Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project

Final Report • September 2017

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METROPOLITAN TRANSPORTATION COMMISSION

BAY AREA TOLL AUTHORITY

AECOM

Acknowledgments

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EXECUTIVE SUMMARY

The Adapting to Rising Tides (ART) program (http://www.adaptingtorisingtides.org), led by the San Francisco Bay Conservation and Development Commission (BCDC), provides support, guidance, tools, and information to help agencies and organizations understand, communicate, and begin to address complex climate change issues. Although the ART project initially focused on Alameda County, the project has since expanded throughout San Francisco Bay (SF Bay or Bay) and is supporting sea level rise (SLR) vulnerability, risk, and adaptation work in several counties. These efforts have advanced the methods and products available to communities to start climate change adaptation efforts. A key product from the early studies was detailed SLR inundation maps that improved on other readily available high-level map products such as the National Oceanic and Atmospheric Administration SLR viewer. However, because these earlier projects were conducted at different times and did not include the entire SF Bay shoreline, the mapping products were not consistent with each other in terms of source data, methods, degree of stakeholder input, map format, and data structure. Local communities and agencies agreed that they needed a consistent Bay-wide SLR inundation mapping product that they could use to identify areas of shoreline inundation and flooding vulnerabilities.

This project, the **Adapting to Rising Tides, Bay Area Sea Level Rise Analysis and Mapping Project**, produces consistent inundation data and mapping products for all nine San Francisco Bay Area counties. This project was funded by the Bay Area Toll Authority (BATA) through the Metropolitan Transportation Commission (MTC); the project extends the tools and products that BCDC and MTC developed through prior efforts as part of the ART program and applies them Bay-wide. AECOM, in collaboration with MTC and BCDC, created these SLR and shoreline overtopping mapping products for the entire SF Bay shoreline.

The SLR inundation mapping products capture permanent inundation and temporary flooding impacts from SLR scenarios from 0 to 66 inches and extreme high tide events from the 1-year to the 100-year extreme tide. The mapping process included discussions with key stakeholders in each county, who reviewed the preliminary maps and provided on-the-ground verification and supplemental data as needed to improve the accuracy of the maps. The products and information produced through this effort can inform the planning and development of adaptation strategies, assist in managing climate change risks, and help identify trigger points for implementing adaptation strategies to address SLR and flooding hazards, at both local and regional scales.

This effort led to the development of a variety of geo-spatial tools and data layers that can assist in identifying shoreline vulnerabilities and formulating and implementing adaptation strategies. These tools and data layers include the following for each of the nine San Francisco Bay Area counties:

- 1-meter resolution topographic digital elevation model (DEM)
- SLR inundation maps showing depth and extent of inundation for 10 scenarios
- Shoreline overtopping potential maps for the 10 scenarios
- SLR and extreme tide matrix (showing the 10 scenarios)
- Discussion of key SLR and flooding vulnerabilities

Section 7, County Methods and Discussion, presents a high-level overview of the key vulnerabilities within each county that may benefit from further examination. The intent of these sections is to highlight areas within each county that may be exposed to SLR and flooding impacts in the near term, either due to daily high tides with low to moderate amounts of SLR or as a result of significant storm surge events, were they to occur today. Each county section also presents a high-level discussion of SLR impacts to bridge approaches that may be of interest to BATA to inform the selection of focus areas for future studies. A summary of these key vulnerabilities is provided in Table E-1. Table E-1, and the subsequent sections of the report, are presented in clockwise order around the Bay's shoreline starting with Marin County and are not ranked or prioritized in any way.

Table E-1. Summary of Key Vulnerabilities Identified in Each County

Timing of Impact	County	Assets Impacted
MHHW + 12''	**Marin**	Larkspur: Tidal waters overtop US 101 in two locations and inundate inland residential and commercial areas of the city. San Rafael: Segments of San Rafael Creek berms are overtopped, resulting in inundation of a 1-mile section of I-580 leading to the San Rafael Bridge touchdown. Sections of US 101 near the city are overtopped.
	Napa	West river bank at Edgerly Island is overtopped at the Napa River, exposing a 4,800 ft section of the California Northern Railroad line to inundation.
	San Mateo	Frontage road along north side of SR 84 at the western touchdown of the Dumbarton Bridge is exposed to inundation.
MHHW + 24''	**Sonoma**	SR 37 exposed to inundation when Petaluma River levees and Port Sonoma shoreline are overtopped.
	Solano	SR 37 is exposed to inundation for a 500 ft section at Mare Island.
	Contra Costa	Martinez: A 2,000 ft section of the Capitol Corridor rail line is exposed to inundation. Northbound on-ramp to I-680 and southbound off-ramp from I-680 are exposed to inundation.
	Santa Clara	Low-lying section of berms overtops, exposing commercial areas of Sunnyvale, NASA Ames Research Center, and a 1-mile section of SR 237.
	San Mateo	Inundation of westbound Dumbarton Bridge access expands to include the adjacent bike path and a 1-mile section of the eastbound lane. The outside lanes of SR 84 are exposed to inundation for 1 mile.
MHHW + 36''	**Marin**	SR 37 is exposed to inundation due to overtopping of Bay-side levees.
	Sonoma	SR 37 is exposed to inundation between Tolay Creek and Sonoma Creek.
	Alameda	Toll plaza and westbound lanes at the Bay Bridge touchdown are exposed to inundation for a 500 ft section. Water overtops low-lying section of shoreline west of Doolittle Drive overpass and several low spots on Doolittle Drive along the east shoreline of Bay Farm Island, exposing much of Oakland International

		Airport property and facilities to inundation.
	Santa Clara	Palo Alto: Water overtops a series of salt pond berms, inundating a 1.2-square-mile residential area and a 2.5-mile section of US 101.
MHHW + 48''	**Sonoma**	A 950 ft section of SR 121 (next to Sonoma Racetrack and Sonoma Valley Airport) is exposed to inundation.
	Alameda	SR 92 and SR 84 are exposed to inundation along a 2,000 ft section of the outer lanes leading to the San Mateo Bridge and Dumbarton Bridge. For SR 92, inundation exposure first occurs about 3,000 ft from the bridge toll plaza, and for SR 84 inundation first occurs about 1,700 ft from the toll plaza. Alameda: Water overtops a low-lying area near the Bay Farm overpass and inundates homes.
	San Francisco	There is isolated exposure to inundation in Mission Bay, Islais Creek, and along the Embarcadero.
MHHW + 52''	**Contra Costa**	Water levels in marsh surrounding I-680 encroach on the shoulder of the outer lane in both directions.
	Alameda	Water overtops the shoreline south of Burma Road to expose residential areas of West Oakland to inundation.
	San Mateo	Foster City: Surrounding low-lying levees are overtopped, exposing the San Mateo Bridge touchdown, a 3-mile section of SR 92, and a 3-mile section of US 101 to inundation.
	San Francisco	Inundation around Mission Bay expands to include the Caltrain station, a 2,000 ft section of the rail lines, and the on-/off-ramps to I-280. Overtopping occurs along a 200 ft shoreline segment, inundating a 550 ft section of US 101 in both directions near Crissy Field.
MHHW + 66''	**Solano**	SR 29 in Vallejo is exposed to inundation for 300 ft from overtopping of Napa River shoreline.
	Contra Costa	Water overtops the Santa Fe Channel shoreline at several locations and inundates a 2,000 ft section of I-580 at about 2 miles from the Richmond–San Rafael Bridge.
MHHW + 84''	**Napa**	SR 121 is exposed to inundation for a small stretch just east of the Napa River and along a 630 ft section at Gasser Drive.
MHHW + 96''	**Sonoma**	Petaluma: A 540 ft section of US 101 and a 2,000 ft section of SR 116 (serves as an on-ramp to US 101) are exposed to inundation.

Notes: MHHW is a tidal datum and is representative of the daily high tide. See Section 1.4.
Bay Bridge = San Francisco–Oakland Bay Bridge
ft = foot/feet
I-280 = Interstate 280
I-580 = Interstate 580
I-680 = Interstate 680
MHHW = Mean Higher High Water
San Mateo Bridge = San Mateo–Hayward Bridge
SR = State Route
US 101 = U.S. Highway 101

CONTENTS

TABLES

FIGURES

ABBREVIATIONS AND ACRONYMS

ART	ADAPTING TO RISING TIDES
BATA	BAY AREA TOLL AUTHORITY
BAY	SAN FRANCISCO BAY
BAY AREA	SAN FRANCISCO BAY AREA
BAY BRIDGE	SAN FRANCISCO–OAKLAND BAY BRIDGE
BAYWAVE	MARIN BAY WATERFRONT ADAPTATION AND VULNERABILITY EVALUATION
BCDC	SAN FRANCISCO BAY CONSERVATION AND DEVELOPMENT COMMISSION
CALTRANS	CALIFORNIA DEPARTMENT OF TRANSPORTATION
CASCADE	COMPUTATIONAL ASSESSMENT OF SCENARIOS FOR THE DELTA ECOSYSTEM
CCC	CALIFORNIA COASTAL COMMISSION
CSMP	CALIFORNIA SHORELINE MAPPING PROJECT
DEM	DIGITAL ELEVATION MODEL
ENSO	EL NIÑO–SOUTHERN OSCILLATION
FEMA	U.S. DEPARTMENT OF HOMELAND SECURITY'S FEDERAL EMERGENCY MANAGEMENT AGENCY
FIRM	FLOOD INSURANCE RATE MAP
FIS	FLOOD INSURANCE STUDY
FT	FOOT OR FEET
GHG	GREENHOUSE GAS
GIS	GEOGRAPHIC INFORMATION SYSTEM
I-80	INTERSTATE 80
I 280	INTERSTATE 280
I-580	INTERSTATE 580
I-680	INTERSTATE 680
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
JPA	JOINT POWERS AUTHORITY
LIDAR	LIGHT DETECTION AND RANGING
M	METER(S)
MHHW	MEAN HIGHER HIGH WATER (TIDAL DATUM)
MLLW	MEAN LOWER LOW WATER (TIDAL DATUM)
MSL	MEAN SEA LEVEL
MTC	METROPOLITAN TRANSPORTATION COMMISSION
NOAA	NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NRC	NATIONAL RESEARCH COUNCIL
NTDE	NATIONAL TIDAL DATUM EPOCH
NVTA	NAPA VALLEY TRANSPORTATION AUTHORITY
OCOF	OUR COAST OUR FUTURE
OPC	CALIFORNIA OCEAN PROTECTION COUNCIL
RICHMOND BRIDGE	RICHMOND–SAN RAFAEL BRIDGE
SAN MATEO BRIDGE	SAN MATEO–HAYWARD BRIDGE
SCTA	SONOMA COUNTY TRANSPORTATION AUTHORITY
SF BAY	SAN FRANCISCO BAY
SFEI	SAN FRANCISCO ESTUARY INSTITUTE
SFO	SAN FRANCISCO AIRPORT
SLR	SEA LEVEL RISE
SR	STATE ROUTE
STA	SOLANO TRANSPORTATION AUTHORITY
US 101	U.S. HIGHWAY 101
USACE	UNITED STATES ARMY CORPS OF ENGINEERS
USGS	UNITED STATES GEOLOGICAL SURVEY
VTA	SANTA CLARA COUNTY VALLEY TRANSPORTATION AUTHORITY

1.0

INTRODUCTION

1. INTRODUCTION

The nine-county San Francisco Bay Area (Bay Area), home to approximately 7 million people, is the nation's fifth most populated metropolitan or urbanized area. Its economy, culture, and landscape—supporting prosperous businesses, vibrant neighborhoods, and productive ecosystems—are linked with a vital system of public infrastructure, including freeways, seaports and airports, railroads, local roads, mass transit, and bicycle and pedestrian facilities that connect the shoreline communities to each other and the rest of the region, the state, the nation, and the world. Neighborhoods, businesses, and entire industries currently exist on the shoreline, which is home to more than 250,000 residents. Low-lying parts of the shoreline have historically experienced coastal flood events (such as the annual king tides and El Niño extreme high tides), and they may experience similar events with increased frequency, duration, and severity in the future as a result of projected sea level rise (SLR). Planners and engineers need tools to evaluate vulnerabilities and risks due to projected inundation and flooding. Over the past several years, various entities such as the San Francisco Bay Conservation and Development Commission (BCDC), the Metropolitan Transportation Commission (MTC), the California Department of Transportation (Caltrans), the San Francisco Public Utilities Commission, and San Mateo, and Alameda Counties have pioneered the development and use of SLR inundation maps to assess shoreline vulnerabilities. These efforts have advanced the methods and products available to communities; however, because these mapping efforts have been conducted at different times and did not include the entire shoreline of San Francisco Bay (SF Bay or Bay), the mapping products are not entirely consistent with each other in terms of source data, methods, degree of stakeholder input, map format, and data structure.

This project, the **Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project**, aims to produce consistent inundation data and mapping products for all nine San Francisco Bay Area counties. This project, funded by the Bay Area Toll Authority (BATA) through the MTC, extends the tools and products developed through prior efforts by BCDC and MTC as part of the Adapting to Rising Tides (ART) program and applies them throughout the Bay Area. AECOM, in collaboration with MTC and BCDC, created this SLR and shoreline overtopping information for the entire SF Bay shoreline using methods and tools developed in prior studies.

This project presents a broad assessment of SF Bay's shoreline exposure to inundation and flooding from SLR scenarios from 0 to 66 inches and extreme tides from the 1-year to the 100-year event. Two distinct impacts (permanent inundation and temporary flooding) can occur from SLR and storm surge or a combination of both. *Permanent inundation* occurs when an area is regularly covered by daily tidal fluctuations. As sea levels rise, additional shoreline areas may be subject to permanent inundation. In contrast, *temporary flooding* occurs when an area is exposed to episodic, short-duration, extreme tide events of greater magnitude than normal tide levels (such as during storm surge or El Niño events). Shoreline and inland areas may be temporarily flooded during an extreme tide event, but may resume their intended function once floodwaters recede. The analyses presented in this report show that as sea levels rise, SF Bay's shoreline and flood protection infrastructure will become increasingly exposed to tide levels currently considered extreme, and over time existing shoreline protection infrastructure will no longer provide the same level of flood protection that it does today. Such shifts in the frequency of extreme tide levels will have important design implications for flood protection infrastructure and for the resilience of valuable shoreline habitats.

Although the products and information provided in this report are not intended for use in the design of shoreline projects, they could inform planning and development of operational strategies, assist in identifying and managing climate-change-related risks, and help identify trigger points for implementing adaptation strategies. These efforts will increase the likelihood of achieving a consistent and reliable level of flood protection for SF Bay's communities over the coming decades and into the next century.

1.1 PROJECT GOALS AND APPROACH

A primary goal of this project is to develop mapping products that will assist local stakeholders to investigate shoreline vulnerabilities, identify locations for adaptation strategies, and evaluate the feasibility of proposed strategies. This goal was achieved following the project approach shown in Figure 1-1. The approach to develop strategies to address flooding and SLR issues along the San Francisco Bay shoreline consists of five steps:

1. Use county-scale SLR and extreme tide inundation and overtopping maps to conduct high-level evaluations of inundation and flooding exposure to identify near-term shoreline vulnerabilities, including the timing of exposure for assets.
2. Ground-truth findings with local experts and identify locations where the inundation maps do not represent local, on-the-ground knowledge of past flood events.
3. Conduct refined shoreline analyses to assess more-detailed vulnerabilities and identify locations to evaluate near-, medium-, and long-term strategies.
4. Develop short-term local strategies to provide benefits to critical assets at immediate risk of impact and medium- to long-term strategies regional strategies to provide benefits to multiple assets and communities at a larger scale.
5. Evaluate strategies and resilience building actions to assess feasibility for implementation.

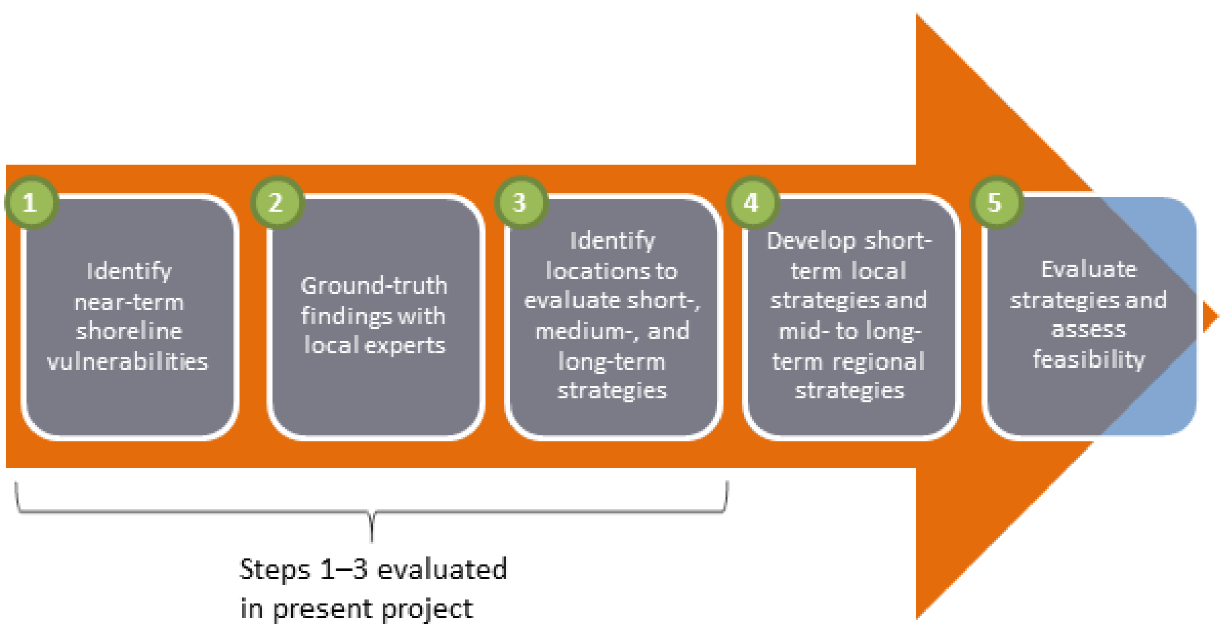

Figure 1-1. Approach to Identify Shoreline Vulnerabilities and Develop Adaptation Strategies

The project developed the products and tools needed to support Steps 1, 2, and 3, above. SLR and extreme tide inundation maps were created for the nine Bay Area counties using an approach that allows one map to represent multiple potential future SLR and extreme tide scenarios (Step 1). Using local knowledge and stakeholder input, areas where the maps did not accurately represent past coastal flood events, such as the inundation that occurs along the shoreline during king tides, the underlying data were examined to refine the maps to more appropriately portray existing shoreline vulnerabilities (Step 2). In addition, the shoreline delineation approach developed for the ART program to assess both shoreline type and overtopping potential can be used to highlight where adaptation strategies along the shoreline may be warranted and to identify when intervention may be required to reduce potential future inland flooding risks (Step 3). *Overtopping potential* refers to the condition where the water surface elevation under a particular SLR scenario exceeds the elevation of the shoreline.

These steps were carried out to support the creation of new SLR inundation mapping products in the following Bay Area counties: Marin, Sonoma, Napa, Solano, Alameda, and Santa Clara. Mapping products for San Francisco, San Mateo, and Contra Costa Counties were adapted from previously completed studies with minor updates in some areas. Mapping products from previously completed counties were reformatted to align the maps and data layers with all other county mapping completed in support of this project. This work results in a consistent regional data set for all Bay Area counties.

1.2 RELATIONSHIP TO PRIOR MAPPING EFFORTS

The ART mapping approach emerged out of work under the ART Program to support Bay shoreline communities in understanding their vulnerability to SLR and integrating adaptation into local and regional planning and decision-making. ART county and local-scale projects involve forming and working closely with multi-sector working groups that represent diverse interests along the shoreline, including managers of wastewater treatment plants, roads, parks, and commercial and industrial areas, to name just a few. The maps initially used for the ART Alameda County project required that the working group and project team narrow the analysis to several scenarios and did not provide the information necessary for asset owners and managers to take progressive action, from addressing temporary flooding at lower water levels to more frequent temporary flooding to permanent flooding. Working closely with the Alameda County ART project working group and reviewing both the exposure maps and the results of the vulnerability assessment, the ART program staff and partners began to identify ways in which a future sea level rise mapping tool could be improved, both in terms of data inputs and in terms of communicating flood impacts.

Regarding data inputs, the ART project team and working group found that regional models were not at the scale of detail and accuracy necessary to accurately characterize the flooding that may occur at specific locations along the shoreline. This occurred due to a variety of factors, including that certain shoreline features, like small water control structures, were not captured in the topographic data produced through LIDAR surveys and without local knowledge, it was difficult to make these corrections and not always possible to make local changes and adjustments to regional models. The project team found that local stakeholders who manage shoreline assets have a wealth of knowledge about which areas do and do not flood during king tides or storms and are able to help identify which shoreline features are missing from the maps, thereby correcting the LIDAR-based topographic data to better match on the ground conditions. This understanding led the way for the creation of a stakeholder review process when designing the ART mapping methodology.

Collaboration with ART working groups also revealed asset managers' concerns regarding low spots and flow pathways. While assets managers want to know if their asset is at risk of flooding, their next questions are: At what water level will the flooding occur? Where will the water come from? Will water overtop the Bay shoreline or the tidal creek or tidal channel? Shoreline overtopping data which enables assessments of these flow pathways and identification of low points in the shoreline was not information that was included in the mapping products that were available at the time.

Cooperation with diverse ART working groups highlighted the challenges of selecting the appropriate sea level rise scenarios and communicating both permanent and temporary flooding. Sea level rise maps and models are often easier to use within a vulnerability assessment if you select several scenarios to use in the analysis (e.g., 12, 24, 36 inches) or extreme water levels (e.g., the 10-year, 50-year, 100-year storm); however, selecting the most appropriate scenarios to support project planning and analysis is not always simple. ART working group members wanted to understand how their asset would be impacted by both temporary and permanent inundation over time, beginning with low levels of flooding so that they could start identifying triggers for action and incremental changes to be made over time. The One Map = Many Futures approach built into the ART maps eliminates the need for pre-determined scenarios. Each ART map reflects a variety of possible sea level rise and extreme tide level combinations. This provided the ART working group members the ability to develop adaptation responses for lower water levels and add to those responses as water levels increase and helped asset owners and managers respond to the water levels that will be an issue for their particular location.

While there are a number of SLR mapping tools available for San Francisco Bay (Table 1-1), the ART maps are unique due to their fine scale resolution, stakeholder review process, overtopping analysis, and One Map = Many Futures approach. As a result, the ART maps are a powerful tool and are the most locally-relevant, locally-refined tool for adaptation planning in the Bay. The table below compares the ART maps to other SLR mapping products available in the Bay. To find a detailed comparison of the ART and U.S. Geological Survey (USGS) Our Coast Our Future (OCOF) mapping products specifically, please see the ART, OCOF comparison document included as an appendix to the San Mateo County Sea Change SLR Vulnerability Assessment Report.

Table 1-1. Comparison of San Francisco Bay SLR Mapping Products

Mapping Product	Base Water Level(s)	SLR Scenarios	Includes Wave Effects?	Includes Shoreline Overtopping?	Stakeholder Review?
ART SLR Maps	MHHW	12 to 108 inches	No	Yes	Yes
USGS OCOF	MHHW, King Tide, 20-year, 100-year Tide Level	0 to 79 inches; 179 inches	Yes	No	Limited
FEMA FIRM	100-year Tide Level and/or Wave Runup	None	Yes	Yes	Yes
FEMA Increase Flooding Scenarios	100-year Tide Level	12, 24, and 36 inches	No	No	No
NOAA SLR Viewer	MHHW	0 to 72 inches	No	No	No

MHHW = Mean Higher High Water
SLR = sea level rise

1.3 OVERVIEW OF REPORT

The organization of this report is summarized below. Sections 2 through 6 present content and methods applicable to all nine Bay Area county maps and products. Section 7 presents county-specific methods and findings. Each county-specific sub-section can be paired with its corresponding SLR inundation mapbook in Appendix A and GIS data catalog (Appendix B) to create a tailored package for local stakeholders in each county. Sections 8 through 10 present the mapping assumptions and caveats, conclusions and next steps, and references, respectively. The specific topics addressed are as follows:

- **Section 2, Sea Level Rise Science,** provides an overview of SLR and coastal hazards, a summary of the state of the science, and a discussion of SLR scenario selection.
- **Section 3, Inundation Mapping,** describes the leveraged hydrodynamic model data, water level analysis, topographic data, and the mapping methods used to create the SLR inundation maps.
- **Section 4, Stakeholder Engagement,** describes the stakeholder engagement process undertaken to incorporate local review and feedback on the maps.
- **Section 5, Shoreline Delineation,** describes the approach to delineate the shoreline and identify shoreline type (e.g., engineered flood protection structure, non-engineered berm).
- **Section 6, Shoreline Overtopping Potential,** describes the methods used to calculate overtopping potential along the shoreline (and adjacent areas) and outlines applications of the maps to identity potential shoreline vulnerabilities.
- **Section 7, County Methods and Discussion,** presents the SLR matrix, discusses the results of the mapping, and identifies vulnerable areas for each county.
- **Section 8, Mapping Assumptions and Caveats,** provides the key caveats associated with the SLR and storm surge inundation maps.
- **Section 9, Conclusions and Next Steps,** discusses the conclusions and the next steps.
- **Section 10, References,** lists the sources used to prepare the report.

1.4 GLOSSARY

The following definitions describe each term as it is used in this report:

Annual maxima: The highest water level recorded during each year in a time series based on a July through June "storm year."

El Niños (within the El Niño–Southern Oscillation [ENSO][1] cycle): A phenomenon in the Pacific Ocean characterized by warmer-than-usual waters in the Eastern Pacific. El Niños are caused by specific changes in winds and currents across the equatorial Pacific, driven by an oscillation in air pressure differences across the Eastern and Western Pacific called the Southern Oscillation. El Niños may result in higher sea levels and larger, more-frequent storms along the California coast.

Extreme tide: Extreme tides are relatively infrequent water level events that are a result of relatively high astronomical tides coupled with a storm surge event. The absolute elevations reached during these events are due to short-term meteorological processes (such as low atmospheric pressure due to storms) and large-scale oceanographic conditions (such as king tides or El Niño conditions). The extreme tide elevations discussed in this assessment do not include any local wind wave effects.

