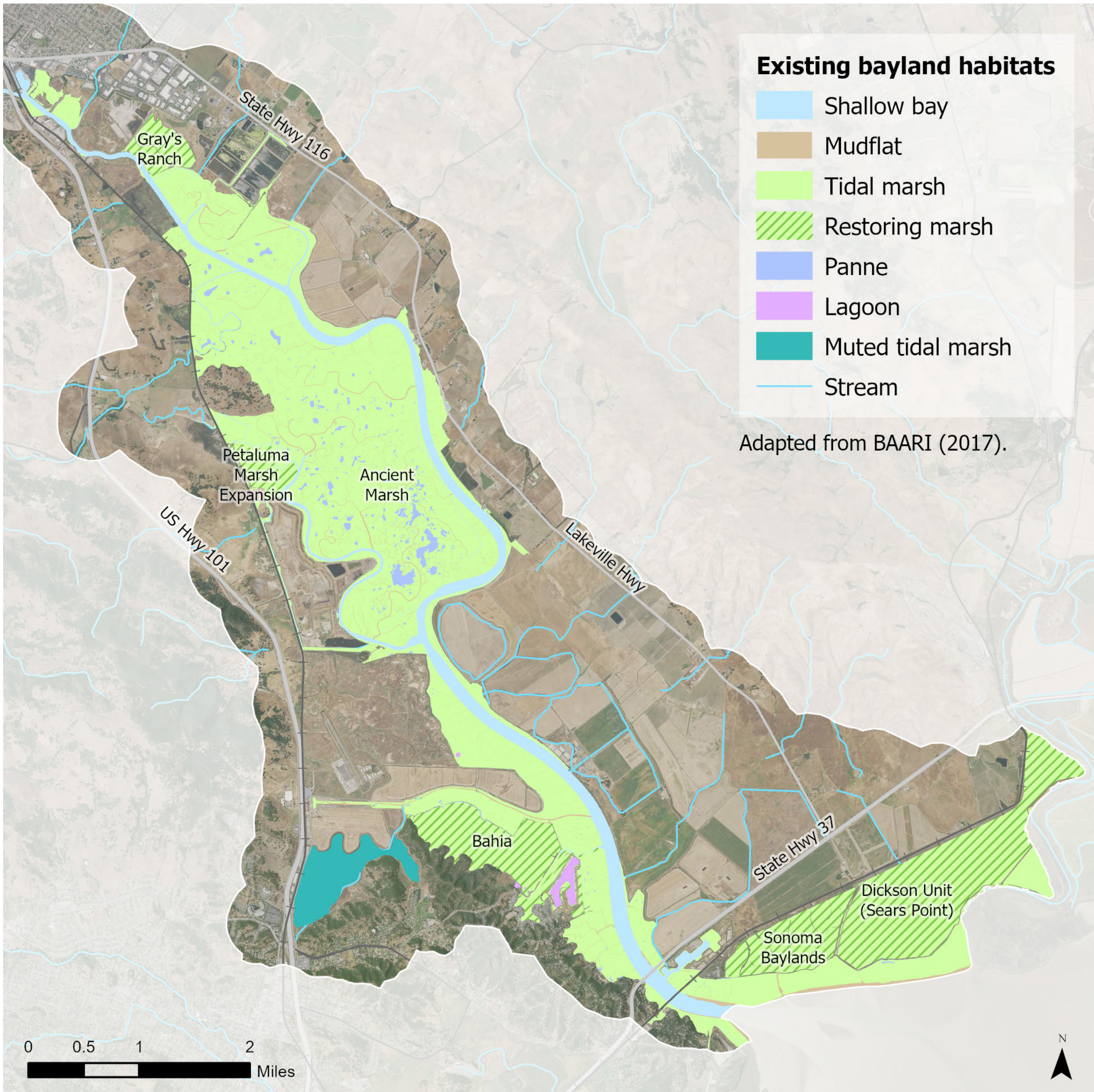

Figure 2.5. Modern bayland habitat types.

Not all Petaluma River tidal marshes are the same; they range in age, salinity, and elevation (among other factors) and thus provide different habitat conditions for several species. The various types of tidal marsh present in the Petaluma River Baylands (millennial, centennial, and new tidal marsh) are described below, as categorized in the Wetlands Regional Monitoring Program Plan (WRMP 2020).

Millennial marshes were formed 2,000 to 5,000 years ago. These marshes are characterized by dense, dendritic channel networks and high-elevation marsh plains, and often support complex vegetative structure and dense populations of endemic wildlife. For these reasons, millennial tidal marshes are commonly used to define desired endpoints for tidal wetland restoration projects. The Petaluma Ancient Marsh is the largest remaining millennial marsh in the San Francisco Estuary.

Millennial tidal marsh (Ancient Marsh).
Photo: Robert Janover, 2019. Courtesy Sonoma Land Trust.

Centennial tidal marshes are 50-150 years old and have been heavily influenced by sediment washing downstream from hydraulic mining, modern land-use practices and urban development. Three main types of centennial tidal marshes can be found within the Petaluma River Baylands: **fringing overwash wetlands, fringing infill wetlands, and reverted wetlands.**

Fringing overwash wetlands at the mouth of the Petaluma River. Photo: Robert Janover, 2019. Courtesy Sonoma Land Trust.

Fringing overwash wetlands are formed by deposition of inorganic sediment and organic debris by currents and wind-waves. This type of wetland tends to exist high in the intertidal zone, lacks extensive tidal channel networks, and tends to retain tidal and wave-driven flood waters. Fringing overwash wetlands can be found at the mouth of the Petaluma River along San Pablo Bay.

Fringing infill wetlands are narrow, linear wetlands that formed along tidal channels between reclamation levees as the channels shoaled and narrowed in response to diking and draining of the floodplain. As these channels have equilibrated to decreases in tidal prism, their fringing infill wetlands have matured, with high marsh plains and dense networks of parallel channels sloping toward the main channel. The tidal marsh found between berms along the Petaluma River channel (e.g. along the river in the Burdell, Lakeville, and Bahia subunits) is considered fringing infill wetland.

Fringing infill wetlands along the Petaluma River in the Lakeville subunit. Photo: Robert Janover, 2019. Courtesy Sonoma Land Trust.

Reverted wetlands exist where tidal action has been restored to formerly reclaimed millennial wetlands due to unplanned levee failures (as opposed to planned restoration projects). Many reverted wetlands are older centennial marshes and can resemble millennial wetlands, with dense dendritic channel networks that serve broad, high-elevation marsh plains. In the Petaluma River Baylands, reverted wetlands exist along San Antonio Creek south of Neils Island and at Gray's Ranch.

Reverted wetlands south of Neils Island with dikes visible but breached (2002). Image courtesy Google Earth.

New tidal marshes are generally immature, low-elevation marshes at the early stages of evolution. These new tidal marshes are often found at recent marsh restoration projects. They can also be found along prograding shorelines where sediments have naturally accumulated to elevations high enough to support colonization by wetland vegetation, and in areas along the tidal-terrestrial transition zone where tidal wetland habitats have prograded over adjacent terrestrial habitats due to sea-level rise. Characteristics of new tidal wetlands most often include extensive subtidal and/or intertidal mudflats, an immature tidal channel network, a general lack of high tide refugia (unless these features are included as part of the restoration design), and vegetation dominated by low marsh species such as Pacific cordgrass. New tidal marshes within the study area include the restoration projects like the Petaluma Marsh Expansion, Bahia and Sears Point (aka Dickson Unit) (Figure 2.1).


New tidal marsh at the Sonoma Baylands restoration. Photo: Robert Janover, 2019. Courtesy Sonoma Land Trust.

Tidal-terrestrial transition zone

The historical landscape featured abundant transition zones between habitat types like grassy hillsides, patches of grassland, oak savanna, and high tidal marsh (Collins et al 2007). Today, much of the area at transition zone elevation is on levees, which can provide ecological value for some species but does not replace all the functions of the historical transition zone habitat (Collins et al. 2007). Transition zone habitat on these artificial features is usually disturbed by occasional maintenance and/or human travel along the tops of levees, and habitat on levees is usually dominated by nonnative vegetation. Although it is rare for dikes to be managed for natural marsh edge conditions, they are now standard components of marsh restoration projects, such as at the Sears Point Tidal Wetlands Restoration Project along San Pablo Bay. California Ridgway's rail, California black rail, and northern salt marsh harvest mouse, along with other marsh wildlife species, depend on this high-tide refuge habitat on the marsh edge (Baye 2008).

While many of the baylands have been cut off from upland habitat by levees, roads, development, and agriculture, the Petaluma River retains some of the Bay's best remaining opportunities to enhance and restore natural transition zone connections (i.e. not on levees). San Antonio Creek, the largest subwatershed of the larger Petaluma River watershed, is one such opportunity on the west shore. Numerous small, unnamed tributary streams on the east shore also have strong potential for restoration as riparian corridor transition zones connected to baylands habitat.

Protecting undeveloped tidal-terrestrial transition zone habitat is one of the best ways to increase resilience of bayland habitats to rising sea levels. If marshes are allowed to naturally adapt by migrating upslope, they have a much greater chance of persistence. Without upland migration opportunities, tidal marshes are subject to drowning and reduced habitat diversity as high marshes convert to low marsh and mudflat over time.

Non-tidal wetlands

Land use changes have resulted in major transformations to non-tidal wetlands throughout the watershed. Wet meadow and vernal pool complexes have declined by 98% and 95% respectively; today, small remnants of wet meadow exist in a number of locations throughout the watershed, particularly along San Antonio Creek within the study area (Baumgarten et al. 2018). Small remnants of vernal pool complex still exist on the valley floor just west of Adobe Creek and near Willow Brook Creek (Baumgarten et al. 2018). Small unnamed tributary streams noted above as likely locations for restoration of transition zones may also be appropriate for restoration of non-tidal wetlands. Seasonal wetlands exist in diked baylands that were formerly tidal wetlands (e.g. at the Burdell Unit).

Muted tidal wetlands

Muted tidal wetlands are managed wetlands where a portion of the total tidal range is allowed to flow in and out, controlled by tide gates or other water control structures. Muted tidal wetlands exist in the study area at the Rush Creek Marsh (230 acres) and Cemetery Marsh (50 acres) in the Bahia subunit (Figure 2.1). Rush Creek Marsh (along Highway 101) is owned and managed by CDFW and is known as the Rush Creek Unit of the Petaluma Marsh Wildlife Area. The Rush Creek Unit drains Rush Creek on the south end and Basalt Creek on the north end. Cemetery Marsh is part of the Rush Creek Open Space Preserve, owned and managed by the Marin County Open Space District. Water circulation was historically a management issue in these marshes, leading to poor water quality and degraded habitat. To address this issue, a 1999 project led by Marin Audubon improved one tide gate, excavated new channels, and replaced culverts (CDM 2000). However, management issues caused by damaged and difficult-to-operate tide gates have continued. Today, only one 24-inch pipe is functioning to drain the Rush Creek Unit and Cemetery Marsh (K. Taylor, pers. comm., Sept. 2022). This creates habitat quality and flood control challenges. During storm events, floodwaters back up from Rush Creek Marsh into Rush Creek and then flood into Novato neighborhoods on either side of Highway 101.

Diked baylands converted for agriculture

Agriculture has been critical to maintaining the rural character of Sonoma County and to protecting the baylands from intensive development. Many of the strategies proposed in this document are only possible because of the agricultural heritage and continued agriculture in this region. Marsh was converted to diked baylands starting in the early 19th and continuing through the mid 20th century, with parcels drained and levees constructed for agricultural production (Baumgarten et al. 2018). Historically, these converted lands were used to grow oats, hay, barley, and beets, and for dairying (Baumgarten et al. 2018). Today, oat hay production, grazing, and vineyards are the most common agricultural uses within the diked baylands. Vineyards are becoming more widespread in the watershed (SRCD 2022). Some diked baylands (e.g. the Burdell unit) are no longer used for agriculture and are managed for seasonal wetland habitat.

Most diked agricultural baylands have subsided several feet relative to surrounding marshes. Consequently, stormwater must be pumped over levees into the Petaluma River or San Pablo Bay to prevent flooding. Pumping needs will increase as groundwater levels rise with sea-level rise and more intense storms associated with climate change become more frequent. The levees surrounding diked baylands, which protect agricultural lands, State Route 37 and the railroad, are not certified flood risk management levees but rather earthen berms privately maintained with permits from public agencies (SRCD 2022). Although public infrastructure relies on functioning stormwater pumps and levees, the cost of this activity is borne by landowners alone. The failure of similar berms along Novato Creek and the resultant flooding of State Route 37 in recent years illustrates the vulnerability of major infrastructure to flooding.

2.6 Species

Tidal marsh habitats, adjacent upland transition zones and uplands, and riparian zones support myriad plant and wildlife species. Agricultural lands support some wildlife, and also may support vernal pool and seasonal wetland plant species, but have lower abundance and diversity of native species than tidally influenced habitats and unperturbed non-tidal wetlands.

Plants

Marshes in this region support a variety of native plant species, including pickleweed *(Sarcocornia pacifica),* Pacific cordgrass *(Spartina foliosa)*, alkali bulrush (*Bolboschoenus maritimus*) , and saltgrass (*Distichlis spicata)* (CDFW 2019). A remnant population of soft bird's beak (*Chloropyron molle* ssp. *molle*), listed as endangered at the federal level and rare at the state level, also exists in the Petaluma River Baylands (Goals Project 2015). As in other marshes in the region, invasive perennial pepperweed (*Lepidium latifolium*) and invasive *Spartina* species (*S. alterniflora* x *S. foliosa*, *S. anglica*, *S. densiflora*, and *S. patens*) pose challenges to the longevity of native vegetation.

The transition zones between tidal marsh and upland habitat usually have the highest diversity of native plant species (Baye et al. 2000). Many wildlife species, including listed species, require adequate flood refuge habitat (escape habitat during periods of high water to avoid drowning) adjacent to tidal marsh (Goals Project 1999, Goals Project 2015). Native plant species of concern (e.g. soft bird's beak) inhabit this high-tide refuge zone and are threatened by invasive weeds (e.g. perennial pepperweed) (Baye 2008).

Wildlife

The marshes of the Petaluma River support California Ridgway's rail (*Rallus obsoletus obsoletus)*, California black rail (*Laterallus jamaicensis coturniculus*), and northern salt marsh harvest mouse (*Reithrodontomys raviventris halicoetes*) (U.S. Fish and Wildlife Service 2013; SRCD 2022). The California Ridgway's rail is listed as endangered at both the state and federal level, as is the northern salt marsh harvest mouse. The California black rail is listed as a species of concern at the federal level and a threatened species at the state level. The ancient Petaluma Marsh and Sonoma Baylands are among the important habitat areas for these threatened and endangered species (U.S. Fish and Wildlife Service 2013; SRCD 2022, Baumgarten et al. 2018).

In addition to the listed species (California Ridgway's rail and California black rail), the Petaluma River Baylands provide important habitat to many other bird species, including waterfowl, shorebirds, songbirds, and raptors. Golden eagle *(Aquila chrysaetos)*, prairie falcon (*Falco mexicanus)*, northern harrier *(Circus cyaneus)*, white-tailed kite (*Elanus leucurus)*, short-eared owl (*Asio flammeus)*, and salt marsh song sparrow (*Melospiza melodia samuelis*) are a few examples (SRCD 2022). Black John Slough and the Bahia restoration area are particularly important habitat areas for both Ridgway's and black rail (Goals Project 2015). The restored lagoons at Bahia as well as other areas provide habitat for bay ducks, diving ducks, wading birds, and shorebirds (U.S. Fish and Wildlife Service 2013; Goals Project 2015).

Modeled tidal marsh bird abundance and density for existing conditions (Stralberg et al. 2011) in each Petaluma River subunit is shown in Table 2.3 and Supplemental Figures F-5 and F-6. The values are the estimated number of individuals of each species within each subunit based on data collected from marshes throughout the estuary including those along the Petaluma River and correlations with GIS layers of environmental conditions.

Table 2.3. Modeled marsh bird abundance for each subunit (Stralberg et al. 2011)

Subunit name	Black rail	California Ridgway's rail	Common yellowthroat	Marsh wren	Song sparrow
Ancient Marsh	1515	50	367	2316	9910
Bahia	126	7	155	622	2151
Burdell	129	6	146	343	1688
City of Petaluma - South	51	8	2	170	751

False Bay	18	2	14	125	395
Haystack	49	1	7	134	422
Lakeville	66	5	8	58	827
San Pablo Bay	1	12	0	69	2292

The Petaluma River watershed is home to at least 25 species of fish, 12 of which are native species (SRCD 2022). Native Central California Coast steelhead (*Oncorhynchus mykiss irideus*) runs exist in the mainstem Petaluma River and tributaries (Goals Project 2015). In recent years, Adobe and Lynch Creeks have had the most steelhead observations among Petaluma River tributaries (NMFS 2016). Lichau, San Antonio, Willow Brook, and Thompson creeks (also tributaries to the Petaluma River) are thought to have supported the spawning and rearing of steelhead in the past (NMFS 2016). Green sturgeon (*Acipenser medirostris*), another listed species, migrate through San Pablo Bay on the way to spawning areas in the Sacramento River and may occur near the mouth of the Petaluma River. Local fishing reports state that the top species to catch in the Petaluma River are striped bass (*Morone saxatilis)*, leopard shark *(Triakis semifasciata)*, bat ray *(Myliobatis californica)*, white sturgeon (*Acipenser transmontanus)*, rainbow trout (*Oncorhynchus mykiss)*, sevengill shark *(Notorynchus cepedianus)*, spotted eagle ray *(Aetobatus narinari)* and largemouth bass *(Micropterus salmoides)*. Striped bass, sturgeon (likely white), and bat rays were observed at the Sears Point Tidal Wetland Restoration Project (Figure 2) in 2016, soon after breaching the levee. Longfin smelt (*Spirinchus thaleichthys*) may also be found near the Petaluma River mouth as they are known to occupy the shoals of San Pablo Bay (USFWS, CDFG, and SLT 2012).

2.7 Protected lands and restoration projects

Within the study area, a total of nearly 9,000 acres are publicly owned or are in conservation ownership by CDFW, Marin County Open Space District, U.S. Fish and Wildlife Service, City of Petaluma, Sonoma Land Trust, Sonoma County Regional Parks, and California Department of Parks and Recreation (SRCD 2022) (Figure 2.6). Additional acreage is protected under conservation easements held by Sonoma County Agriculture and Open Space District and Sonoma Land Trust.

