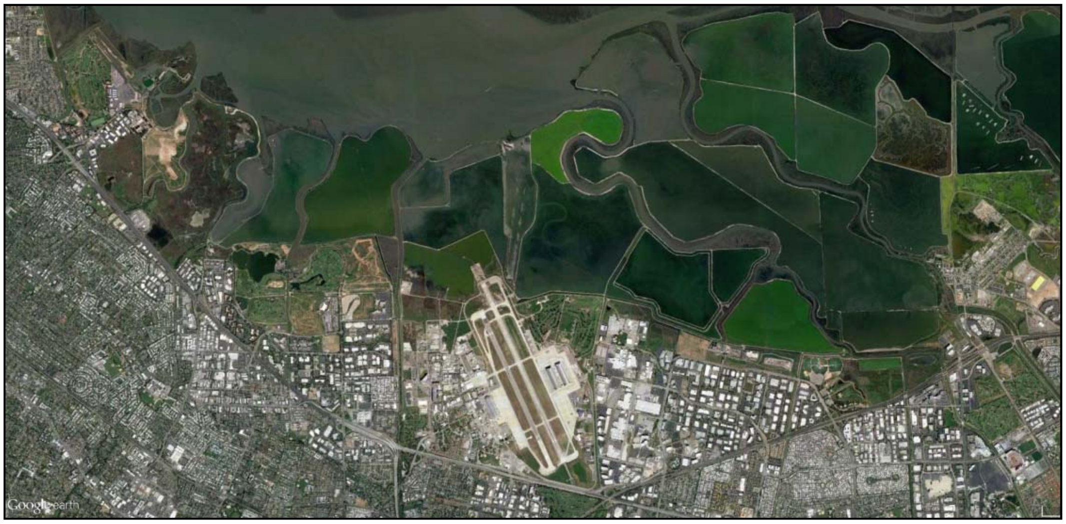
Preliminary Feasibility Study for South San Francisco Bay Shoreline

Economic Impact Areas 1 - 10

Final Evaluation Report



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ACKNOWLEDGEMENT

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1.0 INTRODUCTION

1.1 Background

This evaluation report summarizes the findings of several pertinent studies for San Francisquito Creek to Guadalupe River Shoreline Feasibility Study under the Local Levee Evaluation Grant (No. 4600009957) that is sponsored by the State Department of Water Resources. The scope of this grant-funded work includes development of a conceptual plan for levee alignments that provides flood protection within the project area, restore the diminished tidal habitats, and provide recreation public access features. An engineering evaluation is subsequently performed to inform the feasibility of levee improvements, environmental enhancements, and recreation improvements in the project area. The entire project shoreline is located south of the Dumbarton Bridge at the far southern end of San Francisco Bay. The study encompasses 18 miles of the bay shoreline in Santa Clara County, which is divided into 11 Economic Impact Areas (EIAs). The specific area for the present study between EIA 1 and EIA 10 is bounded on the west by San Francisquito Creek in Palo Alto and on the east by Guadalupe River in San Jose, as shown in Figure 1. It is noted that the feasibility study in EIA 11 within the City of San Jose was previously performed by the Corps of Engineers, San Francisco District (USACE-SFD, 2014a).

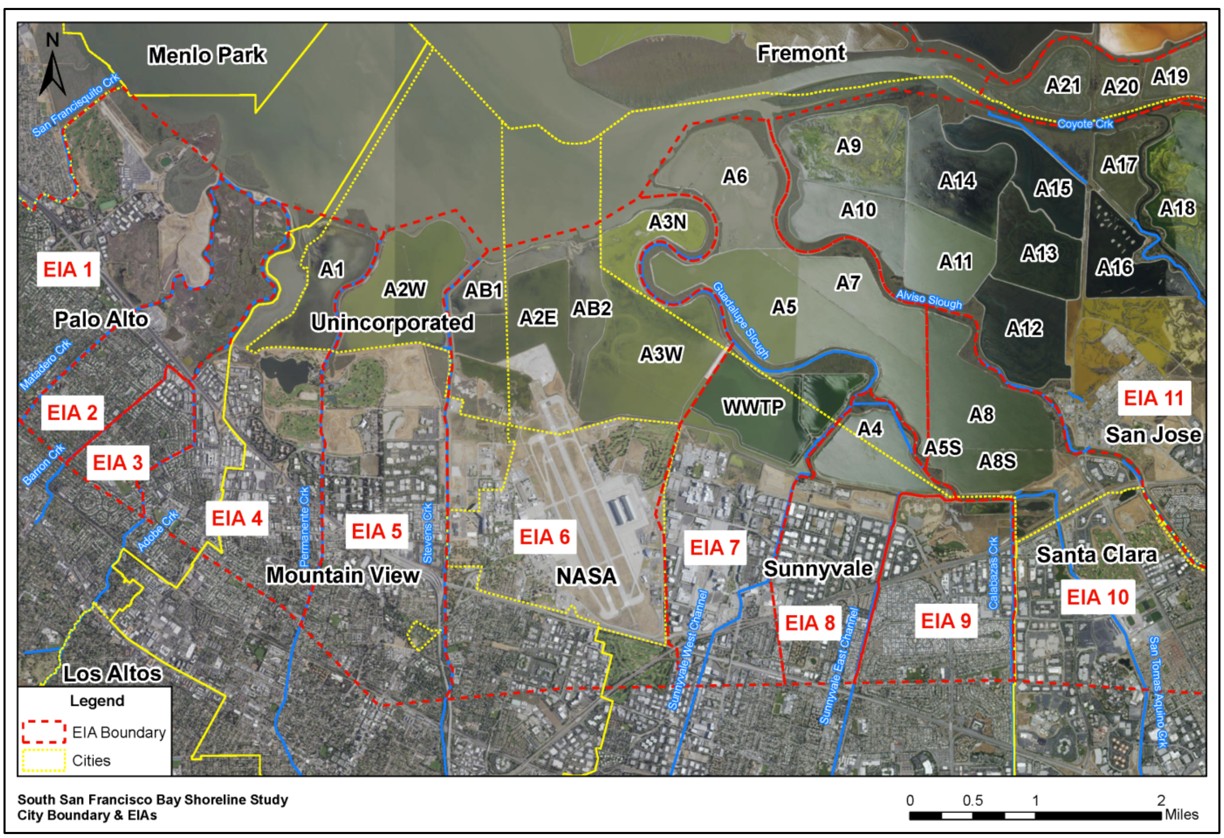


Figure 1. Project Site Location

The ten EIAs are comprised primarily of various creeks, sloughs and drainage channels, two airfields, one flood basin, two water quality control plants, one recycling processes station and a number of salt ponds that were previously used for salt production by Cargill, Inc. Table 1 presents the included EIAs for the jurisdiction of individual local or federal agency, while Table 2 lists the key infrastructures located in each EIA. The neighboring EIAs are separated by one of the creeks that drain into the bay except for EIA 6 and EIA 7, which are defined based on land use and ownership (see Table 1 & Table 2). Urban developments within these EIAs include commercial buildings, private dwellings and public infrastructures.

Table 1. Included EIA within Individual Agency

Agency	Included EIA
City of Palo Alto	EIA 1, EIA 2 & EIA 3
City of Mountain View	EIA 4, EIA 5 & EIA 6
Federal Agency (NASA)	EIA 6
City of Sunnyvale	EIA 7, EIA 8 & EIA 9
City of San Jose	EIA 10
City of Santa Clara	EIA 10

Table 2. Key Public Infrastructure in each EIA

EIA	Key Public Infrastructure	City
EIA 1	Palo Alto Airport, Palo Alto Water Quality Control Plant (PAWQCP) & Highway 101	City of Palo Alto
EIA 2	Palo Alto Flood Basin (PAFB) & Highway 101	City of Palo Alto
EIA 3	Highway 101	City of Palo Alto
EIA 4	Highway 101	City of Mountain View
EIA 5	Highway 101, Closed Sanitary Landfill, Regional Parks, City Fire Station, & City Sanitary Pump Station	City of Mountain View
EIA 6	NASA Ames Research Center & Moffett Airfield, and Highway 101	Federal Agency (NASA)
EIA 7	Sunnyvale Water Pollution Control Plant (SWPCP), Highway 101 & Highway 237	City of Sunnyvale
EIA 8	SWPCP, SMaRT Station Highway 101 & Highway 237	City of Sunnyvale
EIA 9	Highway 237	City of Sunnyvale
EIA10	Highway 237	City of San Jose and City of Santa Clara

1.2 Study Purpose

The project area has considerable risk for storm-induced flooding within the low-lying terrain that is currently protected by non-engineered levees. The flood risk will substantially increase due to potential future sea level rise (SLR) from global warming. In addition to flood risk, the past creation of commercial salt harvesting ponds along the south bay shoreline has resulted in a loss of most of the tidal marsh habitat within the project area. The performed subtasks under this project evaluation grant are:

- Review the geotechnical investigation of the existing outer and inner levees via field exploration and laboratory testing data and the developed recommendations for new levee construction;
- Formulate the alignment of the proposed protective levee, which incorporates local agencies' needs and requirements not only for flooding protection but also enhancement of environmental and recreational opportunity;
- Review the validated topographic and bathymetric data sources that were used to establish an accurate modeling domain;
- Perform long wave modeling to assess the storm-induced water surface elevation (WSE) under various combinations of astronomical tide and surge (residual) tide resulting from coastal storm, including three future sea level rise (SLR) scenarios (i.e., low, intermediate and high). This modeling effort includes both the existing conditions and the with-project under which the protective levee is implemented;
- Perform statistic analysis of water surface elevation via the Monte Carlo simulation (MCS) technique to obtain various return storm frequencies at the present day and in the future under different SLR projections;
- Generate inundation maps to illustrate the likely footprint of the 100-year coastal storm-induced inundation within the project area;
- Estimate the potential damage to properties and infrastructures (coastal storm only) and to preliminarily determine the economic justification to implement the proposed protective levee for all ten EIAs by comparing the project cost and associated storm-damage reduction (i.e., claimed benefits); and
- Analyze riverine hydraulics to investigate the flow capacity of nine creeks, excluding San Francisquito Creek, within the project area, and the minimum levee/flood wall elevations to provide the 100-year flood protection level. The creek hydraulics of San Francisquito Creek has been extensively studied by the Corps of Engineers, San Francisco District.

1.3 Pertinent Study Reports

Individual study reports that are used to compile this evaluation report and considered as appendices are listed as follows.

Appendix I: "Preliminary Feasibility Study for South San Francisco Bay Shoreline, Economic Impact Areas 1-10, Long Wave Modeling Report", Final Report, Prepared by Anchor QEA, February 2017.

The purpose of this long wave modeling study is to provide a set of lookup tables of maximum water surface elevations (WSEs) at selected locations for 1,080 model cases. Predictions of maximum WSE for various hydrodynamic conditions span a wide range of astronomical tides, storm surge, wind, levee failures, and three SLR projections for both existing (without-project) and with-project conditions. The report summaries present an overview of the results under the existing and with-project conditions in Year 0 (2017) and Year 50 (2067), respectively.

Appendix II: "Preliminary Feasibility Study for South San Francisco Bay Shoreline, Economic Impact Areas 1-10, Statistic Analysis of Water Surface Elevation Via Monte Carlo Simulation", Final Report, Prepared by Noble Consultants Inc., February 2017.

The primary purpose of this preliminary statistic analysis is to calculate the water surface elevations (WSEs) under various return storm frequencies at the present day in 2017 and in Year 2067 under three SLR projections in order to estimate the potential damage to properties and infrastructures. Look-up tables generated from the long wave modeling study form the basis from which the Monte Carlo Simulation technique is applied to derive the return WSEs as well as 5% and 95% confidence limits. The crest elevation of the proposed protective levee along the study shoreline can also be determined for an economic analysis to assess the project cost and associated storm-damage reduction.

Appendix III: "Preliminary Feasibility Study for South San Francisco Bay Shoreline, Economic Impact Areas 1-10, Coastal Storm Damage Risk Analysis", Final Report, Prepared by Noble Consultants Inc., February 2017.

This storm damage risk analysis derives the preliminary economic damages within the project area extending from EIAs 1 to 10, based on the Flood Damage Reduction Analysis (HEC-FDA) software that was developed by the USACE for use in flood risk management feasibility studies. The approach is consistent with the planning policies and procedures of the U.S. Army Corps of Engineers. The results indicate that a large, low annual probability storm event (e.g., 100-year storm event) is estimated to cause approximately $300 million in structure and content damage. In 50 years and with a sea-level rise consistent with the USACE high projection, a low annual probability (i.e., 1% occurrence) is estimated to cause as much as $765 million in structure and content damage. With a construction cost of approximately $120 million for a proposed protective levee that essentially eliminates the risk of coastal flooding over the fifty year period, the project benefit-cost ratio (BCR) would be greater than unity.

Appendix IV: "Preliminary Feasibility Study for South San Francisco Bay Shoreline, Economic Impact Areas 1-10, Hydraulic Analysis", Final Report, Prepared by Noble Consultants Inc., March 2016.

The hydraulic analysis was conducted based on the unsteady HEC-RAS models that were developed by the Corps for the South San Francisco Bay Shoreline Study. In total, nine creeks, which are formulated in five separate HEC-RAS models, are Matadero Creek, Barron Creek, Adobe Creek, Permanente Creek, Steven Creek, Sunnyvale West Channel, Sunnyvale East Channel, Calabazas Creek and San Tomas Aquino Creek. This hydraulic analysis excludes San Francisquito Creek because its hydraulics has been extensively studied by the Corps of Engineers, San Francisco District. The computed maximum water surface profiles during the 100-year flow event under the existing conditions in Year 0 (2017) and three future SLR projected conditions in Year 50 (2067)were compared to the channel bank top elevations to determine whether the channels meet the 100-year protection criteria.

2.0 PROJECT CONCEPTUAL PLANS

2.1 Proposed Preliminary Protective Levee

The proposed preliminary coastal levee alignment extends for approximately 14.33 miles as shown in Figure 2. The protective levee alignment was formulated after consultations with local and federal agencies in the area including Cities of Palo Alto, Mountain View, Sunnyvale, and San Jose, County of Santa Clara, California State Coastal Conservancy, U.S. Fish and Wildlife Service, and National Aeronautics and Space Administration (NASA). Table 3 presents the breakdown of the sectional length in each EIA. It is noted that the actual length of the to-be-built levee section in each EIA may be shortened, depending on the elevation of the existing ground.

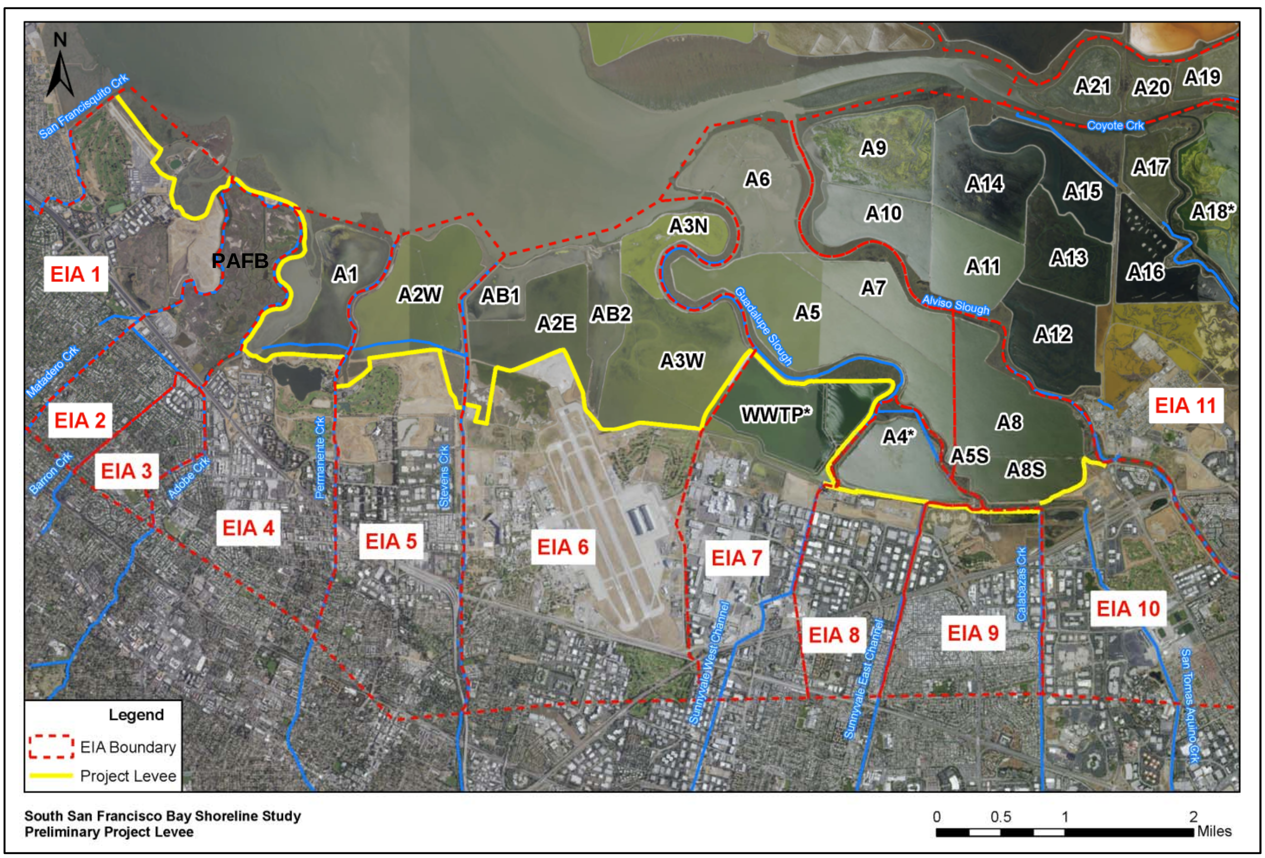


Figure 2. Proposed Alignment of Protective Levee

Table 3. Breakdown of Levee Length in Each EIA

EIA	Preliminary Levee Length	
	(feet)	(Miles)
1	9,408	1.78
2/3	10,595	2.01
4	4,355	0.82
5	7,638	1.45
6	14,776	2.80
7	15,968	3.02
8	4,359	0.83
9	4,613	0.87
10	3,957	0.75
Total	75,669	14.33

The preliminary levee alignment is established, based on its protection for public infrastructures, as listed in Table 2, and commercial buildings and residential dwellings in the project area. Although the ground elevation of the open land immediately landward of the planned levee alignment in EIA 10 is relatively high, the levee protection is still proposed for future coastal development. The proposed levee alignment also ensures that any alteration of internal levees between the salt ponds would not increase the susceptibility of coastal flooding under the South Bay Salt Pond Restoration Project (SBSPRP).