Mean Higher High Water: Average height of the higher high tides of each day during the current National Tidal Datum Epoch, which is a specific 19-year period (1983 to 2001) adopted by NOAA to perform tidal computations.

Overtopping potential calculation: Overtopping potential refers to the condition where the water surface elevation associated with a particular SLR scenario exceeds the elevation of a shoreline asset. Overtopping potential does not account for the physics of wave run-up and overtopping. It also does not account for potential vulnerabilities along the shoreline protection infrastructure that could result in complete failure of the flood protection infrastructure through scour, undermining, or breach after the initial overtopping occurs. The overtopping potential results visually show which segments of the shoreline are first impacted and the depth to which each segment is overtopped during the mapped scenarios.

Storm surge: A storm surge is an abnormal rise of water generated by high winds and low atmospheric pressure in the presence of a storm that is over and above the predicted astronomical tide. The magnitude of a storm surge and the height of an astronomical tide are additive: when the sum of the two is unusually large, an extreme tide occurs.

Tidal datum: A tidal datum is the daily tide water level computed using records observed during the current National Tidal Datum Epoch (see definition in the discussion of Mean Higher High Water, above).

Tides: The regular upward and downward movement of the level of the ocean due to the gravitational attraction of the moon and the sun and the rotation of the earth. Also called "astronomical tides." SF Bay experiences two high tides and two low tides of unequal height each day.

[1] ENSO is a natural oceanic-atmospheric cycle. El Niño conditions are defined by prolonged warming in the Pacific Ocean sea surface temperatures. Typically, this happens at irregular intervals of 2 to 7 years, and it can last anywhere from 9 months to 2 years.

2.0

SEA LEVEL RISE SCIENCE

2. SEA LEVEL RISE SCIENCE

2.1 SUMMARY OF THE SCIENCE

The science associated with SLR is regularly updated, revised, and strengthened. Although there is no doubt that sea levels have risen and will continue to rise at an accelerated rate over the coming century, it is difficult to predict with certainty what amount of SLR will occur within a given time frame. The uncertainties increase over time (i.e., the uncertainties associated with 2100 projections are greater than those associated with 2050 projections) because of uncertainties in future greenhouse gas (GHG) emissions, the sensitivity of climate conditions to GHG concentrations, and the overall capabilities of climate models. The projections presented in this document draw on the best available science for California as of April 2017.

In March 2013, the California Ocean Protection Council (OPC) adopted the National Research Council (NRC) report *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* (NRC 2012) as the best available science on SLR for the state (OPC 2013). The California Coastal Commission (CCC) also supported the use of the NRC 2012 report as the best available current science, noting that SLR science is continually advancing, future research may enhance the scientific understanding of how the climate is changing, and therefore there is a need to regularly update projections (CCC 2015). The NRC report includes discussions of historical SLR observations, three likely SLR projections for the coming century, high and low extremes for SLR, and insight into the potential impacts of a rising sea for the California coast.

The NRC projections for San Francisco relative to the year 2000 are appropriate for all Bay Area counties. Table 2-1 presents the local projections (mean ± one standard deviation of climate model simulation results). These projections (e.g., 6 ± 2.0 inches in 2030) represent the *likely* SLR values based on a moderate level of GHG emissions and extrapolation of continued accelerating land ice melt patterns plus or minus one standard deviation. The extreme limits of the *ranges* (e.g., 2 and 12 inches for 2030) represent *unlikely but possible* levels of SLR using both low and very high emissions scenarios and, at the high end, including significant land ice melt that was not anticipated at the time of publication but acknowledged as having potential to occur. These projections include the sum of contributions from thermal expansion of seawater, wind-driven components, land ice melting, and vertical land motion.

Table 2-1. Sea Level Rise Estimates for the Bay Area Relative to the Year 2000

Year	Most Likely Projections (inches)	Range (inches)
2030	6 ± 2	2 to 12
2050	11 ± 4 *	5 to 24
2100	36 ± 10	17 to 66

Source: NRC 2012.

* As a simplifying assumption, the 2050 most likely value selected for the inundation mapping effort is 12 inches rather than the 11 inches noted in the table.

Note: Sea level rise projections shown above do not take into account local effects within each county such as local tectonics and subsidence.

Since the release of the NRC 2012 report, climate change modeling and SLR projections have continued to evolve. The Intergovernmental Panel on Climate Change (IPCC) has released its Fifth Assessment Report, *Climate Change 2013: The Physical Science Basis*, which provided updated consensus estimates of global SLR (IPCC 2013). More recent updates, including NOAA's *Global and Regional Sea*

Level Rise Scenarios for the United States (2017) and California's *Rising Seas in California: An Update on Sea-Level Rise Science* (Griggs et al. 2017), present SLR projections in a risk-based context. These new ways of thinking about climate change risks provide even more tools to planners and engineers as they develop adaptation plans for the coming century. As discussed later in this report, the SLR inundation maps produced as part of this project have the flexibility to be interpreted and applied to ever-changing SLR projections and do not require adoption of specific SLR amounts to be useful. As a result, future updates to California's SLR planning guidance (anticipated in 2018) can be easily incorporated into the use of these existing mapping products, with the caveat that if the recommended SLR projections exceed the 66-inch upper-range scenario currently adopted in the maps presented in this project, additional higher-range scenario maps may need to be developed.

2.2 SEA LEVEL RISE AND COASTAL HAZARDS

SF Bay waters experience two low tides and two high tides of unequal height each day. MHHW is the average elevation of the highest daily tide. King tides are unusually high but predictable astronomical tides that occur approximately two to four times per year, generally between December and February. As seas have risen, king tides have begun to cause annual flooding of low-lying coastal areas. Some low-lying areas along the shoreline, such as the San Francisco Embarcadero and Mill Valley, already experience inundation due to coastal hazards such as king tides. A significant portion of the SF Bay shoreline is made up of wetlands and open bays that has been converted into developed areas by fill placement. These filled lands are at risk from current flooding and sea level rise due to subsidence or sinking, which is common for areas lying on top of soft and compressible bay mud. An additional concern is the influence of rising sea level on groundwater levels, which will further increase the risks of subsidence in these areas.

The SF Bay shoreline comprises a variety of shoreline types and features, including natural tidal marshes and mudflats, a network of non-engineered berms, engineered flood protection structures (e.g., levees and floodwalls), and engineered shoreline protection features (e.g., bulkheads, revetments, riprap). These features all serve as the first line of both structural and ad hoc defense to protect the densely built inland areas from coastal hazards. Many facilities of economic importance are near the shoreline, including San Francisco International Airport (SFO), Oakland International Airport, the Port of Oakland, and a number of transit corridor assets such as Interstate 580 (I-580), U.S. Highway 101 (US 101), and the San Francisco–Oakland Bay Bridge (Bay Bridge), Dumbarton Bridge, and Richmond–San Rafael Bridge (Richmond Bridge) touchdowns.

Short-term factors also elevate the waters of SF Bay along the shoreline, including El Niño, storm surge and waves, and for some portions of the Bay, freshwater discharge from creeks and sloughs during rainfall-runoff events. When one or more of these factors combine to raise Bay waters above predicted tide levels, the result is a temporarily higher water level called an *extreme tide*. Extreme tides can reach several feet higher than typical daily high tides and result in damaging coastal floods. Understanding the additive impact of such factors to produce temporary flooding is crucial for planning in the coastal environment. Extreme tides are generally characterized in terms of probability: a 1-percent-annual-chance tide (or 100-year extreme tide) is the coastal water level elevation that has a 1 percent chance of occurring in any given year. Likewise, a 20-percent-annual-chance tide (or 5-year extreme tide) is the coastal water level elevation that has a 20 percent chance of occurring in any given year. Section 2.3 discusses the water level elevations associated with various extreme tides in SF Bay.

Table 2-2 summarizes several factors that affect existing water levels along the Bay shoreline. The table indicates the relative magnitude of these components rather than a particular elevation.

Table 2-2. Factors That Influence Local Water Level Conditions in Addition to Sea Level Rise

Factors Affecting Water Level	Typical Magnitude * (feet)	Period of Influence	Typical Frequency
Daily tidal range	5 to 7	Hours	Twice daily
King tides	1 to 1.3	Hours	One to four times/year
Storm surge	0.5 to 3	Days	Several times a year to every 100 years, depending on height
Wind-driven waves	0.5 to 3	Hours	Daily to several times a year
El Niño	0.3 to 1.5	Months to Years	2 to 7 years

* BakerAECOM 2013, 2015; DHI 2013.

The following coastal flood hazards may increase due to SLR and other climate-change-induced changes to atmospheric-oceanic processes:

- **Daily tidal inundation:** As sea levels rise, the elevation of MHHW will continually increase. Without action, this increase in elevation will result in increased permanent inundation of low-lying areas.
- **Annual high tide inundation (king tides):** King tides result in temporary inundation, and they are associated with nuisance flooding, such as occasional inundation of low-lying roads, boardwalks, and waterfront promenades. Typical king tides raise coastal waters approximately 14 inches above MHHW. In the winter (December, January, and February), king tides may be exacerbated by winter storms, making these events more dramatic. Without protective action, this regular, predictable flooding will occur more frequently and affect larger areas as sea levels rise.
- **Extreme high tide inundation (storm surge):** Depending on the type and intensity of cause(s), extreme tides range from 15 inches above MHHW (1-year extreme tide) to 42 inches above MHHW (100-year extreme tides) or higher. In one such recent event (December 11, 2014), Bay waters rose 18 inches above predicted tide levels due to coastal storm conditions during a heavy rain event.
- **Weather and weather cycles:** Climate change may affect the frequency and/or intensity of coastal storms, El Niño cycles, and related processes. During El Niño winters, atmospheric and oceanographic conditions in the Pacific Ocean produce severe winter storms that impact Bay shorelines. No clear consensus has emerged about these projected changes, but a commonly identified trend is a tendency toward increased elevation of snowpack and correspondingly more precipitation falling in Delta watersheds as rain. This trend may increase the frequency of higher Delta flows into the Bay.
- **Waves:** Large waves, whether generated within the Bay or by large Pacific storms, can damage unprotected shorelines and drive floodwaters even higher. Typical impacts include damage to coastal structures such as levees, docks and piers, wharves, and revetments; backshore inundation due to wave overtopping of structures; and erosion of natural shorelines.
- **Precipitation combined with high tides:** When large rainfall events co-occur with particularly high tides, coastal waters can impede the drainage of rivers, creeks, and stormwater systems to the Bay, resulting in inland flooding during storms. Typical impacts during high or extreme tides include failure of storm drainage infrastructure, drainage restrictions through outfalls, backup of floodwaters into low-lying areas during precipitation events, road closures, and neighborhood flooding.

2.3 SLR MAPPING SCENARIOS

The impacts of SLR are often visualized using inundation maps. Typically, maps represent specific SLR scenarios (e.g., 16 inches of SLR above MHHW) or extreme tide water levels (e.g., the 1-percent-annual-chance tide). However, selecting the most appropriate SLR scenario to map in support of project planning, exposure analyses, or SLR vulnerability and risk assessments is not simple. This approach requires pre-selecting appropriate SLR and extreme tide scenarios that meet all project needs.

Rather than pre-selecting specific SLR scenarios for SF Bay, the 10 individual sets of inundation maps selected for each county represent a range of possible scenarios associated with extreme tide levels and SLR ranging from 12 to 108 inches, representing combinations of 0 to 66 inches of SLR with extreme tides from the 1-year to the 100-year extreme tide. The scenario selection relied on the extreme water-level analysis described in Section 3. The goal of scenario selection was to identify 10 scenarios that can represent the current NRC SLR projections, as presented in Section 2.1, and also approximate a range of storm surge events. Because there are many possible SLR amounts in between 0 and 66 inches, the maps should be flexible enough to accommodate future changes in SLR projections as the science evolves. The 10 scenarios were consistent among all counties, but because the water levels vary throughout the Bay, each county has different sets of representative combinations of SLR and storm surge—this approach is described below using the SLR and extreme tide matrix concept.

Each of the mapped scenarios approximates either (1) permanent inundation scenarios or (2) temporary flood conditions from specific combinations of SLR and extreme tides likely to occur before 2100. For example, in Marin County the water elevation associated with the MHHW + 36 inches of SLR scenario is similar to the water elevation associated with a combination of 24 inches of SLR and a 1-year extreme tide (king tide). Therefore, a single map can represent either event. Although inundation maps can approximate the temporary flood extent associated with an extreme tide, they illustrate neither the duration of flooding nor the potential mechanism(s) for draining floodwaters once the extreme tide recedes. Figure 2-1 presents a representative cross section of a shoreline that illustrates the distinction between permanent inundation and temporary flooding.

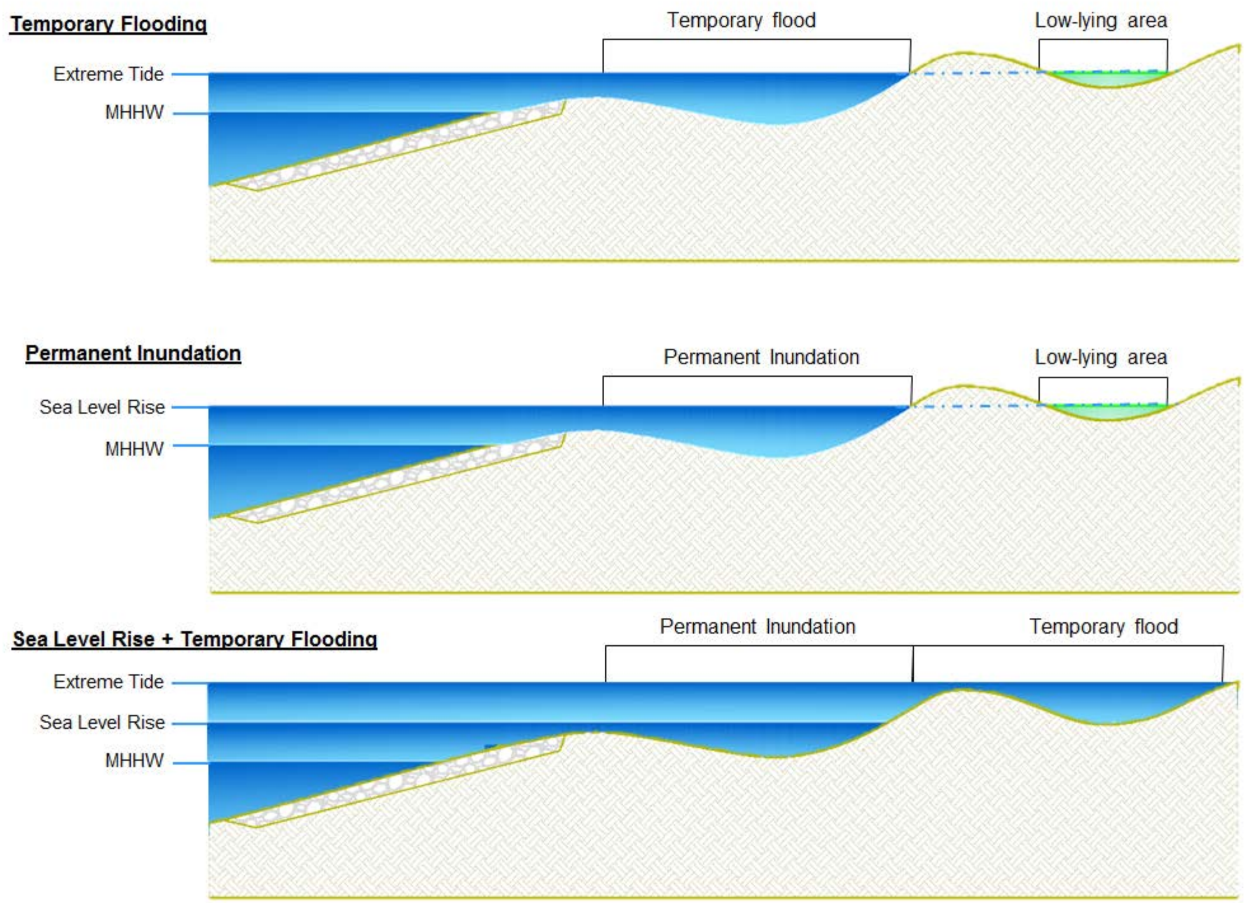

Figure 2-1. Shoreline Cross Section Showing Permanent Inundation and Temporary Flooding

The first six scenarios (12, 24, 36, 48, 52, and 66 inches of SLR above MHHW) relate directly to the NRC SLR estimates, and they capture a broad range of scenarios between the most-likely scenario and the high end of the uncertainty range at both mid-century and the end of the century:

1. 12-inch SLR ≈ 2050 most-likely SLR scenario
2. 24-inch SLR = 2050 high end of the range; or an existing 5-year extreme tide
3. 36-inch SLR = 2100 most-likely SLR scenario; or an existing 50-year extreme tide
4. 48-inch SLR ≈ 2100 upper 85 percent confidence interval; or 6 inches of SLR plus a 100-year extreme tide
5. 52-inch SLR ≈ 12-inch SLR plus 100-year extreme tide
6. 66-inch SLR = 2100 upper-end SLR scenario; or 24-inch SLR plus 100-year extreme tide

Inundation maps were also created for Bay water level elevations of 77, 84, 96, and 108 inches above MHHW. These levels are above current predictions for SLR likely to occur by 2100, but they are helpful in illustrating short-term flooding that could occur when extreme tides are coupled with SLR:

7. 77 inches above MHHW ≈ 36-inch SLR plus 100-year extreme tide
8. 84 inches above MHHW ≈ 48-inch SLR plus 50-year extreme tide
9. 96 inches above MHHW ≈ 66-inch SLR plus 25-year extreme tide
10. 108 inches above MHHW ≈ 66-inch SLR plus 100-year extreme tide

The 10 SLR inundation mapping scenarios are listed in Table 2-3 along with the applicable water level range for each scenario.

Table 2-3. Sea Level Rise Mapping Scenario (Inches above MHHW)

Mapping Scenario	Reference Water Level	Applicable Range for Mapping Scenario (Reference ± 3 inches)
Scenario 1	MHHW + 12"	MHHW + 9 to 15"
Scenario 2	MHHW + 24"	MHHW + 21 to 27"
Scenario 3	MHHW + 36"	MHHW + 33 to 39"
Scenario 4	MHHW + 48"	MHHW + 45 to 51"
Scenario 5	MHHW + 52"	MHHW + 49 to 55"
Scenario 6	MHHW + 66"	MHHW + 63 to 69"
Scenario 7	MHHW + 77"	MHHW + 74 to 80"
Scenario 8	MHHW + 84"	MHHW + 81 to 87"
Scenario 9	MHHW + 96"	MHHW + 93 to 99"
Scenario 10	MHHW + 108"	MHHW + 105 to 111"

MHHW = Mean Higher High Water
" = inches

Although Table 2-3 lists only 10 mapped scenarios, these maps represent over 50 combinations of SLR and extreme tide levels in each county. These combinations can be identified using the SLR and extreme tide matrix, which shows the relationship between each mapped scenario and different combinations of SLR and extreme tide. An example SLR matrix for Marin County is shown in Table 2-4. The water levels in the matrix were grouped using a tolerance of ± 3 inches to increase the applicable range of each mapped scenario. For example, Scenario 3 (MHHW + 36 inches) can be used to approximate all extreme tide/SLR combinations that produce a water level in the range of MHHW + 33 inches to MHHW + 39 inches, including:

- 1-year extreme tide event coupled with 24 inches of SLR;
- 2-year extreme tide event coupled with 18 inches of SLR;
- 5-year extreme tide event coupled with 12 inches of SLR;
- 25-year extreme tide event coupled with 6 inches of SLR, and
- 50-year extreme tide event under existing conditions (no SLR).

Similar equivalent SLR and extreme tide levels for other map scenarios can be identified using the SLR matrix for each county. The SLR inundation maps in Appendix A also indicate the equivalent scenarios represented by each map for ease of reference. The SLR and extreme tide matrices for each county are presented in Section 7.

Table 2-4. Example Sea Level Rise and Extreme Tide Matrix

Sea Level Rise Scenario	Daily Tide	Extreme Tide (Storm Surge)						
	+SLR (in)	1yr	2yr	5yr	10yr	25yr	50yr	100yr
	Water Level above MHHW (in)							
Existing Conditions	0	14	18	23	27	32	37	42
MHHW + 6”	6	20	24	29	33	38	43	48
MHHW + 12”	12	26	30	35	39	44	49	54
MHHW + 18”	18	32	36	41	45	50	55	60
MHHW + 24”	24	38	42	47	51	56	61	66
MHHW + 30”	30	44	48	53	57	62	67	72
MHHW + 36”	36	50	54	59	63	68	73	78
MHHW + 42”	42	56	60	65	69	74	79	84
MHHW + 48”	48	62	66	71	75	80	85	90
MHHW + 52”	52	66	70	75	79	84	89	94
MHHW + 54”	54	68	72	77	81	86	91	96
MHHW + 60”	60	74	78	83	87	92	97	102
MHHW + 66”	66	80	84	89	93	98	103	108

Note: Example Sea Level Rise Matrix shown is from Marin County.
in = inch(es)
MHHW = Mean Higher High Water
SLR = sea level rise
yr = year(s)

3.0

INUNDATION MAPPING

3. INUNDATION MAPPING

Inundation maps are an important tool for evaluating potential exposure to future SLR and extreme tide conditions, and the most up-to-date maps should be used during project planning and design. The maps help evaluate when (under what amount of SLR and/or extreme tide) and by how much (what depth of inundation or flooding) an asset will be exposed.

This section presents the methods and data sources used to develop the SLR inundation maps presented in Appendix A. The key steps in developing the SLR inundation mapping products include: 1) estimating existing conditions tidal datums and extreme tides, 2) combining existing water level estimates with SLR projections to estimate future conditions tidal datums and extreme tides, and 3) develop inundation extent and depth layers by subtracting the land surface elevation from the water surface elevations.

3.1 LEVERAGED DATA SOURCES

The Bay-wide SLR and extreme tide inundation mapping relied on two primary data sources:

- **Hydrodynamic modeling data.** Hydrodynamic model output was required to assess daily and extreme tide levels throughout SF Bay. The use of modeled water levels was preferred over individual tide gage analyses because of the high spatial density provided in the model output for the entirety of the Bay shoreline. This project leveraged water levels from a regional San Francisco Bay hydrodynamic modeling study completed as part of the FEMA San Francisco Bay Area coastal study (DHI 2013).

  The FEMA model output was archived in 15-minute time steps, as described in DHI (2013). The water level simulations extended from January 1, 1973, to December 31, 2003, in the Central and North Bay and from January 1, 1956, to December 31, 2009, in the South Bay. The regional model was calibrated and validated to observed historical data from nine tide stations within the Bay. A total of 900+ output points along the Bay shoreline were used to characterize the spatial variability of water levels throughout the project area.

- **Topographic data.** High-quality topographic data were leveraged for the terrain development and shoreline delineation tasks. The primary data set was the light detection and ranging (LiDAR)[2] data collected by USGS and NOAA as part of the California Shoreline Mapping Project (CSMP) (OPC 2016). USGS managed the data collection in the South Bay, and NOAA managed the data collection in the North Bay. This combined data set provides complete coverage of the shoreline areas up to the 16 ft (5-meter [m]) elevation contour. The collected LiDAR data have a vertical accuracy of +/- 0.05 m based on the tested root mean square error for all checkpoints (Dewberry 2011a, 2011b). This accuracy exceeds that specified in the USGS National Geospatial Program LiDAR Guidelines and Base Specifications (USGS 2010). Additional topographic, bathymetric, survey, and field verification data sets were leveraged to build seamless 1-meter horizontal resolution DEM data sets in each county. The specifics of the terrain development effort in each county are presented in Section 7. It should be noted that the topographic DEMs produced as part of this project were developed specifically for the purposes of the SLR inundation mapping and may not accurately represent topography or bathymetry in areas not critical for capturing inundation and flooding processes along the shoreline and inland areas. For example, the DEM in areas below MHHW or above the highest SLR scenario may not be accurately represented, as they do not have an impact on the results of the inundation mapping.

[2] LiDAR (light detection and ranging) is an aerial-based topographic survey method that uses optical sensors to map topographic landforms and elevations.

3.2 EXISTING TIDAL DATUMS AND EXTREME TIDE LEVELS

The daily and extreme tide levels under existing conditions were calculated at each model output point along the project area shoreline. The daily high tide and extreme high tide levels are the primary data sets used to develop the SLR and extreme tide matrix, which is used to further interpret the SLR inundation maps.

Daily High Tide. The MHHW tide level was selected to represent the typical daily high tide. The MHHW tide level for existing conditions was calculated using model hindcast data corresponding to the most recent National Tidal Datum Epoch (NTDE), which spans 1983 through 2001. The MHHW tide level is the average of the higher of the two high tides of each day recorded during the NTDE.

Extreme High Tides. Extreme tide elevations were calculated using the 31-year or 54-year record of the simulated time series from the FEMA model output locations. The water level statistics used to represent the extreme tides include the 1-, 2-, 5-, 10-, 25-, 50-, 100-year tide levels. These values are generally consistent with the values FEMA estimated for the preliminary FIRMs and Flood Insurance Studies (FIS) for the Bay.

The following steps were completed to calculate the extreme tide elevations at each model output point:

- Annual maximum water levels were extracted based on a July–June “storm year,” consistent with the FEMA coastal hazard analysis. Figure 3-1 shows an example water level time series and the extracted annual maxima for one model output point.

