SEA-LEVEL RISE VULNERABILITY AND ADAPTATION

Planning Study

Prepared for
City of Redwood City

July 2024

Redwood Landing Marina, Feb. 9, 2020

Photo Credit: California King Tides Project

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Page

TABLE OF CONTENTS

Page

Figures

Page

Tables

Appendices

1. INTRODUCTION

1.1 Project Background

Environmental Science Associates (ESA) is assisting the City of Redwood City (City) by assessing its vulnerability to future flooding with sea-level rise, and by developing conceptual alternatives to mitigate the risk. The City has over ten miles of Bay shoreline (**Figure 1**) with a variety of flood protection measures, including earthen berms and levees of varying heights, floodwalls, and a drainage network that transfers stormwater runoff to the Bay during periods of rain. The Bay also influences tidal water bodies (Redwood Shores Lagoon and Redwood Creek) that propagate coastal flood effects adjacent to areas of the City.

Much of the City along the Bay shoreline is currently mapped within FEMA Special Flood Hazard Areas (also referred to as the 100-year floodplain), indicating the extent where flooding could occur during a 1% annual chance flood hazard event. With sea-level rise, the risk for flooding will increase. Nearby cities are undertaking similar planning studies to address the long-term risk, with coordination and oversight from the County of San Mateo (County of San Mateo 2018, OneShoreline 2023a), and other regional entities such as the Bay Conservation and Development Commission (BCDC) and the State of California (State). The City intends to develop and execute a plan to continue protecting its developed areas from coastal flood risk with the addition of sea-level rise. This study informs this effort by describing the City's current flood protection, assessing the current and future flood vulnerability, and proposing adaptation strategies to mitigate flood hazards. The City intends to use this study to select and implement an approach for addressing sea-level rise hazards.

1.2 Scope of the Project

As a whole, this project comprises a first phase planning study that builds on prior regional planning work at the State and County of San Mateo (County) levels. It is intended to provide an initial foundation for future work that addresses the City's vulnerability, prepares for adaptation strategies, advances flood protection, and protects ecosystems and the environment. The project included several phases:

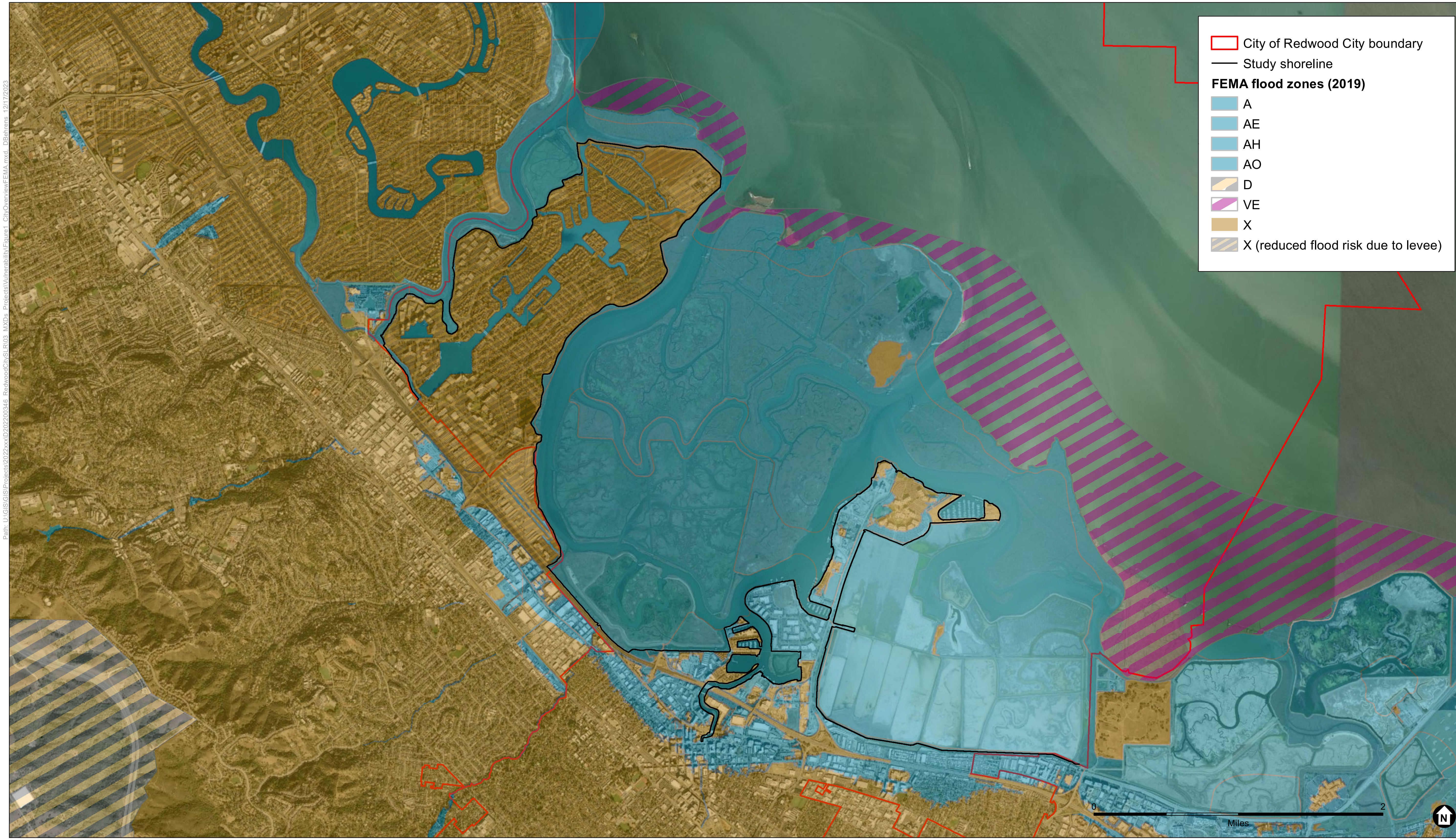
1) **Review of information and identification of data gaps (Appendices B and C):** ESA reviewed relevant documents, plans, and drawings for the first stage of the study. This stage also included a topographic survey of the shoreline and known areas of flooding concern. These are summarized in Appendices A and B, respectively.

2) **Vulnerability assessment (Chapter 2):** Redwood City's shoreline was organized into a series of reaches, and available information was used to identify the major sources of flooding in each reach. Sea-level rise scenarios were identified and reviewed with the City, and the assessment used these as the basis for quantifying potential flood vulnerabilities along the shoreline at future time horizons. This stage included a series of meetings with City engineering and planning staff to ground-truth and discuss early findings.

3) **Adaptation assessment (Chapter 3):** Following from the vulnerability assessment, the adaptation assessment outlines priority adaptation strategies to address flood hazards along the shoreline of the City.

These range from upgrading or replacing the existing series of unaccredited shoreline berms and protection structures to raising the elevation of the shoreline, as well as protecting offshore marshes and upgrading the City's stormwater system.

These assessments have been reviewed by City staff and attorneys, and they are included as chapters in this report. The report concludes with a brief chapter on next steps, which outlines recent regional guidelines and identifies how this report fits within a broader adaptation plan. Public workshops are anticipated in 2024, which will help to frame the next steps of the project.



SOURCE: County of San Mateo, ESRI, FEMA, Redwood City

D202200346 Redwood City SLR Vulnerability Study

Figure 1.
City of Redwood City boundary, shoreline, and flood zones

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2. VULNERABILITY ASSESSMENT

This chapter identifies the major sources of flooding along the City's shoreline and considers how this exposure will be exacerbated by sea-level rise. This assessment was informed by a review of existing data sources pertaining to the City shoreline (**Appendix B**). Then, the chapter lays out the approach for assessing vulnerability, by delineating shoreline reaches and comparing the flood sources to shoreline elevation profiles. By combining the information about flooding sources with the assessment factors such as reach elevations, this chapter then provides reach-by-reach vulnerability assessments.

2.1 Sources of Flooding

This section describes the major sources of flooding along the Redwood City shoreline, which are primarily elevated Bay water levels, but also include runoff and emergent groundwater.

2.1.1 Bay Water Levels

Pacific Ocean water levels propagate through the Golden Gate and largely determine water levels in San Francisco Bay. Under typical conditions, ocean water level fluctuations are caused by astronomic tides. As indicated by their name, astronomic tides are generated in the ocean by forces between the Earth, the Sun, and the Moon. These tidal fluctuations are well-understood and can be predicted with high accuracy. The highest astronomic tides of each year—i.e., the 1-year annual recurrence events—are commonly referred to as "king tides" (see **Appendix A** for a glossary of terms). Tidal water level fluctuations are commonly extracted at distinctive phases of the tide and then averaged to provide representative elevations known as tidal datums. Three common tidal datums to characterize the tide range are mean higher-high water (MHHW), mean sea level (MSL), and mean lower-low water (MLLW). Tidal datums, measured relative to North American Vertical Datum of 1988[1] (NAVD88), are available from the NOAA Redwood City station as shown in **Table 1**.

Table 1 also includes the estimated peak still water levels (SWL) for the 1-year, 10-year, and 100-year recurrence events (alternately called the 99%, 10%, and 1% annual chance[2] events, respectively) Bay water levels. Note that still water levels do not include the additional effects of wave runup. Peak still water levels are provided by AECOM (2016) based on aggregated hydraulic modeling that was conducted for FEMA (DHI, 2011). The FEMA modeling hindcasted multiple decades of Bay water levels and was analyzed to estimate tidal datums and extreme water levels along the Bay shoreline. Note that the base flood elevation (BFE) used for assessing risk along the Bay shoreline is the 100-year event's water surface elevation, consistent with State guidance (BCDC 2021).

Flood conditions above the typical astronomic tides are caused by atmospheric and oceanic processes. The processes that raise ocean water levels are mostly associated with winter storm events, so the resulting water level increase is often termed 'storm surge'. Storm-related processes that cause surge are lower atmospheric pressure and wind. In addition, changes in large-scale oceanic circulation, particularly during winters with El Niño

[1] This study uses the North American Vertical Datum of 1988 (NAVD88) as a reference point for measuring and comparing elevations of water levels, flood management measures, and development subject to flooding.

[2] 'Annual chance' refers to the probability of a flood event being equaled or exceeded each year. An alternate naming convention is based on the return interval concept, where the return interval is the inverse of the annual chance. For example, the 99% annual chance may also be called the 1-year event and the 1% annual chance may also be called the 100-year event.

conditions, can cause higher-than-normal water levels for several months at a time. Depending on the intensity of each of these processes, as well as their coincident occurrence relative to astronomic tides, storm surge can result in water levels up to three feet higher than just astronomic tides. Winter storm winds can also generate waves that may pose an additional flood hazard, particularly when the waves ride on storm-surge-elevated water surfaces.

TABLE 1
TIDAL DATUMS AND EXTREME WATER LEVELS AT REDWOOD CITY

	Tidal Datums at Redwood City ft NAVD88
100-year recurrence Still Water Level (SWL)[1]	10.7
Highest Observed Tide (12/3/1983 19:42)[2]	9.6
10-year recurrence SWL[1]	9.4
1-year recurrence SWL ('King Tide')[1]	8.4
Mean Higher High Water (MHHW)[2]	7.0
Mean High Water (MHW)[2]	6.4
Mean Sea Level (MSL)[2]	3.2
Mean Low Water (MLW)[2]	1.2
North American Vertical Datum (NAVD88)[2]	0.0
Mean Lower Low Water (MLLW)[2]	-1.2

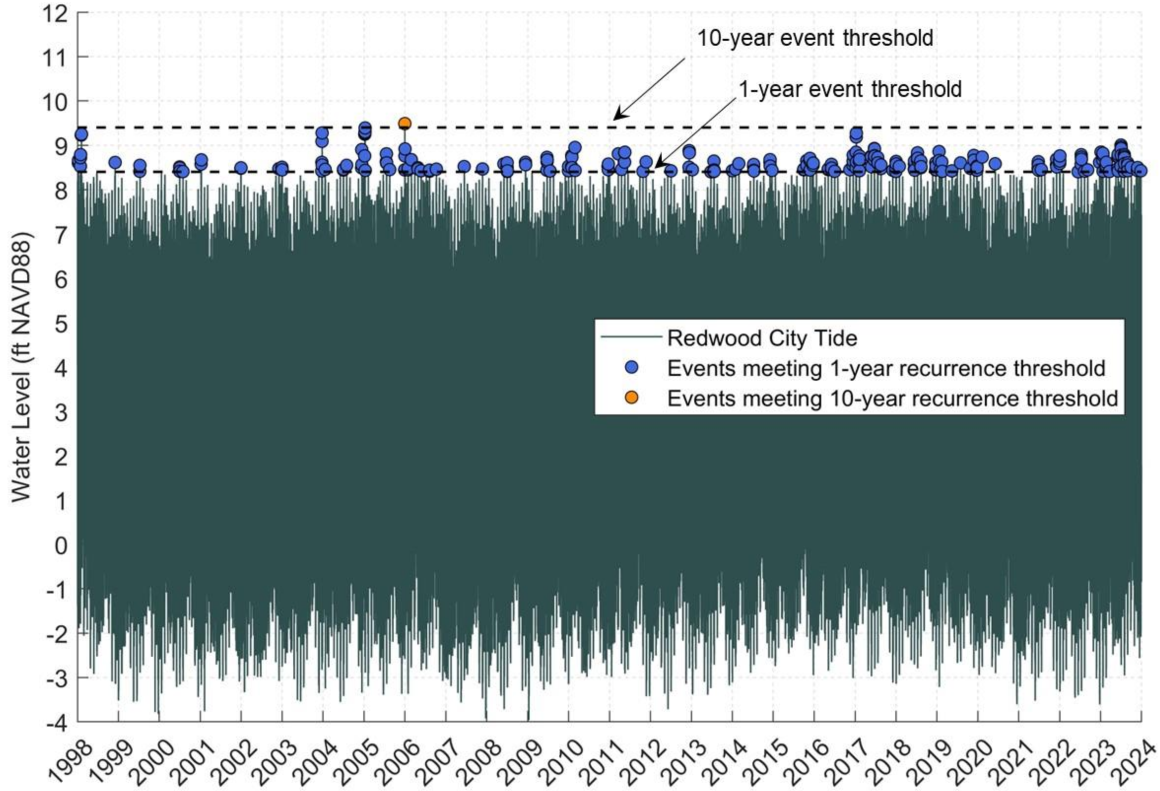
[1] AECOM (2016)
[2] NOAA Station 9414523. NOAA Tidal Datum Elevations are based on the 1983-2001 Tidal Epoch

Historical Flooding Events

Historical Bay high water level events at the NOAA Redwood City gauge from the last several decades are listed in **Table 2**, along with the still water levels.

The highest recorded event occurred during a temporary period of gauge operation in 1983, during the December 1983 event that caused high water levels throughout the Bay. During this event, water levels reached 9.6 feet NAVD88, between a 10- and 100-year recurrence event. Since 1997 when the NOAA gauge was reinstalled for continuous operation at Redwood City through December 2023, there have been more than 12 events with daily high tide levels meeting or exceeding 9 feet NAVD88. The highest of these occurred in January 2005, when peak daily water levels exceeded 9 feet for four days in a row. FEMA (2019) also reports on prior known flooding events in the City, with major flooding occurring in 1973.

Figure 2 illustrates the tidal record at the NOAA gauge, along with the 1-year and 10-year recurrence still water levels from AECOM (2016). In the 26 years that tide data are available, the 1-year recurrence level has been surpassed by an increasing number of events per year. This is partly a response to shifts in large scale climatic patterns in the Pacific Ocean but is also an indication of the effect of sea-level rise over time.



SOURCE: NOAA Redwood City Tide Station

D202200346 Redwood City SLR Vulnerability Study

Figure 2.
Tidal water levels at NOAA Redwood City Tide Station from 1998 to 2024.

TABLE 2
HIGH WATER LEVELS SINCE 1998 AT NOAA REDWOOD CITY GAUGE (FT NAVD88)

1% annual chance (100-year)[1]	10.7
Highest Observed Tide (12/3/1983 19:42)[3]	9.6
December 31, 2005[3]	9.5
10% annual chance (10-year)[1]	9.4
January 11, 2005[2]	9.4
December 24, 2003[3]	9.3
January 12, 2017[3]	9.3
February 6, 1998[3]	9.2
February 27, 2010[3]	9.0
January 22, 2023[3]	8.8
99% annual chance (1-year, approx. king tide)[1]	8.4

[1] Based on AECOM (2016)

[2] Peak water levels were above 9.2 ft NAVD88 for every day from 1/8/2005-1/11/2005

[3] NOAA Station 9414523

2.1.2 Expected Change with Sea-Level Rise

The accumulation of human-produced greenhouse gases in the Earth's atmosphere is causing and will continue to cause the trapping of heat, thereby causing global warming and climate change. Along the Bay shoreline, climate change will cause sea-level rise due to thermal expansion of the ocean's waters and melting of ice sheets. Over the last century, the tide gauge in San Francisco has recorded sea-level rise of eight inches. In addition to these observed sea-level rise trends, the best available science, as reviewed specifically for California (Griggs et al., 2017; OPC, 2018), predicts that sea-level rise will continue and accelerate throughout this century and into the next century. Because specifics about future greenhouse gas emissions and climate response are not fully known, the exact sea-level rise scenario that will occur is not precisely known at this time. However, considering a range of all but the most extreme scenario, sea-level rise by 2100 is projected to be between two and nearly seven feet in San Francisco Bay by 2100 (OPC, 2018).

Table 3 lists sea-level rise projections for San Francisco in 2030, 2050, 2070, and 2100 relative to sea level in 2000, projections which are shown graphically in **Figure 3**. San Francisco is the closest tide gauge location to Redwood City for which sea-level rise projections are provided and it provides projections of sufficient accuracy for planning in Redwood City (OPC, 2018). The 'likely range' for low risk aversion is estimated to have a 66% chance of occurrence, whereas the medium-high risk aversion range is estimated to have only a 0.5% chance of exceedance. The range within each of these scenarios, e.g., 2.4 to 3.4 ft for the low-risk aversion scenario in 2100, accounts for the range of future greenhouse gas emissions.

TABLE 3
SEA-LEVEL RISE PROJECTIONS FOR SAN FRANCISCO, IN FEET ABOVE 2000 BASELINE

Scenario	2030	2050	2070	2100
66% Likely Occurrence: Low Risk Aversion	0.5	1.1	1.5 - 1.9	2.4 – 3.4
0.5% Chance of Exceedance: Medium-High Risk Aversion	0.8	1.9	3.1 – 3.5	5.7 – 6.9

Source: OPC (2018)
Note: 2030 and 2050 values are for the high emissions scenario. Ranges reported above for 2070 and 2100 reflect both the low and high emissions scenarios.

Table 4 shows how extreme water levels at the confluence of Redwood Creek and the Bay would change with different amounts of sea-level rise. The table's cells are shaded to indicate correspondence between existing conditions with zero sea-level rise and future conditions. For example, the existing 10-year water level of 9.4 ft NAVD88 will occur with a 1-year return interval with one foot of sea-level rise and with a daily return interval with two feet of sea-level rise. These intervals were chosen to best illustrate the concept with conventional intervals.

TABLE 4
FUTURE WATER SURFACE ELEVATION WITH SEA-LEVEL RISE AT REDWOOD CITY, IN FEET NAVD88

Annual Chance (Return Interval)	0 ft SLR	1 ft SLR	2 ft SLR	3 ft SLR	5 ft SLR
Daily MHHW	7.1	8.1	9.1	10.1	11.1
99% annual chance (1-year)	8.4	9.4	10.4	11.4	12.4
10% annual chance (10-year)	9.4	10.4	11.4	12.4	13.4
1% annual chance (100-year)	10.7	11.7	12.7	13.7	14.7

Source: AECOM (2016) Point ID 757 and OPC (2018)

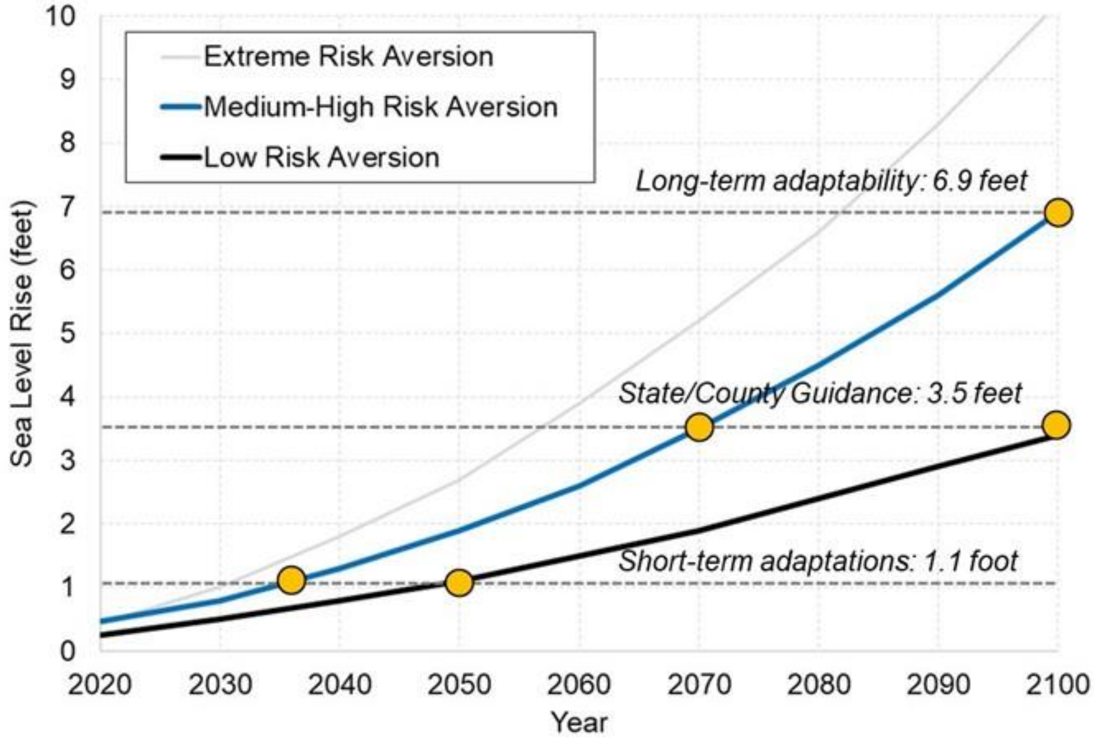
This study focuses on flooding from elevated Bay water levels, but it should be noted that climate change is expected to also cause more extreme precipitation events (Swain et al. 2018), which would likely increase flood hazards from stormwater and creek discharge. However, this aspect of climate change was not characterized in this study.