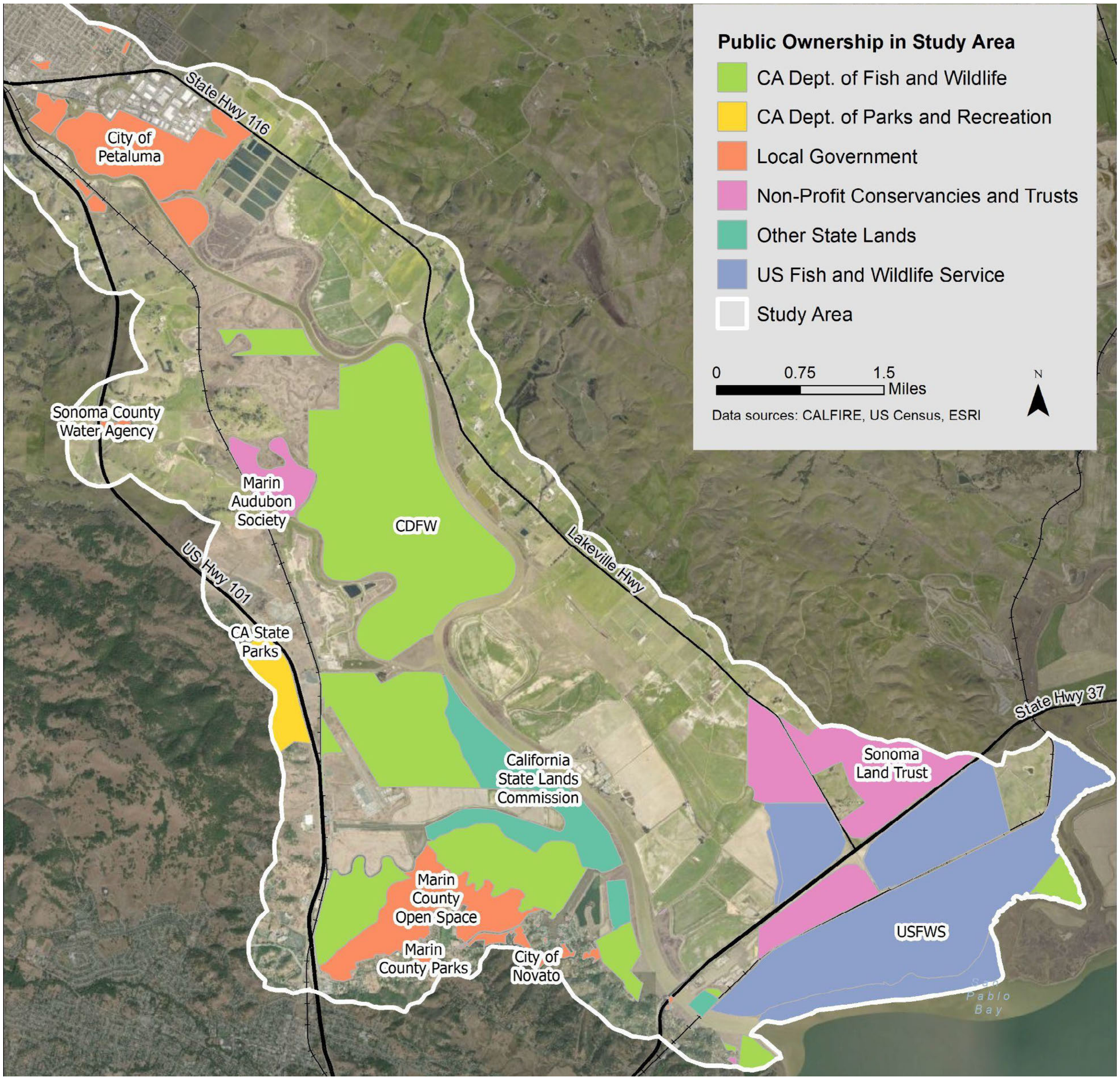

Figure 2.6. Publicly and privately owned protected lands within the study area. Conservation easements are not shown.

Tidal and non-tidal wetland restoration and protection projects are underway or completed at a number of sites in the Petaluma River Baylands. Key tidal marsh restorations include the 284-acre Petaluma Marsh Expansion project (2006), the 200-acre Bahia restoration (2008), the 45-acre Carl's Marsh restoration (1994), the 305-acre Sonoma Baylands restoration (1996), and the 970-acre Sears Point restoration (2015), which was renamed to the Dickson Unit of the San Pablo Bay National Wildlife Refuge upon transfer of the property from Sonoma Land Trust to USFWS. A complete list and figure of restoration and enhancement projects (including non-tidal marsh projects) compiled from EcoAtlas (CWMW 2019) is provided in Supplemental Table F-2 and Figure F-7.

Mitigation banks

Two privately owned mitigation banks exist or are under development in the watershed. Halo Ranch is a 186-acre bank in development located southwest of Lakeville Highway, about two miles southeast of the City of Petaluma. A proposal has been submitted to convert a hayfield to a mitigation bank for wetland and riverine habitat, including both tidal wetlands and seasonal wetlands (USACE 2018). Mitigation banking is underway at the approved Burdell Ranch Wetland Mitigation Bank, where 24 acres of seasonal wetlands were created. Additional banks have been discussed.

2.8 Road and rail

Transportation infrastructure represents the greatest constraint to restoration and resilience in the Petaluma River Baylands. Highway 101 and the SMART railroad line run along the western edge of the Petaluma River Baylands while SMART and State Route 37 run through much of the southern portion. State Route 116 and Lakeville Road (commonly referred to as Lakeville Highway) traverse the eastern edge, occasionally passing through lower elevation areas of former marsh. Construction of these transportation corridors contributed to direct habitat loss and continues to interrupt hydrologic connections from watersheds to the baylands.

Significant portions of this infrastructure are dependent on an aging system of levees and stormwater pumps that are largely maintained and operated by private landowners at their own expense. During the winters of 2016/17 and 2018/19, a section of State Route 37 in the adjacent Novato Creek baylands experienced significant flooding resulting in prolonged road closures that forced commuters to find alternative routes. Such extreme flooding from the combined effects of storm events and sea-level rise will become increasingly frequent in decades to come (State Route 37 – Baylands Group 2017).

State Route 37

State Route 37 is a key transportation corridor connecting Vallejo in the east to Novato in the west. It runs along the southern edge of the study area, bisecting lands owned by Sonoma Land Trust, CDFW, and the San Pablo Bay National Wildlife Refuge (Dickson Unit, North Parcel, Leonard Ranch), as well as private lands. The roadway is low-lying and highly vulnerable to flooding and sea-level rise. Nine of the top fifteen highway segments ranked as climate change adaptation priorities for Caltrans District 4 (Bay Area) are on State Route 37 (Caltrans 2020).

Both State Route 37 and the East-West SMART rail line separate restoring habitats at Sonoma Baylands and Dickson Unit (Sears Point) from the adjacent Petaluma baylands, limiting hydrologic connectivity and tidal prism. The need to maintain the existing level of flood protection for State Route 37 presents a major constraint to restoration.

State Route 37 flooding and congestion relief planning efforts provide a historic opportunity to reconnect the baylands to the Bay. A collaborative effort between transportation agencies and conservation organizations is well underway. Findings of two recent studies (MTC's Segment A Design Alternatives Assessment and Caltrans' Planning and Environmental Linkages Report) point to the solution of an elevated, piled causeway along the current alignment. If the road is raised on an elevated, piled causeway, and the adjacent rail line co-located on the causeway, the range of restoration alternatives that are possible is greatly expanded. The causeway would allow more tidal prism through the Petaluma River crossing and enable hydrologic connectivity between existing and future tidal and transitional habitats.

Raising State Route 37 on a piled causeway along its present alignment is the preferred alternative identified by the Caltrans Planning and Environmental Linkages (PEL) process (Caltrans 2022). After completion of the PEL, next steps include construction of an "interim" project focused on congestion relief (implementation anticipated approximately 2025) followed by construction of the "ultimate" causeway adaptation project (implementation anticipated approximately 2040). SMART has indicated interest in exploring the possibility of including freight and passenger rail as part of the overall transportation corridor improvement, combining highway and railroad right of ways on a causeway to allow removal of the existing railroad embankment (SMART 2022).

Petaluma River SMART rail and State Route 37 bridges. The current channel width of the Petaluma River under the State Route 37 bridge is 790 feet. Based on hydraulic geometry calculations, the channel width needed to restore all of the Petaluma River Baylands to tidal action is 2,220 feet (MTC 2022). Photo courtesy Sonoma Land Trust.

Lakeville Highway

Lakeville Highway[2] connects the City of Petaluma with State Route 37. Lakeville Highway runs along the eastern side of the Petaluma River Baylands and interrupts bayland-upland connectivity for much of its length. The southernmost 0.75 miles, terminating at the junction with State Route 37, is entirely within diked baylands and is vulnerable to flooding from storm surges and sea-level rise. This segment overtops at sea levels just two feet above today's high tide (per the ART Bay Area Flood Explorer). Adaptation strategies for this segment may involve raising it on a piled causeway in conjunction with the raising of State Route 37 . Multiple creeks pass under Lakeville Highway throughout its length, including Adobe Creek, Ellis Creek, and numerous small unnamed tributaries. To accommodate future sea-level rise, groundwater rise, and extreme precipitation events, these tributary crossings should be expanded to promote full hydrologic connectivity, and allow them to serve as migration corridors for marsh and terrestrial species. When sea levels rise to three feet and beyond, further adaptation of the roadway near Lakeville may also be required to prevent erosion and flood damage.

Highway 101

Highway 101 is a major interstate highway along the west coast of the United States. In the study area, it connects Novato to Petaluma. Highway 101 interrupts upland transition zone connectivity for over 10 miles along the western edge of the Petaluma River Baylands. Near Novato, it also creates a barrier to tidal connectivity and bayland migration from the Bahia subunit to the uplands. Father north, the bridge at San Antonio Creek limits flow from the watershed and traps woody debris. Stormwater currently impounds along the highway in multiple locations. These locations should be evaluated to determine where and whether they could be modified to allow for increased riverine and tidal flow under future climate conditions.

The roadway is vulnerable to flooding with climate change, and segments of Highway 101 within the study area have been identified as Priority 2 and Priority 3 adaptation segments by Caltrans District 4 (Caltrans 2020). The section of 101 west of the Bahia subunit is subject to overtopping at four feet above today's high tides (per the ART Bay Area Flood Explorer). Multidimensional flood modeling (including fluvial, coastal, and groundwater flooding) is needed to develop appropriate adaptation strategies for this area, including Rush Creek, Basalt Creek, Rush Creek Marsh, and Cemetery Marsh as well as Highway 101 and inland neighborhoods.

---

[2] Lakeville Highway (a state highway) becomes Lakeville Road (a county road) south of Stage Gulch Road. For the purpose of this report, we refer to its entire length as Lakeville Highway.

SMART Rail (East-West)

The East-West SMART rail line (aka the Brazos Junction Branch) connects the SMART North-South rail line in Novato to the Union Pacific Railroad (Capitol Corridor) in Fairfield. Active as a freight line today, there may be opportunities to develop passenger rail in the future to connect Marin County with the Capitol Corridor and/or the Vallejo Ferry Terminal (SMART 2022). Freight and passenger rail can reduce the number of trucks and cars on the road, so there is interest in expanding rail capacity in this area, especially given congestion issues on State Route 37.

As it exists today, the east-west SMART rail line is a primary barrier to habitat and hydrologic connectivity in the study area. Bisecting miles of diked baylands and current transition zone habitat, the low lying rail line is largely built on top of aging earthen embankments, with the exception of a trestle bridge at the mouth of the Petaluma River. The existing Petaluma River bridge is shorter than the State Route 37 bridge and may create a bottleneck to restoration by inhibiting the width of the channel (tidal prism and channel width will increase in the future as baylands are restored to tidal action).

Both State Route 37 and the rail line are at substantial risk of flooding if the unengineered earthen levees and stormwater pumps that are operated by private landowners fail; both road and rail have been damaged by flooding in the past (SMART 2022). When future flood protection costs exceed profits derived from agriculture or other means, these rail line segments will become increasingly vulnerable to flooding. Once flooding occurs, it will be difficult to raise the tracks and may require much more expensive rebuilding.

Transportation planning discussions have included the possibility of developing an integrated multimodal transportation facility that would change the existing rail alignment and put both SMART rail and State Route 37 on a combined causeway across the Petaluma River Baylands between Novato and Sears Point (Caltrans 2022). Depending on landowner participation, this solution would allow reconnection of San Pablo Bay to newly restored marshes and adjacent uplands, and allow full hydrologic reconnection of the baylands by removing the impediment of the Petaluma River rail bridge. SMART has expressed interest in this potential adaptation project, which may facilitate expansion of freight and passenger rail service in addition to advancing flood protection and wetland restoration goals (SMART 2022).

SMART Rail (North-South)

The segment of North-South SMART rail line within the study area runs parallel to Highway 101 and connects Novato to Petaluma. Regular commuter trains on this corridor provide service between the Larkspur Ferry Terminal and Santa Rosa, with a planned northward expansion to Healdsburg and Cloverdale.

The rail line is vulnerable to flooding from sea-level rise and presents a barrier to tidal connectivity and freshwater flows from the watersheds. According to a 2014 vulnerability assessment (SMART 2014), there are four key segments of the North-South rail line in the study area that are vulnerable to tidal flooding within the next 50 years (considering a 100-year tide level in 2065): one near Mile Post 31 (Burdell subunit), two near Mile Post 32 (behind Redwood Landfill) and one near Mile Post 36 (Haystack subunit) (Figure 2.7). For reference, the sea-level rise projection used in this 2014 assessment was 1.8 feet by 2065, which falls slightly above the "Likely" range provided by the most recent state sea-level rise guidance (between the suggested values for projects with "low risk aversion" and "medium-high risk aversion") (CA OPC 2018). The assessment was focused on exposure to tidal flooding and did not consider combined flooding (including the potential for more intense rainfall events due to climate change) nor rising groundwater levels, both of which will also influence flood vulnerability of the rail line.

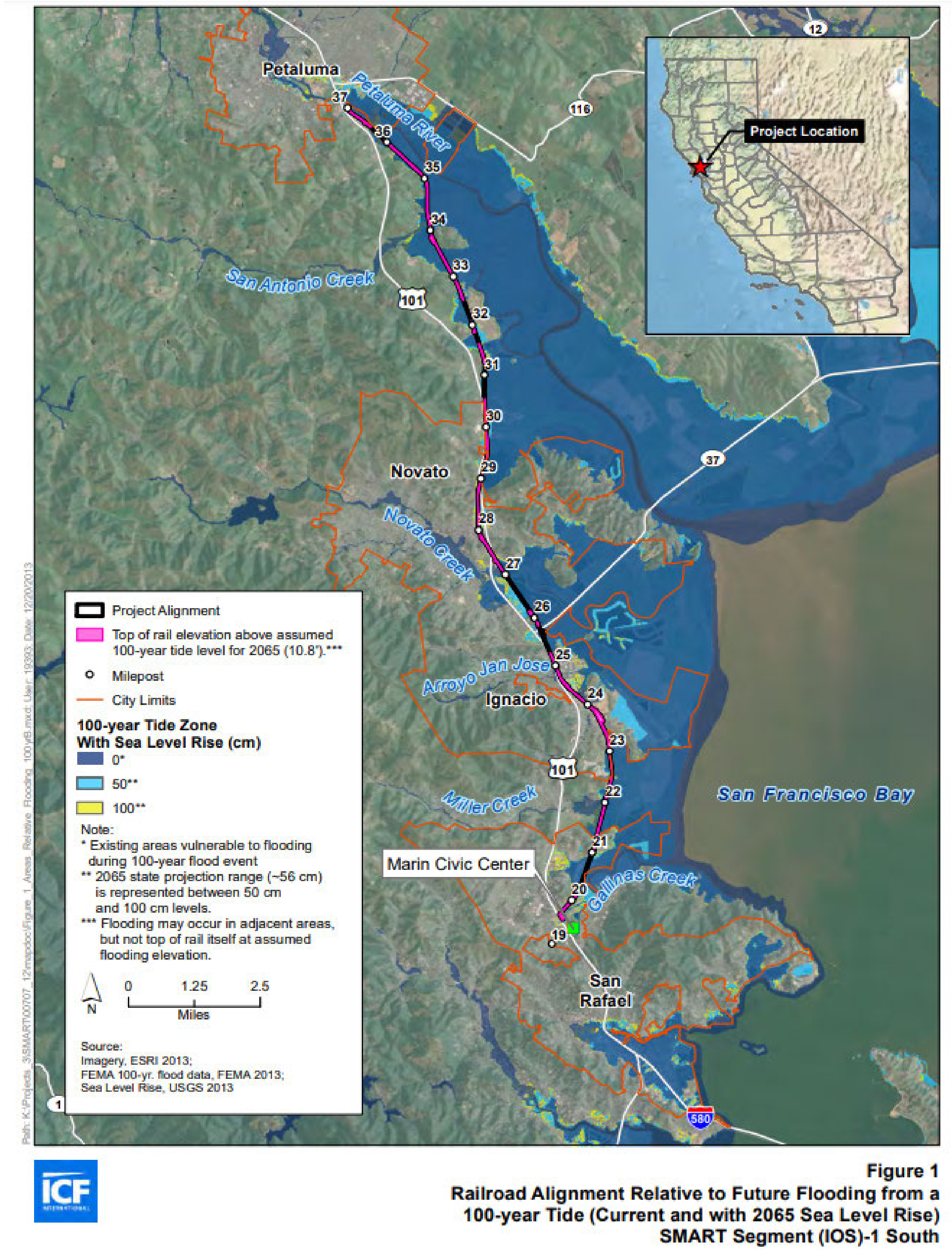

Figure 2.7. Exposure of North-South SMART line to flooding from sea-level rise. Figure 1 from SMART 2014.

The rail line constrains tidal flows, inhibiting habitat connectivity and future marsh migration as sea levels rise. Extreme tides (100 year tide level) may already be constrained at the bridge crossing at Mile Post 31.75 (behind Redwood Landfill) and at the crossing at Mile Post 35.56 (Haystack subunit). Extreme tides may be constrained in the future at other bridge crossings if they are not improved. These include potential constraints by 2040 at Schultz Slough (near Milepost 34) and by 2050 at the Petaluma River bridge (SMART 2014).

In the Burdell, Ancient Marsh and Haystack subunits, the north-south rail line is the primary barrier to upland marsh migration and watershed-bayland connectivity. What is considered an “extreme” tide today will occur with increasing frequency until eventually it becomes the level of the daily high tide. As this occurs, marshes can slowly begin to migrate inland and upland, but only if undersized culverts and bridges are enlarged and raised or the rail line is raised onto a causeway. These actions would increase the resilience of the railroad to flooding and the ability of tidal marshes to adapt to sea-level rise.

2.9 Other infrastructure

Gnoss Field

Also known as Marin County Airport, Gnoss Field is a small, regional, single-runway public airport located in subsided, diked baylands near the City of Novato in the Burdell subunit. The airport is operated by Marin County Department of Public Works and is primarily used by small jets and propeller-driven aircraft. The airport occupies 120 acres east of Highway 101, including an undeveloped runway safety area to the northwest of the runway. A proposal to extend the runway is currently under review by the Federal Aviation Administration (FAA). In 2016, the FAA recommended the originally proposed 1,100-foot runway extension be reduced, as only 300 feet were necessary (County of Marin 2016). The FAA’s current preferred alternative as of 2019 involves shifting the runway roughly 100 feet to the north and extending it 300 feet to the northwest. The proposed project also involves extending the levees and realigning drainages with impacts to about seven acres of wetlands (FAA 2019). Maintaining Gnoss Field in the subsided baylands requires pumping stormwater to keep the airport dry.

The airport runway is bordered by the diked seasonal wetlands of the Burdell Unit, owned and managed by CDFW. CDFW is currently evaluating alternatives to restore the site, including tidal wetland restoration, which would provide a net benefit to the airport by increasing resilience of surrounding lands and decreasing the amount of seasonal open water habitat, which would reduce the likelihood of bird strikes. The primary challenges to restoration are balancing stormwater management needs with tidal restoration and navigating the complexities associated with an existing seasonal wetland mitigation bank at the site.

The FAA will provide input on any actions that could increase risk of wildlife hazard and/or bird strike.

Redwood Landfill and Recycling Center

Redwood Landfill and Recycling Center, owned and operated by Waste Management, is located north of the Burdell Unit and east of Highway 101, between the ancient Petaluma Marsh and the SMART tracks. It is the primary landfill serving Marin County and occupies 420 acres, about half of which (222.5 acres) are dedicated to landfill. The remaining acreage of the site is used for recycling, reuse services and composting. The landfill is permitted as a Class III disposal facility for non-hazardous materials and is allowed to accept 2,310 tons of material each day (WM 2020). The landfill is projected to reach its 26.1 million cubic yard capacity around 2032 (R. Khany, pers. comm., February 2023).

Prior to its establishment in 1958, the landfill site was used for agriculture (San Francisco Bay Regional Water Quality Control Board 2009). In 2003, 180 acres of the landfill property were sold to Marin Audubon and restored to tidal wetlands. A 2005 Environmental Impact Report covered multiple updates to the landfill's permit conditions, including environmental controls like leachate management and the configuration of the perimeter levee (Redwood Landfill Solid Waste Facilities Permit Revision Final Supplemental EIR 2005).

Once the landfill is closed and capped, there may be opportunities for upland habitat restoration and park or other open space development. Ongoing management will be required to ensure surrounding habitats are protected from detrimental impacts from landfill leachate as sea levels rise.

Ellis Creek Water Recycling Facility

The Petaluma Department of Water Resources and Conservation opened the Ellis Creek Water Recycling Facility in 2009. Funds from the California Coastal Conservancy and the Sonoma County Agricultural Preservation and Open Space District were used to purchase the site, which doubles as a wildlife sanctuary (Petaluma Wetlands Alliance 2019). Sonoma County Agricultural Preservation and Open Space District holds an easement over much of the site.