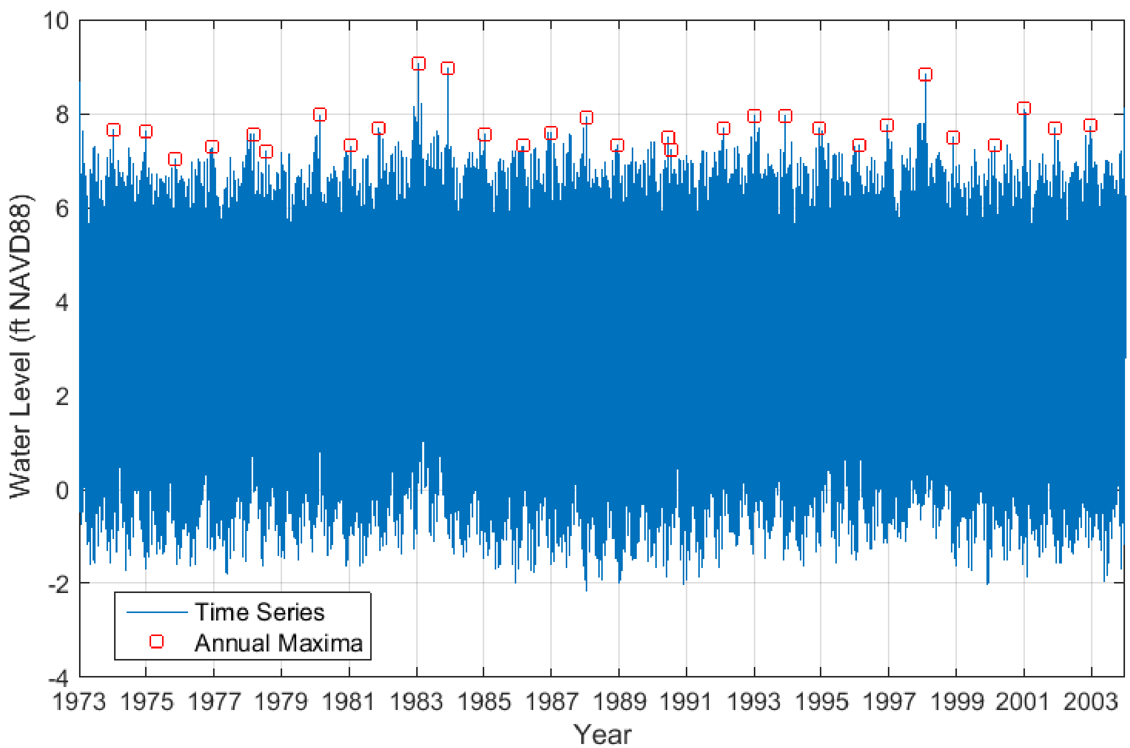

Figure 3-1. Example Water Level Time Series and Annual Maxima Data Set

- A Generalized Extreme Value probability distribution was fitted to the annual maxima data set, and extreme tide elevations were calculated at each return period from the 2- to 100-year tide levels.

- The 1-year extreme tide elevation for each model output point was approximated by extrapolating the extreme tide curves out to the 1-year level.

3.3 FUTURE TIDAL DATUMS AND EXTREME TIDE LEVELS

For simplicity, future tidal datums and extreme tide levels were estimated at each model output point by adding each SLR amount to the existing conditions tide levels. This approach is referred to as the "linear superposition method"; this approach relies on the assumption that daily and extreme tide level increases in response to SLR are equal to the increase in mean sea level (e.g., a 1 ft rise in mean sea level [MSL] translates to a 1 ft increase in MHHW or the 100-year tide level). This assumption does not account for factors that may modify tidal hydrodynamics over time. For example, as sea level rises, the mean water depth of the Bay will increase, which could affect the way in which tides propagate through the Bay, thereby changing the tide range at a given location.

Holleman and Stacey (2014) used a hydrodynamic model to simulate the effects of SLR on Bay water levels. The model showed that in the absence of implementing large-scale adaptation measures (such as regional levee systems), the linear superposition approach is appropriate within the Bay. Although small changes in the tidal range were observed, these changes were minor compared with the amount of SLR examined.

Similarly, as part of the Adapting to Rising Tides project (AECOM et al. 2011), AECOM evaluated hydrodynamic modeling completed by the USGS for the Computational Assessment of Scenarios for the Delta Ecosystem (CASCADE) Project (Knowles 2009) to evaluate tidal amplification due to SLR. That assessment found that along the Alameda County shoreline, the MHHW tidal datum may increase by an additional 0.3 ft in response to a 55-inch (4.6 ft) increase in MSL and that the diurnal tide range (Mean Lower Low Water [MLLW] to MHHW) may increase by 0.5 ft. The change in tide range modeled by Knowles (2009) is also considered small relative to the amount of SLR examined; therefore, the linear superposition approach in San Francisco Bay is reasonable.

The linear superposition approach expands the utility of the existing conditions tidal datum and extreme tide water levels because increases in water levels due to SLR and extreme tides can be modeled in the same way. Thus, a wide range of future SLR scenarios can be evaluated without tedious and expensive numerical modeling of future conditions. As the science of SLR progresses, this approach can also accommodate changes to future sea level projections. This approach is appropriate for high-level planning purposes; it is not intended to take the place of more detailed, site-specific hydrodynamics modeling or engineering analyses. It should also be noted that this approach may be a conservatively low estimate for future extreme water levels because it does not consider climate change factors that may increase the frequency and severity of large storm events over time. At present, trends in increasing storm surge associated with climate change are not clear for the Northern California coast and the San Francisco Bay Area (NRC 2012), and this topic is an area of active research.

3.4 CREATION OF WATER SURFACE DIGITAL ELEVATION MODELS

The water surface DEMs represent the elevation of water over the inland topography for a given SLR scenario. The first step in creating a water surface DEM was to create the MHHW water surface DEM. The MHHW elevation was calculated at 900+ model output points along the entire Bay shoreline and projected inland along shore-perpendicular transects to provide complete coverage of inland areas. Transects extend inland beyond the expected limit of inundation under the highest SLR scenario and are spaced at an appropriate density (approximately 2,500 feet apart, on average) to capture variations in tide levels and the underlying topography. The resulting MHHW DEM has a horizontal resolution of 1 m by 1 m to match the resolution of the topographic DEM. Each SLR scenario (e.g., 12, 24, 36, 48 inches) was added to the MHHW water surface DEM to develop the future conditions water surface DEMs.

The resulting water surface DEMs are an extension of the tidal water surface at the shoreline over the inland topography. This approach represents a conservative estimate of the inland area that may be inundated under each mapped scenario. The MHHW tidal water surface represents an average of the daily high tide conditions over the 19-year NTDE, and therefore daily high tide levels may exceed this average elevation approximately 50 percent of the time.

This method does not take into account the associated physics of overland flow, dissipation, levee overtopping, storm duration, or potential shoreline or levee erosion associated with extreme water levels and waves. To account for these processes, a more sophisticated modeling effort would be required. However, given the uncertainties associated with SLR and future land use changes, development, and geomorphic changes that will occur over the next 100 years, a more sophisticated modeling effort may not necessarily provide more accurate results. Section 8 presents additional key caveats associated with the overall approach for developing the inundation maps appropriate for assessing exposure at a screening level.

3.5 DEPTH AND EXTENT OF FLOODING

Depth of flooding raster[3] files were created by subtracting the land surface DEM from the water surface DEM. Both DEMs were generated using a 1 m horizontal resolution with the same grid spacing to allow for grid cell to grid cell subtraction. The resultant DEM (or "inundation depth raster") provides both the inland extent and the depth of projected inundation.

The final step in creating the depth and extent of flood maps is an assessment of hydraulic connectivity. The method described by Marcy et al. (2011) employs two rules for assessing whether a grid cell is inundated. A cell must be below the assigned water surface DEM elevation value, and it must be connected to an adjacent grid cell that was either flooded or open water. This method applies an "eight-side rule" for connectedness, where the grid cell is considered "connected" if any of its cardinal or diagonal directions is connected to a flooded grid cell. Compared to earlier inundation mapping efforts, this approach better identifies inundated areas. Earlier efforts showed areas as inundated solely based on elevation (i.e., even if there was no hydraulic pathway to the Bay to allow flooding). The hydraulic connectivity assessment removes areas from the inundation zone if they are protected by levees or other topographic features that prevent inland inundation. This assessment also removes areas that are low lying but inland and not directly connected to an adjacent inundated area.

Appendix A presents the 10 SLR inundation maps for each county. The shades of blue represent various depths of inundation, shown in 2 ft depth increments, ranging from 0 feet to greater than 16 feet of inundation. Hydraulically disconnected low-lying areas are displayed in green. It is possible that the low-lying areas may be connected through culverts, storm drains, or other features not captured within the

[3] A raster consists of a matrix of pixels organized into a surface area grid where each grid cell contains a value representing information (e.g., water depth values).

DEM; therefore, it is important to note that there may be an existing or future flood risk within these areas. In addition, these low-lying areas may be at risk of flooding from below due to increasing groundwater elevations. Figure 3-2 illustrates an inland, disconnected low-lying area.

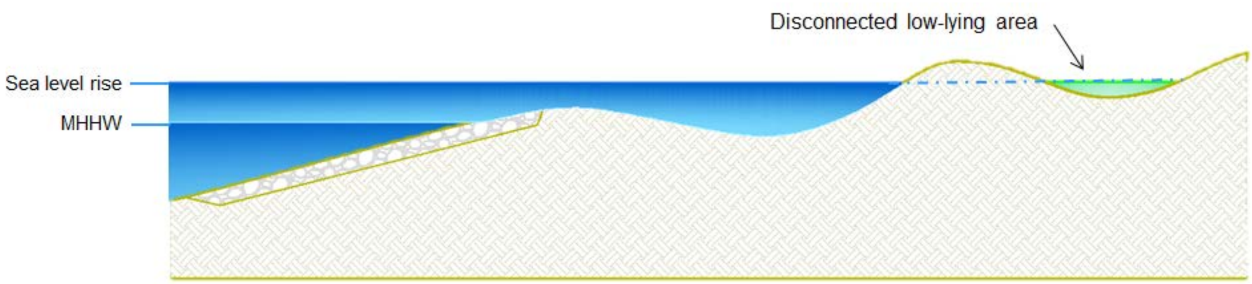

Figure 3-2. Example Shoreline Cross Section Showing Disconnected Low-Lying Area

An example map panel from the inundation mapping in Marin County is shown in Figure 3-3. The legend along the right side of the map provides key information for interpreting the data shown on the map:

- **Map scenario:** The SLR inundation scenario shown on the map is indicated in the top portion of the legend. The MHHW + 36” SLR scenario in Marin County is shown in Figure 3-3.
- **Equivalent map scenarios:** Equivalent map scenarios, as determined by the SLR matrix, are listed below the figure title. In Figure 3-3, the MHHW + 36” map can also be interpreted to be representative of the following additional scenarios: 50-year extreme tide, 25-year extreme tide + 6” SLR, 5-year extreme tide + 12” SLR, 2-year extreme tide + 18” SLR, and 1-year extreme tide + 24” SLR.
- **Shoreline overtopping potential:** This legend indicates the depth of inundation or flooding along the delineated shoreline features. Overtopping depths are calculated by subtracting the ground elevation from the water surface elevation. Green segments indicate areas of shallow overtopping, and red and purple segments indicate areas of deep overtopping. Gray segments indicate areas of no overtopping. The shoreline delineation and overtopping methodology is described in more detail in Sections 5 and 6.
- **Sea level rise inundation:** This legend indicates the depth of inundation or flooding over land and water features. Light blue indicates areas of shallow inundation and dark blue indicates areas of deeper inundation.

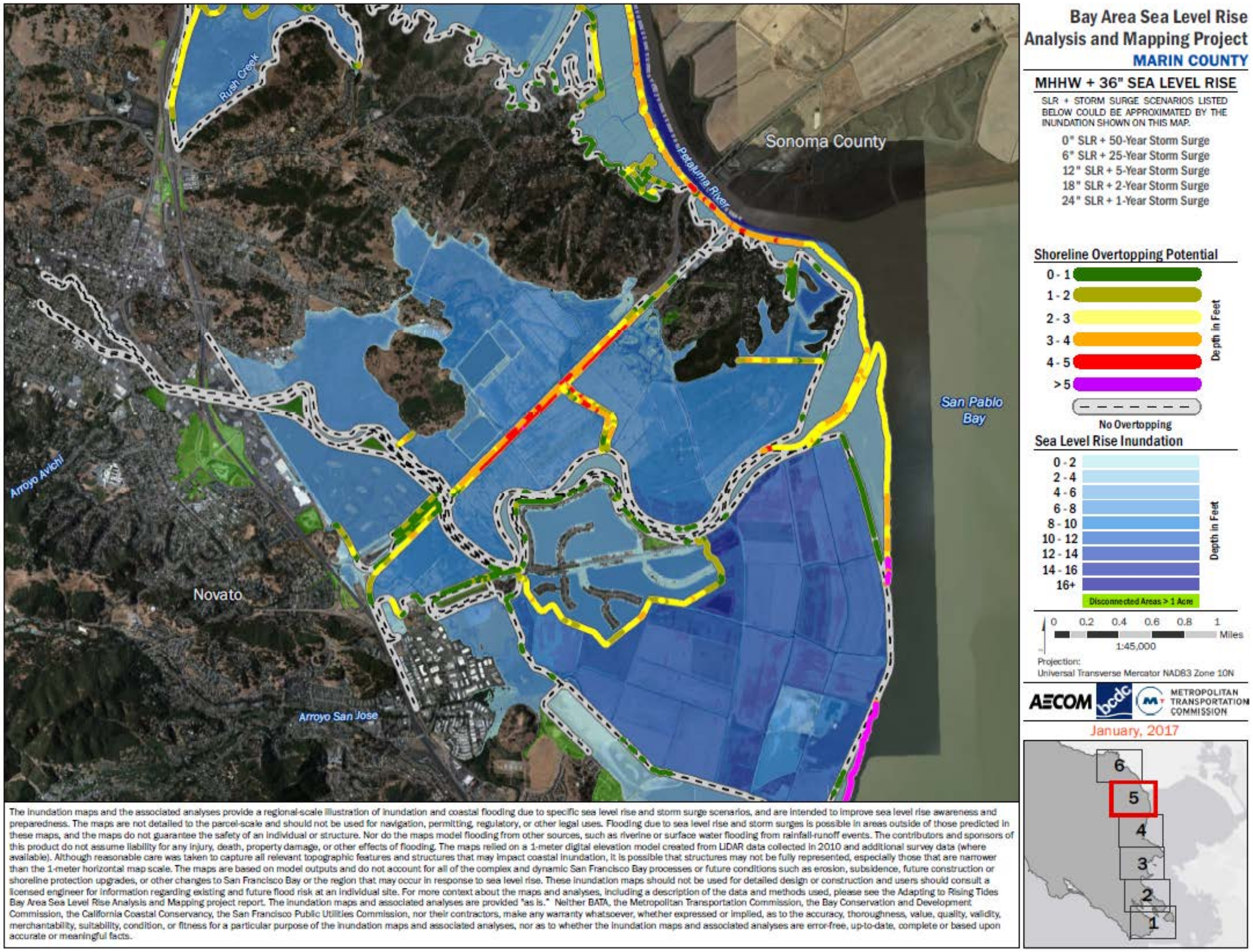

Figure 3-3. Example SLR Inundation Map Panel

4.0

STAKEHOLDER ENGAGEMENT

4. STAKEHOLDER ENGAGEMENT

Stakeholder engagement in support of this effort was led by BCDC with support from MTC. Review of draft maps by stakeholders was a key step in the project to develop the most robust and accurate shoreline mapping and analysis products possible for all nine counties. To produce the best products possible, the project team worked with each county, reaching out to stakeholders who know the local shoreline topography and current flood conditions. Although stakeholder outreach varied, the starting point for outreach was generally congestion management agencies and flood managers. The county-specific discussions in Section 7 provide details on the stakeholder engagement approach and the participants in each county.

After presenting the project to county stakeholders, usually at an in-person meeting, the project team requested that stakeholders review online, draft map scenarios that reflected the potential inland extent and depth of inundation for 12, 24, and 36 inches of SLR and the potential overtopping of the shoreline based on its current elevation. These scenarios were selected because they reflect water levels that could be seen today and are easier for stakeholders to consider based on existing and available local knowledge and information. For example, annual king tides are typically 12 inches above today's high tide in most parts of the Bay. A 5- to 10-year extreme tide during a storm event can elevate the Bay by 24 inches, and a 50-year extreme tide can elevate it by 36 inches. The project team asked stakeholders to review and provide feedback on these draft maps to help identify (1) locations that are known to flood today when tides are elevated but are not shown as inundated in the draft maps, or (2) areas shown as inundated that have not flooded during past extreme tides.

The project team engaged stakeholders in the mapping work by reaching out by phone and email and convening groups for presentations in each county.[4] An online viewer was created for each county; these viewers allowed users to evaluate the three SLR scenarios and enabled them to provide comments directly on the maps. Comments were also accepted by email. At times, stakeholder comments led the project team to request stakeholder help in accessing additional data.

Feedback received resulted in the project team working directly with stakeholders to identify areas where levees, tide gates, roadways, or other shoreline features were misrepresented in the underlying topographic data. Corrections were made and incorporated into the final maps.

[4] Presentations on the mapping and feedback process were carried out in all counties except for Marin, where such presentations were deemed unnecessary because county staff were concurrently carrying out a Bay shoreline sea vulnerability assessment. County planning staff felt that they could review the maps based on their own shoreline stakeholder outreach efforts.

5.0

SHORELINE DELINEATION

5. SHORELINE DELINEATION

5.1 BACKGROUND

The Bay shoreline comprises a variety of shoreline types and features. These include natural tidal marshes and mudflats, a network of non-engineered berms, engineered flood protection structures (e.g., levees and floodwalls), roads and railways, and engineered shoreline protection features (e.g., bulkheads, revetments, and riprap), all of which serve as the first line of either structural or ad hoc defense to protect the densely built inland areas from coastal hazards.

The San Francisco Estuary Institute (SFEI) delineated the SF Bay shoreline, building on the ART methods developed for Alameda County (SFEI 2016). AECOM used this shoreline delineation to evaluate levels of shoreline flood protection and coastal flood vulnerability. Although not all shoreline features provide equal flood protection, in general shoreline features such as bluffs, berms, embankments, roads, railroad embankments, sea walls, levees, tide gates, and upland hills all act to constrain the tidal influence of the Bay. The shoreline delineation identifies the highest point—or crests—of these features as they occur along the shoreline, and the delineation includes information on the feature type and its crest elevation. The delineation also includes river and creek banks within the downstream tidally influenced areas.

This shoreline delineation is used to produce overtopping maps (Section 6). Overtopping maps identify shoreline low points and flood pathways for each of the 10 mapped scenarios. In many cases, large areas of flooding may occur through localized low points, and in other cases a shoreline is uniformly low and overtopping occurs over long stretches of low elevation. Overtopping maps are necessary to identify the scale of strategy necessary to prevent local flooding.

5.2 APPROACH

AECOM leveraged the shoreline delineation completed by SFEI using Geographic Information System (GIS) tools (SFEI 2016). The SFEI approach to digitize the shoreline followed the methods used for the ART program (AECOM et al. 2011) and the Alameda County Shoreline Vulnerability Assessment (AECOM 2015). SFEI's shoreline delineation includes information on the major shoreline types that may impact coastal flooding and was used for the overtopping potential analyses following a quality assurance/quality control review by AECOM.

Major features that could provide flood protection up to a Bay water level of 120 inches (10 ft) above existing MHHW[5] were delineated, including embankments along open channels of rivers and creeks. LiDAR data were used as the primary source for locating and delineating the shoreline, in conjunction with high-resolution aerial photography and other local data.

A combination of both high-resolution planar and oblique imagery was also crucial in distinguishing both the locations and the types of shoreline features. June 2014 aerial imagery from ArcGIS Online and Google maps oblique imagery were used while digitizing in GIS.

In locations where shorelines had natural features in the foreshore (e.g., wetlands) and developed or natural features in the backshore (e.g., levees), both features were delineated. Flood barriers (e.g., tide gates) in channels, major roads, rail lines, and embankments were also identified in the SFEI shoreline delineation.

[5] This scenario was not selected for inundation mapping as part of this assessment, but it was used by SFEI to complete the shoreline delineation for the entire Bay as it represents an upper boundary beyond the extent of inundation and flooding expected for the remainder of the century.


PORT OF
SAN FRANCISCO

6.0

SHORELINE OVERTOPPING POTENTIAL

6. SHORELINE OVERTOPPING POTENTIAL

Overtopping potential refers to the condition where the water surface elevation under a particular SLR scenario exceeds the elevation of the shoreline. This method of using overtopping potential provides a high-level assessment of where Bay waters may overtop the shoreline, exposing inland areas to inundation. The overtopping potential layer depicts the depth of water over the delineated shoreline features under each of the 10 SLR scenarios. Overtopping could occur temporarily during a large flood or permanently after a particular amount of SLR. This layer illustrates not only where overtopping may occur, but also how deep the water may be on average over any particular section of shoreline.

The pathways for inundation from the Bay and overland cannot always be assessed when viewing the inundation maps by themselves. The overtopping data identify the potential sources of future flood events and, when combined with the inundation layer, help to determine the actual flow paths that lead to inland flooding. By identifying specific locations along the shoreline that are overtopped, this layer provides critical insight for flood protection planning. For example, the inland inundation of a low-lying area may be caused by the overtopping of a short segment of levee. The overtopping layers will indicate where exactly along the levee this overtopping occurs.

6.1 METHODS

The average depth of inundation along the shoreline delineation was calculated for each 100 ft segment of shoreline. Overtopping potential was calculated by overlaying the shoreline delineation on each of the 10 SLR inundation depth rasters, and an average depth of inundation for each 100 ft shoreline segment was calculated. Figure 6-1 illustrates the concepts of overtopping (when the water level exceeds the shoreline elevation) and freeboard (when the shoreline elevation exceeds the water level). As sea level rises, additional lengths of shoreline will be overtopped as freeboard decreases.

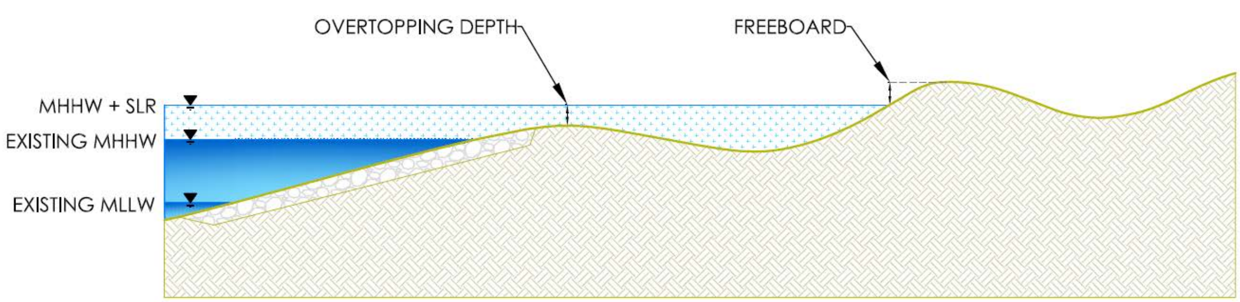

Figure 6-1. Representative Shoreline Cross Section Illustrating Overtopping and Freeboard

6.2 APPLICATION OF OVERTOPPING POTENTIAL MAPS

Appendix A presents the shoreline overtopping potential for each of the 10 SLR scenarios for each county. The overtopping depths are grouped into 1 ft depth increments for visualization purposes only. The overtopping depths in the GIS database are more varied than shown.[6] In addition to the maps contained in this report, the shoreline overtopping potential data layers are available as digital shapefiles, which provide additional information on overtopping depth (available from BCDC).

The overtopping assessment should be considered a planning-level tool only, as this type of assessment does not account for the physics of wave run-up. This assessment also does not account for the condition and structural integrity of the shoreline flood protection infrastructure (or roadway or railway embankments that are providing ad hoc flood protection); if this infrastructure were in poor condition, it could result in partial or complete failure through scour, undermining, or breach after an initial overtopping occurs.

The maps show overtopping potential for inland high ground, which can act as a barrier to flooding and inundation. Showing inland overtopping can illustrate increases in overtopping depth as floodwaters progress landward after overtopping the bayfront shoreline. Overtopping and flooding over inland areas can also occur without overtopping at the adjacent bayfront shoreline, if there is “backdoor” pathway of flooding from a different portion of the shoreline. The overtopping maps can highlight these pathways of flooding to inland areas.

Figure 6-2 shows an example cross section of a shoreline where the primary bayfront shoreline is not overtopped, but lower-lying areas directly behind it could be inundated or flooded. In this case, a flood pathway has allowed flooding to reach the inland areas without overtopping the immediate bayfront shoreline. Because the overtopping and SLR inundation maps do not consider the duration of storms or potential mechanisms for draining floodwaters from inundated land once extreme high tide levels recede, the maps show flooding of inland areas at an elevation equal with the Bay. This approach means that the depth of flooding and overtopping shown on the maps may be more severe than during an actual flood event, especially for areas with flood mitigation strategies in place. For example, Foster City and other areas have the ability to hydraulically pump floodwaters from inland areas to the Bay during flood events, which may lessen the severity of the flooding shown on the maps.

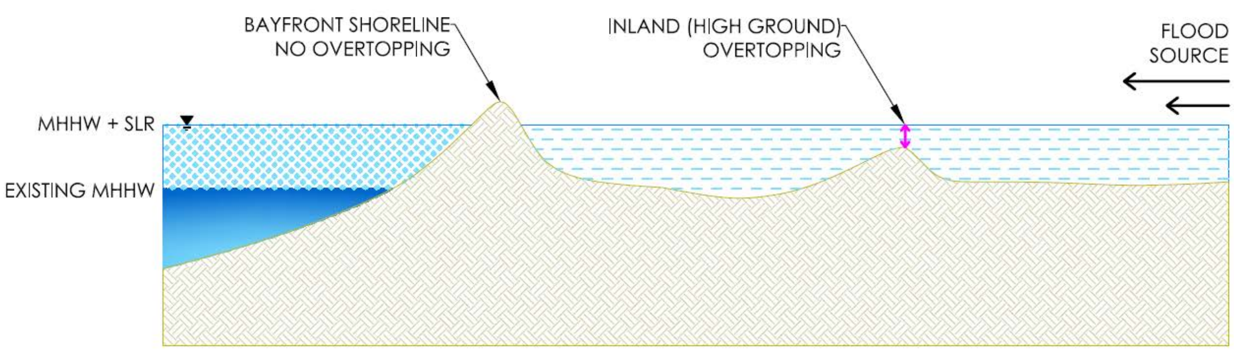

Figure 6-2. Shoreline Cross Section Illustrating Flooding of Inland Areas

[6] Overtopping depth is calculated to the nearest 0.01 ft and then grouped into 1 ft depth increments for mapping purposes.