2.1.3 Flooding Scenarios

After reviewing State sea-level rise guidance (OPC, 2018; OPC, 2020) and guidance from the County (OneShoreline 2023a) and others, and in coordination with City staff, four scenarios were selected from **Table 3** for evaluating future vulnerability of the City. These are summarized in **Table 5** and **Figure 3** below.

TABLE 5
FUTURE WATER LEVEL SCENARIOS WITH SEA-LEVEL RISE AT REDWOOD CITY

Scenario	Amount	Note
Present-Day	BFE + 0.0 feet	100-year flood event under existing conditions
Short-term adaptations	BFE + 1.1 feet	100-year flood event with short-term sea-level rise. Water levels that occur about once per year (e.g. ‘king tides’) would instead occur as average daily high tide. Likely to occur between 2035 and 2050.
Target planning	BFE + 3.5	Recommended by State guidance for adaptation by mid-century (OPC, 2020). Similar to ‘Medium’ SLR scenario of 3.3 ft applied by County of San Mateo et al. (2018). Similar to low-risk aversion case of 3.4 ft by 2100. Likely to occur between 2070 and 2100.
Long-term adaptability	BFE + 6.9	Consistent with medium-high risk aversion case for 2100. Intended to consider the capacity for long-term adaptability. Similar to ‘High’ SLR scenario applied by County of San Mateo et al. (2018). 0.5% chance of occurring by 2100, more likely after 2100.



SOURCE: Ocean Protection Council 2018

D202200346 Redwood City SLR Vulnerability Study

Figure 3.
California sea-level rise projections

2.1.4 Inundation Maps

Inundation maps are used as a way of understanding the potential spatial extents of flooding from either shoreline overtopping or combined shoreline overtopping and high creek flows. Publicly available flood maps represent hypothetical conditions, using the best available elevation data at the time of each particular study. They are useful as guides but should be considered together with local shoreline vulnerability information and other contextual information.

FEMA

FEMA develops Flood Insurance Studies (FISs) and Flood Insurance Rate Maps (FIRMs) for the purpose of informing the public of flood risks, to inform building policy in risk-prone areas, and to control the chance of damage to property (FEMA 2000). Within the Bay, the FIRMs rely on model simulations to look at peak water levels along the shoreline. For shorelines without FEMA-accredited levee systems, these water levels are then projected inland to see where they exceed the ground surface elevation and where inundation could occur. FEMA FIRMs typically show Special Flood Hazard Areas (SFHA) as colored zones indicating the extent of the 1% annual chance and 0.2% annual chance flood events. These events can happen as a result of flooding on the Bay side from high tides and storm surge. The FIRMs include base flood elevations that account for wind waves. However, FEMA does not consider sea-level rise when generating FIRMs.

The most recently published FEMA FIRM for the study area was accepted in April 2019. BakerAECOM (2014) presented the coastal floodplain mapping and overland wind wave modeling that were used to develop a new map. Compared to the prior map developed in 2012, the most recent update shows a significantly greater extent of flooding in the City during the 1% annual chance flood event. SFHAs mapped on the revised FIRM are shown on **Figure 1**. The BFE for the 1% annual chance flood event varies along Redwood City's shoreline from elevations 10 to 13 feet NAVD88. The BFEs are derived from the 1-percent-annual-chance Total Water Level (TWL), which includes SWL and wave runup.

Sea-Level Rise Inundation Maps from BCDC

Sea-level rise flood maps provided by the Adapting to Rising Tides (ART) effort (BCDC 2017) provide indication of potential future flood hazards. These were used to visualize the predicted extents and depths of flooding from sea-level rise. It is important to note that the flood hazard maps developed by BCDC and FEMA show different extents and depths of flooding in some areas of the City. This is a result of a difference in methodology (e.g. FEMA mapping only considers current conditions and does not account for sea-level rise) and resolution of the shoreline levee system.

Inundation Extents

FEMA hazard zones are included in the City overview map (**Figure 1**). **Figure 4** shows the inundation extents corresponding to the flooding scenarios in **Table 5** using the BCDC ART maps. The inundation extents shown by the BCDC ART map for the present-day 100-year storm is relatively comparable to FEMA's effective 100-year floodplain. Notably, FEMA includes a few more inland patches in the 100-year floodplain, such as a stretch behind Veterans Boulevard and another in the Friendly Acres neighborhood behind Highway 101 – this may be attributable to the two sources' differing methods.

The potential flooding shown on these maps are generally consistent with observed flooding as reported by City staff or through photos in the California King Tides Project (**Appendix D**). City staff reported winter 2022-23 flooding in the Friendly Acres neighborhood (during some rain events in January 2023) and at the tidally influenced open concrete culvert near 1180 Main Street (during 12/31/22 storm).

2.1.5 Combined Flooding from Runoff and High Bay Levels

While this study mainly focuses on vulnerability of Redwood City to coastal flooding from the Bay, other processes can affect water level, including combined flooding events caused by the coincidence of large rainfall events, high tides, and storm surge. Elevated Bay water levels may then impede the drainage of creeks and stormwater systems to the Bay, resulting in watershed-sourced flooding more severe than flooding due to watershed runoff or coastal storm surge events on their own. The lower portion of Belmont Creek, as well as Cordilleras Creek, Redwood Creek, and the Bayfront Canal are known sources of local flooding exacerbated when high rainfall coincides with elevated Bay water levels. **Table 6** details the peak flow rates for each drainage and provides notes on known causes of flooding.

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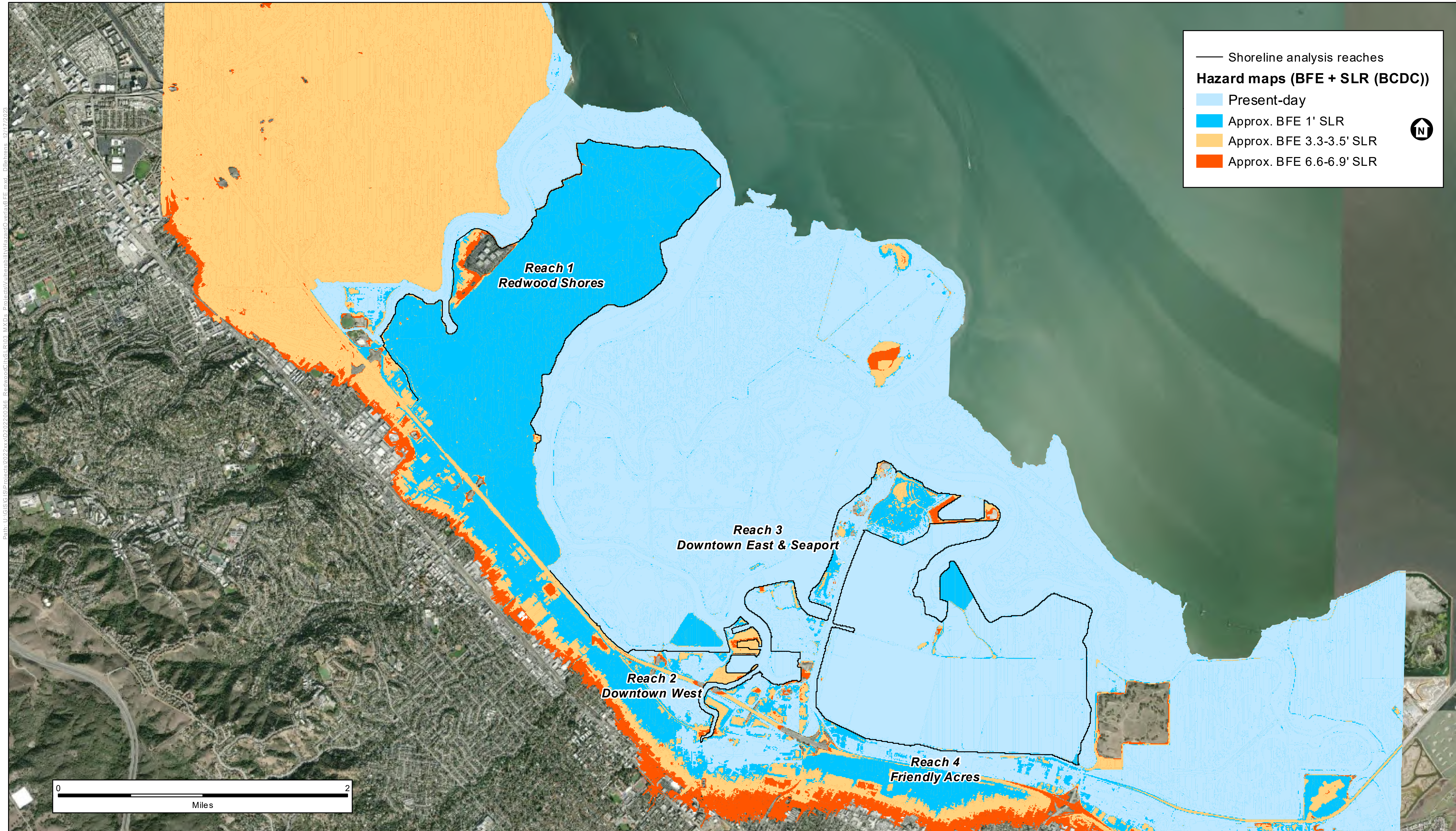


SOURCE: BCDC, ESRI, USGS

Note that hazard mapping amounts and extents are approximate.

D202200346 Redwood City SLR Vulnerability Study

Figure 4
BCDC Flood Hazard Mapping

TABLE 6
CREEKS AND DRAINAGE CHANNELS INFLUENCING FLOODING WITHIN REDWOOD CITY

Drainage	Peak Flood Events (cfs) 1% annual chance (100-year) event	2% annual chance (50-year) event	10% annual chance (10-year) event	Notes
Belmont Creek	1,400	1,200	660	Urban creek with 2.8-square mile watershed, mostly within the City of Belmont, discharging to Belmont Canal southwest of Redwood Shores. Bank overflow and spilling into lower industrial areas of City of Belmont. Flooding reduced after recent drainage improvements, and no flooding is reported within Redwood City
Cordilleras Creek	850[1]	700	525	Urban creek with 3.6-square mile watershed, draining to the Bay near the Veterans Blvd offramp. Culvert blockage from debris sometimes occurs during major rainfall events. FEMA (2019) estimates that 100-year recurrence runoff event would cause 170 cfs of spillover flows eastward into Redwood City. Also noted as a concern from City staff in 2023.
Redwood Creek	4,000	3,300	1,900	Urban creek with 9.3-square mile watershed, draining through downtown Redwood City. Historically overflowed its banks in 1940, 1955, and 1958 floods, prior to major improvements along the shoreline (FEMA 2019). Drainage influenced by high tides when high Bay water levels coincide with high rainfall, especially near portions of the creek upstream of Bradford Street where the creek is intermittently conveyed in underground culverts.
Bayfront Canal and Atherton Channel[2]	3,904	--[3]	2,577	Canal capturing runoff from a 9.5-sq. mi. urban drainage encompassing parts of Unincorporated San Mateo County, Redwood City, Menlo Park, Woodside and Atherton. Flow is conveyed by a series of pump stations, siphons, and the Atherton Channel, and drains to the Bay via a managed tide gate connected to Flood Slough (NHC 2018). Flooding of adjacent neighborhood occurs when high tides prevent drainage via the tide gate. The canal currently drains to an adjacent storage area to the south when water levels exceed 7.5 ft NAVD88, and into the Cargill salt ponds to the north when water levels exceed 9 ft NAVD88. Recently completed siphon project designed by BKF (2017) would reduce occurrence of flooding of into Cargill salt ponds and local neighborhoods immediately south of the canal by diverting floodwaters into former salt ponds east of Flood Slough that are now managed by USFWS.

[1] FEMA (2019) notes that 170 cfs of flow spills out of the creek and into Redwood City during the 1-percent annual chance flood event.

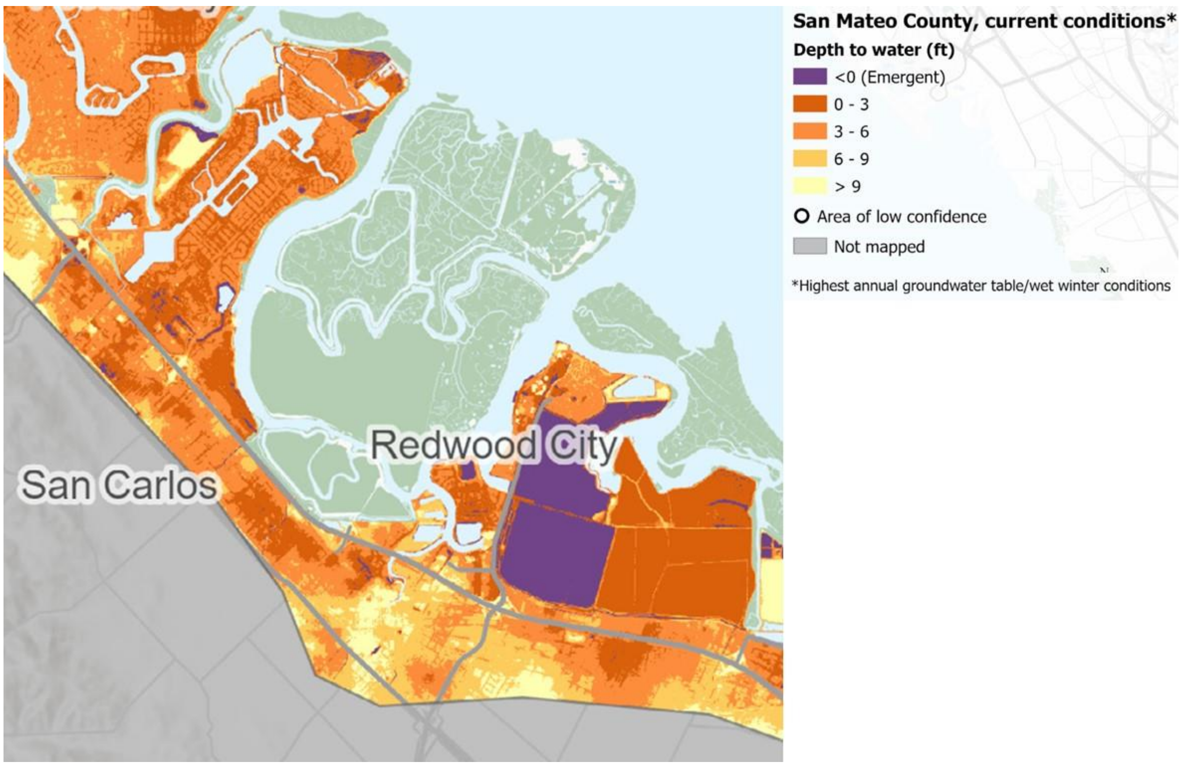
[2] from Table 4.3 in BKF (2017). Note that this is computed as the sum of the peak flow rates from the seven modeled subbasins that drain into the canal. Therefore, this estimate does not take into account the different times at which these individual peak flows reach the canal.

[3] not reported in BKF 2017.

2.1.6 Emergent Groundwater

May et al. (2022) note that most local governments in the Bay Area have not yet incorporated groundwater rise into their vulnerability assessments and adaptation plans. Rising groundwater tables will put strain on the existing stormwater system within the City, requiring more frequent pumping in low-lying areas of all four reaches identified in this report. Conceptual strategies are still being developed at the regional level that address coastal flooding, sea-level rise, and groundwater rise together are still in conceptual stages (Habel et al., 2020), and these are expected to be an important component of the continued planning process (May et al., 2020).

Figure 5 shows present-day groundwater conditions in Redwood City, and **Figure 6** shows groundwater conditions in the future with 12”, 36”, and 84” of sea-level rise (the closest mapped intervals to the sea-level rise intervals in **Figure 3**). Today, groundwater is generally at least 3 ft below the ground surface, with emergent groundwater present largely in just the former salt ponds with scattered patches in the other reaches. These areas of emergent groundwater are largely projected to get surface flooding with 12” of sea-level rise. With 36” of sea-level rise, the extents of coastal flooding, emergent groundwater, and combined coastal flooding and emergent groundwater expand beyond the bounds of the salt ponds. With 84” of sea-level rise, all four reaches are at risk from both emergent groundwater and coastal flooding, including the entire interior of Redwood Shores and the former salt ponds. While interventions such as floodwalls and levees can mitigate flooding from the Bay, mitigating groundwater requires different types of interventions such as updated stormwater networks and higher capacity pump stations. These interventions also differ in effectiveness, required maintenance/operations, cost, and timescales.

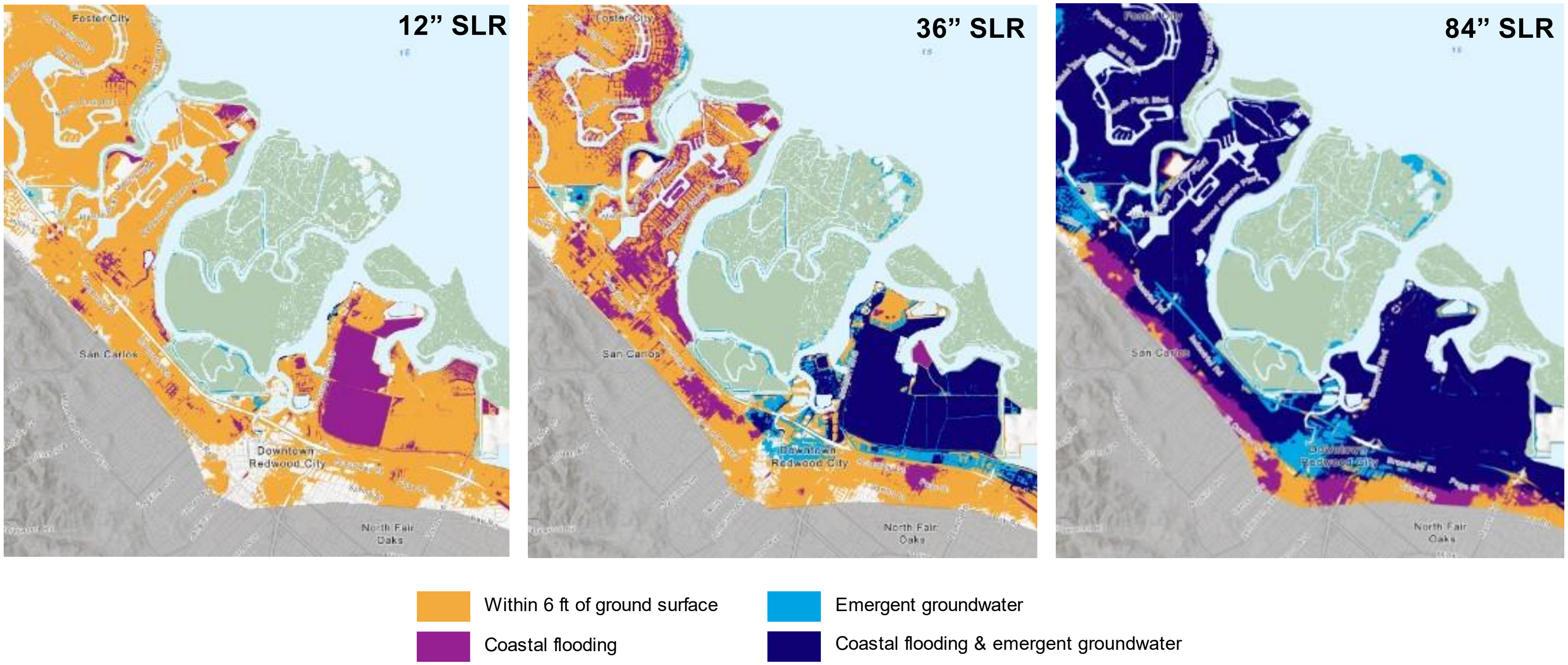


SOURCE: May et al., 2022

D202200346 Redwood City SLR Vulnerability Study

Figure 5.
Current groundwater mapping

Rising groundwater may also inundate contaminated soil, possibly affecting the toxicity and mobility of these contaminants. Their transport under future sea-level rise and groundwater conditions could pose health risks to exposed communities. Redwood City contains a number of sites with hazardous materials, but assessing the vulnerability of these specific sites to sea-level rise was outside the scope of the study. California’s Department of Toxic Substances Control released guidance for considering sea-level rise during cleanup of hazardous substances and waste (DTSC 2023), which may be considered for future sea-level rise planning or adaptation efforts.