The plant is located southwest of the City of Petaluma on Lakeville Highway in the Lakeville subunit. The treatment facility occupies 90 acres of a 270 acre site and includes 30 acres of "polishing wetlands," which use natural processes to perform a final step in the water purification process (Petaluma Wetlands Alliance 2019). The 2,200 million gallons of recycled water the plant produces each year irrigate agricultural land, golf courses, and parks in the summer and effluent is discharged to the Petaluma River in the winter (Water Technology 2020). Petaluma may be looking for alternatives to winter discharge such as expanded irrigation or expanding municipal recycled water use.

The water recycling facility site contains seasonal wetlands and tidal marsh along the Petaluma River, downslope from the polishing wetlands. The tidal marsh developed following an unplanned and gradual breach of the outboard levee that began around 1999. Ellis Creek, a tributary to the Petaluma River, runs between the polishing ponds and other treatment ponds onsite.

There are several miles of publicly accessible trails on site, including a trail that connects to nearby Shollenberger Park. The trails offer excellent opportunities for viewing birds and other wildlife.

Quarry and asphalt plant

The Dutra Group (often referred to as Dutra) comprises three companies: Dutra Dredging, Dutra Marine Construction, and Dutra Materials. Dutra supplies aggregate in Northern California, with quarries, plants, and distribution centers across the nation. In addition to the San Rafael Rock Quarry and Richmond Plant, Dutra plans to build an asphalt plant along the Petaluma River. The diked and cleared bayland property is along the western bank of the Petaluma River just north of the Petaluma city limits in the Haystack subunit. The proposed 38-acre asphalt plant would be constructed directly across from Shollenberger Park and wetlands.

Dutra Materials Haystack Landing project is advertised as a benefit to the community at-large by including wetland restoration and enhancement for economic and climate resilience in the Petaluma Watershed. It is unclear what the restoration component of Dutra's proposed actions will entail, as communication attempts with Dutra representatives during the public outreach for this document were unsuccessful.

The operation as planned will require ongoing dredging of the Petaluma River to provide access for large barges. The proposed construction and operation of the asphalt plant is strongly opposed by some members of the community due to concerns about air quality, habitat degradation, barge access near delicate ecological areas, contaminants, increase in noise pollution, discharge violations, and overall health risk from carcinogens to the nearby community.

Port Sonoma Marina

Port Sonoma Marina is located on the east bank of the Petaluma River where it meets San Pablo Bay. It is an area of high sediment supply and was historically dredged on an annual basis to maintain operations. It is now listed as permanently closed and continues to accrete sediment. Some of the remaining infrastructure includes buildings, mooring infrastructure with vessels, a fueling station, pavement, and elevated fields of dried dredge spoils. If the owners were interested in restoring the site, additional study would be needed to determine whether there are contaminants from paint, petroleum products, or other sources, and remaining infrastructure and vessels would need to be removed.

The Marina borders the south side of State Route 37 and the highway is raised along much of its northern boundary. Restoration would provide an opportunity for greater tidal exchange and more continuous marsh connectivity between the San Pablo Bay and False Bay subunits. The high dredge spoil areas could provide transition zone and upland habitat if left in place or could be used in shoreline erosion rehabilitation projects, as was done at the 2021 Sears Point Levee Adaptive Management Project (Sonoma Land Trust 2022).

Additional considerations

North of Black John Slough and east of Gnoss Field in the Burdell subunit are four radio towers operated by KCBS-AM San Francisco. These towers are located on a diked peninsula surrounded by fringing marsh. Each tower is approximately 500 feet (150 meters) tall.

Pacific Gas & Electric Company transmission lines and gas pipelines run through the study area. Restoration constraints associated with the ongoing need to access and maintain this infrastructure would be addressed during site-specific restoration planning.

2.10 Public access

Plans for public access in the study area can be found in several existing documents including the Sonoma County Bicycle and Pedestrian Plan (Sonoma County 2010), and the San Francisco Bay Trail and San Francisco Water Trail websites (MTC 2023). Some of these plans have already been partially implemented.

Existing Land Access

Located near Highway 101 and the City of Petaluma, the most popular access point in the study area is the seven-mile complex of trails that travel around and through Shollenberger Park, Alman Marsh and the Ellis Creek Water Recycling Facility. These trails offer excellent opportunities for hiking, strolling and birdwatching, among other activities.

At the southern end of the study area in the San Pablo Bay National Wildlife Refuge, the Bay Trail and other spur trails offer more than five miles of trails overlooking developing marshes at Dickson Unit (Sears Point) and Sonoma Baylands and through diked agricultural baylands.

In the southwest portion of the river near Novato, Marin County Parks owns and manages the 522-acre Rush Creek Preserve, which provides nearly seven miles of trails adjacent to wetlands and forested hillsides.

Existing Water Access

There are three areas to launch watercraft along the river. With careful attention to the tides and to winds, boaters can access the entire river.

The City of Petaluma operates the Marina and Turning Basin next to the Sheraton Hotel at Highway 101 just south of Petaluma.

Lakeville Landing Marina is a privately operated boat launch located off Lakeville Highway across from Tolay Lake Regional Park.

On the west side of the river near the confluence with the bay is the Black Point Boat Launch, operated by Sonoma County Regional Parks.

Future Access

There is increasing enthusiasm for more access to the Petaluma River, particularly in the area around the City of Petaluma, outside of the study area. Various groups including the City of Petaluma, the Friends of the Petaluma River, Petaluma River Park, and others are planning new parks and trails.

On the lower river, Sonoma County Regional Parks and the Water Trail are exploring possibilities for new access points and potential overnight destinations accessible only by boat. It cannot be overstated that public access must consider the sensitivity of ecological resources when considering new access points. For example, the Ancient Marsh is intact and supports rare and threatened species in large part because access is difficult. Few refuges exist for these species in the San Francisco Bay Estuary, and the Ancient Marsh is unique among them because of its age, condition, and projected resilience into the future. Detailed analyses of the compatibility of recreation in such areas is paramount, perhaps most critically for increased access in the vicinity of Ancient Marsh.

Nonetheless, future access considerations are important components of restoration projects. While recreation and conservation are not always compatible, there are many examples of compatible uses. Restoration planning has tended to consider public access after restoration designs are in place. This has created tension with public access planners, who would like access designs to be considered earlier in the planning process.

To balance these public needs and benefits, future projects should consider the possibility, type, and adaptability of public access at the outset of project planning, and throughout the planning process. Adaptability is mentioned because public access may be possible in early stages of marsh restoration and then become increasingly difficult, as is the case at the Dickson Unit (Sears Point). There, project designers included a kayak launch, which became a Water Trail access point. However, rapid accretion of sediment, a mark of success for marsh restoration, has recently made kayaking nearly impossible, except on the highest tides. As the marsh fills with vegetation in the years and decades to come, kayaking will no longer be possible. Dickson Unit (Sears Point) also includes a long segment of the Bay Trail on its levee. While this is a premier site to overlook the developing marsh, it is possible that if and when SR 37 is raised, there may be an opportunity to breach this levee. New access points will need to be discussed at that time.

The critical point is that flexibility to move with changing conditions must be a component of any and all future access, including a shared understanding that access may be temporary in some locations and incompatible with sensitive ecological resources in others.

Public Access Guiding Principles

In consideration of these and other factors, we offer several guiding principles to assist with future projects.

- Options for public access should be considered early in the project design.
- Before access is included in site design, attempt to ensure that resources, including funding and the entity responsible for the design, construction, maintenance, law enforcement and ownership of the access facility, have been identified to the extent feasible.
- Build trails from natural materials that may deteriorate with sea-level rise, flooding, and inundation without harm to surrounding habitat.
- All access should be adaptable to ensure ongoing facility safety and maintenance. Facility safety and maintenance needs may change with anticipated changing landscape conditions.

2.11 Cultural resources

A Cultural Resources Report was prepared by Far Western Anthropological Research Group, Inc. (Far Western) in March 2023. Because the report contains confidential information about the locations and characteristics of archaeological sites and tribal cultural resources, the technical report is not included in this study for public review but can be made available to agencies and other professionals for review as necessary. The cultural study included a records search and archival review, outreach with Graton Rancheria, and a geoarchaeological site sensitivity assessment. No cultural resource survey nor other field identification efforts were conducted as part of this study.

Records Search and Archival Review

The records search was conducted on February 20, 2023, and included the entire Petaluma Baylands Study Area. The purpose of the records search is to identify previously recorded archaeological and tribal resources that have been documented within the Study Area. Cultural resources include prehistoric and historic-era archaeological sites and objects, as well as extant historic structures, buildings, and locations of important historic events or sites of traditional and/or cultural importance to various groups. This records search did not include review of built environment resources or searches of the California Department of Transportation (Caltrans) historic bridge inventory and the Office of Historic Preservation's (OHP) Built Environment Resources Directory (BERD).

The records search identified 428 previously conducted cultural resource studies within the Study Area. The records search identified 85 previously recorded archaeological resources within the Study Area: 49 of these resources are precontact, 30 date to the historic era, five contain both precontact and historic-era components, and one site contains precontact, protohistoric, and historic-era components.

Precontact resources recorded within the Study Area include shell midden and shellmound sites, most located along the bay margin and at confluences of freshwater sources and marsh, and bedrock mortars, most commonly along ridges and hillsides containing bedrock outcrops. Many of these precontact resources also contain associated artifact assemblages, such as shell beads, flaked stone tools and lithic debitage, charmstones, marine shell, and faunal remains. It is not uncommon for precontact midden and shellmound sites to contain human burials. Historic-era resources recorded within the Study Area include structural remains associated with ranching and homesteading, roads and railroad grades, and other abandoned infrastructure. Some of these historic-era resources also contain associated artifact assemblages, including domestic refuse scatters or privies containing materials such as bottles, cans, and ceramics, and structural debris including brick, milled lumber, and structural hardware. Several sites identified within the Study Area contain a combination of precontact and historic-era features and deposits as described above.

A search of the following inventories: National Register of Historic Places (National Register), California Register of Historical Resources (California Register), California Historic Landmarks, and California Points of Historical Interest identified 10 listed historic properties or historical resources within the Study Area. Historic properties are cultural resources that have been nominated and listed to the National Register, and historical resources are cultural resources that have been nominated and listed to the California Register. Properties listed on these registers include buildings, structures, sites, objects, and districts that are considered historically significant and meet certain criteria that deem them eligible for preservation.

The following resources are listed on both the National and California Registers. All of these resources are in the study area but are located within the City of Petaluma North subunit, which was not analyzed for this report.

- Petaluma Historic Commercial District (Petaluma),
- Old Petaluma Opera House (147-149 Kentucky Street, Petaluma),
- Philip Sweed House (301 Keokuk Street, Petaluma),
- Ellis Martin House (1197 E. Washington Street, Petaluma),
- Petaluma Silk Mill (420 Jefferson Street, Petaluma),
- U.S. Post Office Petaluma (120 4th Street, Petaluma),
- Free Public Library of Petaluma (20 4th Street, Petaluma), and
- Fashion Shop and Stephen Porcella House (800 Grant Avenue and 1009 Reichert Avenue, Novato), (National Register 2022; OHP 2022b).

Two additional resources within the Study Area are only listed on the California Register: Rancho Olompali and the Camilo Ynitia Adobe (California Historical Landmark No. 210), both located in Olompali State Historic Park in Novato (OHP 2022a, 2022b).

Far Western reviewed online historical maps and aerial photographs depicting features such as roads, buildings, other structures and infrastructure, and waterways. The objectives of this archival review were to generally reconstruct the history of land use within the Study Area and to provide additional information regarding the potential for the presence of historic-era resources. Historical maps and photographs were reviewed at several online repositories, in particular the US Geological Survey (USGS) repository, National Oceanic and Atmospheric Administration (NOAA) Historical Shoreline Surveys, the David Rumsey Map Collection, and Digital Collections of the Bancroft Library, among others. The Cultural Resources Report discusses major historical themes and anticipated historic-era resource types that may be unrecorded within the Study Area.

Geoarchaeological Analysis

The following discussion details the methods for assessing potential for buried and submerged archaeological sites. The ability to locate buried and submerged sites generally depends on whether or not sensitive landforms are adequately explored using appropriate methods and research strategies. This can be an especially difficult problem where archaeological sites are buried by natural sediments, submerged by sea level rise and historical-modern waterway manipulation, and/or covered by artificial deposits or structures (e.g., fill, levees, roads, buildings).

The challenge of identifying buried sites can be effectively and efficiently managed to comply with existing regulatory frameworks and mandates when an informed and integrated "good faith" approach is properly implemented. Early site detection helps alleviate or prevent costly delays that often occur when unknown resources are discovered after earth moving has begun and late discovery protocols are necessary, particularly if human remains are present. This can help to ensure that project budgets and schedules (i.e., critical path) are not inadvertently affected by late archaeological discoveries, especially where deep and/or extensive earth-disturbances will occur in sensitive landforms. As an added benefit, these studies allow planners, archaeologists, and resource managers to better account for the full archaeological record, and thereby acknowledge the importance of the human past and its inherent value for others.

The geoarchaeological analysis indicates that the potential for buried and submerged sites is Highest or High in approximately 31 percent of the Study Area, Moderate in 30.6 percent of the Study Area, Low in 14 percent of the Study Area, and Lowest in the remaining 24.3 percent of the Study Area. A detailed discussion including maps and sensitivity modeling is provided in the Cultural Resources technical report.

Chapter 3: Future conditions

3.1 Sea-level rise

The most recent sea-level rise projections recommended for use in planning projects are provided in the State of California Sea-Level Rise Guidance (2018 update) (CA OPC 2018). The guidance provides probabilistic decadal projections of sea-level rise, with respect to a baseline from the year 2000, based on high and low emission scenarios and location on the California coast. The recommended projections for San Francisco are shown in Figure 3.1. The "risk aversion" language allows project proponents to gauge which projection to use; for projects with low risk aversion, it is recommended to use the curve that is most likely to occur, while projects with high risk aversion should use the more conservative, higher projections even though they have a lower probability of occurrence. Projections used for the marsh evolution modeling in this report (Appendix D) are 1.9 feet in 2050 and 6.9 feet in 2100, in line with the medium-high risk aversion curve (blue) shown in Figure 3.1.

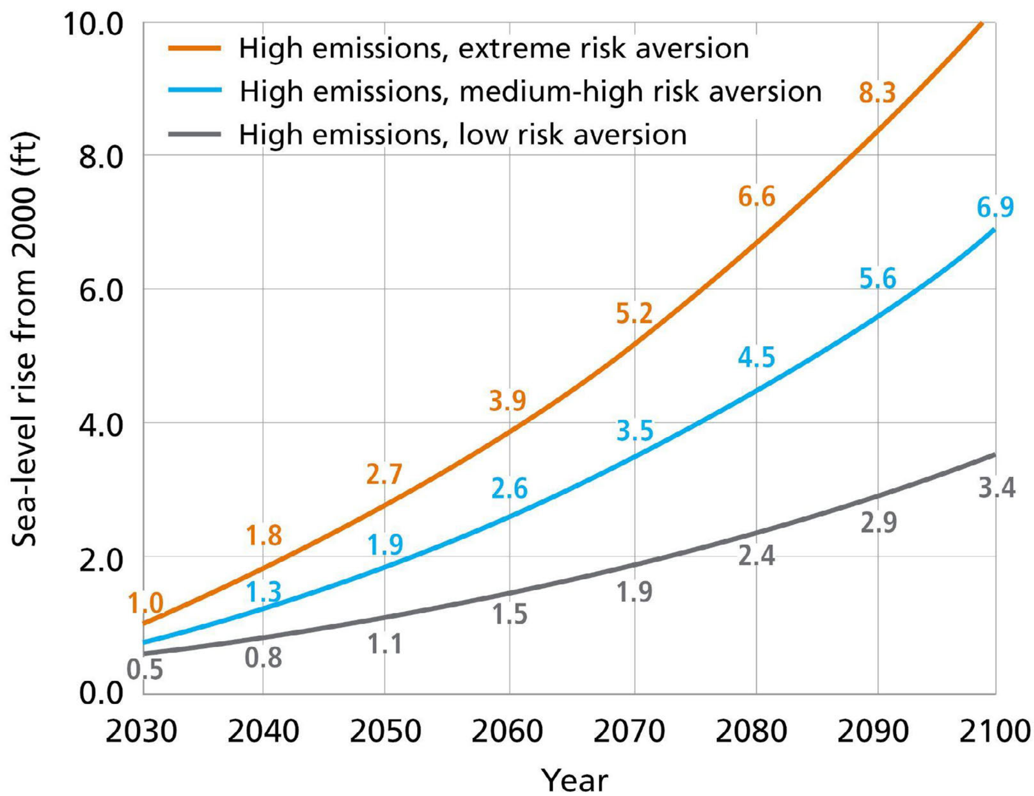

Figure 3.1. Projected sea-level rise (in feet) for San Francisco (adapted from Table 1, pg 18, CNRA-OPC 2018). All three curves shown on the chart are for a high-emissions scenario.

The San Francisco Bay Shoreline Flood Explorer (https://explorer.adaptingtorisingtides.org/home) provides visualizations of projected flooding and levee overtopping for various water levels. The tool also provides information about how these water levels correspond to projected flooding; for example, 24" above today's daily high tides corresponds to daily high tides with 24" sea-level rise (projected by 2050), but also corresponds to a 5-year storm surge with today's sea levels.

3.2 Future geomorphic changes

With significant sea-level rise projected in San Francisco Bay by 2100 under existing emissions trajectories (CA OPC 2018), both the marshes and the low-lying diked baylands of the Petaluma River will be vulnerable. Diked baylands are exposed to flooding from multiple sources: rainfall, runoff from watersheds, rising and emergent groundwater due to sea-level rise, and levee overtopping from coastal high water events. Marshes are also vulnerable, with increased frequency of inundation from higher sea levels likely to accelerate bank erosion and habitat conversion in tidal wetlands (Goals Project 2015). In addition to sea-level rise, climate change is projected to increase the frequency and severity of storm flooding, droughts and extreme weather events in the area (Cornwall et al. 2014). These changes will influence precipitation and streamflow patterns and vegetation distribution throughout the watershed.

Tidal marshes in the Petaluma watershed are expected to undergo varying responses to sea-level rise, depending on position within the sedimentation gradient along the Petaluma River, and initial topography (diked bayland or existing tidal marsh). The southern area, which is relatively richer in suspended sediment supply, is more likely to sustain fringing tidal marshes where they exist today, and support tidal marsh restoration that is currently in progress. This applies to those areas that experience full tidal exchange, as opposed to areas less directly connected to the Bay (for example, along Black John Slough). However, even in upstream areas, relatively high sediment loads from the Petaluma watershed mean that marshes have high potential to maintain elevation as sea levels rise.

The Ancient Marsh may be subject to bank erosion along the river, and expansion of pannes and low marsh within its marsh plain as tidal energy increases. Native species diversity may be lost as lower marsh zones expand and upper marsh zones contract. With little upland migration space, the Ancient Marsh is at risk of drowning with high rates of sea-level rise projected late in the century and beyond (Thorne et al. 2018). Reconnecting marshes to upland migration space is therefore a key objective of the Petaluma River Baylands Strategy.

3.3. Tidal marshes as an adaptation strategy

Tidal marshes, in conjunction with tidal flats, can mitigate flooding from storm surges, waves, and tidal currents through a combination of shoaling and friction effects. Marshes help reduce wave run-up on and erosion of levees, enabling landward seawalls or levees to be lower and reducing maintenance costs.

Reed et al. (2018) summarize the role of tidal marsh vegetation in flood risk management as:

- reduce direct wave action on unprotected structures during storms;
- reduce wave run-up and overtopping of flood risk management levees during storms, thus limiting flooding;
- reduce erosion of flood risk management levees during and between storms by attenuating waves to a size that does not cause damage;
- increase net sedimentation by creating more quiescent conditions on the marsh.

There are two ways marsh vegetation attenuates waves: directly, through vegetation-induced friction, and indirectly, by contributing biomass and trapping fine sediment to maintain the elevation of the marsh platform.

In some parts of the Petaluma River watershed, restoration projects will target reconnection to undeveloped marsh migration space and upland habitat. These efforts would likely be focused primarily on habitat preservation. In other places, marsh restoration and promotion of marsh migration may also yield additional benefits for the infrastructure and development behind levees by providing the flood risk management benefits described above.

Chapter 4: Findings

This chapter presents a summary of the landscape conditions in the study area, based on materials compiled for the existing conditions section, input from community members and technical advisors, and two additional sets of scientific analyses conducted for this effort. The two analyses were conducted to determine (1) the current geomorphic resilience of the Petaluma River Baylands to sea-level rise, and (2) their projected evolution as sea levels rise.