7.0

COUNTY METHODS AND DISCUSSION


Matson

7. COUNTY METHODS AND DISCUSSION

This section presents a summary of the methods and findings within each of the nine Bay Area counties. The discussion for each county includes the county-specific SLR matrix, stakeholder engagement process, topographic DEM modifications, and discussion and interpretation of the inundation mapping results. The discussion and interpretation sub-section presents a high-level overview of key vulnerabilities within each county that may benefit from further examination. The intent of these sub-sections is to highlight areas within each county that may be exposed to SLR and flooding impacts in the near term, due to either daily high tides with low to moderate amounts of SLR or significant storm surge events, were they to occur today. Each county section also presents a high-level discussion of SLR impacts to bridge approaches that may be of interest to BATA to inform the selection of focus areas for additional future studies.

Table 7-1 summarizes the key transportation assets exposed to future water level conditions based on the scenarios evaluated. The amount of SLR required to expose transportation infrastructure varies considerably across the Bay Area counties, with the earliest impacts occurring during the MHHW + 12-inch SLR scenario in Marin, Napa, and San Mateo Counties and during later SLR scenarios in other counties.

Table 7-1. Summary of Key Vulnerabilities to Transportation Assets Identified in Each County

County	Assets Impacted	Timing of Impact
Marin	<u>Larkspur</u>: Tidal waters overtop US 101 in two locations and inundate inland residential and commercial areas of the city. <u>San Rafael</u>: Segments of San Rafael Creek berms are overtopped, resulting in inundation of a 1-mile section of I-580 leading to the San Rafael Bridge touchdown. Sections of US 101 near the city are overtopped.	MHHW + 12”
	SR 37 inundated due to overtopping of bayside levees.	MHHW + 36”
Sonoma	SR 37 exposed to inundation when Petaluma River levees and Port Sonoma shoreline are overtopped.	MHHW + 24”
	SR 37 is exposed to inundation between Tolay Creek and Sonoma Creek.	MHHW + 36”
	A 950 ft section of SR 121 (next to Sonoma Racetrack and Sonoma Valley Airport) is exposed to inundation.	MHHW + 48”
	<u>Petaluma</u>: A 540 ft section of US 101 and a 2,000 ft section of SR 116 (serves as an on-ramp to US 101) are exposed to inundation.	MHHW + 96”
Napa	West river bank at Edgerly Island is overtopped at the Napa River, exposing a 4,800 ft section of the California Northern Railroad line to inundation.	MHHW + 12”
	SR 121 is exposed to inundation for a small stretch just east of the Napa River and along a 630 ft section at Gasser Drive.	MHHW + 84”
Solano	SR 37 is exposed to inundation for a 500 ft section at Mare Island.	MHHW + 24”
	SR 29 in Vallejo is exposed to inundation for 300 ft from overtopping of	MHHW + 66”

County	Assets Impacted	Timing of Impact
	Napa River shoreline.	
Contra Costa	Martinez: A 2,000 ft section of the Capitol Corridor rail line is exposed to inundation. Northbound on-ramp to I-680 and southbound off-ramp from I-680 are exposed to inundation.	MHHW + 24”
	Water levels in marsh surrounding I-680 encroach on the shoulder of the outer lane in both directions.	MHHW + 52”
	Water overtops the Santa Fe Channel shoreline at several locations and inundates a 2,000 ft section of I-580 at about 2 miles from the Richmond Bridge.	MHHW +66”
Alameda	Toll plaza and westbound lanes at the Bay Bridge touchdown is exposed to inundation for a 500 ft section. Water overtops low-lying section of shoreline west of Doolittle Drive overpass and several low spots on Doolittle Drive along the east shoreline of Bay Farm Island, exposing much of Oakland International Airport property and facilities to inundation.	MHHW + 36”
	SR 92 and SR 84 are exposed to inundation along a 2,000 ft section of the outer lanes leading to the San Mateo Bridge and Dumbarton Bridge. For SR 92, inundation exposure first occurs about 3,000 ft from the bridge toll plaza, and for SR 84 inundation first occurs about 1,700 ft from the toll plaza. Alameda: Water overtops a low-lying area near the Bay Farm overpass and inundates homes.	MHHW + 48”
	Water overtops the shoreline south of Burma Road to expose residential areas of West Oakland to inundation.	MHHW + 52”
Santa Clara	Low-lying section of berms overtops, exposing commercial areas of Sunnyvale, NASA Ames Research Center, and a 1-mile section of SR 237.	MHHW + 24”
	Palo Alto: Water overtops a series of salt pond berms, inundating a 1.2-square-mile residential area and a 2.5-mile section of US 101.	MHHW + 36”
San Mateo	Frontage road along north side of SR 84 at the western touchdown of the Dumbarton Bridge is exposed to inundation.	MHHW + 12”
	Inundation of westbound Dumbarton Bridge access expands to include the adjacent bike path, and a 1-mile section of the eastbound lane. The outside lanes of SR 84 are inundated for 1 mile.	MHHW + 24”
	Foster City: Surrounding low-lying levees are overtopped, exposing the San Mateo Bridge touchdown, a 3-mile section of SR 92, and a 3-mile section of US 101 to inundation.	MHHW + 52”

County	Assets Impacted	Timing of Impact
San Francisco	There is isolated exposure to inundation in Mission Bay, Islais Creek, and along the Embarcadero.	MHHW + 48”
	Inundation around Mission Bay expands to include the Caltrain station, a 2,000 ft section of the rail lines, and the on-/off-ramps to I-280. Overtopping occurs along a 200 ft shoreline segment, inundating a 550 ft section of US 101 in both directions near Crissy Field.	MHHW + 52”

Bay Bridge = San Francisco–Oakland Bay Bridge
ft = foot/feet
I-280 = Interstate 280
I-580 = Interstate 580
I-680 = Interstate 680
MHHW = Mean Higher High Water
NASA = National Aeronautics and Space Administration
Richmond Bridge = Richmond–San Rafael Bridge
San Mateo Bridge = San Mateo–Hayward Bridge
SR = State Route
US 101 = U.S. Highway 101
” = inch(es)

7.1 MARIN COUNTY

SLR MATRIX

The SLR matrix for Marin County is presented in Table 7-2. The 10 possible scenarios (provided as individual sets of inundation maps in Appendix A) represent combinations of 0 to 66 inches of SLR with extreme tides from the 1-year to the 100-year return period. The values shown in the table present the daily and extreme tide levels above MHHW for Marin County and are an average of the water levels at all model output points along Marin's bayshore.

Table 7-2. Marin County Sea Level Rise and Extreme Tide Matrix

Sea Level Rise Scenario	Daily Tide	Extreme Tide (Storm Surge)						
	+SLR (in)	1yr	2yr	5yr	10yr	25yr	50yr	100yr
	Water Level above MHHW (in)							
Existing Conditions	0	14	18	23	27	32	37	42
MHHW + 6"	6	20	24	29	33	38	43	48
MHHW + 12"	12	26	30	35	39	44	49	54
MHHW + 18"	18	32	36	41	45	50	55	60
MHHW + 24"	24	38	42	47	51	56	61	66
MHHW + 30"	30	44	48	53	57	62	67	72
MHHW + 36"	36	50	54	59	63	68	73	78
MHHW + 42"	42	56	60	65	69	74	79	84
MHHW + 48"	48	62	66	71	75	80	85	90
MHHW + 52"	52	66	70	75	79	84	89	94
MHHW + 54"	54	68	72	77	81	86	91	96
MHHW + 60"	60	74	78	83	87	92	97	102
MHHW + 66"	66	80	84	89	93	98	103	108

in = inch(es)
MHHW = Mean Higher High Water
SLR = sea level rise
yr = year(s)

STAKEHOLDER ENGAGEMENT

The stakeholder outreach and review process in Marin County was unique, as the Marin Bay Waterfront Adaptation and Vulnerability Evaluation (BayWAVE) Sea Level Rise Vulnerability Assessment was being carried out concurrently. This work is led by the Marin County Department of Public Works. Rather than engaging a broader stakeholder group, Marin County Public Works requested that county staff working on the BayWAVE evaluation be the sole reviewers of the draft maps. After the County review of the draft ART maps was completed, BCDC staff presented the project at a BayWAVE stakeholder meeting as an informational item.

Marin County Stakeholder Engagement
Draft Marin maps were shared with the following groups for review: • County of Marin Public Works, representing 115 assets managers (and 350 built and natural resource assets) interviewed under the BayWAVE Marin Shoreline Sea Level Rise Vulnerability Assessment

DEM MODIFICATIONS

The topographic data used for this analysis were derived from the topographic LiDAR data from USGS and NOAA. The SLR inundation mapping was completed on a 1-meter DEM and generally resolved topographic features of interest to accurately represent inundation of inland areas. The bare-earth LiDAR DEM was manually adjusted in some areas to account for recent levee breaches, new levees, and water control structures that were missing or misrepresented in the original DEM.

The following manual adjustments were made to the DEM:

- Two locks were added at the north and south location of the Bel Marin Keys.
- A breach was added to the bayfront levee of Hamilton Airfield.
- Bridges that were not removed from the bare-earth LiDAR data were removed (to allow inundation of upstream areas).
- Missing culverts and openings that allow inundation of upstream areas were added.
- Tide gates and water control structures (such as pump stations) that block inundation of upstream areas were added.

A detailed list of the modifications to the Marin County topographic DEM, including locations and modified elevations, is provided in the topographic DEM metadata (available from BCDC).

DISCUSSION AND INTERPRETATION OF RESULTS

Summary of Impacted Assets for Marin County	Timing of Impact
Larkspur: Tidal waters overtop US 101 in two locations and inundate inland residential and commercial areas of the city. San Rafael: Segments of San Rafael Creek berms are overtopped, resulting in inundation of a 1 mile section of I-580 leading to the San Rafael Bridge touchdown. Sections of US 101 near the city are overtopped.	MHHW + 12’’
SR 37 exposed to inundation due to overtopping of bayside levees.	MHHW + 36’’

I-580 = Interstate 580
MHHW = Mean Higher High Water
SR = State Route
US 101 = U.S. Highway 101
’’ = inch(es)

The Marin County shoreline comprises natural tidal marshes, berms and engineered flood and shoreline protection features. Corte Madera Creek, San Rafael Creek, Gallinas Creek, Novato Creek, and Petaluma River run through the county and flow into the Bay, providing a flooding pathway for elevated waters in the Bay to reach inland areas.

AECOM reviewed the SLR inundation maps and identified key vulnerabilities that may benefit from further evaluation in Marin County. The following discussion presents a high-level overview of potential SLR impacts to low-lying areas and US 101 in Larkspur and San Rafael and State Route (SR) 37 in the vicinity of Novato.

The low-lying areas bordering the Bay shoreline and the rivers and creeks listed above are at immediate risk for inundation, including the communities of San Rafael and Larkspur. During the MHHW + 12'' scenario, Larkspur may be exposed to inundation from water flowing over the south bank of Corte Madera Creek. The maps show that tidal waters could travel south and overtop US 101 in two locations and continue landward to inundate commercial and residential areas of the city, as shown on Figure 7-1.[7] The impacted areas indicated by the orange circles on the figure are critical transportation assets.

San Rafael may experience inundation from the overtopping of isolated segments of the San Rafael Creek berm. The maps show (see Figure 7-2) that water from the creek flows landward along I-580, overtopping an almost 1-mile section leading up to the Richmond Bridge touchdown. In addition, a short section of US 101 shows overtopping in this area.

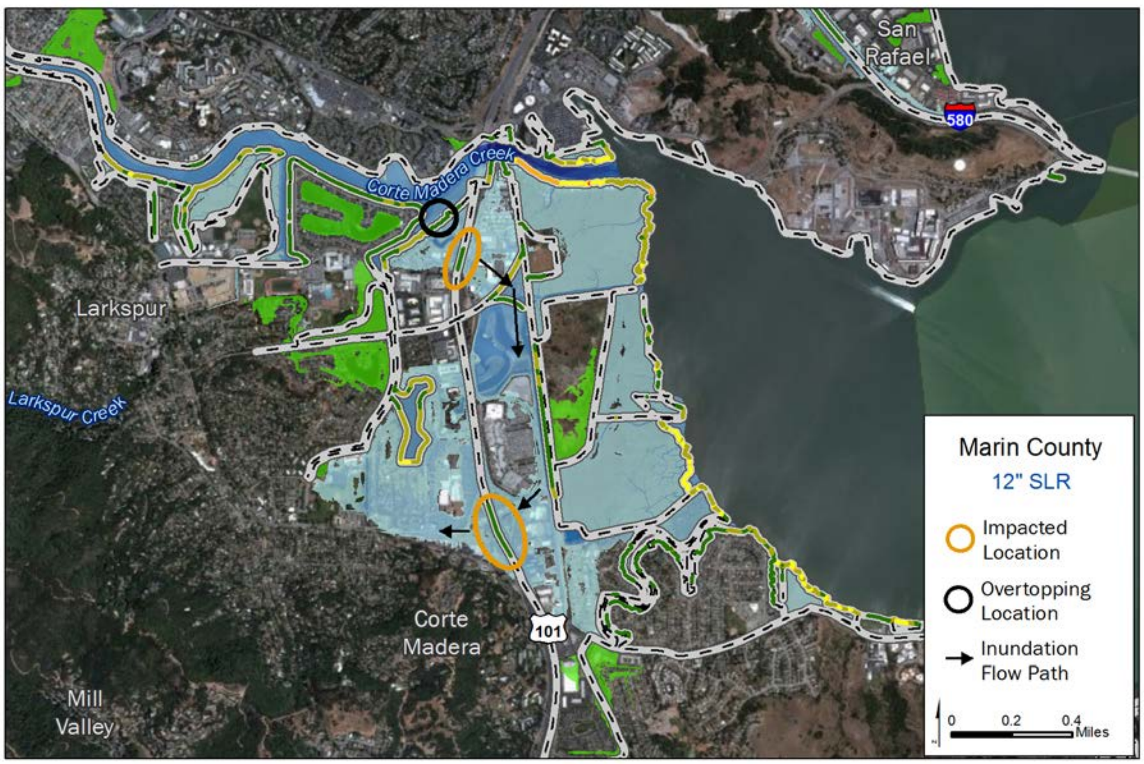

Figure 7-1. Inundation in Larkspur in the MHHW + 12'' scenario

[7] See Section 3.5 for an explanation of the inundation depth and potential shoreline overtopping symbology shown on the focus area figures below.

Figure 7-2. Inundation in San Rafael in the MHHW + 12'' scenario

Many low-lying areas in northern Marin are protected by berms and levees; if these berms and levees are overtopped, widespread inundation may result. An example is the area on either side of SR 37 between Novato Creek and Sonoma Creek. This area is protected by bayside berms and the levee along Novato Creek. In the MHHW + 36" SLR scenario, a small section of the bayside berm becomes overtopped, which triggers the overtopping of the inland berms and SR 37. This overtopping results in the potential inundation of the entire low-lying area, as shown on Figure 7-3. Flooding in this area and the section of SR 37 crossing over Novato Creek could potentially be more severe if combined with the effects of rainfall and high riverine discharge in addition to the future elevated Bay water levels. The SR 37 crossing over Novato Creek is also prone to flooding from high rainfall events, when the adjacent detention basins fill and water flows over low-lying sections, as has been observed in recent (2017) winter storms. Flooding along SR 37 has been previously investigated in a Caltrans study performed by University of California, Davis and AECOM (UC Davis 2015).

Figure 7-3. Inundation near SR 37 in the MHHW + 36'' scenario

7.2 SONOMA COUNTY

SLR MATRIX

The SLR matrix for Sonoma County is presented in Table 7-3. The 10 possible scenarios (provided as individual sets of inundation maps in Appendix A) represent combinations of 0 to 66 inches of SLR with extreme tides from the 1-year to the 100-year return period. The values shown in the table present the daily and extreme tide levels above MHHW for Sonoma County and are an average of the water levels at all model output points along Sonoma's bayshore.

Table 7-3. Sonoma Sea Level Rise and Extreme Tide Matrix

Sea Level Rise Scenario	Daily Tide	Extreme Tide (Storm Surge)						
	+SLR (in)	1yr	2yr	5yr	10yr	25yr	50yr	100yr
	Water Level above MHHW (in)							
Existing Conditions	0	15	19	24	28	34	38	43
MHHW + 6"	6	21	25	30	34	40	44	49
MHHW + 12"	12	27	31	36	40	46	50	55
MHHW + 18"	18	33	37	42	46	52	56	61
MHHW + 24"	24	39	43	48	52	58	62	67
MHHW + 30"	30	45	49	54	58	64	68	73
MHHW + 36"	36	51	55	60	64	70	74	79
MHHW + 42"	42	57	61	66	70	76	80	85
MHHW + 48"	48	63	67	72	76	82	86	91
MHHW + 52"	52	67	71	76	80	86	90	95
MHHW + 54"	54	69	73	78	82	88	92	97
MHHW + 60"	60	75	79	84	88	94	98	103
MHHW + 66"	66	81	85	90	94	100	104	109

in = inch(es)
MHHW = Mean Higher High Water
SLR = sea level rise
yr = year(s)

STAKEHOLDER ENGAGEMENT

The project team coordinated with the Sonoma County Transportation Authority (SCTA), Sonoma County Water Agency, and Sonoma County Agricultural Preservation and Open Space District to conduct stakeholder outreach. The Sonoma County sea level rise maps were presented at two meetings convened at SCTA. The first meeting was with the SCTA board, and the second meeting was with SCTA staff and the Sonoma County Regional Climate Protection Authority. The project team connected with most of the stakeholders through these meetings and following up with two dozen contacts through email. All of the stakeholders received access to the online viewer to review the maps and provide input either directly in the viewer or through email. Input on the maps was evaluated by the project team and appropriate changes were made to the maps.

Sonoma County Stakeholder Engagement

Draft Sonoma maps were shared with the following groups for review:

- Sonoma County Transportation Authority
- Sonoma County Regional Climate Protection Authority
- Bay Area Open Space Council
- GAIA Consulting Inc.
- Sonoma Ecology Center
- United States Fish and Wildlife Service
- Point Blue Conservation Science
- California Coastal Commission
- Ducks Unlimited
- Sonoma Land Trust
- City of Petaluma
- City of Petaluma, Planning and Zoning
- Sonoma County, Agriculture and Open Space District
- Sonoma County, Permit and Resource Management Department
- Sonoma County, Planning Department
- Sonoma County, County Fire and Emergency Services
- Sonoma County, Department of Health Services
- Sonoma County, Transportation and Public Works
- Sonoma County Water Agency
- City of Sonoma

DEM MODIFICATIONS

The topographic data used for this analysis were derived from the topographic LiDAR data from USGS and NOAA. The SLR inundation mapping was completed on a 1-meter DEM and generally resolved topographic features of interest to accurately represent inundation of inland areas. The bare-earth LiDAR DEM was manually adjusted in some areas to account for recent levee breaches, new levees, and water control structures that were missing or misrepresented in the original DEM.

The following manual adjustments were made to the DEM:

- A breach was added to the bayfront levee of Sears Point.
- The levee protecting the Camp 2 pond was reconnected.
- The levee on the landward side of Sears Point was added.
- Bridges that were not removed from the bare-earth LiDAR data were removed (to allow inundation of upstream areas).
- Missing culverts and openings that allow inundation of upstream areas were added.
- Tide gates and water control structures (such as pump stations) that block inundation of upstream areas were added.

A detailed list of the modifications to the Sonoma County topographic DEM, including locations and modified elevations, is provided in the topographic DEM metadata (available from BCDC).

DISCUSSION AND INTERPRETATION OF RESULTS

Summary of Impacted Assets for Sonoma County	Timing of Impact
SR 37 exposed to inundation when Petaluma River levees and Port Sonoma shoreline are overtopped.	MHHW + 24’’
SR 37 is exposed to inundation between Tolay Creek and Sonoma Creek.	MHHW + 36’’
A 950 ft section of SR 121 (next to Sonoma Racetrack and Sonoma Valley Airport) is exposed to inundation.	MHHW + 48’’
Petaluma: A 540 ft section of US 101 and a 2,000 ft section of SR 116 (serves as an on-ramp to US 101) are exposed to inundation.	MHHW + 96’’

ft = foot/feet
MHHW = Mean Higher High Water
SR = State Route
US 101 = U.S. Highway 101
’’ = inch(es)

The Sonoma County shoreline is characterized by coastal marshes and farmlands built on reclaimed low-lying fill that are disconnected from the Bay by a series of levees. Developed areas in this county are small and far inland. Petaluma is 10 miles up the Petaluma River and does not become affected by inundation until the MHHW + 96’’ scenario (although the combined effects of riverine and coastal flooding were not evaluated in detail as part of this project).

AECOM reviewed the SLR inundation maps and identified key vulnerabilities that may benefit from further evaluation in Sonoma County. The following discussion presents a high-level overview of potential SLR impacts to SR 37 near Sonoma Creek, SR 121 near the Sonoma Valley Airport, and US 101 and SR 116 in the vicinity of Petaluma.

The most significant asset at risk in this county is SR 37, which runs across the county from the Petaluma River to Sonoma Creek. In the MHHW + 24’’ scenario, the mapping indicates that water travels up the Petaluma River and overtops low spots along the river levees and Port Sonoma shoreline. Behind this system of levees sits a large area with ground elevations below sea level and a 2.5-mile section of SR 37 that has a road elevation between 2 and 4 ft (North American Vertical Datum of 1988). When water overtops the levee, it moves landward to inundate this section of SR 37 and the lands surrounding it, as is shown on Figure 7-4.[8]

In the MHHW + 36’’ scenario, the stretch of SR 37 from Tolay Creek to Sonoma Creek on Tubbs Island, a low-lying field protected by levees, is exposed to inundation. In the MHHW + 36’’ map, these levees overtop in isolated locations and result in the inundation of Tubbs Island and the 2-mile section of SR 37 that spans the island, as is shown on Figure 7-5.

Later scenarios bring increased inundation to other parts of the county. For example, the MHHW + 48’’ scenario shows inundation of a 950 ft section of SR 121 next to the Sonoma Racetrack and the Sonoma Valley Airport, near Schellville. The MHHW + 96’’ scenario shows inundation of 540 ft of US 101 near Petaluma and inundation of SR 116 for 2,000 ft starting from the US 101 overpass, which also serves as an on-ramp to US 101.

[8] See Section 3.5 for an explanation of the inundation depth and potential shoreline overtopping symbology shown in the focus area figures below.

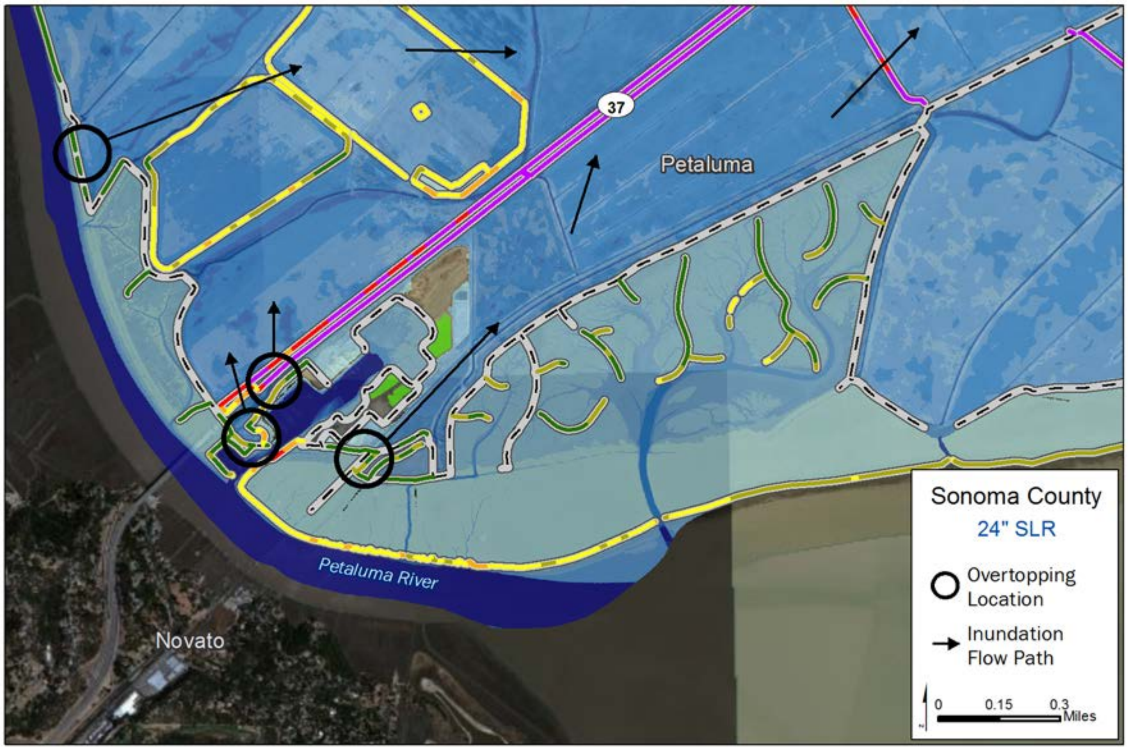

Figure 7-4. Inundation at SR 37 near Port Sonoma in the MHHW + 24'' scenario

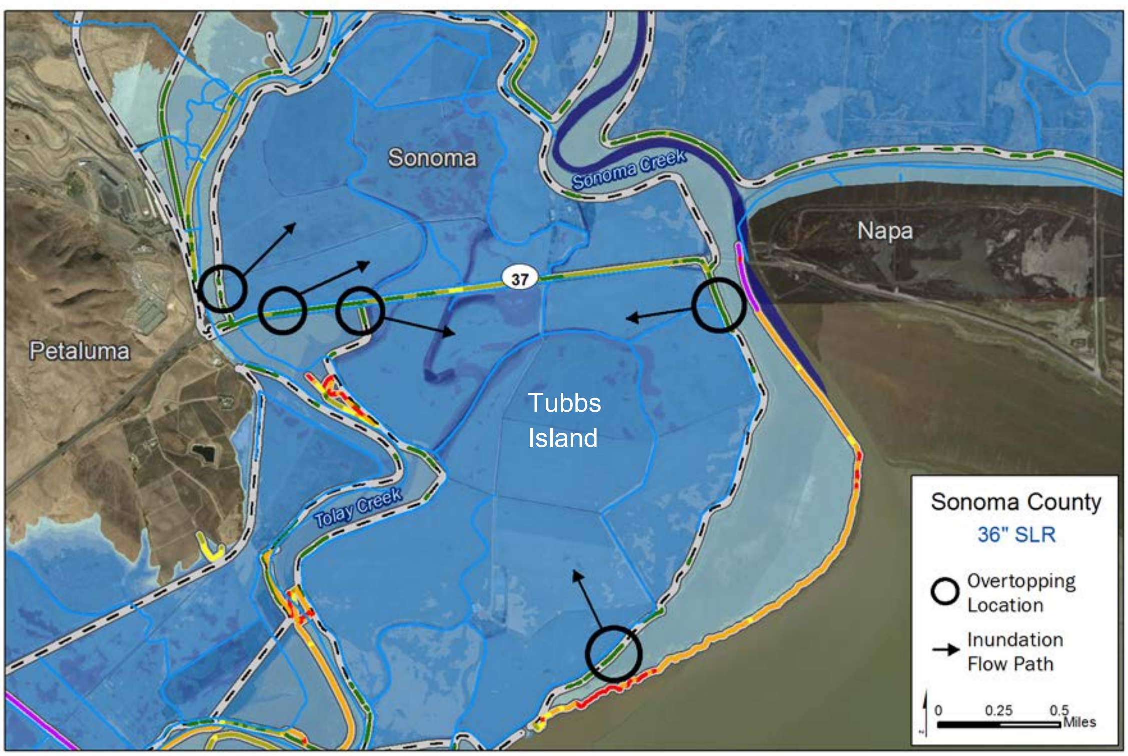

Figure 7-5. Inundation at Tubbs Island in the MHHW + 36'' scenario

7.3 NAPA COUNTY

SLR MATRIX

The SLR matrix for Napa County is presented in Table 7-4. The 10 possible scenarios (provided as individual sets of inundation maps in Appendix A) represent combinations of 0 to 66 inches of SLR with extreme tides from the 1-year to the 100-year return period. The values shown in the table present the daily and extreme tide levels above MHHW for Napa County and are an average of the water levels at all model output points along Napa's bayshore.