2.2 Improvement of Environmental Opportunity

The San Francisco Bay is an estuary that drains water from major rivers and creeks in the region, and from the surrounding mountains and passes through the bay to the Pacific Ocean. Historically, salt was naturally harvested by the Native Americans in the South San Francisco Bay. Commercial production of salt from the South Bay began in the mid eighteen century. By the 1930s, almost half of the south bay that was historical tidal marshes has been converted into salt ponds. Over time, the San Francisco Bay has lost the majority of its coastal wetlands and tidal marsh as a result of bay-land conversion to salt ponds, agriculture usage and urban development. The proposed coastal levee along with the ongoing SBSPRP will allow the existing retired salt ponds to again connect the existing salt ponds with bay waters to create vital ecosystems for a variety of threatened and endangered species. The coastal protective levee also provides a sufficient habitat buffer zone which benefits the recovery of listed species by serving as refuge area during high tide and large storm events. The proposed levee alignment also ensures that any alteration of internal levees between the salt ponds would not increase the susceptibility of coastal flooding under the South Bay Salt Pond Restoration Project.

2.3 Enhancement of Recreational Activity

This preliminary shoreline study encompasses recreational opportunities that are compatible with the protection against coastal flooding. American with Disabilities Act compliant trails will be built on top of the new proposed coastal levee along with viewing platforms and benches. The new coastal levee can contribute additional 3.14 miles of trail, as listed in Table 4. Figure 3 presents the preliminary coastal levee alignment (yellow line), the existing trails (dark blue dash line) and the added trial segments (pink line).

Table 4. Additional Trail Length

EIA	Newly Added Trail Length (feet)
1	1,861
5	2,648
6	8,094
10	3,957
Total	16,560 (3.14 miles)

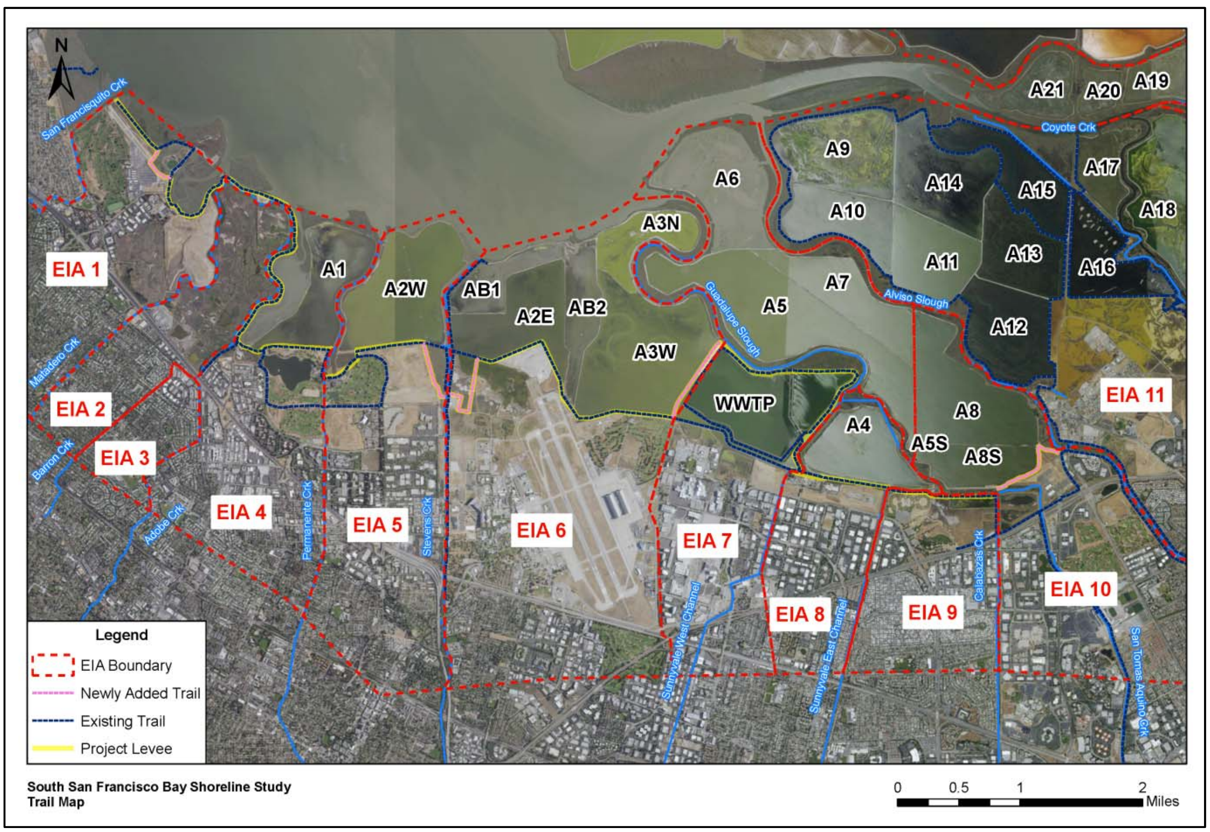


Figure 3. Existing and Project-Added Trail Map

3.0 PRESENT AND FUTURE SEA LEVEL RISE CONDITIONS

The ocean level has never remained constant over geologic time, but has risen and fallen relative to the land surface. A trendline analysis of yearly Mean Sea Level (MSL) data recorded at the San Francisco Golden Gate tide gage from 1987 to 2015 indicates that the MSL upward trend is approximately 0.0064 ft/yr (NOAA, 2016). Also, positive departure from the MSL typically occurs during strong El Nino episodes and consequently increases the likelihood of coincident storm waves and higher storm surge.

A report issued by National Research Council in 1987 (NRC, 1987) presented the estimated eustatic sea level rise rates for three different projected scenarios. These curves were modified by the Corps of Engineers in 2009 (USACE, 2009) and updated in 2013 (USACE, 2013) for incorporating the future sea level change in planning any USACE projects. The following projected formula was used to deduce the values of future sea level rise for the South San Francisco Bay. Three sea level rise scenarios (low, intermediate, high) were projected under this guidance.

$$SLR(t) = E_{local}\, t + bt^2$$

Where *SLR(t)* is the amount of sea level rise from the base year of 1992,
E_{local} is the historic trend at a local gage station per year,
b = 0.0000271 is a constant for Curve I (low),
b = 0.00007 is a constant for Curve II (intermediate),
b = 0.000113 is a constant for Curve III (high), and
t is the year difference between 1992 and the subject year

Table 5 presents the estimated values of future SLR under three projected scenarios, which is identical to the values used in the Corps study for EIA 11 (USACE-SFD, 2014b). It is noted that additional recent studies to project SLR in the future were prepared (NRC, 2012 & COCAT, 2013) to update the SLR projections. The estimated SLR in the future is slightly higher than the guidelines issued by the Corps of Engineers. It is noted that additional recent studies (NRC, 2012 & COCAT, 2013) to assess future SLR scenarios do project a slightly higher value than the guidelines issued by the Corps of Engineers. Nevertheless, to be consistent with the EIA 11 study (USACE-SFD, 2014b), the projected SLR scenarios were used in this preliminary feasibility study.

Table 5. Projected Sea Level Rise 50 Years from Base Year

SLR Projection	Sea Level Rise (ft)		
	Low (SLR Curve I)	Intermediate (SLR Curve II)	High (SLR Curve III)
	0.51	1.01	2.59

Note: Based on the Tide Gage (No. 9414290) and the base year of 2017
Source: USACE-SFD, 2014b

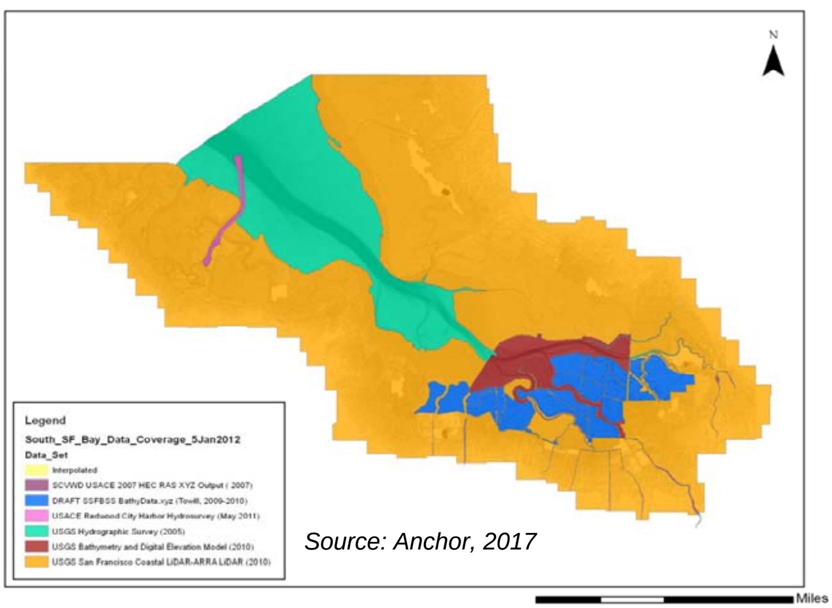
4.0 ENGINEERING EVALUATION

4.1 Bathymetry and Topography

As part of this preliminary study, a model simulation was required perform the long wave hydrodynamic analysis. Various bathymetric and topographic data were used to establish a high resolution model grid in the study area (Anchor, 2017). These data sets are:

1) Santa Clara Valley Water District (SCVWD) USACE 2007 RAS XYZ Output (2007)
2) Draft SSFBSS BatgtData.xyz (Towill, 2009-2010)
3) USACE Redwood City Harbor Hydrosurvey (May 2011)
4) USGS Hydrographic Survey (2005)
5) USGS San Francisco Coastal LiDAR-ARRA LiDAR (2010)
6) USGS Bathymetry and LIDAR Digital Elevation Model (2010)

These data sets are reliable and accurately referenced to a consistent nationwide vertical datum (USACE, 2009a & 2009b). Therefore, the data sets herein used to generate a high resolution of Digital Elevation Model (DEM) are currently compliant to the Corps of Engineers requirements (USACE-SFD, 2013). Figure 4 illustrates the footprint of each data source. In addition, Levee crest elevations for the ten creeks (i.e., San Francisquito Creek, Matadero Creek, Barron Creek, Adobe Creek, Permanente Creek, Stevens Creek, Sunnyvale West Channel, Sunnyvale East Channel, Calabazas Creek and San Tomas Aquino Creek) that are located within the study area were obtained from SCVWD and the Corps of Engineers, San Francisco District. These data are incorporated into the overall topographic data. The topographic data of these ten creeks were previously used in the hydraulic analysis of the creeks (NCI 2009 & 2016). Figure 5 shows the contours that were generated for all combined bathymetric and topographic data sources.



Source: Anchor, 2017

Figure 4. Data Sets Used to Generate A High Resolution of DEM

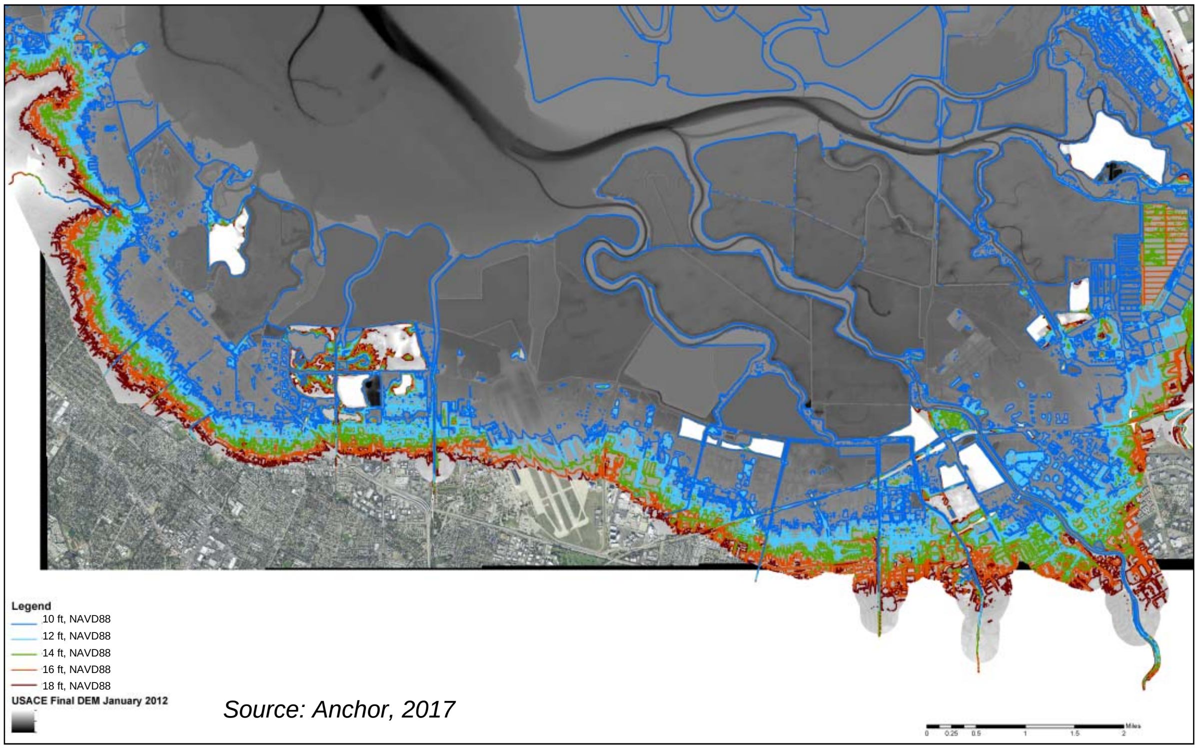


Figure 5. Generated Contours at 2-foot Interval

4.2 Geotechnical Investigation

South San Francisco Bay is a north-northwest-trending subsiding basin that is filled primarily with Quaternary alluvium deposits and with estuarine (bay) muds (AMEC, 2010). Alluvium deposits are sediments that were eroded from the surrounding Santa Cruz Mountains and Diablo Range uplands. The alluvial sediments that consist of sands, gravels, silts and clays with highly variable permeability are historically transported and deposited by streams and creeks. The low-permeable bay muds are composed of Quaternary alluvium and wind-blown sand deposits.

4.2.1 Outer Levee Evaluation

The outer levees were generally constructed during the later half of the 20th Century (Geomatrix, 2008) as boundaries of salt ponds at the South San Francisco Bay for salt production. The levees were constructed using bay muds that were excavated from adjacent salt ponds. The levees with a crest of 8 to 15 feet in width are typically 5 to 10 feet higher than the mean water level in the south bay. The un-engineered levee embankments are highly irregular and have a side slope of about 3 to 1 (horizontal to vertical) or flatter. Different degrees of erosion resulting from the localized scouring are observed on both bay and pond sides of the levees (Geomatrix, 2008). The levees were periodically raised or widened to fit the need for the operation of harvesting the salt. The levee fill materials are variable in strength, but typically are dry near the crest and are wet and soft at the base.

A comprehensive subsurface exploration at relevant locations along the outer levee boundary was conducted in 2007 (Geomatrix, 2008). Figure 6 shows the boring locations (yellow circle) where the sediment samples were collected for reliability analyses including unit weight, grain size analysis, permeability, consolidation and shear strength parameters, and standard penetration test (SPT), etc. The derived physical characteristics of the outer levees were used to assess the probability of levee failure at different water levels (USACE-SFD, 2014b). Also, the recommended physical parameters of sediments to be used for the project levee construction are also provided.

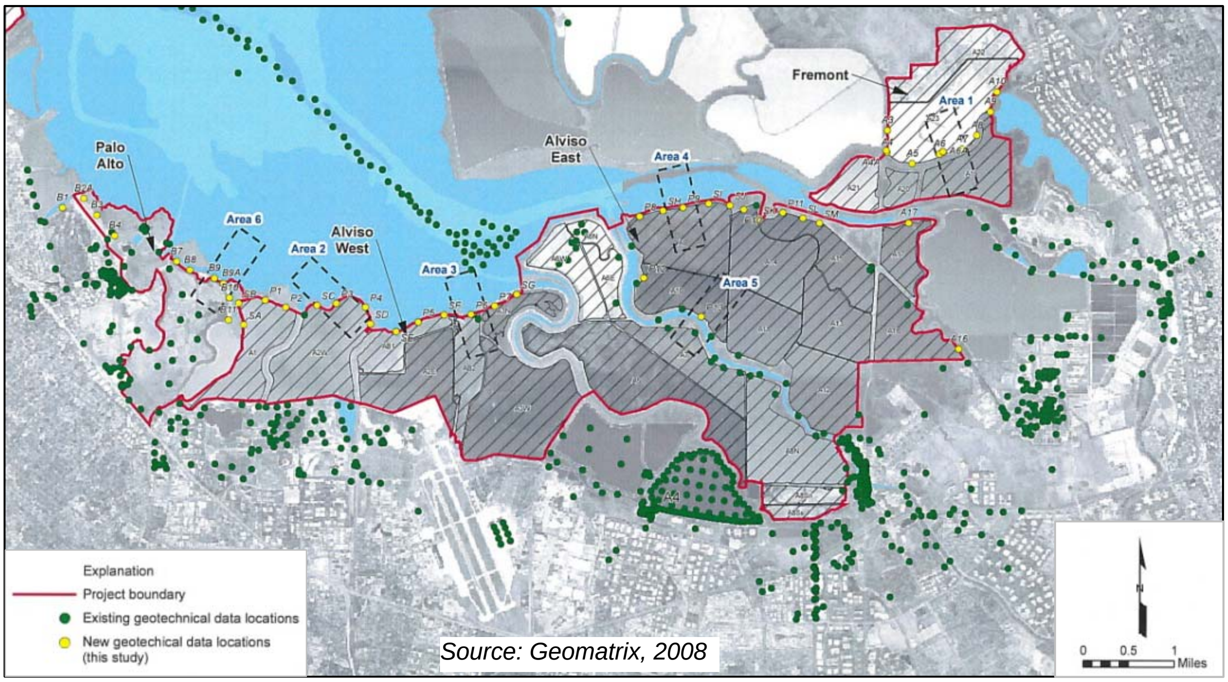


Figure 6. Geotechnical Exploration Map for Outer Levees

4.2.2 Inner Levee Evaluation

Inner levees within the project area were constructed mostly after the mid 1900s to impound water for salt production and provide a certain degree of flood protection for the landward development. Bay muds that were directly dredged within the ponds are the primary source material for the levee construction. Inner levees that are irregular in cross section range 2 to 15 feet above the ground and have a crest of 7 to 30 feet in width. Similar to the outer levees, the embankment slopes are on the order of 3 to 1 (H to V) or flatter.

A geotechnical exploration of inner levees was conducted in 2010 for several designated regions as illustrated in Figure 7 (AMEC, 2010). These regions that are located within the project area include interior levees of the Palo Alto Baylands and along Palo Alto Flood Basin and Charleston Slough, southern levees of Ponds A2E, AB2, A3W, southern levees of Guadalupe Slough, and interior levees along the southern boundary of Ponds A4 and A8s.

Sediment samples collected at various boring locations (see Figure 7) were analyzed to determine the physical characteristics including unit weight, grain size analysis, permeability, consolidation and shear strength parameters, and standard penetration test (SPT), etc. The derived physical characteristics of the inner levees were similarly used to assess the probability of levee failure at different water levels (USACE-SFD, 2014b). The recommended physical parameters of sediments to be used for the project levee construction are also provided.

