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CLIMATE CHANGE SYNTHESIS

South Bay Salt Pond Restoration Project Phase 2

January 2020

South Bay Salt Pond Restoration Project
Phase 2 Climate Change Synthesis Report

Report to the South Bay Salt Pond Restoration Project and the California Wildlife Foundation

Final – January 2020

Prepared by

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SAN FRANCISCO BAY
RESTORATION AUTHORITY

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Cover photo: Projected flood extent in South San Francisco Bay with 3 ft of sea level rise.
(Source: ART Bay Area Flood Explorer, https://explorer.adaptingtorisingtides.org; aerial imagery: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community)

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1. INTRODUCTION

The San Francisco Estuary (hereafter, Estuary) contains some of California's most important ecosystems, providing human communities with invaluable benefits ranging from commercial and sport fishing, pollutant filtration, strengthened shorelines, and habitat for diverse species, including many endangered and endemic species. The people of the San Francisco Bay Area value these benefits and, in an attempt to recover large-scale historical losses, have invested in the restoration of vast acres of baylands to tidal marsh and other productive habitats. Bay Area voters passing the Measure AA parcel tax in 2016 exemplifies the strong community support for protecting and restoring the Bay's wetland habitats.

As the largest tidal wetland restoration project on the West Coast, the South Bay Salt Pond Restoration Project (Project) plays a critical role in protecting and restoring the Estuary. When complete, the Project will have restored 15,100 acres of industrial salt ponds to a rich mosaic of tidal wetlands and other habitats. The Objectives as defined by the Project's Adaptive Management Plan (Trulio et al. 2007) are to:

1. Create, restore, or enhance habitats of sufficient size, function, and appropriate structure to:
    a. Promote restoration of native special-status plants and animals that depend on South San Francisco Bay habitat for all or part of their life cycles.
    b. Maintain current migratory bird species that utilize existing salt ponds and associated structures such as habitat berms.
    c. Support increased abundance and diversity of native species in various South San Francisco Bay aquatic and terrestrial ecosystem components, including plants, invertebrates, fish, mammals, birds, reptiles and amphibians.
2. Maintain or improve existing levels of flood protection in the South Bay area.
3. Provide public access opportunities compatible with wildlife and habitat goals.
4. Protect or improve existing levels of water and sediment quality in the South Bay and take into account ecological risks caused by restoration.
5. Implement design and management measures to maintain or improve current levels of vector management, control predation on special status species and manage the spread of non-native invasive species.
6. Protect the services provided by existing infrastructure (e.g. power lines).

As the Project moves into construction of its Phase 2 actions, the potential effects of climate change are a primary issue of concern, and there is a pressing need to understand how climate change may affect the ability to achieve the above Project Objectives. This Climate Change Synthesis is intended as a first step to address this need and is guided by three main goals:

1. To provide context for adaptive management as the Project moves forward,
2. To identify the anticipated key impacts of climate change to Project Objectives, and
3. To offer potential strategies or actions that address climate change impacts and could be implemented in the coming Project phases.

Our approach in developing this report was to build on existing summaries of climate change information that have been synthesized for the San Francisco Bay region and the Project by conducting a targeted literature review focusing on climate change factors that could inhibit achieving Project Objectives. Climate change information was summarized as part of the Phase 1 Studies Summary (Valoppi 2018), so we have focused on synthesizing recent information not already discussed in detail.

This Climate Change Synthesis will, along with a Science Synthesis (Wood et al. 2019; hereafter Science Synthesis Report), be used to inform the Phase 2 Science Framework for the Project. The Science Framework will guide the prioritization of management decisions, including future studies and monitoring for the Project. The Phase 2 science will ultimately provide the scientific foundation for the types of implementation considered for future phases of the Project.

2. RECENT CLIMATE CHANGE PROJECTIONS AND EFFECTS RELEVANT TO THE PROJECT

The San Francisco Bay Area is characterized by a Mediterranean climate with warm, dry summers and cool, wet winters. The cool ocean and bay waters help moderate temperatures, keeping winters warmer and summers cooler relative to regions further inland. The region is already experiencing changes in both average conditions and extreme events related to changes in sea level, precipitation, and temperature, and these changes are projected to accelerate depending on the long-term trajectory of global greenhouse gas emissions (Ackerly et al. 2018). These climate changes increase stressors such as heat events, flooding, and changes in sediment dynamics and water quality, which have the potential to affect the ability of the Project to achieve its long-term objectives.

2.1. SEA LEVEL RISE

2.1.1. Mean sea level

Long-term sea levels are rising as a result of climate change, caused primarily by thermal expansion of oceans and melting of land-based ice. However, sea level is not the same everywhere across the globe. In the Pacific, regional sea level trends are also affected by climate cycles such as the Pacific Decadal Oscillation (PDO[1]) and El Niño Southern Oscillation (El Niño). More locally in the San Francisco Bay Area, relative sea level is also affected by rates of vertical land motion from tectonic uplift or subsidence, groundwater pumping, marsh accretion, and compaction (Ackerly et al. 2018).

Most places along the California coast have experienced a rise in sea level of 4-8 inches (10-20 cm) in the 20th Century (Griggs et al. 2017), or a mean annual rise of 1-2mm/year. The recent historical rate of sea level rise measured at the Redwood City tide gauge is 2.47 mm/year (1974-2018), with acceleration noted since 2011 (NOAA 2019). The recent acceleration is consistent with observations throughout the West Coast, and is in part a result of a strong 2015 El Niño and the transition in the PDO cycle (Hamlington et al. 2016). Until recently, the PDO cycle has been suppressing the rate of regional sea level rise along the West Coast (Bromirski et al. 2011).

The magnitude and pace of increase in sea level over the next century will partly depend on the trajectory of global greenhouse gas emissions, though a certain amount of rise will occur even if all emissions stopped today due to a lag effect with ocean warming (Griggs et al. 2017). The most alarming recent science indicates the potential for large, catastrophic contributions from Antarctic ice sheet loss (DeCanto and Pollard 2016), which will have a disproportionately high impact on sea level along the California coast (Griggs et al. 2017).

The Ocean Protection Council (OPC) convened a Science Advisory Team to synthesize the latest sea level rise science for the state in 2017 (Griggs et al. 2017), which led to a 2018 update to the State of California Sea Level Rise Guidance (OPC 2018). At the same time, researchers were developing scenarios for the California Fourth Climate Assessment (Pierce et al. 2018). The main difference between the two

[1] Pacific Decadal Oscillation is a long-lived El Niño-like pattern of Pacific ocean-atmosphere climate variability.

efforts was that the Fourth Climate Assessment scenarios included the potential for Antarctic ice sheet loss in the probabilistic assumptions, while the OPC Guidance considered Antarctic ice sheet loss as a separate "H++ scenario". We focus on the projections from the OPC work (Griggs et al. 2017, OPC 2018) because it is specifically intended to guide sea level rise adaptation planning.

The "low emissions" scenario, known as Representative Concentration Pathway (RCP) 2.6, requires aggressive emissions reductions and corresponds most closely to the 2015 Paris Climate Agreement goal of <2 °C of warming. The RCP 2.6 emissions pathway results in projected median sea level rise of 1.6 ft (0.5 m) by 2100, with an upper range (5% probability) of 3.2 ft (1 m) (Figure 1). The high emissions "business-as-usual" scenario (RCP 8.5) results in projected median sea level rise of 2.5 ft (0.76 m), and an upper range (5% probability) of 4.4 ft (1.3 m) by 2100. Notably, the projections under low and high emissions scenarios largely overlap until 2050, when the projections begin to diverge. The H++ "extreme event" scenario (low probability, but physically possible with high consequence) projection is for 10.2 ft (3.1 m) of rise by 2100, with rapid acceleration beginning mid-century.

Recommendations from the latest OPC Sea Level Rise Guidance (OPC 2018) for projects with a lifespan beyond 2050 are to consider a range of low, medium-high, and extreme projections, depending on risk tolerance related to the adaptive capacity of the project and the magnitude of consequence should the project underestimate sea level rise. The recommended range of projections to consider for the Project area are presented in Table 1.

Figure 1. Projections of sea level rise for the San Francisco tide gauge (Credit: Griggs et al. 2017). Dark red and dark blue lines indicate median (50% probability) projections for the given emissions scenario (RCP 2.6 = "low emissions", RCP 8.5 = "high emissions"). Dashed lines indicate the 5% and 95% probabilities for the given emissions scenarios and are colored in to emphasize the range between these two probabilities. The H++ scenario is the extreme case (low probability, but physically possible with high consequence) that factors in potential for ice-loss from Antarctica.

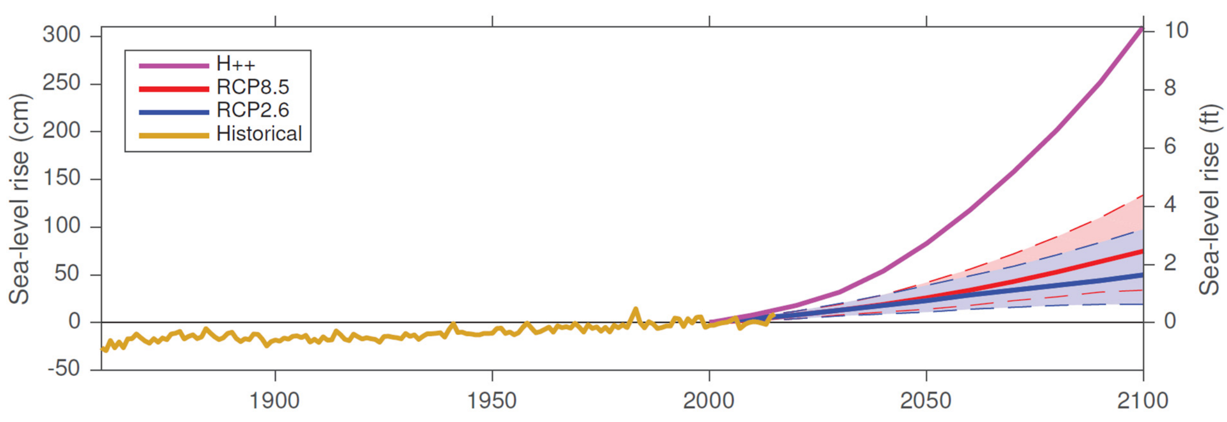


Table 1. Recommended range of sea level rise projections to consider for planning for the South Bay Salt Pond Restoration Project area, based on 2018 OPC Sea Level Rise Guidance and projections for the San Francisco tide gauge.