The first set of analyses focused on baylands resilience is described in more detail in Appendix C: Geomorphic Analysis. The analyses focused on metrics such as marsh elevation relative to the tides, elevation distribution within marshes, marsh vegetation coverage, and availability of marsh migration space. The appendix provides more detail about the methods used to develop the marsh and diked bayland resilience metrics as well as a more comprehensive set of figures and tables describing each metric and its application to the various subunits of the Petaluma River Baylands.

The second set of analyses focused on modeling bayland habitat evolution is described in more detail in Appendix D: Marsh Evolution. The model quantifies changes in elevation based on changes in sea level, assuming constant supplies of inorganic sediment and organic material from 2010 to 2100. The model does not account for other physical processes such as erosion. Additionally, sites are either prescribed as open or closed to tidal connection. Thus there is no variation assumed in the model regarding the extent of tidal flow to locations that are either near or far away from the Petaluma River or other tidal sources. The model allows us to make high-level predictions about the area of different habitat types in response to changes in sea level, both where marshes exist today and where marshes can move to in the future with upland migration or in response to restoration.

We focused the analysis methods and the summary provided here on two key factors identified in the project goals: conserving marshes and restoring diked baylands. The broad descriptions of each "condition" below are generalizations based on the results of the geomorphic resilience and marsh evolution models. These conditions helped guide the development of strategies to achieve the project goals. The conditions are not mutually exclusive, and many areas may exhibit overlapping conditions.

4.1 Condition 1: High marshes with high resilience

Some of the existing marshes of the Petaluma River are high elevation marshes that provide essential mid- and high- marsh habitat today. Areas of marsh with particularly high resilience according to the geomorphic and marsh evolution analyses exist at the Ancient Marsh, adjacent Gambinini Marsh in the Haystack subunit, and in the fringing marshes along the Petaluma River in the Burdell and Lakeville subunits. These marshes scored highly on several marsh resilience metrics, with high marsh plain elevations and substantial portions of marsh above mean high water elevation (Figure 4.1). According to the marsh evolution modeling we performed (Appendix D), these marshes are well-positioned to persist as sea levels rise; however, their resilience is limited by lack of migration space (Thorne et al. 2018). Our modeling indicates that marshes in the Petaluma baylands at mid-marsh elevation today are likely to accrete sediment rapidly, with the area of mid-marsh habitat increasing up until 1.9 feet of sea-level rise. The model also predicts that there is sufficient sediment to maintain that elevation throughout much of the century, with conversion to low marsh occurring when sea levels rise about five feet. These results are consistent with recent WARMER-2 modeling focused on marsh plant community transitions (Buffington et al. 2021). Plant communities in Petaluma marshes are unlikely to shift by 2100 under low sea-level rise scenarios. Under high sea-level rise scenarios, marshes are likely to transition to low marsh (cordgrass-dominated) by mid-century, and mudflat by 2100.

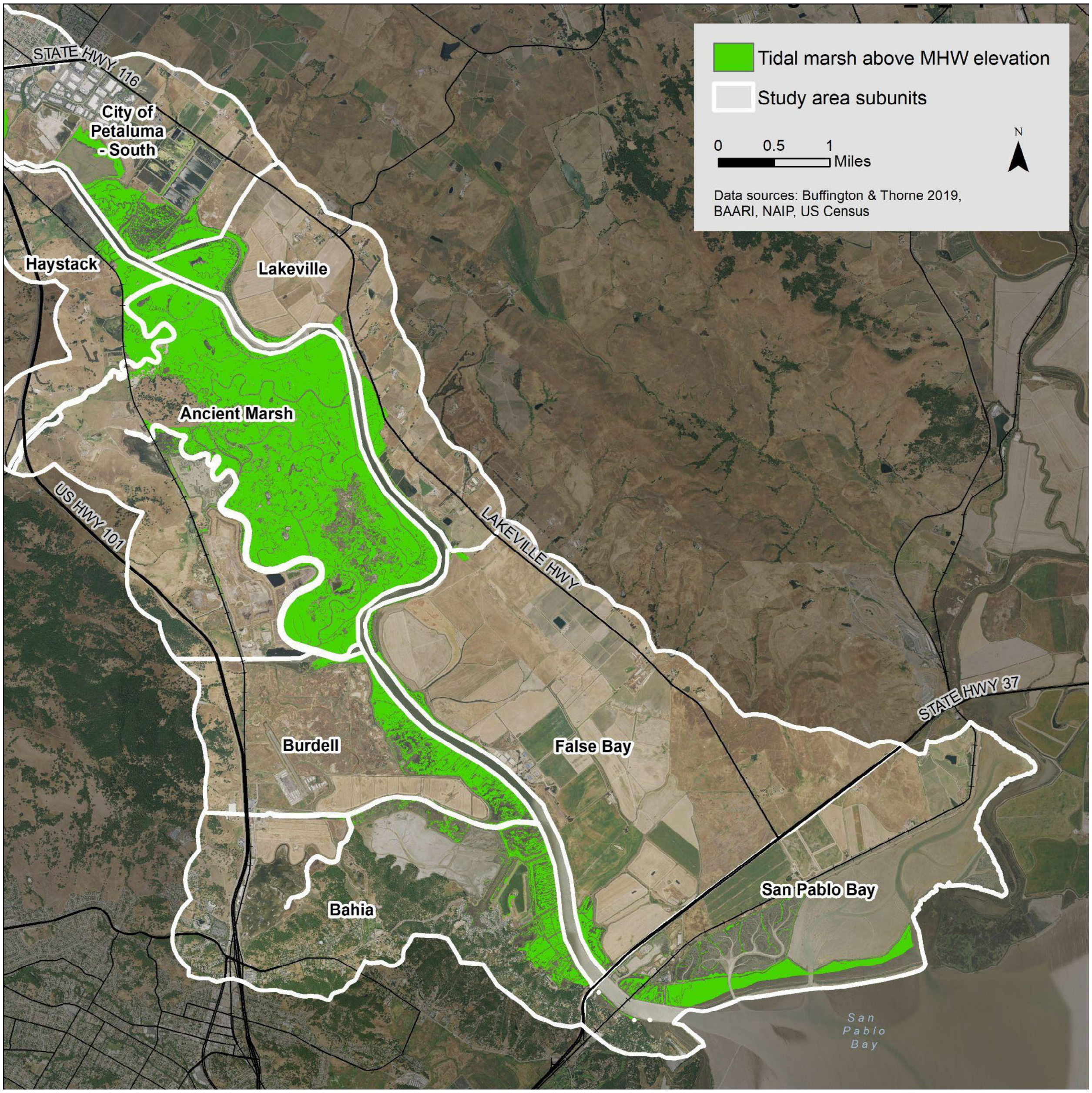

Figure 4.1. Existing tidal marshes with elevation above mean high water (MHW). Due to high initial elevation, these marshes are well-positioned to persist and continue building elevation as sea levels rise; however, at high rates of sea-level rise (projected for 2100 and beyond) they are likely to transition to low marsh and mudflat.

4.2 Condition 2: Restoring, low-elevation, tidally-connected areas

A number of restored future marshes in the Petaluma River Baylands are still in the process of rapidly accreting sediment and developing into tidal marshes. These newer restored marshes scored low for elevation and vegetation-based marsh resilience metrics, as they are still accreting and are still below marsh elevation at mudflat or subtidal levels. However, if the marsh resilience metrics were to be reanalyzed in the future, they likely would show rapid improvement as sediment accretes and vegetation establishes. The marsh evolution model indicates that these restorations, while below marsh elevation today, are likely to reach low to mid-marsh by mid-century, even with 1.9-2.6 ft of sea-level rise, and persist as low marsh through the end of the century. The model predicts that with 6.9 feet of sea-level rise there will be 1,100 acres of low marsh and 7 acres of mid marsh in these restoration sites. Examples of areas with this condition include the Ancient Marsh subunit (Petaluma Marsh Expansion and Restoration project), Bahia subunit (Bahia restoration), the City of Petaluma South subunit (Gray's Ranch), and the San Pablo Bay subunit (Sears Point and Sonoma Baylands[3] restorations) (Figure 4.2).

[3] Sonoma Baylands, restored to tidal action in 1995, has already reached low to mid-marsh elevation.

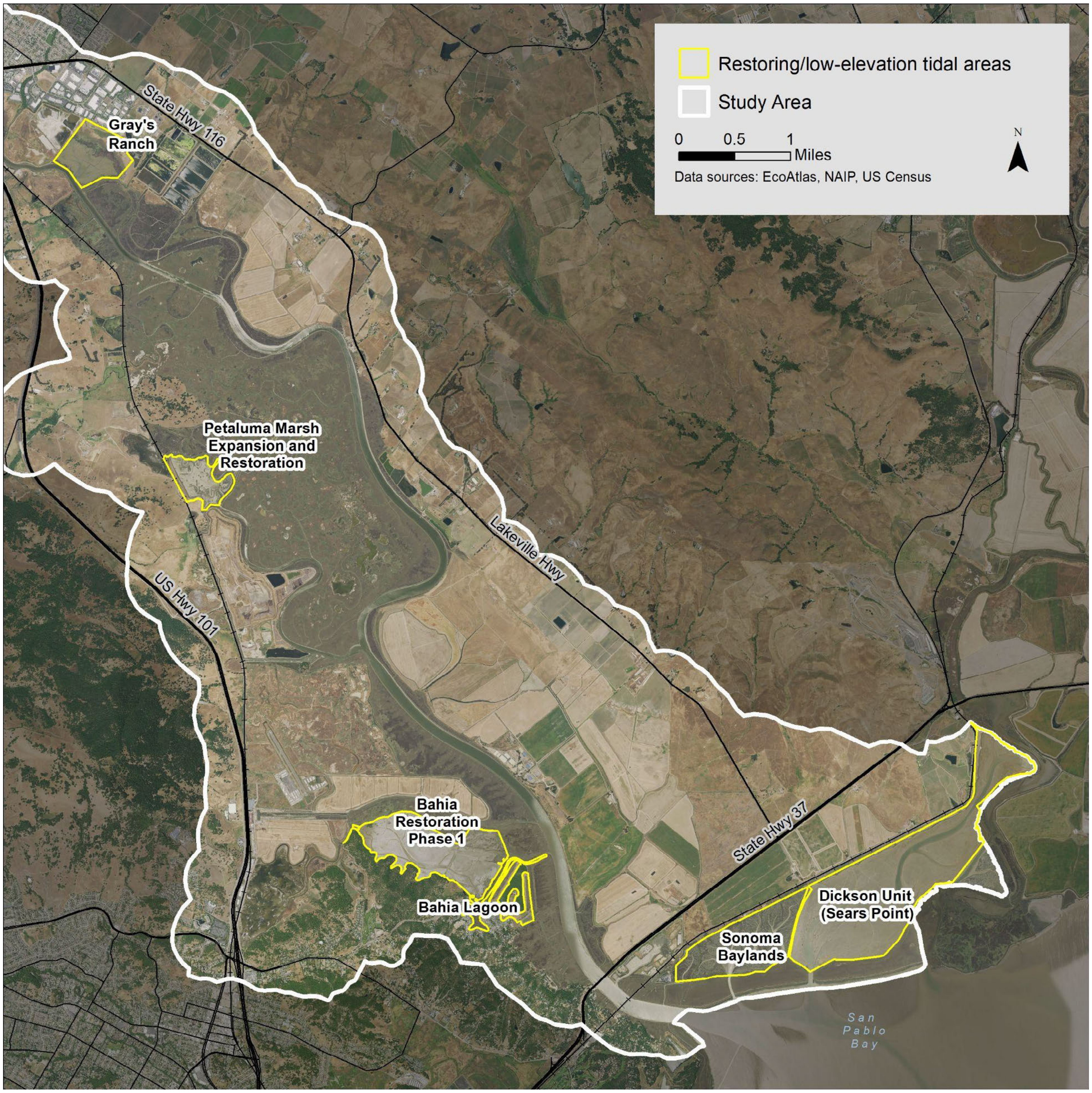

Figure 4.2. Restoring, low-elevation, tidally-connected areas. Marsh evolution modeling predicts that these sites will reach low to mid-marsh elevation by mid-century and persist as low marsh through the end of the century.

4.3 Condition 3: Marshes not connected to protected migration space

Many of the high-quality (Condition 1) and restoring (Condition 2) marshes face the same challenge: limited marsh migration space. Though the marsh evolution model indicates that they may persist late into the 21st century through vertical accretion, eventually rising seas will drown these marshes if there is no space for them to migrate. Elevation mapping conducted for the San Francisco Bay Adaptation Atlas (SFEI and SPUR 2019) identifies areas at migration space elevation in the Petaluma River Baylands. Analysis provided in Appendix C shows where this migration space is connected to existing marsh and where it is separated by barriers (roads, rail, etc.). If marshes in the Petaluma River Baylands are reconnected to migration space, 550 acres of new marsh could establish in areas above today's tidal elevation by 2100.

The major hindrance to the resilience of the Ancient Marsh and other marshes west of the Petaluma River is the barriers to marsh migration posed by transportation infrastructure, primarily the North-South SMART rail line. Higher sea levels will create more vulnerabilities for the rail line itself (flooding, erosion, damage to tracks and bridges, loss of service, etc.) (SMART 2014). In addition, the presence of the rail line inhibits the ability of marshes to adapt to sea-level rise by restricting the ability of the highest tides to pass through bridges and culverts, hindering the process of marsh migration. Extreme tides today are constrained at Basalt Creek, Rush Creek, San Antonio Creek, and other unnamed crossings, and more crossings will present constraints as sea levels rise (SMART 2014; see Table 1). A recent study of U.S. Pacific coastal wetlands found that the Ancient Marsh has extremely high vulnerability to sea-level rise relative to other marshes, largely due to the complete lack of migration space caused by the presence of the railroad berm separating the marsh from upland areas (Thorne et al. 2018). Similarly, State Route 37 and the East-West SMART line inhibit the ability of San Pablo Bay marshes to migrate inland and upland with sea-level rise.

Other marshes in the study area face different limitations to marsh migration, including large expanses of low-lying subsided diked baylands between existing marshes and migration space (False Bay, Lakeville subunits), and lack of shallow slopes for marsh migration (Bahia and Burdell subunits) (Figure 4.3).

In some areas, there are no physical barriers to marsh migration, but marsh migration space is currently unprotected from land use changes that could prevent migration in the future if there is incompatible development. Connected but unprotected marsh migration space exists in the City of Petaluma - South and Lakeville subunits.

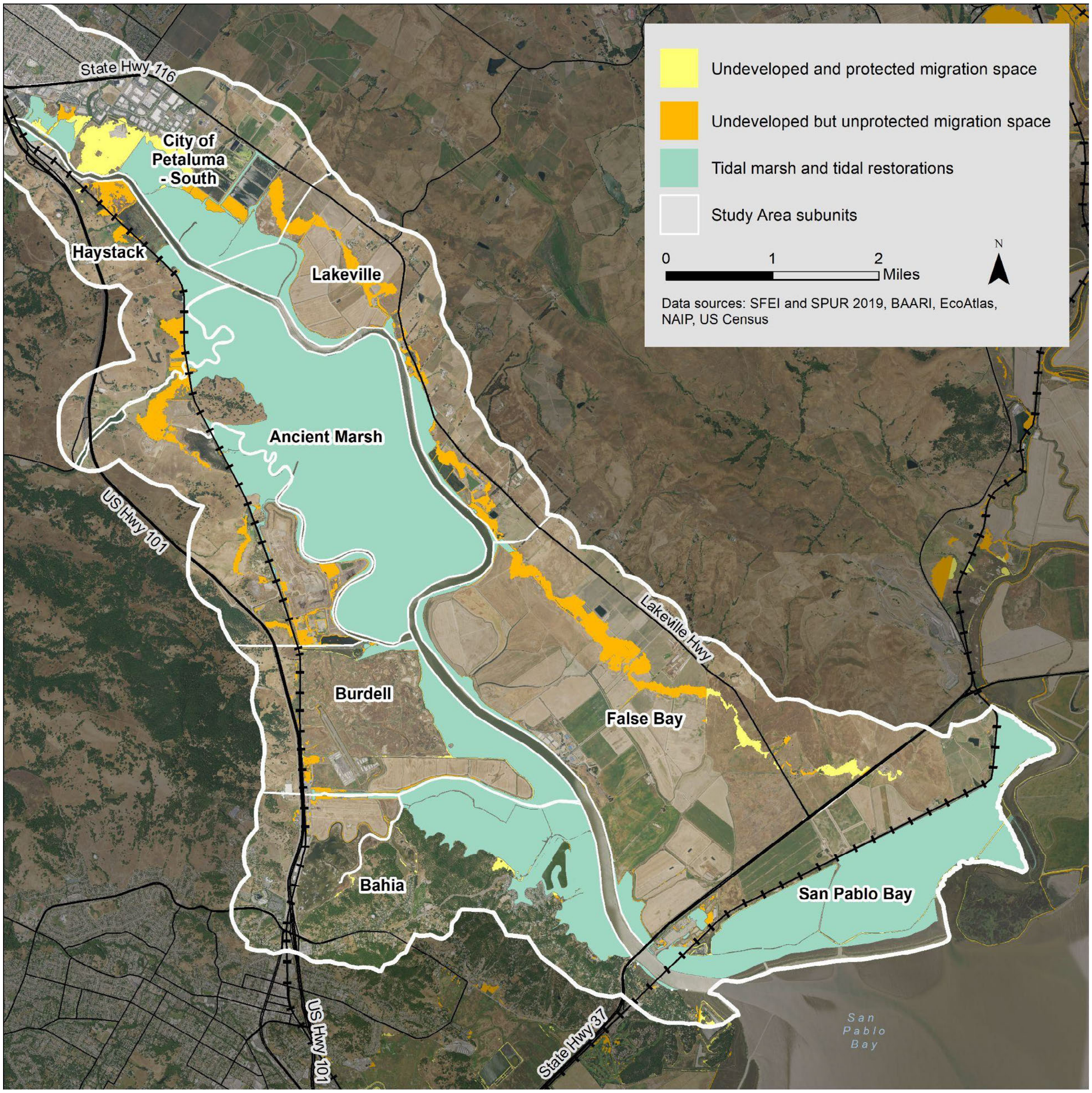

Figure 4.3. Open space at appropriate elevation for marsh migration in the study area. However, marshes are largely disconnected from this migration space due to barriers created by roads, rail, and diked baylands. Of the migration space that exists, only a small portion is protected from development.

4.4 Condition 4: Diked baylands disconnected from tidal action and vulnerable to flooding

In addition to investigating the resilience of marshes to sea-level rise, the geomorphic and marsh evolution analyses explored the resilience of diked baylands. These are found throughout the study area. In several subunits, there are extensive areas of former baylands which have been cut off from tidal action to create lands for agriculture, development, or other uses (e.g. Burdell, Cloudy Bend, False Bay). Many of these areas are low in elevation and are surrounded by levees, which are subject to overtopping as sea levels rise. These levees will require more maintenance as overtopping events become more frequent. Pumping costs will also increase as sea level and groundwater levels rise, and as rainfall events become more intense. The geomorphic analysis used two metrics to determine the resilience of diked baylands to sea-level rise: (1) percent of area below mean sea level; and (2) levee height, from the SF Bay Shore Inventory (SFEI 2016), which corresponds to overtopping probability. False Bay is the lowest in elevation of the diked baylands in the study area, with 89% of the diked area below mean sea level (Figure 4.4). In many of the subunits, levees overtop in places at 24” inches above today’s MHHW. In some, for example on the north side of the Burdell Unit, levees overtop at just 12” above today’s high tides (king tide elevation).

Previous analyses at the estuary scale determined that restoration must be initiated by 2030 or starting elevations should be raised through beneficial reuse of dredge material in order to achieve marsh elevations after restoration (Goals Project 2015). This is consistent with the marsh evolution model (Appendix D), which indicates that if diked baylands are restored by 2030, even the most subsided areas could persist (at least as low marsh) through the end of the century. Restoring all the diked baylands today could result in an additional 8,281 acres of marsh habitat even with 6.9 ft of sea-level rise, assuming sediment supplies are constant and similar to recent conditions. However, restoring subsided baylands to tidal action will affect the sediment budget, so this assumption may not hold.