Table 7-4. Napa County Sea Level Rise and Extreme Tide Matrix

Sea Level Rise Scenario	Daily Tide	Extreme Tide (Storm Surge)						
	+SLR (in)	1yr	2yr	5yr	10yr	25yr	50yr	100yr
	Water Level above MHHW (in)							
Existing Conditions	0	15	19	24	27	33	37	42
MHHW + 6"	6	21	25	30	33	39	43	48
MHHW + 12"	12	27	31	36	39	45	49	54
MHHW + 18"	18	33	37	42	45	51	55	60
MHHW + 24"	24	39	43	48	51	57	61	66
MHHW + 30"	30	45	49	54	57	63	67	72
MHHW + 36"	36	51	55	60	63	69	73	78
MHHW + 42"	42	57	61	66	69	75	79	84
MHHW + 48"	48	63	67	72	75	81	85	90
MHHW + 52"	52	67	71	76	79	85	89	94
MHHW + 54"	54	69	73	78	81	87	91	96
MHHW + 60"	60	75	79	84	87	93	97	102
MHHW + 66"	66	81	85	90	93	99	103	108

in = inch(es)
MHHW = Mean Higher High Water
SLR = sea level rise
yr = year(s)

STAKEHOLDER ENGAGEMENT

The project team coordinated with the Napa Valley Transportation Authority (NVTA) to conduct stakeholder outreach. NVTA organized a meeting of NVTA and Napa County Flood Control and Water Conservation District staff and invited the project team to discuss the project and map review process. NVTA staff assisted with outreach to other departments and cities through email, and Napa County Flood Control and Water Conservation District staff led the process of compiling map comments. Colleagues at the California State Coastal Conservancy also suggested involving additional stakeholders, whom the project team contacted by email. The project team evaluated the input on the maps and made changes, as appropriate.

Napa County Stakeholder Engagement

Draft Napa maps were shared with the following groups for review:

- Napa Valley Transportation Authority
- Napa County Flood Control and Water Conservation District
- City of American Canyon, Public Works
- City of American Canyon, Community Development
- County of Napa, Public Works, Flood and Watershed Management Division
- Napa County, Department of Planning, Building, and Environmental Services
- Napa County, Regional Park and Open Space District
- Napa County Resource Conservation District
- State Water Resources Control Board

DEM MODIFICATIONS

The topographic data used for this analysis were derived from topographic LiDAR data from USGS and NOAA. The SLR inundation mapping was completed on a 1-meter DEM and generally resolved topographic features of interest to accurately represent inundation of inland areas. The bare-earth LiDAR DEM was manually adjusted in some areas to account for recent levee breaches, new levees, and water control structures that were missing or misrepresented in the original DEM.

The following manual adjustments were made to the DEM:

- The levee crest height was adjusted along the Napa River at Milton Road.
- Two breaches were added to the levee at the Napa Plant Site.
- Two breaches were added to the levee at West End Pond.
- Tide gates and water control structures (such as pump stations) that block inundation of upstream areas were added.

A detailed list of the modifications to the Napa County topographic DEM, including locations and modified elevations, is provided in the topographic DEM metadata (available from BCDC).

DISCUSSION AND INTERPRETATION OF RESULTS

Summary of Impacted Assets for Napa County	Timing of Impact
West river bank at Edgerly Island is overtopped at the Napa River, exposing a 4,800 ft section of the California Northern Railroad line to inundation.	MHHW + 12”
SR 121 is exposed to inundation for a small stretch just east of the Napa River and along a 630 ft section at Gasser Drive.	MHHW + 84”

ft = foot/feet
MHHW = Mean Higher High Water
SR = State Route” = inch(es)

Napa County is set back from the SF Bay shoreline, though it is hydraulically connected to the Bay via the Napa River, which runs north to south through the middle of the county and discharges into the Bay. The tidal marshes of Solano County lie in between the southern edge of Napa County and the Bay shoreline;

these marshes do not provide any flood protection from tidal flooding and SLR, as they are low lying and generally have elevations at or below MHHW. The majority of the county is composed of tidal marsh and freshwater ponds. The city of Napa sits on the shoreline of the Napa River, north of SR 121.

AECOM reviewed the SLR inundation maps and identified key vulnerabilities that may benefit from further evaluation in Napa County. The following discussion presents a high-level overview of potential SLR impacts to the California Northern Railroad line and SR 121 near Napa River.

Inundation of critical assets, such as major highways, roads, bridges, or large residential areas, is limited and is projected to occur in the later scenarios. However, the California Northern Railroad line, which runs east-west across the county, is an exception. Because the rail line is sitting on low-lying marsh, it is exposed to inundation in the MHHW + 12'' scenario. Project mapping shows that water overtops the west river bank downstream of the rail line, at Edgerly Island, and flows over the marsh areas to inundate an approximately 4,800 ft section of rail line west of the Napa River.

In the MHHW + 84'' scenario, the mapping shows that a short section of SR 121 is exposed to inundation, just east of the Napa River. Water overtops the east bank of the river and also flows up Tulucay Creek to inundate a 630 ft section of SR 121 at the intersection with Gasser Drive, as shown on Figure 7-6.[9] The overtopping of this part of the river first occurs in the MHHW + 36'' scenario; however, inundation of SR 121 does not occur until the MHHW + 84'' scenario because the road elevation is higher than the surrounding area.

Although the maps do not show extensive inundation of critical areas, it is important to note that this analysis only considered coastal flooding and did not incorporate the combined effect of riverine and coastal conditions. Extreme coastal water levels that occur in the Bay can increase the riverine water levels and increase the severity of riverine flooding during large rainfall events.

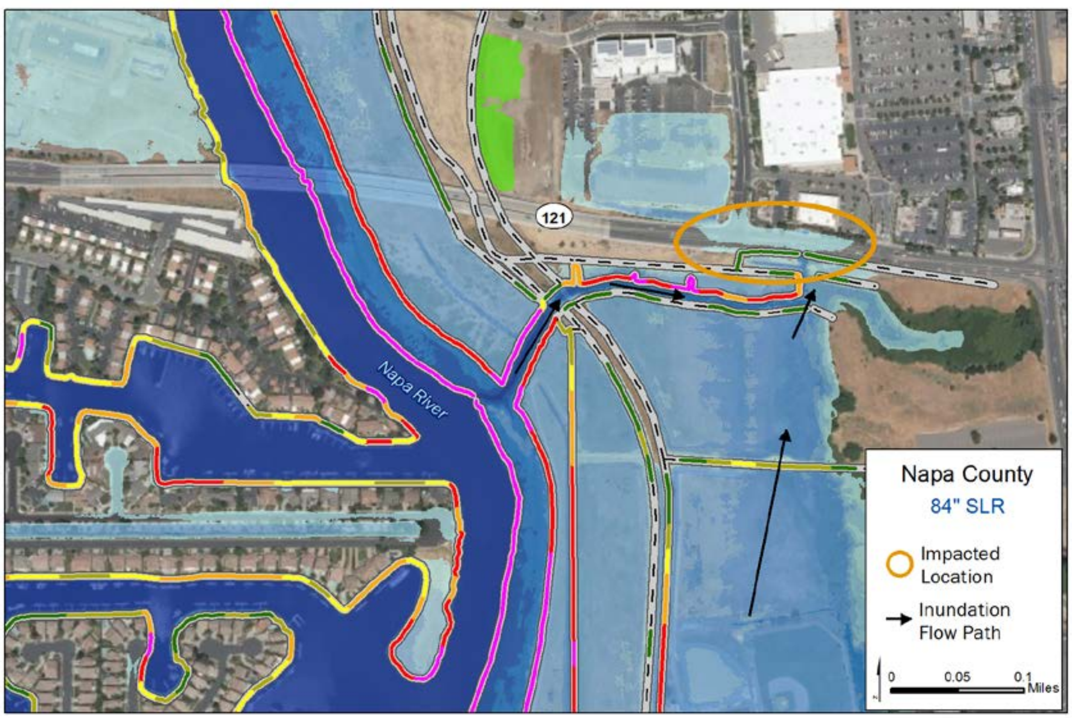

Figure 7-6. Inundation of SR 121 in the MHHW + 84" scenario

[9] See Section 3.5 for an explanation of the inundation depth and potential shoreline overtopping symbology shown in the focus area figures below.

7.4 SOLANO COUNTY

SLR MATRIX

The SLR matrix for Solano County is presented in Table 7-5. The 10 possible scenarios (provided as individual sets of inundation maps in Appendix A) represent combinations of 0 to 66 inches of SLR with extreme tides from the 1-year to the 100-year return period. The values shown in the table present the daily and extreme tide levels above MHHW for Solano County and are an average of the water levels at all model output points along Solano's bayshore.

Table 7-5. Solano County Sea Level Rise and Extreme Tide Matrix

Sea Level Rise Scenario	Daily Tide	Extreme Tide (Storm Surge)						
	+SLR (in)	1yr	2yr	5yr	10yr	25yr	50yr	100yr
	Water Level above MHHW (in)							
Existing Conditions	0	15	18	23	27	32	36	41
MHHW + 6"	6	21	24	29	33	38	42	47
MHHW + 12"	12	27	30	35	39	44	48	53
MHHW + 18"	18	33	36	41	45	50	54	59
MHHW + 24"	24	39	42	47	51	56	60	65
MHHW + 30"	30	45	48	53	57	62	66	71
MHHW + 36"	36	51	54	59	63	68	72	77
MHHW + 42"	42	57	60	65	69	74	78	83
MHHW + 48"	48	63	66	71	75	80	84	89
MHHW + 52"	52	67	70	75	79	84	88	93
MHHW + 54"	54	69	72	77	81	86	90	95
MHHW + 60"	60	75	78	83	87	92	96	101
MHHW + 66"	66	81	84	89	93	98	102	107

in = inch(es)
MHHW = Mean Higher High Water
SLR = sea level rise
yr = year(s)

STAKEHOLDER ENGAGEMENT

The project team coordinated with Solano Transportation Authority (STA) to conduct stakeholder outreach. STA invited the project team to present at the Solano County Flood Control and Sea Level Rise Forum. The forum was designed to discuss a range of efforts to organize cities, STA, and flood managers around sea level rise issues. The following groups were represented at the meeting: the Suisun Resource Conservation District; County of Solano Resource Management; the Cities of Suisun, Rio Vista, Vallejo, and Benicia; and the Solano County Water Agency. STA took the lead in organizing map review in the county. The project team contacted additional shoreline asset managers, including the Port of Benicia, San Francisco Bay National Estuarine Research Reserve, California Department of Fish and Wildlife; and the California Department of Water Resources. The project team evaluated the input on the maps and made changes, as appropriate.

Solano County Stakeholder Engagement

Draft Solano maps were shared with the following groups for review:

- Solano Transportation Authority
- Suisun Resource Conservation District
- County of Solano, Resource Management
- City of Suisun, Public Works
- City of Rio Vista, Public Works
- City of Vallejo, Public Works
- City of Vallejo, Flood Control and Sanitary District
- Solano County, Water Agency
- City of Benicia, Public Works
- Port of Benicia
- San Francisco Bay National Estuarine Research Reserve
- California Department of Fish and Wildlife
- California Department of Water Resources
- GAIA Consulting
- Solano Land Trust

DEM MODIFICATIONS

The topographic data used for this analysis were derived from topographic LiDAR data from USGS and NOAA. The SLR inundation mapping was completed on a 1-meter DEM and generally resolved topographic features of interest to accurately represent inundation of inland areas. The bare-earth LiDAR DEM was manually adjusted in some areas to account for recent levee breaches, new levees, and water control structures that were missing or misrepresented in the original DEM.

The following manual adjustments were made to the DEM:

- A floodwall was added at the Benicia wastewater treatment plant.
- A floodwall was added at the western edge of the Port of Benicia (perpendicular to Bayshore Road).
- Two breaches were added to the levee along Cullinan Ranch.
- A levee was added to the south side of Cullinan Ranch.
- Missing culverts and openings were added to allow inundation of upstream areas.

A detailed list of the modifications to the Solano County topographic DEM, including locations and modified elevations, is provided in the topographic DEM metadata (available from BCDC).

DISCUSSION AND INTERPRETATION OF RESULTS

Summary of Impacted Assets for Solano County	Timing of Impact
SR 37 is exposed to inundation for a 500 ft section at Mare Island.	MHHW + 24''
SR 29 in Vallejo is exposed to inundation for 300 ft from overtopping of Napa River shoreline.	MHHW + 66''

ft = foot/feet
MHHW = Mean Higher High Water
SR = State Route
'' = inch(es)

Solano County has a long shoreline that starts in San Pablo Bay and extends east to Grizzly Bay and the confluence of the Sacramento River. The shoreline is mostly composed of tidal marshes and wildlife areas. Residential, commercial, and industrial areas occur along the shoreline from Vallejo to Benicia, but they are generally at high elevation, where inundation impacts are limited.

AECOM reviewed the SLR inundation maps and identified key vulnerabilities that may benefit from further evaluation in Solano County. The following discussion presents a high-level overview of potential SLR impacts to critical transportation assets in Solano County, with a focus on SR 37 near Napa River and SR 29 in south Vallejo.

The main transportation assets in Solano County are the Benicia and Carquinez Bridge touchdowns that lead to Interstate 80 (I-80) and Interstate 680 (I-680). These touchdown areas and the interstates that follow them are at high elevations, and the maps show no exposure to inundation in the areas immediately landward of the touchdown areas. However, in the MHHW + 66' scenario, a 100 ft segment of I-680 is exposed to inundation approximately 6 miles north of the Benicia Bridge touchdown.

Another significant transportation asset in Solano County is SR 37, which runs along the shoreline for 8 miles before cutting north to intersect with I-80. In the MHHW + 24'' scenario, the maps show that a 500 ft section of SR 37 at Mare Island is exposed to inundation. Water flows over the fronting marsh and overtops a low-lying segment of SR 37. In the MHHW + 36'' scenario, the inundation of SR 37 increases to include an additional 1,300 ft segment, as shown on Figure 7-7. In this scenario, inundation occurs from overtopping of the low-lying shoreline along the Napa River, in addition to overtopping from the bayfront marsh.

The mapping shows that SR 29, which runs through Vallejo, close to the Napa River shoreline, is first exposed to inundation in the MHHW + 66'' scenario. Inundation occurs along a 300 ft segment, approximately 400 ft northwest of the intersection of SR 29 and the state rail line. The highway sits landward of an industrial zone that includes the Vallejo Sanitation and Flood Control District. This zone is first exposed to inundation in the MHHW + 48'' scenario and is fully inundated in the MHHW + 66'' scenario as water overtops the entire length of the Napa River shoreline and flows landward to inundate SR 29, as shown on Figure 7-8.

Figure 7-7. Inundation of SR 37 in the MHHW + 36'' scenario

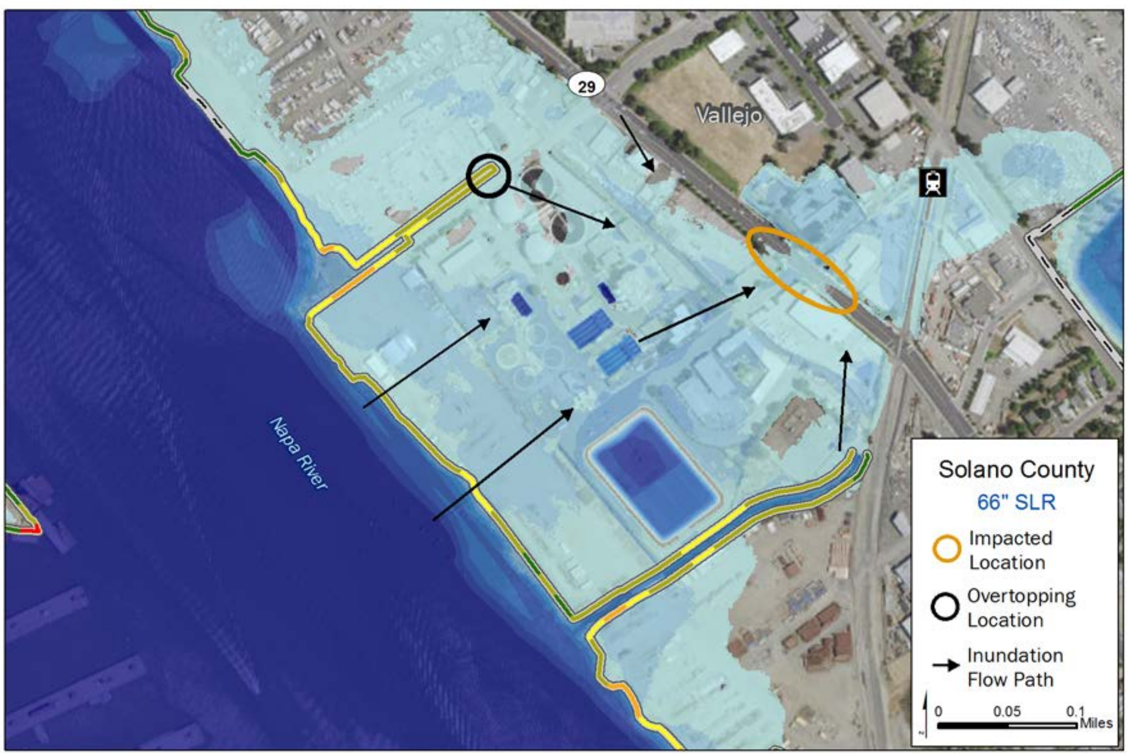

Figure 7-8. Inundation of SR 29 in the MHHW + 66" scenario

7.5 CONTRA COSTA COUNTY

SLR inundation mapping products for Contra Costa County were originally developed as part of the Adapting to Rising Tides: Contra Costa County Assessment and Adaptation Project (AECOM 2016c; BCDC 2017). The project team reformatted the SLR inundation maps and supporting GIS data layers developed for that project to align them with all other county mapping completed in support of this effort (the Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project).

SLR MATRIX

The SLR matrix for Contra Costa County is presented in Table 7-6. The 10 possible scenarios (provided as individual sets of inundation maps in Appendix A) represent combinations of 0 to 66 inches of SLR with extreme tides from the 1-year to the 100-year return period. The values shown in the table present the daily and extreme tide levels above MHHW for Contra Costa County and are an average of the water levels at all model output points along Contra Costa's bayshore.

Table 7-6. Contra Costa Sea Level Rise and Extreme Tide Matrix

Sea Level Rise Scenario	Daily Tide	Extreme Tide (Storm Surge)						
	+SLR (in)	1yr	2yr	5yr	10yr	25yr	50yr	100yr
	Water Level above MHHW (in)							
Existing Conditions	0	14	18	23	27	32	36	41
MHHW + 6"	6	20	24	29	33	38	42	47
MHHW + 12"	12	26	30	35	39	44	48	53
MHHW + 18"	18	32	36	41	45	50	54	59
MHHW + 24"	24	38	42	47	51	56	60	65
MHHW + 30"	30	44	48	53	57	62	66	71
MHHW + 36"	36	50	54	59	63	68	72	77
MHHW + 42"	42	56	60	65	69	74	78	83
MHHW + 48"	48	62	66	71	75	80	84	89
MHHW + 52"	52	66	70	75	79	84	88	93
MHHW + 54"	54	68	72	77	81	86	90	95
MHHW + 60"	60	74	78	83	87	92	96	101
MHHW + 66"	66	80	84	89	93	98	102	107

in = inch(es)
MHHW = Mean Higher High Water
SLR = sea level rise
yr = year(s)

STAKEHOLDER ENGAGEMENT

Robust stakeholder engagement was conducted as part of the Adapting to Rising Tides: Contra Costa County Assessment and Adaptation Project (AECOM 2016c; BCDC 2017). No additional stakeholder engagement beyond that effort was conducted for the current project.

DEM MODIFICATIONS

The topographic data used for this analysis were derived from topographic LiDAR data from USGS and NOAA. The SLR inundation mapping was completed on a 1-meter DEM and generally resolved topographic features of interest to accurately represent inundation of inland areas. The bare-earth LiDAR DEM was manually adjusted in some areas to account for recent levee breaches, new levees, and water control structures that were missing or misrepresented in the original DEM.

A detailed list of the modifications to the Contra Costa County topographic DEM, including location and modified elevations, is provided in the topographic DEM metadata (available from BCDC).

DISCUSSION AND INTERPRETATION OF RESULTS

Summary of Impacted Assets for Contra Costa County	Timing of Impact
Martinez: A 2,000 ft section of Capitol Corridor rail line is exposed to inundation. Northbound on-ramp to I-680 and southbound off-ramp from I-680 are exposed to inundation.	MHHW + 24''
Water levels in marsh surrounding I-680 encroach on the shoulder of the outer lane in both directions.	MHHW + 52''
Water overtops the Santa Fe Channel shoreline in several locations and inundates a 2000 ft section of I-580 at about 2 miles from the Richmond Bridge.	MHHW +66''

ft = foot/feet
I-580 = Interstate 580
I-680 = Interstate 680
MHHW = Mean Higher High Water
Richmond Bridge = Richmond–San Rafael Bridge
SR = State Route
'' = inch(es)

Contra Costa is a large county with a diverse shoreline consisting of tidal marshes, wildlife areas, and regional parks, interspersed with industrial plants, refineries, and residential areas. The shoreline is also a connection point to Marin County via the Richmond Bridge and to the North Bay via the Carquinez and Benicia Bridges.

AECOM reviewed the SLR inundation maps and identified key vulnerabilities that may benefit from further evaluation in Contra Costa County. The following discussion presents a high-level overview of potential SLR impacts to the Capitol Corridor rail line, I-680 in the vicinity of Martinez, and I-580 at about 2 miles from the Richmond Bridge.

The first asset projected to be impacted in this county is the Capitol Corridor rail line, sections of which show as inundated in Martinez in the MHHW + 24'' scenario. The rail line in this part of the county is on a low-lying wildlife regional preserve. As water flows over the fronting marsh and up Peyton Slough, it overtops the banks of the slough to inundate a large portion of the preserve and a 2000 ft section of the rail line, as shown on Figure 7-9.[10] The mapping also indicates that water may flow under the I-680 overpass adjacent to the Benicia Bridge toll area, inundating the northbound on-ramp and southbound off-ramp of the interstate. The presence of the tide gates in Peyton Slough was not accounted for because the DEM for this project was taken from the 2016 Contra Costa Inundation Project, and the tide

[10] See Section 3.5 for an explanation of the inundation depth and potential shoreline overtopping symbology shown in the focus area figures below.

gates were not integrated into the DEM in that project. This non-integration of the tide gates allowed water to flow up the slough and inundate the upstream area. In the MHHW + 36'' scenario, water overtops levees adjacent to the tide gates and results in a similar inundation pattern, as shown on Figure 7-9. The inundation patterns in this area after accounting for the presence of the tide gates could be further evaluated.

Figure 7-9. Inundation in Martinez in the MHHW + 24'' scenario

Due to the steep shoreline along much of Contra Costa County, impacts to other infrastructure such as bridges, highways, and residential areas do not become significant until the MHHW + 52'' and MHHW + 66'' SLR scenarios. In the MHHW + 52'' scenario, the water levels in the marsh surrounding I-680 rise past the highway deck elevation and begin to encroach on the shoulder and outer lanes in both directions. The MHHW + 66'' scenario causes water to overtop the Santa Fe Channel shoreline at several locations and travel landward to inundate a 2,000 ft low-lying section of I-580 2 miles from the Richmond Bridge, as shown on Figure 7-10.