Risk profile	Sea Level Rise (low - high emissions)	Use considerations
Low risk aversion	2.4-3.4 feet (0.7-1.0 m)	Appropriate for adaptive, lower consequence decisions, but will not adequately address high impact, low probability events
Medium-high risk aversion	5.7-6.9 feet (1.7-2.1 m)	A precautionary projection that can be used for less adaptive, more vulnerable projects or populations that will experience medium to high consequences as a result of underestimating sea level rise. Again, this value may underestimate the potential for extreme sea level rise.
Extreme risk aversion	10.2 feet (3.1 m)	For high consequence projects with a design life beyond 2050 that have little to no adaptive capacity, would be irreversibly destroyed or significantly costly to relocate/repair, or would have considerable public health, public safety, or environmental impacts should this level of sea level rise occur, the H++ extreme scenario should be included in planning and adaptation strategies

2.1.2. Extreme water level events

Coastal water levels are affected not just by static changes in regional mean sea level, but by a combination of dynamic water level components including storm surge (driven by winds and atmospheric pressure), seasonal and climatic cycle effects (e.g., from El Niño), tides, wave runup, and backflow from riverine discharge. Sea level rise can affect coastal flooding directly (i.e., permanently flooding low-lying areas), but also indirectly during episodic events because it alters water depths, changing the dynamics of waves, tides, and storm surges (Vitousek et al. 2017). Thus, long-term changes in wave climate (e.g., changes in magnitude, frequency, and tracks of storms and storm surge), sea level rise, and changes in frequency of seasonal events like El Niño can alter the frequency of extreme water level events that result in episodic coastal flooding and erosion (Vitousek et al. 2017, Barnard et al. 2015).

The wave climate within the Project area is dominated by locally generated wind-waves, and will continue to be largely sheltered from changes in the Pacific Ocean wave climate (e.g., changes to long-period swell) (O'Neill et al. 2017). Large wind-generated waves occur when high wind speed of sufficient duration blows over a long fetch (the distance over water that the wind blows in a single direction), conditions which tend to occur during winter storm events (NCDC 2013, as cited in O'Neill et al. 2017), which typically come from the southerly direction (Ross 2001, as cited in O'Neill et al. 2017). Present day nearshore maximum wave heights in the South Bay are typically <1.6 ft (<0.5 m), and the magnitude of extreme wave heights is not projected to change very much (±5%; O'Neill et al. 2017). Storm-related extreme wave heights are projected to increase slightly in some localized nearshore areas of the Alviso complex in the near-term (2010-2040) and midcentury (2041-2070), but decrease toward end-century (2071-2100) (O'Neill et al. 2017). Storm-related extreme wave heights nearshore of the Ravenswood complex are projected to decrease throughout the 21st century, and results around Eden Landing are neutral with some potential for increase in midcentury (2041-2070) (O'Neill et al. 2017).

Even a small amount of sea level rise is projected to significantly increase the frequency of extreme water level events globally (Vitousek et al. 2017). Along the West Coast, 4 inches (10 cm) of sea level rise is projected to transform the 50-year water level event of today (which has a 2% probability of occurring in any given year today), into a 10-year water level event (10% probability in any given year). In addition, the frequency of El Niño events, such as those that occurred in 1982-83, 1997-98, and 2015-16, are expected to occur more frequently (Cai et al. 2014). The main impact to the Project would be more frequent, seasonally elevated water levels as high as 12 inches (30 cm) above normal (Barnard et al. 2015, 2017), potentially exacerbated in winter when combined with increased riverine discharge that also accompanies El Niño events (see Extreme Precipitation Events below). The net effect is that today's 100-year coastal water level event is projected to occur every 1-5 years by 2050 for much of California (Barnard and Erikson, personal communication).

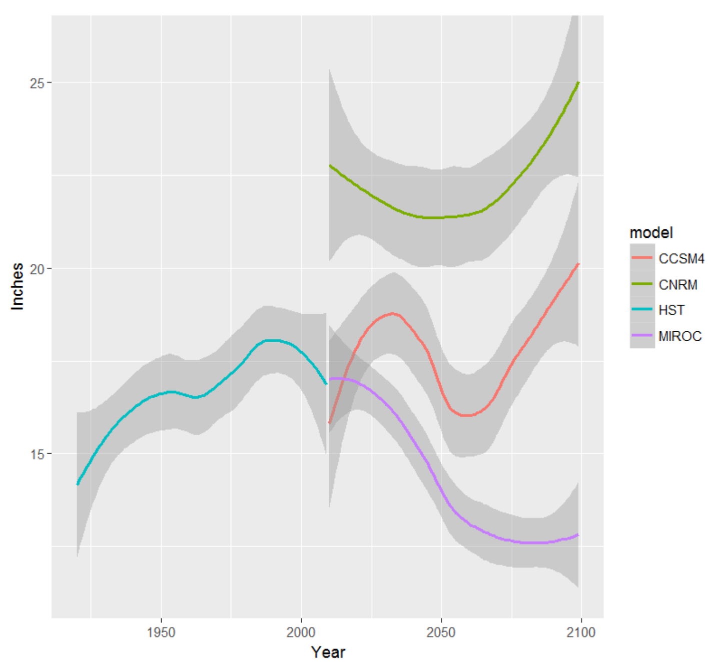
2.2. PRECIPITATION AND ASSOCIATED RUNOFF

2.2.1. Annual precipitation

From 1976 to 2005, there was no discernible trend in annual total precipitation in the Bay Area (Ackerly et al. 2018). Historically, total annual precipitation was highly variable from year to year. From 1950 to 2005, annual precipitation varied between 11.7 and 61.1 inches (30 and 155 cm) (Ackerly et al. 2018). This variability can result in rapid transitions between drought years and high rainfall years, presenting challenges for both water storage and flood risk management. The mean annual total precipitation across the five watersheds that drain to the South Bay (Appendix A) from 1976-2005 was 17.7 inches (±1.8 inches, standard deviation [45 ± 4.6 cm]; USGS 2014).

There is considerable variability in projections of future changes in precipitation from global climate models in terms of both direction and magnitude (Pierce et al. 2018). Multi-model averages project a slight increasing trend in annual precipitation by the end of the century (4.6 inches [11.7 cm] with RCP 8.5 models; Ackerly et al. 2018). However, some individual models do exhibit pronounced changes in annual trends. Focusing on the high emissions RCP 8.5 scenario, the CNRM (Centre National de Recherchés Météorologiques) model projects a much wetter future, the CCSM4 (Community Climate System Model) projects a somewhat wetter future particularly in the latter half of the 21st century and the MIROC (Model for Interdisciplinary Research on Climate) model projects a much drier future (Figure 2).

Figure 2. Total annual precipitation for the five watersheds in South San Francisco Bay. Observed historic (HST) data from 1920-2009 and three future precipitation models (2010-2099) using the "business-as-usual" high emissions RCP 8.5 scenario. Each line represents a loess smooth function fit to the data. The shaded portion around the line represents the variation from the five watersheds included (see watershed map in Appendix A). (Source: USGS 2014).



2.2.2. Seasonal precipitation

Downscaled future climate models for the state of California indicate changes in seasonal precipitation patterns. Multi-model mean projections show a 20% increase in winter precipitation, with a corresponding decrease during the spring by about 20% (Pierce et al. 2018). Projections from the wetter CNRM and CCSM4 models for the five watersheds in the South Bay agree with that statewide pattern of wetter winters and drier springs (Figure 3). The dry MIROC model predicts declines in precipitation consistently across all months (Figure 3). All three future models also project that the annual peak in precipitation will occur earlier, in December and early January, as compared to the historic peak in mid-January (Figure 3). Both of the wetter models indicate a shorter and more intense rainy season in the future.

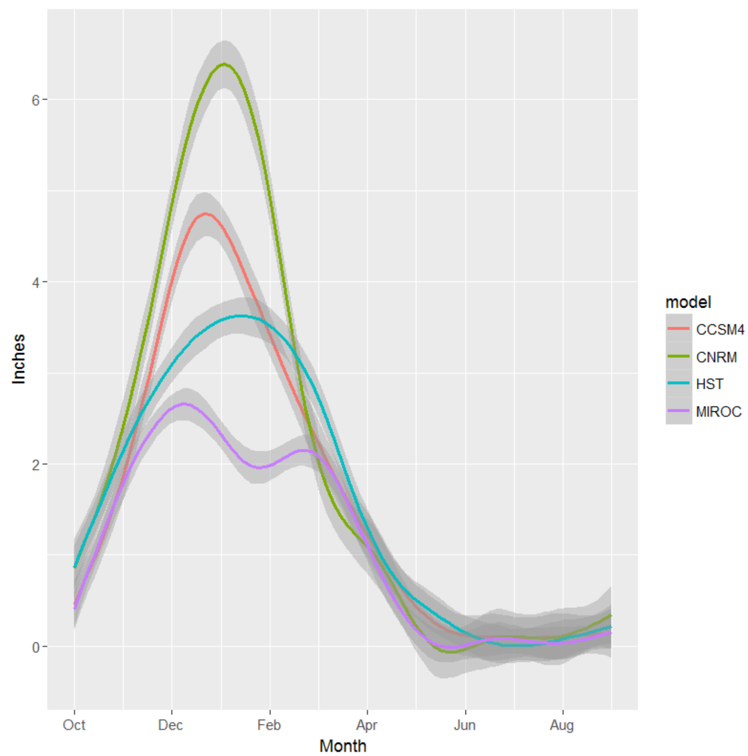


Figure 3. Total monthly precipitation averaged across the five watersheds in South San Francisco Bay for observed historic (1976-2005, HST) and three future climate models (2070-2099). The lines represent a loess smoothed fit to the data. The shaded region around the line indicates the variability in the trend estimate based on interannual variability over the 30-year period and the spatial variation between the five watersheds included (see watershed map in Appendix A). (Source: USGS 2014)