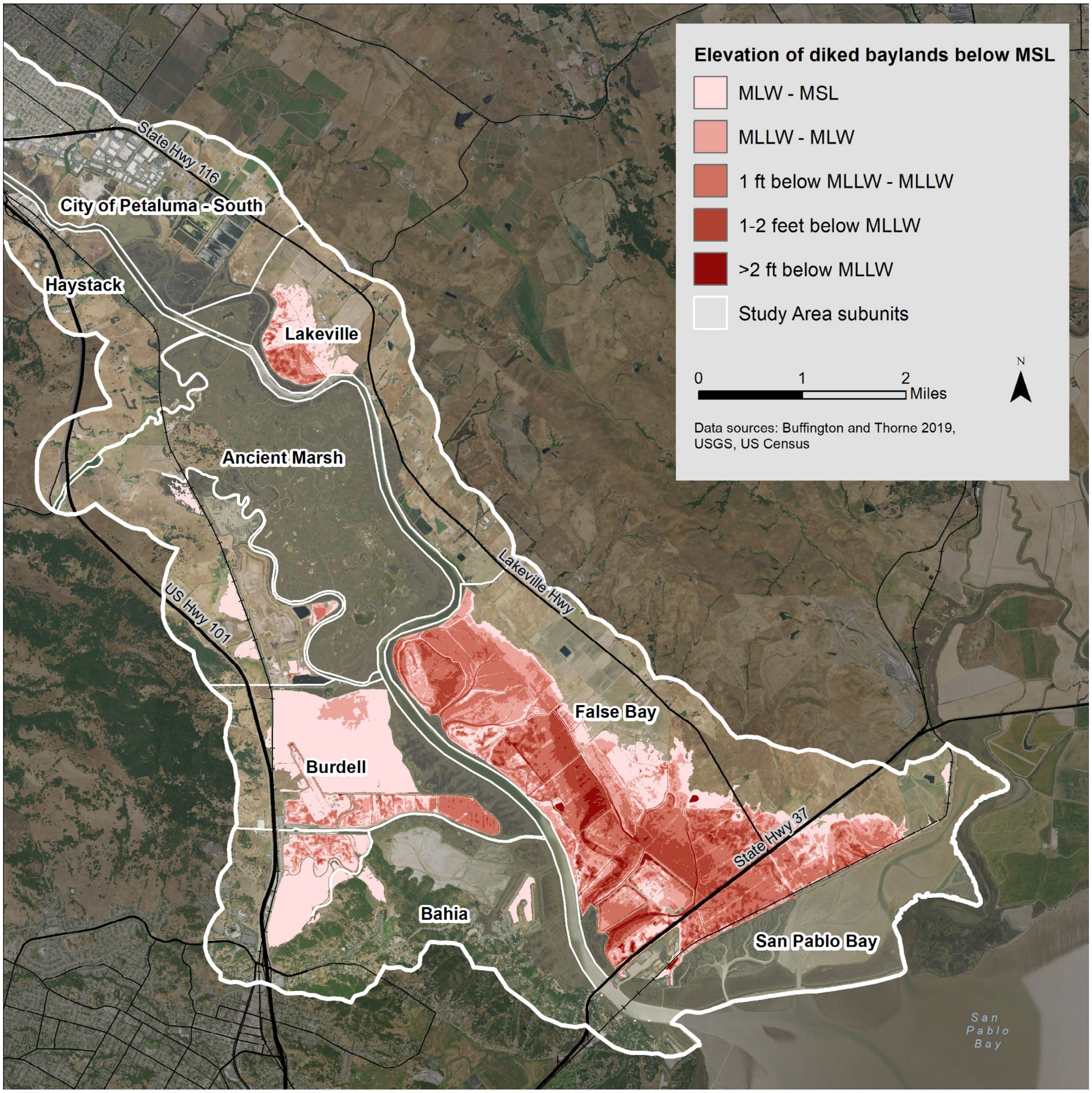

Figure 4.4. Low-lying diked baylands with elevations below mean sea level (MSL) are vulnerable to flooding from levee overtopping. MLLW is Mean Lower Low Water; MLW is Mean Low Water.

4.5. Condition 5: Sedimentation necessitates regular channel dredging

The history of diking and draining of tidal marsh and channelization of streams and sloughs has decreased tidal prism in the Petaluma baylands and resulted in continued sedimentation in the main Petaluma River channel. Dredging is expensive, energy-intensive, and disruptive to subtidal habitats. Restoration of the Petaluma baylands could potentially increase tidal prism by expanding the floodplain into a dense network of tidal channels where sediment would deposit, thereby reducing or eliminating the need for regular dredging to maintain a navigable channel. Changes to channel morphology resulting from dredging may also impact flood risk in the upper river, including the City of Petaluma (Li et. al, 2021). More research and modeling is needed to better understand how baylands restoration could impact dredging needs and flooding.

Chapter 5: Overarching strategies

In this section we connect each of the analysis findings described above to strategies for achieving the project goals:

> "to conserve and restore baylands and adjacent habitats and to promote the growth and resilience of populations and habitats of native species within the study area while maintaining and increasing the ecosystem services provided to human communities."

We link the strategies to one or more of the recommended regional strategies for baylands resilience from the consensus-driven Baylands Ecosystem Habitat Goals Update (Goals Project 2015).

5.1 For Condition 1: High marshes with high resilience

Strategies for marshes with this condition can focus on protection and maintenance rather than restoration or creation. For example, strategies may focus on conserving native plants and managing invasive species, including using rare plant and wildlife surveys to prioritize conservation actions in marshes, transition zones, and riparian corridors. Actions may also include developing adaptive management thresholds for more intensive management interventions like thin-layer sediment placement. High elevation marshes may also benefit from enhanced watershed connections that deliver sediment and freshwater to the marsh. Sediment delivery can increase marsh resilience to sea-level rise while freshwater can recreate some of the fresh-to-salt marsh habitat gradient that historically existed in the watershed.

These strategies relate to the following Baylands Goals recommendations:

- Actively recover, protect, and monitor wildlife and plant populations.
- Restore estuary–watershed connections that nourish the baylands with sediment and freshwater.

5.3 For Condition 2: Restoring, low-elevation, tidally-connected areas

Near-term strategies for these restoration sites should focus on adaptive management to encourage continued accretion and vegetation establishment. For example, strategies may include enhancing tidal connectivity or improving sediment delivery from watersheds by enhancing connectivity from creeks to baylands. Assuming these areas eventually reach marsh elevation, strategies align with those for Condition 1: High elevation, high resilience marshes. Many recent restorations are also limited by lack of migration space; therefore, strategies for Condition 3 may also apply.

These strategies relate primarily to the following Baylands Goals recommendation:

- Restore and protect complete baylands ecosystems as soon as possible.

5.2 For Condition 3: Marshes not connected to protected migration space

Various strategies can be used to protect and expand marsh migration opportunities in the study area, depending on the current barriers. For places where connected marsh migration space exists but is unprotected, strategies can focus on land conservation and transition zone enhancement (e.g., invasive vegetation management). For places where marshes are currently disconnected from migration space, strategies can focus on reconnecting marshes to adjacent migration space so they can shift naturally upland and inland as sea levels rise. In some cases, this may also involve enhancing and expanding connections to watersheds to allow delivery of freshwater and sediment to nourish marshes, and to allow upstream migration of marshes. Given that transportation infrastructure (roads and rail lines) are major barriers to marsh migration in the Petaluma River Baylands, a key strategy is to work with transportation agencies to raise roads and rail on causeways, elevating this infrastructure to reduce barriers to the movement of water, sediment, and species. Where infrastructure is not raised on causeways, bridge crossings and culverts should be raised and expanded to reduce constraint of tidal flows. If and when causeways are built, flood protection levees constructed to protect the transportation infrastructure may need to be breached or removed to enable tidal flow and unobstructed marsh migration. In some cases, such as Dickson Unit (Sears Point) and Sonoma Baylands, these levees have Bay Trail alignments on their crests. To avoid these trails standing in the way of restoration, local agencies and communities should consider relocation or replacement with other recreation infrastructure in a manner consistent with the Guiding Principles presented in Section 2.10.

These strategies relate primarily to the following Baylands Goals recommendation:

- Plan for the baylands to migrate.

5.4 For Condition 4: Diked baylands disconnected from tidal action and vulnerable to flooding

A combination of strategies (or phased implementation) may be employed to restore some areas to tidal action while enhancing habitat value and reducing further subsidence of areas that remain diked. Strategies for restoring diked baylands should be carefully considered to prevent newly restored areas from becoming sediment sinks that may be detrimental to the accretion potential of existing healthy marshes nearby. There are many precedents for tidal restoration of diked baylands in the study area (Figure 4.2); lessons learned from these projects can inform design, monitoring, and adaptive management strategies for future restorations. Where possible, tidal restorations should be connected to upper watersheds and upland transition zones to ensure restoration of complete marsh systems and connection to habitat-sustaining landscape processes. Where tidal restoration is not possible in the near term, interim strategies like promoting seasonal wetland habitat can be pursued.

These strategies relate primarily to the following Baylands Goals recommendations:

- Design complexity and connectivity into the baylands landscape
- Restore the baylands to full tidal action before 2030

5.5 For Condition 5: Sedimentation necessitates regular channel dredging

More research is needed to determine how implementation of tidal restoration projects may affect sediment flows, however, it is expected that expanding the floodplain by opening up more diked baylands to tidal action will increase tidal prism and reduce sedimentation within the main Petaluma River channel. Specifically, restoring diked baylands to marshes will increase the number and extent of new tidal channels, which could serve as a sediment sink and reduce sedimentation in the confined river channel. Hydrodynamic modeling is needed to determine whether and how reduced channel dredging and strategic restoration actions (e.g. tidal wetland restoration, levee setbacks) may affect upstream flooding, positively or negatively, particularly as sea levels rise.

Many of the restoration projects proposed as elements of the Petaluma River Baylands Strategy would benefit from sediment placement. For example, sediment can be placed in subsided diked areas to increase elevation prior to restoration of tidal action, or it can be sprayed as a thin layer on top of existing marsh to supplement natural sediment accretion as sea-level rise accelerates. Transporting dredge material is costly, inefficient, and generates greenhouse gas emissions. Therefore, local priority sites for beneficial use should be identified as placement locations for future dredging efforts that are required in the Petaluma River. Priority sites for alluvial sediment dredged from local detention basins (e.g. Adobe Creek) can also be identified. This material can be used for alluvial fan, marsh, and stream restoration.

These strategies relate to the following Baylands Goals recommendation:

- Develop and implement a comprehensive regional sediment-management plan, building on existing regional sediment-management work that emphasizes the use of all suitable dredged or excavated sediment from the estuary, local rivers and streams, flood-control channels, local reservoirs, and other watershed sources.

Chapter 6: Landscape Vision

The strategies outlined in Chapter 5 as well as input from scientific advisors and other stakeholders informed the development of a Landscape Vision for the Petaluma baylands. Two key uncertainties influence the implementation of the Landscape Vision: existing transportation infrastructure and private land ownership. Therefore, several other scenarios accounting for these uncertainties are presented in Chapter 7.

The Landscape Vision includes restored estuary-watershed connections, space for baylands to migrate both inland and upstream, and diked baylands restored to full tidal action. This represents a vision for the future of the Petaluma baylands that protects a suite of complete ecosystems (including mudflats, low marsh, marsh plain, high marsh, transition zones, seasonal wetlands, and seasonal and perennial creeks) providing a range of diverse and connected habitats.

Restoration of marshes that can connect to available migration space and to creek corridors should be prioritized. Though near-term restoration is paramount (Goals Project 2015), we acknowledge that the sooner restoration occurs, the less time remains for continued use of the land for other purposes, including agriculture.

Implementation of the Landscape Vision is not possible without the collaboration of willing private landowners. While some landowners are interested in near-term restoration, it is likely that greater buy-in will occur as flooding and other climate effects become more pronounced. Therefore, multiple phases of restoration are likely to be required to achieve this expansive vision. Timing of restoration will affect habitat development; subsided diked baylands restored after 2040 are likely to reach mudflat but not marsh elevations by 2100 (see Appendix D). Therefore, not all the area shown as tidal marsh in Figure 6.1 may reach tidal marsh elevations; instead, it may remain mudflat or subtidal habitat, depending on timing of restoration, sediment supply and rates of sea-level rise. The future habitats shown for existing diked baylands after tidal restoration (Figure 6.1) are proxies largely based on historical habitat mapping. For example, False Bay is shown as a mix of tidal marsh, mudflat, and shallow subtidal habitat, as it was historically, prior to diking and draining. True habitat acreages resulting from restoration will not match exactly with these historical conditions.

Letter labels are included in Figure 6.1 to orient the reader to location references in the text below. Some locations are also referred to by name and can be found in Figure 2.1.

Under the Landscape Vision (Figure 6.1), diked baylands in the Haystack subunit would be restored and reconnected to protected migration space (A). The north-south rail line would be raised on a causeway to allow full reconnection of watersheds west of the Petaluma River with the Ancient Marsh and Gambinini Marsh (B). This would restore flows of freshwater and sediment to the Ancient Marsh and provide essential marsh migration space and upland transition zone habitat. Expanding existing trestle bridges/culverts and adding new ones under the railroad levee could also allow more tidal prism under the rail line; however, connectivity will ultimately be limited by the presence of the railroad levee. The raised causeway would allow more tidal prism underneath the rail and allow marshes to extend inland into their historical footprints and beyond as sea-level rises (C). Though expensive, raising the rail line would decrease the vulnerability of the rail to flooding and erosion from increasing sea levels.

Once the Redwood Landfill is closed and capped (currently anticipated in 2032) (R. Khany, pers. comm., February 2023), it could be converted to a public park or open space overlooking the expansive Ancient Marsh and the Petaluma River (D). Corollaries for this type of shoreline landfill-to-park conversion exist all around San Francisco Bay (examples include Wetlands Edge Park in American Canyon, Cesar Chavez Park in Berkeley, Oyster Bay Regional Shoreline in San Leandro, Byxbee Park in Palo Alto, and Bedwell Bayfront Park in Menlo Park).

The Burdell Unit would be partially restored to tidal marsh, with a setback levee constructed to protect the Gnoss Field Airport (E). Placement of dredge sediment prior to restoration at the Burdell Unit could accelerate tidal marsh establishment and reduce ponded habitat, which could be desirable for Gnoss Field to reduce the potential for bird strike at the airport. The raised north-south rail line would continue along a portion of the Burdell Unit to where it meets high ground. This would allow reconnection of the watershed west of the rail line directly to the tidal marsh, allowing gravity flow from adjacent hill slopes to the Petaluma River and limited marsh migration. In the event that Gnoss Field operations are discontinued, this area could also be tidally restored.

South of the Burdell Unit, diked baylands would be reconnected to Black John Slough (F). A setback levee would need to be maintained behind these restored areas to protect Highway 101 from flooding. Improvements could be included in strategic locations to provide enhanced connectivity from baylands to upland watersheds west of Highway 101. Radio aerials would need to be protected and an access berm maintained (G).

Rush Creek and Cemetery Marshes would be maintained in muted tidal condition to allow for management of stormwater flows from Novato, but the existing tide gate would be improved (possibly in conjunction with creek channel improvements) to allow better tidal exchange while maintaining flood protection for upstream communities (H). More study is needed to determine an appropriate solution. Eventually, sea levels will rise high enough that the tide gate will no longer be functional and a longer-term solution will need to be explored.

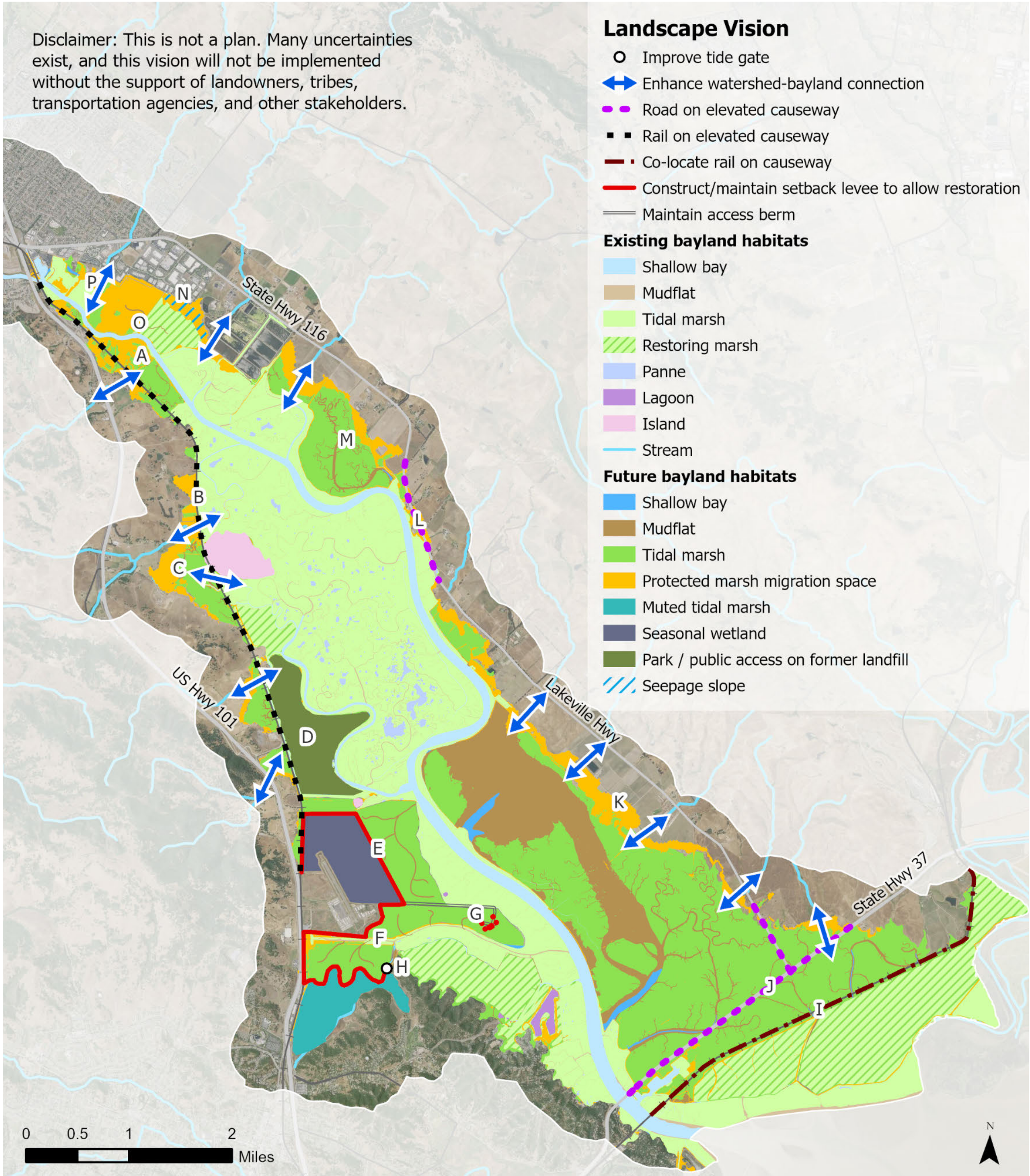

Figure 6.1. The Landscape Vision includes extensive baylands restoration, enhanced connections between tidal marshes and watersheds (see Chapter 5 for details on marsh-watershed connectivity) and transportation infrastructure raised to allow marsh migration. Some of the area represented as future tidal marsh may not reach marsh elevations and instead provide mudflat or subtidal habitat, depending on timing of restoration and rates of sediment accretion and sea-level rise.

The east-west rail line (I) would be co-located with State Route 37 on a raised causeway (J), allowing tidal connectivity between the Sonoma Baylands and Dickson Unit (Sears Point) restorations and restored tidal baylands in False Bay. Existing flood protection levees at these restoration sites would be breached or lowered and the Bay trail reestablished at a suitable location. A section of Lakeville Highway and the interchange with State Route 37 would also need to be raised on a causeway. Given extremely low land elevations and historical habitats, not all of False Bay and adjacent diked baylands may reach tidal marsh elevation; some may remain subtidal and mudflat habitat. The earlier restoration is implemented, the more likely it is that restored diked baylands will reach marsh elevation by 2100 (Appendix D). Importantly, this restored area connects to a large swath of protected migration space bayward of Lakeville Highway, allowing natural upland marsh migration to progress as sea levels rise (K). Along this stretch, connections to watersheds would be enhanced by improving culverts under Lakeville Highway to allow better passage of water, sediment, and wildlife.