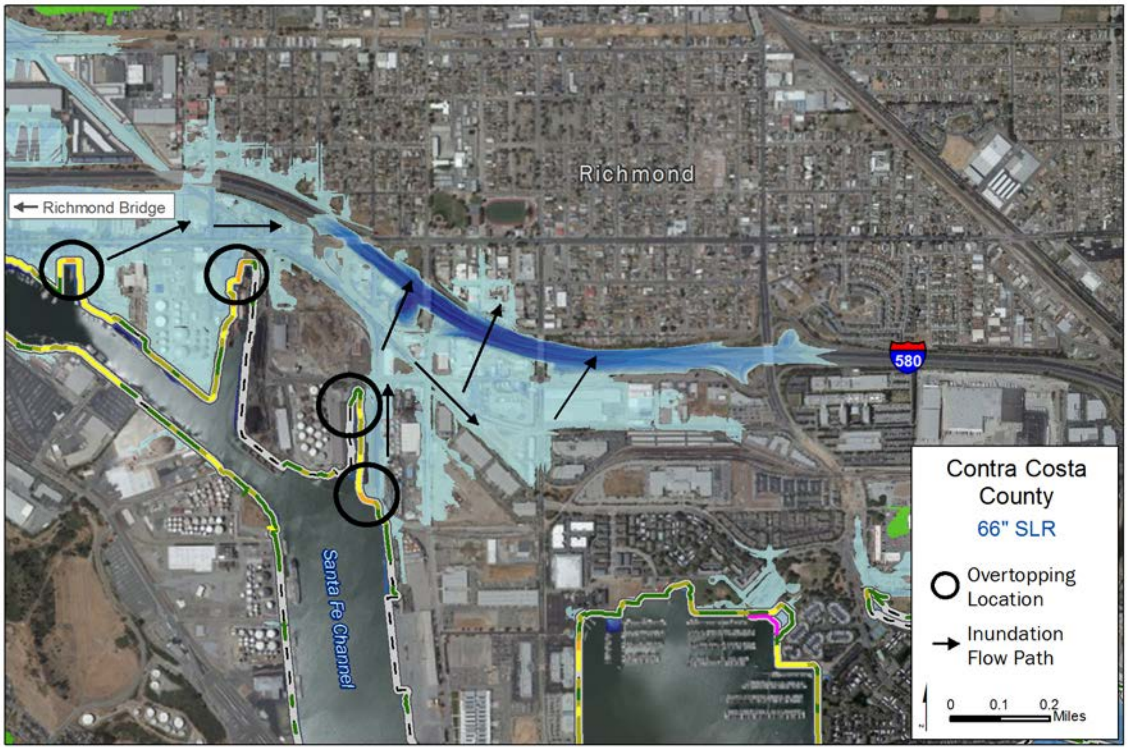

Figure 7-10. Inundation near the Richmond Bridge in the MHHW + 66'' scenario

7.6 ALAMEDA COUNTY

SLR MATRIX

The SLR matrix for Alameda County is presented in Table 7-7. The 10 possible scenarios (provided as individual sets of inundation maps in Appendix A) represent combinations of 0 to 66 inches of SLR with extreme tides from the 1-year to the 100-year return period. The values shown in the table present the daily and extreme tide levels above MHHW for Alameda County and are an average of the water levels at all model output points along Alameda's bayshore.

Table 7-7. Alameda Sea Level Rise and Extreme Tide Matrix

Sea Level Rise Scenario	Daily Tide	Extreme Tide (Storm Surge)						
	+SLR (in)	1yr	2yr	5yr	10yr	25yr	50yr	100yr
	Water Level above MHHW (in)							
Existing Conditions	0	15	19	24	27	32	37	42
MHHW + 6"	6	21	25	30	33	38	43	48
MHHW + 12"	12	27	31	36	39	44	49	54
MHHW + 18"	18	33	37	42	45	50	55	60
MHHW + 24"	24	39	43	48	51	56	61	66
MHHW + 30"	30	45	49	54	57	62	67	72
MHHW + 36"	36	51	55	60	63	68	73	78
MHHW + 42"	42	57	61	66	69	74	79	84
MHHW + 48"	48	63	67	72	75	80	85	90
MHHW + 52"	52	67	71	76	79	84	89	94
MHHW + 54"	54	69	73	78	81	86	91	96
MHHW + 60"	60	75	79	84	87	92	97	102
MHHW + 66"	66	81	85	90	93	98	103	108

in = inch(es)
MHHW = Mean Higher High Water
SLR = sea level rise
yr = year(s)

STAKEHOLDER ENGAGEMENT

Robust stakeholder engagement was conducted as part of the Adapting to Rising Tides project (AECOM et al. 2011) and the Alameda County Shoreline Vulnerability Assessment (AECOM 2015). No additional stakeholder engagement beyond that effort was conducted for the current effort.

DEM MODIFICATIONS

The topographic data used for this analysis were derived from topographic LiDAR data from USGS and NOAA. The SLR inundation mapping was completed on a 1-meter DEM and generally resolved topographic features of interest to accurately represent inundation of inland areas. The bare-earth LiDAR DEM was manually adjusted in some areas to account for recent levee breaches, new levees, and water control structures that were missing or misrepresented in the original DEM.

The following manual adjustments were made to the DEM:

- The elevation of the levee surrounding pond E10 was adjusted to reflect its new height.
- The elevation of the levee surrounding pond E12 was adjusted to reflect its new height.
- The elevation of the levee surrounding pond E13 was adjusted to reflect its new height.
- The elevation of the levee surrounding pond E14 was adjusted to reflect its new height.
- The elevation of the levee surrounding pond E9 was adjusted to reflect its new height.
- A series of breaches were added to the wall of Pond E9.
- The elevation of the levee surrounding pond E8A was adjusted to reflect its new height.
- A series of breaches were added to the wall of Pond E8A.
- The elevation of the levee surrounding pond E8X was adjusted to reflect its new height.
- The elevation of Burma Road was adjusted to reflect the newly constructed road.

A detailed list of the modifications to the Alameda County topographic DEM, including the locations and modified elevations, is provided in the topographic DEM metadata (available from BCDC).

DISCUSSION AND INTERPRETATION OF RESULTS

Summary of Impacted Assets for Alameda County	Timing of Impact
Toll plaza and westbound lanes at the Bay Bridge touchdown is exposed to inundation for a 500 ft section. Water overtops low-lying section of shoreline west of Doolittle Drive overpass and several low spots on Doolittle Drive along the east shoreline of Bay Farm Island, exposing much of Oakland International Airport property and facilities to inundation.	MHHW + 36''
SR 92 and SR 84 are exposed to inundation along a 2,000 ft section of the outer lanes leading to the San Mateo Bridge and Dumbarton Bridge. For SR 92, inundation exposure first occurs about 3,000 ft from the bridge toll plaza, and for SR 84 inundation first occurs about 1,700 ft from the toll plaza. Alameda: Water overtops a low-lying area near the Bay Farm overpass and inundates homes.	MHHW + 48''
Water overtops the shoreline south of Burma Road to expose residential areas of West Oakland to inundation.	MHHW + 52''

Bay Bridge = San Francisco–Oakland Bay Bridge
ft = foot/feet
MHHW = Mean Higher High Water
San Mateo Bridge = San Mateo–Hayward Bridge
SR = State Route
US 101 = U.S. Highway 101
'' = inch(es)

Alameda is a large county with a varied shoreline. In the northern part of the county, the shoreline is a mix of recreational use and light industrial and commercial uses, with dense residential areas immediately inland of the shore. South of Oakland International Airport, the shoreline is composed of salt and tidal ponds, recreational areas, wastewater utilities and plants, and wetlands. The county contains many transportation assets, including the Bay Bridge, the San Mateo–Hayward Bridge (San Mateo Bridge), and Dumbarton Bridge touchdowns.

AECOM reviewed the SLR inundation maps and identified key vulnerabilities that may benefit from further evaluation in Alameda County. The following discussion presents a high-level overview of potential SLR impacts to Doolittle Drive, the Bay Bridge toll plaza, SR 92, SR 94, and low-lying areas near the Bay Farm overpass in the city of Alameda.

The first scenario to expose critical assets to inundation is the MHHW + 36’’ scenario. In this scenario, the mapping indicates that the toll plaza of the Bay Bridge touchdown is exposed to inundation for approximately 500 ft. The inundation at this location was been previously evaluated as part of the ART project (AECOM 2015; AECOM et al. 2011). The mapping also shows the potential exposure of the Oakland International Airport in this scenario. Water overtops a low-lying section of the shoreline west of the Doolittle Drive overpass and several low spots on Doolittle Drive along the east shoreline of Bay Farm Island, as shown on Figure 7-11. [11] The inundation proceeds inland to impact much of the airport property and facilities, including the main runways.

Figure 7-11. Inundation of Oakland International Airport in the MHHW + 36’’ scenario

In the MHHW + 48’’ scenario, SR 92 leading to the San Mateo Bridge and SR 84 leading to the Dumbarton Bridge are exposed to inundation. In both cases, water overtops the fronting bayside berm, travels inland across the salt ponds, and inundates the low-lying areas of the highways. In this scenario, the inundation occurs for approximately 2,000 ft along the outer lanes of the highways. However, as the scenarios progress, the extent of inundation increases to cover the entire width of the road. On SR 92, inundation first occurs 3,000 ft from the bridge toll plaza, and on SR 84 inundation first occurs 1,700 ft from the toll plaza, as shown on Figure 7-12.

[11] See Section 3.5 for an explanation of the inundation depth and potential shoreline overtopping symbology shown in the focus area figures below.

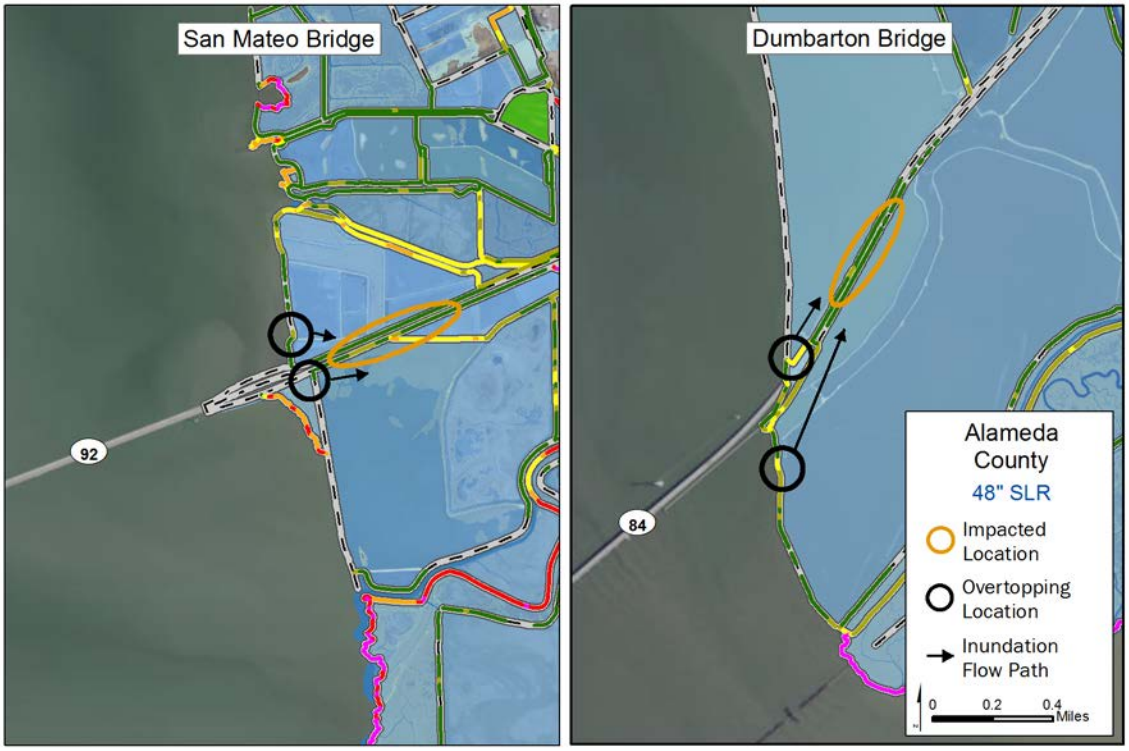

Figure 7-12. Inundation of SR 92 and SR 84 at the San Mateo and Dumbarton Bridges, in the MHHW + 48'' scenario

In the MHHW + 52'' scenario, the mapping indicates that the low-lying areas inland of the Bay Bridge touchdown are exposed to inundation. Water overtops the shoreline south of Burma Road and travels over the industrial areas to the residential areas of West Oakland.

7.7 SANTA CLARA COUNTY

SLR MATRIX

The SLR matrix for Santa Clara County is presented in Table 7-8. The 10 possible scenarios (provided as individual sets of inundation maps in Appendix A) represent combinations of 0 to 66 inches of SLR with extreme tides from the 1-year to the 100-year return period. The values shown in the table present the daily and extreme tide levels above MHHW for Santa Clara County and are an average of the water levels at all model output points along Santa Clara's bayshore.

Table 7-8. Santa Clara Sea Level Rise and Extreme Tide Matrix

Sea Level Rise Scenario	Daily Tide	Extreme Tide (Storm Surge)						
	+SLR (in)	1yr	2yr	5yr	10yr	25yr	50yr	100yr
	Water Level above MHHW (in)							
Existing Conditions	0	14	20	24	28	34	40	47
MHHW + 6"	6	20	26	30	34	40	46	53
MHHW + 12"	12	26	32	36	40	46	52	59
MHHW + 18"	18	32	38	42	46	52	58	65
MHHW + 24"	24	38	44	48	52	58	64	71
MHHW + 30"	30	44	50	54	58	64	70	77
MHHW + 36"	36	50	56	60	64	70	76	83
MHHW + 42"	42	56	62	66	70	76	82	89
MHHW + 48"	48	62	68	72	76	82	88	95
MHHW + 52"	52	66	72	76	80	86	92	99
MHHW + 54"	54	68	74	78	82	88	94	101
MHHW + 60"	60	74	80	84	88	94	100	107
MHHW + 66"	66	80	86	90	94	100	106	113

in = inch(es)
MHHW = Mean Higher High Water
SLR = sea level rise
yr = year(s)

STAKEHOLDER ENGAGEMENT

The project team coordinated with the Santa Clara County Valley Transportation Authority (VTA), the Santa Clara Valley Water District, and the Santa Clara County Office of Sustainability to conduct stakeholder outreach. These stakeholders recommended that the project team connect with Joint Venture Silicon Valley's Sea Level Rise Discussion Group, which is a group that convenes a number of Santa Clara County stakeholders. The group generally includes staff from the County of Santa Clara, the Bay-adjacent cities of Milpitas, San Jose, Santa Clara, Sunnyvale, Mountain View, and Palo Alto as well as relevant agencies, including the California State Coastal Conservancy, the United States Fish and Wildlife Service, and the San Francisquito Creek Joint Powers Authority (JPA). BCDC staff presented the project and draft maps and provided information on how to provide input on the online viewer. There was strong participation from a number of organizations, and many reviewed the draft maps and provided input. The project team evaluated the input on the maps and made changes, as appropriate, to the maps.

Santa Clara County Stakeholder Engagement

Draft Santa Clara maps were shared with the following groups for review:

- Santa Clara Valley Transportation Authority
- California State Coastal Conservancy
- Tetratech
- SV Joint Venture
- Office of Emergency Services, County of Santa Clara
- San Francisco Bay National Wildlife Refuge Complex, United States Fish and Wildlife Service
- Office of Sustainability, County of Santa Clara
- Santa Clara Valley Water District
- Cities of Milpitas, San Jose, Santa Clara, Sunnyvale, Mountain View, and Palo Alto
- San Francisquito Creek JPA
- San Francisco Bay Restoration Authority

DEM MODIFICATIONS

The topographic data used for this analysis were derived from topographic LiDAR data from USGS and NOAA. The SLR inundation mapping was completed on a 1-meter DEM and generally resolved topographic features of interest to accurately represent inundation of inland areas. The bare-earth LiDAR DEM was manually adjusted in some areas to account for recent levee breaches, new levees, and water control structures that were missing or misrepresented in the original DEM.

The following manual adjustments were made to the DEM:

- A tide gate was added to the entrance of Soap Pond.
- A tide gate was added to the entrance of Charleston Slough.
- A series of breaches were added to the wall of Pond A6.
- The elevation of the levee surrounding pond A6 was adjusted to reflect its new height.
- The elevation of the levee surrounding pond A16 was adjusted to reflect its new height.
- A series of breaches were added to the levee of Pond A17.
- The elevation of the levee surrounding pond A17 was adjusted to reflect its new height.
- A tide gate was added at the location of the Pond A8 notch.

A detailed list of the modifications to the Santa Clara County topographic DEM, including locations and modified elevations, is provided in the topographic DEM metadata (available from BCDC).

DISCUSSION AND INTERPRETATION OF RESULTS

Summary of Impacted Assets for Santa Clara County	Timing of Impact
Low-lying section of berms overtops, exposing commercial areas of Sunnyvale, NASA Ames Research Center, and a 1-mile section of SR 237.	MHHW + 24''
Palo Alto: Water overtops a series of salt pond berms, inundating a 1.2-square-mile residential area and a 2.5-mile section of US 101	MHHW + 36''

MHHW = Mean Higher High Water
NASA = National Aeronautics and Space Administration
SR = State Route
US 101 = U.S. Highway 101
'' = inch(es)

The developed edge of the Santa Clara County shoreline is fronted by former salt ponds that are often more than 1 mile wide. These former salt ponds are ringed by non-engineered berms built over the past century to hydraulically separate the pond areas from the Bay. These berms protect the low-lying area of Palo Alto, Mountain View, Alviso, and San Jose.

AECOM reviewed the SLR inundation maps and identified key vulnerabilities that may benefit from further evaluation in Santa Clara County. The following section presents a high-level overview of potential SLR impacts to low-lying areas, SR 237, and US 101.

The majority of the berms are constructed to elevations higher than MHHW + 24'', except for a few short segments that are projected to overtop in this scenario (see Figure 7-13[12]). This overtopping results in areas of potential inundation that encroach on the commercial areas of Sunnyvale, including the NASA Ames Research Center, and a 1-mile segment of SR 237 where inundation occurs over the full width of the road.

In the MHHW + 36'' scenario, more sections of the fronting berms overtop, leading to widespread inundation exposure in the areas behind the berms, including the Palo Alto Airport and long sections of US 101. In Palo Alto, the maps indicate that water overtops a series of salt pond berms and inundates an approximately 1.2-square-mile residential area of Palo Alto, including a 2.5-mile section of US 101, as shown on Figure 7-14.

[12] See Section 3.5 for an explanation of the inundation depth and potential shoreline overtopping symbology shown in the focus area figures below.

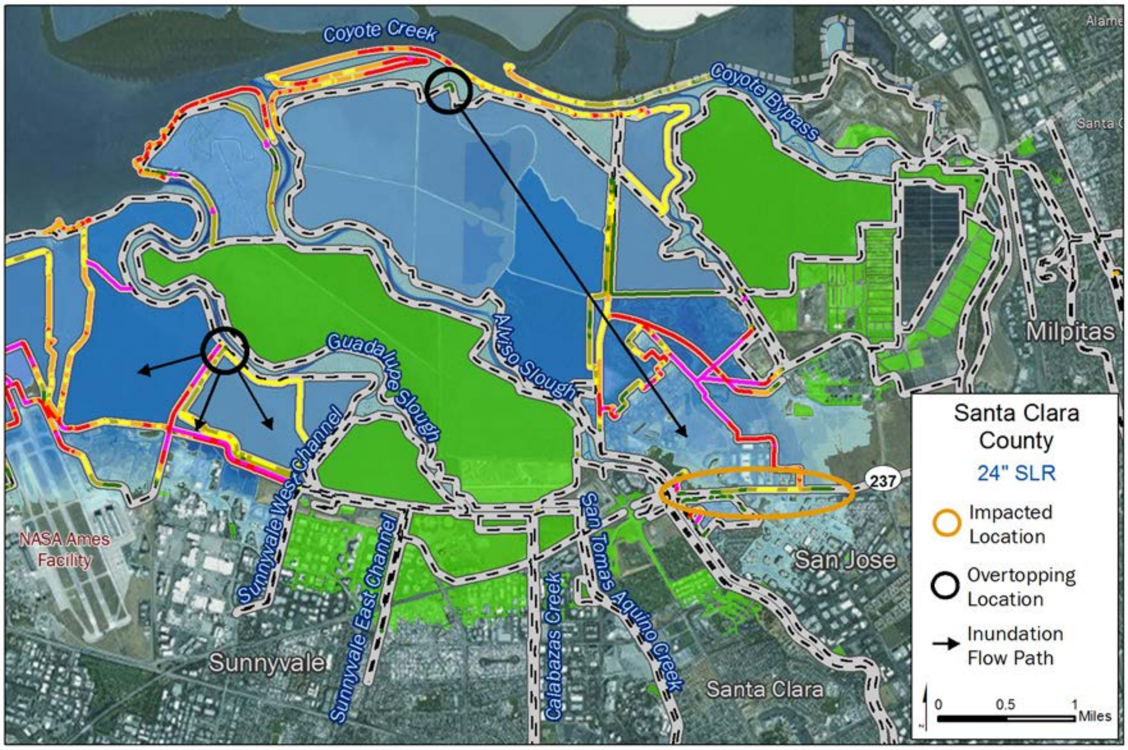

Figure 7-13. Inundation in Sunnyvale in the MHHW + 24'' scenario

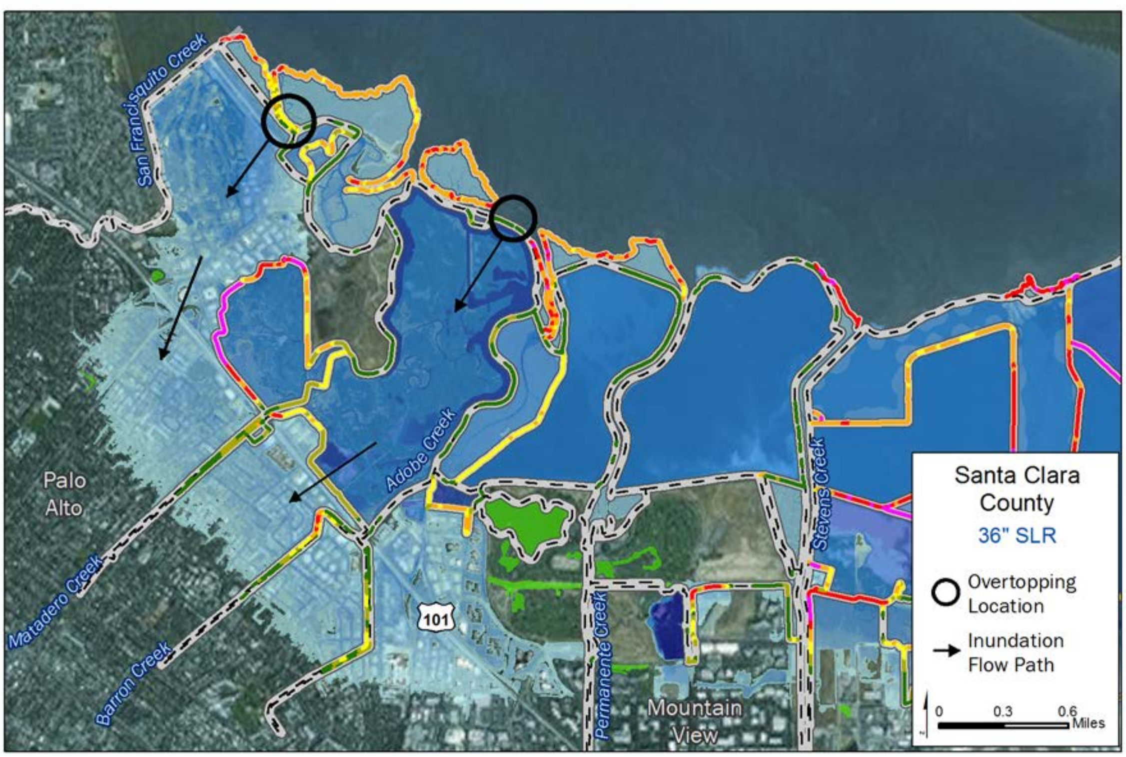

Figure 7-14. Inundation in Palo Alto in the MHHW + 36'' scenario

7.8 SAN MATEO COUNTY

SLR inundation mapping products for San Mateo County were originally developed as part of the San Mateo County Sea Level Rise Vulnerability Assessment. AECOM developed these prior mapping products for the California State Coastal Conservancy (AECOM 2016b). The project team reformatted the SLR inundation maps and supporting GIS data layers developed for that study to align with all the other county mapping completed in support of this effort (the Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project).

SLR MATRIX

The SLR matrix for San Mateo County is presented in Table 7-9. The 10 possible scenarios (provided as individual sets of inundation maps in Appendix A) represent combinations of 0 to 66 inches of SLR with extreme tides from the 1-year to the 100-year return period. The values shown in the table present the daily and extreme tide levels above MHHW for San Mateo County and are an average of the water levels at all model output points along San Mateo's bayshore.

Table 7-9. San Mateo Sea Level Rise and Extreme Tide Matrix

Sea Level Rise Scenario	Daily Tide	Extreme Tide (Storm Surge)						
	+SLR (in)	1yr	2yr	5yr	10yr	25yr	50yr	100yr
	Water Level above MHHW (in)							
Existing Conditions	0	15	19	24	27	32	37	42
MHHW + 6"	6	21	25	30	33	38	43	48
MHHW + 12"	12	27	31	36	39	44	49	54
MHHW + 18"	18	33	37	42	45	50	55	60
MHHW + 24"	24	39	43	48	51	56	61	66
MHHW + 30"	30	45	49	54	57	62	67	72
MHHW + 36"	36	51	55	60	63	68	73	78
MHHW + 42"	42	57	61	66	69	74	79	84
MHHW + 48"	48	63	67	72	75	80	85	90
MHHW + 52"	52	67	71	76	79	84	89	94
MHHW + 54"	54	69	73	78	81	86	91	96
MHHW + 60"	60	75	79	84	87	92	97	102
MHHW + 66"	66	81	85	90	93	98	103	108

in = inch(es)
MHHW = Mean Higher High Water
SLR = sea level rise
yr = year(s)

STAKEHOLDER ENGAGEMENT

Robust stakeholder engagement was conducted as part of *Sea Level Rise & Overtopping Analysis for San Mateo County's Bayshore* (AECOM 2016b). No additional stakeholder engagement beyond that effort was conducted for the current effort.

DEM MODIFICATIONS

The topographic data used for this analysis were derived from topographic LiDAR data from USGS and NOAA. The SLR inundation mapping was completed on a 1-meter DEM and generally resolved topographic features of interest to accurately represent inundation of inland areas. The bare-earth LiDAR DEM was manually adjusted in some areas to account for recent levee breaches, new levees, and water control structures that were missing or misrepresented in the original DEM.