2.2.3. Extreme precipitation events

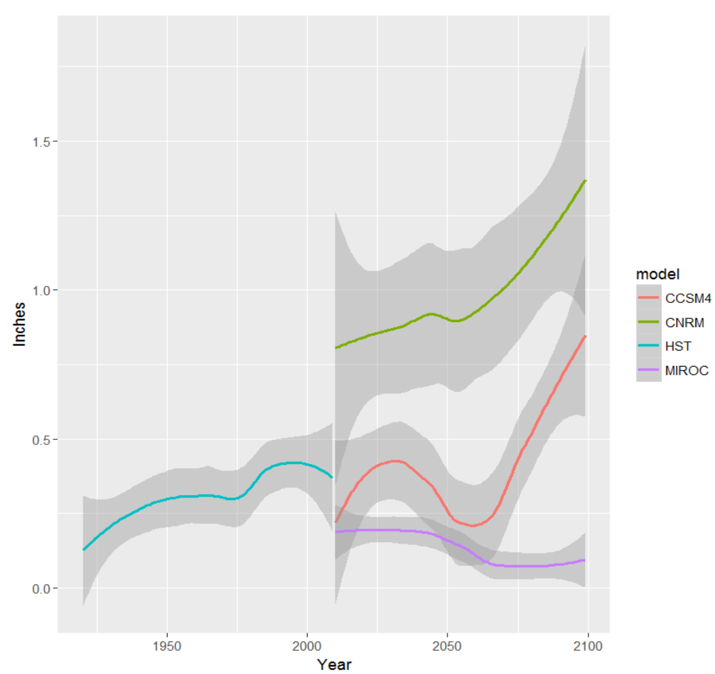
The study of future extreme precipitation events is an emerging area of climatic research and one that is difficult to resolve because the spatial resolution of General Circulation Models (GCMs) is too coarse to capture important mechanisms. There are lines of evidence that suggest that, as climate warms, the atmosphere can hold more moisture, resulting in more extreme precipitation. Climate models used in California's Fourth Climate Assessment projected up to a 37% increase in precipitation during the largest rain events by the end of the century for the RCP 8.5 high emissions scenario (Ackerly et al. 2018). The 1983 El Niño resulted in historic flooding across the state and more locally in the Alviso community. The total annual precipitation in the South Bay during 1983 was not exceeded in any year between 1920 and 2009. However, both the CNRM and the CCSM4 models project increases in the number of years in the future with total annual rainfall greater than 1983. The CNRM model projects five years exceeding the 1983 total while the CCSM4 model projects three years exceeding the 1983 total. The frequency of El Niño events is also projected to increase (see Extreme Water Level Events above).

At the same time that we need to prepare for more rainfall, managers in the Bay Area will also need to prepare for extended periods of drought. Recent analyses of extreme precipitation events provide evidence that single year droughts are likely to increase by 80% in Northern California after 2050 (Swain el al. 2018). Although some future modeling does not project a change in the frequency of multi-year drought from the recent historical record (Swain et al. 2018). Paleo-climatic data provide evidence that California has experienced droughts that lasted decades to centuries (Cook et al. 2010). The 1976 drought in California was only matched one other year between 1920-2009, yet future climate models in the South Bay all project future increases in the number of years with less precipitation than 1976. The drier MIROC model projects a dramatic increase in the number of drought years in the future, with 21 years between 2010-2099 that have less precipitation than 1976. The wetter CCSM4 and CNRM models project 12 and 4 years, respectively, with less precipitation than 1976 between 2010 and 2099. Additionally, increasing air temperatures will result in a greater water deficit in soils even if precipitation increases. Together with declines in the snowpack in the Sierras, drought and drying conditions will result in greater demand for water storage throughout California, including reservoirs in the Bay Area, so that sufficient supply is available for drinking water, irrigation and other human needs. At the same time, concentrated precipitation during shorter periods of the winter (Swain et al. 2018) may result in forced releases of water from reservoirs during storm events resulting in less water available during the dry season. Changes in the management of local reservoirs to maximize storage could affect the flows and water temperatures in the channels and sloughs of the Project.

2.2.4. Runoff

Projections of future changes in runoff are very sensitive to what climate model is used for modeling, but typically these projections are positively correlated with precipitation patterns. As with total annual precipitation, both the CCSM4 and CNRM climate models project an increase in runoff in the future. The CNRM model with the RCP 8.5 scenario projects a dramatic increase in runoff throughout the 21st century within the five watersheds of the South San Francisco Bay (Figure 4). The CCSM4 model projects runoff comparable to historic runoff for the first ¾ of the 21st century but then projects increases after 2075 (Figure 4). The MIROC model projects decreases in future runoff throughout the 21st century.

Figure 4. Annual runoff from the five watersheds in the South San Francisco Bay, based on observed historic data (HST, 1920-2009) and three future climate models using the RCP 8.5 high emissions scenario. Each line is a loess smoothed function fit to the data from each year and watershed. The shaded area around each line represents the error in the trend line estimate based on interannual variability and the spatial variability among watersheds. Note that the five watersheds included in this analysis are all relatively flat topographically (see watershed map in Appendix A). Watersheds upslope have substantially more runoff but the data we extracted from the lower watersheds don't include this runoff. (Source: USGS 2014).



2.3. TEMPERATURE

Air temperatures in the Bay Area have been increasing over the recent historical period. Between 1950 and 2005, annual average maximum temperatures have increased 1.7°F (Ackerly et al. 2018). Most future models consistently project a continued and accelerated increase of temperatures throughout the 21st century with higher greenhouse gas emissions corresponding with greater increases in temperature (Ackerly et al. 2018). Under the high emissions scenario (RCP 8.5) multi-model averages for the Bay Area project an increase in annual mean warming of 4.4°F by mid-century and 7.2°F by the end of the century (2070-2100; Ackerly et al. 2018).

Projected changes in air temperature are fairly consistent across seasons and are of a magnitude that are extreme enough to cause changes to both human communities and ecosystems. For example, air temperature often is a key constraint on the distribution of species. Note that the models project that common summer maximum temperatures at the end of the century equal or exceed the most extreme temperatures from the 20th century (Figure 5). Similar patterns are projected by the models when considering winter temperatures as well (Figure 6).

Figure 5. Box and whisker plots of maximum summer air temperature for observed historic (HST, 1920-2009) and modeled future periods (2010-2099) for five watersheds in the South Bay (see watershed map in Appendix A). The line in the middle of each box is the median value (50% quantile) of the data for each 30-year time period. The upper and lower hinges (box corners) correspond to the 25th and 75th percentile of the data respectively (first and third quartile). The whiskers extend to the highest and lowest values that are 1.5 times the distance between the box hinges (inter-quartile range). Values beyond the whiskers are considered outliers and are plotted as points. Values within the boxes for a time period are more common, or closer to "normal" conditions for the 30-year period. Values at the end of whiskers and/or points can be considered more extreme years for the climate variable. The wider the plot and whiskers the greater the year to year variability in climate. Comparisons across time in the graph can be made by comparing the "normal" conditions in one time period to the extreme years in others.

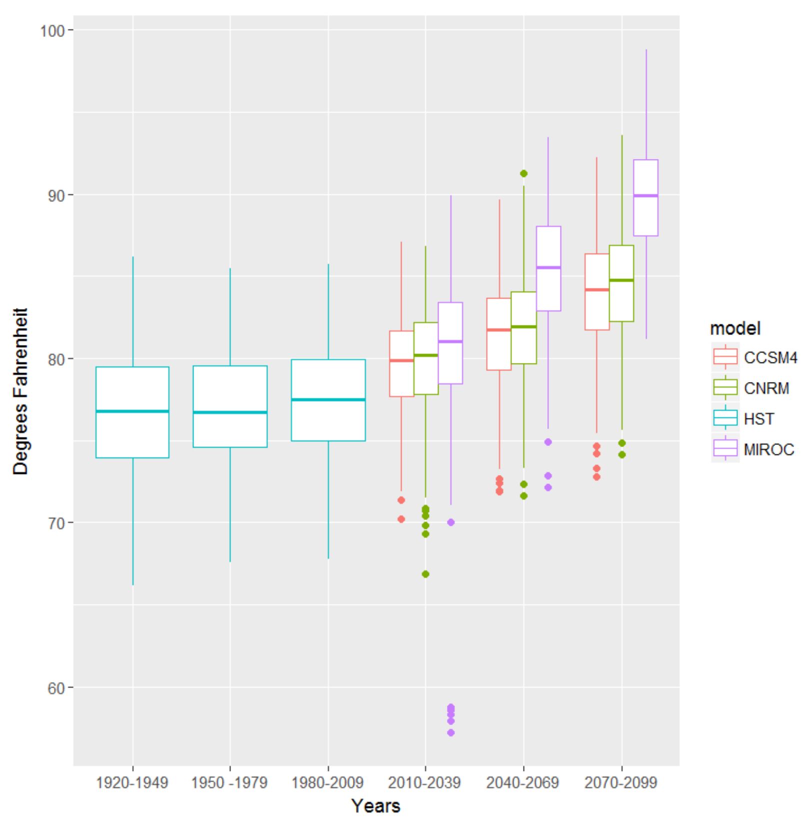
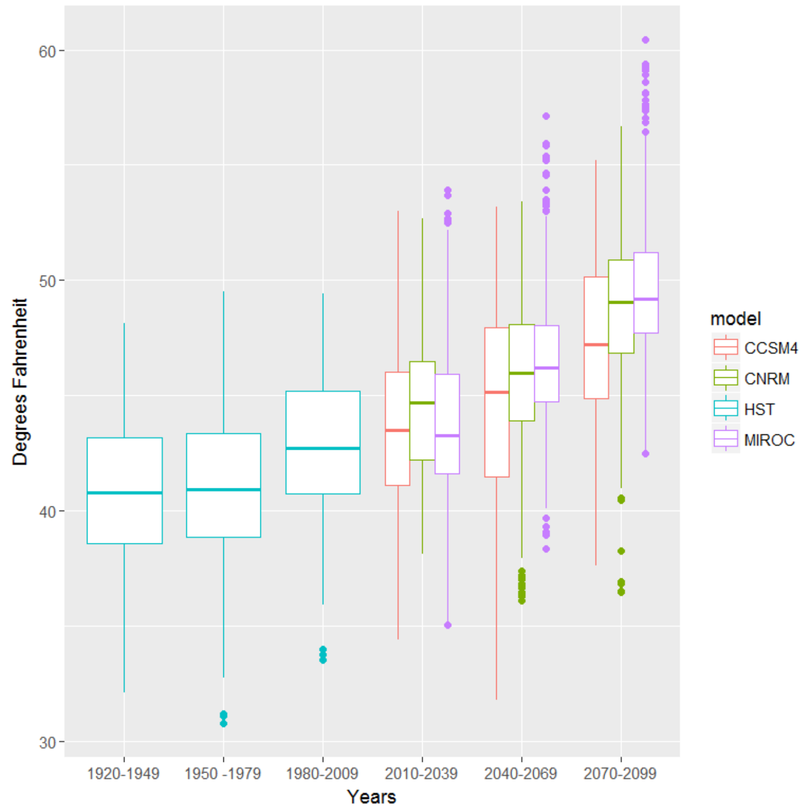


Figure 6. Box and whisker plots of minimum winter temperature for observed historic (HST, 1920-2009) and modeled future periods (2010-2099) for five watersheds in the South Bay (see watershed map in Appendix A). The line in the middle of each box is the median value (50% quantile) of the data for each 30-year time period. The upper and lower hinges (box corners) correspond to the 25th and 75th percentile of the data respectively (first and third quartile). The whiskers extend to the highest and lowest values that are 1.5 times the distance between the box hinges (inter-quartile range). Values beyond the whiskers are considered outliers and are plotted as points. Values within the boxes for a time period are more common, or closer to “normal” conditions for the 30-year period. Values at the end of whiskers and/or points can be considered more extreme years for the climate variable. The wider the plot and whiskers the greater the year to year variability in climate. Comparisons across time in the graph can be made by comparing the “normal” conditions in one time period to the extreme years in others



Not only will seasons become warmer, but typical summer conditions will occur earlier and persist longer in the spring and summer. For example, historically peak maximum summer temperatures occurred during July in the South Bay (Figure 7). However, by 2070-2099 historical July temperatures will be exceeded in May and persist through October. Considering temperature alone, summers will be substantially warmer and summer-like temperatures will persist for longer periods of the year.