SOURCE: May et al., 2022

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Figure 6.
Groundwater conditions with sea-level rise

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2.2 Vulnerability Assessment Approach

The study approach integrated several different methods and data sources to assess the City's vulnerability to coastal flooding with sea-level rise. The shoreline was first delineated into several reaches – and in some cases they were further divided into subreaches at the neighborhood scale. Then vulnerable spots and potential flooding pathways were identified, in part by comparing existing shoreline elevations against still water levels.

2.2.1 Reach Delineation

The varied land uses, geomorphic features, and potential vulnerability pathways along the City's shoreline warrant the delineation of several reaches for analysis, which are depicted in **Figure 7**. The sections below provide contextual information about each of the reaches that was used when considering vulnerability. Factors considered when characterizing the vulnerability include:

- Most likely locations for initial overtopping during storms
- Potential extents of flooding
- Contextual information (sources of flooding, flood risks in adjacent connected areas, property ownership, etc).

Reach 1: Redwood Shores Peninsula

Reach 1 encompasses the Redwood Shores Peninsula, from the City boundary on Belmont Slough to the San Carlos Airport. The Peninsula is bounded by Belmont Creek, Belmont Slough, San Francisco Bay, and Steinberger Slough. The inner lagoon has a regulated tidal connection to the Bay via tide gates. Inflow through the culverts are managed and then pumps return water from the lagoon to the Bay. This allows for some tidal mixing in the lagoon, while maintaining lagoon water levels below flood levels. Most of the Reach 1 shoreline consists of a levee improved in 2010 (City of Redwood City, 2020) to maintain its FEMA accreditation. The Bay Trail occupies the crest of the levee for much of its length. At the northeastern corner of the peninsula, the Silicon Valley Clean Water wastewater treatment plant augmented the levee with vinyl sheet pile wall constructed around 2010 (Bohley Consulting). The southern end of Reach 1 connects to a levee around San Carlos Airport (owned and managed by San Mateo County), which is in the City of San Carlos. Redwood City is collaborating with San Carlos and San Mateo County's OneShoreline regarding the status of this levee.

The City received a letter from FEMA in April 2020 notifying it that the levees around Redwood Shores no longer met the requirements for FEMA accreditation, based on the most recently adopted NFIP mapping standards from April 2019 and site-specific analysis (STARR II, 2019). As a result, Redwood Shores is mapped as being in a seclusion area on the current FIRM. This designation means that while flood hazard information from the previous effective FIRM will be maintained for now, in the future the map may be updated to show the increased flood hazard associated with a non-accredited levee system. A non-accredited levee system is not considered as reducing the flood risk from the base flood, such that properties within a non-accredited levee system face more stringent building code and flood insurance requirements. The seclusion process allows for updated flood hazard analyses to be conducted before the FIRM is modified. With support from OneShoreline in the spring of 2021, the City applied for FEMA funding to begin planning and design of an improved levee system and it awaits the outcome of that application.

Reach 2: Downtown West

Reach 2 consists of the central shoreline of the City from the confluence of Pulgas Creek with the sloughs behind Bair Island, and along the western shore of Redwood Creek, below Bradford Street. The western half of the reach is fronted by an earthen embankment with a paved bike path. East of Bair Island Road, the shoreline consists of a peninsula containing recent developments north of Blu Harbor Boulevard (constructed around 2017 (ENGEO 2018)) and south of Blu Harbor Boulevard (constructed 2003). Farther south, the shoreline is a relatively high embankment until it meets Highway 101. Underneath the highway, the shoreline is a paved bike path protected by a concrete flood wall. The western shore of Redwood Creek upstream of the highway is mainly bordered by private properties protected by an earthen berm with varying crest elevations. This shoreline does not have a consistent level of flood protection. Upstream of Bradford Street, the creek is conveyed through underground culverts.

Reach 3: Downtown East & Seaport

Reach 3 consists of the eastern shore of Redwood Creek and the western shore of Seaport Peninsula. The eastern shore of Redwood Creek upstream of Highway 101 is protected by a mix of earthen berms and paved areas abutting the creek. A similar mix is present downstream (bayward) of the highway and at the shoreline of the Inner Harbor. While part of the Inner Harbor shoreline is under development, Maple Street has historically been prone to flooding during annual king tide events (**Figure 8a**), with water overtopping the boat ramp at the terminus of the road. This can prevent drainage of the portion of Maple Street upstream of Highway 101 (**Figure 8b**).

Farther north, portions of the Seaport district are protected by newly constructed concrete flood wall and levee improvements submitted to FEMA for accreditation review in 2023. The area immediately to the north that includes the Redwood City Marina and the Port of Redwood City Public Fishing Pier are protected by an uneven earthen berm and are prone to annual flooding during king tides.

Continuing northward, the Port of Redwood City is protected in some areas by a metal bulkhead and in others by berms. While the site floods at a low point along the shoreline, much of its infrastructure is flood-proofed and the port can withstand several days of disruption during storm events (County of San Mateo 2018). At the northern end of the peninsula, the business park and marina have relatively high shorelines.

SOURCE: BCDC, County of San Mateo, ESRI, FEMA, Redwood City

D202200346 Redwood City SLR Vulnerability Study

Figure 7
Shoreline Analysis Reaches

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SOURCE: California Coastal Commission –
California King Tides Project

D202200346 Redwood City SLR Vulnerability Study

Figure 8.
King Tide flooding at Maple Street (a) &
backing up to Highway 101 (b)

Reach 4: Friendly Acres

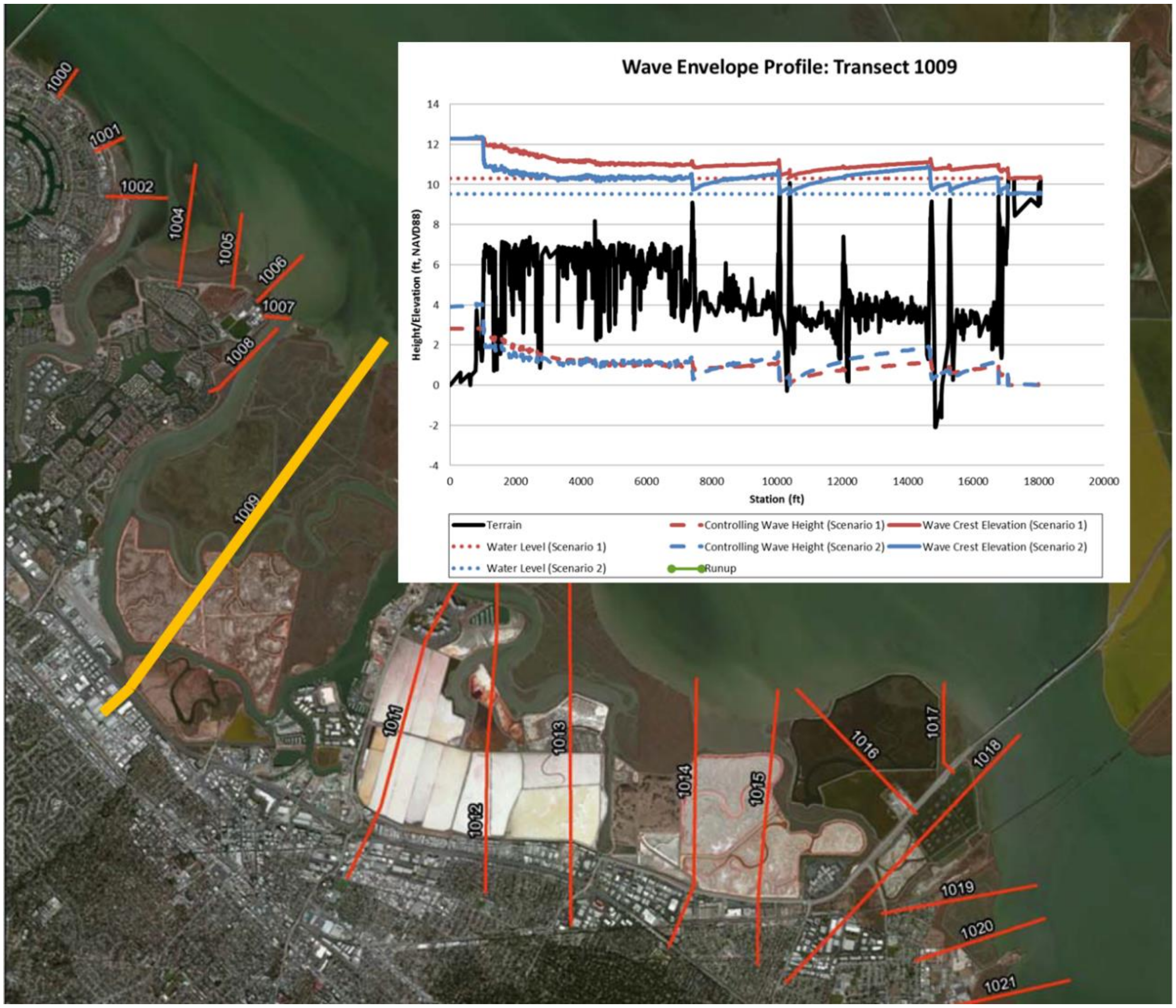
Reach 4 consists of the interior shoreline between the Cargill salt ponds and the adjacent neighborhoods of Friendly Acres to the south and Seaport Blvd to the west. Both Friendly Acres and Seaport Blvd are fronted by earthen berms on land owned by Cargill. These berms, approximately 9-10 ft NAVD88 in crest elevation, are generally lower than the outboard levees along the Bay-side edge of the Cargill property. This is because these landward berms are not directly exposed to Bay water levels and are instead intended for managing water levels within the salt ponds. Although Cargill's salt ponds are no longer in regular use for salt production, this series of earthen berms is higher than the interior shoreline and could provide protection from waters coming from the salt ponds. The ponds could be inundated during extreme high Bay water levels, from precipitation, and/or from spillover from the Bayfront Canal.

The Bayfront Canal is prone to flooding when high rainfall events coincide with high Bay tides on Flood Slough, which make it difficult to drain collected runoff through the gate. This lack of drainage impacts adjacent neighborhoods to the south such as Friendly Acres, which drain to the Canal.

The Friendly Acres neighborhood relies on pump stations to convey stormwater to Bayfront Canal. The Canal terminates in a tide gate that drains the collected urban runoff by gravity into Flood Slough. In the last several decades, high tides on Flood Slough coinciding with rainfall events have prevented drainage in the canal and led to flooding in the neighborhoods to the south in 40 of the last 70 years, most recently in 2017 (OneShoreline, 2023b). OneShoreline recently completed a project that diverts water from Bayfront Canal into managed ponds in the Don Edwards San Francisco Bay National Wildlife Refuge for temporary detention. The use of these former salt ponds located east of Flood Slough reduces the flood hazards from Bayfront Canal to developed areas south of the canal and the salt ponds north of the canal. The project was a collaborative effort between local and federal agencies.

Offshore Marshes

The tidal marshes offshore of the City's shoreline are part of the historical landscape (Point Blue Conservation Science 2019; May et al., 2022) and shelter much of Reaches 1-4 from wind waves. Significant marshes fronting the City's shoreline include those on Bird Island, Radio Point, Bair Island, Redwood Point, and Greco Island. The marsh vegetation facilitates sediment deposition and anchors deposited sediment, which results in bed elevations higher than the adjoining mudflat. In addition, when water levels meet or exceed the elevation of the marshplain, the marsh vegetation removes energy from wind waves (BCDC and ESA PWA 2013). Because of these marshes, the FEMA Base Flood Elevation is reduced by one to four feet from the Bay side of marshes as compared to the City shoreline inboard of marshes. An example of the wave attenuation predicted by FEMA for the transect that cuts through Bair Island is shown in **Figure 9**. This attenuation of wave heights by marshes also attenuates the erosion hazard of the inboard shoreline.



SOURCE: BakerAECOM 2014

D202200346 Redwood City SLR Vulnerability Study

Figure 9.
WHAFIS Analysis Results for Bair Island Transect

A study by Point Blue (2019) projected the evolution of the marshes in front of the City in response to sea-level rise and modeled the wave attenuation across the projected future marsh conditions. The marshes are anticipated to accumulate material and grow upwards with sea-level rise due to both organic matter accretion and sediment deposition, thereby preserving their capacity to attenuate waves. If higher but less likely rates of sea-level rise occur (e.g., 6.9 feet by 2100), the marshes may lose elevation relative to flood events and provide less wave attenuation in the future. However, even in this case, the marshes are expected to provide attenuation benefits into the second half of the century and could be augmented in the future with restoration actions and sediment placement.

2.2.2 Elevation Profiles

Two-panel figures for each reach illustrate the shoreline in both plan view and profile view (**Appendix E**). These figures are intended to help identify low-lying locations along the City's shoreline, indicating where they exist spatially on the shoreline and indicating how they compare to present-day storm water levels. Additionally, the profiles can help illustrate discontinuities in flood protection structures.

This study used the shoreline delineation from BCDC's Adapting to Rising Tides (ART) project as a starting point for the profiles. The ART project digitized major features providing flood protection and corrected against planar and oblique imagery (BCDC 2017). Some stretches include parallel features in the foreshore and backshore (e.g., wetlands fronting a levee).

For this study, the linework from the ART project was compared to a 2017 LiDAR dataset (San Mateo County) provided by the City as well as both ESRI aerial imagery and Google Earth oblique/3D visualizations. Because the purpose of this study is to understand sea-level rise vulnerability, shoreline linework was adjusted to follow the shoreline features that likely provide inland protection from tidal flooding.

The City also provided plan sets of various flood protection projects around the City (**Appendix B**), which were roughly digitized to show those protection structures too narrow or new to be represented in the 2017 LiDAR. Note that this digitization was not exact, nor was it comprehensive of every shoreline protection structure in City limits. The structures not represented in the profiles remain a data gap outside the scope of this planning-level study. The profiles were additionally checked and augmented by including ESA survey data from March 2023 (**Appendix C**).

Finally, the 1-, 10-, and 100-year storm still water levels (AECOM 2016) were plotted onto each profile figure to provide context on present-day vulnerability.

2.3 Vulnerability Assessments by Reach

Using the approach outlined above, this section describes the vulnerability findings for each reach and applicable subreaches. This information is also summarized in **Table 7**.

Reach 1: Redwood Shores Peninsula

Redwood Shores Peninsula (**Figure E-1** in **Appendix E**) sits behind a levee whose crest elevation ranges between 12.0 and 14.7 ft NAVD. The levee was previously FEMA-accredited, so this largely residential reach is mapped as Zone X (reduced flood risk due to levee) on FEMA's National Flood Hazard mapping. However, in 2019, FEMA issued a notice to the City about the impending loss of accreditation and mapped Redwood Shores as a secluded area. Addressing this issue remains an active project today.

These elevations are mostly at or above the current 100-year still water level, so this stretch of the shoreline is fairly well-protected at present. The combination of high ground and levees around the entire peninsula means the protection is fairly uniform within the reach without the particular vulnerability present in other reaches.

This reach ends on the eastern side at City limits where Redwood City meets the San Mateo County San Carlos Airport. Protection of the airport itself is outside of the City's jurisdiction. However, the levee continues around the airport and provides part of contiguous flood protection for Redwood Shores.

Reach 2: Downtown West

The downtown reach (**Figure E-2** in **Appendix E**) begins at the eastern end of the San Carlos Airport and follows the shoreline behind Bair Island, through the developed marinas, and back to the upstream end of the west bank of Redwood Creek. Shoreline elevations in this stretch are noticeably more variable than in Reach 1. Some portions of the reach have shoreline protection structures.

The reach behind Bair Island (from Station 0+00 to approximately 80+00) is generally low-lying and below the 100-year SWL. This low-lying area includes the southern portion of Bair Island Road, which is the access route to residential communities at the northern end of the road.

The shoreline between Stations 80+00 through approximately 160+00 wraps around residential marina communities on the peninsula at the end of Bair Island Road. Starting near the intersection of Bair Island Road and Sea Anchor Drive (approx. Sta 80+00), a concrete flood wall starts and runs north along the shoreline at approximate elevation 14-15 ft NAVD. This is also the ground surface elevation for most of the peninsula north of Blu Harbor Boulevard, which was raised and developed in 2017. South of Blu Harbor Boulevard, which was mostly developed in 2003, the ground surface elevations are 12-13 ft NAVD. While the protection around both communities is largely sufficient for the present-day, the varying levels of protection means that the two developments are vulnerable at the elevation of the lower structure.

From Station 160+00 to the Highway 101 crossing (Sta 200+00), the shoreline is high enough so as to map the residential community behind it out of the FEMA 100-year floodplain, but still within the 500-year floodplain. The largely commercial area from the highway crossing to the upstream end of Redwood Creek's open channel reach is mapped into the 100-year floodplain. ESA survey of this reach generally supported the LiDAR-derived elevation values in this stretch, suggesting that this area is a vulnerability pathway for this reach.

For this reach, a stormwater master plan (Wood Rodgers, 2017) found that in 2017, only the City's K-Mart pump station and associated pipe networks had capacity to handle the 30- or higher events. None of the other pump stations along this reach have capacity for the 30-year event. There is some capacity within the existing system to handle the 10-year event.

Reach 3: Downtown East & Seaport

This reach (**Figure E-3** in **Appendix E**) runs from the upstream end of Redwood Creek's east bank, along several commercial areas and the Port of Redwood City and ends at the northwest corner of the Cargill Salt Ponds. The shoreline elevation in this reach varies widely, and like Reach 2, it contains a few non-contiguous shoreline protection structures – one along the east bank of Redwood Creek and another surrounding the development approximately between Sta 80+00 – 155+00

As in Reach 2, the lack of uniformity in shoreline protection means that some areas may be vulnerable to lateral flooding that overtops the shore in adjacent parts of the reach. Notably, inland of the recently-breached managed wetland around Sta 70+00 – 80+00, the PG&E Substation appears to have no additional shoreline protection. This segment of the shoreline is a potential flood pathway for areas inland. While Seaport Boulevard runs through the spine of this reach just as Highway 101 did for much of Reach 2, in this reach the road is not raised relative to the shoreline and most of the commercial and maritime infrastructure is outboard of the road.

The Port of Redwood City, which spans most of this reach, has both un-engineered and engineered embankments. Though it has a relatively low minimum shoreline elevation, the infrastructure there can withstand brief periods of inundation (County of San Mateo 2018). It is therefore not particularly vulnerable at present but may require significant adaptation actions in the future. Additionally, flooding of Seaport Boulevard due to the low spot near the breached managed wetland or through the Port itself may inundate Seaport Boulevard, restricting access to the Port as well as points further north.

Reach 4: Friendly Acres

Reach 4 (**Figure E-4** in **Appendix E**) runs along the backside of the Cargill salt ponds from the northwest corner down along Seaport Boulevard and along the outboard side of the Bayfront Canal.

The alignment for this reach follows an embankment with a crest elevation roughly near the 100-year Bay still water level. Levees on the outboard side of the Cargill salt ponds typically keep unimpaired Bay water from reaching this alignment. Flooding may come from overtopping the ponds or from the Bayfront Canal.

2.3.1 Summary

A summary of the vulnerabilities along each reach is presented in **Table 7**. At a subreach scale, the approximate minimum shoreline elevation is compared with the nearest local base flood elevation for the 100-year coastal flood event for present-day conditions and three amounts of sea-level rise. The difference between the shoreline elevation and the flood elevations is referred to as ‘freeboard’. Positive freeboard indicates that the shoreline is higher than the flood waters and inland flooding is unlikely. Negative freeboard indicates that the flood waters are higher and would cause inundation inland of the shoreline.

An important component of **Table 7** is the inclusion of the primary and secondary flood sources for each subreach. In some cases, flood defenses varied at subreach boundaries. This means that even for relatively high portions of the shoreline, the primary flood vulnerability could be lateral flooding from adjacent segments of shoreline during an overtopping event.