The following supplemental topographic data sources were also incorporated into the DEM:

- United States Army Corps of Engineers (USACE) South Bay bathymetric survey (in 2009)
- USACE dredging surveys (in 2003)
- City of San Mateo bayfront levee improvements (in 2012)
- San Mateo Creek flood control improvements (in 2002)
- Redwood Shores Exterior Levee Segment III Maintenance Project (in 2009)
- Redwood Shores Levee Improvement Project (in 2009)
- East Palo Alto Runnymede Storm Drain Phase II Project (in 2014)
- Foster City levee surveys (received 2016)
- City of Foster City: Levee Pedway Topographic Survey (in 2011)
- Survey data from the SFO shoreline protection system (received 2015)
- Survey data for the U.S. Coast Guard property at SFO (received 2016)

The following additional field verification data was also examined:

- Burlingame floodwall along the San Francisco Bay Trail (in 2016)

The following manual adjustments were made to the DEM:

- The levees along Redwood Shores were adjusted to reflect a 2009 improvement project.
- The levees along the San Mateo bayfront were adjusted to reflect a 2012 improvement project.
- The levees surrounding Foster City and along Seal Slough were adjusted to reflect the Foster City levee surveys.
- The levees along San Mateo Creek were adjusted to reflect a 2002 flood control improvement project.
- The road and crest elevations along the U.S Coast Guard property at SFO were adjusted to reflect new survey data.
- A tide gate was added at the entrance of Runnymede storm drain.
- The bridge deck elevation of Dumbarton Bridge was extracted from the raw LiDAR data and added to the DEM.
- The elevation of the wall along the Bay Tail was extracted from the raw LiDAR data and added to the DEM.

A detailed list of the modifications to the San Mateo County topographic DEM, including locations and modified elevations, is provided in the topographic DEM metadata (available from BCDC).

Summary of Impacted Assets for San Mateo County	Timing of Impact
Frontage road along north side of SR 84 at the western touchdown of the Dumbarton Bridge is exposed to inundation.	MHHW + 12''
Inundation of westbound Dumbarton Bridge access expands to include the adjacent bike path and a 1-mile section of the eastbound lane. The outside lanes of SR 84 are exposed to inundation for 1 mile.	MHHW + 24''
Foster City: Surrounding low-lying levees are overtopped, exposing the San Mateo Bridge touchdown, a 3-mile section of SR 92, and a 3-mile section of US 101 to inundation.	MHHW + 52''

MHHW = Mean Higher High Water
San Mateo Bridge = San Mateo–Hayward Bridge
SR = State Route
US 101 = U.S. Highway 101
'' = inch(es)

The San Mateo shoreline runs from the end of Candlestick Point at the San Francisco–San Mateo county line to the outfall of San Francisquito Creek, approximately 2.5 miles south of the Dumbarton Bridge. The shoreline is mostly composed of wetlands, former salt ponds, and developed commercial areas, including SFO.

AECOM reviewed the SLR inundation maps and identified key vulnerabilities that may benefit from further evaluation in San Mateo County. The following section presents a high-level overview of potential SLR impacts to Dumbarton Bridge access, SR 84, SR 92, US 101, and access to the San Mateo Bridge in the Foster City area.

The mapping indicates that some of the salt ponds in the south part of the county may be exposed to inundation in the MHHW + 12'' scenario, including the ponds surrounding the north side of the Dumbarton Bridge touchdown. In this scenario, the inundation extends beyond these ponds to the westbound bridge access road, impacting the full length of the road. Water flows from the westbound lane and covers the entire width of the road for approximately half of the road length. In the MHHW + 24'' scenario, the inundation surrounding the bridge touchdown increases to include the bike path adjacent to the eastbound lane and the eastbound access road, as shown on Figure 7-15.[13] The mapping indicates that the inundation in this area extends for approximately 1 mile starting from the bridge touchdown at the bayfront. The sources of inundation for this scenario include overtopping from the bayfront berms and breaches in the Ravenswood pond system. The road surface leading from the touchdown is also first impacted in the MHHW + 24'' scenario, as water encroaches onto the road surface, impacting the outside lane on either side of SR 84. During a site visit conducted after completion of the San Mateo County mapping project (AECOM 2016b), AECOM staff observed a low protective wall along the north side of the access road constructed as part of the Dumbarton Bridge Seismic Retrofit project; this wall may reduce flood vulnerabilities in this area. This area could be evaluated further to understand the effect of the wall in reducing flood and SLR vulnerabilities in this area.

[13] See Section 3.5 for an explanation of the inundation depth and potential shoreline overtopping symbology shown in the focus area figures below.

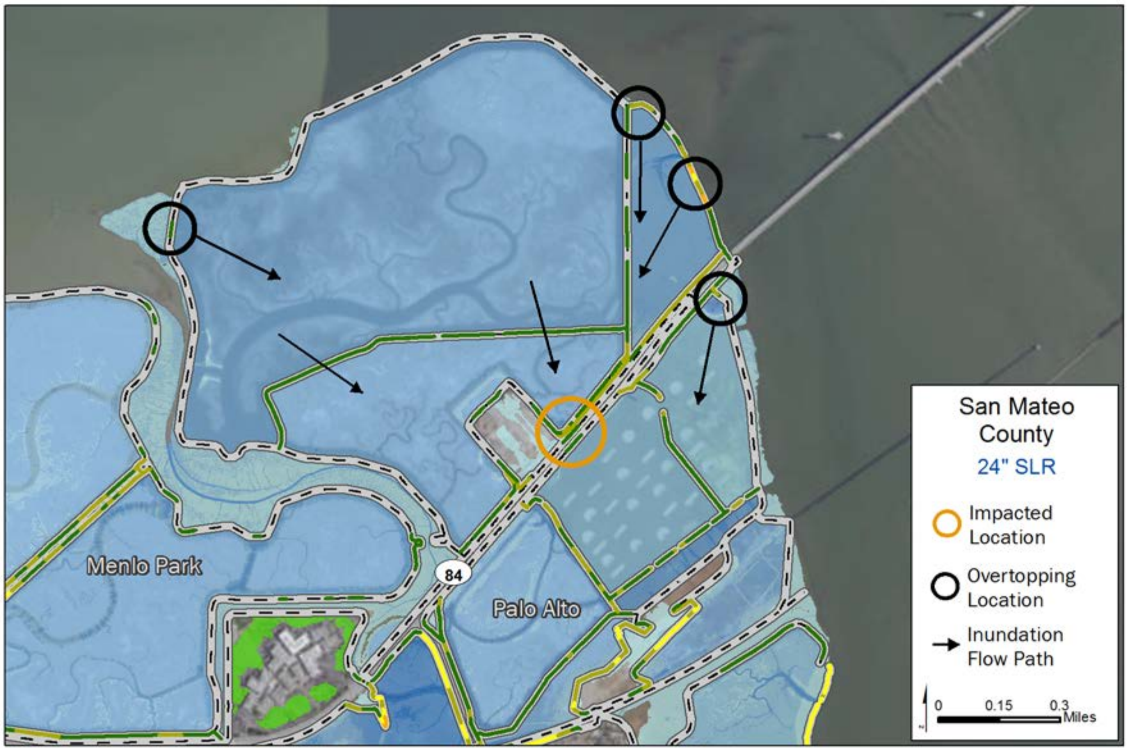

Figure 7-15. Inundation at the Dumbarton Bridge Touchdown in the MHHW + 24'' scenario

Note: SLR inundation mapping does not take into account temporary flood barrier constructed by Caltrans along the north frontage road of the Dumbarton Bridge in 2010.

The San Mateo Bridge touchdown is in Foster City, a low-lying area protected by levees. This area is protected from inundation through the MHHW + 48'' scenario, as the levees are at a relatively high elevation. In the MHHW + 52'' scenario, the mapping shows overtopping of the levee that results in widespread potential inundation of the low-lying area behind the levee, including the bridge touchdown, a 3-mile section of SR 92 and a 3-mile section of US 101, as shown on Figure 7-16.

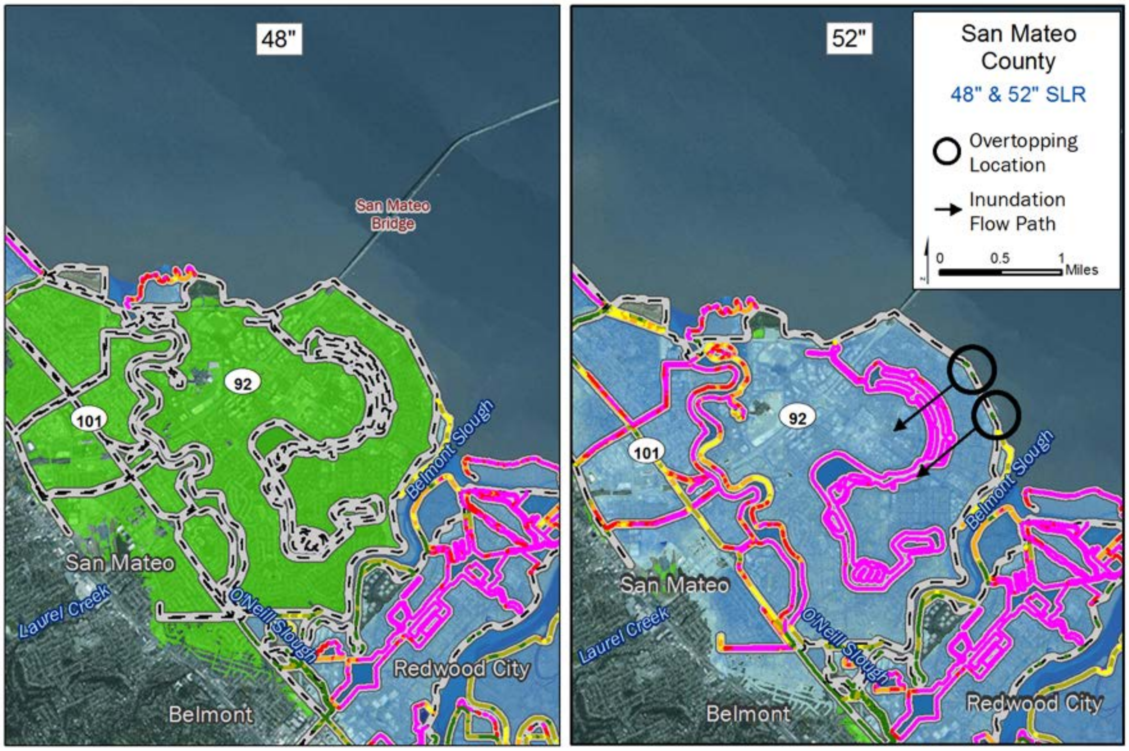

Figure 7-16. Inundation near the San Mateo Bridge in the MHHW + 48 and 52'' scenarios

7.9 SAN FRANCISCO CITY AND COUNTY

SLR inundation mapping products for the City and County of San Francisco were originally developed as part of the San Francisco Public Utilities Commission Sewer System Improvement Program Climate Change Adaptation Plan (in preparation at time of this report). The SLR inundation maps and supporting GIS data layers developed for that study were reformatted by the project team to align with all other county mapping completed in support of the Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project. In addition, the sea level rise inundation mapping of the piers completed for the Port of San Francisco (AECOM 2016a) was combined with the complete San Francisco data set to create a unified data set.

SLR MATRIX

The SLR matrix for San Francisco County is presented in Table 7-10. The 10 possible scenarios (provided as individual sets of inundation maps in Appendix A) represent combinations of 0 to 66 inches of SLR with extreme tides from the 1-year to the 100-year return period. The values shown in the table present the daily and extreme tide levels above MHHW for San Francisco County and are an average of the water levels at all model output points along San Francisco's bayshore

Table 7-10. San Francisco Sea Level Rise and Extreme Tide Matrix

Sea Level Rise Scenario	Daily Tide	Extreme Tide (Storm Surge)						
	+SLR (in)	1yr	2yr	5yr	10yr	25yr	50yr	100yr
	Water Level above MHHW (in)							
Existing Conditions	0	12	19	23	27	32	36	41
MHHW + 6"	6	18	25	29	33	38	42	47
MHHW + 12"	12	24	31	35	39	44	48	53
MHHW + 18"	18	30	37	41	45	50	54	59
MHHW + 24"	24	36	43	47	51	56	60	65
MHHW + 30"	30	42	49	53	57	62	66	71
MHHW + 36"	36	48	55	59	63	68	72	77
MHHW + 42"	42	54	61	65	69	74	78	83
MHHW + 48"	48	60	67	71	75	80	84	89
MHHW + 52"	52	64	71	75	79	84	88	93
MHHW + 54"	54	66	73	77	81	86	90	95
MHHW + 60"	60	72	79	83	87	92	96	101
MHHW + 66"	66	78	85	89	93	98	102	107

in = inch(es)
MHHW = Mean Higher High Water
SLR = sea level rise
yr = year(s)

STAKEHOLDER ENGAGEMENT

Robust stakeholder engagement was conducted as part of the San Francisco Public Utilities Commission Sewer System Improvement Program Climate Change Adaptation Plan. No additional stakeholder engagement beyond that effort was not conducted for the current effort.

DEM MODIFICATIONS

The topographic data used for this analysis were derived from topographic LiDAR data from USGS and NOAA. The SLR inundation mapping was completed on a 1-meter DEM and generally resolved topographic features of interest to accurately represent inundation of inland areas. The bare-earth LiDAR DEM was manually adjusted along the shoreline to incorporate the deck elevations of the many piers and docks along the San Francisco waterfront (AECOM 2016a). A detailed list of the modifications to the San Francisco County topographic DEM, including locations and modified elevations, is provided in the topographic DEM metadata (available from BCDC).

DISCUSSION AND INTERPRETATION OF RESULTS

Summary of Impacted Assets for San Francisco County	Timing of Impact
There is isolated exposure to inundation in Mission Bay, Islais Creek, and along the Embarcadero.	MHHW + 48''
Exposure to inundation around Mission Bay expands to include the Caltrain station, a 2,000 ft section of the rail lines, and the on-/off-ramps to Interstate 280 (I-280). Overtopping occurs along a 200 ft shoreline segment, inundating a 550 ft section of US 101 in both directions near Crissy Field.	MHHW + 52''

ft = foot/feet
I-280 = Interstate 280
MHHW = Mean Higher High Water
US 101 = U.S. Highway 101
'' = inch(es)

The San Francisco shoreline is highly developed and mostly composed of constructed shoreline features such as revetments, bulkheads, ports, and pier structures. Dense commercial and residential development is present immediately behind the shoreline.

AECOM reviewed the SLR inundation maps and identified key vulnerabilities that may benefit from further evaluation in San Francisco County. The following section presents a high-level overview of potential SLR impacts to low-lying areas of Mission Bay, Islais Creek, the Embarcadero, I-280, and US 101.

The SLR inundation mapping indicates that significant inundation does not occur until the MHHW + 48'' scenario, at which point small and isolated areas in Mission Bay, Islais Creek, and along the Embarcadero are projected to become inundated. In the MHHW + 52'' scenario, inundation around Mission Bay expands to include the Caltrans station and a 2,000 ft segment of the rail lines. This location also experiences inundation of the on-/off-ramps to I-280. Inundation in this area is a result of water overtopping the Mission Bay shoreline and traveling up a low-lying creek, as shown on Figure 7-17.[14]

In the north part of the county, flooding may occur over short segments of US 101 in the MHHW + 52" scenario (Figure 7-18). Water flows into Crissy Field Marsh, overtopping a 200 ft shoreline segment and continuing onto the adjacent road, traveling landward and inundating a 550 ft section of US 101.

[14] See Section 3.5 for an explanation of the inundation depth and potential shoreline overtopping symbology shown in the focus area figures below.

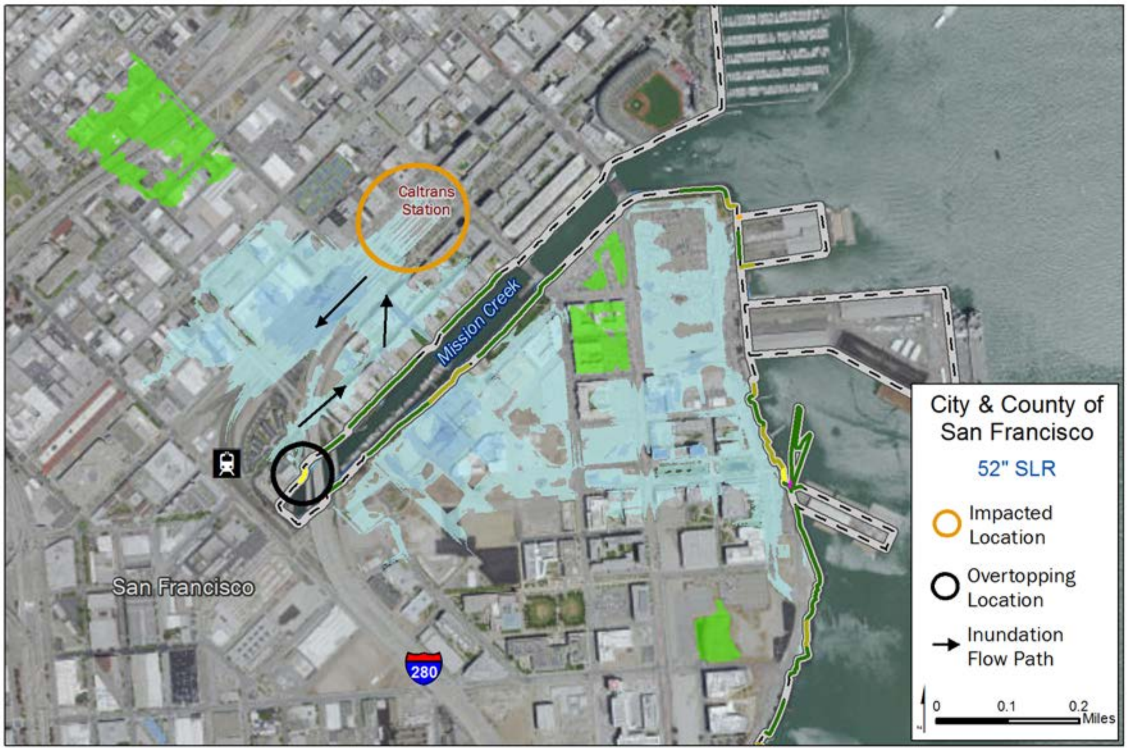

Figure 7-17. Inundation in Mission Bay in the MHHW + 52" scenario

Figure 7-18. Inundation at Crissy Field, San Francisco in the MHHW + 52''

8.0

MAPPING ASSUMPTIONS AND CAVEATS

8. MAPPING ASSUMPTIONS AND CAVEATS

The inundation maps are intended to be used as a screening-level tool to assess exposure to future SLR and extreme tide/storm surge–induced coastal flooding. These maps represent a “do nothing” future scenario, and although they rely on the best available and current information and data sources, they are still associated with a series of assumptions and caveats, as described below.

- The inundation scenarios associated with an increase in future MHHW (SLR above MHHW) represent areas that could be inundated permanently on a regular basis by tidal action. The inundation scenarios associated with extreme tide levels and storm surge represent periodic or temporary inundation associated with coastal flooding. The inundation maps for extreme tide scenarios do not consider the duration of flooding or the potential mechanism for draining the floodwaters from the inundated land once the extreme high tide levels recede.
- The bathymetry of San Francisco Bay and the topography of the landward areas, including levees and other flood and shore protection features, are assumed to remain constant. No potential physical shoreline changes are included in the analysis and mapping. The accumulation of organic matter in wetlands, potential sediment deposition and/or resuspension, and subsidence that could alter San Francisco Bay hydrodynamics and/or bathymetry are not captured within the SLR scenarios. An online data viewer created by Point Blue Conservation Science provides information on projected wetland evolution in response to sea level rise and sediment supply (http://data.prbo.org/maps/sfbmap_html.php).
- The maps do not account for future construction or levee upgrades. The mapping methods also do not consider the existing condition or age of the shore protection assets. No degradation or levee failure models have been analyzed as part of the inundation mapping effort.
- The maps do not account for flooding from potential increases in the groundwater table as sea levels rise.
- The maps do not account for water flow through water control structures such as culverts or tide gates.
- The inundation and flooding depths shown on heavily vegetated marsh plain surfaces may not be accurate due to vegetation interference with the bare-earth LiDAR signal, which may bias topographic elevation data high in these areas.
- The levee heights and the heights of roadways and/or other topographic features that may affect floodwater conveyance are derived from the USGS and NOAA 2010 LiDAR data. Although this data set represents the best available topographic data, the data have not been extensively ground-truthed, and levee crests may be overrepresented or underrepresented by the LiDAR data. It is possible that features narrower than the 1 m horizontal map scale may not be fully represented.
- The inundation depth and extent shown on the MHHW maps are associated with the typical high tide to approximate the maximum extent of future daily tidal inundation. This level of inundation can also be referred to as “permanent inundation” because it represents the area that would be inundated regularly. Tides in San Francisco Bay exhibit two highs and two lows in any given day, and the daily high tide on any given day may be higher or lower than the MHHW tidal elevation.
- The depth and extent of inundation for an extreme coastal storm event (e.g., including local wind and wave effects) were not included in this project. These processes could have a significant effect on the ultimate depth of inundation associated with a large coastal wind/wave event, especially near the shoreline.

- The inundation maps do not account for localized inundation associated with any freshwater inputs, such as rainfall-runoff events, or the potential for riverine overbank flooding in the local tributaries associated with large rainfall events. Inundation associated with changing rainfall patterns, frequency, or intensity as a result of climate change is also not included in this analysis.
- The science of climate change is constantly evolving and SLR projections have a wide range of values.

9.0

CONCLUSIONS AND NEXT STEPS


Matson

9. CONCLUSIONS AND NEXT STEPS

The Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project led to the development of a variety of geo-spatial tools and data layers that can assist with identifying shoreline vulnerabilities and formulating and implementing adaptation strategies. These tools and data layers include the following for each of the nine Bay Area counties:

- A 1-meter resolution topographic DEM
- SLR inundation maps showing depth and extent for 10 scenarios
- Shoreline overtopping potential maps for 10 scenarios
- SLR and extreme tide matrix
- Discussion of key SLR and flooding vulnerabilities

The SLR inundation maps provide a first step for identifying assets exposed to increased flooding and/or inundation from rising seas and storm surge. The overtopping maps help illustrate the primary inundation pathways from the Bay and show the depth of potential inundation over shoreline segments for each inundation scenario. Using these tools, stakeholders can understand shoreline asset exposure to a broad range of SLR projections. In addition, the tools help identify where shoreline vulnerabilities may exist and roughly identify the timing for adaptation actions to maintain or improve existing levels of shoreline flood protection.

The tools and products highlight areas where near-term shoreline adaptation strategies may be necessary, and they can also illustrate when local adaptation efforts are no longer sufficient, and regional collaboration is required to reduce or mitigate flood risks.

The tools and data layers are for planning-level assessments only. They should not be used for engineering design or construction purposes without consultation with a qualified engineering professional. However, these products help identify where additional detailed information is needed to confirm shoreline vulnerabilities and can support the need for additional engineering analysis.

Several next steps could improve on the foundation provided in this project. Most notably, the consideration of wave hazards, precipitation-based flooding (and interaction between coastal and riverine flood events), changes in future storm intensity and frequency, and changes in groundwater levels. These next steps are considered in more detail below.

- **Wave hazards.** For shorelines and developments directly along the bayshore, the consideration of wave hazards is required. Wave hazards, such as wave run-up and overtopping, are dependent on the shoreline type, roughness, slope, and other factors that require more detailed analysis than that presented in this project. In addition, wave run-up may not increase linearly with SLR (i.e., a 1 ft increase in SLR may lead to more than a 1 ft increase in wave run-up). A coastal engineering assessment is required for both existing conditions and proposed adaptation strategies to adequately consider wave hazards and how they might change in the future with SLR.

- **Combined coastal-riverine events.** Extreme storm events in the Bay Area, particularly during El Niño winters, often include extreme Bay water levels and precipitation. The cumulative impacts of rainfall runoff and storm surge were not considered in this project; however, the combination of these factors would further exacerbate inland flooding. In nearshore developed areas, particularly in areas behind flood protection infrastructure with topographic elevations below the Bay water surface elevation during an extreme event, it is important to consider the impacts of heavy rainfall and storm surge occurring together.

- **Climate change and storminess.** Changes in storm frequency and magnitude due to climate change were also not examined in this project, but an evaluation of these dynamics may provide further insight into when adaptation strategies need to be implemented.
- **SLR and groundwater.** Rising groundwater tables, primarily associated with SLR, can also impact flooding and drainage by reducing infiltration and sub-surface storage of runoff. The impacts of rising groundwater tables on watershed flooding are not well understood. With higher groundwater tables and rising sea levels, existing drainage systems will become less effective over time, and they may become completely ineffective with higher levels of SLR. Evaluation of these factors is recommended as a next step before adaptation strategies are implemented.

10.0

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10. REFERENCES

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A

INUNDATION AND OVERTOPPING MAPS

APPENDIX A. INUNDATION AND OVERTOPPING MAPBOOKS

See county mapbooks attached under separate cover

B

GIS DATABASE CATALOG

Photo Courtesy of Contra Costa Flood Control and Water Conservation District

APPENDIX B. GIS DATABASE CATALOG

GIS DATABASE CATALOG – MARIN COUNTY

Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project

This GIS database catalog describes all of the GIS datasets produced for the sea level rise and overtopping analysis for Marin County, California. Metadata is included in FGDC CSDGM Metadata format within 'Marin_SLR_ART_2017', which is viewable (and exportable) in ArcGIS.

COORDINATE SYSTEM: UTM ZONE 10N

- Horizontal Datum: North American Datum 1983 (NAD83) UTM Zone 10N - Meters
- Vertical Datum: North American Vertical Datum of 1988 (NAVD88) - Feet

The GIS data produced from this study are contained within a single folder titled "MarinCo_OT_Inundation". This folder contains all of the GIS products produced from the analysis as well as source files. These are described in more detail below:

/Marin_lyr/

This folder contains two ArcGIS layer files (.lyr). These layers files can be added into ArcMap (.mxd) so that the inundation feature classes (found within the geodatabase) can be easily classified.

1. *symbology_inundation_raster.lyr*

   For visualizing the inundation rasters produced for each of the 10 total inundation scenarios.

2. *symbology_inundation_poly.lyr*

   For visualizing the inundation polygons produced for each of the 10 total inundation scenarios.

3. *symbology_lowlying.lyr*

   For visualizing the low-lying polygons produced for each of the 10 total inundation scenarios.