Similar to projected summer temperatures, winters of the future will be unlike winters of the past. By the end of the 21st century, models project maximum monthly temperatures in December and January to be similar to historic March temperatures (Figure 7).

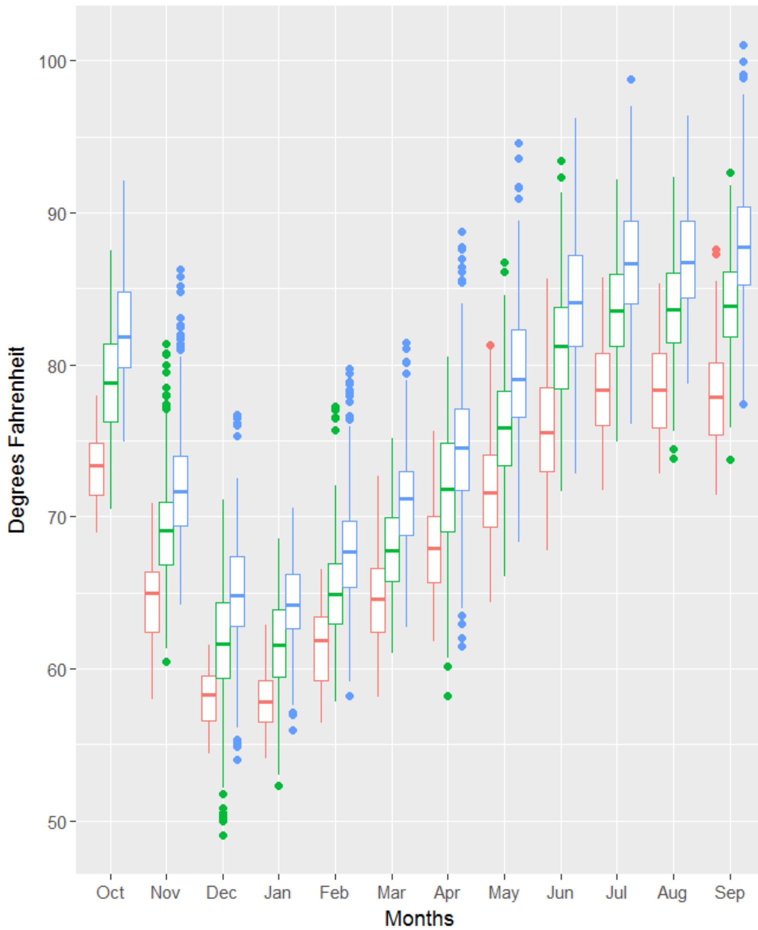


Figure 7. Box and whisker plots of maximum temperature for each month of the year for observed historical climate data (1980-2009) and three future climate models for five watersheds in the South Bay (see watershed map in Appendix A). The data are summarized for each 30-year time period in the data. Note that historical data are added to each future projections panel to enable comparisons.

Similar to air temperature, future models consistently project an increase in sea-surface temperature with increasing greenhouse gas emissions. By the end of the 21st century, models project that sea-surface temperatures will increase between 2.3°F and 4.9°F along the West Coast of the United States (Jewett and Romanou 2017). We can expect water temperature increases to lead to greater oxygen loss from ocean and estuarine waters through absolute warming of water temperatures and through an increase in the seasons in which hypoxia is more likely to occur (Jewett and Romanou 2017).

3. POTENTIAL SHORELINE CHANGES IN PROJECT AREA

Impacts from planned and potential future changes to the shoreline adjacent to Project areas (Figure 8) could exacerbate climate-related impacts. Increased urban shoreline development, such as that being considered at the Cargill Saltworks site in Redwood City[2], will likely require constructing new or improving existing flood risk management infrastructure. In addition, it may increase demand for recreational opportunities (exacerbating wildlife-public use conflicts), and decrease opportunity to strategically relocate communities and infrastructure away from the shoreline in order to create space for marshes to migrate further inland in response to rising seas. How adjacent landowners or jurisdictions ultimately adapt their shorelines or choose to let them degrade in light of sea level rise is a major uncertainty. However, the Project is either leading or has already been in collaboration with most of the planned shoreline protection projects (Figure 8) that would directly influence Project complexes,

[2] https://sanfrancisco.cbslocal.com/2019/08/20/805707/

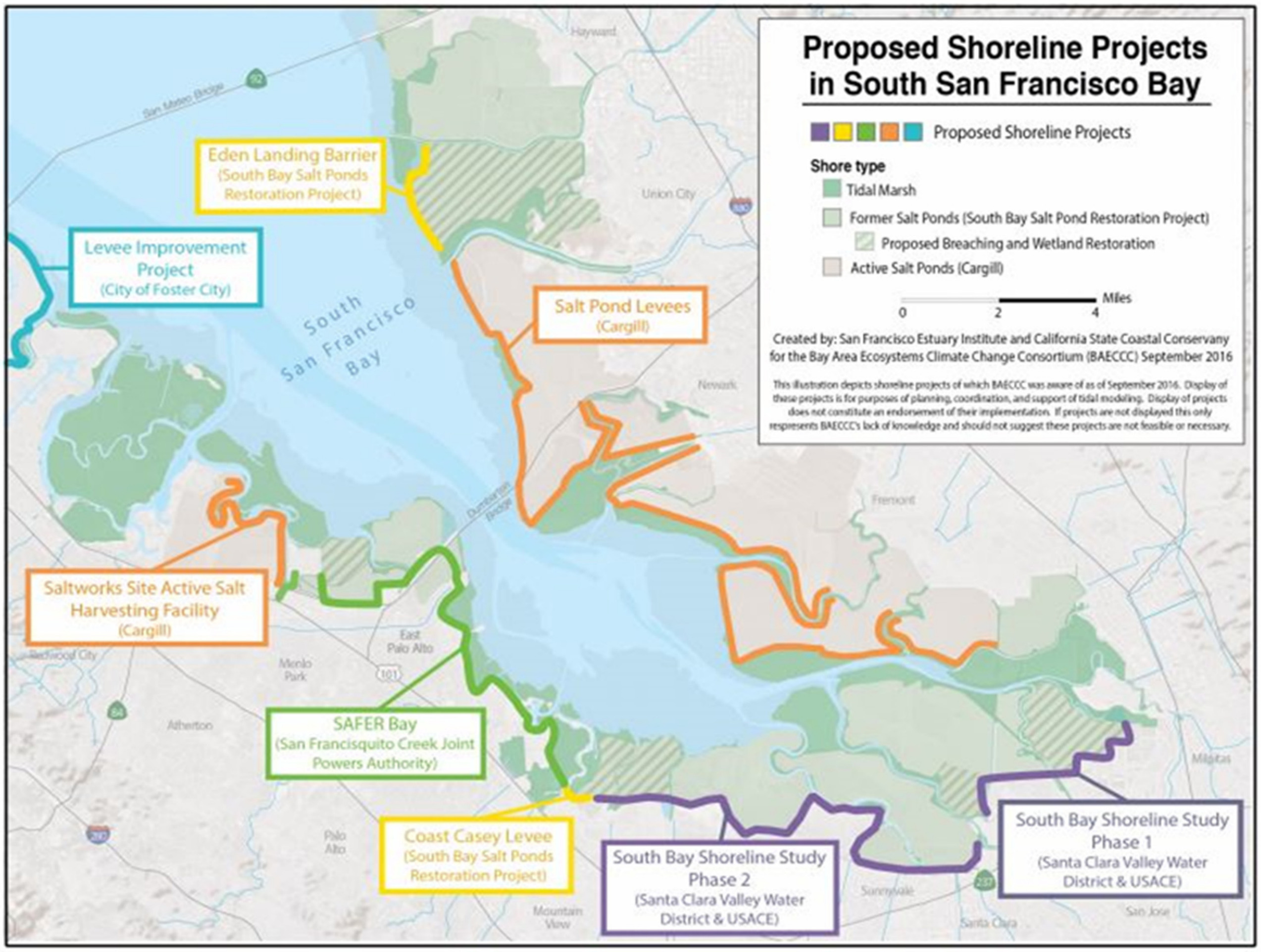
including the Eden Landing Barrier (Eden Landing complex), South Bay Shoreline Study (Alviso complex), Coast Casey Levee, and SAFER Bay (Ravenswood complex), and is in regular communication with Cargill.

Additionally, recent studies have shown that shoreline armoring in one part of the Estuary could increase water surface elevations in other regions of the Estuary, resulting in increased flood risk to habitat and adjacent communities (Wang et al. 2018). For example, there is strong spatial interdependence among the three counties of the South Bay (Alameda, Santa Clara, and San Mateo), where armoring of any individual county has a significant amplifying effect on flooding in the other two counties (Wang et al. 2018). Armoring as far north as Marin and Napa counties can increase water levels in the South Bay as well, particularly at high (4.9 ft [1.5 m]) sea level rise (Wang et al. 2018). Though the effect is small (<4 in [10 cm] increase in maximum water levels), it can increase penetration distance of new inundation waters inland by ~150 ft (50 m) or more (Wang et al. 2018). Considering that many shoreline jurisdictions are already planning for hardened shoreline protection (e.g., Foster City, San Francisco), decisions made at the local level with regard to shoreline protection measures have the potential to have wide ranging impacts. Thus, the Project should continue to coordinate with regional- and county-scale efforts currently underway aimed at developing strategies to adapt to rising seas.