TABLE 7
REDWOOD CITY SHORELINE VULNERABILITY BY SUBREACH

Focus Area #	Adjacent Water Body	Public Landmarks	Potential Cause of Flooding	Type of Flood Protection	Land Ownership	Approx. Minimum Shoreline Elevation (ft NAVD)	Flood Routes	Approx. BFE (ft NAVD)	Freeboard relative to BFE and SLR			
									SLR: +0’	+1.1’	+3.5’	+6.9’
Reach 1: Redwood Shores												
1a	Belmont Slough	City Boundary to RWC Public Library	Coastal	Embankment	City (Bay Trail)	10.5	**Primary:** shoreline overtopping from Belmont Slough	10	0.5	-0.5	-3	-6.4
1b	Belmont Slough	RWC Library Cove	Coastal	Embankment	City (Bay Trail)	12.0	**Primary:** shoreline overtopping from Belmont Slough. **Secondary:** Redwood Shores Lagoon.	10	2	1	-1.5	-4.9
1c	Belmont Slough	RWC Public Library to Shell Pkwy	Coastal	Embankment	City (Bay Trail)	13.0	**Primary:** shoreline overtopping from Belmont Slough. **Secondary:** Redwood Shores Lagoon.	10	3	2	-0.5	-3.9
1d	Belmont Slough	Shell Pkwy to the Preserve	Coastal	Embankment	City (Bay Trail)	12.0	**Primary:** shoreline overtopping from Belmont Slough. **Secondary:** Redwood Shores Lagoon.	10	2	1	-1.5	-4.9
1e	Belmont Slough	The Preserve	Coastal	Engineered embankment	City (Bay Trail)	12.5	**Primary:** shoreline overtopping from Belmont Slough. **Secondary:** Redwood Shores Lagoon.	10	2.5	1.5	-1	-4.4
1f	Belmont Slough	Preserve to Silicon Valley Clean Water (SVCW)	Coastal	Embankment	Private	13.0	**Primary:** shoreline overtopping from Belmont Slough. **Secondary:** Redwood Shores Lagoon.	13	0	-1	-3.5	-6.9
1g	SF Bay, Steinberger Slough	SVCW	Coastal	Vinyl Sheet-pile wall	Private	12.5	**Primary:** Adjacent flooding from 1f and 1h or shoreline overtopping of the sheet-pile walls	11	1.5	0.5	-2	-5.4
1h	Steinberger Slough	SVCW to San Carlos Airport	Coastal	Embankment	City (Bay Trail)	12.0	**Primary:** shoreline overtopping from Steinberger Slough. **Secondary:** Redwood Shores Lagoon.	12	0	-1	-3.5	-6.9
Reach 2: Downtown												
2a	Steinberger Slough	City Boundary to Whipple Ave	Combined Coastal and Creek	Embankment	City (Bike path)	10	**Primary**: shoreline overtopping Steinberger Slough	11	-1	-2	-4.5	-7.9

Focus Area #	Adjacent Water Body	Public Landmarks	Potential Cause of Flooding	Type of Flood Protection	Land Ownership	Approx. Minimum Shoreline Elevation (ft NAVD)	Flood Routes	Approx. BFE (ft NAVD)	Freeboard relative to BFE and SLR			
									SLR: +0'	+1.1'	+3.5'	+6.9'
2b	Steinberger Slough (south branch)	Whipple Ave to Sea Anchor Dr (bayward of Hwy 101)	Coastal	Embankment	City (Bike path)	9.5	**Primary**: shoreline overtopping Steinberger Slough **Secondary**: Adjacent flooding from 2c, 2d	11	-1.5	-2.5	-5	-8.4
2c	Smith Slough, Redwood Creek	Blu Harbor	Coastal	Concrete flood wall	Private	15.0	**Primary**: adjacent flooding from 2c **Secondary**: Shoreline overtopping from Smith Slough	11	4	3	0.5	-2.9
2d	Redwood Creek	Bair Island Marina	Coastal	Embankment	Private	9.0	**Primary**: shoreline overtopping from Redwood Creek	10	-1	-2	-4.5	-7.9
2e	Redwood Creek (west bank)	Sea Anchor Dr to Hwy 101 crossing over Redwood Cr	Combined Coastal and Creek	Embankment, concrete flood wall	Private	9.5	**Primary**: shoreline overtopping from Redwood Creek	10	-0.5	-1.5	-4	-7.4
2f	Redwood Creek (west bank)	Hwy 101 to Bradford Street	Combined Coastal and Creek	Embankment and earthen berms	Private	10	**Primary**: shoreline overtopping from Redwood Creek **Secondary**: Flooding from Cordilleras Creek	10	0	-1	-3.5	-6.9
Reach 3: Downtown to Seaport Boulevard												
3a	Redwood Creek (east bank)	Hwy 101 to Bradford Street	Combined Coastal and Creek	Embankment and earthen berms	Private	10.5	**Primary:** shoreline overtopping from Redwood Creek	10	0.5	-0.5	-3	-6.4
3b	Redwood Creek (east bank)	Inner Harbor: Hwy 101 to Maple Street	Combined Coastal and Creek	Embankment and earthen berms	Private	7.0	**Primary:** shoreline overtopping at terminus of Maple Street	10	-3	-4	-6.5	-9.9
3c	Redwood Creek (east bank)	Inner Harbor: Maple Street to Seaport Blvd	Combined Coastal and Creek	Earthen berm and metal bulkhead	Private	7.0	**Primary:** adjacent flooding from 3b **Secondary:** shoreline overtopping from Redwood Creek. Overtopping of Seaport Blvd from 4	10	-3	-4	-6.5	-9.9
3d	Redwood Creek (east bank)	Seaport	Coastal	Concrete floodwall	Private	14.0	**Primary:** shoreline overtopping from Redwood Creek **Secondary:** shoreline overtopping from Redwood Creek. Overtopping of Seaport Blvd from 4	11	3	2	-0.5	-3.9

Focus Area #	Adjacent Water Body	Public Landmarks	Potential Cause of Flooding	Type of Flood Protection	Land Ownership	Approx. Minimum Shoreline Elevation (ft NAVD)	Flood Routes	Approx. BFE (ft NAVD)	Freeboard relative to BFE and SLR			
									SLR: +0'	+1.1'	+3.5'	+6.9'
3e	Redwood Creek (east bank)	Port of Redwood City	Coastal	Embankment and earthen berms	Private	8.0	**Primary:** shoreline overtopping from Redwood Creek **Secondary:** shoreline overtopping from Redwood Creek. Overtopping of Seaport Blvd from 4	11	-3	-4	-6.5	-9.9
3f	SF Bay	Seaport Business Park	Coastal	Embankment	Public (walking path)	9.5	**Primary:** shoreline overtopping from SF Bay	11	-1.5	-2.5	-5	-8.4
3g	SF Bay	Westpoint Harbor	Coastal	Embankment	Private	10.5	**Primary:** shoreline overtopping from SF Bay	12	-1.5	-2.5	-5	-8.5
Reach 4: Friendly Acres												
4	Cargill Salt Ponds, Bayfront Canal	--	Coastal	Embankment	Private	5.0	**Primary:** Bayfront Canal. Flooding from Bay would occur only after Ponds overtop at 9.5'.	12	-7	-8	-10.5	-13.9

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3. ADAPTATION STRATEGIES

This chapter details the development of a series of conceptual adaptation measures for the City's shoreline. These are intended to be a first level of concepts, for review by the City and discussion and refinement with stakeholders.

3.1 Local and Regional Context for Adaptation Targets

The public safety portion of City's General Plan (City of Redwood City, 2010) includes the goal calling for the City to "[m]itigate against and adapt to climate change" (Goal PS-5). As part of this effort, a new ordinance in the City's zoning code was adopted in 2018 for the Mixed-Use Waterfront Zoning District with measures to address sea-level rise (City of Redwood City, 2018). These measures, from Article 57.10, call for adaptation strategies to accommodate three feet of sea-level rise via elevation of the lowest floor of structures, setbacks from the shoreline, and managed retreat to facilitate tidal marsh, as well as levees and seawalls that meet FEMA accreditation standards.

In 2018, San Mateo County (County) assessed vulnerabilities to flooding exacerbated by sea-level rise (County of San Mateo, 2018). This study demonstrated the risks posed to the County's Bay-front communities and helped spawn the San Mateo County Flood and Sea Level Rise Resiliency District, the agency known as "OneShoreline". Since its founding in 2020, OneShoreline has collaborated with cities (including Redwood City for the Redwood Shores Sea Level Rise Protection Project and Bayfront Canal Flood Control Project) and has developed guidelines for protecting and enhancing the Bay shoreline (OneShoreline, 2023a). These guidelines recommend policies and zoning code changes to help achieve elevating the shoreline to protect from coastal flooding. The guidelines interpret State guidance (OPC, 2018; OPC, 2020) for the County, and provide a Map of Future Conditions that recommends target elevations for the County's Bay shoreline, including the City's shoreline. The map's proposed shoreline elevations are targeted to maintain FEMA accreditation for up to 3.5 ft of sea-level rise.

California recently passed Senate Bill 272, which requires regional shoreline adaptation plans to be approved by 2034 for all nine Bay Area counties, with oversight from BCDC. The specifics regarding plan implementation are currently under development by BCDC. Although these specifics are not yet known, the adaptation approaches described in this memo are consistent with existing planning guidance from the State and County which are likely to inform the implementation of SB 272.

3.2 Approach to Adaptation

Based on the local and regional context discussed in the previous section, this adaptation memo targets the long-term goal of protecting the City's shoreline for FEMA accreditation with 3.5 ft of sea-level rise. Planning for this amount of sea-level rise nearly corresponds to the City's zoning code for the Mixed-Use Waterfront Zoning District, with the slight change of planning for 3.5 ft instead of 3 ft of sea-level rise. This slight increase brings this study's target into agreement with more recent State (OPC, 2020) and County (OneShoreline, 2023a) guidance. While outside the scope of this study, the City could consider reviewing and incorporating newer County guidance into their zoning code.

While many parts of the City are within the 100-year FEMA floodplain, the level of vulnerability varies from region to region. As described in the Vulnerability Memo (**Chapter 2**), some areas are already exposed to flooding from the 99% annual chance event, whereas others face flood hazards from 10% to 1% annual chance events. Each foot of sea-level rise will increase flood frequency, such that an elevation vulnerable to the 1% annual chance today will be vulnerable to the 10% annual chance with one foot of sea-level rise.

Because of land ownership, cost, conflicts with existing structures and infrastructure, it will likely be difficult to achieve the long-term target for all of the City in the next decade. For some portions of the shoreline, shorter-term measures that protect for a lower level of coastal flood hazard may be warranted.

Much of the low-lying and shorefront areas of the City are privately owned. These areas will require coordination by and with the City and County to address flooding. Publicly owned parcels or shoreline reaches which have existing levees and easements are likely to facilitate City implementation.

In the long-term, a comprehensive strategy for the City's shoreline will require outreach and partnerships with private landowners.

Many of the areas in Redwood City that are predicted to flood during extreme events are interconnected by low-lying flow pathways landward of the shoreline. Hence, even though one area may have its immediate shoreline elevated above extreme flood water levels, inland portions of the area and/or access to inland portions may be susceptible from flooding via other, lower elevation sections of the shoreline.

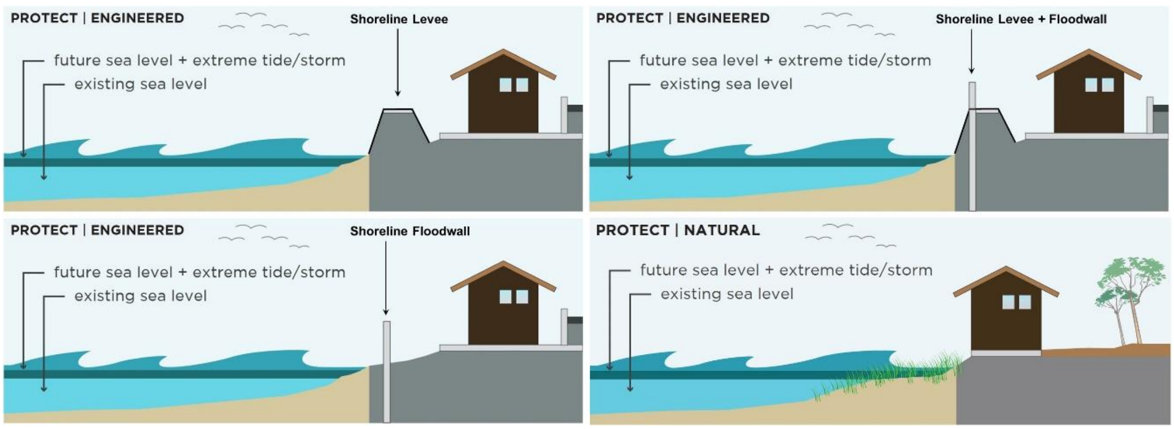
3.2.1 Adaptation Measure Selection

There are four general categories of adaptation to increase the resilience to flood-induced sea-level rise hazards, as defined by the California Coastal Commission (2018): protect, accommodate, retreat, and hybrid.

- **Protect:** these strategies employ an engineered structure, such as a levee or a floodwall, to defend development in its current location without changes to the development itself.
- **Accommodate:** these strategies employ methods that modify existing developments or design new developments to tolerate intermittent flooding, such as elevating structures and flood-proofing utilities to reduce consequences of inundation.
- **Retreat:** these strategies involve relocation or removal of existing development out of hazard areas and limit the construction of new development in vulnerable areas.

- **Hybrid:** these strategies combine measures from the three strategies described above, such as accommodating over the short-term and relocating long-term.

Protect in place is a common adaptation strategy. For example, OneShoreline's Map of Future Conditions (OneShoreline, 2023b) calls for the County's entire Bay shoreline to be raised to elevations of 16-18 ft NAVD88 to protect bayfront development. This strategy enables developed areas of the City to be protected from flooding that could endanger public safety and/or damage structures and infrastructure. Accordingly, the primary adaptation measures considered are levees and floodwalls, which are illustrated in **Figure 10**.



SOURCE: Modified from original illustration in City and County of San Francisco 2016

D202200346 Redwood City SLR Vulnerability Study and Adaptation Plan

Figure 10.
Conceptual cross-sections with levees and floodwalls

3.2.2 Shoreline Protection Considerations

At the municipal scale, the choice of strategy illustrated in **Figure 10** ultimately depends on the site context, regional guidance, and local constraints. This section describes some of the constraints that were considered for this study.

Earthen Levees

Earthen levees consist of compacted sediment, composed primarily of clay and mud. To meet FEMA accreditation standards, they need to be comprised of suitable material that is geotechnically engineered to resist seepage, hydraulic forces, slope failure, and seismic events. Where levees are not constructed with sufficient resilience to these failure modes, levees can be replaced with levees engineered to more robust specifications or sheet pile flood walls can be embedded within the levees to address these vulnerabilities. Particularly when suitable materials are available, levees are typically less expensive than other barriers to construct. Levee elevations may be built to achieve FEMA accreditation standards by providing minimum freeboard above the local base flood elevation. Levees also provide adaptive capacity, meaning that their level of flood protection can be augmented in the future by building floodwalls on the levee crest. For these reasons, levees are generally the preferred measure for flood protection.

Floodwalls

A difficult aspect of using levees for shoreline defense is that they typically include a crest width of up to 20 feet with restrictions on maximum side slope, which results in a substantial width of shoreline for their construction. Floodwalls provide an alternative to levees in space-constrained contexts. They may require buttressing depending on height and material but in general have a much smaller footprint. Tradeoffs for this smaller footprint may include higher costs as compared to levees and the discontinuity of vertical walls for public access and outboard habitats. In some instances, a combination of floodwall and levee may be used, in which floodwalls are used for portions of the levee trapezoid, so the overall footprint is not as wide, and the vertical height of the floodwall is limited, to allow for shoreline visitors to see over or for earthen fill to soften abrupt transitions for habitat.

Marshes

Redwood City's extensive tidal marshes provide valuable ecosystem services as well as flood protection. Wetlands provide habitat for various birds and aquatic life, and in particular, Bair Island, Bird Island, and Greco Island are home for endangered and listed species as well as thousands of migratory shorebirds. During storms, these marshes can attenuate wave energy, thereby reducing flood and erosion risks. However, tidal marshes themselves face the risk of erosion or drowning due to sea-level rise if sediment supply is not adequate to keep pace with increased water levels and more frequent inundation. Monitoring existing marsh extents, maintaining their elevation by supplementing their sediment supply, and/or restoring marshes are also important adaptation measures to consider.

Due to their wave, erosion, and flood attenuation functions, marshes are considered one of a number of nature-based solutions (NBS) for addressing sea-level rise impacts. In contrast to traditional "grey" infrastructure like levees and seawalls, marshes and other NBS incorporate natural elements that provide ancillary benefits, such as wetland habitat and water quality filtering. Note that flood protection cannot ordinarily be accomplished through NBS alone. Rather, NBS are generally used together with traditional engineered infrastructure.

NBS approaches are not limited to marsh restoration and include a range of approaches such as augmenting offshore tidal flats with sediment, reconnecting sediment sources from Bay watersheds to the tidal wetlands adjacent to the creek mouths, improvement of transition areas between marshes and upland areas (sometime referred to as 'ecotone slopes' or 'horizontal levees'), application of beaches to reduce erosion of marsh and built shoreline edges, and several others (see SFEI and SPUR 2019). Recent NBS projects that have been constructed include Heron's Head Shoreline Park improvements within the Port of San Francisco, Aramburu Island, and the restoration of the Ravenswood segment of the South Bay Salt Ponds. A number of bay-wide and regional efforts are currently underway to build on lessons learned from these constructed NBS projects and to inform future application of NBS.

Habitat Opportunities & Constraints

For purposes of this study, new levees and floodwalls are assumed to minimize fill of existing wetlands and tidal marsh. This minimizes potential impacts to these habitats and reduces the compensatory mitigation that would be required as part of a flood protection project. However, because these levees and floodwalls need to be located along the shoreline and may face other constraints, avoiding all wetland impacts may not be feasible. The various impacts, which may include levee/floodwall footprint, fill, and wave deflection onto nearby habitats, would be analyzed as part of the environmental permitting process for any new project.

When conditions are favorable, the flood protection elements could be combined with fill to create higher elevation habitats, such as ecotone slopes, which provide a transitional slope between marsh and upland areas. One common form is referred to as a horizontal levee, which consists of a hardened core like those of traditional levees but with much gentler outboard slopes which can be planted and designed to provide valuable habitat. While such fill is technically being placed on existing wetlands, regulatory agencies have started to recognize and encourage construction of such features, particularly in areas where the existing wetlands are of suboptimal quality, such as within managed wetlands primarily configured for salt extraction. Such fill should follow best practices for wetland habitat improvement, such as being placed inland and above existing tidal marsh, and comply with regulatory guidance (BCDC, 2019).

Space Constraints

For coastal levees and floodwalls, the minimum freeboard is at least two feet above the base flood elevation, and, if higher, at least one foot above the total water level. Total water level refers to the elevation reached by both storm surge and wave runup.

The FEMA base flood elevation along the outboard side of the City's shoreline ranges from 11 to 13 ft NAVD. The higher values are where exposure to wave runup adds to the still water level of storm surge during extreme flood events. Therefore, design flood elevations to address just present-day FEMA accreditation would be between 13 feet NAVD (for areas without wave exposure plus the minimum FEMA freeboard of two feet) and 15 ft NAVD (for areas with wave exposure where freeboard is one foot above total water levels). Adding on 3.5 ft of sea-level rise, the resulting elevations are 16-17 ft NAVD, as per OneShoreline Map of Future Conditions (OneShoreline, 2023b).

The Redwood City shoreline defined in the Vulnerability Assessment (**Chapter 2)** is further divided into subreaches for the purposes of determining flood barrier type and approximate height necessary. Redwood City is a dense, urban area with residential, commercial, and industrial land use that constrain the footprint available for flood protection. However, given the cost savings and adaptive capacity afforded by levees, levees are the assumed flood protection measure wherever there appears to be enough space for their implementation. Floodwalls are chosen based on existing space and infrastructure. Working with private landowners will be crucial to design and implementation. Recommendations in the following sections should be considered preliminary, as many opportunities and constraints specific to each parcel have not yet been identified for this high-level planning study.Long Term Land Use Planning

While changes to the City's General Plan, Specific Plan, and/or zoning ordinance fall outside the scope of this study, when updating these documents, reserving space for flood protection could provide more flexibility for including NBS and potentially allow for more continuity in flood protection features as well. Such changes could also mitigate against coastal squeeze, or the loss of coastal habitats if they are not allowed space to move inland as sea-level rise progresses. Refer to One Shoreline's Planning Policy Guidance and forthcoming Public Infrastructure Guidance for suggested text on updating City plans or ordinances.

3.3 Adaptation Strategies by Reach

This section outlines the proposed strategies for each of the four reaches of Redwood City shown in **Figure 7**. The number of proposed strategies varies by reach and encompasses both short- and long-term measures. Short-term measures are anticipated to be completed in the next 5-10 years and could be interim efforts that accommodate less than 3.5 ft of sea-level rise. Long-term measures are those that would provide FEMA accreditation with 3.5 ft sea-level rise, which should be sufficient for sea-level rise projected to be likely through 2100.

These adaptation strategies have only been developed at a planning level, for purposes of coordinating a City-wide plan to adapt to sea-level rise. Coordination is required since flooding can enter the developed areas from just one parcel or subreach but then spread to inundate many more. Many of the parcels which would host adaptation measures are privately owned. Permission from the property owners and regulatory agencies would be needed for implementation, and the adaptation measures would need to be refined in coordination with each parcel owner's preferences and regulatory agencies' requirements. Refinements at the parcel scale and that consider all the site-specific conditions that inform fully designed construction projects are beyond the scope of this present study.

Adaptation strategies focus primarily on the threat of flooding from the Bay and secondarily on vulnerabilities in the stormwater drainage system, sea-level rise effects on marshes, and other factors on a reach-by-reach basis. Accordingly, the primary adaptation measure for all reaches is to raise the low-lying parts of the shoreline with a levee (if space permits) or floodwall.

Reach 1: Redwood Shores

Reach 1 encompasses the Redwood Shores peninsula, tying into the City boundaries with Foster City to the north and to the south with San Carlos. The peninsula is largely surrounded by a levee improved in 2010 (City of Redwood City, 2020), which is further augmented around the Silicon Valley Clean Water facility with vinyl sheet pile wall. The Bay Trail runs along the levee crest through much of the reach.

These measures had been sufficient to meet FEMA accreditation, meaning the developed areas in Redwood Shores were mapped into Zone X and landowners were not required to purchase flood insurance. However, after FEMA's adoption of updated flood maps in 2019, the City received a letter from FEMA in April 2020 notifying them that the levees around Redwood Shores no longer met their accreditation requirements. In collaboration with OneShoreline, a recent FEMA grant is anticipated in 2024 to study and design the levee improvement measures in this reach. Levee improvements with crest elevations of 16-17 ft NAVD are likely to be considered, to meet OneShoreline's guidance to design for FEMA accreditation for up to 3.5 ft sea-level rise.

Known Issues

Because of its past history of FEMA accreditation, this reach is fairly well-protected. The existing levees previously met FEMA geotechnical requirements for accreditation, even if their crest elevations have since been determined to be deficient. The shoreline elevations are currently about 12 ft NAVD. Re-obtaining accreditation will be important to avoid mapping all of the residents in this reach into the floodplain.