In the Lakeville subunit where the road encroaches close to the marshes today, Lakeville Highway would be raised on an elevated causeway to allow more space for marshes to migrate inland of the roadway and to reduce roadway flooding as sea levels rise (L). The Cloudy Bend area would be restored to marsh with connections to protected migration space (M).

At the Ellis Creek Water Recycling Facility in the City of Petaluma - South subunit, a seepage slope would be added bayward of the constructed wetlands (N), supplementing freshwater flows from Ellis Creek and adding freshwater and brackish marsh habitat in an area where wet meadows were historically widespread (Baye 2016; Baumgarten et al. 2018). The seepage slope would recreate some of the historical fresh-to-brackish marsh habitat gradient that historically existed in this location. Removal of berms in lower Ellis Creek would enable floodplain inundation during periods of high flow.

Gray’s Ranch would be connected to Shollenberger Park with a new tidal channel, allowing marshes to migrate to higher elevations over the long term (O). Adobe Creek would be reconnected to adjacent baylands, allowing better delivery of freshwater and sediment to marshes of the upper Petaluma baylands (P). This could also include efforts to enhance beneficial use of excavated sediment from the Adobe Creek detention basin.

6.1 Value of the Landscape Vision

One of the major overarching strategies outlined in Chapter 5 was to connect marshes, particularly the high-value Ancient Marsh, to protected migration space. Under the Landscape Vision major barriers to marsh migration are removed, increasing the resilience of the Ancient Marsh and San Pablo Bay restorations to sea-level rise. 6.5 miles of existing railway behind the Ancient Marsh would be raised on an elevated causeway to allow inland marsh migration and habitat connectivity to the tidal-terrestrial transition zone. 3.9 miles of rail and 4.6 miles of highway would be raised along the east-west SMART and State Route 37 corridor, allowing reconnection of San Pablo Bay marsh restorations to adjacent transition zone and upland habitat.

Table 6.1 provides a summary of the additional habitat area provided by the Landscape Vision. Note that tradeoffs are inherent in restoration of these habitats; conversion of existing land uses is required to achieve the gains in habitat acreage detailed in Table 6.1. In most cases this means conversion of existing diked agricultural land and seasonal wetland habitat to tidal habitats (marsh, mudflat, shallow subtidal, and marsh migration space). Seasonal wetland habitat acreages are not shown in Table 6.1 as the area of seasonal wetlands varies depending on rainfall and management choices. Seasonal wetlands at the Burdell Unit are enhanced under the Landscape Vision and may be enhanced elsewhere as a near-term strategy prior to tidal restoration (see Chapter 8).

The habitat acreages in Table 6.1 are based on the map in Figure 6.1 and are given as a general reference, not as exact predictions of future habitats; habitat trajectories will depend on timing of restoration, rates of sea-level rise, and sediment supply

Table 6.1. Additional habitat area under the Landscape Vision.

	Existing area (ac)	Additional habitat area (ac) under the Landscape Vision
Tidal marsh	6,711[a]	4,478 (67% increase)
Shallow bay	845	74 (9% increase)
Muted tidal marsh	240	-
Park/public access on former landfill	-	371
Mudflat	208	1,307 (628% increase)
Marsh migration space for the Ancient Marsh[b]	-	164
Marsh migration space (total)	301[c]	925 (307% increase)
Seepage slope	-	40

[a] includes marsh panne and restoring marsh

[b] includes migration space behind Gambinini Marsh and Redwood Landfill

[c] most of this area is marginal migration space on existing levees, with the exception of a few City of Petaluma-owned areas in the City of Petaluma - South subunit

Chapter 7: Other scenarios

The diked baylands and adjacent uplands of the Petaluma River are composed of a large mix of public and private lands bisected by transportation infrastructure and rich with cultural resources. The uncertainty created by these variables precludes the possibility of implementing the Landscape Vision as a single large effort. Instead, it is likely to be a complex and multi-stage process that depends on decisions by transportation agencies, private landowners, tribes, and other stakeholders. While it is not feasible to consider all the possible scenarios, this chapter describes four scenarios based on two key uncertainties that are most identifiable: raising of transportation infrastructure and participation of private landowners.

Table 7.1 provides a summary of the range of scenarios, which are then detailed in the text and maps of this chapter. Letter labels are included in the scenario maps to orient the reader to location references in the text. Some locations are also referred to by name and can be found in Figure 2.1.

Table 7.1. Summary of restoration scenarios that may arise depending on management and land use decisions of transportation agencies and private landowners.

Scenario	Description
No-action	No restoration strategies are implemented. Assumes existing levees will be maintained but not raised, and pumping will continue. As sea levels rise, levees are overtopped and diked baylands are flooded. Depending on location and elevation, existing marshes persist until the late century before shifting to low marsh, mudflat or subtidal habitat.
Public Land Only	Restoration is limited only to properties already owned by public agencies. On private land, this scenario assumes levees are raised and lands are pumped dry for the foreseeable future.
No Causeways	Assumes roadways and railways are maintained in their current condition or protected by levees rather than being raised on causeways. Restoration is possible, but the level of landscape connectivity in the Landscape Vision cannot be achieved.
East-West Causeway Only	A compromise between the No Causeways and Landscape Vision, assuming construction of an east-west causeway for State Route 37 and SMART rail, but no north-south SMART rail causeway.

7.1 No-action scenario

Under the No-action scenario, no restoration strategies are implemented, existing levees are maintained but not raised, and pumping continues. As sea levels rise, the existing levees are overtopped, and diked baylands (primarily agricultural lands) are flooded. The map in Figure 6.3 shows flooding at three feet above today's MHHW. This water level represents a 50-year storm surge[4] today, a king tide with two feet sea-level rise, or a daily high tide (MHHW) with three feet sea-level rise. Three feet of sea-level rise is anticipated for San Francisco Bay as early as 2070, and two feet of sea-level rise as early as 2050 (CA OPC 2018). Many sections of levee within the study area will overtop sooner, at just one or two feet above MHHW (see Appendix C Figures 12-13). One foot above MHHW is king tide elevation under today's conditions, and two feet above MHHW could occur today with a 5-year (20% annual chance) storm surge. Even occasional overtopping due to extreme tides and storm surges is likely to make continued maintenance of levees and pumping more challenging and expensive as sea levels increase.

While landowners will continue to make repairs to keep land dry, increases in flooding, associated increased pumping, and emergency levee repairs are likely to make agricultural uses in diked baylands more difficult and less financially rewarding over time. Eventually, when levees are no longer repaired, "unplanned restoration" will occur as a result of levee failure and subsequent tidal flooding. However, this is more likely to happen later in the century when the rate of sea-level rise is greater. This would leave less time for marsh vegetation to establish and accretion to occur, making it more difficult to restore marshes, and more difficult for them to keep pace with sea-level rise. Based on marsh evolution modeling (Appendix D), existing marshes, such as the Ancient Marsh, and the restored marshes of Bahia, Sonoma Baylands, and Dickson Unit (Sears Point) (Figure 5.3) are expected to keep pace with sea-level rise through 2100 due to high sediment supply from San Pablo Bay and adjacent watersheds. However, deeply subsided diked baylands, such as False Bay, Burdell, and Cloudy Bend, restored after 2040, are unlikely to ever reach marsh elevations, instead remaining at mudflat elevation through 2100. Therefore, the No-action scenario does not increase resilience of Petaluma bayland habitats to sea-level rise in the Petaluma baylands in the near-term nor the long-term.

[4] Storm surge is the increase in water levels during a storm due to high winds and low atmospheric pressure.

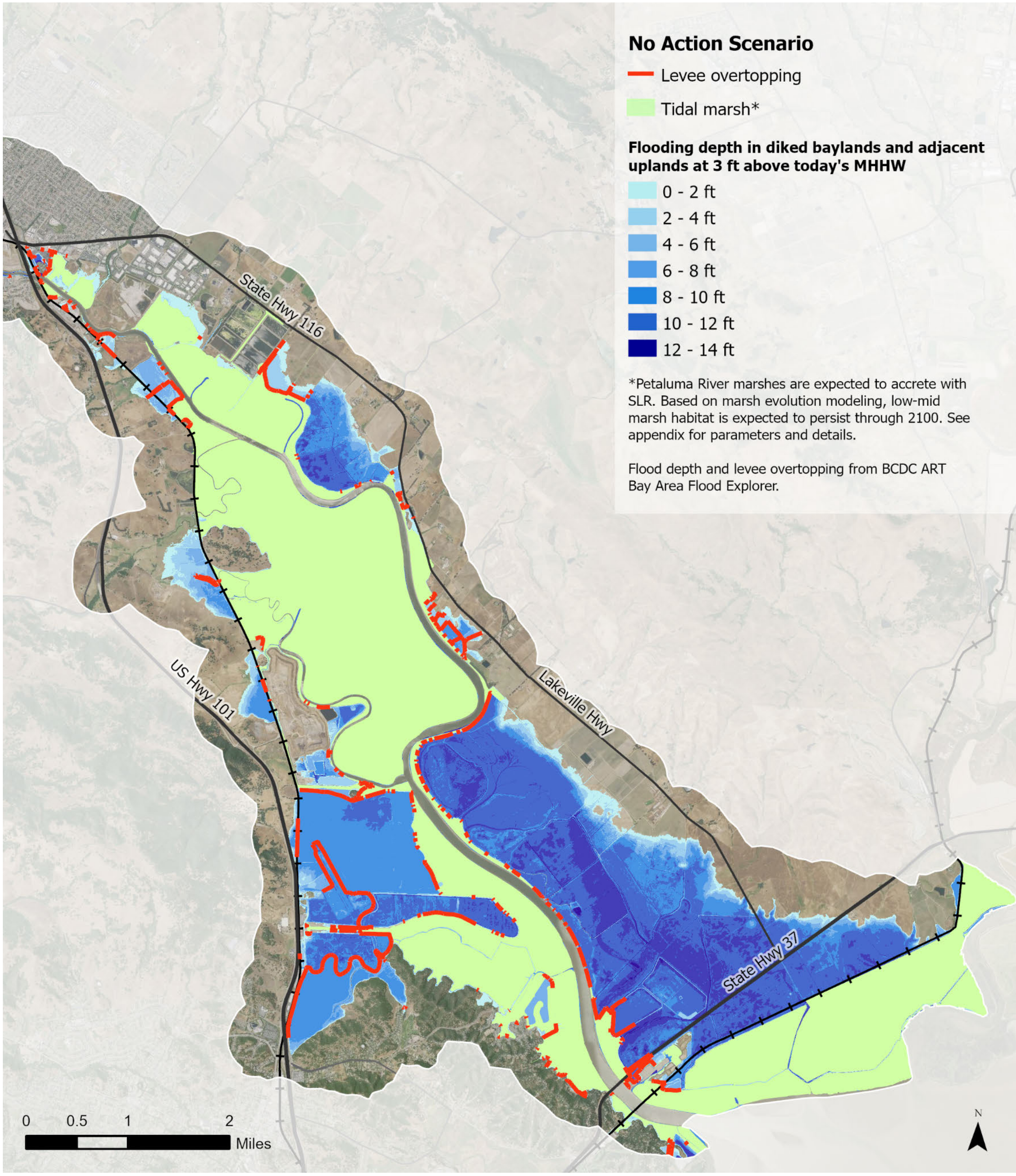

Figure 7.1. No-action scenario, showing water levels at 3 ft above today's MHHW. This water level represents a 50-year storm surge today, a king tide with 2 ft sea-level rise, or a daily high tide (MHHW) with 3 ft sea-level rise. While marshes would be underwater during a storm surge today, they are expected to accrete with sea-level rise, maintaining elevation relative to the tides to 3 ft sea-level rise and beyond (see Appendix D for details).

7.2 Public Land Only scenario

In the Public Land Only scenario, restoration occurs only on public land, with levees constructed to protect surrounding privately-owned land from flooding. This scenario was developed to demonstrate the constraints associated with the participation of private landowners in implementing the Landscape Vision.

There are thousands of acres of public land available for conservation and restoration in the Petaluma River Baylands. These lands are owned and managed by California Department of Fish and Wildlife, USFWS, State Lands Commission, Sonoma Water, City of Santa Rosa, and City of Petaluma: organizations with varying missions, goals, and objectives. Other factors may also affect their willingness and ability to participate in carrying forward this Strategy and timelines for doing so. The California Department of Fish and Wildlife's Burdell Unit is an illustrative example: there is a willing partner agency, but pre-existing encumbrances on the land need to be reconciled to allow restoration to proceed. On the other hand, unifying conservation and resilience needs greatly increase the likelihood of implementing synergistic restoration actions. In the Burdell Unit case, the unifying need is that wetland restoration may increase the resilience of Gnoss Field to flooding.

Figure 7.2 shows the application of the Landscape Vision, but limited to properties already owned by public agencies. In addition to assuming landowning agencies are willing and able to participate, this scenario also assumes the willingness of other organizations, including regulatory bodies and private transportation agencies (i.e. SMART), to support and/or participate. On private land, this scenario assumes levees are raised and maintained, with lands pumped dry for the foreseeable future (i.e., the status quo). The extent of habitat restoration that is possible is greatly reduced in this case relative to the Landscape Vision (Table 7.1), limited to the Burdell Unit (A), where restoration planning is already in progress, and the areas adjacent to State Route 37 (B). The costs associated with building setback levees to protect private land may make this scenario considerably more expensive in terms of restoration costs per acre. In addition, the property boundaries may not be feasible or cost-effective locations for building levees, depending on existing topography. Public-private land swaps could facilitate a more feasible and cost-effective approach to restoration, depending on landowner willingness.

This scenario achieves some objectives in terms of expanding tidal marsh and connecting marsh to migration space, but the area of connected migration space is far more limited than in the Landscape Vision. It does not achieve the sweeping restoration and resilience goals that the Landscape Vision does. However, this scenario has the least impact in the near term to existing private uses of the land, including agriculture.

The Public Land Only scenario does not show any changes to the North-South rail line (C) because the land behind the rail line is all privately owned, so construction of improved culverts, tide gates, or causeways would not allow any restoration of public land behind the railway. The railway, roadways, and private land behind levees shown in this scenario will continue to be vulnerable to flooding, and maintenance will become increasingly difficult as sea levels rise.

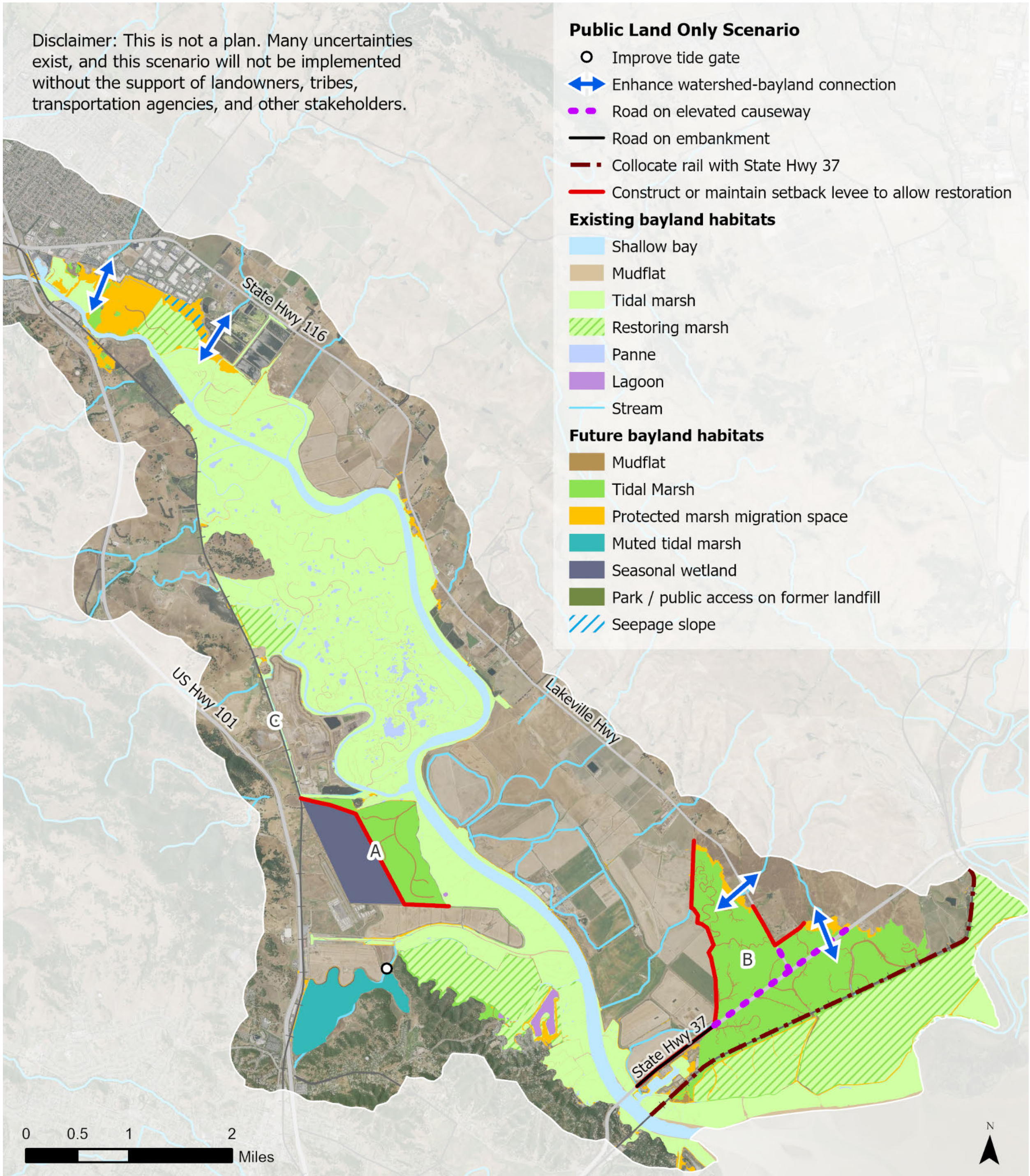

Figure 7.2. In the Public Land Only scenario, restoration occurs only on public land, with levees constructed to protect surrounding privately-owned land from flooding. The map demonstrates the limited extent of restoration possible in the absence of collaboration with willing private landowners.

7.3 No Causeways scenario

The fate of the Petaluma River Baylands is strongly intertwined with management decisions about State Route 37, Lakeville Highway, and the SMART rail lines (described in Section 2.8). The timing and type of improvements to these facilities will have tremendous consequences for the resilience of the Petaluma River Baylands and the transportation infrastructure itself. Removing barriers early and allowing connectivity underneath transportation corridors will enhance resilience over the long term by allowing natural processes to progress (sediment accretion, marsh migration). The longer the transportation barriers are maintained, the longer natural tidal processes and marsh migration will be inhibited, reducing the resilience of bayland habitats to sea-level rise.

The scenario presented in Figure 7.3 represents the implementation of the Landscape Vision (Figure 6.1) but without the benefit of roadways and railways being raised on elevated causeways. Though a State Route 37 causeway seems likely based on ongoing planning processes (Caltrans PEL), timing of construction may not align with timing of restorations. In this scenario, the north-south rail line and Lakeville Highway are maintained at their current conditions/elevations, while State Route 37 is protected by levees.

Although the extent of restoration under this scenario appears similar to the Landscape Vision and East-West Causeway Only scenarios in terms of acreage, key differences exist. Acreage is not equal to functionality; though the area of tidal habitat restored is large, watershed connectivity and access to marsh migration space would remain limited or blocked, thus reducing or eliminating the capacity for marshes and other habitats to adapt and build resilience to flooding This scenario is also likely to be expensive and difficult to implement due to the numerous levees that are required. Nearly eight miles of levee would be needed to protect State Route 37 and SMART rail between the Petaluma River and Sears Point. In addition to the environmental costs (e.g., imported fill material, carbon emissions) associated with constructing these long levees, they would also create barriers to the flow of water, sediment, and wildlife, making the level of landscape connectivity shown in the Landscape Vision impossible to achieve.