These local and regional sea level rise adaptation efforts include Marin County BayWAVE, San Mateo County Sea Change, BCDC's Adapting to Rising Tides Bay Area project, and the Bay Area flood managers leading the San Francisco Bay Regional Coastal Hazards Adaptation Resiliency Group (CHARG). There are also project-specific efforts that are developing design alternatives for various shoreline areas, including SAFER Bay and the East Palo Alto/Dumbarton Bridge resilience studies in San Mateo County. All of these efforts have been informed by the work of Wang et al. (2018) and regional efforts to support integration of natural and nature-based measures for shoreline adaptation, including the San Francisco Bay Shoreline Adaptation Atlas (SFEI and SPUR 2019), and Sea Level Rise Adaptation Framework (Point Blue Conservation Science et al. 2019). We discuss natural and nature-based shoreline protection measures in more detail in the section on Potential Mitigation or Measures Relevant to the Project below.

Lastly, wetland restoration outside of the Project complexes could decrease sediment available for restoration within the Project; however, the largest demand will likely come from North Bay projects, and it is unclear how wide-ranging their effects on sediment dynamics might be. Based on a review of the Habitat Projects data currently in the EcoAtlas (California Wetlands Monitoring Workgroup 2019), the vast majority of planned restoration areas in the South Bay are part of the Project itself. There are wetland restoration projects planned in the Central Bay, but they are much smaller in total area. For example, just north of the Eden Landing complex, the ~100 acre Oliver Salt Ponds are planned for restoration as part of the Hayward Shoreline Enhancement Project. In the North Bay, however, there is significant restoration planned (California Wetlands Monitoring Workgroup 2019), including the Novato Baylands (8,900 acres), and the Sonoma Baylands (5,000 acres). Deposition volumes on shoals in the Far South Bay and in the breached Alviso ponds suggest that much of the deposited sediment originates from the Bay rather than the Guadalupe River (Van der Wegen et al. 2018, Foxgrover et al. 2019), though there are caveats discussed in more detail in the Science Synthesis Report. However, quantifying the fraction of sediment supplied to the North Bay (from the Delta as well as tributaries like the Napa River and Sonoma Creek) that gets transported to the South Bay is an active area of research. Therefore, it is unclear the influence that large-scale planned restorations in the North Bay might have on the Project in terms of sediment.

Figure 8. Proposed new shoreline projects or enhancements to existing shoreline protection in South San Francisco Bay, including those associated with the Project. Note that the Eden Landing Barrier involves raising an existing levee. This illustration depicts shoreline projects of which the Bay Area Ecosystems Climate Change Consortium (BAECCC) was aware of as of September 2016. The Cargill levees (in orange) are existing salt pond berms/levees that would need to continue to be maintained or enhanced. (Credit: SFEI and the State Coastal Conservancy, prepared for BAECCC 2016).



4. POTENTIAL IMPACTS TO PROJECT OBJECTIVES

4.1. HOW SEA LEVEL RISE COULD AFFECT PROJECT OBJECTIVES

Potential impacts from sea level rise were discussed in the Phase 1 Studies Summary (Valoppi 2018), and the latest projections have increased (Figure 1; Table 1). The primary concern continues to be the potential for significant loss of tidal habitats (a) if rates of vertical accretion are unable to keep pace with increasing water levels (“marsh drowning”), and (b) because of limited potential for tidal wetlands to move inland and become established at higher elevations due either to naturally steep topography or urban development that backs existing baylands (“coastal squeeze”) (Ackerly et al. 2018). Given that the latest projections of sea level rise show water surface elevations continuing to increase, other emerging issues of concern for the Project are potential for additional stress on water control structures and levees and/or overtopping of levees surrounding managed ponds, and potential for intermittent (e.g., during extreme water level events) or permanent inundation of areas that support recreational use (i.e., trails, facilities, or access points) or service needs of existing infrastructure (e.g., power lines). The key uncertainties in terms of impact to Project objectives remain the same as those identified in Valoppi (2018)—namely, the rate of sea level rise and whether long-term availability of sediment will be enough for tidal wetland elevations to keep pace with changes in water levels.

4.1.1. Potential changes in sediment dynamics

Inter-annual climatic variability (e.g., wet vs. dry years), land use change, and climate change drivers are critical to future sediment supply. Schoellhamer et al. (2018) conclude that the net effect of changes affecting sediment supply from the Delta to the Bay going forward “are uncertain, but appear likely to produce little net change in present sediment supply.” Factors influencing sediment supply from the Delta include legacy effects from Sierra/Central Valley land use change, hydraulic mining, and dam construction, as well as current and future effects from changes in storm intensity, rainfall, snowpack, water management, invasive aquatic vegetation, sea level rise, and declines in wind speed. Sudden changes in supply could also occur, for example through unplanned breaches that permanently inundate Delta islands or from a record flood.

Schoellhamer et al. (2018) conclude that existing monitoring data on local tributary inputs to the Bay are insufficient to determine current trends. Given that the majority of sediment to the Bay is now coming from local sources (rather than the Delta), forecasting trends in future supply will require improving monitoring and modeling of local tributaries to account for multiple interacting drivers. Regional efforts are underway to begin a more coordinated approach to understanding future sediment dynamics, and these were discussed in the Science Synthesis Report.

There is an interplay between wet and dry years, as well as Delta vs. local tributary sources that complicates forecasting of future sediment delivery to the Lower South Bay. Higher flow years tend to mobilize and deliver more sediment to the Bay as a whole, and locally to the Project as was observed in the Guadalupe River during WY 2017 (Foxgrover et al. 2019). However, net sediment import from the Central to the Lower South Bay decreases during wet years (Livsey et al. in review, as cited in Schoellhamer et al. 2018; Shellenbarger et al. 2013), because the gradient in salinity between the North and South Bay drives the circulation of sediment (Livsey et al. 2018, Downing-Kunz et al. 2017). While the majority of sediment delivered from small tributaries during high flows is more likely to be trapped in the Bay (delivered directly through slough channels to Bay mudflats), larger freshwater discharges from the Central Valley can cause net export of sediment out the Golden Gate. With changes in future discharge patterns, the net effect on future pond accretion or water quality effects[3] from these interacting mechanisms is unclear.

4.1.2. Potential impacts to tidal habitats

Valoppi (2018) summarized three key studies that showed similar patterns of projected habitat change and thresholds for rates of sea level rise and sediment availability that would continue to support marsh habitat over the century (Stralberg et al. 2011, Schile et al. 2014, and Takekawa et al. 2013). We re-examine the Stralberg et al. (2011) results, in light of the latest sea level rise projections (Table 1). The highest sea level rise curve used for modeling by Stralberg et al. (2011), reached 5.4 ft (1.65 m) by 2100, which is just below the “medium to high risk aversion” scenario recommendation in the latest OPC Guidance (5.7-6.9 ft; Table 1). Results indicated that subtidal elevations (< -1.8 m rMHHW) today could

[3] For example, reduction in suspended sediment concentrations increases the depth of light penetration in the water column, leading to increased phytoplankton productivity and potential reductions in water quality such as dissolved oxygen.

achieve mid-marsh elevations (-0.2 to 0.1 m rMHHW) and sustain them to the end of the century only in areas with high sediment availability (suspended sediment concentrations > 250 mg/L). While this may be possible in the high sediment region of the Far South Bay (Alviso complex), Eden Landing and the Ravenswood ponds are in a lower sediment region (Stralberg et al. 2011, Jaffe and Foxgrover 2006a and b, Foxgrover et al. 2004), where initial elevations would need to already be at mid-marsh or higher to sustain marsh for any length of time (Stralberg et al. 2011). The Ravenswood ponds are already largely at mid-marsh elevation (D. Halsing, pers. comm.), which bodes well.

In addition, even for the Far South Bay the results from Stralberg et al. (2011) assume the subtidal areas are currently open to tidal action. More recent studies suggest that if we don't breach diked subsided areas to restore to tidal action before mid-century (when the rate of sea level rise is projected to accelerate), they may never achieve desired marsh elevation (Point Blue Conservation Science et al. 2019), and areas restored by 2030 are more likely to be resilient (Goals Project 2015). This will be especially true if global emissions continue to be high, and there is a small probability but potentially catastrophic shift in habitat if instability in the Antarctic ice sheet leads us down the extreme "H++" scenario (Figure 1, Table 1). The hydrodynamic modeling developed by Van der Wegen (2018) for the Alviso area could potentially be leveraged to provide more detailed elevation change information under future sea level rise scenarios.

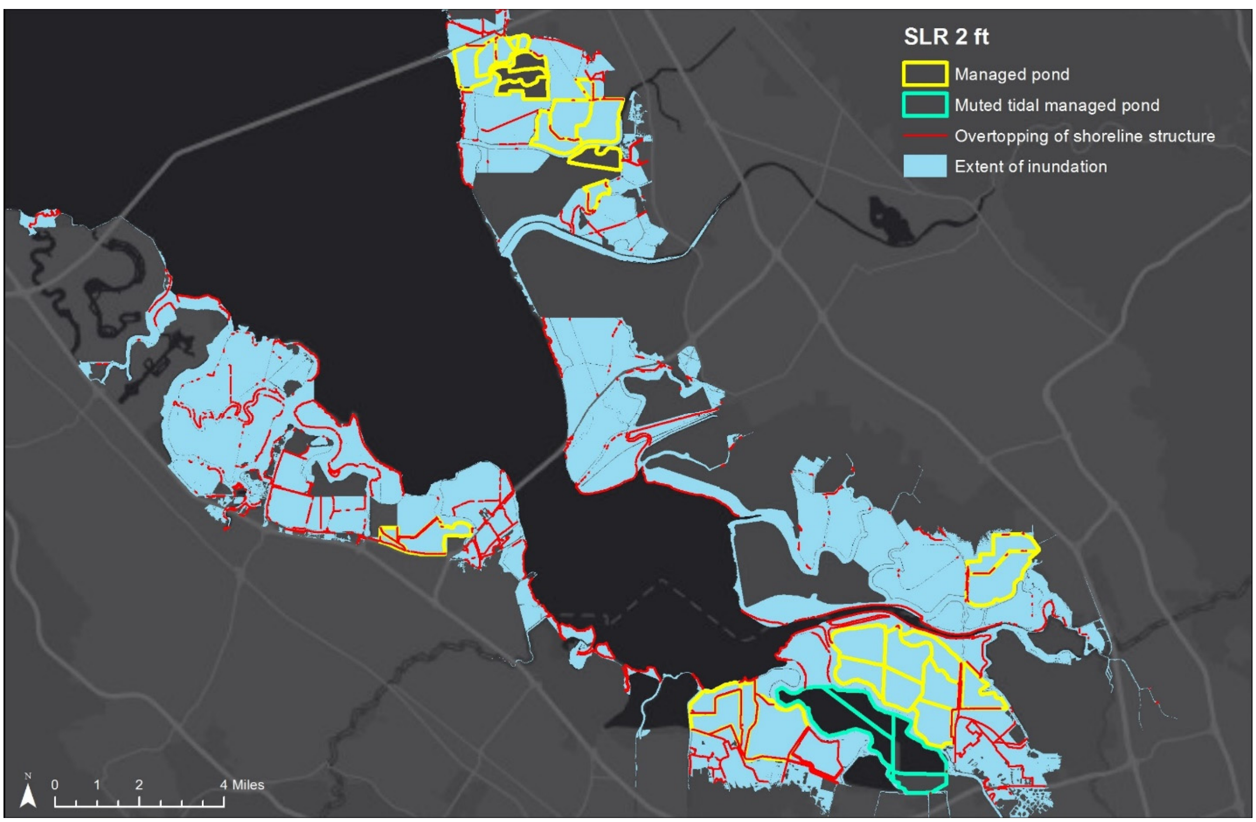
Mudflat and shallow subtidal habitat in its current locations are also vulnerable to sea level rise, but there is much greater opportunity space for mudflats to migrate inland (i.e., onto current marsh-elevation surfaces) than for higher elevation tidal habitats such as marsh and transition zone, particularly if the Estuary as a whole is considered. In other words, we are much more likely to lose significant area of marsh and transition zone habitat than we are of mudflat habitat (and mudflat-associated species such as shorebirds and shallow intertidal species such as diving ducks) across the Estuary as a whole over the long-term. However, we do not have contemporary examples of drowning marshes so it is difficult to predict if the habitat provided by a drowned marsh will be similar to the current mudflat and shallow subtidal habitat for shorebirds and diving ducks. Potential Estuary-scale habitat shifts should be considered when thinking about the ultimate desired mix of habitats for the Project, because the Far South Bay has some of the best potential to sustain marsh elevations.