To prevent flooding around the ends of this reach's levees will require coordination with the adjoining cities of Foster City and San Carlos, to tie-in this reach to similar level of protection in the adjoining cities.

Proposed Strategies

Primary Strategy: Raise Shoreline Elevations and Bay Trail

Raising the levee to 16-17 ft NAVD would help prevent flooding of Reach 1 during a present-day 100-year flood event, as well as meet FEMA freeboard requirements for a 100-year event with approximately 3.5 feet of sea-level rise.

Impacts to aesthetics and recreation resulting from the higher shoreline edge can be mitigated by raising and integrating the Bay Trail with the levee crest. This strategy assumes that the footprint of the new, higher levees would prioritize overlapping on parking areas or green spaces and minimizing placement in designated wetlands and open waters of the Bay. In more constricted sections a new flood wall could be used. Both options would have benefits for the region outside of Reach 1 by reducing flooding and disruption of service of Highway 101.

The construction cost of these levee improvements is estimated at $83,900,000. With contingency, environmental compliance and permitting, project management, and construction administration, the full Reach 1 improvement cost estimate is $154,300,000.

Additional Strategies and Considerations

Maintain marshes: Bird Island and other marshes on the north and west sides of this reach likely provide some attenuation and habitat benefit, and maintaining these marshes through monitoring and restoration may help them continue to provide these benefits even as sea level continues to rise.

Protect key infrastructure: The Silicon Valley Clean Water facility provides wastewater treatment to the City and several adjacent cities. Its continued functioning is essential to the removal and treatment of sewage, to protect the population of these cities and Bay habitats. In accordance with Regional Water Quality Control Board guidance, the sea-level rise vulnerability and adaptation plan for this facility should be updated every five years, in conjunction with the facility's updates to its wastewater discharge permit.

Reach 2: Downtown West

Reach 2 begins near the mouth of Pulgas Creek, winds around outboard of several housing developments and Village Park and follows the west bank of Redwood Creek to the upstream extent of Redwood Creek's open channel. The western portion of this reach's shoreline runs closely parallel to Highway 101, and the eastern portion is primarily residential with some commercial developments as well.

An extensive set of marshes lie bayward of this reach. Bair Island stretches as much as 3.4 miles offshore of Reach 2. Marshes attenuate waves, and thereby reduce the exposure of inland development to flooding from wave runup.

Known Issues

Three general areas of this reach fall into the current FEMA floodplain: 1) the development between Whipple Avenue and Sea Anchor Drive, 2) the development along Uccelli Drive in the north part of this reach, and 3) inland of Highway 101 and extending west from the left bank of Redwood Creek. This last region may be exposed to combined fluvial and bay flooding.

Shoreline elevations in this reach are variable, ranging from elevations around 10 ft NAVD along the Bay Trail just outboard of the highway, to elevations of up to 15 ft for the walls surrounding the residential Blu Harbor development. However, floodwaters that overtopped the shoreline at lower elevations can still bring overland flooding to those parts of the reach with higher shoreline defenses.

For this reach, a stormwater master plan (Wood Rodgers, 2017) found that only the K-Mart pump station has capacity to handle the 100-year event, although this pump station's pipe network only has capacity for the 30-year event. None of the other pump stations have capacity for the 30-year event. There is some capacity to handle the 10-year event. To meet FEMA accreditation standards, this interior drainage system would need to keep stormwater ponding to less than one foot deep.

Some census tracts in this reach east of El Camino Real rank between the 80th-85th percentile nationally on the Demographic Index, which is assessed on the basis of the two socioeconomic factors named in Executive Order 12898 on Environmental Justice. Higher rankings can indicate more vulnerable populations and those less able to prepare for and respond to hazards.

This reach may also experience flooding during extreme events from Cordilleras Creek. City staff indicated that the creek is known to flood in the vicinity of Industrial Road.

Proposed Strategies

Adaptation strategies for Reach 2 are shown in **Figure 11**.

Primary Strategy: Raise Shoreline Elevations and Bay Trail

Given the variety of existing flood protection and the dense development through much of this reach, the recommended adaptation measures are a mixture of floodwalls and levees at different heights. Raising the shoreline to 16-17 ft NAVD throughout the reach would help prevent flooding of Reach 2 during a present-day 100-year flood event, as well as have capacity for a 100-year event with approximately 3.5 feet of sea-level rise. It would also be a sufficient height to be accredited by FEMA under present-day conditions, so long as other accrediting requirements are also met.

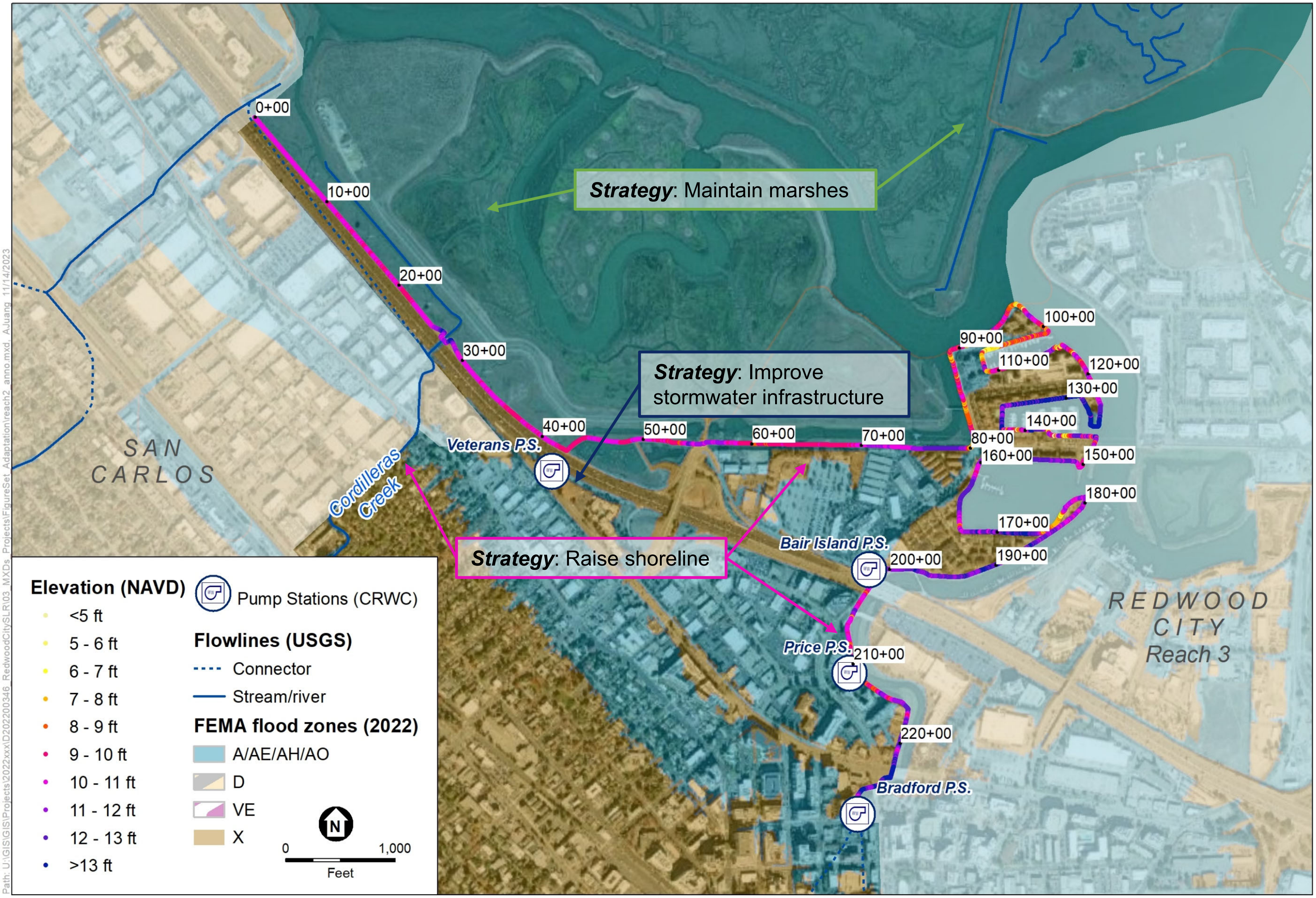
The estimated construction cost for raising the shoreline along Reach 2 is $53,600,000. With contingency, environmental compliance and permitting, project management, and construction administration, the full Reach 2 improvement cost estimate is $98,600,000.

Additional Strategies and Considerations

Improve stormwater infrastructure: The Drainage Master Plan recommends improving pump stations first, then pipe systems, and all three of the watersheds in this reach are at the top of the priority rankings based on an analysis of deficient pipe length, associated flooding, and condition assessments. Retrofitting this reach to 30-year capacity (pipes) and 100-year capacity (pumps) would cost an estimated $22.3 million, not including 50% redundancy on pump station improvements (Wood Rodgers, 2017). As of the end of 2023, the City has completed full design for the Bradford Pump Station. Construction is pending on FEMA's approval of the design. In 2024, the City is anticipating the award of a FEMA grant for design, permitting, and construction services to improve the Price Pump Station, which is located on the landward side of Reach 2.

Maintain marshes: As discussed in the vulnerability assessment, prior wave modeling (BakerAECOM, 2014) shows the marsh between Reach 2 and the open Bay provides wave height reductions of about 1-2 feet. Maintaining these marshes through monitoring and restoration may help them continue to provide substantial benefits even as sea level continues to rise.

Monitor changes in the groundwater table: As part of the long-term adaptation process, the City should participate in regional coordination efforts focusing on groundwater management, and in the short-term should consider the effect of rising groundwater levels when considering capital improvements related to stormwater infrastructure. The City should document localized flooding in low-areas of the City on an annual basis, as these areas are expected to worsen over time.



SOURCE: USGS, FEMA, CRWC

D202200346 Redwood City Sea-Level Rise Vulnerability Study and Adaptation Plan

Figure 11
Adaptation Strategies for Reach 2

ESA

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Reach 3: Downtown East & Seaport

Reach 3 follows the right bank of Redwood Creek and then runs outboard of development along the north side of Seaport Boulevard. Notable infrastructure in this reach includes a marina off of Maple Street, a PG&E substation just south of the intersection of Seaport Boulevard and Chesapeake Drive, and the Port of Redwood City. Land use in this reach is primarily commercial and industrial.

Like Reach 2, this reach also benefits from significant areas of marshes bayward of the shoreline. Bair Island sits to the north and west, while a portion of Greco Island extends across the northeast corner of this reach.

Known Issues

Significant portions of this reach are within the FEMA floodplain. These areas indicate flooding from low points of Redwood Creek, the boat ramp at Maple Street, along the length of the Port of Redwood City. A breach in the berm surrounding the wetland across Redwood Creek from Maple Street may also provide another flooding pathway. Additionally, this reach may experience extensive inland flooding conveyed along Seaport Boulevard. A developed portion of this reach, Seaport Center, recently completed a levee and floodwall improvement project and plans to seek FEMA accreditation for this effort. The elevations of this project range from about 11 to 14 ft NAVD, so while they may be sufficient for accreditation with existing conditions, they are likely to lose accreditation with the addition of about one foot of sea-level rise. Some segments of this levee and floodwall system were designed to maintain FEMA accreditation for up to about two feet of sea-level rise. Hence, this system does not meet the city's long-term target of FEMA accreditation for up to 3.5 ft of sea-level rise.

Reach 3 is also part of the Eastern Low-Lying Area evaluated in the 2017 Drainage Master Plan (Wood Rodgers). The analysis delineated five watersheds within Reach 3, including one (Bradford) that spans both Reach 2 and Reach 3. Of these, four were found to have sufficient pump station capacity for the 10-year event and three have sufficient pipe capacity for the same event. Only the K-Mart and Peninsula/Boardwalk watersheds were rated as having any capacity to handle the 30-year event (Wood Rodgers, 2017). Additionally, Bair Island, Bradford, and Price Pump Stations, along with 87 manholes, are located in the 100-year flood plain.

Two important agencies have low-lying infrastructure in this reach. The PG&E substation was previously afforded some protection by the wetlands to the west and by the berm surrounding the wetlands. However, the breach in that berm has elevated the flooding risk for this electrical infrastructure.

Further north, the Port of Redwood City generally has the lowest shoreline of this reach at 9 ft NAVD. Port facilities are floodproofed such that they can sustain several days of disruption during storm events (County of San Mateo 2018). A recent wharf replacement project was designed to accommodate 1.5 ft of sea-level rise for this structure and the immediate adjoining shoreline (Gerwick, Inc., 2014). However, other portions of the Port's low-lying shoreline present a vulnerability pathway to inland properties and to Seaport Boulevard, a primary access road to Port property.

Proposed Strategies

Primary Strategy: Raise Shoreline Elevations

Given the variety of existing flood protection and development density through this reach, the recommended adaptation measures are a mixture of floodwalls and levees. Generally, the segment of Reach 3 along Redwood Creek is more space-constrained and would not have space to accommodate a levee footprint without significant incursion on existing properties and buildings. East and north of Maple Street, there may be room to protect the shoreline with levees, which also provide adaptive capacity for future protection through either raising the levee or supplementing with a floodwall on top.

Raising the shoreline to 16-17 ft NAVD throughout the reach would help prevent flooding of Reach 3 during a present-day 100-year flood event, as well as have capacity for a 100-year event with approximately 3.5 feet of sea-level rise and still meet FEMA freeboard accreditation standards.

The estimated construction cost for raising the shoreline along Reach 3 is $78,200,000. With contingency, environmental compliance and permitting, project management, and construction administration, the full Reach 3 improvement cost estimate is $143,900,000.

Additional Strategies and Considerations

Improve stormwater infrastructure: The Drainage Master Plan recommends improving pump stations first, then pipe systems. The watersheds in this reach are ranked as lower priority than those in Reach 2, but the Bradford and Maple pump stations should be prioritized since they do not have an overland release point that can mitigate flooding if rendered inoperable during large events. Retrofitting this reach to 30-year capacity (pipes) and 100-year capacity (pumps) would cost an estimated $12.6 million, not including 50% redundancy on pump station improvements (Wood Rodgers, 2017). Note the estimate above does not include Bradford Pump Station, which is located on the Reach 2 side of the watershed.

Maintain marshes: As discussed for Reach 2, maintaining the marshes in front of Reach 3 through monitoring and restoration may help them continue to provide substantial wave attenuation benefits even with climate change.

Monitor changes in the groundwater table: The City should document localized flooding in low areas of the City on an annual basis, as these areas are expected to worsen over time. Understanding changes in the groundwater levels at the local level will assist with planning efforts, including prioritization for adaptation.

Reach 4: Friendly Acres

Reach 4's endpoints connect to Reach 3 and to the proposed SAFER Bay levee project under development by Menlo Park. Development just inland of Reach 4 is largely residential to the east and a mix of commercial and residential to the west. The FEMA BFE in this reach is 12 ft NAVD.

Recurrent flooding in the drainage area of the Bayfront Canal prompted an evaluation of this system's hydraulics (BKF Engineers, 2017). Between 2017-2022, OneShoreline, Redwood City, Menlo Park, Atherton, the U.S. Fish and Wildlife Service, and the County of San Mateo undertook a project to reduce flooding by diverting some of the flow from Atherton Channel and Bayfront Canal. The diverted flow is routed into wetlands in Menlo Park that are owned and managed by the U.S. Fish and Wildlife Service.

Known Issues

Nearly all of the development described above is mapped into the FEMA 100-year floodplain. City staff also described significant observed ponding in developed areas just landward of this reach after the 2022 holiday storms, such as the Friendly Acres neighborhood. Some census tracts in this reach rank between the 80th-91st percentile nationally on the Demographic Index, which is assessed on the basis of the two socioeconomic factors named in Executive Order 12898 on Environmental Justice. Higher rankings can indicate more vulnerable populations and those less able to prepare for and respond to hazards.

Although drainage on the landward side of this reach has not been studied, overlaying of stormwater infrastructure on FEMA's National Flood Hazard Layer suggests that drainage infrastructure in this reach may also be insufficient and a contributing cause to ponding observed in this area. Ninety-four manholes, plus the 5th Avenue pump station, the Douglas Street pump station, and the Broadway pump station (BKF, 2017) are all mapped into the 100-year floodplain.

Proposed Strategies

Primary Strategy: Raise Shoreline Elevations

Raising the shoreline to 17 ft NAVD throughout the reach would help prevent flooding of Reach 4 during a present-day 100-year flood event, as well as have capacity for a 100-year event with approximately 3.5 feet of sea-level rise. It would also be a sufficient height to be accredited by FEMA under present-day conditions, so long as other accrediting requirements are also met.

Reach 4 is the least space-constrained of the reaches considered in this study, with the salt ponds potentially able to accommodate the additional width needed for the levee footprint. With the addition of more fill on the outboard side of this levee, this effort could also build an ecotone slope into the salt ponds that would provide habitat diversity and transgression space for tidal habitats to move upwards with sea-level rise, instead of being drowned out.

The estimated construction cost for raising the shoreline along Reach 4 is $105,500,000. With contingency, environmental compliance and permitting, project management, and construction administration, the full Reach 4 improvement cost estimate is $194,100,000.

Additional Strategies and Considerations

Improve stormwater infrastructure: The stormwater management system landward of Reach 4, comprised of pipes, pump stations, and the Bayfront Canal, has demonstrated deficiencies with regards to adequately removing stormwater from the neighborhoods in this area due to coincident tidal constraints. An assessment of this system should consider its capacity to meet its performance criteria in the face of climate change. Three key assessments for each pump station are:

- What is the potential for increased inflow to the pump station due to more frequent levee overtopping due to sea-level rise, elevated groundwater levels caused by sea-level rise, and/or increased precipitation due to higher rainfall intensity and frequency?
- Can the pump station provide its design discharge capacity when pumping to Bay or drainage channels whose water levels are elevated by sea-level rise?
- Is the pump station itself and its supporting infrastructure (e.g. power supply, maintenance access) vulnerable to inundation from greater flood hazards due to sea-level rise?

Provide Bay Trail connectivity: The Bay Trail does not currently connect along Reach 4. The crest of a new levee along this reach could also host a new segment of the trail that connects to existing trail segments at either end of Reach 4.

Monitor changes in the groundwater table: The City should document localized flooding in low-areas of the City on an annual basis, as these areas are expected to worsen over time. Having an understanding of changes in the groundwater levels at the local level will assist with planning efforts, including prioritization for adaptation.

3.4 Cost Estimates

While flood management measures can provide definite public benefits, the cost to achieve these benefits is an important consideration. For this study, rough order of magnitude implementation costs ("cost estimate") were developed for the measures which would progress to the City's long-term flood management objectives. The intent of these cost estimates is to inform long-term city planning as rough order-of-magnitude approximations. These estimates are based on the conceptual-level adaptation strategies (**Section 3.2**), according to the methodology described below.

In addition to construction of flood management measures, the cost estimates also include related soft costs for engineering, design, and permitting. To account for uncertainties surrounding these costs, the estimates include design and environmental compliance allotments, but do not include environmental mitigation, utility re-location, or right-of-way costs. Tables F-1 through F-5 in

Appendix F provide additional details on these soft costs. The cost estimates made for this study are rough order of magnitude estimates in 2023 dollars and have an anticipated accuracy range of +50%/-30%. Further planning and design are needed to reduce uncertainties and improve the accuracy of the cost estimate.

Note that stormwater improvement cost estimates cited in Chapter 3 were performed by Wood Rodgers; refer to the Eastern Low Lying Area Drainage Master Plan (Wood Rodgers, 2017) for costing assumptions and details. These costs are not included in **Table 8**, which focuses on coastal flood protection.

The cost estimates per reach, in 2023 dollars, are summarized in **Table 8** below.

TABLE 8
COST ESTIMATES BY REACH

Reach	Construction Subtotal	Construction Contingency	Design, Env. Compliance, Inspection, and Project Management	Project Contingency	Total
1	$83,900,000	$25,200,000	$36,900,000	$8,400,000	$154,300,000
2	$53,600,000	$16,100,000	$23,600,000	$5,400,000	$98,600,000
3	$78,200,000	$23,500,000	$34,400,000	$7,900,000	$143,900,000
4	$105,500,000	$31,700,000	$46,500,000	$10,600,000	$194,100,000
				Total	**$590,900,000**

4. NEXT STEPS

While adaptation approaches have varied for different cities and counties throughout San Francisco Bay, a number of recent guidance documents have captured a general framework that is common across most projects. Some useful guidance documents include the County's 2018 sea-level rise vulnerability study (County of San Mateo 2018), the Adaptation Atlas developed by SFEI and SPUR (2019), and the recent Planning Policy Guidance provided by OneShoreline (2023). While SFEI and SPUR (2019) mainly focus on nature-based approaches, the process they outline for developing adaptation pathways for the Bay shoreline is useful in the context of this project:

- Step 1: Assess vulnerabilities, exposure, and risk to sea level rise,
- Step 2: Filter adaptation options,
- Step 3: Consider desired futures and goals
- Step 4: Create scenarios composed of adaptation measures
- Step 5: Evaluate trade-offs and prioritize strategies and scenarios
- Step 6: Develop adaptation pathways to achieve desired outcome/scenario

This study comprises the first step in this process. The vulnerabilities and potential adaptation measures outlined in Chapters 2 and 3 of this report set the stage for focused dialogue with the City, shoreline communities, and stakeholders. Anticipated public workshops led by the City in 2024 will be the basis for communicating these findings to the public and beginning steps 2 and 3 above. Steps 4 and 5 are typically completed in the form of feasibility studies for specific segments of the shoreline, eventually leading to design and construction of projects. Step 6 can be visualized as a series of projects linked together over several phases to ultimately protect the City's shoreline.