Between the Petaluma River and the north-south rail line, diked baylands in the Haystack subunit would be restored to tidal marsh and connected to adjacent migration space (A). Along the length of the rail line adjacent to the west edge of the Ancient Marsh and Gambinini Marsh, existing culverts and trestle bridges would be expanded/improved to allow as much tidal range as possible into the valleys behind the railway (B). Bridge crossings currently presenting constraints to tidal flows that could be prioritized for improvements have already been identified in prior studies (SMART 2014; see Table 1). Enhancing and maintaining hydrologic connections under the rail line will allow more flow of water, sediment, and species between the watersheds and the baylands.

In the near term, the improved culverts and bridges could likely accommodate the full tidal range including extreme tides, allowing the development of tidal marsh inland (west) of the railroad. Over time, this tidal marsh would tend to expand as sea levels rise. This expansion could be associated with a larger tidal prism that may be restricted by the size of the culverts/bridge crossings and continued presence of the railroad berm. If this occurs, the result could be reduced tidal range inland of the railway that inhibits marsh migration. At this point, the marsh inland (west) of the railroad would be considered muted tidal marsh. The railroad barrier would restrict the highest tides from entering the marsh, hindering the ability of marshes to migrate upland into available migration space.

Restoration actions for the Burdell (C) and Bahia (D) areas match those described for the Landscape Vision.

Near San Pablo Bay (E), the No Causeways scenario represents the inverse of the Public Land Only scenario (Figure 7.2). Without raising State Route 37 on a causeway, restoration of public land in the vicinity of the State Route 37/Lakeville Hwy interchange is not possible. Instead, a levee is constructed to protect State Route 37 and the existing rail line. Rather than restoring public lands and protecting private lands, public lands are protected from tidal flows while existing private lands north of the transportation infrastructure are restored and reconnected to the Petaluma River.

Restoration actions for False Bay (F) and City of Petaluma - South (G) match those described for the Landscape Vision.

In the Lakeville area (H), the roadway is maintained and culverts improved, rather than baylands being reconnected to upland habitat by raising the road on an elevated causeway. Eventually a levee may be required to protect the roadway from flooding.

As with the Public Land Only scenario, this scenario is not necessarily a feasible option for restoration in the Petaluma baylands. Instead, it serves as a demonstration of the constraints presented by existing transportation infrastructure. If these transportation corridors are not raised out of the floodplain on an elevated causeway, much of the habitat vision laid out in the Landscape Vision cannot be achieved. Bayland habitats cannot be fully reconnected to migration space, upland transition zones, and watersheds. The significant amount of levee/embankment shown in Figure 7.3 may not be feasible to construct given the amount of fill material that would be required. These longer levees would largely need to be built over Bay Mud, which presents geotechnical constraints, and would also become increasingly difficult and expensive to maintain as sea levels rise higher.

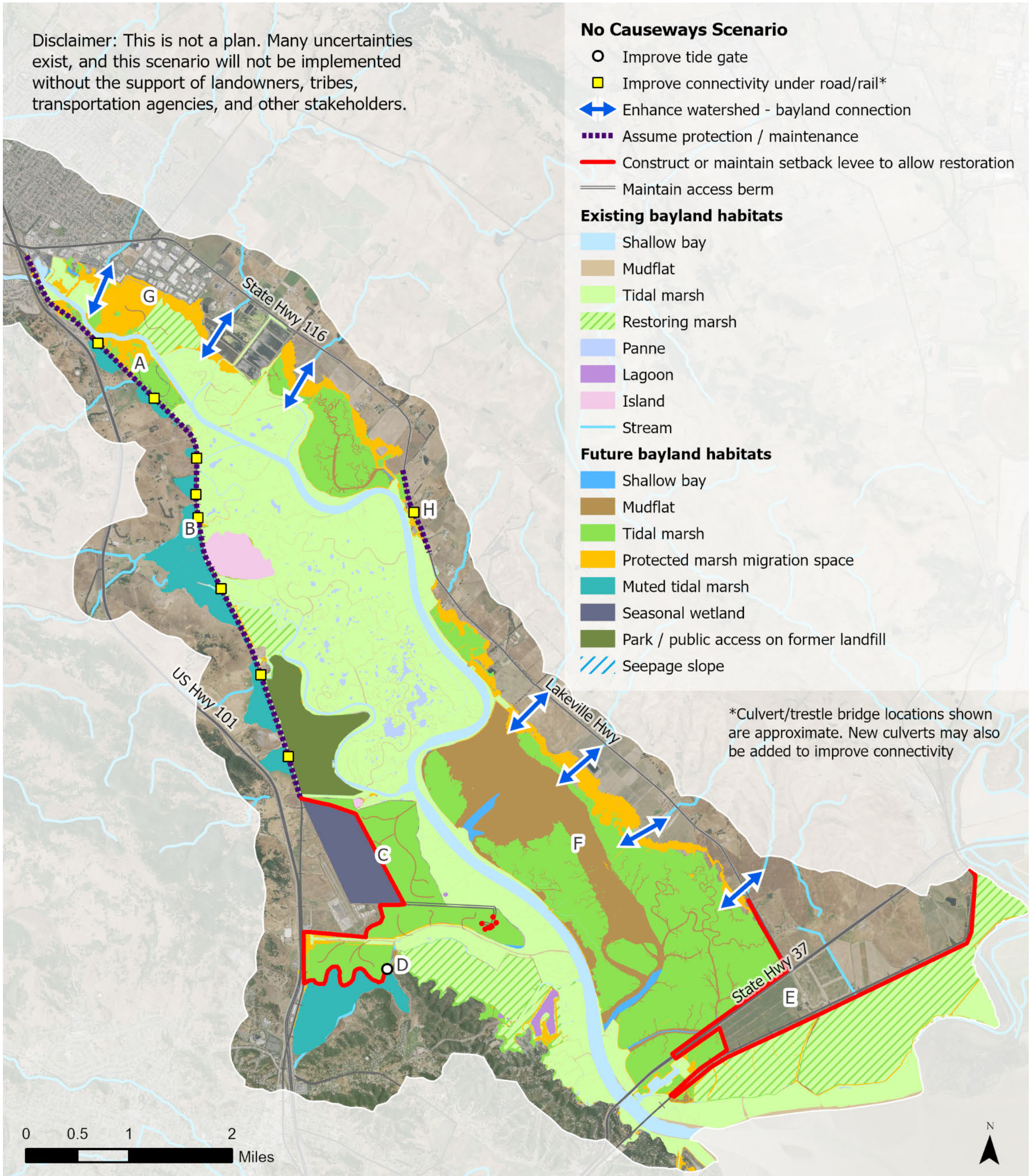

Figure 7.3. The No Causeways scenario demonstrates the implementation of the Landscape Vision but without the benefit of roadways and railways being raised on elevated causeways. Instead, levees are constructed to protect infrastructure from flooding when baylands are restored to tidal action.

7.4 East-West Causeway Only scenario

An east-west causeway for State Route 37 and SMART rail appears likely based on the Caltrans Planning and Environmental Linkages Study (Caltrans 2022) and SMART's draft white paper (SMART 2022). A causeway for the north-south SMART rail corridor seems unlikely, however. In consideration of this, the East-West Causeway Only restoration scenario includes full restoration east of the Petaluma River, facilitated by the new causeway, while restoration west of the river is limited by the north-south rail line. Though the acreages of restored habitat are similar to those for the Landscape Vision, it is important to note that this scenario does not achieve the same level of connectivity to marsh migration space for the Ancient Marsh, an important consideration given the value of this millennial marsh habitat.

Figure 7.4 represents the East-West Causeway Only scenario. Along the north-south SMART rail line west of the river (A), this scenario matches the No Causeways scenario. Existing culverts and trestle bridges would be expanded/improved to allow as much tidal range as possible into the valleys behind the railway. Details on the anticipated benefits of this enhanced connectivity as well as the restrictions on habitat evolution due to the continued presence of the rail corridor match those described for the No Causeways Scenario and are described in section 7.3.

Restoration actions for the Burdell (B) and Bahia (C) areas match those described for the Landscape Vision. However, in the East-West Causeway Only scenario, State Route 37, a portion of Lakeville Highway, and the east-west rail line are raised on a causeway (D), allowing full reconnection of tidal habitat from San Pablo Bay through False Bay and connecting to marsh migration space (E). Existing flood protection levees at the Dickson Unit (Sears Point) and Sonoma Baylands restoration sites would be breached or lowered and the Bay trail reestablished at a suitable location.

A low-lying section of Lakeville Highway is not raised on a causeway, but connectivity under the road is enhanced (F). Actions for the City of Petaluma-South subunit (G) match those described for the Landscape Vision.

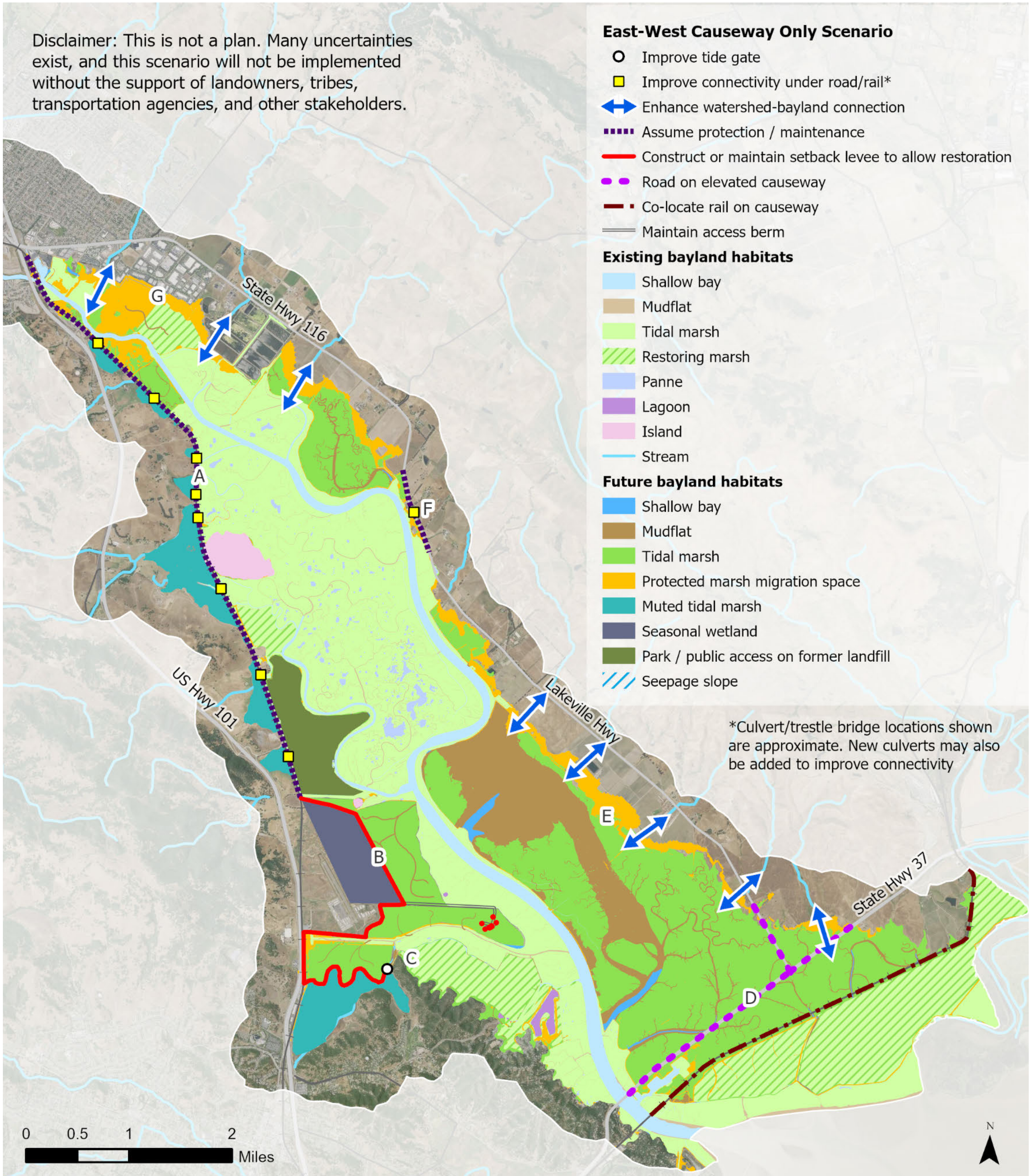

Figure 7.4. The East-West Causeway Only scenario demonstrates full restoration east of the Petaluma River, once State Route 37 and the east-west SMART rail line are collocated on a raised causeway. West of the Petaluma River, restoration is limited by the north-south rail line, which is not raised on a causeway.

7.5 Comparing scenarios

Acres of additional habitat that would be created under each scenario relative to the Landscape Vision are provided in Table 7.1. Lengths of levee and causeway required under each scenario are also provided in Table 7.1. These acreages and lengths are based on the habitats and infrastructure improvements as drawn in Figures 6.1 and 7.1-7.4.

Given the importance of providing marsh migration space for the Ancient Marsh,, values relevant to marsh migration for this area (length of barrier removed and area of migration space preserved) are highlighted in Table 7.1. These values are also highlighted for recently restored baylands in the San Pablo Bay subunit which are also currently disconnected from upland migration space due to transportation infrastructure barriers.

Table 7.1. Approximate length of barriers to marsh migration removed, area of existing and additional future habitat associated with each scenario as compared to the Landscape Vision, and required causeway and levee lengths. All as drawn in Figures 6.1 and 7.1-7.4.

	Landscape Vision	**Public Land Only**	**No Causeways**	**East-West Causeway Only**
	Length of marsh migration barrier removed (miles)			
Ancient Marsh	6.5 (rail)	No barrier removal	No barrier removal	No barrier removal
San Pablo Bay restorations	3.9 (rail/levee) 4.6 (road)	Same as Landscape Vision	No barrier removal	Same as Landscape Vision
	Habitat area relative to Landscape Vision (acres)			
Tidal marsh	4,478 ac	-2,924 ac (-65%)	-1,120 ac (-25%)	-318 ac (-7%)
Shallow bay	74 ac	-67 ac (-91%)	-5 ac (-7%)	-0 ac (-0%)
Muted tidal marsh	240 ac	-0 ac (-0%)	+196 ac (+82%)	+196 ac (+82%)
Park/public access on former landfill	371 ac	-371 ac (-100%)	-0 ac (-0%)	-0 ac (-0%)
Mudflat	1,307 ac	-1280 ac (-98%)	-84 ac (-6%)	-26 ac (-2%)
Marsh migration space for the Ancient Marsh[a]	164 ac	-164 ac (-100%)	-164 ac (-100%)	-164 ac (-100%)
Marsh migration space (total)	925 ac	-684 ac (-74%)	-267 ac (-29%)	-226 ac (-24%)
Seepage slope	40 ac	-0 ac (-0%)	-0 ac (-0%)	-0 ac (-0%)
	Infrastructure length (mi)			
Causeway[b]	11.2	2.0	N/A	3.6
Levee[c]	5.4	6.7	12.6	4.9

[a] includes migration space behind Gambinini Marsh and Redwood Landfill

[b] includes road, rail, and combined road/rail causeways.

[c] levee lengths are provided only for setback levees that facilitate restoration

Chapter 8: Near-term actions

8.1 Interim actions

On the way to implementation of the Landscape Vision, smaller-scale restoration actions may be pursued in the near term in collaboration with willing property owners. During stakeholder meetings, several landowners and lessees expressed a desire to continue farming in the Petaluma baylands for as long as feasible. At the same time, they expressed frustration about the increasing costs and challenges associated with maintaining levees and pumps to keep the land dry. Some of these stakeholders were interested in both continuing to farm for the near future *and* participating in conservation and restoration projects to benefit agricultural viability and habitat resilience.

Along the length of the north-south rail line spanning the back of the Ancient Marsh, culverts and trestle bridges could be expanded/improved to allow as much tidal prism as possible into the valleys inland (west) of the railway. The crossings already present constraints to tidal flow have been identified (SMART 2014) and should be prioritized for near-term action. Culvert/bridge crossing improvement and marsh enhancement may impact land use adjacent to the rail line and will require further research and discussion with individual landowners to determine feasibility. In the near term, expanding, adding, and maintaining culverts and trestle bridges could allow for the full tidal prism to flow under the railroad.

In diked agricultural baylands where levee overtopping and erosion is a concern, construction of setback levees can be pursued as an alternative to repair of existing levees. New fringing marsh could establish outboard of setback levees. The minimum levee setback distance needed for habitat and erosion benefit will need to be determined on a project-by-project basis. While these fringing marshes do provide benefits for tidal marsh species, they do not connect to marsh migration space, and they do not meet the goals of creating complete baylands systems nor reconnecting baylands to watersheds. However, levee setbacks and restoration of fringing marshes may be mutually beneficial for landowners and for baylands habitats, as they can reduce levee erosion and slow land subsidence while increasing available habitat. Areas for setback levees would need to be carefully considered to ensure they achieve management and restoration objectives and do not preclude long-term adaptation. Further discussions with private landowners in these areas are needed to determine the cost-effectiveness and viability of pursuing this type of restoration.

Landward of levees, seasonal wetlands can be promoted by decreasing pumping of rainwater to promote ponding later into the season. This allows continued agricultural use and provides freshwater wetland habitat for waterbirds. During periods of drought, ponded winter habitat in

San Francisco Bay becomes particularly important for the 6-8 million waterfowl that use the Central Valley. Specifically, freshwater wetlands at the edges of the Bay would benefit dabbling ducks, which prefer managed wetlands over tidal habitats (Cassaza, 2021). In addition, seasonal wetlands would slow subsidence as decomposition of organic matter in the soil is reduced when land is kept wet. This would increase the resilience of future baylands habitats when False Bay eventually returns to tidal action, planned or unplanned. This strategy is more likely to be successful during wet years than drought years. A critical constraint is invasive species management; prolonged artificial impoundment of water for seasonal wetlands has led to large infestations by Australian bentgrass (*Agrostis avenacea*) (Meisler 2012), stinkwort (*Dittrichia graveolens*) and yellow star thistle (*Centaurea solstitialis*). Bentgrass can be managed by reducing the period of ponding, grazing in the spring before heightened silica content makes it unpalatable, and/or mowing before seed heads mature. Close coordination with the Marin Sonoma Mosquito Abatement District would be necessary to prevent elevated mosquito populations. While seasonal wetlands in diked baylands are not a sustainable long-term restoration target, these benefits may make this strategy worth pursuing in the near term. Seasonal wetland restoration may be pursued in more landscape-appropriate areas (outside the historical baylands).

8.2 Starting implementation of the Landscape Vision

Implementing the Landscape Vision calls on voluntary participation of landowners, either through sale of fee title interest, conservation easement, and/or changes in land use practices. The number, size, and configuration of privately owned parcels means that a flexible approach will be needed to address the parcel-by-parcel nature of conservation planning and implementation, and to ensure that conservation actions are planned strategically and efficiently to maximize habitat benefits and minimize costs. For example, acquiring and restoring tidal action to a parcel surrounded by private, non-conservation parcels would require surrounding the restoration property with levees, driving the cost/benefit ratio beyond what is practical. Instead, an “acquire and hold” strategy might be prudent in this situation. The existing land use might remain unchanged until additional connected parcels make restoration feasible.

Although a large core of protected land is already under public ownership, acquisition of adjacent lands from willing sellers can expand the extent of natural areas, offering increased connectivity and patch size that promotes and enables natural processes such as species movement, flooding, and marsh migration to occur. Such processes build resilience against chronic and sudden perturbations. Some of these privately owned areas are already functioning tidal marsh with little threat of development. However, strategic acquisition may still be important to enable large-sale management actions such as control of invasive species (e.g., perennial pepperweed) or to enable access for cultural practices, natural history education and other interpretive work that furthers public appreciation of and engagement with these vital areas.

Where new lands are acquired for immediate or near-term restoration, project designs will need to carefully consider changes to hydrodynamics and tidal prism to ensure that the levees of other properties remaining in their current uses are not undermined by restoration of neighboring properties. Similarly, landowners in regions such as False Bay have interconnected stormwater pumping systems. Any restoration or changes in land use must consider impacts on neighboring lands. This is not to say that neighboring lands might not see a benefit or reduction in flooding—only that it is an essential consideration.