Potential loss of marsh and transition zone habitat with sea level rise has implications for marsh-dependent species such as the salt marsh harvest mouse (*Reithrodontomys raviventris*) and California Ridgway's rail (*Rallus obsoletus obsoletus*). The impact of rising seas was identified as the "most threatening effect of climate change to Bay Area wildlife... because of the limited potential for wetlands to move inland and become established (Ackerly et al. 2018)." Species will be subjected to additional stressors even before the ultimate habitat conversions occur (e.g., marsh converts to mudflat) because of the projected increase in frequency of extreme water level events. The need for habitat connectivity and higher elevation refugia is particularly critical to mitigate extreme events.

4.1.3. Potential impacts to managed ponds

Impacts to managed ponds from rising seas include an increased stress on water control structures and berms/levees surrounding the ponds, as well as erosion from wind-waves. With just 2 ft (0.6 m) of increased water levels, several of the levees surrounding managed ponds may overtop (Figure 9), making it difficult to maintain desired water level conditions inside the ponds as needed to achieve Project Objectives for species (e.g., snowy plover) or water quality, particularly given limited operations and maintenance funds. Episodic overtopping could occur now in these areas with a 5-year storm surge, or permanently from 2 ft (0.6 m) of sea level rise that we might see as early as 2050 (Figure 9). Depending on the integrity of the surrounding levees, there may be erosion and levee failure that occurs even before overtopping, particularly with bay-facing levees subject to wind wave action with no fronting mudflat or marsh buffer. Managers have already observed increased erosion this past fall when high winds overlapped with a high tide, generating large wind-waves that eroded outer berms (R. Tertes, pers. observation). In addition, higher water levels on the exterior of managed ponds will make it more difficult to drain ponds as necessary for management if they continue to rely solely on gravity for drainage. All of these potential impacts affect the ability of the Project to achieve Objectives related to managed pond species (waterbirds, fish), water quality, and flood-risk management.

Figure 9. Extent of inundation and potential overtopping of berms/levees surrounding South Bay Salt Pond Restoration Project managed ponds with 2 ft (0.6 m) of increased water level. This could correspond to current conditions with a 5-year storm surge, or 2 ft (0.6 m) of sea level rise. Managed ponds displayed include those that will be managed following Phase 2 actions (Ravenswood ponds R3, R5, S5), but do not include ponds that are currently managed but will be restored to tidal action in Phase 2 (A1, A2W, E1, E2, E4, and E7).



Data sources: pond geospatial boundaries from EcoAtlas (California Wetlands Monitoring Workgroup 2019); managed/muted designations provided by D. Halsing, pers. comm; overtopping and inundation from BCDC Adapting to Rising Tides Flood Explorer.

4.2. HOW CHANGES IN PRECIPITATION AND ASSOCIATED RUNOFF COULD AFFECT PROJECT OBJECTIVES

4.2.1. Increasing precipitation

If rainfall is concentrated in shorter seasons of the year coupled with increasing precipitation, flood risk management efforts will face increasing pressure. Combinations of tidal and riverine flooding during El Niño events have caused significant flooding in regions of the South Bay: 1982-1983 in Alviso and 1997-1998 in East Palo Alto. If El Niño events and large atmospheric river events become more common, then we can expect greater amounts of runoff as saturated soils will only be able to absorb limited amounts of rainfall. As noted above, the combinations of storms with rising seas will exacerbate current flooding vulnerabilities.

Heavy precipitation events also have the potential to affect water quality objectives for the Project. For example, large rain events can increase inorganic mercury within the Guadalupe River (McKee et al. 2018). The increase in inorganic mercury itself may not have a negative effect on ecosystems within the Project, but if mercury settles within managed or restored ponds, then more mercury is available to convert to methylmercury once conditions are suitable. Similarly, large rain events could bring more sediment downstream that could affect water quality, but also promote marsh accretion. If precipitation were to increase on average, this can result in seasonally fresher and colder water, which can affect biotic productivity in the Estuary and communities such as fish that prefer these conditions. Although cooler water conditions also limit eutrophication (a positive effect on water quality), the winter timing of precipitation means changes in precipitation patterns won't have much of an effect on eutrophication, which is greatest in the summer.

Precipitation patterns and El Niño events affect songbird productivity and abundance in coastal (Chase et al. 2005), riparian (Howell et al. 2006, Nur et al. 2006), and estuarine (Nur et al. 2012) environments. Wetter conditions were associated with higher songbird productivity and abundance the following year, but the timing of precipitation was important. Rain during late winter and early spring were more favorable. The increased vegetation height and cover were likely responsible as these features are also associated with increased nest success. Species are likely to have individualistic responses to precipitation driven changes to habitat so it is unlikely that the benefits documented for songbirds are generalizable to all other taxa.

4.2.2. Decreasing precipitation

If we experience decreases in average annual precipitation, the drier conditions will result in changes in vegetation patterns in tidal marsh, upland transition zone, and in upland habitats. The combination of decreasing precipitation and increasing air temperatures will result in drier soils favoring vegetation, fish and wildlife species that can tolerate drier conditions. Vegetation productivity and cover are generally lower in drier conditions. The loss of cover could have population level effects on species that rely on the transition zone during high water events. A recent study showed that California Ridgway's rail and other tidal marsh birds were more abundant in marshes with adjacent transition zones that have taller and denser vegetation (Nur et al. 2018). Thus, decreasing precipitation could cause changes in vegetation patterns that could affect habitat for both vegetation and wildlife species.

Decreasing precipitation will also likely cause greater demand for upstream water storage for human uses, which would potentially alter stream flows into the Estuary and have adverse impacts on water quality and fish objectives. Increasing water storage would likely decrease stream flows into the Estuary, resulting in higher salinity bay waters extending into the upper Estuary. Additionally, channels with higher stream flows tend to have higher suspended sediment concentrations, which helps limit light penetration that drives primary productivity, resulting in higher dissolved oxygen. Therefore, decreases in flows caused by increasing water storage could degrade water quality in the Estuary.

Statewide declines in precipitation would increase demand for water storage that could have far-reaching effects. Waterbirds are known to move between wetland habitats in the Central Valley and the coast depending on the amount of precipitation, with many species showing preference for coastal wetlands during dry years. If water that has been designated for wildlife refuges in the Central Valley is diverted to water storage or ground water replenishment, then it is likely this will put additional pressure on coastal wetlands, possibly resulting in exceedance of the carrying capacity of these habitats.

4.3. HOW CHANGES IN TEMPERATURE COULD AFFECT PROJECT OBJECTIVES

The magnitude of temperature changes that are projected for the San Francisco Bay are great enough that we could expect to see changes in ecological communities that occur within all Project habitats. Although cool bay waters will continue to moderate high air temperature extremes in the future, this effect could be diminished. It is thus possible that future temperatures could exceed tolerances of many native species in the Estuary including plants, fish and wildlife.

The individual responses of species to temperature makes it difficult to predict exactly how communities will change. For example, paleo-ecological studies of vegetation response to past global warming events have documented continental scale, species-specific shifts in geographic ranges resulting in novel combinations of biological communities (Williams et al. 2004), and modeling of the responses of birds to future climate projects similar results (Stralberg et al. 2009). Patterns of the occurrence of migratory species will likely shift as these species track favorable environmental conditions across the landscape. At the same time new species will likely begin to track favorable climate conditions into the region resulting in novel biological interactions with uncertain impacts on the composition of the bayland ecosystem.

Although modeling can be used to project the response of species to warming air or water temperatures, a simpler approach is to proceed with the assumption that species that are at the southern end of their geographic distribution in the Estuary may be more likely to become extirpated with large temperature increases. Similarly, we can look at the biological composition of estuaries south of San Francisco as an analog of the communities we may expect to see in the San Francisco Estuary in the future.

Shallow waters in ponds, sloughs and streams in the Estuary will also experience increases in water temperature as Bay Area climate warms. Thus, we can expect that aquatic species will also be affected by warming temperatures. For example, longfin smelt prefer the cooler water temperatures that occur in South Bay tidal channels and sloughs during winter storms, and may be extirpated by warming winter water temperatures. However, habitats with greater tidal mixing should have relatively cooler water temperatures, thus ensuring higher resilience to warming water temperatures.

Increasing temperatures may also cause declines in water quality in the South Bay. The relatively shallow water in the South Bay is more susceptible to warming with increasing air temperatures. The high nutrient concentrations in the South Bay, combined with increasing water temperatures, will likely increase primary productivity for longer periods of the year, leading to longer periods of low dissolved oxygen, higher probability of harmful algal blooms and methyl-mercury production. Historically, water quality in the South Bay has been poorest in the late summer and early fall when monthly temperatures are highest (MacVean et al 2018). As summer-like temperatures extend into the spring and fall, we can expect longer periods of lower water quality. In particular, increasing temperatures may present challenges to maintaining pond habitat for waterbirds and other aquatic species without exacerbating declines in water quality in the ponds and adjacent habitats.