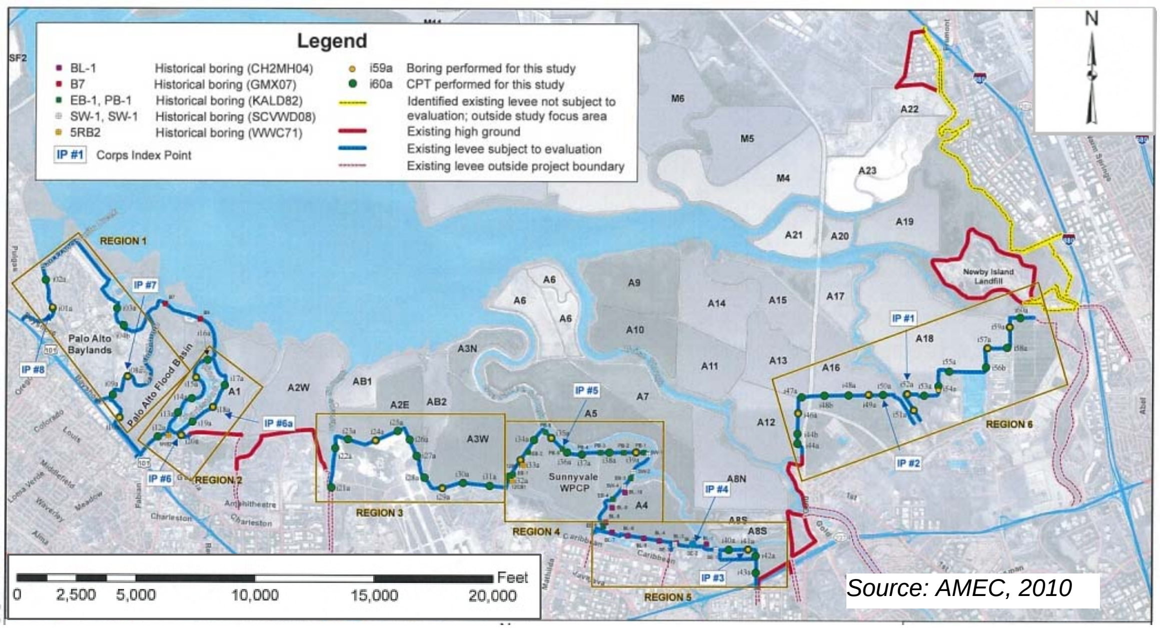


Figure 7. Geotechnical Exploration Map for Inner Levees

4.3 Long Wave Modeling

Long wave simulations consist of various forcing parameters such as astronomical tide, residual surge, wind speed, and wind direction under the without- and with- project conditions. The simulations were performed for a set of synthesized events that cover the ranges of all the controlling parameters including the currently updated salt pond restoration in Year 0 (2017) and Year 50 (2067) with three future SLR projections.

Table 6 presents the four (4) selected astronomical tides and three (3) residual surges for a combination of 12 basic cases. A sea level rise ranging from 0.51 feet for the low projection to 2.59 feet for the high estimation (see Table 5) was added to the existing astronomical tide for the simulations in Year 50. The Year 50 simulations also incorporate the anticipated accretion within the project ponds, as well as estimated channel evolution in the vicinity of the project area. The simulations also include both the without-breach and with-breach conditions at the various levee locations (Anchor, 2017).

The simulated water levels are used to interpolate the resulting water surface elevations for all synthesized events that are randomly selected by the Monte Carlo Simulation (MCS) process. Table 6 also lists the values and conditions of forcing parameters that were used in the synthesized events for the long wave simulations in 2017 (Year 0) and 2067 (Year 50), respectively. The Year 50 simulations include three scenarios (low, intermediate and high) of the future SLR projection.

Table 6. Parameters Used for Long Wave Model Simulations

Year	*SLR (ft)*	*Outer Levee Breached*	*Astronomical Tide (ft, NAVD)*	*Residual Surge (ft)*	*Wind Direction (deg)*	*Wind Speed (mph)*
Year 0 (2017)	0	Yes No	5.15 5.85 6.55 7.25	0.5 1.5 2.5	292.5^o 315^o	20 30 40
Year 50 (2067)	0.51 (Low)	Yes No	5.66 6.36 7.06 7.76	0.5 1.5 2.5	292.5^o 315^o	20 30 40
	1.01 (Intermediate)	Yes No	6.16 6.96 7.56 8.26	0.5 1.5 2.5	292.5^o 315^o	20 30 40
	2.59 (High)	Yes No	7.74 8.44 9.14 9.84	0.5 1.5 2.5	292.5^o 315^o	20 30 40

4.3.1 Impact of Winds

The wind setup for each wind simulation event was calculated as the difference between the peak water surface elevation from the simulations with- and without- wind. As a result, the calculated wind setup at locations within the ponds includes both wind induced setup as well as any additional wind induced overtopping of the outer pond levees that results from the wind setup. A preliminary analysis indicates that two primary winds directions of 292.5^o and 315^o can induce a measurable setup and also produce locally-generated waves due to the major alignment of the south bay and the geographic location of the study area. To assure adequate lookup events to be used for interpolation in the statistic analysis, four specific events (among the 12 basic cases) with different combinations of two (2) astronomical tides and two (2) residual surges are chosen. The four doublets of astronomical tide and residual surge are (5.15, 0.5), (5.15, 2.5), (7.25, 0.5) and (7.25, 2.5). Six wind scenarios combining two different wind directions and three speeds, as seen in Table 6, were simulated for each event, resulting in a total of twenty-four simulations for the four interpolated events.

4.3.2 Levee-Breached Zones

To limit the total cases of long wave model simulations, various EIAs are lumped into one levee-breached zone within which all levees are breached at the same time if levee failure occurs. In total, five levee-breached zones are designated as described in the long wave modeling report (Anchor, 2017). Table 7 lists the included EIAs for each zone, while Figure 8 illustrates the zone boundary associated with individual EIAs.

Table 7. Defined Levee-Beached Zone

Levee-Breach Zone	EIA
Zone 1	EIA 1, EIA 2 & EIA 3
Zone 2	EIA 4 & EIA 5
Zone 3	EIA 6 & EIA 7
Zone 4	EIA 8 & EIA 9
Zone 5	EIA 10

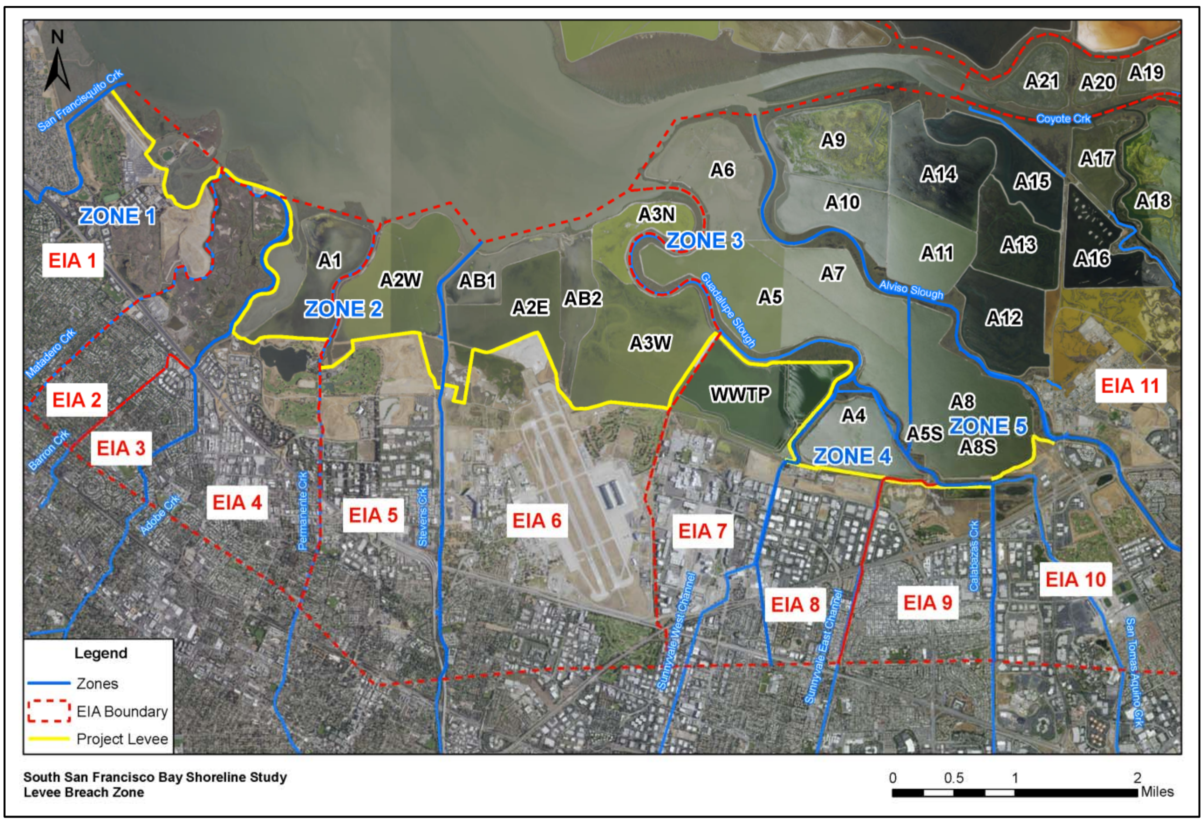


Figure 8. Levee-Breached Zones

4.3.3 Long Wave Look-up Tables

Long wave simulations to formulate the required look-up tables consist of various forcing parameters such as astronomical tide, residual surge, wind speed, and wind direction under the Year 0 and Year 50 conditions.

4.3.3.1 Without Project Conditions

The hydrodynamic simulations in Year 0 (2017) under the without project conditions incorporates the current salt pond operations in the winter months, which connects all salt ponds (A1 through A 18, as seen in Figure 1) to various creeks, sloughs, channels, and flood basins via culverts, pipes and siphons (Anchor, 2017). The Year 50 (2067) simulations were based on the resulting accretion in the project area and erosion in the south bay as a consequence of future sea level rise (MacWilliams et al., 2015). Since salt ponds in the project area will not be restored to tidal ponds unless a protective levee is in place to protect the landward development, it is assumed that no additional salt ponds are restored under the future without-project conditions.

Table 8 lists the total scenarios modeled under the without project conditions, including 180 individual events for Year 0 and the same 180 events for each projected sea level rise rate in Year 50. 720 events in total were simulated to form the basis for the MCS process to predict the return frequency of the storm-induced water surface elevation (WSE) throughout the project area. The ground elevation near the project levee between Calabazas Creek and San Tomas Aquino Creek in EIA 10 is very high (higher than +14 ft, NAVD), and as a result, no levee breach scenario was modeled in EIA 10.

4.3.3.2 With Project Conditions

The model setup for the long wave (hydrodynamic) simulations under the with-project conditions is similar to the without-project conditions in Year 0, except the installation of the proposed protective levee, as illustrated in Figure 2. The Year 50 simulations under the with-project conditions take into account the marsh accretion within individually restored ponds as well as three projected sea level rises.

No outer levee-breached conditions in EIA 1 through EIA 3 for Year 0 or Year 50 were modeled as the alignment of the protective levee is situated at the most bayward location. Several changes of pond configuration are noted that under the South Bay Salt Pond Restoration Project (SBSPRP), Ponds A2E, portions of Ponds AB2 and A3W remain as managed ponds in Year 50 with project conditions, as illustrated in Figure 9.

The levee between Pond A2E and Pond AB1 and a portion of Pond AB2 is to be raised and a new levee will be constructed across Ponds AB2 and A3W (see Figure 9) in Year 50. The crest elevation of the constructed levee is planned to be +13 feet NAVD88, which provides an equivalent level of protection to the outer levee bayward of Ponds AB1 and AB2. The raised pond levee north of the managed Ponds A3W and A2E is higher than the existing bayward levee of Pond A3N. Therefore, bay waters that overtop the outer levee into the ponds may be contained in AB1 and AB2 in lieu of failure for the outer and raised levee (i.e., the estimated water levels in Pond A3W will be lower than the inclusion of levee failure for the outer levee).

Table 8. Simulation Scenario Matrix under Without Project Conditions

Without Project Scenario	*Year*	*SLR Rate*	*Inner Breaches*	*Outer Breaches*	*Number of Simulations*
Existing Levee	0 (2017)	None	None	None	36
			EIA 1 to EIA 3	EIA 1 to EIA 3	36
			EIA 4 & EIA 5	EIA 4 & EIA 5	36
			EIA 6 & EIA 7	EIA 6 & EIA 7	36
			EIA 8 & EIA 9	EIA 8 & EIA 9	36
			EIA 10	EIA 10	0
Existing Levee with Pond Restoration	50 (2067)	Curve I (Low)	None	None	36
			EIA 1 to EIA 3	EIA 1 to EIA 3	36
			EIA 4 & EIA 5	EIA 4 & EIA 5	36
			EIA 6 & EIA 7	EIA 6 & EIA 7	36
			EIA 8 & EIA 9	EIA 8 & EIA 9	36
			EIA 10	EIA 10	0
	50 (2067)	Curve II (intermediate)	None	None	36
			EIA 1 to EIA 3	EIA 1 to EIA 3	36
			EIA 4 & EIA 5	EIA 4 & EIA 5	36
			EIA 6 & EIA 7	EIA 6 & EIA 7	36
			EIA 8 & EIA 9	EIA 8 & EIA 9	36
			EIA 10	EIA 10	0
	50 (2067)	Curve III (High)	None	None	36
			EIA 1 to EIA 3	EIA 1 to EIA 3	36
			EIA 4 & EIA 5	EIA 4 & EIA 5	36
			EIA 6 & EIA 7	EIA 6 & EIA 7	36
			EIA 8 & EIA 9	EIA 8 & EIA 9	36
			EIA 10	EIA 10	0
				Total Number of Simulations	*720*

Source: Anchor, 2017

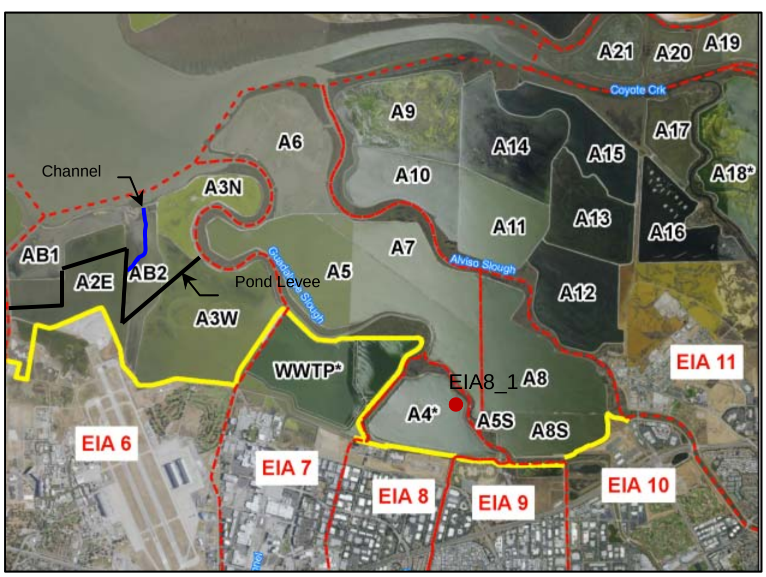


Figure 9. Proposed New Pond Levee

To be consistent with the breach conditions that were modeled under the without-project conditions, the breach of the outer levee in EIA 6 is considered in the simulation scenarios. A similar breach condition in EIA 8 (i.e., Pond A4) for Year 50 is also evaluated under the with-project conditions, as also illustrated in Figure 9. Lumped levee breach scenarios with a specific zone of EIA 6, EIA 7 & EIA 8 were modeled for the three future SLR projections in Year 50. Table 9 lists the total scenarios simulated to generate the look-up tables of storm-induced water surface. In total, 360 simulation scenarios were modeled under the with-projection conditions. Similar to the without-project conditions, no levee-breached scenarios were modeled in EIA 10 under both the existing and future SLR conditions.

Table 9. Simulation Scenario Matrix under With Project Conditions

Project-Alternative (With Project) Scenario	*Year*	*SLR Rate*	*Inner Breaches*	*Outer Breaches*	*Number of Simulations*
Preliminarily Propose Levee Alignment with Pond Restoration	0 (2017)	None	None	None	36
				EIA 1 to EIA 3	0
				EIA 4 & EIA 5	36
				EIA 6 & EIA 7	36
				EIA 8 & EIA 9	36
				EIA 0	0
	50 (2067)	Curve I (Low)	None	None	36
				EIA 6 to EIA 8	36
		Curve II (Intermediate)	None	None	36
				EIA 6 to EIA 8	36
		Curve III (High)	None	None	36
				EIA 6 to EIA 8	36
				Total Number of Simulations	*360*

Source: Anchor, 2017

4.4 Statistic Analysis of Water Surface Elevation (WSE)

A statistic analysis using the MCS technique was performed to obtain the recurring frequency of the storm-induced water surface elevation. The applied technique is a statistical approach to predict an uncertain system by recreating a random process to solve a problem which cannot be easily evaluated by a standard numerical analysis. This technique allows for the random sampling of a pre-defined (known) occurrence distribution of each individual element to statistically characterize the behavior of the uncertain system.

4.4.1 Treatment of Levee Failure

The protective outer levees within the project area are susceptible to breaching failure, which is a combined effect of seepage-induced erosion (a static process) and water overtopping (a dynamic process). A method was formulated by the Engineering Research and Development Center (ERDC) during the initial South San Francisco Bay Shoreline Feasibility Study (Lee, 2009a & Lee, 2009b). Additional analysis of the levee failure criterion, based on the available geotechnical information, was later performed and a set of failure probability in relation to the bay water level was established to reevaluate the Federal interest and economic justification for a future project in EIA 11 (USACE-SFD, 2014b). The new criterion assumes that outer levees are the only line of protection and a breach failure at outer levees will result in a subsequent breach at inner levees above a specific threshold loading. Table 10 shows the estimated probability of the two failure mechanisms of levee erosion and overtopping as well as the combined probabilities for different water surface elevations. The assigned failure probability in related to the static WSE is considered to be very conservative.

Table 10. Probability of Levee Failure Due to Erosion and Overtopping

Static WSE	Probability of Failure		
(NAVD88, ft)	Erosion	Overtopping	Combined
12	0.30	1.00	1.00
11	0.30	0.85	0.90
10	0.25	0.20	0.40
9	0.20	0.05	0.25
8	0.10	0.0	0.10
7	0.0	0.0	0.0

Source: USACD-SFD, 2014b

4.4.2 Control Parameters

Various control parameters that dictate the WSE at the protective levee during a storm event include astronomical tide, residual surge, and wind direction and speed (Andes & Wu, 2012). Table 11 briefly describes each parameter and the derivation of the associated probability of occurrence. In total, five control parameters are employed in this MCS process.