The guidelines above are broadly consistent with the approach set forward recently by OneShoreline (2023) for cities within San Mateo County. In particular, its Community Resilience Goal 1 (CR-1) includes the following action:

> *'Sea Level Rise Adaptation Plan: Using the County's 2018 Sea Level Rise Vulnerability Assessment as a basis, develop a [City/County] Sea Level Rise Adaptation Plan to develop a clearly defined and locally supported suite of adaptation strategies for Future Conditions. Through inclusive, transparent, and sustained engagement with impacted communities, this Plan should expand the understanding of sea level rise risks to the [City/County], communicate these risks to the public, and develop implementable adaptation strategies that pairs updated land use policies, zoning and building code revisions, improved data collection/monitoring, and built and Natural Infrastructure project planning.'*

4.1 Potential Funding Sources

Implementing adaptation measures will require funding and will likely need to come from supplemental sources besides the City's general fund or local assessments. Collaboration with other stakeholders can support funding efforts. Other funding options to explore are summarized in **Table** along with web links to the relevant resources.

TABLE 9

POTENTIAL FUNDING SOURCES

Potential Funding Source	Purpose	Additional Information
Flood Mitigation Assistance (FMA)	Reduce or eliminate claims against the NFIP by reducing long-term risk of flood damage to buildings insurable under NFIP	Cal OES http://www.caloes.ca.gov/cal-oes-divisions/hazard-mitigation/pre-disaster-flood-mitigation FEMA https://www.fema.gov/flood-mitigation-assistance-program
Pre-Disaster Mitigation (PDM)	National competitive program focused on mitigation project and planning activities that address multiple natural hazards	Cal OES http://www.caloes.ca.gov/cal-oes-divisions/hazard-mitigation/pre-disaster-flood-mitigation FEMA https://www.fema.gov/pre-disaster-mitigation-grant-program
Repetitive Flood Claims (RFC)	Reduce flood claims against the NFIP through flood mitigation; properties must be currently NFIP insured and have had at least one NFIP claim	FEMA https://www.fema.gov/media-library-data/20130726-1621-20490-8359/rfc_08_guidance_final_10_30_07.pdf
Severe Repetitive Loss (SRL)	Reduce or eliminate the long-term risk of flood damage to SRL residential structures currently insured under the NFIP	FEMA https://www.fema.gov/pdf/nfip/manual201205/content/20_srl.pdf
Hazard Mitigation Grant Program (HMGP)	Activated after a presidential disaster declaration; provides funds on a sliding scale formula based on a percentage of the total federal assistance for a disaster for long-term mitigation measures to reduce vulnerability to natural hazards	Cal OES http://www.caloes.ca.gov/cal-oes-divisions/recovery/disaster-mitigation-technical-support/404-hazard-mitigation-grant-program FEMA https://www.fema.gov/hazard-mitigation-grant-program
Proposition 1 Climate Ready Grants	Climate Ready Grants are focused on supporting planning, project implementation and multi-agency coordination to advance actions that will increase the resilience of coastal communities and ecosystems	Coastal Conservancy http://scc.ca.gov/climate-change/climate-ready-program/
Measure AA	San Francisco Bay-specific program for restoring habitat, protecting communities from floods, and increasing shoreline public access	San Francisco Bay Restoration Authority http://sfbayrestore.org/sf-bay-restoration-authority-grants.php
Continuing Authorities Program (CAP)	CAP is to plan, design, and construct flood damage reduction projects. CAP projects do not require project-specific authorization from Congress.	U.S. Army Corps of Engineers, San Francisco District https://www.spn.usace.army.mil/Missions/Projects-and-Programs/Continuing-Authorities-Program/
Building Resilient Infrastructure and Communities	Supports hazard mitigation projects and proactive measures to support community resilience. Interested in innovative partnerships	FEMA https://www.fema.gov/grants/mitigation/building-resilient-infrastructure-communities

Potential Funding Source	Purpose	Additional Information
Specifically Authorized Projects (General Investigations Program)	Cost-sharing, co-sponsored investigations toward civil works water resources projects	USACE https://www.fema.gov/emergency-managers/practitioners/recovery-resilience-resource-library/specifically-authorized

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Appendix A.
Glossary of Terms

100-year (or 1% annual chance) flood event: A flood event that has a 1% chance of being exceeded in any given year. This doesn't mean it will happen exactly every 100 years, but rather that there's a 1-in-100 chance of it being exceeded in any given year.

Accreditation: Status granted by FEMA certifying that a levee system meets the design, data, and documentation requirements of Title 44, Chapter 1, Section 65.10 of the Code of Federal Regulations (44 CFR 65.10) and therefore is understood to reduce base flood hazard.[1]

Base Flood Elevation (BFE): Defined by FEMA as the "elevation of surface water resulting from a flood that has a 1% chance of equaling or exceeding that level in any given year." Denoted on Flood Insurance Rate Maps with various symbols, including more commonly AE, AH, AO, and VE.[2]

El Niño: The warm phase of a larger atmospheric and ocean cycle called the El Niño-Southern Oscillation (ENSO). It is characterized by unusually warm ocean temperatures in the central and eastern equatorial Pacific Ocean. During El Niño warming, the equatorial trade winds weaken or even reverse direction, allowing higher water levels to pile up in the Pacific Coast of the United States.

Federal Emergency Management Agency (FEMA): The federal agency that is responsible for implementing the National Flood Insurance Program (NFIP), which includes mapping flood hazard zones.

Flood Insurance Study (FIS): FEMA's compilation and presentation of flood risk data for specific watercourses, lakes, and coastal flood hazard areas within a community. When a flood study is completed for the NFIP, the information and maps are assembled into an FIS. The FIS report contains detailed flood elevation data in flood profiles and data tables.

Flood Insurance Rate Map (FIRM): Official map of a community on which FEMA has delineated the Special Flood Hazard Areas (SFHAs), the Base Flood Elevations (BFEs) and the risk premium zones applicable to the community.

Freeboard: An additional amount of height above a specified flood elevation used as a factor of safety. For example, for FEMA accreditation, a levee's crest elevation must have at least two feet of freeboard above the BFE's still water level.

King Tides: This describes the highest predicted high-tide and lowest low-tide events of the year. They are the exceptionally high tidal range caused by the year's most favorable alignment of gravitational pull of the Earth, the Sun, and the Moon.

North American Vertical Datum of 1988 (NAVD88): the official reference system in the United States for measuring and relating elevations to the Earth's surface.

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[1] https://www.fema.gov/sites/default/files/documents/fema_meeting-criteria-accrediting.pdf

[2] https://www.fema.gov/node/404233#:~:text=The%20elevation%20of%20surface%20water,%2C%20V1%E2%80%93V30%20and%20VE.

Seclusion mapping: a FEMA mapping process that shows portions of the FIRM as subject to future changes in flood hazard mapping designation, pending additional flood hazard analyses.

Special Flood Hazard Area: regions designated by FEMA as potentially being inundated by the flood event having a 1-percent chance of being equaled or exceeded in any given year.

Still water level (SWL): the average level of the water surface that accounts for tides but not waves or wave setup.

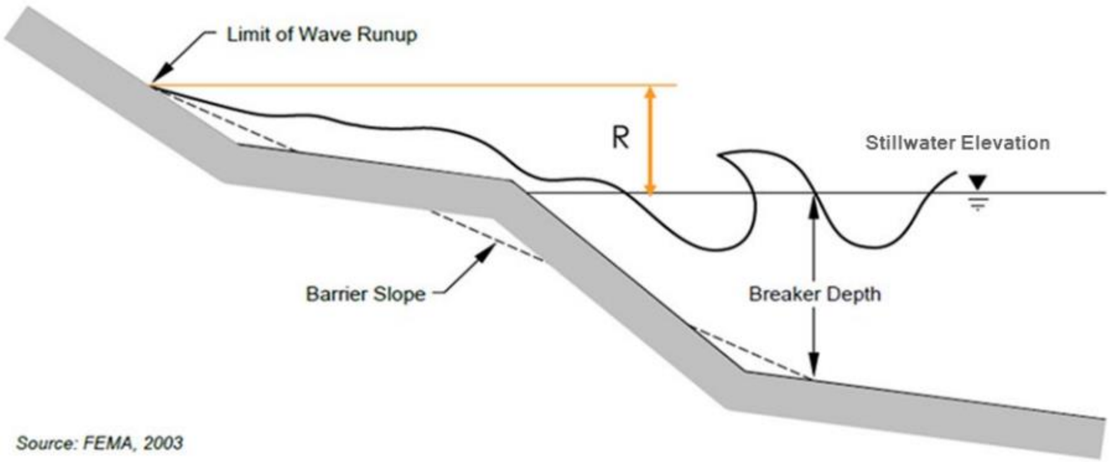
Tidal datum: Standardized reference elevations used to understand and measure water levels in relation to the tide. They are defined numerically by statistically averaging a range of tidally-varying water levels. Examples include mean higher high water (MHHW), mean sea level (MSL), and mean lower low water (MLLW).

Total water level (TWL): an estimate of the water level at the shoreline resulting from tides, storm surge, and wave runup.

Wave Height Analysis for Flood Insurance Studies (WHAFIS): FEMA-approved model that is used to simulate wave heights for coastal flood insurance mapping.

Zone X: Area of minimal flood hazard, usually depicted on FIRMs as above the 500-year flood level. Zone X is the area determined to be outside the 500-year flood and/or protected by a levee system from 100-year flood.

Wave runup: the inland vertical extent of waves as they break and run up the shore. Dependent on site-specific characteristics.



SOURCE: FEMA 2003, reproduced in FEMA 2021

D202200346 Redwood City SLR Vulnerability Study

Figure A-1
Wave Runup Schematic

Appendix B.
Data Sources

TABLE 1.

KEY DATA SOURCES REVIEWED FOR REDWOOD CITY SEA LEVEL RISE VULNERABILITY STUDY

Item	Description	Availability	Source
Regional Flood Studies and Policy Guidance			
FEMA National Flood Hazard Layer	Areal flood extents of 100-year flood zone (from most recent effective maps), as well as locations of Letters of Map Change (LMC).	2023	FEMA (2023)
FEMA Coastal Flood Levels	Most recent FIS, effective April 5, 2019. Flood levels are from combined high Bay water levels, winds, wave runup along few transects	2019	FEMA (2019)
Floodplain Mapping TSDN for San Mateo County	Report providing methodology for coastal hazard assessments in San Mateo County, as well as basis for recent flood map revisions	2014	BakerAECOM (2014)
USGS CoSMoS Flood Maps	Areal flood extents, depths for existing flood scenarios and flooding with sea-level rise.	0-500cm SLR, up to 100-year recurrence event	USGS (Ballard et al. 2016)
BCDC Adapting to Rising Tides hazard maps	Areal flood extents, levee overtopping depths for a range of future water levels. Each hazard map can be interpreted as a combination of different SLR amounts and different storm events	12-108” SLR, up to 100-year recurrence event	BCDC (2017)
FEMA Flood Insurance Study	Most recent FIS, effective April 5, 2019	2019	FEMA (2019)
San Mateo County SeaChange Project	Countywide vulnerability assessment indicating including maps of flooded areas with sea-level rise, and contextual information about the timing of flooding and asset exposure.	2018	County of San Mateo (2018)
OneShoreline Planning Guidance Policy document for San Mateo County	Guidance document for municipalities along the County’s Bay shoreline, with SLR-preparedness recommendations for new or substantial private development.	2023	OneShoreline (2023)
California Coastal Commission (CCC) Guidelines	Guidance documents providing information on expected sea-level rise in the State of California and a framework for incorporating this into the planning process for shoreline development.	2018, 2021	CCC (2018, 2021)
Physical Processes (Existing)			
Redwood City Tides	Hourly tide levels at Redwood City gage (#9414523)	1974-1976, 1983-1984, 1997-2023	NOAA (2023)
Local tidal datums and extreme levels	Tidal datums and extreme stillwater levels for analysis points around the perimeter of San Francisco Bay	2016	AECOM (2016)
Shoreline Features and Elevations (Existing and Planned)			
GIS data of shoreline features	City GIS layers of basins, flapgates, inlets, lagoon maintenance areas, levees, mains, manholes, pump stations, structures	2023	City of Redwood City
GIS map of shoreline levee certification status	GIS shapefiles indicating the presence of accredited and unaccredited levees	2021	City of Redwood City
GIS map of public and private assets within the floodplain	GIS shapefiles of public assets developed as part of the SeaChange San Mateo study for mapping vulnerability	2016	County of San Mateo (2016)
County digital elevation model	Mosaic dataset	2017	County of San Mateo
Blu Harbor Grading Plan	Grading plan with proposed seawall elevations for residential community.	2018	RWC Harbor Communities (2018a)

Item	Description	Availability	Source
Bair Island Road Improvements	Proposed road improvements near Blu Harbor and the Villas adjacent to Bair Island	2018	RWC Harbor Communities (2018b)
Seaport Centre Levee Survey	Surveyed levee profiles around Seaport Centre, pre- and post-construction. Latter includes revised floodplain boundary exhibit showing as-built elevations	2010, 2023	BKF Engineers (2010b, 2023)
Sheetpile wall drawings for Silicon Valley Clean Water	Vinyl sheet design for wastewater treatment plant adjacent to Redwood Shores (formerly South Bayside System Authority)	2010	Bohley Consulting (2010)
Bayfront Canal flap gate drawings	As-built drawings of canal flap gate for original and repaired configuration	1944, 1990	Leslie Salt Company (1944), BKF (1990)
Redwood Shores Preserve grading plans	2010 Grading plans for levee setback and marsh restoration along the northeastern edge of Redwood Shores Peninsula.	2010	BKF (2010a)
Redwood Shores Levee Improvement Project	2009 As-built drawings of levee improvements along the exterior of Redwood Shores Peninsula.	2009	BKF (2009)
Redwood Shores Peninsula: 2020 Status Report on Levee Certification	Report from City detailing the certification status of levee segments of the levee system surrounding Redwood Shores Peninsula. Provides reference to prior studies and upgrades	2020	City of Redwood City (2020)
Natural Infrastructure			
SF Bay Shoreline Adaptation Atlas	Report identifying adaptation strategies for each portion of the Bay shoreline, and the presence of natural features such as mudflats and marshes adjacent to the Bay shoreline	2019	SFEI and SPUR (2019)
San Mateo Wetlands Vulnerability Study	Modeling study identifying the long-term vulnerability of existing marshes within and adjacent to Redwood City shoreline	2019	Point Blue Conservation Science (2019)
Local flood studies: Drainage			
Locations of known flooding areas within Redwood City	Google Earth KMZ file of 8 areas within the City known to have nuisance flooding during high rain or high rain combined with high tides	2023	City of Redwood City (2023)
Eastern Low-Lying Area Drainage Master Plan	Analysis of response to 1%, 3.3%, and 10% annual exceedance probability rainfall/runoff storms and recommended improvements to convey those floods. Includes pump station plans, vulnerability, and recommended improvements.	2017	Wood Rodgers (2017)
Bayfront Canal Improvement Project: Design Development Alternatives Report	Study of existing conditions and 6 alternatives for reducing flooding along Bayfront Canal area. Recommendations provided for using adjacent salt ponds as storage area.	2003	Winzler and Kelly (2003)
Bayfront Canal Sheetpile Wall Locations	WRECO review of their 2011 hydrology and hydraulics report, with recommended sheet pile wall locations and heights. Includes Bayfront Canal profiles	2015	WRECO (2015)
Bayfront Canal Hydrology and Hydraulic Evaluation	Review of key drainage elements and past studies, models, hydrology information. Provides recommendations for Flood Slough pump station, increased embankment heights, and connection to managed salt ponds.	2017	BKF (2017)
Bayfront Canal and Atherton Channel Flood Protection	Review of prior modeling and development of XPSWMM model of effectiveness of ongoing design to reduce flooding in the canal by connecting to adjacent managed salt ponds	2018	NHC (2018)
Local flood studies: Coastal			

Item	Description	Availability	Source
Redwood Shores Levee System / Coastal Engineering Assessment	Report evaluating the deficiencies in levee system along Reach 1 and identifying mitigation concepts to help remove FEMA Special Flood Hazard Area designation	2009	Moffatt & Nichol (2009)
Asset Vulnerability Profile: Silicon Valley Clean Water WWTP	Report segment detailing how the WWTP is highly vulnerable to sea level rise. The site is protected by a vinyl sheetpile wall which would be expected to experience overtopping at MHHW + 4' of sea-level rise	2018	County of San Mateo (2018)
Asset Vulnerability Profile: Port of Redwood City	Report segment detailing how the Port is moderately vulnerable to sea level rise. The site already experiences nuisance flooding during the 1-year annual recurrence event, which would worsen in the future.	2018	County of San Mateo (2018)

Appendix C.
Elevation Data Collection & LiDAR

In April 2023, ESA conducted a limited topographic survey of the shoreline and known areas that are prone to recurrent flooding. The purpose of this was to provide a check on large-scale data provided by the City (such as the 2017 LiDAR-based digital elevation model (DEM)), to field-verify elevations of flood prone areas, and to account for the fact that much of the shoreline is currently being built up in different areas, superseding prior elevation data (e.g. Seaport Centre levee improvements). The ESA team also met with City staff to understand areas of vulnerability along the city shoreline and inland areas. The information gathered from this meeting was used to inform RTK-GPS topographic survey targets.[1]

The survey mainly covered stretches of the downtown area adjacent to Redwood Creek and infrastructure along Seaport Drive. ESA also surveyed points in Friendly Acres and at the culvert near 1180 Main Street. An area in the Friendly Acres neighborhood bound approximately by 2nd St., Broadway, Bell St., and Hoover St., flooded several times in the Winter 2022-2023 season. During the New Year's Eve 2023 storm, the area near 1180 Main St. experienced flooding when Redwood Creek overtopped and flowed out of bank. The creek is tidally influenced and travels in an open concrete culvert at that location.

Overall, the survey data were found to compare favorably with the elevations sampled from the DEM (see Figures 1-6). This indicates that the DEM is sufficiently accurate to be used for this planning-level study. Areas where elevations differ from the DEM are consistent with recent documents that discuss ongoing improvements to the shoreline. For example, as noted on Figure 1, the 2023 RTK-GPS data points are four or more feet higher than the 2017 LiDAR data because this section of the shoreline has been raised with added fill in 2020-2022. Along part of the shoreline in Seaport area (Figure 2), a floodwall has recently been constructed which raises the shoreline elevation to about 13.7-14.5 ft NAVD, as compared to the ground surface elevation at the time of the 2017 LiDAR, which was only about 10-11 ft NAVD. At other shoreline locations that have not be recently re-graded, LiDAR elevations agree with RTK-GPS elevation to within a half a foot, as indicated by the color within the 2023 data points nearly matching the color of the nearby 2017 LiDAR data. Survey data that fall on the shoreline profile lines presented to the City at the in-person April meeting will be incorporated into later revisions of those maps.