Other constraints may also arise as individual parcels are restored. One key consideration is land contamination. For decades, Class B biosolids from the City of Santa Rosa’s Laguna Treatment Plant, as well as other sources, have been applied to large acreages of diked agricultural baylands within the study area, particularly in the Lakeville, False Bay, and San Pablo Bay subunits. The baylands provide a relatively low cost disposal area for this community byproduct while also boosting the productivity of hayfields. However, it is unclear whether and how the legacy of this practice will impact environmental quality following future flooding of baylands from tidal wetland restoration or unplanned flooding resulting from sea level rise and storms. A preliminary review found that the contaminant levels in soils at land application sites are below recommended wetland criteria for most metals, but that wetland criteria are exceeded for some metals (Table 2, Bay Area Biosolids Coalition and others 2022). More research is needed to determine the potential impacts of and best practices for restoring tidal action to baylands sites where biosolids have been applied. Additionally, the impacts of future biosolids land application on restoration efforts should be carefully weighed against the benefits of continued or expanded land application. The Laguna Treatment Plant is studying alternatives for disposal but this may take a decade or more to achieve. A recent white paper provides an overview of the potential constraints and opportunities associated with land application of biosolids in the baylands (Bay Area Biosolids Coalition and others 2022).

8.3 Recommendations for further study

Further scientific analysis is needed as a basis for decision making regarding several elements of this Strategy. Improved hydrodynamic modeling is needed to better understand the challenges and opportunities associated with improving habitat and flood management at Rush Creek and Cemetery Marsh, including how long an improved tide gate may be able to achieve habitat and flood management goals. Hydrodynamic modeling is also needed at a broader scale to understand how changes in the Petaluma River Baylands, including tidal restoration and reduced channel dredging, will influence flood conditions in the City of Petaluma.

Sediment supply is a key uncertainty that will determine the evolution of restoration projects. Restoring sooner rather than later, reactivating alluvial fans at creek mouths, and/or using dredge material to increase base elevations prior to tidal restoration can increase the likelihood of restored baylands reaching marsh elevation and persisting as tidal marshes as rates of sea-level rise increase. There is variation in sediment supply across the Petaluma baylands, with highest sediment supply near the mouth of the river. Science-informed decision-making on dredging and beneficial use of sediment could enhance the resilience of restoration projects undertaken in areas with lower sediment supply.

Qualified professional archaeologists and Native American representatives should continue to provide cultural resources recommendations and establish potential decision-making considerations for future projects within the Petaluma Baylands Strategy Study Area. The background information and outreach meetings with Graton Rancheria as presented in the Cultural Resources Report demonstrate cultural and tribal resources sensitivity within the Study Area and provide numerous avenues for further studies including, but not limited to: fieldwork, tribal management practices, and cultural landscape analysis.

Chapter 9: Conclusion

The Petaluma River Baylands Strategy provides a comprehensive Landscape Vision for the baylands in addition to multiple scenarios that take into account the range of opportunities and constraints associated with working in a diverse landscape. The large number of privately owned parcels, infrastructure uncertainties, and multitude of land use complexities mean that any restoration efforts in the baylands will be pursued strategically over time, as opportunities arise rather than in one sweeping effort.

Arguably, the most important factors influencing implementation of the Petaluma River Baylands Strategy are the participation by private landowners and transportation corridor improvements. In particular, the timelines of each of these factors will influence how, when, and where pieces of the Landscape Vision can be implemented. Where private landowners choose not to participate, minimizing incompatible land uses that could inhibit future restoration is a key consideration. Continued close coordination with transportation agencies to ensure that transportation improvements advance conservation objectives is essential to implementation of this Strategy.

Given the importance of timing in tidal marsh restoration, multiple efforts are underway to expedite regulatory processes. These include programmatic California Environmental Quality Act (CEQA) review processes by California Department of Fish and Wildlife and by the State Board. For more information on regulatory considerations for project implementation, refer to Appendix E. These processes are new and broad application for projects like those highlighted here could shorten project timelines potentially by months or years.

This Strategy reflects a conservation vision, and more detail will be needed as projects are planned and implemented. Additional steps needed at the project scale will include development of restoration designs, conducting hydrodynamic, geotechnical and other studies, development of environmental compliance strategies, collaboration with tribes, and early consideration of public access. Wherever possible, individual projects should be designed to contribute toward implementation of the Landscape Vision. The overarching strategies outlined in Chapter 5 (e.g. protection of marsh migration space, connectivity from baylands to watersheds) can be refined at the site scale based on local conditions. Over time, coordinated and thoughtful implementation of restoration and conservation projects can contribute to achieving a connected, resilient, and biodiverse landscape in the Petaluma River Baylands.

References

Barnard, P. L., M. van Ormondt, L. H. Erikson, J. Eshleman, C. Hapke, P. Ruggiero, P. N. Adams, and A. C. Foxgrover. 2014. Development of the Coastal Storm Modeling System (CoSMoS) for Predicting the Impact of Storms on High-Energy, Active-Margin Coasts. Natural Hazards 74:1095-1125.

Baumgarten, S.A., Clark, E.E., Dusterhoff, S.R., Grossinger, R.M., Askevold, R.A. 2018. Petaluma Valley Historical Hydrology and Ecology Study. Prepared for the Sonoma Resource Conservation District and U.S. Environmental Protection Agency. A Report of SFEI-ASC's Resilient Landscapes Program, SFEI Publication #861, San Francisco Estuary Institute, Richmond, CA.

Bay Area Biosolids Coalition, Bay Area Clean Water Agencies, Ducks Unlimited, San Francisco Bay Joint Venture, San Francisco Estuary Institute, and Sonoma Land Trust. Biosolids in the Baylands: Exploring compatibility of biosolids use with wetland restoration in the San Francisco Baylands. 2022.

Baye, P.R., Faber, P.M., Grewell, B. 2000. Tidal marsh plants of the San Francisco Estuary. Pages 9-32 in: Olofson PR, ed. 2000. Baylands Ecosystem Species and Community Profiles: life histories and environmental requirements of key plants, fish, and wildlife. Goals Project (Baylands Ecosystem Habitat Goals), San Francisco Regional Quality Control Board, Oakland, California.

Baye, P. 2008. Vegetation Management in Terrestrial Edges of Tidal Marshes, Western San Francisco Estuary, California. Prepared for Marin Audubon Society.

Baye, P.R. 2016. Memorandum: Preliminary project concept for Ellis Creek bayland horizontal levee, Petaluma Marsh. Submitted to Carlos Diaz, Environmental Science Associates.

Buffington, K.J., and Thorne, K.M. 2019. LEAN-corrected San Francisco Bay digital elevation model, 2018: U.S. Geological Survey data release, https://doi.org/10.5066/P97J9GU8.

Buffington, K. J., Janousek, C. N., Dugger, B. D., Callaway, J. C., Schile-Beers, L. M., Borgnis Sloane, E., & Thorne, K. M. 2021. Incorporation of uncertainty to improve projections of tidal wetland elevation and carbon accumulation with sea-level rise. Plos one, 16(10), e0256707.

CA OPC (California Ocean Protection Council). 2018. State of California sea-level rise Guidance: 2018 Update.

Caltrans. 2020. Caltrans Adaptation Priorities Report: District 4. 2020.

Caltrans. 2022. State Route 37 Planning and Environmental Linkages Study. Prepared by ICF and Jacobs for Caltrans District 4.

Casazza, M.L., McDuie, F., Jones, S., Lorenz, A., Overton, C., Yee, J., Feldheim, C., Ackerman, J., Thorne, K., 2021. Waterfowl use of wetland habitats informs wetland restoration designs for multi-species benefits. J Appl Ecol. 58:1910–1920. https://doi.org/10.1111/1365-2664.13845

CDFW (California Department of Fish and Wildlife). 1982. Draft Management Plan for Petaluma State Wildlife Area.

CDFW (California Department of Fish and Wildlife). 2015. California State Wildlife Action Plan, 2015 Update: A Conservation Legacy for Californians. Edited by Armand G. Gonzales and Junko Hoshi, PhD. Prepared with assistance from Ascent Environmental, Inc., Sacramento, CA.

CDFW (California Department of Fish and Wildlife). 2019. “Petaluma Marsh Wildlife Area.” Updated 11/7/19. Accessed 12/6/19. https://www.wildlife.ca.gov/Lands/Places-to-Visit/Petaluma-Marsh-WA

CDM. 2000. San Pablo Bay Watershed Restoration Framework Program. http://www.krisweb.com/biblio/nsfb_usace_campdressermcgee_2000.pdf

Collins, J., Didonato, J., Geupel, G., Grenier, L., Kucera, T., Lidicker, B., Rainey, B., Rotterborn, S., Grossinger, R., Brewster, E., Larned, K., Salomon, M. 2007. Ecological Connections between Baylands and Uplands: Examples from Marin County. Prepared for the Marin Audubon Society, Marin Conservation League, Marin Baylands Advocates, and the Sierra Club. A Report of SFEI-ASC’s Wetlands Science Program, SFEI Publication #521, San Francisco Estuary Institute, Richmond, CA.

Cornwall, C., S. Moore, D. DiPietro, S. Veloz, L. Micheli, L.Casey, M. Mersich. 2014. Climate Ready Sonoma County: Climate Hazards and Vulnerabilities. Prepared as part of Climate Action 2020 by North Bay Climate Adaptation Initiative for Sonoma County Regional Climate Protection Authority. Santa Rosa, CA.

County of Marin. 2016. “Proposed airport runway extension reduced.” https://www.marincounty.org/main/county-press-releases/press-releases/2016/dpw-gnoss-050216

CWMW (California Wetlands Monitoring Workgroup). EcoAtlas. Accessed 12/6/19. https://www.ecoatlas.org.

Dusterhoff, S., McKnight, K., Grenier, L., Kauffman, N. 2021. Sediment for Survival: A Strategy for the Resilience of Bay Wetlands in the Lower San Francisco Estuary. SFEI Contribution No. 1015. San Francisco Estuary Institute: Richmond, CA.

FAA (Federal Aviation Administration). 2019. Draft Supplement to the Final Environmental Impact statement: Extend Runway 13/31 Gnoss Field Airport. Public hearing presentation. http://www.gnossfieldeis-eir.com/pdf/Updated%20Final%20FAA%20DVO%20SEIS%20-%20Public%20Hearing%2008-12-2019.pdf

Federated Indians of Graton Rancheria. 2023. https://gratonrancheria.com/culture/history/. Accessed 4/13/2023.

Ganju, N. K., Defne, Z., Kirwan, M. L., Fagherazzi, S., D'Alpaos, A., & Carniello, L. 2017. Spatially integrative metrics reveal hidden vulnerability of microtidal salt marshes. Nature Communications, 8, 14156.

Goals Project. 1999. Baylands Ecosystem Habitat Goals. A Report of Habitat Recommendations Prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. U.S. Environmental Protection Agency and S.F. Bay Regional Water Quality Control Board, San Francisco and Oakland, CA.

Goals Project. 2015. The baylands and climate change: what we can do. Baylands Ecosystem Habitat Goals Science Update 2015. California State Coastal Conservancy. Oakland, California.

Hayden, M., L. Salas, N. Eliott, D. Jongsomjit, S. Veloz, N. Nur, J. Wood, H. Papendick, and K. Malinowski. 2019. Informing sea-level rise adaptation planning through quantitative assessment of the risks and broader consequences of tidal wetland loss: A case study in San Mateo County.

Li, S., T. Wahl, S.A. Talke, D.A. Jay, P.M. Orton, X. Liang, G. Wang, and L. Liu. 2021. Evolving tides aggravate nuisance flooding along the U.S. coastline. Science Advances, 7(10).

Marin County Open Space District. 2019. “Rush Creek Preserve.” Accessed 12/6/19. https://www.marincountyparks.org/parkspreserves/preserves/rush-creek

Meisler, J. 2012. Best laid plans...Australian bentgrass (*Agrostis avenacea*) invades following seasonal wetland enhancement. Cal-IPC News. Summer 2012 - Volume 20 Number 3. https://www.cal-ipc.org/docs/resources/news/pdf/Cal-IPC_News_Summer12.pdf

MTC (Metropolitan Transportation Commission). 2022. State Route 37 Ultimate Sea Level Rise Resilience Design Alternatives Assessment - Marin–Sonoma (US 101 – SR 121). https://scta.ca.gov/wp-content/uploads/2022/03/SR37DAA_US101_SR121_Report.pdf

MTC (Metropolitan Transportation Commission). 2023. Regional Trails and Parks. https://mtc.ca.gov/operations/regional-trails-parks. Accessed 4/20/2023.

NMFS (National Marine Fisheries Service). 2016. Final Coastal Multispecies Recovery Plan for California Coastal Chinook Salmon, Northern California Steelhead and Central California Coast Steelhead. Volume 4: Central California Coast Steelhead DPS.

Nowacki, D. J., & Ganju, N. K. 2019. Simple metrics predict salt‐marsh sediment fluxes. Geophysical Research Letters, 46(21), 12250-12257.

OHP (California State Parks: Office of Historic Preservation). 2022a. California Historical Landmarks: Marin County https://ohp.parks.ca.gov/?page_id=21429. Accessed 8/2022.

OHP (California State Parks: Office of Historic Preservation). 2022b. California Historical Resources: Marin County https://ohp.parks.ca.gov/ListedResources/?view=county&criteria=21. Accessed 8/2022.

Petaluma Wetlands Alliance. 2019. “Ellis Creek Water Plant.” Accessed 1/9/20. https://petalumawetlands.org/wetlands/

Raposa, K. B., Wasson, K., Smith, E., Crooks, J. A., Delgado, P., Fernald, S. H., ... & Puckett, B. 2016. Assessing tidal marsh resilience to sea-level rise at broad geographic scales with multi-metric indices. Biological Conservation, 204, 263-275.

Redwood Landfill Solid Waste Facilities Permit Revision, Final Supplemental Environmental Impact Report. 2005. Prepared for County of Marin by ESA, Environmental Science Associates. SCH No. 1991033042. https://www.marincounty.org/~/media/files/departments/cd/planning/environmental-impact/redwoodlandfill/redwoodlandfillfeirvol_i.pdf?la=en

Reed, D., B. van Wesenbeeck, P. M. Herman, and E. Meselhe. 2018. Tidal Flat-Wetland Systems as Flood Defenses: Understanding Biogeomorphic Controls. Estuarine, Coastal and Shelf Science.

Robinson, A., Fulfrost, B., Lowe, J., Nutters, H., Bradt, J. 2017. Transition Zone Mapping Methodology: Integrating the Bay Margin and Upper Boundary Methods. San Francisco Estuary Partnership, San Francisco Estuary Institute. Sept. 2017.

San Francisco Bay Regional Water Quality Control Board. 2009. Order No R2-2009-0053: Updated Waste Discharge Requirements And Rescission Of Order No. 95-110 For: Redwood Landfill, Inc. Class III Solid Waste Disposal Facility, Novato, Marin County. https://www.waterboards.ca.gov/rwqcb2/board_decisions/adopted_orders/2009/R2-2009-0053.pdf

Sanderson EW, Ustin SL, Foin TC. 2000. The influence of tidal channels on the distribution of salt marsh plant species. Plant Ecology 146:29-41

Schile, L.M., Callaway, J.C., Morris, J.T., Stralberg, D., Parker, V.T., Kelly, M. 2014. Modeling Tidal Marsh Distribution with sea-level rise: Evaluating the Role of Vegetation, Sediment, and Upland Habitat in Marsh Resiliency. PLoS ONE 9(2): e88760. https://doi.org/10.1371/journal.pone.0088760

SFBJV (San Francisco Bay Joint Venture). 2022. Restoring the Estuary - A Framework for the Restoration of Wetlands and Wildlife in the San Francisco Bay Area. Richmond, CA.

SFEI (San Francisco Estuary Institute). 2016. San Francisco Bay Shore Inventory: Mapping for Sea Level Rise Planning. San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA.

SFEI and Peter Baye. 2020. New Life for Eroding Shorelines: Beach and Marsh Edge Change in the San Francisco Estuary. Publication #984, San Francisco Estuary Institute, Richmond, CA.

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

Siegel Environmental. 2022. Sears Point Tidal Marsh Restoration Project Monitoring Report, Years 1 through 5, October 2015 to October 2020. Prepared for Sonoma Land Trust.

SMART (Sonoma-Marin Area Rail Transit). 2014. Sea Level Rise Vulnerability Assessment and Adaptation Strategy for Initial Operating Segment (IOS)-1 South and Haystack Landing Bridge Replacement. Prepared by ICF, GHD, and SMART for the San Francisco Bay Regional Water Quality Control Board. https://www.sfestuary.org/wp-content/uploads/2014/05/SMART-IOS1S-SLR-2014.pdf

SMART (Sonoma-Marin Area Rail Transit). 2022. State Route 37 Highway Improvements and SMART – Draft White Paper. Board of Directors Packet, April 6, 2022.

Sonoma County. 2010. 2010 Sonoma County Bicycle and Pedestrian Plan. https://sonomacounty.ca.gov/a/107749

Sonoma Land Trust. 2022. Sears Point Levee Adaptive Management Project: As Built Report. Prepared by Siegel Environmental for Sonoma Land Trust.

SRCD (Sonoma Resource Conservation District). 2022. Petaluma River Watershed Conservation and Enhancement Plan.

Stralberg, D., Brennan, M., Callaway, J. C., Wood, J. K., Schile, L. M., Jongsomjit, D., ... & Crooks, S. 2011. Evaluating tidal marsh sustainability in the face of sea-level rise: a hybrid modeling approach applied to San Francisco Bay. PloS one, 6(11).

State Route 37 – Baylands Group. 2017. San Pablo Baylands: Ensuring a Resilient Shoreline.

Takekawa, J. Y., Thorne, K. M., Buffington, K. J., Spragens, K. A., Swanson, K. M., Drexler, J. Z., ... Casazza, M. L. 2013. Final report for sea-level rise response modeling for San Francisco Bay estuary tidal marshes. US Geological Survey.

Thorne, K., G. Macdonald, G. Guntenspergen, R. Ambrose, K. Buffington, B. Dugger, C. Freeman, C. Janousek, L. Brown, J. Rosencranz, J. Hlomquist, J. Smol, K. Hargan, J. Takekawa. 2018. U.S. Pacific coastal wetland resilience and vulnerability to sea-level rise. Science Advances. Vol. 4, no. 2, eaao3270. DOI: 10.1126/sciadv.aao3270

USACE (U.S. Army Corps of Engineers), San Francisco District. 2018. Public Notice for Halo Ranch Mitigation Bank Project. Public Notice Number 2017-00478N.

USFWS (U.S. Fish and Wildlife Service). 2011. San Pablo Bay National Wildlife Refuge Final Comprehensive Conservation Plan. Prepared by USFWS San Francisco Bay National Wildlife Refuge Complex

USFWS (U.S. Fish and Wildlife Service). 2013. Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California. Sacramento, California. xviii + 605 pp.

USFWS (U.S. Fish and Wildlife Service). 2019. Natural Resource Management Plan for the San Francisco Bay National Wildlife Refuge Complex. National Wildlife Refuge System, Pacific Southwest Region, Sacramento, CA.

USFWS (U.S. Fish and Wildlife Service), CA Department of Fish and Game (CDFG), and Sonoma Land Trust (SLT). 2012. Sears Point Wetland and Watershed Restoration Project, Sonoma County, CA; Final Environmental Impact Report and Environmental Impact Statement.

Veloz, S. D., N. Nur, L. Salas, D. Jongsomjit, J. Wood, D. Stralberg, and G. Ballard. 2013. Modeling climate change impacts on tidal marsh birds: Restoration and conservation planning in the face of uncertainty. Ecosphere 4.

Veloz, S., Wood, J., Jongsomjit, D., Block, G., and Robinson, K. F. 2016. San Pablo Bay National Wildlife Refuge Climate Adaptation Plan. USFWS.

Wasson, K., Ganju, N. K., Defne, Z., Endris, C., Elsey-Quirk, T., Thorne, K. M., Freeman, C. M., Guntenspergen, G., Nowacki, D. J., & Raposa, K. B. 2019. Understanding tidal marsh trajectories: evaluation of multiple indicators of marsh persistence. Environmental Research Letters: ERL [Web Site], 14(12), 124073.

Waste Management (WM). 2020. “Redwood Landfill.” Accessed 1/9/20. http://redwoodlandfill.wm.com/index.jsp

Water Technology. 2020. “Ellis Creek Water Recycling Facility.” Accessed 1/9/20. https://www.water-technology.net/projects/ellis-creek/

WRMP (Wetlands Regional Monitoring Program). 2020. San Francisco Estuary Wetland Regional Monitoring Program Plan prepared by the WRMP Steering Committee. San Francisco Estuary Partnership, San Francisco, CA.