Table 11. Control parameters for Monte Carlo Simulation

Control Parameter	*Derivation of Probability of Occurrence*
Number of Storms Per Year	Based on historical storm events per year that satisfies the sampling criteria of astronomical and residual surge
Astronomical Tide	Astronomical tides obtained from selected historical storm events
Residual Surge	Residual surge obtained from selected historical storm events
Wind Direction	Based on the historical wind data recorded at San Francisco Airport for wind-setup estimate
	Based on the historical wind data recorded at Moffett Field to be used for estimation of locally-generated waves
Wind Speed	Based on wind data recorded at San Francisco Airport for selected wind directions
	Based on wind data recorded at Moffett Field for selected wind directions

Review of the past storm records indicate that two to three storm events occur in a single year on average. The CDF curves for these three parameters (number of storms annually, astronomical tide and residual surge) were obtained from the past documented record (NCI, 2012). Historically recorded data of wind direction and speed at San Francisco Airport (SFO) that is located in the central bay and at Moffett Field located in the south bay were respectively analyzed to derive the CDF curves for assessment of wind-induced setup and locally-generated fetch-limited waves. The CDF curves for wind direction and speed were derived from the meteorological data collected at these two stations (NCI, 2012).

4.4.3 Simulation Results

Each Monte Carlo simulation was executed for a 500-year duration. A comparison was made between 100, 200 and 500 simulations for determining the statistics of the 1000-year occurrence frequency. It was found that the difference of the results from these three numbers of simulations is minimal. Nevertheless, 500 simulations, each with a duration of 500 years, were still selected for all simulation scenarios to derive the statistical representation. The results from multiple Monte Carlo Simulations including both without- and with- project conditions in Year 0 and Year 50 are respectively presented herein. Figure 10 shows the location map of the simulated stations and the corresponding ground elevations in feet, NAVD. Table 12 lists the representative WSE locations selected in each EIA as well as the indication of whether they are situated bay-ward of the proposed protective levee or not.

4.4.3.1 Without Project Conditions

The water surface elevation in terms of flood stage frequency at various locations in each EIA was computed for both Yr-0 and Yr-50 conditions. In general, the modeled water level at WSE stations for the Year 0 simulations is higher under the non-breach levee conditions than under the levee-breached conditions if the WSE stations are significantly influenced by the tidal exchange. These WSE stations are predominantly along outer levees or in the channels between the salt ponds. When the outer levees are breached, tidal waters rush into various salt ponds (i.e., the flooding zone is expanded), which reduce the water level at WSE stations that are prone to flooding under the non-breach conditions.

On the contrary, the water levels at those WSE stations that are relatively dry under the non-breach conditions are higher under the levee-breached conditions because the flooded area is expanded to include these stations. Under three future SLR scenarios (i.e., Year 50), the computed return water levels are proportionally increased in correspondence with the projected SLR rates. Elevated water levels due to the effect of high-projected sea level rise can overtop inner levees, which results in the slightly lower WSEs at some stations than would be predicted by adding sea level rise to the WSEs that are derived in Year 0.

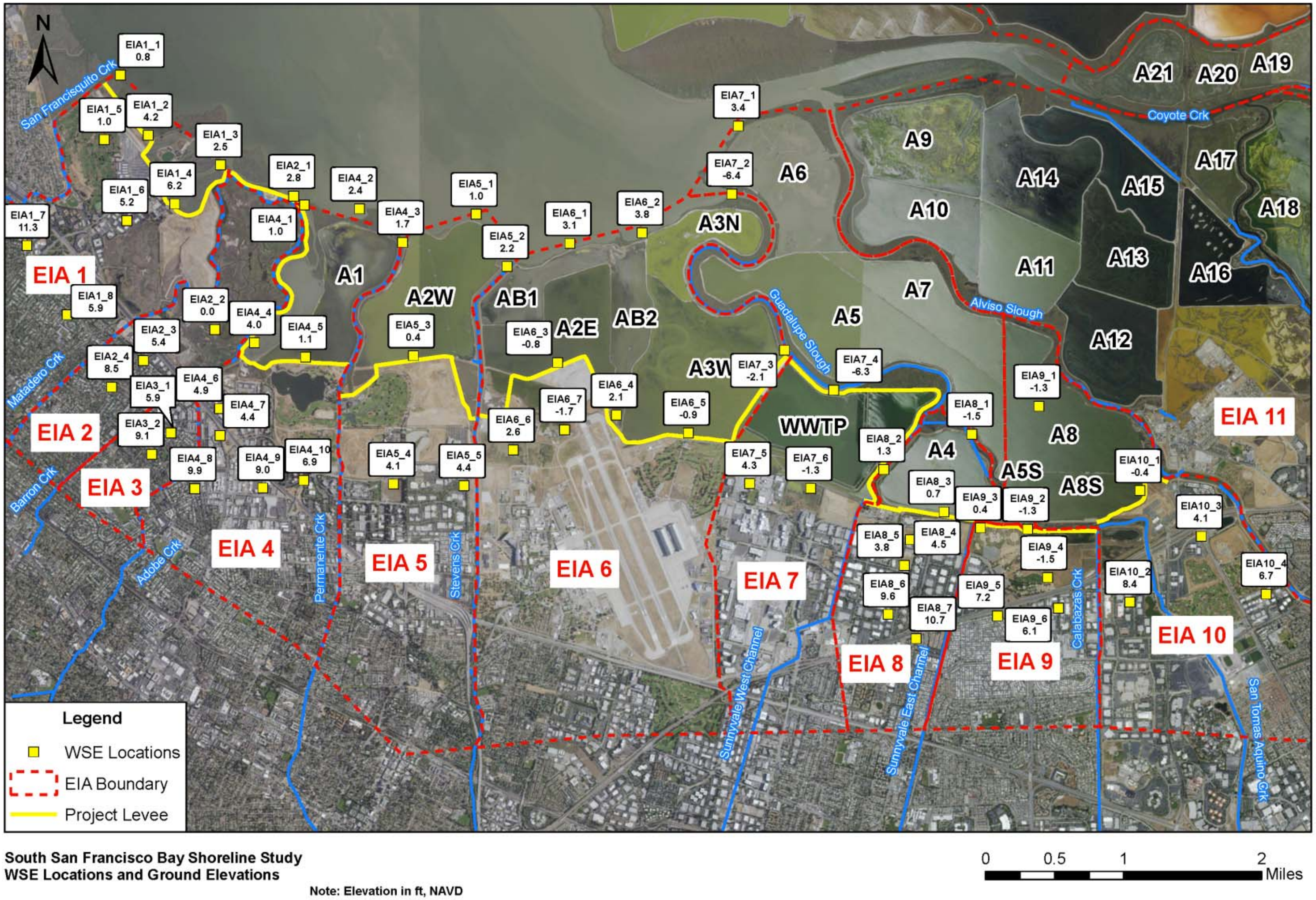


Figure 10. Locations of Modeled Water Surface Elevation

Table 12. Representative WSE Stations within Each EIA

EIA 1	Bayward	EIA1_1 through EIA1_4	EIA 6	Bayward	EIA6_1 through EIA6_5
	Landward	EIA1_5 through EIA1_8		Landward	EIA6_6 and EIA6_7
EIA 2	Bayward	EIA2_1	EIA 7	Bayward	EIA7_1 through EIA7_4
EIA 3	Landward	EIA2_2 through EIA2_4		Landward	EIA7_5 and EIA7_6
	Landward	EIA3_1 and EIA3_2	EIA 8	Bayward	EIA8_1 through EIA8_3
EIA 4	Bayward	EIA4_1 through EIA1_5		Landward	EIA8_4 through EIA8_7
	Landward	EIA4_6 through EIA1_10	EIA 9	Bayward	EIA9_1 and EIA9_2
EIA 5	Bayward	EIA5_1 through EIA5_3		Landward	EIA9_3 through EIA9_6
	Landward	EIA5_4 through EIA5_5	EIA 10	Bayward	EIA10_1
				Landward	EIA10_2 through EIA10_4

Figure 11 illustrates the calculated 100-year WSEs at all modeled stations in individual EIAs under the existing conditions (Year 0). The 100-year WSEs along the bay edge of the shoreline (e. g., EIA2_1 & EIA4_1) are about +10.8 feet, NAVD and can be higher along the creeks due to the hydraulic inflows. The highest WSE is at Station EIA9_2, which has a water level of +12.3 feet, NAVD (see Figure 11). EIA9_2 that is situated near the confluence of Sunnyvale East, Calabazas Creek, and San Tomas Aquino Creek in EIA 9 is significantly impacted by the combined creek flows that can overtop the creek levee and spread into EIA 9. As a consequence, the deduced 100-year WSE at EIA9_2 in Year 0 is the highest within the entire project area. A similar impact area can also be observed in EIA 3, which is situated landward of Highway 101. When levee failure occurs in the Palo Alto Flood Basin (PAFB), basin waters in the PAFB can extend up into Adobe and Barron Creeks and flow into EIA 3 (e.g., at EIA3_1) resulting in an inundated EIA 3. It is noted that the modeled creek inflows that are proportional to the residual surge are less than the 100-year creek flows (Anchor, 2017).

The 100-year WSEs in the project area under three future SLR scenarios are respectively illustrated in Figure 12 to Figure 14. The maximum WSE is at +13.0 feet, NAVD along the south bay shoreline in EIA 1 and EIA 2. The computed WSEs are slightly lower along the eastern shoreline of the south bay (i. e., EIA 4 to EIA 7). The computed WSEs have a similar trend as described for the WSEs in Year 0, except under the SLR Curve III scenario. Under this high SLR projection, the high bay waters can overtop outer levees even without levees being breached and, as a result, flooding occurs within the entire floodplain. The calculated 100-yr WSEs at the landward stations can be the same as the stations along the shoreline. It can also slightly reduce the water level at locations (e.g., EIA9_2 in Zone 4) that are strongly influenced by creek inflows.