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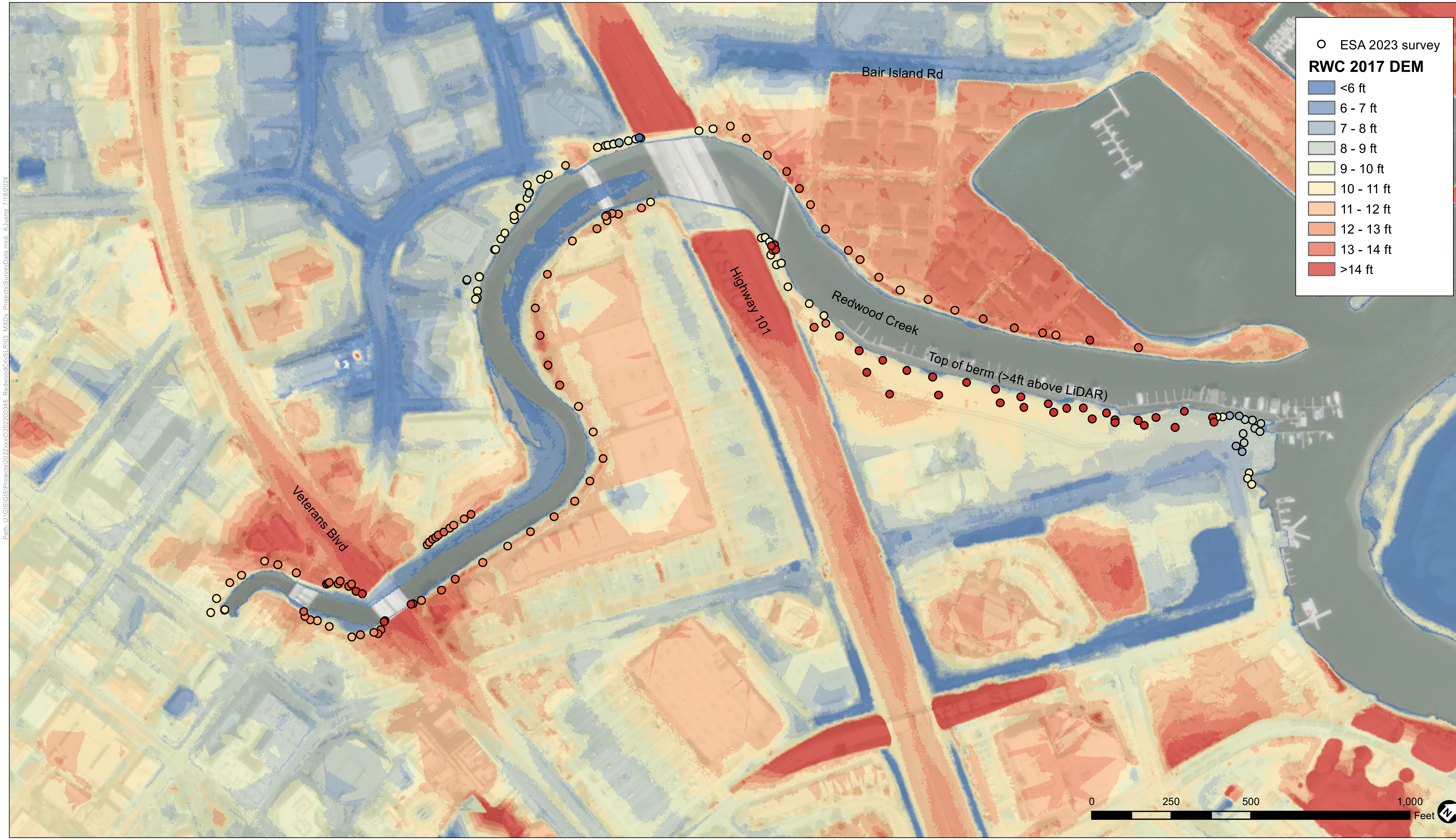
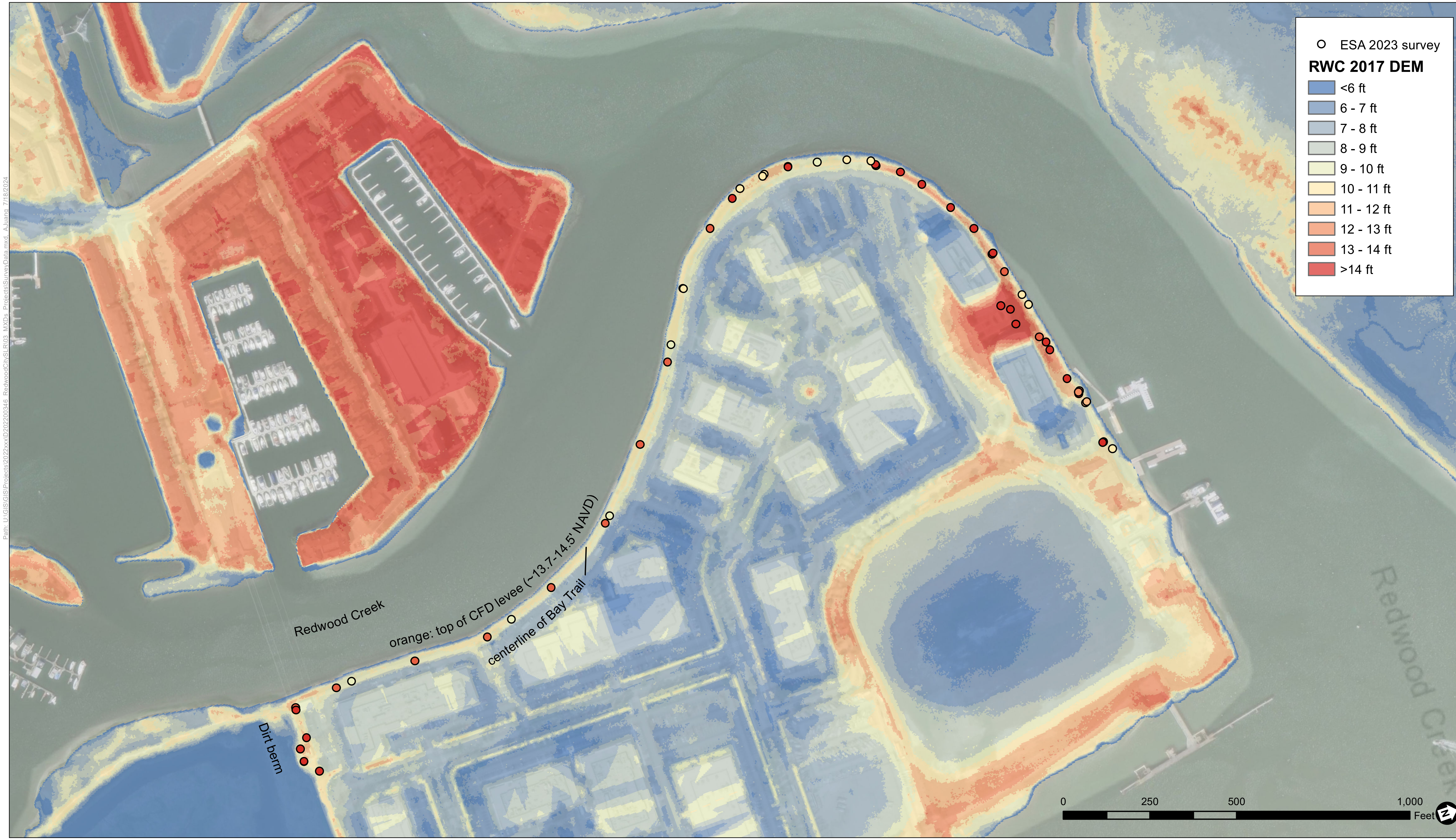
[1] ESA performs land surveys to augment traditional surveying services for the purposes of planning, monitoring of project performance, and other specific uses consistent with Geologic and Landscape Surveys as defined in the Professional Land Surveyors' Act (California Business and Professionals Code). ESA does not provide traditional land survey services such as property boundaries and maps for general use by others but if needed, these traditional surveying services can be accomplished by a licensed, professional land surveyor as a sub-consultant to ESA.



SOURCE: County of San Mateo, ESA, ESRI, NOAA, Redwood City

D202200346 Redwood City SLR Vulnerability Study

Figure 1
Survey vs DEM: Redwood Creek open channel (Reaches 2 and 3)



SOURCE: County of San Mateo, ESA, ESRI, NOAA, Redwood City

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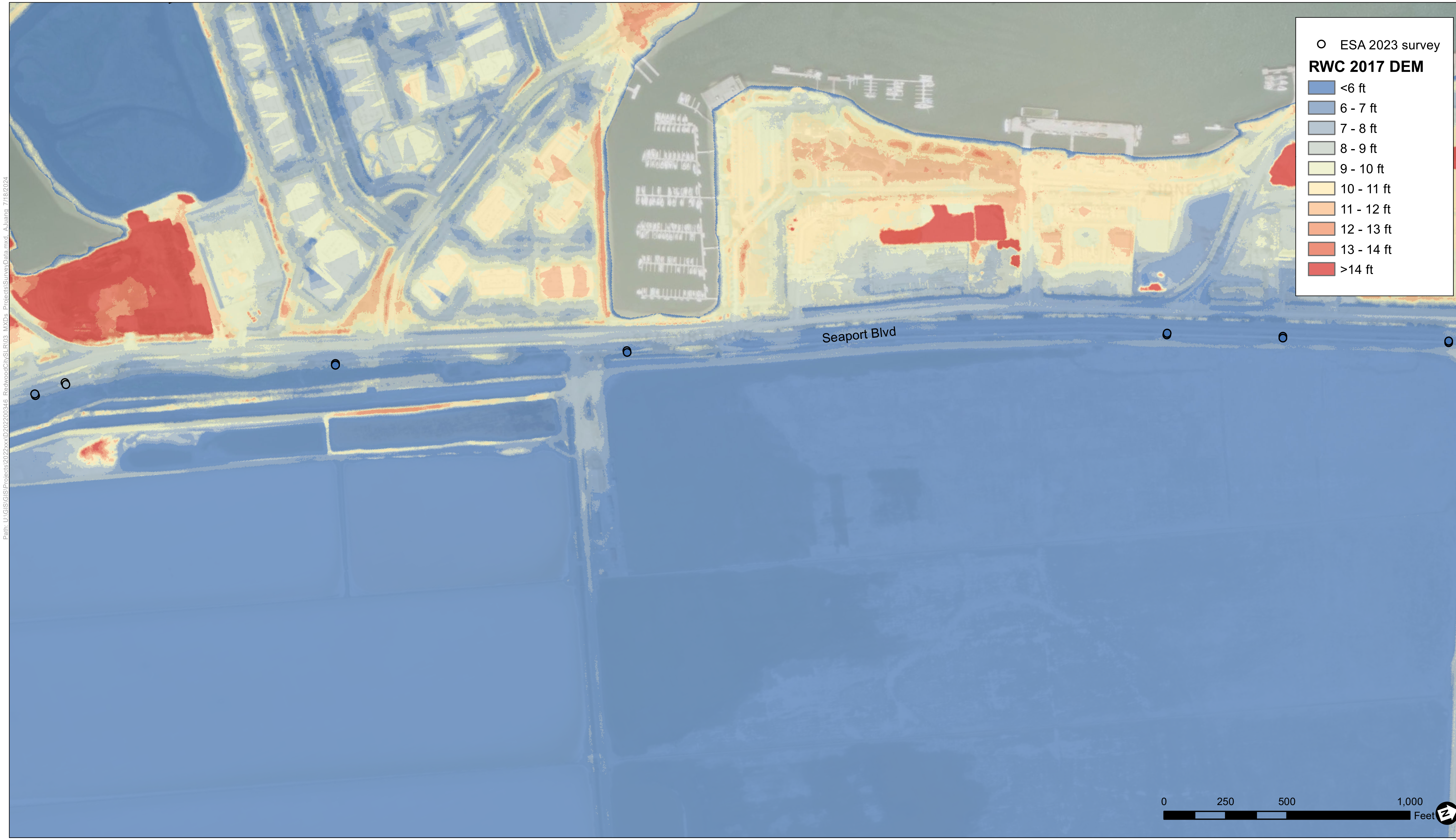
Figure 2
Survey vs DEM: Downtown-Seaport (Reach 3)



SOURCE: County of San Mateo, ESA, ESRI, NOAA, Redwood City

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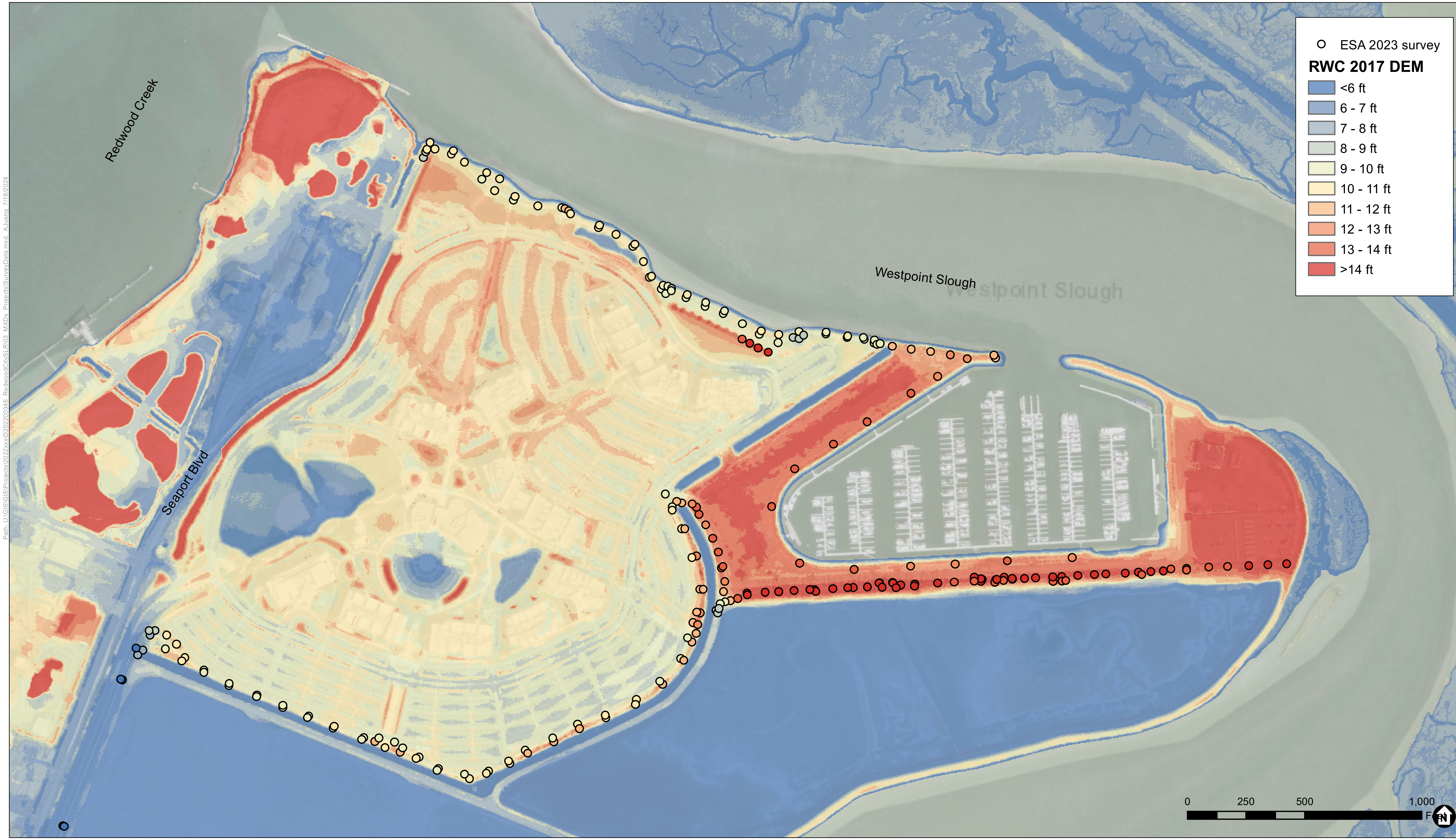
Figure 3
Survey vs DEM: Bay Trail



SOURCE: County of San Mateo, ESA, ESRI, NOAA, Redwood City

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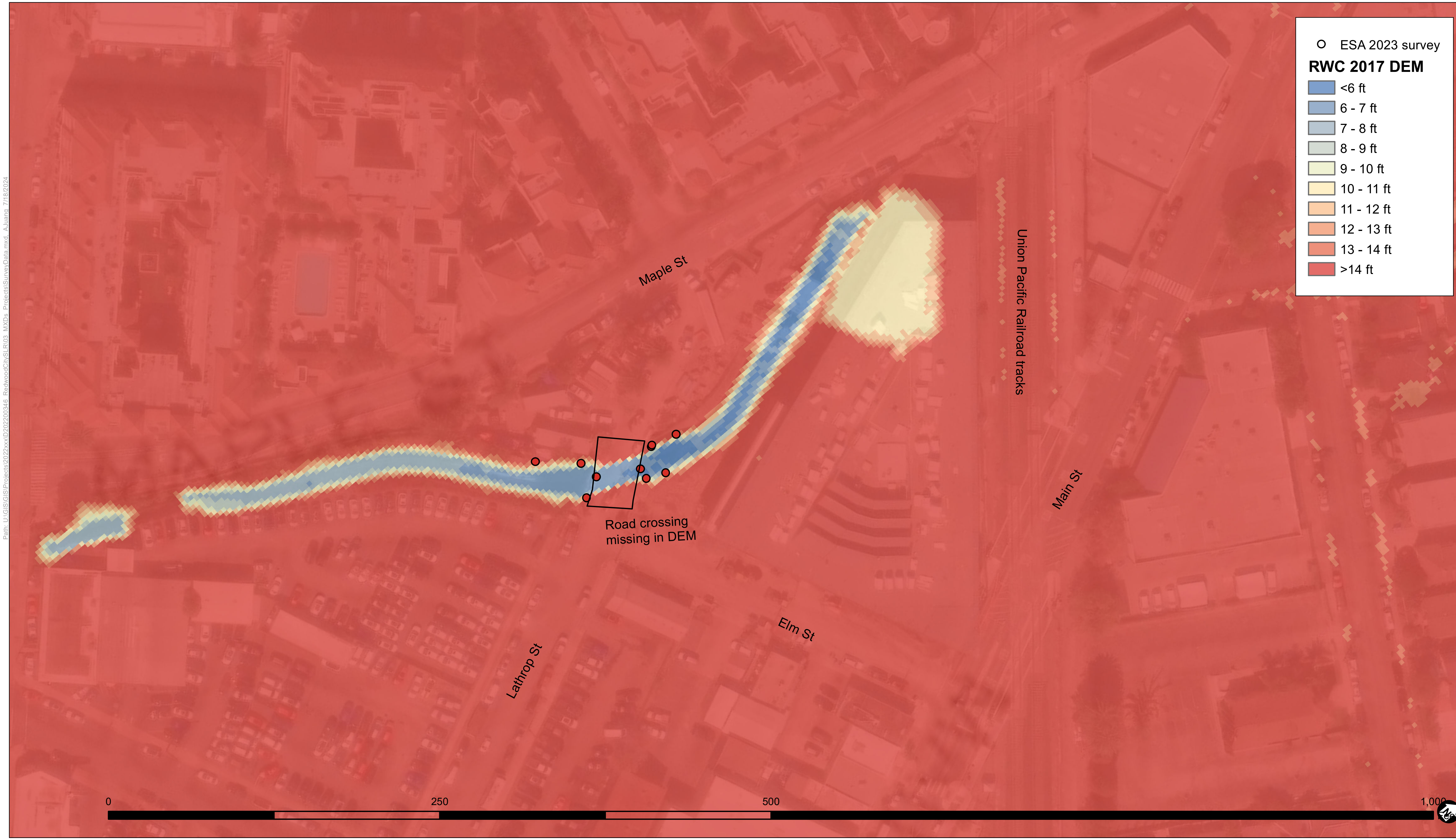
Figure 4
Survey vs DEM: Westpoint Harbor



SOURCE: County of San Mateo, ESA, ESRI, NOAA, Redwood City

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Figure 5
Survey vs DEM: 1180 Main St

SOURCE: County of San Mateo, ESA, ESRI, NOAA, Redwood City

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Figure 6
Survey vs DEM: Friendly Acres neighborhood

Appendix D.
City Shoreline Photos from California King Tides Project

Location Map of recent King Tide photos

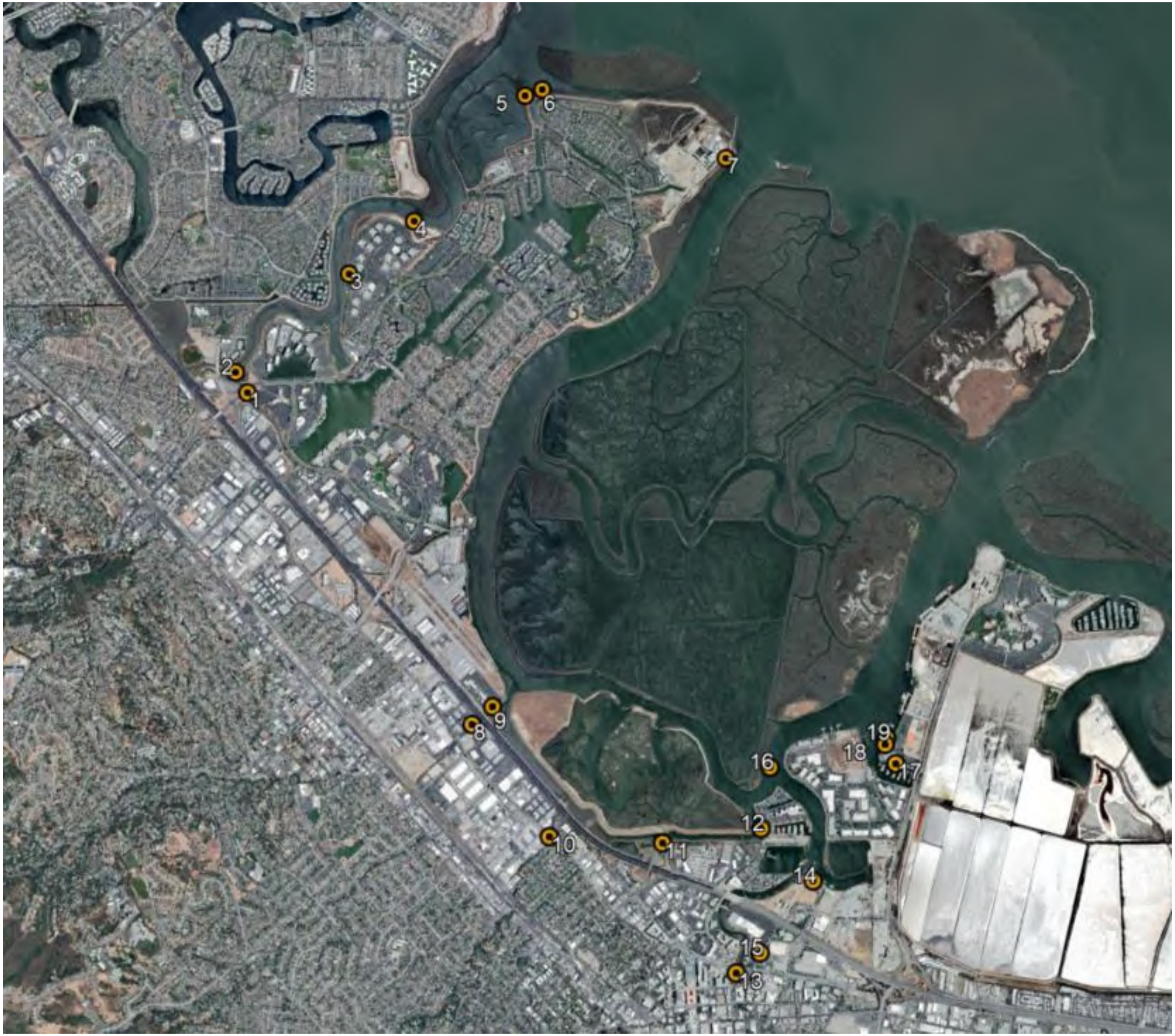


Photo 1: 1/21/2023: Belmont Creek, from Shoreway Road

Source: California King Tides Project

Photo 2: 1/21/2023: Belmont Slough, facing north from confluence with Belmont Creek