Although air temperatures are projected to increase throughout the Bay Area, shoreline areas will continue to be cooler than inland areas as the cool bay waters reduce air temperatures. The natural temperature relief of the bay may encourage greater use from inland visitors of Project trails and other public access features, although lack of shade may discourage visitors when Bay Area temperatures are high. The potential increase in public use of the Project area could exacerbate the negative effects on wildlife of trail use and maintenance of public access features.

5. POTENTIAL MITIGATION OR ADAPTATION MEASURES RELEVANT TO THE PROJECT

The following measures are aimed at reducing the risks or mitigating the impacts of some of the key climate change issues discussed above. The measures discussed below are in no way comprehensive, but are intended as a starting point for consideration by the Project Management Team as they develop their Phase 2 Science Framework.

5.1. MEASURES FOR NATURE-BASED SHORELINE ADAPTATION TO REDUCE FLOODING AND EROSION HAZARDS

Natural and nature-based measures—sometimes called living shorelines, green or natural infrastructure—are often less-understood options for adapting to sea level rise (Sutton-Grier et al. 2018). Unlike single purpose flood or erosion control infrastructure, natural and nature-based features can achieve multiple benefits, including protective (i.e., hazard reduction), social, ecological, and economic benefits (Arkema et al. 2015). Natural and nature-based adaptation measures can take many forms, including restored oyster reefs and seagrass beds, marshes, beaches, and hybrid measures like ecotone levees (Sutton-Grier et al. 2018, SFEI and SPUR 2019). They can reduce the vulnerability of ecosystems and human communities to flood hazards related to climate change while also providing a wide array of additional benefits, including fish and wildlife habitat, recreational opportunities, and carbon sequestration potential. In addition, because natural and nature-based measures work with, rather than against, coastal processes of sediment and water movement, they tend to enhance adjacent coastal ecosystems and are inherently designed to change and adapt as seas rise. We recognize that natural and nature-based measures will be implemented in concert with more traditional armoring measures as part of comprehensive adaptation strategies developed around the Estuary in response to rising seas. We focus on them here because they are aligned with the Project's habitat restoration focus.

SFEI and SPUR (2019) identified and mapped the suitability of several nature-based measures appropriate to the Estuary, which could provide additional ideas for managing the Project in light of climate change, and for collaborating on with adjacent flood control managers. The Project already focuses on tidal marsh restoration, and mudflat augmentation is discussed in more detail in the Measures to Enhance Sediment Deposition section. Other measures suitable in the Project area include nearshore reefs, beaches, polder management, ecotone levees, and migration space preparation, which are described in more detail below. **Descriptions are largely direct quotes from SFEI and SPUR 2019, and suitable location information comes from maps in the same source.** We note that suitable locations mapped by SFEI and SPUR (2019) are based on *existing* environmental conditions. Suitability could be enhanced in other locations with modifications (e.g., via grading to change existing elevations, via levee/berm setbacks or managed retreat to increase available space). Suitability criteria used for mapping of each nature-based measure are described in Appendix 5 of SFEI and SPUR (2019).

- **Nearshore reefs:** Reefs made of materials such as oyster shell and baycrete (a cement mixture that includes Bay sand and shells) that provide hard substrate for shellfish including native Olympia oysters (*Ostrea lurida*) and other aquatic plants and animals. Nearshore reefs can also reduce wave transmission at lower tidal elevations and stabilize areas in their lee.
    - *Suitable locations in the Project area:* West side between the Dumbarton Bridge and confluence with San Francisquito Creek.
    - *Examples*: As part of the San Francisco Bay Living Shorelines Project, led by the State Coastal Conservancy, reefs have been installed in locations in San Rafael, Hayward, and most recently (2019) at Giant Marsh in Richmond.
- **Beaches:** Coarse or composite estuarine beaches are dynamic features that can consist of a mixture of sand, shell, gravel, or cobble. Beaches include a supratidal beach berm and a beach face. The lowest portion of the beach is often characterized by a low tide terrace and transition to tidal flat. The low tide terrace limits the duration that the beach is exposed to waves and also limits the size of the waves. The focus here is on coarser gravel and cobble beaches which can dissipate wave energy over shorter distances and therefore are generally more suitable within the urbanized and constrained Estuary.
    - *Suitable locations in the Project area:* Ravenswood and Eden Landing complexes, at the mudflat-marsh transition or outboard of bay-facing levees
    - *Examples:* implemented at Arambaru Island (Richardson Bay, Marin County); conceptual designs developed for Corte Madera Ecological Reserve and Blackie's Pasture in Tiburon (contact Kathy Boyer, SFSU)
- **Polder management:** Polders are low-lying areas of land that would normally be inundated by regular tides if they were not protected by dikes. Polders are the diked, ditched, and drained historical marshes and mudflats that are locally known in San Francisco Bay as "diked baylands." They are often subsided. The current and former (i.e., Project) salt ponds in the South Bay qualify as polders.

  Managing polders includes maintaining dikes, water control structures, and/or pumps to manage water levels at desired levels or to prevent flooding, depending on their purpose. If a polder is intentionally or accidentally returned to tidal action, the additional tidal prism will need to be accommodated as will the increased demand for sediment within the polder. Polders that have to remain dry, such as agricultural or residential areas, need maintained dikes or levee-like berms that are high enough to provide the required level of protection and that can be adapted to accommodate future sea level rise. They are also vulnerable to flooding from rainfall and runoff ponding behind the dikes; stormwater detention and pumping is likely to increase with more urbanization and climate change.

  In a planned restoration, the topography may be graded before breaching and dredged sediment may be placed to raise elevations. Filling a polder with dredged sediment, such as at Sonoma Baylands and Hamilton Airfield Wetland Restoration, requires a large dredging project such as the deepening of channels at the Port of Oakland. Details on lessons learned from the Cullinan Ranch beneficial re-use effort were included in the sediment chapter of the Science Synthesis Report, and the feasibility of a similar direct placement approach is currently being explored for Eden Landing (D. Halsing, pers. comm.).

Methods such as warping and levee lowering may allow the more gradual introduction of sediment into polders, by natural means, to reduce the impacts of catastrophic dike failures. Warping is the process of gradually building up the height of the mudflat or marsh within a polder by opening tide gates and letting in sediment-laden water on the flood tide, closing the tide gates to allow the sediment to fall out of the water column over several tides, and then letting the clear water out slowly on a subsequent ebb tide. An alternative could be to lower the outboard levee to allow sediment-laden water to enter the site at high water and then slowly drain over time, which would trap the sediment in the polder.

- *Suitable locations in the Project area:* There are many polders in the Far South Bay, as well as the eastern shore between the Dumbarton and San Mateo bridges (including Eden Landing).
- *Examples*: Palo Alto Flood Basin (Santa Clara County), Hamilton Wetland Restoration Project (Marin County), Cullinan Ranch (Solano County)

- **Ecotone levees:** Ecotone levees are gentle slopes or ramps (with a length to height ratio of 20:1 or gentler) that are typically constructed bayward of flood risk management levees and landward of a tidal marsh. They typically stretch from an adjacent upland or a levee crest to the marsh surface, and they can provide wetland-upland transition zone habitat when properly vegetated with native clonal grasses, rushes, and sedges. They can attenuate waves, provide high-tide refuge for marsh wildlife, and allow room for marshes to migrate upslope with sea level rise. Ecotone levees are already being planned for Phase 2 of the Project.
  - *Suitable locations in the Project area:* There are areas suitable for ecotone levees between many of the Project ponds and landward infrastructure/development. They are also likely suitable in some mid-complex areas where existing berms could be improved, though these are not mapped in SFEI and SPUR (2019).
  - *Examples*: South San Francisco Bay Shoreline Project (Valley Water and USACE), Oro Loma Sanitary District

- **Migration space preparation:** Migration space refers to areas at appropriate topographic elevations that could support estuarine-upland transition zones now and in the future with sea level rise. These are often natural wetland-upland transition zone areas adjacent to present and potential marshes that could be protected, enhanced, or restored to allow marshes to migrate landward as sea level rises. Lands that provide migration space are scarce and in demand as they are generally situated between the lower limits of developed upland areas and the upper limits of diked or tidal baylands.
  - *Suitable locations in the Project area:* There are patches of area suitable for migration space adjacent to the Project area in the Far South Bay (e.g., northwest of Pond A22 and near Alviso).
  - *Current examples:* Rush Ranch Open Space Preserve and China Camp (San Francisco Bay National Estuarine Research Reserve)

5.2. MEASURES TO MITIGATE IMPACTS OF EXTREME EVENTS

Increased variability in climate means that fish and wildlife species of interest to the Project will be subjected to more frequent, episodic stress from extreme water levels, precipitation events or droughts, and temperature extremes. Maintaining or increasing habitat connectivity is a critical component of any strategy focused on mitigating impacts of extreme events, because it provides opportunities for species to seek refugia. Note that we discuss enhancement of transition zone habitat via ecotone levees above, and creek-bayland reconnections below, though both are relevant in this context as well.

5.2.1. High tide refuge islands

Innovative habitat enhancement techniques such as the construction of high tide refuge islands (also called marsh mounds) within a tidal marsh habitat have been employed in an attempt to speed the recovery of endangered species' populations and increase their resilience to sea level rise and increased storm intensity, while reducing the impacts of other stressors (such as elevated levels of predation). High tide refuge islands can provide marsh birds and mammals with vegetative cover that is above extreme high tide levels to escape high waters and hide from predators. The State Coastal Conservancy and H.T. Harvey and Associates have constructed high tide refuge islands at 13 sites in the South Bay and one site in the Central Bay (H.T. Harvey and Assoc. 2015 and G. Archbald pers. comm.; see map in Appendix B). Each earthen island was located adjacent to a tidal marsh channel and was constructed using marsh mud excavated from a nearby channel edge. Marsh sod (mostly perennial pickleweed) from the excavation area was used to cover the mound which was also planted with gumplant and saltgrass. Mound footprints were about 25 ft long by 10 ft wide (7.6 m by 3 m) and the first islands built in 2012 protruded about 2 ft (0.6 m) above the marsh plain (top elevation 1 ft above MHHW) (H.T. Harvey and Assoc. 2015). To improve gumplant survival and provide more suitable cover during extreme tides, elevations of subsequent high tide refuge islands were increased by 0.5 to 0.7 ft, to a target construction elevation of 1.5 to 1.7 ft above MHHW, which allows for settling to an anticipated 1.1 to 1.4 ft above MHHW in the first year (H.T. Harvey and Assoc. 2015).