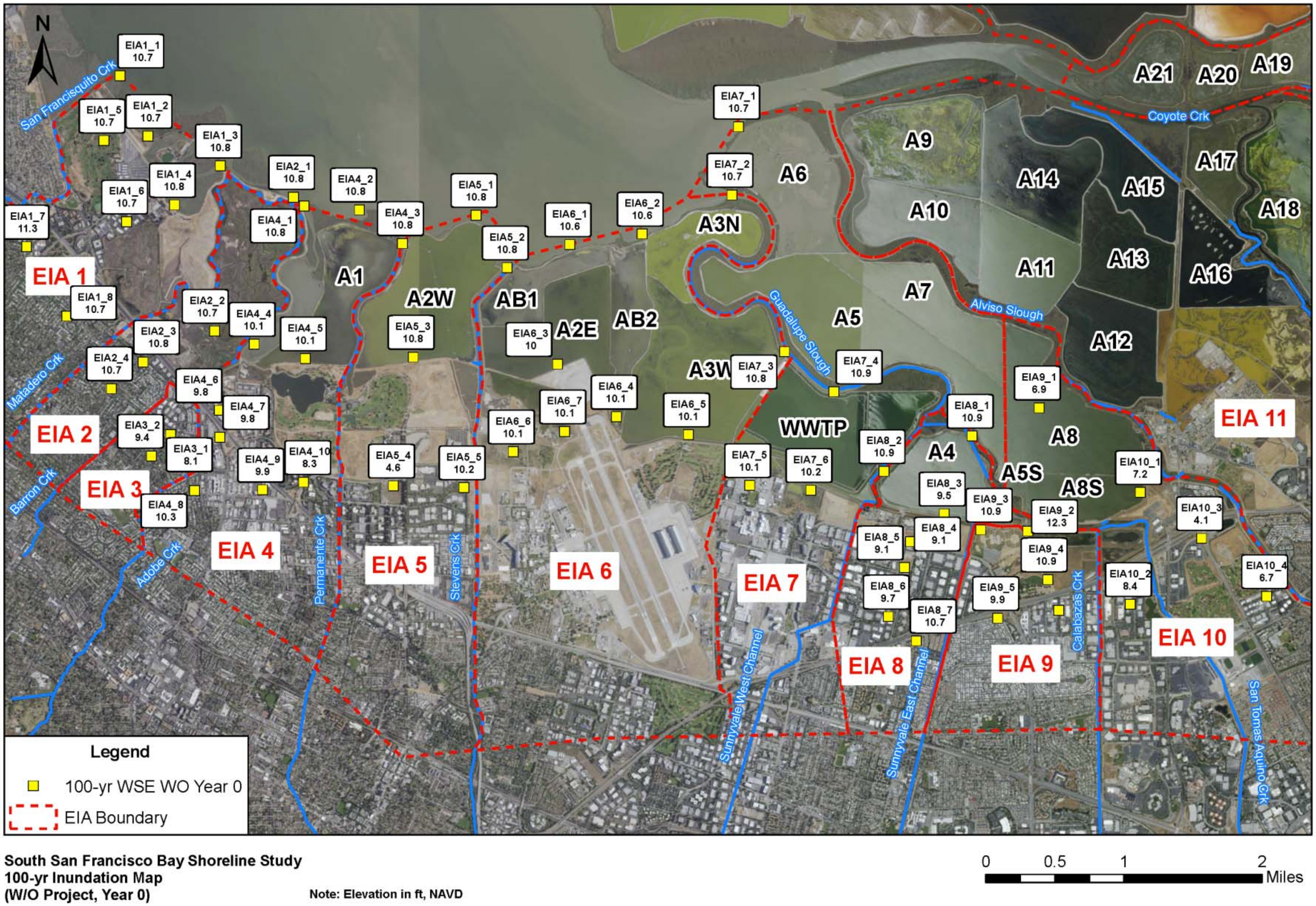


Figure 11. 100-year WSE under Without Project Condition in Year 0

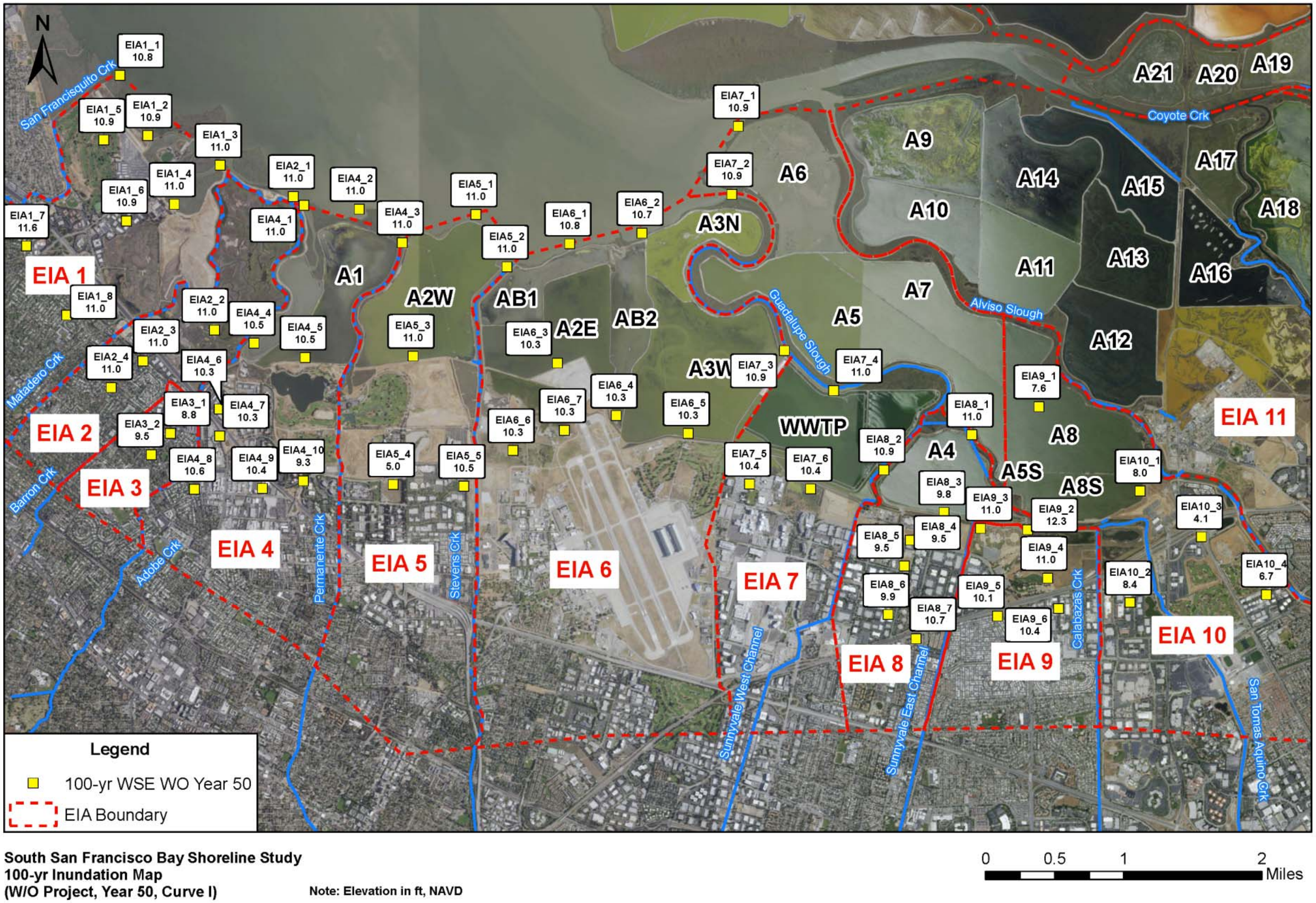


Figure 12. 100-year WSE under Without Project Condition in Year 50 SLR Curve I

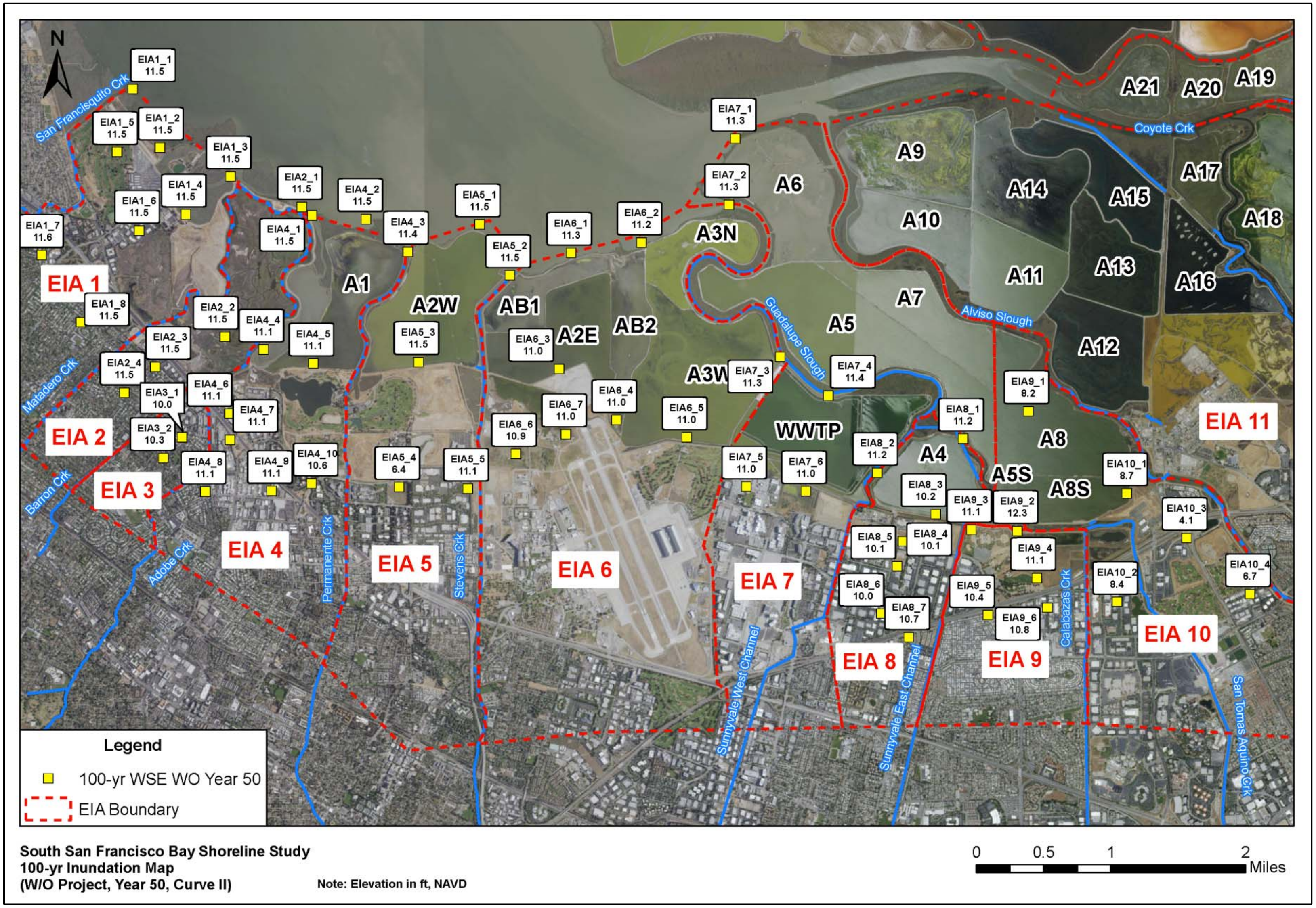


Figure 13. 100-year WSE under Without Project Condition in Year 50 SLR Curve II

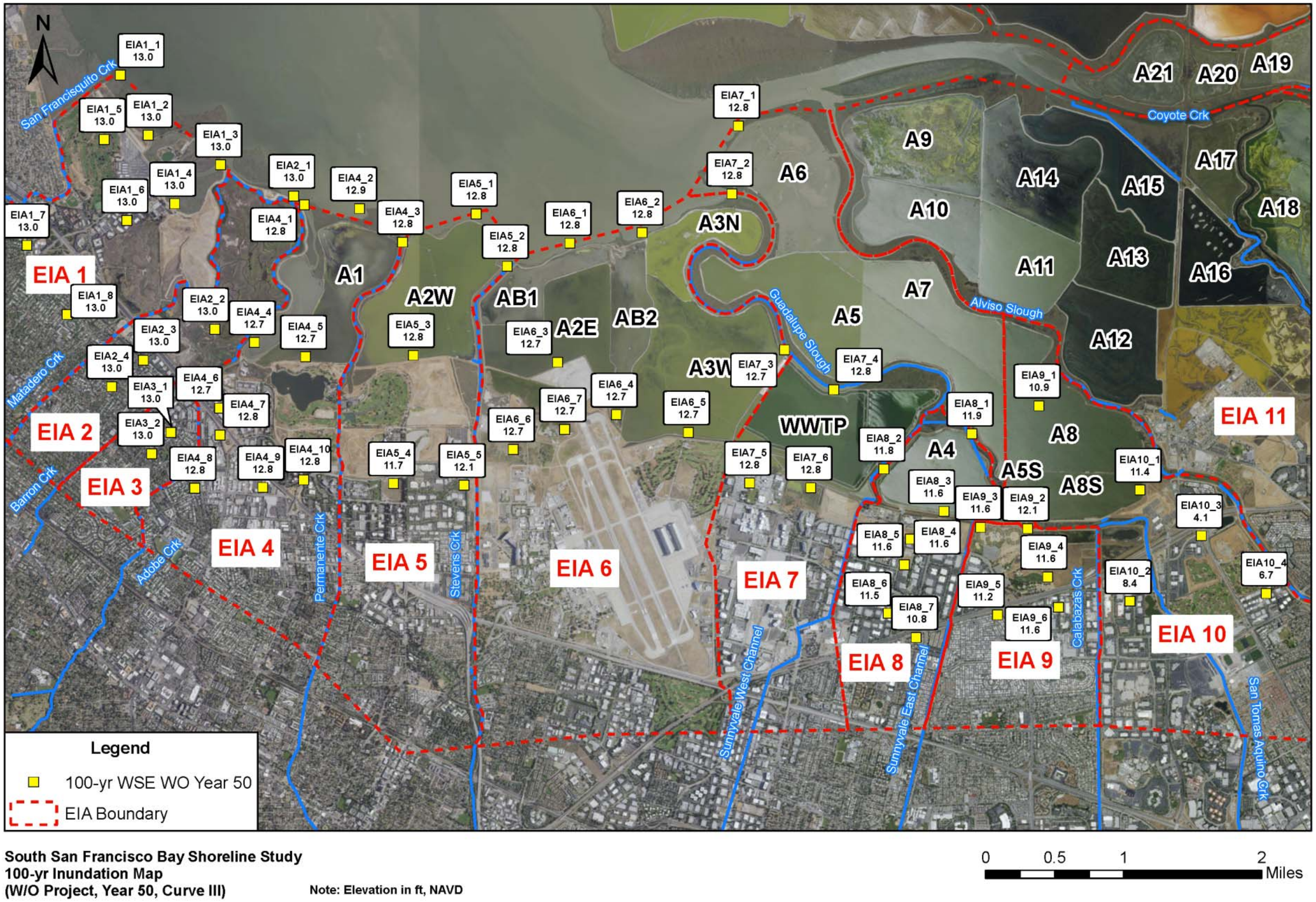


Figure 14. 100-year WSE under Without Project Condition in Year 50 SLR Curve III

4.4.3.2 With Project Conditions

Flood stage frequency with confident limits was obtained for the proposed preliminary levee alignment that extends for approximately 14.3 miles, as presented in Figure 2. Compared to the WSEs under the existing without-project conditions, the storm-induced WSE tends to be indifferentiable along the south bay shoreline when the protective levee is in place and under existing conditions. WSE stations located landward of the protect levee are dry except at Station EIA2_2.

Figure 15 shows the WSEs at pertinent stations, excluding the landward stations of the protective levee, in individual EIAs in Year 0. Although Station EIA2_2 is located landward of the project levee and in the PAFB, it is flooded for all scenarios (existing and future) under the with-project conditions. The inundation at EIA2_2 is attributed to that water level in the flood basin is controlled by the inflows from Matadero Creek, Adobe Creek and Barron Creek, and the capacity of the outlet structures to release flows during low tide cycles. Thus, the predicted water levels in the PAFB (i.e., EIA2_2) under the with-project conditions are not related to coastal flooding or overtopping of the protective levee, but instead are reflected to the tributary inflows from these three creeks. The WSEs that are predicted within the PAFB should not be considered 100-year water level. The inflows from the three creeks used in the simulations are based on an empirical correlation to the residual surge and are considerably lower than the 100-year creek flows.

Under three future SLR scenarios (i.e., Year 50), the computed return water levels are proportionally increased in correspondence with the projected SLR rates except at a few stations. The deduced 100-year WSEs at all pertinent stations are respectively illustrated in Figure 16 to Figure 18 for all analyzed future conditions. The maximum WSEs in Year 50 under the high projected SLR (Curve III) range from +13.0 feet, NAVD in EIAs 1 through 4 to +13.3 feet, NAVD in EIA 8. Table 13 summarizes the highest computed WSE in each EIA, which forms the basis for determining the crest elevation of the proposed protective levee.

4.4.3.1 Comparison of 100-year WSE between Without and With Project

A comparison of the calculated WSEs Indicates that the 100-year WSEs for the project conditions, in general, are equal to or slightly higher than the without project conditions. This is due to the fact that the bay water can overtop or breach the existing outer levee under the without project conditions, but is not allowed to overtop or breach the proposed protective levee. However, several locations in EIA 8 and EIA 9 exhibit some different trends between without and with project conditions, as presented in Table 14.

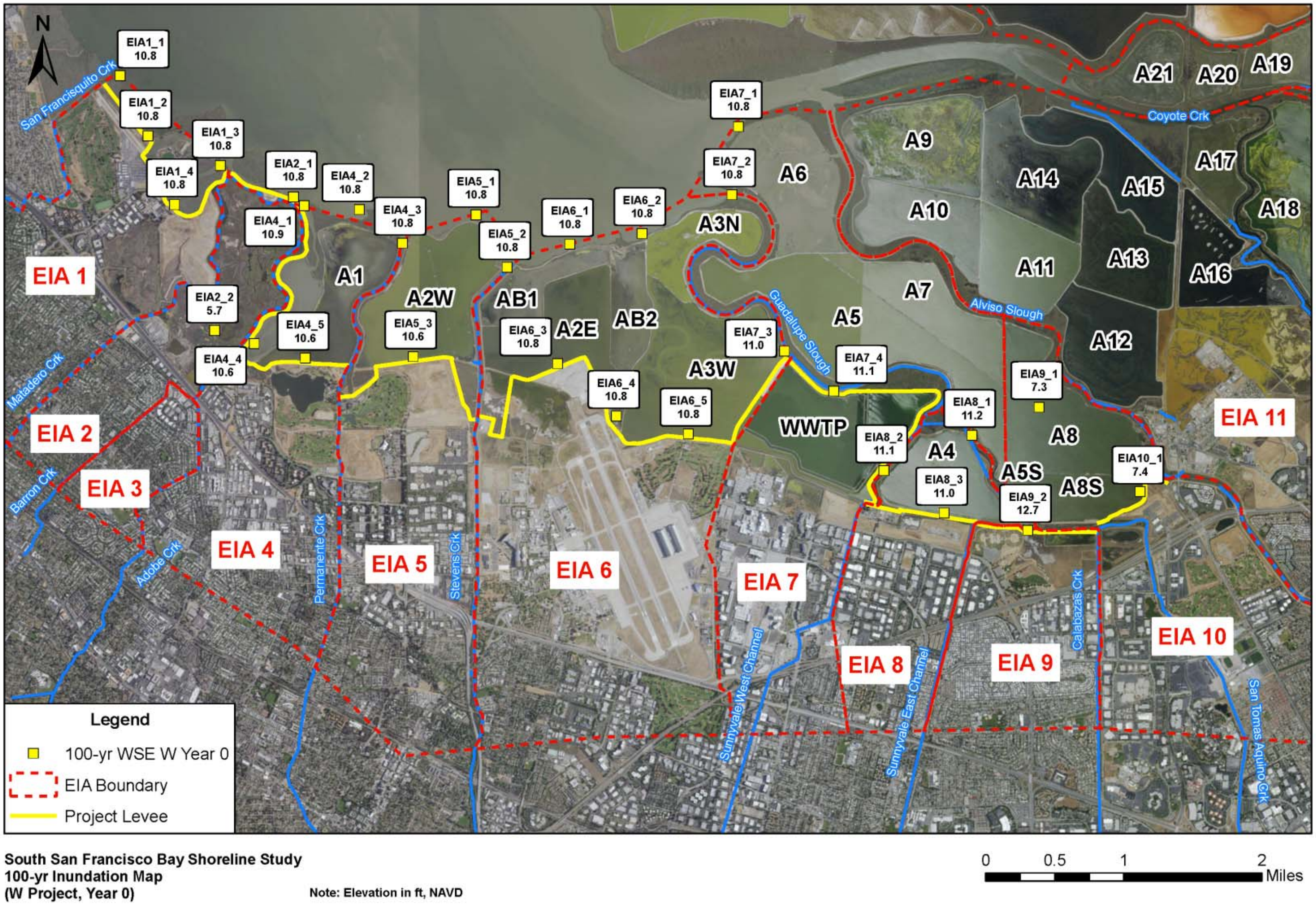


Figure 15. 100-year WSE under With Project Condition in Year 0

South San Francisco Bay Shoreline Study
100-yr Inundation Map
(W Project, Year 50, Curve I)

Note: Elevation in ft, NAVD

0 0.5 1 2 Miles

Figure 16. 100-year WSE under With Project Condition in Year 50 SLR Curve I

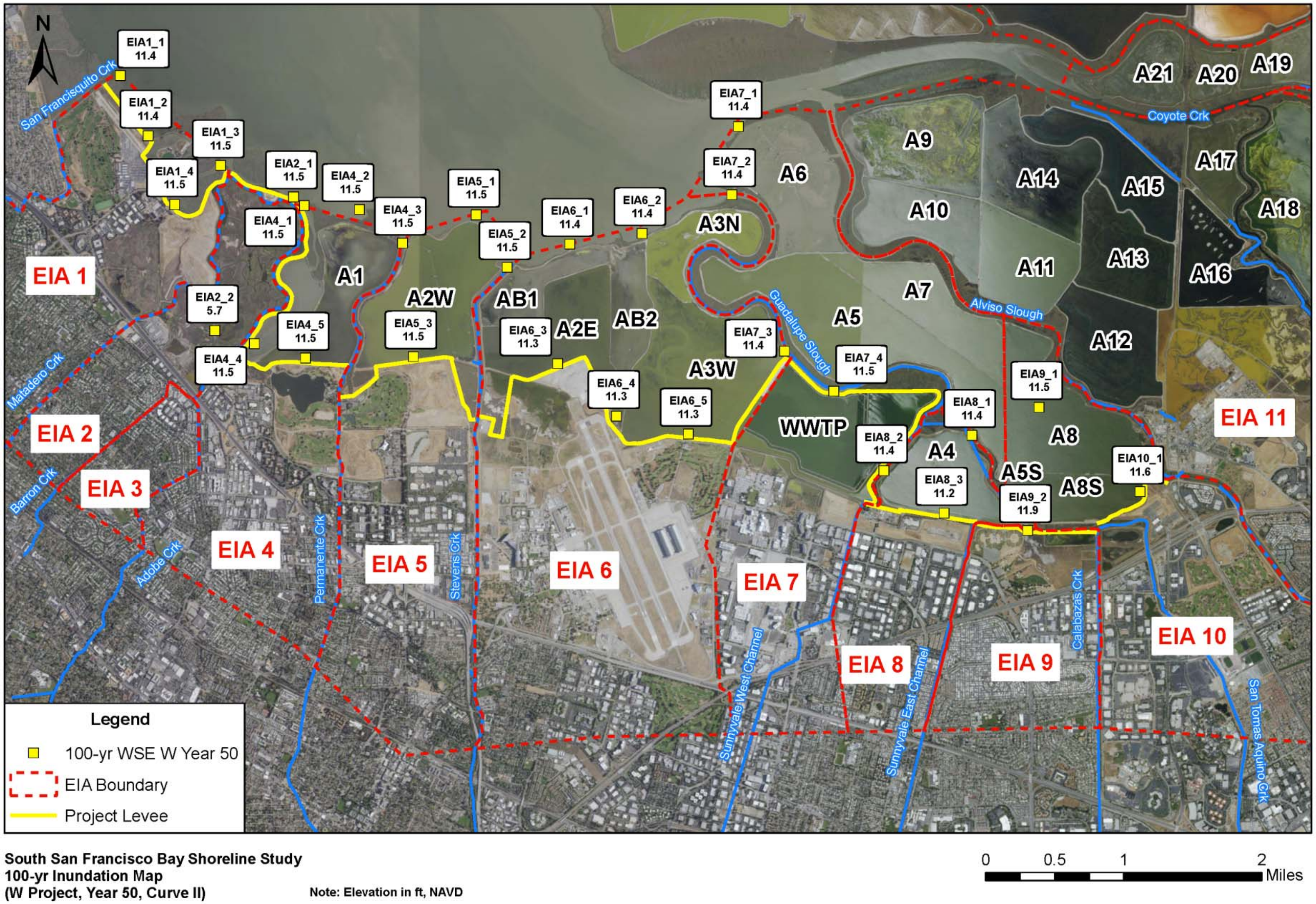


Figure 17. 100-year WSE under With Project Condition in Year 50 SLR Curve II

Figure 18. 100-year WSE under With Project Condition in Year 50 SLR Curve III

Table 13. Highest WSE Estimated in Each EIA

EIA	Highest WSE (ft, NAVD)
EIA 1 to EIA 5	+13.0
EIA 6 & EIA 7	+13.1
EIA 8	+13.3
EIA 9 & EIA 10	+13.2

Table 14. Comparison of 100-Year WSEs in EIA 8 & EIA 9

Station ID	Ground Elv. ft, NAVD	Without Project Conditions				With Project Conditions			
		WSE in ft, NAVD				WSE in ft, NAVD			
		Yr 0	Yr 50 & I	Yr 50 & II	Yr 50 & III	Yr 0	Yr 50 & I	Yr 50 & II	Yr 50 & III
EIA8_1	-1.5	10.9	11.0	11.2	11.9	11.2	10.8	11.4	13.3
EIA8_2	1.3	10.9	10.9	11.2	11.8	11.1	10.9	11.4	13.3
EIA8_3	0.7	9.5	9.8	10.2	11.6	11.0	10.6	11.2	13.3
EIA9_1	-1.3	6.9	7.6	8.2	10.9	7.3	11.0	11.5	13.2
EIA9_2	-1.3	12.3	12.3	12.3	12.1	12.7	11.4	11.9	13.2

Note: Yr 50 & I indicates in Year 50 under the SLR Curve I, etc.

These trends and reasons are delineated below:

- WSES at EIA9_2 are much higher than adjacent stations under the without project conditions in both Year 0 and Year 50. EIA8_1, EIA8_2 and EIA8_3 are respectively located in Guadalupe Slough, Moffett Channel (connected to Sunnyvale West Channel) and Pond A4. EIA9_2 is located at the confluence of Sunnyvale East Channel, Calabazas Creek, and San Tomas Aquino Creek. Water surface elevations at EIA8_1 to EIA8_3 are not as strongly influenced by the flow from these three tributaries as the channel capacity increases downstream toward the south bay, while EIA9_2 is more strongly influenced by the inflows from the three tributaries. As a consequence, water levels at EIA9_2 are strongly dominated by fluvial rather than coastal water surging effects and consequently higher than adjacent locations. It is noted that 100-year creek inflows were not used in the long wave modeling (i.e., coincident flows with peak surge are smaller than 100-year flows). This is indicative that 100-year water level at EIA9_2, due to the significant impact of creek inflows, is potentially higher than the 100-year WSEs derived from the MCS analysis.