Source: California King Tides Project

Photo 3: 1/21/2023: At corner of Bridge Pkwy and Island Dr

Source: California King Tides Project

Photo 4: 1/21/2023: hydraulic structure immediately north of Bridge Pkwy

Source: California King Tides Project

Photo 5: 12/4/2021: northern edge of the Preserve

Source: California King Tides Project

Photo 6: 12/4/2021: near Bird Island

Source: California King Tides Project

Photo 7: 11/16/2020: southern edge of SVCW sheet pile wall

Source: California King Tides Project

Photo 8: 1/21/2023: Pulgas Creek, facing northeast (Hwy 101 in the distance)

Source: California King Tides Project

Photo 9: 1/19/2019: Bike trail and Highway 101 from San Carlos Airport

Source: California King Tides Project

Photo 10: 1/21/2023: Cordilleras Creek at Industrial Road

Source: California King Tides Project

Photo 11: 2/9/2020: E. Bayshore Rd near Highway 101 offramp

Source: California King Tides Project

Photo 12: 12/24/2022: Pedestrian trail west of Bair Island Rd

Source: California King Tides Project

Photo 13: 1/11/2020: Main St Bridge, facing west

Source: California King Tides Project

Photo 14: 1/21/2023: Maple St near Bair Island Aquatic

Source: California King Tides Project

Photo 15: 6/18/2013: Facing north along Walnut Street near Highway 101

Source: California King Tides Project

Photo 16: 1/21/2023: Seaport flood wall, from Redwood Creek immediately north of Blu Harbor

Source: California King Tides Project

Photo 17: 1/21/2023: Sequoia Yacht Club

Source: California King Tides Project

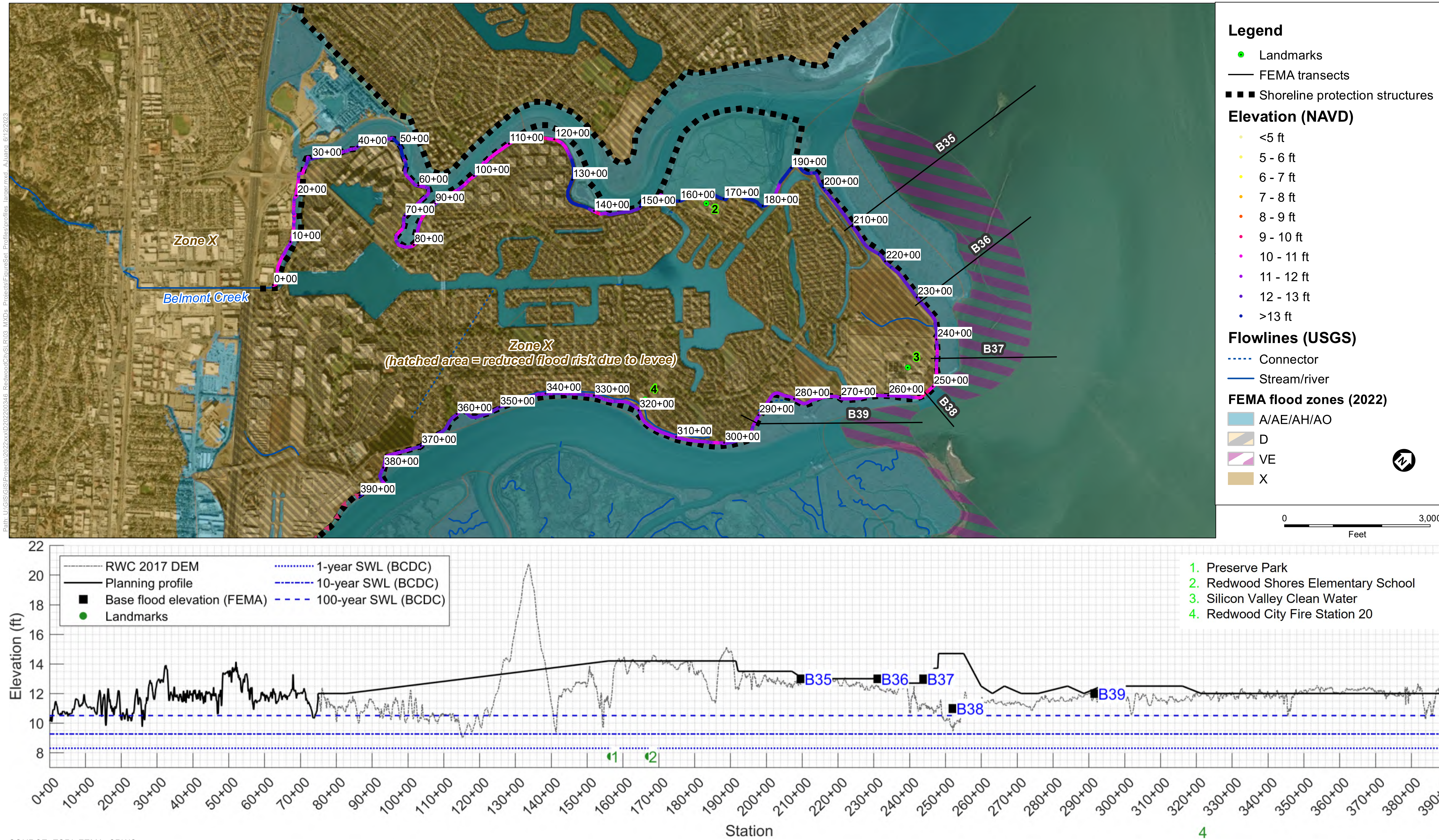
Photo 18: 2/9/2020: near Port of Redwood City Public Fishing Pier

Source: California King Tides Project

Photo 19: 2/9/2020: near Port of Redwood City Public Fishing Pier

Source: California King Tides Project

Appendix E. Subreach Vulnerability Assessment



SOURCE: ESRI, FEMA, CRWC

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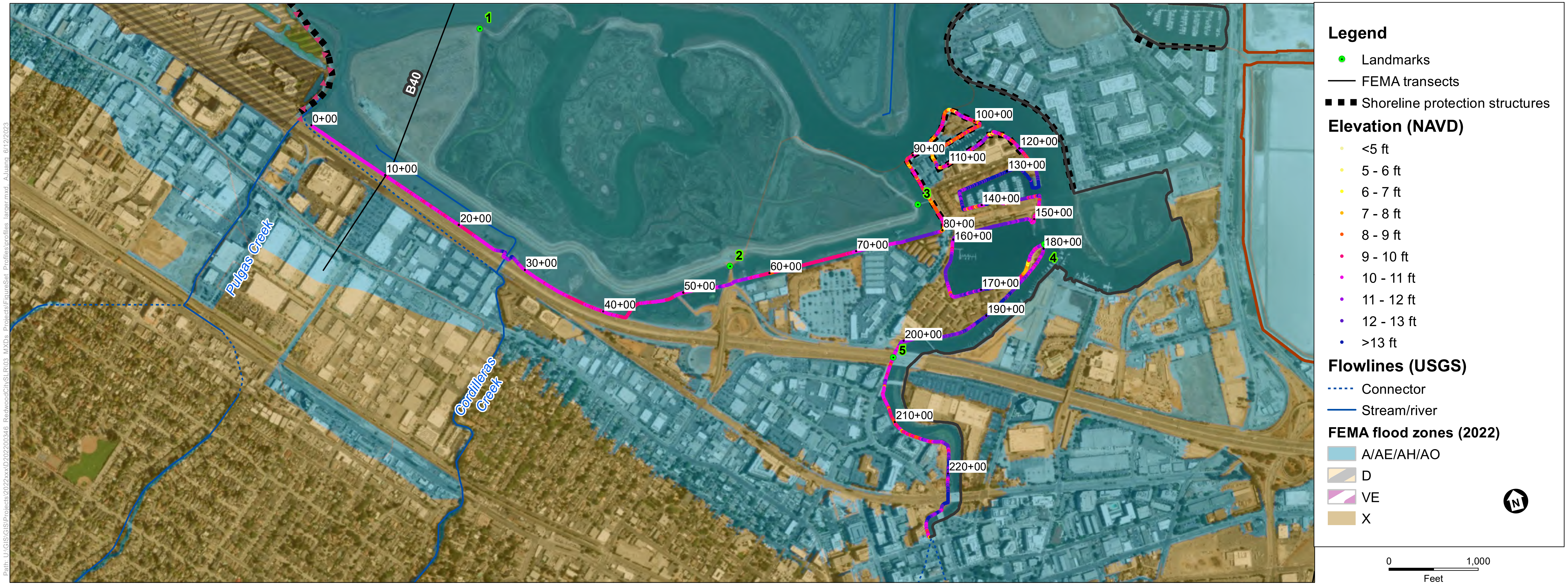
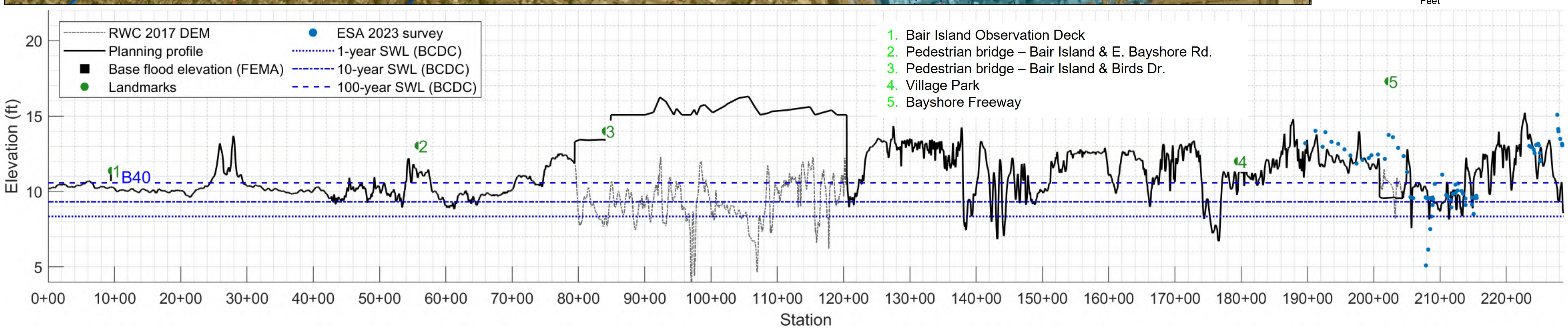
Figure E-1
Shoreline Profile for Reach 1





SOURCE: ESRI, FEMA, CRWC

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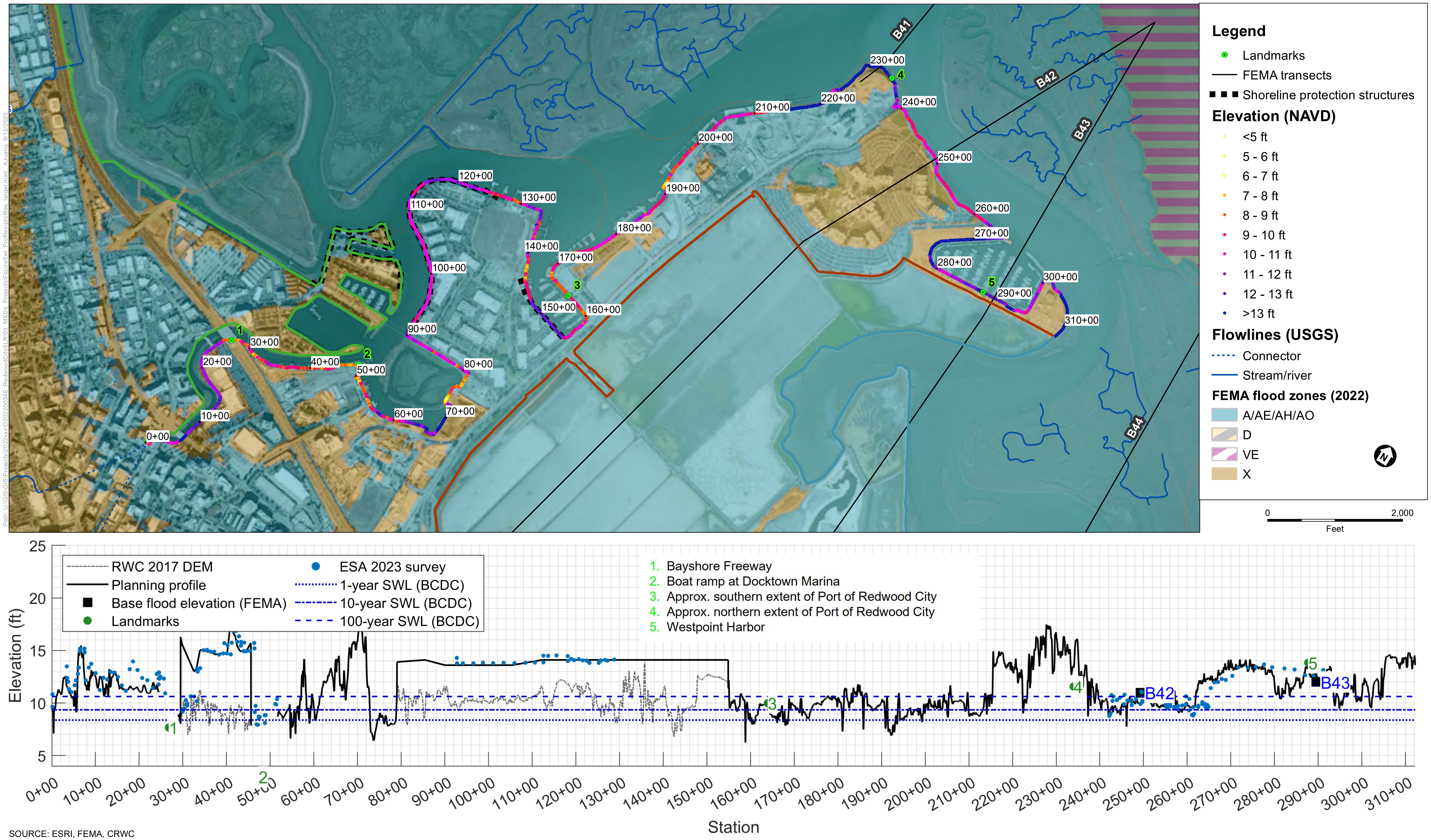
ESA

Figure E-2
Shoreline Profile for Reach 2



SOURCE: ESRI, FEMA, CRWC

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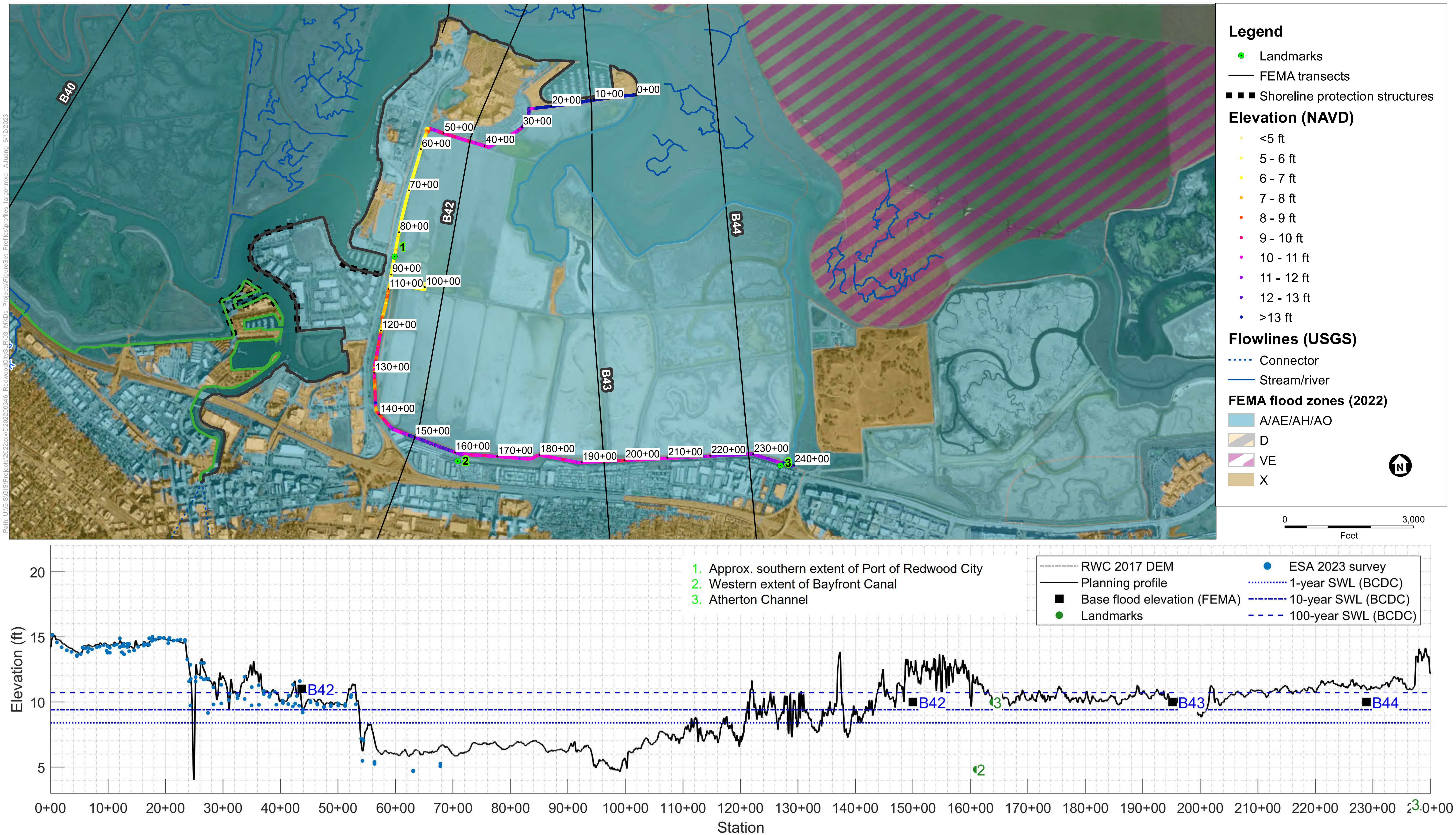
ESA

Figure E-3
Shoreline Profile for Reach 3



SOURCE: ESRI, FEMA, CRWC

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Figure E4
Shoreline Profile for Reach 4

Appendix F.
Cost Estimates

TABLE F-1
REACH 1 COST ESTIMATE

Construction Costs

Line	Item	Quantity (ft)	Unit	Unit Cost	Cost
1	Raise levee	39,040	LF	varies	$ 83,900,000
2	Build floodwall	-	LF	varies	$ -
Contingency				30%	$ 25,200,000
Subtotal: Construction					**$ 109,000,000**

Other Costs

Design	20%	$ 16,800,000
Environmental Compliance & Permitting	20%	$ 16,800,000
Project Management	2%	$ 1,700,000
Construction Admin & Inspection	2%	$ 1,700,000
Project Contingency	10%	$ 8,400,000

Total Cost	**$ 154,300,000**

TABLE F-2
REACH 2 COST ESTIMATE

Construction Costs

Line	Item	Quantity (ft)	Unit	Unit Cost	Cost
1	Raise levee[1]	10,190	LF	varies	$ 22,500,000
2	Build floodwall	12,670	LF	varies	$ 31,200,000
Contingency				30%	$ 16,100,000
Subtotal: Construction					**$ 69,700,000**

Other Costs

Design	20%	$ 10,800,000
Environmental Compliance & Permitting	20%	$ 10,800,000
Project Management	2%	$ 1,100,000
Construction Admin & Inspection	2%	$ 1,100,000
Project Contingency	10%	$ 5,400,000

Total Cost	**$ 98,600,000**

[1] Levee length encompasses Spur Park.

TABLE F-3
REACH 3 COST ESTIMATE

Construction Costs

Line	Item	Quantity (ft)	Unit	Unit Cost	Cost
1	Raise levee	25,680	LF	varies	$ 60,600,000
2	Build floodwall[1]	5,530	LF	varies	$ 17,600,000
Contingency				30%	$ 23,500,000
Subtotal: Construction					**$ 101,700,000**

Other Costs

Design	20%	$ 15,700,000
Environmental Compliance & Permitting	20%	$ 15,700,000
Project Management	2%	$ 1,600,000
Construction Admin & Inspection	2%	$ 1,600,000
Project Contingency	10%	$ 7,900,000

Total Cost	**$ 143,900,000**

[1] Part of the shoreline for which a floodwall is recommended is currently under construction.

TABLE F-4
REACH 4 COST ESTIMATE

Construction Costs

Line	Item	Quantity (ft)	Unit	Unit Cost	Cost
1	Raise levee	24,010	LF	varies	$ 105,500,000
2	Build floodwall	-	LF	varies	$ -
Contingency				30%	$ 31,700,000
Subtotal: Construction					**$ 137,100,000**

Other Costs

Design	20%	$ 21,100,000
Environmental Compliance & Permitting	20%	$ 21,100,000
Project Management	2%	$ 2,200,000
Construction Admin & Inspection	2%	$ 2,200,000
Project Contingency	10%	$ 10,600,000

Total Cost	**$ 194,100,000**