If the technique proves effective, these islands could help marsh birds and mammals survive the increasingly frequent extreme tide events that are predicted. However, the islands are designed to provide high tide refuge habitat based on existing conditions, and would need to be raised as sea level rise occurs to continue to provide refuge habitat over the long-term. In addition, early results on their effectiveness in providing measurable benefits to target species such as California Ridgway's rails were inconclusive due to the lack of replication to compare high tide refuge island locations and the limited number of years post-restoration (Wood et al. 2017). The islands may provide nesting areas for wildlife that would be protected from rising waters. However, constructed islands could also attract predators, increasing the risk to marsh-dependent wildlife. This restoration measure should be considered pilot and should be implemented within a statistical design framework to maximize the ability to assess the actual benefits to wildlife. Addressing the uncertainty around this marsh enhancement technique will help the Project select the best adaptation measures.

In contrast to high tide refuge islands constructed within existing marshes, some mounds like those at Sears Point are constructed prior to levee breaching in restoration sites to help reduce wind-wave erosion, promote sediment retention, and to hasten vegetation colonization after tidal action is restored. The tops of these mounds are often designed to be at or below the eventual (i.e., restored) tidal marsh plain. In this case, the mounds are not anticipated to provide benefits to marsh-dependent wildlife. However, they may be used by shorebirds and other waterbirds during the early stages of restoration.

5.2.2. Artificial floating islands

Another novel approach to providing high tide refugia for special-status wildlife species (e.g., California Ridgway's rail, salt marsh harvest mouse) is the use of artificial floating islands, which are anchored within and on the edge of marshes and made with high-density foam for flotation and woven palm leaf screens to provide cover (Overton et al. 2015). They have been piloted in locations within San Francisco Bay, and showed use by California Ridgway's rails at sites in San Leandro Bay (Overton et al. 2015) but had mixed results at other sites (Casazza et al. 2014). Sites in the Gallinas Creek area had moderate use but sites on the western side of South San Francisco Bay did not have appreciable use. As with the high tide refuge islands, the population-level response to artificial floating islands is still unclear and needs further investigation.

5.3. MEASURES TO ENHANCE SEDIMENT DEPOSITION IN THE FACE OF RISING SEAS

5.3.1. Creek-baylands reconnections

Historically, local tributaries fanned out as they reached the Bay, delivering watershed-derived sediment to tidal wetlands at the creek/bay interface. Many of these creeks have been confined by levees and flood control channels at the Bay edge, bypassing the tidal wetland transition and flowing directly into the deeper Bay (SFEI 2018). Reconnecting creeks to their former floodplains/baylands (e.g., via levee breaches) can enhance natural delivery of sediment directly to tidal wetlands, increasing their ability to keep pace with rising seas. The Project is already planning reconnection of Alameda Creek to baylands with Phase 2 restoration at Eden Landing. Additional opportunities exist in the Project area to improve delivery of sediment from local watersheds more directly to Project areas, most recently mapped by SFEI and SPUR (2019; pgs 92-93). A more detailed assessment of creek-bayland reconnection opportunities and constraints was also developed for the Calabazas Creek/ San Tomas Aquino Creek, and Pond A8 area of the Alviso complex (SFEI 2018), and the Project is working with the Santa Clara Valley Water District to further develop this concept and seek funding for design and NEPA/CEQA compliance (D. Halsing, pers. comm.).

5.3.2. Strategic (indirect) placement of sediment

Strategic placement refers to indirect delivery of sediment by purposefully placing sediment in strategic locations where natural hydrodynamic processes (e.g., resuspension and tidal action) can transport sediment to desired locations (i.e., onto mudflats or marsh plains). It has been practiced for decades by the US Army Corps of Engineers (USACE) for beneficial reuse of sandy materials, but much less for fine sediments (Galiani et al. 2019) like those needed by tidal habitats in the Bay. In the San Francisco Estuary, the practice has been explored through modeling (MacWilliams et al. 2012, as cited in BCDC and ESA/PWA 2013; Bever et al. 2014), recommended as part of marsh adaptation strategies (e.g., BCDC and ESA/PWA 2013), and the USACE has developed a Strategic Placement Framework as part of its Long Term Sediment Management Program. These studies are already being incorporated into wetland restoration proposals submitted to the USACE as part of a pilot beneficial use of dredge material program (State Coastal Conservancy 2018).

Benefits of strategic placement include some logistical efficiencies relative to direct placement (e.g., less handling required for construction, lower hauling distance, less permitting required) as well as reduced short-term impacts to ecology relative to direct placement (Galiani et al. 2019). Allowing natural processes to feed tidal habitats means deposition occurs at a more natural rate and more variable spatial pattern. The constraints of strategic placement are that fine grained sediment is highly dispersive, increasing local turbidity and sedimentation on non-target resources, and thus transporting only a fraction of the total placed sediment to the desired location. The fraction that makes it to the target location can be increased with increasing proximity of placement (Bever et al. 2014), but it does require placement of several times more sediment to achieve desired elevation gains in target locations as compared to direct placement methods.

5.3.3. Direct placement: thin-layer sediment augmentation

Thin-layer sediment augmentation is a method involving the application of a thin layer of dredge sediment directly to the surface of an existing mudflat or marsh, such that the placement is carefully planned to a thickness believed to maintain natural system processes and functions without causing elevation-based habitat alterations (Hine 2016). The technique can be used to create terrestrial-tidal marsh sediment connections along the landward edges of marshes and to increase the elevation of mudflats or marshes that may not otherwise be able to keep pace with rising sea levels. Depending on the site and placement within the site, mixed riverine (for wetland-upland transition zones) and/or estuarine dredged sediment can be used. The practice has been implemented much more frequently on the Gulf and East Coast, was piloted on the West Coast on 16 acres of marsh at the Seal Beach National Wildlife Refuge in 2016 (Judge et al. 2018, Thorne et al. 2019), and has been piloted to build ecotone levee (transition zone habitat) slopes at the Deer Island Basin as part of the Novato Creek Dredged Sediment Beneficial Reuse Project (Toms and Leventhal 2017).

These techniques can provide benefits in the form of marsh resilience in areas with low suspended sediment availability, high marsh wildlife habitat creation, as well as other benefits associated with tidal marsh habitat (flood attenuation, water filtration, recreation, carbon sequestration, etc.). Method constraints include costs associated with source sediment analysis and handling, hauling distance, permitting, compaction problems, short-term ecological impacts to special-status species (e.g., resident small mammals) due to burial of vegetation, burial of marsh features such as channels and ponds, and general flattening of the site.

This technique contrasts with the more conventional use of dredged sediment to build bed elevations in subsided diked baylands or polders prior to levee breaching or during the early years of restoration before vegetation has established (see Polder Management in Section 5.1 above).

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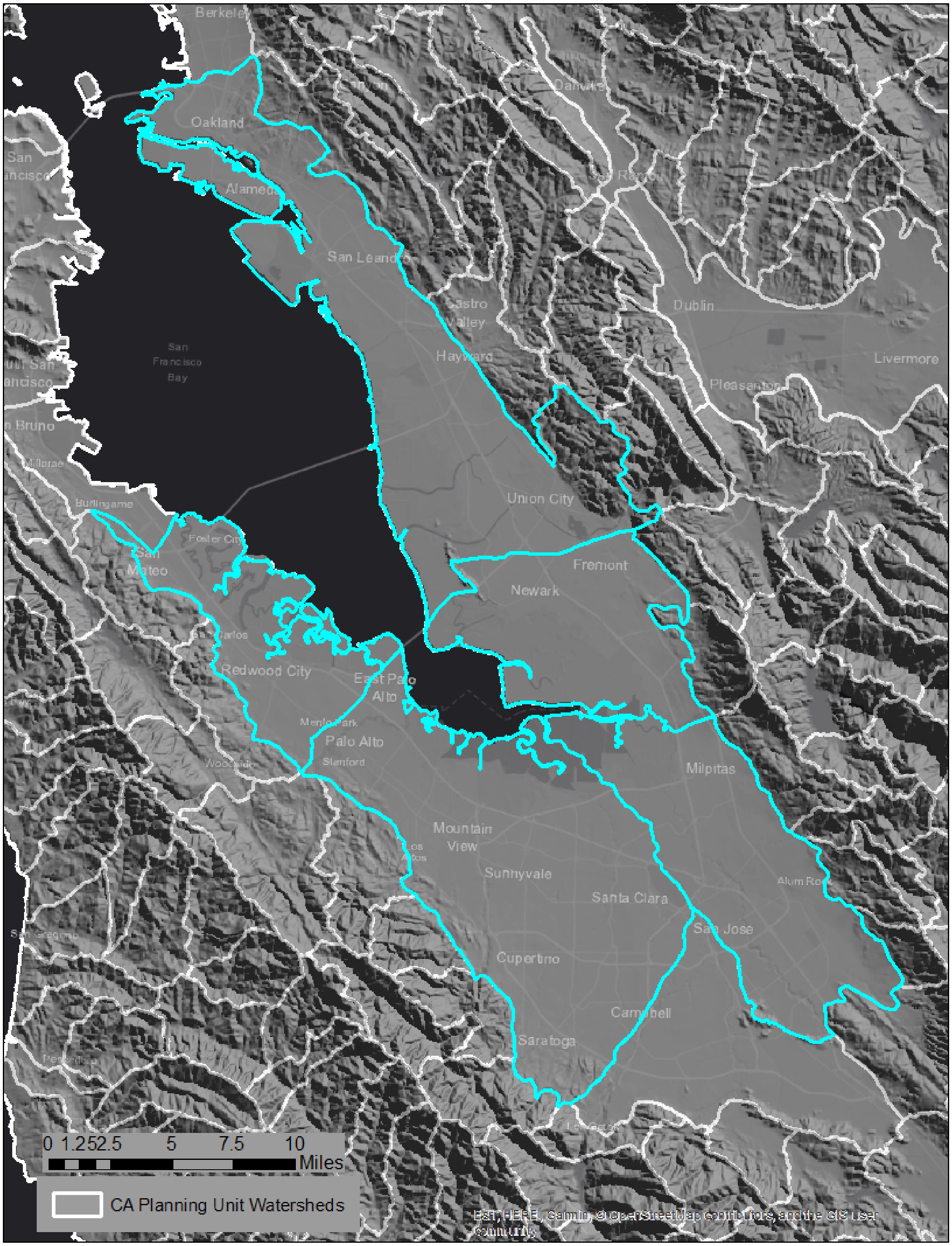
APPENDIX A

Map of the five watersheds for which USGS (2014) precipitation, runoff, and temperature data (climate grids 270 x 270 m) were summarized to generate Figures 2-7. Data were downloaded from https://geo3.pointblue.org/watershed-analyst/



APPENDIX B

Map of constructed high tide refuge island locations in San Francisco Bay. Refuge islands were also constructed at Faber Marsh in 2017-18 (not shown on map, located between Cooley Landing and Palo Alto Baylands). Source: HT Harvey and Associates 2015.