- Under the project conditions, the 100-year WSEs for a low SLR projection in Year 50 are lower than in Year 0. The WSEs in EIA 8 & EIA 9 are influenced by adjacent creek inflows, pond restoration and the protective levees. No pond restoration is implemented in Year 0, only the installation of the project levee. However, both the extensive pond restoration and protective levees are implemented in Year 50.

The effect of the inflows from Sunnyvale East Channel, Calabazas Creek, and San Tomas Aquino Creek are responsible for elevating water levels during the higher surge events, particularly at EIA 9_2. After the completion of pond restoration in Year 50, the additional breach in Pond A8S (see Figure 9) significantly reduces the increase of water level from the creek inflows, as the inflows can be transported to the bay through the ponds rather than through a narrow creek channel. Thus, the pond restoration and levee breach in Pond A8S significantly reduce water levels at EIA9_2 and to a lesser extent at EIA 8_1 and EIA8_2 in Year 50, particularly for the Low SLR. Under the Low SLR projection, the effect of pond restoration tends to be greater at these locations than the effect of sea level rise. Consequently, water levels with a low SLR projection in Year 50 can be lower than these WSEs derived in Year 0. As the SLR rate increases (i.e., intermediate or high projection), the SLR effect gradually becomes more dominant than that of the pond restoration at these locations (see EIA8_1 to EIA8_3), which results in higher water levels under the intermediate and high SLR projections.

4.5 Flood Mapping

4.5.1 100-Year Flood Map Under Existing Conditions (Year 0)

Based on the computed 100-Year WSEs and ground elevations at all selected stations in all EIAs, an inundation map was prepared for the without project conditions in Year 0. Figure 19 illustrates the generated inundation map. Between EIA 1 and EIA 4, the footprint of the 100-year inundation extends landwards beyond Highway 101, although the inundation depth is relatively shallow. The Palo Alto Airport and PAWQCP, a waste water treatment plant, located in EIA 1 are flooded as well. The ground elevations within EIA 5 are relatively high, except at a few low-lying areas where the inundation occurs due to storm water flowing into the subject locations from creeks. In EIA 6, the bayward area of the Moffett Airfield is flooded. The SWPCP (the second waste water treatment plant in the region) located in EIA 7 is also inundated. The footprints of coastal flooding in EIA 8 and EIA 9 both extend to Highway 237.

4.5.2 100-Year Flood Map Under Future Without Project (Year 50)

Figure 20 to Figure 22 show the predicted 100-year inundation maps that take into account the three future SLR projections in Year 50 under the without-project conditions. The footprint of the inundation area under the SLR conditions is larger with greater inundation depths as compared to what is shown in Year 0. Intuitively, the high SLR projection (e.g., Curve III) yields the largest floodplain and deepest inundation depth among the three future SLR scenarios.

4.6 Economic Analysis

A preliminary economic analysis was performed to quantify the coastal flood risk in the study area extending from EIA 1 to EIA 10. This preliminary analysis establishes the foundation upon which a more detailed and comprehensive flood damage assessment, alternative plans, and benefit-to-cost (B/C) analysis can be developed in the next phase of this feasibility study. The analysis focuses on direct flood damage to structures and their contents in the floodplain. A detailed analysis report is provided on the listed reference in Section 1.3.

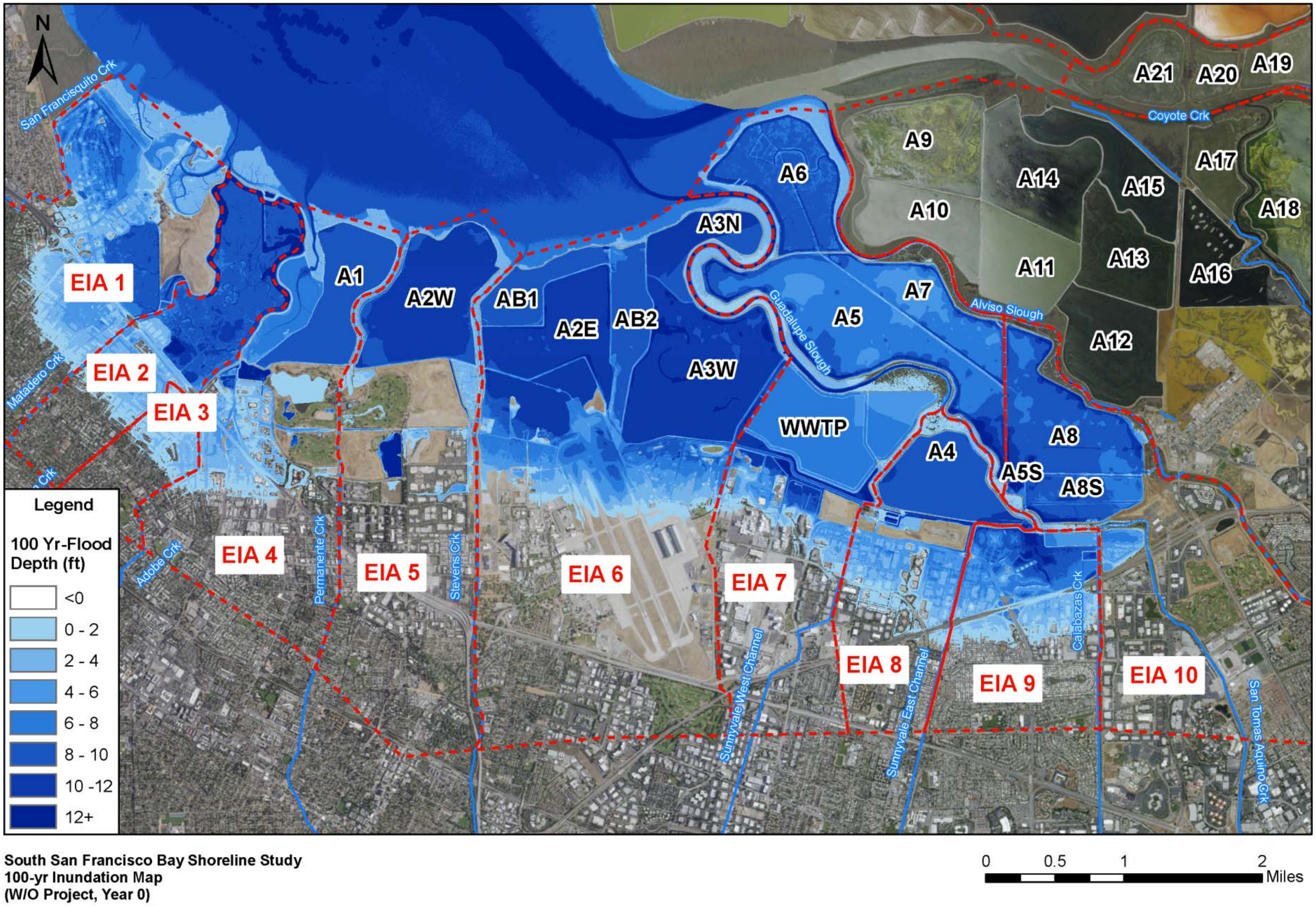


Figure 19. 100-year Inundation Map Without Project in Year 0

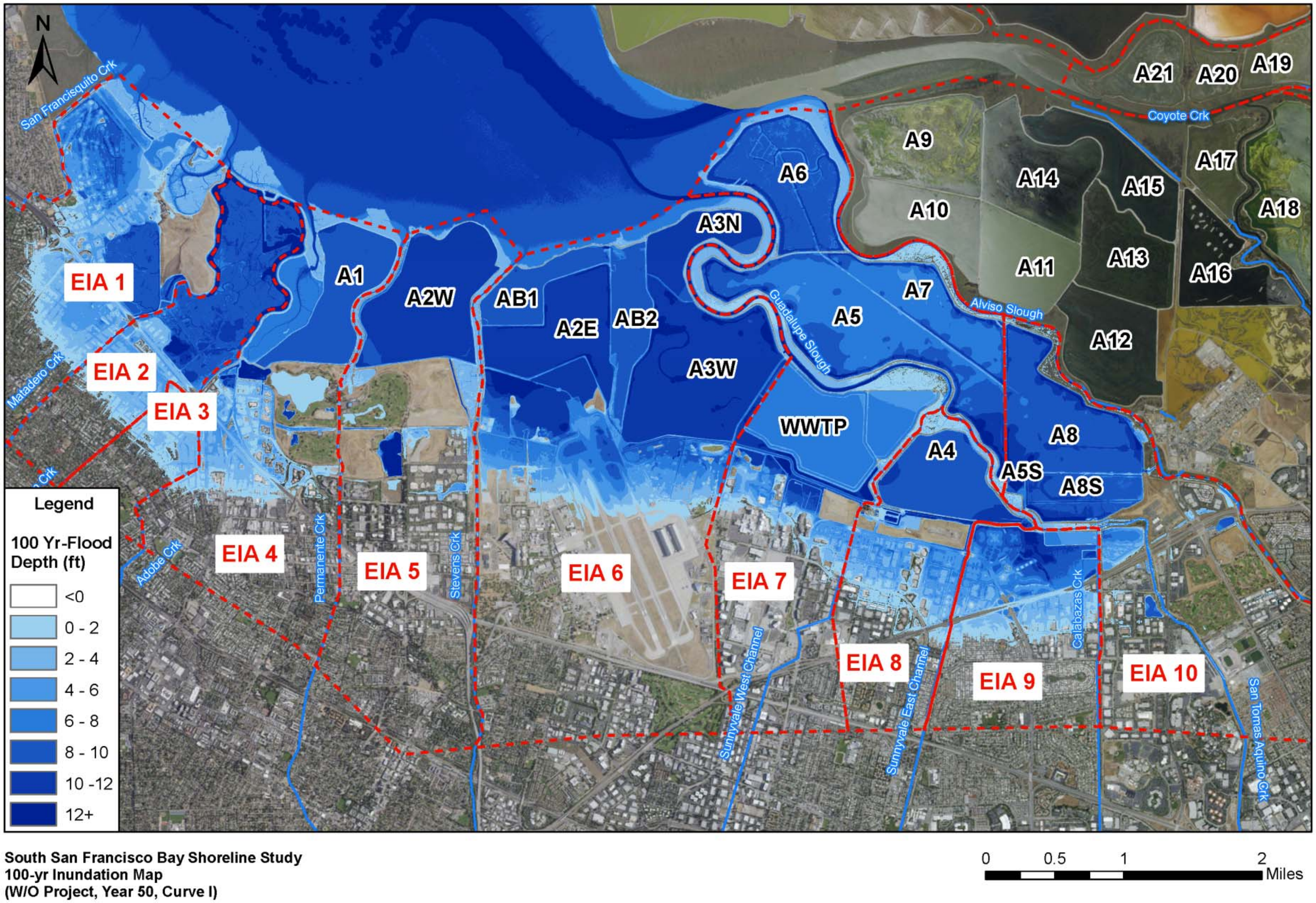


Figure 20. 100-year Inundation Map Without Project in Year 50 SLR Curve I

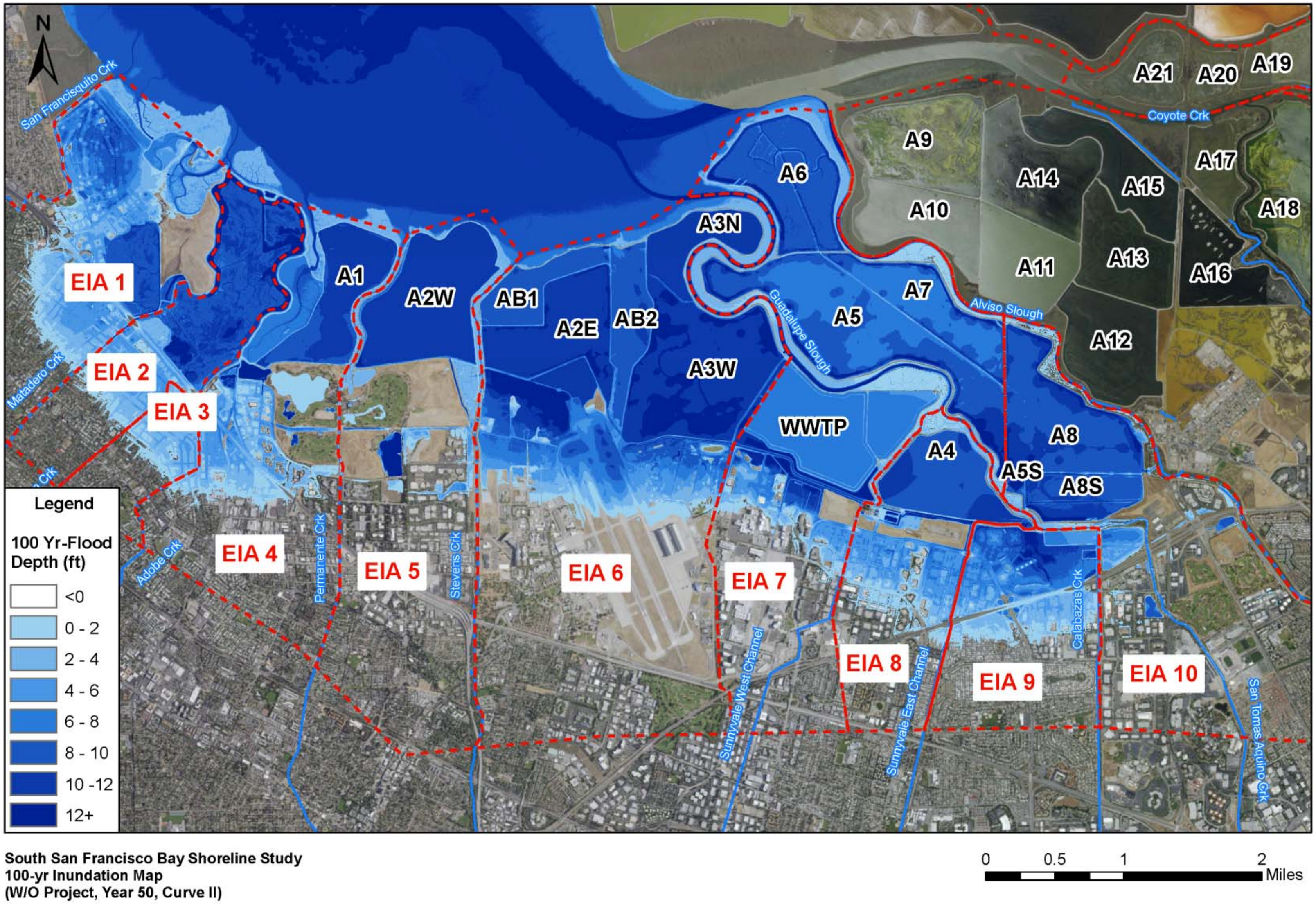


Figure 21. 100-year Inundation Map Without Project in Year 50 SLR Curve II

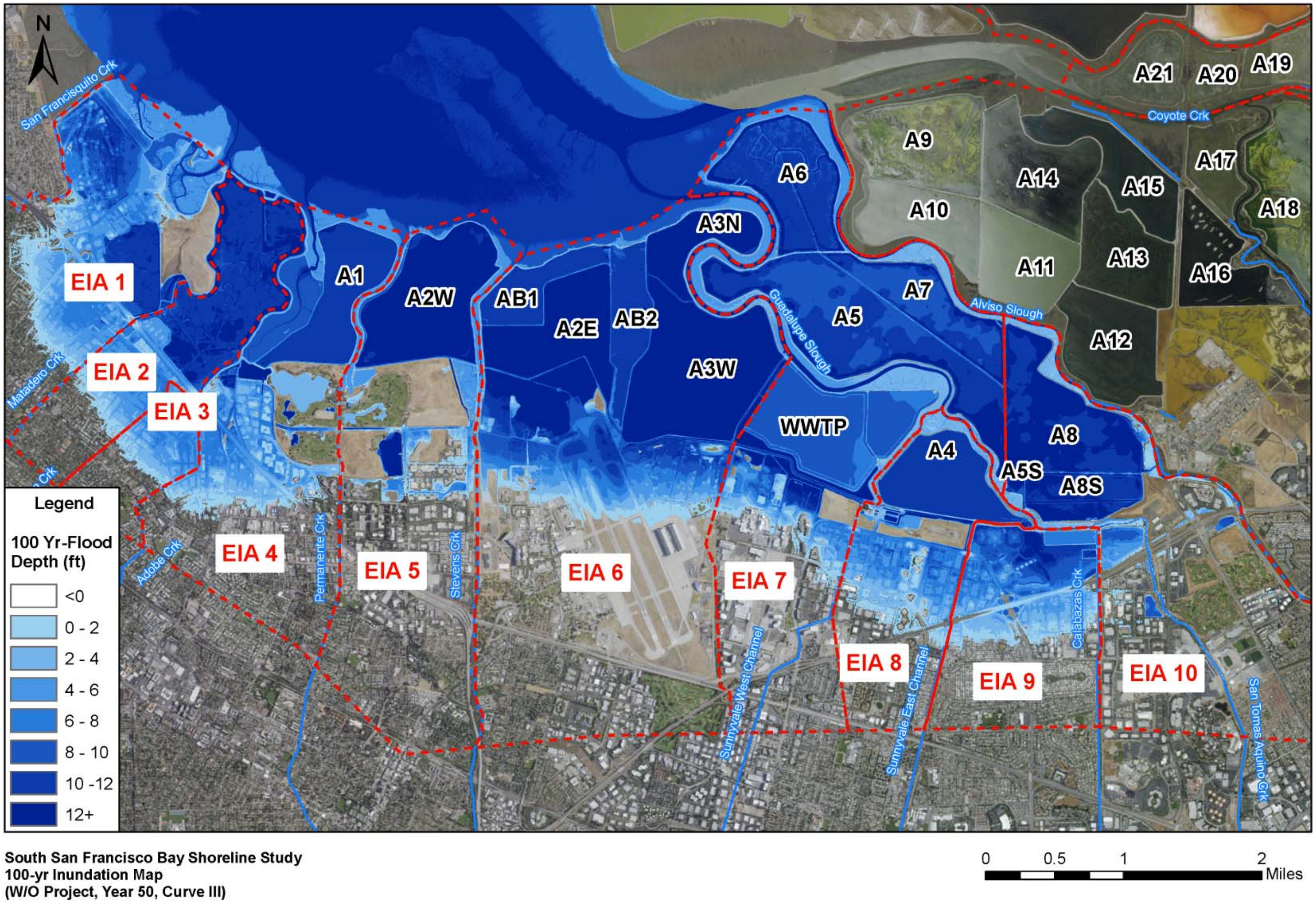


Figure 22. 100-year Inundation Map Without Project in Year 50 SLR Curve III

4.6.1 Values at Risk in the Study Area

The study area is a densely-developed urban area that has private dwellings, businesses, and critical public infrastructures. The area is part of the larger so-called Silicon Valley, and as such many of the businesses are in information technology, manufacturing, and research and development. Within the extent of this study area as shown in Figure 23, there are approximately 3,000 residential, commercial, industrial, and public structures with an estimated depreciated replacement value of $2.7 billion, excluding the two water pollution control plants (PAWQCP & SWPCP) and one recycling processing center (i.e., SMaRT Station) located in EIAs 1, 7 and 8.

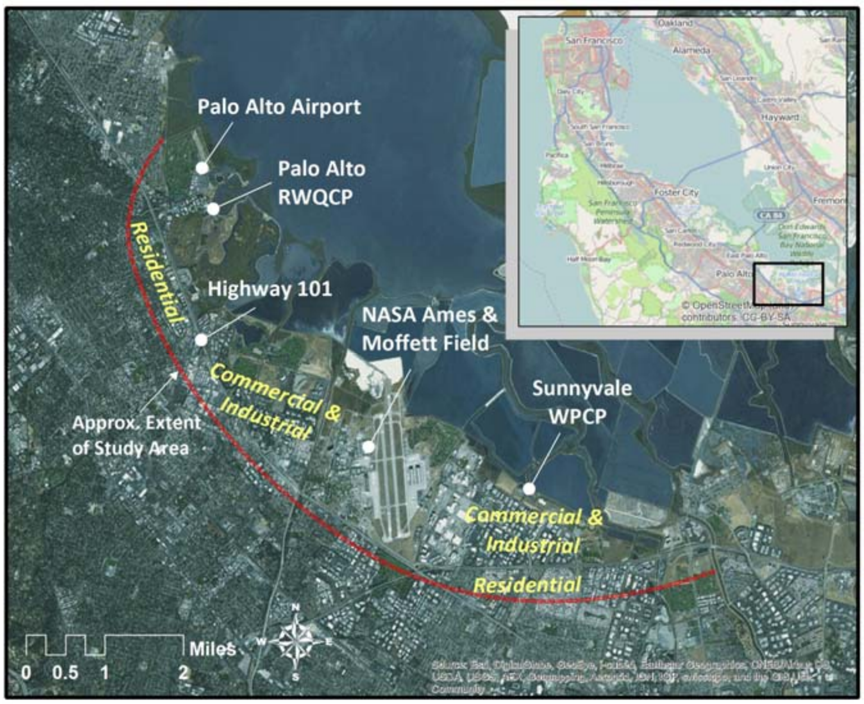


Figure 23. Critical Infrastructure & General Land Use in the Study Area

4.6.2 Modeling of Direct Flood Damage

Coastal flooding in the area can occur as the result of overtopping or breaching of the existing non-engineered levees that are currently the only line of defense for the landward development from the bay-water intrusion.

The economic damages were estimated using the HEC-FDA that was developed and certified by the USACE for use in flood risk management feasibility studies. The damage estimation was based on the assumption that there is no accounting for changes in the number or type of structures within the study floodplain over the analyzed period. In other words, it does not consider the mitigation actions by residents and businesses to reduce their flood risk after being significantly or repetitively flooded. The likely actions can be the relocation of the structures or operations out of the floodplain and/or without being rebuilt at the same locations. The flood risk analysis considers three different rates of future sea-level rise between a base year (2017, or "Year 0") and at a single future year (2067, or "Year 50").

4.6.3 Levee Construction Cost

The geotechnical explorations that were conducted in the project area included all eleven (11) EIAs. It was found that the physical properties of in-situ sediment used to construct the non-engineered levees within the 11 EIAs are almost identical. Therefore, the design criteria used in the levee design for EIA 11 (HDR, 2013) are applicable to EIAs 1 through 10. Similar to the cross section of the protective levees that were designed for EIA 11, the preliminary protective levees that are proposed in EIAs 1 to 10 will have a freeboard of 2 feet with a side slope of 3 to 1 (horizontal to vertical). The levee crest will be 16 feet in width and an access road with 6-inch thick gravel on the crest (HDR, 2013). It is noted that the length of levee sections in EIAs 4, 5 and 10 will be shorter because the existing ground of the levee alignment in these EIAs is partially higher than the required crest elevation of these levee sections. Figure 24 shows the shortened levee length in these three EIAs (identified in dark circles) as well as the full lengths of levee sections in the remaining EIAs. The sectional lengths are reduced to 1,358 feet, 1,369 feet, and 577 feet in EIAs 4, 5 and 10, respectively.

Figure 24. Required Protective Levee Sections

Construction activities include clearing, grubbing and stripping of work areas to provide the permanent and temporary construction easement. Hydro-seeding is planned for erosion protection. Due to the existence of thick bay mud within the project area, excavation below the bottom of the existing levees to build the levee foundation is necessary. The physical properties of the bay mud also require the use of wick drains prior to and during the construction to reduce the settlement time and strengthen the filled soil so as to speed up the levee construction. Table 15 to Table 17 present the preliminary cost estimates for constructing the proposed protective levees extending from EIA 1 to EIA 10 under the three SLR scenarios, based on the estimated construction cost for the EIA 11 feasibility study. It is noted that no proposed levee is located in EIA 3.

Table 15. Preliminarily Estimated Levee Construction Cost for Low SLR Projection

EIA	Proposed Levee Length	Crest Elevation	Required Levee Length	Unit Cost	Subtotal
	(ft)	(ft, NAVD88)	(ft)	($/lf)	($)
1	9,408	13.0	9,408	970	9,125,800
2	10,595	13.0	10,595	970	10,277,200
3	-	-	-	-	-
4	4,355	13.0	1,358	970	1,317,300
5	7,638	13.0	1,369	970	1,327,900
6	14,776	12.8	14,776	920	13,593,900
7	15,968	13.1	15,968	1,000	15,968,000
8	4,359	13.1	4,359	1,000	4,359,000
9	4,613	14.7	4,613	1,420	6,550,500
10	3,957	13.1	577	1,000	577,000
				Total	$ 63,097,000
				Including 25% Contingency	$ 78,871,000

Table 16. Preliminarily Estimated Levee Construction Cost for Intermediate SLR Projection

EIA	Proposed Levee Length	Crest Elevation	Required Levee Length	Unit Cost	Subtotal
	(ft)	(ft, NAVD88)	(ft)	($/lf)	($)
1	9,408	13.5	9,408	1,100	10,348,800
2	10,595	13.5	10,595	1,100	11,654,500
3	-	-	-		
4	4,355	13.5	1,358	1,100	1,493,800
5	7,638	13.5	1,369	1,100	1,505,900
6	14,776	13.3	14,776	1,050	15,514,800
7	15,968	13.5	15,968	1,100	17,564,800
8	4,359	13.4	4,359	1,080	4,707,700
9	4,613	14.7	4,613	1,420	6,550,500
10	3,957	13.6	577	1,130	652,000
				Total	$ 69,993,000
				Including 25% Contingency	$ 87,491,000

Table 17. Preliminarily Estimated Levee Construction Cost for High SLR Projection

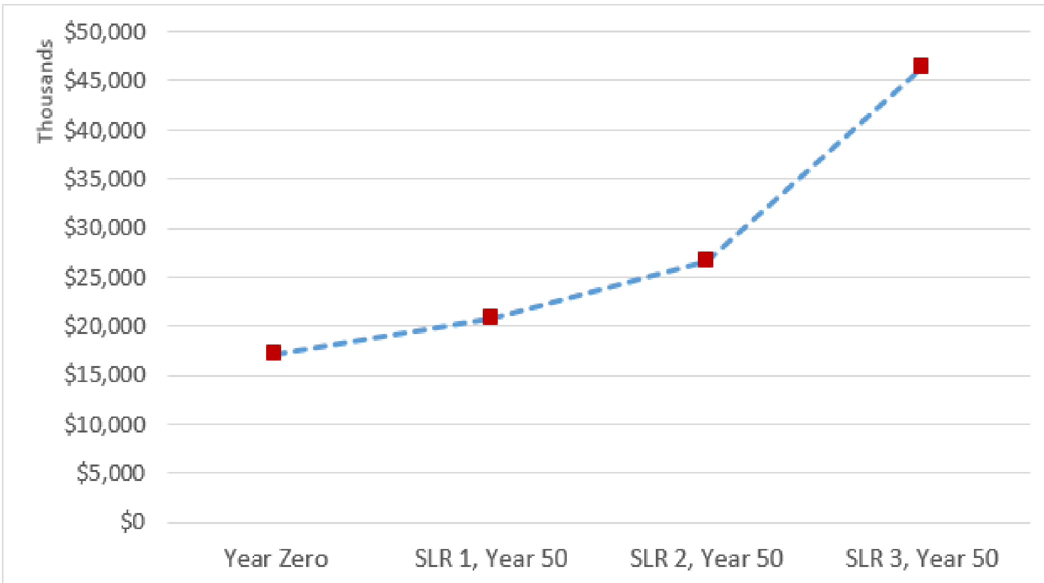
EIA	Proposed Levee Length	Crest Elevation	Required Levee Length	Unit cost	Subtotal
	(ft)	(ft, NAVD88)	(ft)	($/lf)	($)
1	9,408	15.0	9,408	1,500	14,112,000
2	10,595	15.0	10,595	1,500	15,892,500
3	-	-	-	-	-
4	4,355	15.0	1,358	1,500	2,037,000
5	7,638	15.0	1,369	1,500	2,053,500
6	14,776	15.1	14,776	1,520	22,459,000
7	15,968	15.1	15,968	1,520	24,271,400
8	4,359	15.3	4,359	1,580	6,887,200
9	4,613	15.2	4,613	1,550	7,150,200
10	3,957	15.2	577	1,550	894,400
				Total	$95,758,000
				Including 25% Contingency	$119,698,000

4.6.4 Estimated Flood Damage

The structures in the study area can be broadly classified based on the type of activity that occurs there. Accurately classifying the structures exposed to flood risk is important because the type of structure is an important determinant of the depreciated replacement value (DRV) of the structure and the assumptions about the value of the contents. For example, a warehouse and an office building of the same size will have different replacement costs due to factors such as the number of interior walls and the need for building aesthetics. The structures in the study area are classified as residential, commercial, industrial, or public. Residential structure types include single-family (SFR), multi-family (MFR), and manufactured housing (MH). Commercial (Com) structures include small and large-scale retail or service operations that serve the local or regional residential areas. Industrial (IND) structures are those devoted to warehousing, distribution, research and business support services, and offices. The baseline inventory of structures and contents in the floodplain used for this report was provided by the Corps of Engineers as developed for the 2010 without-project feasibility study in the project area. Minor updating has been done to the structure valuations to account for the increased cost of construction between 2010 and 2016. Finally, while many of the commercial and industrial structures in the floodplain are multiple stories high, the DRV estimated for this analysis applies only to the first floor of these buildings since the flood depths are not expected to reach beyond the first floor of these buildings.

The Flood Damage Reduction Analysis (HEC-FDA) software that is a hydro-economic model was used to estimate the expected annual damages under the without-project conditions. The application is based on the three relevant relationships of 1) annual exceedance probability vs water stage, 2) water stage vs damage, and 3) annual exceedance probability vs damage. The derived water stage can then be used to establish the relationship between annual exceedance probability and damage from which the expected annual flood damage is subsequently obtained via the weighted probability-damage computation. An equivalent annual damage value in

2017 (Year 0) and 2067 (Year 50) over the 50 year period of analysis is then computed under three different SLR scenarios, based on a discount rate of 3.125%. Figure 25 graphically depicts the expected annual damage estimated for the entire study area



Note: based on a discount rate of 3.12%

Figure 25. Expected Annual Damage in 2017 (Year 0) and 2067 (Year 50) under Three SLR Scenarios

4.6.5 Estimated Flood Damage and Project Benefit in Individual EIA

A 100-year storm event (i.e., 1% annual chance of exceedance storm) is estimated to cause approximately $300 million in structure and content damage in the floodplain under the present conditions (i.e., year 0). In 50 years and with the sea-level rise following the high (SLR Curve III) projection, the same 100-year storm will cause as much as $765 million in structure and content damage. It is noted that these estimates only include direct damage associated with structures and contents without considering the disruption in water treatment services at either or both of the water quality plants (PAWQCP & SWPCP) as well as the SMaRT Station. The service interruption can potentially result in very significant but as of yet un-quantified environmental and economic impacts. The Expected Annual Damage for the entire study area in 2017 (current conditions) is $17 million. With future sea-level rise over the next 50 years, the Expected Annual Damage will increase over time. Combining the deduced flood damages in 2017 and 2067, Expected Annual Damage (EAD) is obtained from an equivalent annual damage value over the 50 year period of analysis (discount the increase at 2016 Federal water resources discount rate of 3.125%). The average EAD is estimated to be $21 million, $27 million, and $46 million under the three future sea-level rise scenarios (SLR Curves I, II, and III).

The project alternative that is analyzed under the with-project condition is an engineered levee, extending from the east bank of San Francisquito Creek to Alviso Slough as illustrated in Figure 2, based on a 2-foot freeboard criterion with a crest elevation at various heights depending upon the projected SLR trend in the future (see Table 15 to Table 17). Preliminary estimates indicate the construction cost of the proposed levee alignment, including a 25% project contingency, at approximately between $63 million and $120 million dollars. It is noted that the cost estimates do not include real estate, mitigation, maintenance, or interest during the levee construction. While no project will completely eliminate all potential damage risk, the likelihood of any significant coastal flood damage over the 50-year period (between 2017 and 2067) with an engineered levee in place is extremely low. It is considered that the chance of encountering a damage event at any time during the 50-year period under even the high sea-level rise scenario (i.e., SLR Curve III) is less than one percent (1%).

A pre-screening review of the damage scenarios indicates that the flood damages do occur under both 2-year and 5-year return WSE conditions, which cannot be validated in the field. The reason is due primarily to the adopted levee failure criterion that results in a high probability of existing levee failure, and consequently high WSEs with frequent flood damage (i.e., every 2 years or 5 years). Therefore, to more realistically reflect what has been observed in the past, the flood damages resulting from events more frequent than the 10-year event were removed from the risk assessment. It is plausible, however, that under the high SLR scenario flood damage may occur as a result of these more frequent events. This would mean that the future equivalent annual damage estimate under this SLR scenario may be underestimated, meaning that the derived B/C ratio of the levee project would also be underestimated. Therefore, if the future SLR trend follows the high projection (i.e., Curve III), the resulting B/C ratios would be much higher. The construction of the protective levee is even more justified.

Based on the above-mentioned assumption, the preliminarily estimated B/C ratios for individual EIAs are summarized in Table 18, while the estimated construction costs, annual damages and resulting B/C ratios for individual EIAs are presented in the subsequent tables. The B/C ratio is defined as the reduced equivalent annual damage divided by the average annual project cost. If the resulting project benefit is higher than the cost required to complete the proposed project, the B/C ratio is greater than one, which implies a favorable and beneficial project. It is noted that EIA 2 and EIA 3 are combined since no protective levee is proposed in EIA 3 and both EIAs are in the jurisdiction of the City Of Palo Alto. Also, the flooding damage displayed for EIA 6 is based on the 2010 USACE analysis of the study area. That report estimated flood risk in EIA 6 to be low, and those estimates were not updated for this report.

EIAs 1 to 3 are primarily residential areas with a small percentage of non-residential parcels with structures for commercial and industrial use. The three EIAs are prone to storm-induced inundation without an elevated protective levee. The computed B/C ratios within this coastal zone, as shown in Table 19 and Table 20, are similar.

Table 18: Preliminarily Estimated Benefit-Cost Ratio in Individual EIA

Individual EIA	Benefit-to-Cost Ratio		
	SLR Scenario		
	Low	Intermediate	High
EIA 1	12.9	12.8	12.6
EIA 2 & EIA 3	15.8	15.8	16.3
EIA 4	24.6	27.5	34.4
EIA 5	0.0	0.0	0.11
EIA 6	0.5	0.5	0.4
EIA 7	0.95	0.98	0.98
EIA 8	15.7	15.9	13.6
EIA 9	9.7	10.0	10.1
EIA 10	0.0	0.0	0.0

Notes: 1) 50-year period of analysis, 2) The assumed interest rate is 3.125%,
& 3) Construction cost excludes real estate & maintenance

Table 19. Preliminarily Estimated Benefit-Cost Analysis in EIA 1

Analyzed Condition	SLR Scenario		
	Low	Intermediate	High
Without-Project Conditions	*Equivalent Annual Flood Damage (in 1,000)*		
	$4,734	$5,327	$7,179
With-Project Condition (Protective Levee in place)	*Equivalent Annual Flood Damage (in 1,000)*		
	$0	$0	$0
Equivalent Annual Damage Reduced	$4,734	$5,327	$7,179
Project Costs (in 1,000)			
Construction Cost	$9,216	$10,349	$14,112
Interest During 48-month Construction	$130	$147	$201
Average Annual Cost (Sum of Construction Cost & Interest)	$368	$418	$570
Net Benefits and Benefit-Cost Ratio			
Annual Net Benefits in 1,000 (EAD Reduced - Average Annual Cost)	$4,366	$4,909	$6,609
Benefit-to-Cost Ratio (EAD Reduced / Average Annual Cost)	12.9	12.8	12.6

Notes: 1) 50-year period of analysis, 2) The assumed interest rate is 3.125%,
& 3) Construction cost excludes real estate & maintenance

EIAs 4 and 5 are primarily commercial and industrial structures including many high-tech companies from the pharmaceutical, biotechnology and information technology (IT) industries. The B/C ratio presented in Table 21 would be high ranging from 20s to 30s in EIA 4. It is noted that the existing ground elevation immediately bayward of Sailing Lake is higher than the required elevation. Thus, the required levee section in EIA 4 is shortened (see Figure 24). The raised area of Shoreline Park in EIA 5 indicates no damage will occur even under the future high SLR scenario. Thus, the levee section proposed in this EIA will not result in any damage reduction. The derived B/C ratio is practically zero, as presented in Table 22. Consequently, a 15-foot or higher protective levee may not be required or only a low-level levee is needed. The levee section to be built in EIA 5 is much shorter than the proposed sectional length (see Figure 24).

Table 20. Preliminarily Estimated Benefit-Cost Analysis in EIA 2 & EIA 3

Analyzed Condition	SLR Scenario		
	Low	Intermediate	High
Without-Project Conditions	*Equivalent Annual Flood Damage (in 1,000)*		
	$6,548	$7,416	$10,454
With-Project Condition (Protective Levee in Place)	*Equivalent Annual Flood Damage (in 1,000)*		
	$0	$0	$0
Equivalent Annual Damage Reduced	$6,548	$7,416	$10,454
Project Costs (in 1,000)			
Construction Cost	$10,277	$11,655	$15,893
Interest During 48-month Construction	$146	$166	$226
Average Annual Cost (Sum of Construction Cost & Interest)	$415	$470	$641
Net Benefits and Benefit-Cost Ratio			
Annual Net Benefits in 1,000 (EAD Reduced - Average Annual Cost)	$6,133	$6,946	$9,813
Benefit-to-Cost Ratio (EAD Reduced / Average Annual Cost)	15.8	15.8	16.3

Notes: 1) 50-year period of analysis, 2) The assumed interest rate is 3.125%,
& 3) Construction cost excludes real estate & maintenance

Table 21. Preliminarily Estimated Benefit-Cost Analysis in EIA 4

Analyzed Condition	SLR Scenario		
	Low	Intermediate	High
Without-Project Conditions			
	$1,309	$1,660	$2,827
With-Project Condition (Protective Levee in Place)	*Equivalent Annual Flood Damage (in 1,000)*		
	$0	$0	$0
Equivalent Annual Damage Reduced	$1,309	$1,660	$2,827
Project Costs (in 1,000)			
Construction Cost	$1,317	$1,494	$2,037
Interest During 48-month Construction	$19	$21	$29
Average Annual Cost (Sum of Construction Cost & Interest)	$53	$60	$82
Net Benefits and Benefit-Cost Ratio			
Annual Net Benefits in 1,000 (EAD Reduced - Average Annual Cost)	$1,256	$1,600	$2,745
Benefit-to-Cost Ratio (EAD Reduced / Average Annual Cost)	24.6	27.5	34.4

Notes: 1) 50-year period of analysis, 2) The assumed interest rate is 3.125%,
& 3) Construction cost excludes real estate & maintenance

Table 22. Preliminarily Estimated Benefit-Cost Analysis in EIA 5

Analyzed Condition	SLR Scenario		
	Low	Intermediate	High
Without-Project Conditions	*Equivalent Annual Flood Damage (in 1,000)*		
	$0	$0	$9
With-Project Condition (Protective Levee in Place)	*Equivalent Annual Flood Damage (in 1,000)*		
	$0	$0	$0
Equivalent Annual Damage Reduced	$0	$0	$9
Project Costs (in 1,000)			
Construction Cost	$1,328	$1,506	$2,054
Interest During 48-month Construction	$19	$21	$29
Average Annual Cost (Sum of Construction Cost & Interest)	$54	$61	$83
Net Benefits and Benefit-Cost Ratio			
Annual Net Benefits in 1,000 (EAD Reduced - Average Annual Cost)	-$54	-$61	-$74
Benefit-to-Cost Ratio (EAD Reduced / Average Annual Cost)	0.00	0.00	0.11

Notes: 1) 50-year period of analysis, 2) The assumed interest rate is 3.125%,
& 3) Construction cost excludes real estate & maintenance

EIA 6 is essentially a military-related facility, namely NASA Ames and Moffett Field. Many of the structures on the NASA property contain specialized, non-standard contents such as lab equipment, supercomputing equipment, compressors, and aircraft parts. The actual replacement values of these contents are unknown. Thus, the estimated potential damages from storm-induced inundation, as shown in Table 23, tend to be underestimated. The actual B/C ratio in this EIA would be much higher.

EIA 7 is exclusively commercial and industrial structures including several well-known companies such as Lockheed Martin and Yahoo. The estimated B/C ratio is slightly less than one. However, the extended levee section in this EIA also protects the storage pond of the Sunnyvale Water Pollution Control Plant (SWPCP). The inundation damage without a protective levee would be extremely high, which is not included in this preliminary analysis. Therefore, the actual B/C ratio would be much higher than the one presented in Table 24. EIA 8 consists exclusively of commercial and industrial buildings with a mix of 60 office structures as research and manufacturing facilities. This EIA also includes the main operation buildings of the SWPCP as well as the SMaRT Station used for processing recyclable materials from residents and businesses in the cities of Sunnyvale, Palo Alto and Mountain View. Thus, the actual B/C ratio with the inclusion of damages associated with these two public facilities would be much higher than those presented in Table 25.

Table 23. Preliminarily Estimated Benefit-Cost Analysis in EIA 6

Analyzed Condition	SLR Scenario		
	Low	Intermediate	High
Without-Project Conditions	*Equivalent Annual Flood Damage (in 1,000)*		
	$301	$307	$363
With-Project Condition (Protective Levee in Place)	*Equivalent Annual Flood Damage (in 1,000)*		
	$0	$0	$0
Equivalent Annual Damage Reduced	$301	$307	$363
Project Costs (in 1,000)			
Construction Cost	$13,594	$15,515	$22,459
Interest During 48-month Construction	$193	$221	$320
Average Annual Cost (Sum of Construction Cost & Interest)	$549	$626	$906
Net Benefits and Benefit-Cost Ratio			
Annual Net Benefits in 1,000 (EAD Reduced - Average Annual Cost)	-$248	-$319	-$543
Benefit-to-Cost Ratio (EAD Reduced / Average Annual Cost)	0.5	0.5	0.4

Notes: 1) 50-year period of analysis, 2) The assumed interest rate is 3.125%,
& 3) Construction cost excludes real estate & maintenance

Table 24. Preliminarily Estimated Benefit-Cost Analysis in EIA 7

Analyzed Condition	SLR Scenario		
	Low	Intermediate	High
Without-Project Conditions	*Equivalent Annual Flood Damage (in 1,000)*		
	$613	$692	$957
With-Project Condition (Protective Levee in Place)	*Equivalent Annual Flood Damage (in 1,000)*		
	$0	$0	$0
Equivalent Annual Damage Reduced	$613	$692	$957
Project Costs (in 1,000)			
Construction Cost	$15,968	$17,565	$24,271
Interest During 48-month Construction	$193	$250	$346
Average Annual Cost (Sum of Construction Cost & Interest)	$644	$709	$980
Net Benefits and Benefit-Cost Ratio			
Annual Net Benefits in 1,000 (EAD Reduced - Average Annual Cost)	-$31	-$17	-$23
Benefit-to-Cost Ratio (EAD Reduced / Average Annual Cost)	0.95	0.98	0.98

Notes: 1) 50-year period of analysis, 2) The assumed interest rate is 3.125%,
& 3) Construction cost excludes real estate & maintenance

EIA 9 includes a mix of industrial, commercial, and residential structures for a total of 110 structures that are within the floodplain. The computed B/C ratios in both EIAs range from 10 to 16 approximately, as respectively presented in Table 26. In EIA 10, all flooding events under the base year (2017) and future conditions (2067) are confined to a low area north of Highway

237. No structures or vital infrastructure in this EIA are at risk from coastal flooding according to the preliminary modeling. Therefore, no benefit can be claimed with the proposed protective levee meaning the computed B/C ratio is zero as seen in Table 27. Also, the required levee section is much shorter than the proposed one (see Figure 24) due to the high ground elevation along the levee alignment in this EIA.

Table 25. Preliminarily Estimated Benefit-Cost Analysis in EIA 8

Analyzed Condition	SLR Scenario		
	Low	Intermediate	High
Without-Project Conditions	*Equivalent Annual Flood Damage (in 1,000)*		
	$2,758	$3,020	$3,780
With-Project Condition (Protective Levee in Place)	*Equivalent Annual Flood Damage (in 1,000)*		
	$0	$0	$0
Equivalent Annual Damage Reduced	$2,758	$3,020	$3,780
Project Costs (in 1,000)			
Construction Cost	$4,359	$4,708	$6,887
Interest During 48-month Construction	$62	$67	$98
Average Annual Cost (Sum of Construction Cost & Interest)	$176	$190	$278
Net Benefits and Benefit-Cost Ratio			
Annual Net Benefits in 1,000 (EAD Reduced - Average Annual Cost)	$2,582	$2,830	$3,502
Benefit-to-Cost Ratio (EAD Reduced / Average Annual Cost)	15.7	15.9	13.6

Notes: 1) 50-year period of analysis, 2) The assumed interest rate is 3.125%,
& 3) Construction cost excludes real estate & maintenance

Table 26. Preliminarily Estimated Benefit-Cost Analysis in EIA 9

Analyzed Condition	SLR Scenario		
	Low	Intermediate	High
Without-Project Conditions	*Equivalent Annual Flood Damage (in 1,000)*		
	$2,577	$2,634	$2,914
With-Project Condition (Protective Levee in Place)	*Equivalent Annual Flood Damage (in 1,000)*		
	$0	$0	$0
Equivalent Annual Damage Reduced	$2,577	$2,634	$2,914
Project Costs (in 1,000)			
Construction Cost	$6,551	$6,551	$7,150
Interest During 48-month Construction	$93	$93	$102
Average Annual Cost (Sum of Construction Cost & Interest)	$264	$264	$289
Net Benefits and Benefit-Cost Ratio			
Annual Net Benefits in 1,000 (EAD Reduced - Average Annual Cost)	$2,313	$2,370	$2,625
Benefit-to-Cost Ratio (EAD Reduced / Average Annual Cost)	9.7	10.0	10.1

Notes: 1) 50-year period of analysis, 2) The assumed interest rate is 3.125%,
& 3) Construction cost excludes real estate & maintenance

Table 27. Preliminarily Estimated Benefit-Cost Analysis in EIA 10

Analyzed Condition	SLR Scenario		
	Low	Intermediate	High
Without-Project Conditions	*Equivalent Annual Flood Damage (in 1,000)*		
	$0	$0	$0
With-Project Condition (Protective Levee in Place)	*Equivalent Annual Flood Damage (in 1,000)*		
	$0	$0	$0
Equivalent Annual Damage Reduced	$0	$0	$0
Project Costs (in 1,000)			
Construction Cost	$577	$652	$894
Interest During 48-month Construction	$8	$9	$13
Average Annual Cost (Sum of Construction Cost & Interest)	$23	$26	$36
Net Benefits and Benefit-Cost Ratio			
Annual Net Benefits in 1,000 (EAD Reduced - Average Annual Cost)	-$23	-26	-36
Benefit-to-Cost Ratio (EAD Reduced / Average Annual Cost)	0.0	0.0	0.0

Notes: 1) 50-year period of analysis, 2) The assumed interest rate is 3.125%,
& 3) Construction cost excludes real estate & maintenance

4.7 Hydraulic Analysis

A hydraulic analysis using the HEC-RAS model was performed to determine the flow capacity of nine creeks located within the project area (i.e., EIA 1 to EIA 10) and the minimum levee/flood wall elevations to provide the 100-year flood protection level. The nine creeks included in the hydraulic analysis are Matadero Creek, Barron Creek, Adobe Creek, Permanente Creek, Stevens Creek, Sunnyvale West Channel, Sunnyvale East Channel, Calabazas Creek and San Tomas Aquino Creek, as shown in Figure 26. It is noted that this hydraulic analysis excludes San Francisquito Creek since the creek's hydraulic conditions have been extensively studied by the Corps of Engineers, San Francisco District. Four scenarios similar to the coastal inundation analysis were conducted in this hydraulic analysis. The four scenarios include the present creek condition in 2017 and three future conditions following three different SLR projections (see Table 5) in 2067, respectively.

The computed maximum water surface profile during the 100-year flow event was compared to the channel bank top elevation to determine if the channel meets the 100-year protection criteria. If the channel is protected by a levee or floodwall, the crest elevation of the levee or floodwall is defined as the bank top elevation. For incised channels, channel bank top is defined as the intersection of the channel side slope with the ground that is approximately flat. It is noted that no free board is added to the total required elevation in the analysis. Therefore, the required minimum channel bank top elevations are defined as the same as the computed 100-year water surface elevations. The results for each creek are summarized as follows.

4.7.1 Matadero Creek

The findings of the channel flow capacity in Matadero Creek are:

- The 100-year water surface elevations exceed the levee/floodwall elevations in the reach between the Park Blvd. Bridge and the Lambert Avenue Bridge.
- The impact of the SLR on the channel water levels is limited to the lower reach of the channel. The 100-year water levels show no difference between the Year 0 and three Year 50 conditions in the reaches upstream of the Ross Way Bridge.

4.7.2 Barron Creek

It is noted that only the lower reach of Barron Creek, which is from its confluence with Adobe Creek to approximately 900 feet upstream of the Louis Road Bridge, was included in the Corp's unsteady HEC-RAS model for this creek. As a result, our hydraulic analysis was also limited to this lower reach. The findings of the channel flow capacity in Barron Creek are:

- The reach downstream of the Louis Road Bridge can accommodate the 100-year flow event for both the Year 0 and three Year 50 conditions (i.e., three SLR projections).
- The reach upstream of the Louis Road Bridge has the flow capacity for the Year 0 condition and the Year 50 conditions under the "low (Curve I)" and "intermediate (Curve II)" SLR projections. However, the 100-year water levels under the Year 50 condition with the "high (Curve III)" SLR projection will exceed the levee/flood wall elevations.

Figure 26. Stream Lines of Nine Analyzed Creeks

4.7.3 Adobe Creek

The derived 100-year channel flow capacity along the creek indicates:

- Adobe Creek does not have the 100-year flow capacity in the reach approximately between the Louis Road Bridge and the Charleston Road Bridge, and within a short reach of incised channel starting at a inline structure located upstream of the SPRR and Alma Street Bridge for all four modeled scenarios.
- The reach between the Meadow Drive Bridge and the Louis Road Bridge will not have the 100-year flow capacity for the Year 50 condition with the “high (Curve III)” SLR projection.

4.7.4 Permanente Creek

Overall, Permanente Creek is capable of providing the 100-year flood protection except at some locations in the lower reach that passes through salt ponds (i.e., downstream of the Boatpond Footbridge).

4.7.5 Stevens Creek

The findings of the channel flow capacity in Stevens Creek are:

- Stevens Creek does not have the 100-year flow capacity in the reach that is approximately between the Hwy 101 Bridge and the Highway 85 Bridge neither at the present time nor under future SLR conditions.
- Stevens Creek also does not have the 100-year flow capacity in the lower reach (approximately 1,600 feet downstream of the Crittenden Lane crossing) that passes through the salt ponds.
- Future sea level rise appears to have a negligible impact on the 100-year water levels in Stevens Creek.

4.7.6 Sunnyvale West Channel

The computed channel flow capacity in Sunnyvale West Channel indicates:

- Sunnyvale West Channel has the 100-year flow capacity for the reach that is upstream of the salt ponds, starting approximately 1,640 feet downstream of the Carl Road crossing.
- The lower reach of Sunnyvale West Channel that passes through the salt ponds does not have 100-year flow capacity at multiple locations, particularly on the left bank side looking downstream (i.e., toward the bay).

4.7.7 Sunnyvale East Channel

Sunnyvale East Channel is capable of accommodating the 100-year creek flow in the upstream floodwall/levee protected reach starting approximately 1,200 feet downstream of the Caribbean

Drive crossing. The downstream reach without any floodwall/levee protection does not have the 100-year flow capacity.

4.7.8 Calabazas Creek

Calabazas Creek generally has the 100-year flow capacity except for the right bank of the lower reach that is downstream of the Bay Trail crossing.

4.7.9 San Tomas Aquino Creek

San Tomas Aquino Creek has the 100-year flow capacity except in the lower reach downstream of the Bay Trail crossing.

5.0 SUMMARY AND RECOMMENDATIONS

5.1 Summary

Pertinent findings under this levee evaluation study are summarized as follows:

- The existing outer levees in the project area are predominantly composed of bay muds that were excavated from the adjacent ponds. The existing inner levees were also constructed with the same baymud material. Some of the inner levees were armored or built with a proper engineering design for additional protection against erosion. Both outer and inner levees were periodically raised or widened with the same practice. Geotechnical exploration for both outer and inner levees was conducted to characterize the physical properties of levee material from EIA 1 to EIA 11. Geotechnical recommendations, based on the derived physical properties of levee material, were provided for any newly proposed protective levee in the project area. The recommended geotechnical design criteria were applied for the EIA 11 feasibility study that was performed by the Corps of Engineers, San Francisco District in 2014.

- Topographic and bathymetric data sources that were acquired from USACE, USGS and SCVWD and validated by the USACE-SFD were applied to prepare the modeling grids for the long wave modeling effort to establish the WSE look-up tables to be used in the statistic analysis. The long wave simulations for the with- and without- levee breaching scenarios consist of 720 events (Table 8) for the without project conditions and 360 events (Table 9) for the with-project conditions in Year 0 and Year 50, respectively. The Year 50 simulations were based on the resulting accretion in the project area, erosion in the south bay and the marsh accretion within individually restored ponds, if applicable, as a consequence of future sea level rise.

- The Monte Carlo simulation technique was applied to deduce the flood stage frequency in the project area from EIA1 to EIA 10, using the compiled WSE look-up tables. Figure 11 to Figure 18 respectively show the derived 100-year WSEs at representative locations throughout the entire project area for all analyzed scenarios. The scenarios include both the with- and without- project conditions in 2017 (Year 0) and 2067 (Year

50) for three different SLR projections. The computed WSEs ranging from +13.1 to +13.3 ft, NAVD (see Table 13) under the high SLR projections, in general, are slightly higher for the with-project conditions. This is due to the fact that the bay water can overtop the existing levee under the without-project conditions, but is not allowed to overtop the proposed protective levee. These maximum WSEs form the basis for designing the crest of the protective levees with an additional 2-foot freeboard, which translates to +15.1 to 15.3 feet, NAVD for the crest elevation.

- Inundation maps for the 100-year WSE were also prepared under the existing and three future SLR conditions as illustrated in Figure 19 to Figure 22, respectively.

- To evaluate the feasibility of constructing protective levees for the ten study EIAs, a preliminary economic analysis was conducted to quantify the coastal flood risk and the resulting benefit for a proposed levee alternative. Based on this preliminary risk assessment, the estimated B/C ratios for individual EIAs are summarized in Table 18.

- In a separate study, a hydraulic analysis of nine creeks located in the project area was performed. The nine creeks are Matadero Creek, Barron Creek, Adobe Creek, Permanente Creek, Stevens Creek, Sunnyvale West Channel, Sunnyvale East Channel, Calabazas Creek and San Tomas Aquino Creek. The computed maximum water surface profiles during the 100-year flow event were used to assess whether the channel meets the 100-year protection criteria under the existing and three future SLR conditions. Individual creek sections susceptible to water overflowing the bank or protective levee were identified.

5.2 Recommendations

The analyzed results and the derived benefit-cost ratios for the proposed levee protective project in each EIA are based on the preliminary analysis of all pertinent studies such as long wave modeling, statistic and economic evaluations. Therefore, a more comprehensive feasibility study is needed to determine, with more certainty, the net benefits of the proposed protective levees. Additional analyses that are recommended to complete the comprehensive phase of the feasibility study are:

- ➢ It is assumed that both outer and inner levees are simultaneously breached in each breach zone, if breach occurs. This condition may, in fact, not occur for each storm event. Therefore, more long-wave simulations are needed to include only the outer or inner levee breached, not both in each simulated storm event.
- ➢ Update the criterion for levee failure under the storm condition to more closely reflect past observations of levee failure.
- ➢ Additional intervening years (e. g., Year 25) between Year 0 and Year 50 need to be evaluated to more accurately quantify the incremental change of flood risk over time under different SLR rates, particularly the high SLR projection.
- ➢ Additional categories of project cost, including real estate, mitigation, and maintenance

following the completion of an EIR/EIS preparation.

- Estimate the changes in land use in the floodplain that may occur in the face of significant or repetitive coastal flooding;
- Damages to the two waste water treatment plants and the SMaRT Station located in the study area;
- Transportation delay costs and any damages to roads and highways in the floodplain; and
- Damages to vehicles and the displacement cost incurred by residents whose homes have been flooded.

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