4. *symbology_overtopping.lyr*

   For visualizing the overtopping lines produced for each of the 10 total inundation scenarios.

5. *symbology_shoreline.lyr*

   For visualizing the shoreline placed under the overtopping layers.

/Marin_SLR_ART_2017.gdb/

This geodatabase contains the SLR analysis and overtopping output for each of the ten scenarios. The sea level rise scenario is indicated by the number appended to the end of the filename. For example, the "landward_inundation_12" raster is the inundation layer for the MHHW + 12-inch scenario.

- ***Inundation Rasters:*** Marin_inundation_rast_x

  These rasters contain extent and depth of land-only inundation (in feet) of the Marin County bayside shoreline under various sea level rise scenarios. The sea level rise scenarios are described in terms of inches above the current conditions mean higher high water (MHHW) tidal datum. These scenarios include: 12", 24", 36", 48", "52", "66", 77", "84","96" and 108" of water level above MHHW.

- ***Inundation Polygons:*** Marin_inundation_poly_x

  These polygons were converted from raster (Marin_inundation_rast_x). They are classified into seven features for each scenario based on the depth (in feet) of the water surface. The field 'DEPTH_FT' includes the following depths: "0 – 2", "2 – 4", "4 – 6", "6 – 8", "8 – 10", "10 – 12", "12+" feet.

- ***Lowlying Polygons:*** Marin_lowlying_poly_x

  These polygons identify low-lying areas greater than one acre. They depict areas that are below the inundated water surface elevation, but are not hydraulically-connected to the inundated areas. The fields included are only used for identifying (and masking) low-lying areas under each sea level rise scenario.

- ***Shoreline Delineation:*** Marin_shoreline

  This polyline layer represents the line delineation along the high point of shoreline features. The dissolved shoreline is intended for visualization purposes.

- ***Overtopping Potential Depth and Shoreline by Type Information:*** Marin_overtopping_line_x

  - Overtopping Potential Depth: These lines depict the elevation of shoreline features relative to future water levels under each of the 10 sea level rise scenarios. The depth of overtopping is represented in the field 'Overtopping Depth (ft).' Null values indicate no overtopping.
  - Shoreline by Type: These lines also represent the shoreline by type classification completed by the San Francisco Estuary Institute (2016). The shoreline by type layer depicts the various shoreline categories as they relate to coastal flooding for a quick reference of natural and altered shorelines. The shoreline types depict natural shorelines, engineered structures or man-made shoreline alterations, and transportation structures. Features were digitized from a variety of sources including LiDAR, satellite, existing infrastructure layers and aerial imagery. For additional information on SFEI's methodology, see: http://www.sfei.org/content/flood-infrastructure-mapping-and-communication-project. Minor corrections to the original SFEI classifications were completed by AECOM as needed.

  For a full description of all attributes in the overtopping potential depth and shoreline by type, please see Table 1 below.

Table 1. Attribute Field Names and Descriptions for *Overtopping Potential* and *Shoreline by Type* Information in GIS Data Layers

Field in GIS layer	Source	Description	Attributes
Class	SFEI	A description of the feature being mapped.	‘Engineered Levee’, ‘Floodwall’, ‘Berm’, ’Shoreline Protection Structure’, ‘Embankment’, ’Transportation Structure’, ’Natural Shoreline’, ’Wetland’, ’Channel or Opening’, ’Water Control Structure’
Transportation Type	SFEI	Separated ‘Transportation Structure’ classification into two sub-classes, ‘Rail’ and ‘Major Road’ based on aerial imagery.	‘Major Road’ or ‘Rail’
Fortified	SFEI	If features were artificially hardened, indicated by the presence of concrete, riprap, or buttressing, than the ‘Fortified’ category was assigned a value of ‘Yes’. The best available aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Fortified field was assigned to all ten primary classification categories. Hardening of the mapped features could of been completed in an ad hoc manner or specifically designed to address wave erosion.	’Yes’ or ’No’

Field in GIS layer	Source	Description	Attributes
Frontage	SFEI	Along the Bay shore, frontage was assigned to features where there is either a 1) wetland, 2) beach, or 3) wetland and beach in front of a feature. Category is assigned as 'Wetland', 'Beach', or 'Wetland and Beach', accordingly. "None' designates Bay shore features with no wetland or beach frontage. A variety of aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Beaches were also identified from our partners at BCDC and were not explicitly mapped as features themselves.	'None', 'Wetland', 'Beach', or 'Beach and Wetland'
Bayshore Defense	SFEI	This field identifies the first line of features along the shoreline which would provide the 'first line of defense' to coastal flooding.	'First line of shoreline defense' or 'Not first line of shoreline defense' or 'Wetland on Bay shore'
Agency Designation	SFEI	Field is populated for all 'Engineered Levees' to show FEMA's designation (e.g., Ac- credited by FEMA, Formerly accredited by FEMA) as referenced from the FEMA MLI (2014) dataset or simply 'Engineered', if a feature was sourced as being engineered for flood management by an agency representative during dataset review meetings.	'Accredited by FEMA' or 'Formerly Ac- credited by FEMA' or 'Engineered' (if designated 'Engineered Levee' in Class field, or 'Engineered' if designated 'Floodwall' in Class field)
Agency Designation Source	SFEI	Source for attributing the 'Engineered Levee' classification.	(e.g., FEMA MLI (2014), CCCFCWCD, pro- vided by local stakeholders)

Field in GIS layer	Source	Description	Attributes
FEMA Accreditation Date	SFEI	The year a structure was accredited by FEMA, based on the FEMA MLI (2014) data- set. Only attributed for 'Engineered Levee' features.	(e.g., 1/15/1990)
Primary Map Source	SFEI	Refers to the primary DEM or other aerial imagery that was referenced for mapping.	(e.g., USGS 2010, NOAA/OPC 2010)
Geographic County	SFEI	The represented Bay Area county.	(e.g., Marin County)
Public/Private	SFEI	Features were assigned ownership (e.g., private, public) based on county parcel data- sets or individual county, city, and agency knowledge, when data was available. The California Protected Areas Dataset (Green Info Network, 2014) was also referenced. While effort has been made to attribute ownership accurately, limitations exist as some mapped features bordered two different parcels and assigning ownership could not be differentiated within the parcel dataset.	'Private' or 'Public'
Owner Details	SFEI	Specific names of owners, when data was available.	(e.g., NCFCWCD)
Maintained By	SFEI	Designates who is responsible for maintenance of a feature. Information was gathered from city, county, and agency representatives, where information was available. Only limited information on maintenance was readily available.	(e.g., USFWS)

Field in GIS layer	Source	Description	Attributes
Comments	SFEI	Additional comments for mapped features	(e.g., engineered levees that also have floodwalls)
Suppress Overtopping	AECOM	Field to designate whether the segment is shown on printed maps. Typical segments that are not shown include wetland segments that are within ~100 feet of primary shoreline, channel openings, or elevated transportation structures with openings.	Yes' or 'No'
Overtopping Depth (ft)	AECOM	Overtopping potential depth (in feet) per shoreline segment. Null values indicate no overtopping.	‘Double' field type.

GIS DATABASE CATALOG – SONOMA COUNTY

Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project

This GIS database catalog describes all of the GIS datasets produced for the sea level rise and overtopping analysis for Sonoma County, California. Metadata is included in FGDC CSDGM Metadata format within 'Sonoma_SLR_ART_2017', which is viewable (and exportable) in ArcGIS.

COORDINATE SYSTEM: UTM ZONE 10N

- Horizontal Datum: North American Datum 1983 (NAD83) UTM Zone 10N - Meters
- Vertical Datum: North American Vertical Datum of 1988 (NAVD88) - Feet

The GIS data produced from this study are contained within a single folder titled "SonomaCo_OT_Inundation". This folder contains all of the GIS products produced from the analysis as well as source files. These are described in more detail below:

/Sonoma_lyr/

This folder contains two ArcGIS layer files (.lyr). These layers files can be added into ArcMap (.mxd) so that the inundation feature classes (found within the geodatabase) can be easily classified.

1. *symbology_inundation_raster.lyr*

   For visualizing the inundation rasters produced for each of the 10 total inundation scenarios.

2. *symbology_inundation_poly.lyr*

   For visualizing the inundation polygons produced for each of the 10 total inundation scenarios.

3. *symbology_lowlying.lyr*

   For visualizing the low-lying polygons produced for each of the 10 total inundation scenarios.

4. *symbology_overtopping.lyr*

   For visualizing the overtopping lines produced for each of the 10 total inundation scenarios.

5. *symbology_shoreline.lyr*

   For visualizing the shoreline placed under the overtopping layers.

/Sonoma_SLR_ART_2017.gdb/

This geodatabase contains the SLR analysis and overtopping output for each of the ten scenarios. The sea level rise scenario is indicated by the number appended to the end of the filename. For example, the "landward_inundation_12" raster is the inundation layer for the MHHW + 12-inch scenario.

- ***Inundation Rasters:*** Sonoma_inundation_rast_x

  These rasters contain extent and depth of land-only inundation (in feet) of the Sonoma County bayside shoreline under various sea level rise scenarios. The sea level rise scenarios are described in terms of inches above the current conditions mean higher high water (MHHW) tidal datum. These scenarios include: 12", 24", 36", 48", "52", "66", 77", "84","96" and 108" of water level above MHHW.

- ***Inundation Polygons:*** Sonoma_inundation_poly_x

  These polygons were converted from raster (Sonoma_inundation_rast_x). They are classified into seven features for each scenario based on the depth (in feet) of the water surface. The field 'DEPTH_FT' includes the following depths: "0 – 2", "2 – 4", "4 – 6", "6 – 8", "8 – 10", "10 – 12", "12+" feet.

- ***Lowlying Polygons:*** Sonoma_lowlying_poly_x

  These polygons identify low-lying areas greater than one acre. They depict areas that are below the inundated water surface elevation, but are not hydraulically-connected to the inundated areas. The fields included are only used for identifying (and masking) low-lying areas under each sea level rise scenario.

- ***Shoreline Delineation:*** Sonoma_shoreline

  This polyline layer represents the line delineation along the high point of shoreline features. The dissolved shoreline is intended for visualization purposes.

- ***Overtopping Potential Depth and Shoreline by Type Information:*** Sonoma_overtopping_line_x

  - Overtopping Potential Depth: These lines depict the elevation of shoreline features relative to future water levels under each of the 10 sea level rise scenarios. The depth of overtopping is represented in the field 'Overtopping Depth (ft).' Null values indicate no overtopping.
  - Shoreline by Type: These lines also represent the shoreline by type classification completed by the San Francisco Estuary Institute (2016). The shoreline by type layer depicts the various shoreline categories as they relate to coastal flooding for a quick reference of natural and altered shorelines. The shoreline types depict natural shorelines, engineered structures or man-made shoreline alterations, and transportation structures. Features were digitized from a variety of sources including LiDAR, satellite, existing infrastructure layers and aerial imagery. For additional information on SFEI's methodology, see: http://www.sfei.org/content/flood-infrastructure-mapping-and-communication-project. Minor corrections to the original SFEI classifications were completed by AECOM as needed.

  For a full description of all attributes in the overtopping potential depth and shoreline by type, please see Table 1 below.

Table 1. Attribute Field Names and Descriptions for *Overtopping Potential* and *Shoreline by Type* Information in GIS Data Layers

Field in GIS layer	Source	Description	Attributes
Class	SFEI	A description of the feature being mapped.	‘Engineered Levee’, ‘Floodwall’, ‘Berm’, ’Shoreline Protection Structure’, ‘Embankment’, ’Transportation Structure’, ’Natural Shoreline’, ’Wetland’, ’Channel or Opening’, ’Water Control Structure’
Transportation Type	SFEI	Separated ‘Transportation Structure’ classification into two sub-classes, ‘Rail’ and ‘Major Road’ based on aerial imagery.	‘Major Road’ or ‘Rail’
Fortified	SFEI	If features were artificially hardened, indicated by the presence of concrete, riprap, or buttressing, than the ‘Fortified’ category was assigned a value of ‘Yes’. The best available aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Fortified field was assigned to all ten primary classification categories. Hardening of the mapped features could of been completed in an ad hoc manner or specifically designed to address wave erosion.	’Yes’ or ’No’

Field in GIS layer	Source	Description	Attributes
Frontage	SFEI	Along the Bay shore, frontage was assigned to features where there is either a 1) wetland, 2) beach, or 3) wetland and beach in front of a feature. Category is assigned as ‘Wetland’, ‘Beach’, or ‘Wetland and Beach’, accordingly. “None’ designates Bay shore features with no wetland or beach frontage. A variety of aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Beaches were also identified from our partners at BCDC and were not explicitly mapped as features themselves.	‘None’, ‘Wetland’, ‘Beach’, or ‘Beach and Wetland’
Bayshore Defense	SFEI	This field identifies the first line of features along the shoreline which would provide the ‘first line of defense’ to coastal flooding.	‘First line of shoreline defense’ or ‘Not first line of shoreline defense’ or ‘Wetland on Bay shore’
Agency Designation	SFEI	Field is populated for all ‘Engineered Levees’ to show FEMA’s designation (e.g., Ac- credited by FEMA, Formerly accredited by FEMA) as referenced from the FEMA MLI (2014) dataset or simply ‘Engineered’, if a feature was sourced as being engineered for flood management by an agency representative during dataset review meetings.	‘Accredited by FEMA’ or ‘Formerly Ac- credited by FEMA’ or ‘Engineered’ (if designated ‘Engineered Levee’ in Class field, or ‘Engineered’ if designated ‘Floodwall’ in Class field)
Agency Designation Source	SFEI	Source for attributing the ‘Engineered Levee’ classification.	(e.g., FEMA MLI (2014), CCCFCWCD, pro- vided by local stakeholders)

Field in GIS layer	Source	Description	Attributes
FEMA Accreditation Date	SFEI	The year a structure was accredited by FEMA, based on the FEMA MLI (2014) data- set. Only attributed for 'Engineered Levee' features.	(e.g., 1/15/1990)
Primary Map Source	SFEI	Refers to the primary DEM or other aerial imagery that was referenced for mapping.	(e.g., USGS 2010, NOAA/OPC 2010)
Geographic County	SFEI	The represented Bay Area county.	(e.g., Sonoma County)
Public/Private	SFEI	Features were assigned ownership (e.g., private, public) based on county parcel data- sets or individual county, city, and agency knowledge, when data was available. The California Protected Areas Dataset (Green Info Network, 2014) was also referenced. While effort has been made to attribute ownership accurately, limitations exist as some mapped features bordered two different parcels and assigning ownership could not be differentiated within the parcel dataset.	'Private' or 'Public'
Owner Details	SFEI	Specific names of owners, when data was available.	(e.g., NCFCWCD)
Maintained By	SFEI	Designates who is responsible for maintenance of a feature. Information was gathered from city, county, and agency representatives, where information was available. Only limited information on maintenance was readily available.	(e.g., USFWS)

Field in GIS layer	Source	Description	Attributes
Comments	SFEI	Additional comments for mapped features	(e.g., engineered levees that also have floodwalls)
Suppress Overtopping	AECOM	Field to designate whether the segment is shown on printed maps. Typical segments that are not shown include wetland segments that are within ~100 feet of primary shoreline, channel openings, or elevated transportation structures with openings.	Yes' or 'No'
Overtopping Depth (ft)	AECOM	Overtopping potential depth (in feet) per shoreline segment. Null values indicate no overtopping.	‘Double' field type.

GIS DATABASE CATALOG – NAPA COUNTY

Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project

This GIS database catalog describes all of the GIS datasets produced for the sea level rise and overtopping analysis for Napa County, California. Metadata is included in FGDC CSDGM Metadata format within 'Napa_SLR_ART_2017', which is viewable (and exportable) in ArcGIS.

COORDINATE SYSTEM: UTM ZONE 10N

- Horizontal Datum: North American Datum 1983 (NAD83) UTM Zone 10N - Meters
- Vertical Datum: North American Vertical Datum of 1988 (NAVD88) - Feet

The GIS data produced from this study are contained within a single folder titled "Napa_OT_Inundation". This folder contains all of the GIS products produced from the analysis as well as source files. These are described in more detail below:

/Napa_lyr/

This folder contains two ArcGIS layer files (.lyr). These layers files can be added into ArcMap (.mxd) so that the inundation feature classes (found within the geodatabase) can be easily classified.

1. *symbology_inundation_raster.lyr*

   For visualizing the inundation rasters produced for each of the 10 total inundation scenarios.

2. *symbology_inundation_poly.lyr*

   For visualizing the inundation polygons produced for each of the 10 total inundation scenarios.

3. *symbology_lowlying.lyr*

   For visualizing the low-lying polygons produced for each of the 10 total inundation scenarios.

4. *symbology_overtopping.lyr*

   For visualizing the overtopping lines produced for each of the 10 total inundation scenarios.

5. *symbology_shoreline.lyr*

   For visualizing the shoreline placed under the overtopping layers.

/Napa_SLR_ART_2017.gdb/

This geodatabase contains the SLR analysis and overtopping output for each of the ten scenarios. The sea level rise scenario is indicated by the number appended to the end of the filename. For example, the "landward_inundation_12" raster is the inundation layer for the MHHW + 12-inch scenario.

- ***Inundation Rasters:*** Napa_inundation_rast_x

  These rasters contain extent and depth of land-only inundation (in feet) of the Napa County bayside shoreline under various sea level rise scenarios. The sea level rise scenarios are described in terms of inches above the current conditions mean higher high water (MHHW) tidal datum. These scenarios include: 12", 24", 36", 48", "52", "66", 77", "84","96" and 108" of water level above MHHW.

- ***Inundation Polygons:*** Napa_inundation_poly_x

These polygons were converted from raster (Napa_inundation_rast_x). They are classified into seven features for each scenario based on the depth (in feet) of the water surface. The field ‘DEPTH_FT’ includes the following depths: “0 – 2”, “2 – 4”, “4 – 6”, “6 – 8”, “8 – 10”, “10 – 12”, “12+” feet.

- ***Lowlying Polygons:*** Napa_lowlying_poly_x

  These polygons identify low-lying areas greater than one acre. They depict areas that are below the inundated water surface elevation, but are not hydraulically-connected to the inundated areas. The fields included are only used for identifying (and masking) low-lying areas under each sea level rise scenario.

- ***Shoreline Delineation:*** Napa_shoreline

  This polyline layer represents the line delineation along the high point of shoreline features. The dissolved shoreline is intended for visualization purposes.

- ***Overtopping Potential Depth and Shoreline by Type Information:*** Napa_overtopping_line_x
  - Overtopping Potential Depth: These lines depict the elevation of shoreline features relative to future water levels under each of the 10 sea level rise scenarios. The depth of overtopping is represented in the field ‘Overtopping Depth (ft).’ Null values indicate no overtopping.
  - Shoreline by Type: These lines also represent the shoreline by type classification completed by the San Francisco Estuary Institute (2016). The shoreline by type layer depicts the various shoreline categories as they relate to coastal flooding for a quick reference of natural and altered shorelines. The shoreline types depict natural shorelines, engineered structures or man-made shoreline alterations, and transportation structures. Features were digitized from a variety of sources including LiDAR, satellite, existing infrastructure layers and aerial imagery. For additional information on SFEI's methodology, see: http://www.sfei.org/content/flood-infrastructure-mapping-and-communication-project. Minor corrections to the original SFEI classifications were completed by AECOM as needed.

For a full description of all attributes in the overtopping potential depth and shoreline by type, please see Table 1 below.

Table 1. Attribute Field Names and Descriptions for *Overtopping Potential* and *Shoreline by Type* Information in GIS Data Layers

Field in GIS layer	Source	Description	Attributes
Class	SFEI	A description of the feature being mapped.	‘Engineered Levee’, ‘Floodwall’, ‘Berm’, ’Shoreline Protection Structure’, ‘Embankment’, ’Transportation Structure’, ’Natural Shoreline’, ’Wetland’, ’Channel or Opening’, ’Water Control Structure’
Transportation Type	SFEI	Separated ‘Transportation Structure’ classification into two sub-classes, ‘Rail’ and ‘Major Road’ based on aerial imagery.	‘Major Road’ or ‘Rail’
Fortified	SFEI	If features were artificially hardened, indicated by the presence of concrete, riprap, or buttressing, than the ‘Fortified’ category was assigned a value of ‘Yes’. The best available aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Fortified field was assigned to all ten primary classification categories. Hardening of the mapped features could of been completed in an ad hoc manner or specifically designed to address wave erosion.	’Yes’ or ’No’

Field in GIS layer	Source	Description	Attributes
Frontage	SFEI	Along the Bay shore, frontage was assigned to features where there is either a 1) wetland, 2) beach, or 3) wetland and beach in front of a feature. Category is assigned as 'Wetland', 'Beach', or 'Wetland and Beach', accordingly. "None' designates Bay shore features with no wetland or beach frontage. A variety of aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Beaches were also identified from our partners at BCDC and were not explicitly mapped as features themselves.	'None', 'Wetland', 'Beach', or 'Beach and Wetland'
Bayshore Defense	SFEI	This field identifies the first line of features along the shoreline which would provide the 'first line of defense' to coastal flooding.	'First line of shoreline defense' or 'Not first line of shoreline defense' or 'Wetland on Bay shore'
Agency Designation	SFEI	Field is populated for all 'Engineered Levees' to show FEMA's designation (e.g., Ac- credited by FEMA, Formerly accredited by FEMA) as referenced from the FEMA MLI (2014) dataset or simply 'Engineered', if a feature was sourced as being engineered for flood management by an agency representative during dataset review meetings.	'Accredited by FEMA' or 'Formerly Ac- credited by FEMA' or 'Engineered' (if designated 'Engineered Levee' in Class field, or 'Engineered' if designated 'Floodwall' in Class field)
Agency Designation Source	SFEI	Source for attributing the 'Engineered Levee' classification.	(e.g., FEMA MLI (2014), CCCFCWCD, pro- vided by local stakeholders)

Field in GIS layer	Source	Description	Attributes
FEMA Accreditation Date	SFEI	The year a structure was accredited by FEMA, based on the FEMA MLI (2014) data- set. Only attributed for 'Engineered Levee' features.	(e.g., 1/15/1990)
Primary Map Source	SFEI	Refers to the primary DEM or other aerial imagery that was referenced for mapping.	(e.g., USGS 2010, NOAA/OPC 2010)
Geographic County	SFEI	The represented Bay Area county.	(e.g., Napa County)
Public/Private	SFEI	Features were assigned ownership (e.g., private, public) based on county parcel data- sets or individual county, city, and agency knowledge, when data was available. The California Protected Areas Dataset (Green Info Network, 2014) was also referenced. While effort has been made to attribute ownership accurately, limitations exist as some mapped features bordered two different parcels and assigning ownership could not be differentiated within the parcel dataset.	'Private' or 'Public'
Owner Details	SFEI	Specific names of owners, when data was available.	(e.g., NCFCWCD)
Maintained By	SFEI	Designates who is responsible for maintenance of a feature. Information was gathered from city, county, and agency representatives, where information was available. Only limited information on maintenance was readily available.	(e.g., USFWS)

Field in GIS layer	Source	Description	Attributes
Comments	SFEI	Additional comments for mapped features	(e.g., engineered levees that also have floodwalls)
Suppress Overtopping	AECOM	Field to designate whether the segment is shown on printed maps. Typical segments that are not shown include wetland segments that are within ~100 feet of primary shoreline, channel openings, or elevated transportation structures with openings.	Yes' or 'No'
Overtopping Depth (ft)	AECOM	Overtopping potential depth (in feet) per shoreline segment. Null values indicate no overtopping.	‘Double' field type.

GIS DATABASE CATALOG – SOLANO COUNTY

Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project

This GIS database catalog describes all of the GIS datasets produced for the sea level rise and overtopping analysis for Solano County, California. Metadata is included in FGDC CSDGM Metadata format within 'Solano_SLR_ART_2017', which is viewable (and exportable) in ArcGIS.

COORDINATE SYSTEM: UTM ZONE 10N

- Horizontal Datum: North American Datum 1983 (NAD83) UTM Zone 10N - Meters
- Vertical Datum: North American Vertical Datum of 1988 (NAVD88) - Feet

The GIS data produced from this study are contained within a single folder titled "Solano_OT_Inundation". This folder contains all of the GIS products produced from the analysis as well as source files. These are described in more detail below:

/Solano_lyr/

This folder contains two ArcGIS layer files (.lyr). These layers files can be added into ArcMap (.mxd) so that the inundation feature classes (found within the geodatabase) can be easily classified.

1. *symbology_inundation_raster.lyr*

   For visualizing the inundation rasters produced for each of the 10 total inundation scenarios.

2. *symbology_inundation_poly.lyr*

   For visualizing the inundation polygons produced for each of the 10 total inundation scenarios.

3. *symbology_lowlying.lyr*

   For visualizing the low-lying polygons produced for each of the 10 total inundation scenarios.

4. *symbology_overtopping.lyr*

   For visualizing the overtopping lines produced for each of the 10 total inundation scenarios.

5. *symbology_shoreline.lyr*

   For visualizing the shoreline placed under the overtopping layers.

/Solano_SLR_ART_2017.gdb/

This geodatabase contains the SLR analysis and overtopping output for each of the ten scenarios. The sea level rise scenario is indicated by the number appended to the end of the filename. For example, the "landward_inundation_12" raster is the inundation layer for the MHHW + 12-inch scenario.

- ***Inundation Rasters:*** Solano_inundation_rast_x

  These rasters contain extent and depth of land-only inundation (in feet) of the Solano County bayside shoreline under various sea level rise scenarios. The sea level rise scenarios are described in terms of inches above the current conditions mean higher high water (MHHW) tidal datum. These scenarios include: 12", 24", 36", 48", "52", "66", 77", "84","96" and 108" of water level above MHHW.

- ***Inundation Polygons:*** Solano_inundation_poly_x

These polygons were converted from raster (Solano_inundation_rast_x). They are classified into seven features for each scenario based on the depth (in feet) of the water surface. The field ‘DEPTH_FT’ includes the following depths: “0 – 2”, “2 – 4”, “4 – 6”, “6 – 8”, “8 – 10”, “10 – 12”, “12+” feet.

- ***Lowlying Polygons:*** Solano_lowlying_poly_x

  These polygons identify low-lying areas greater than one acre. They depict areas that are below the inundated water surface elevation, but are not hydraulically-connected to the inundated areas. The fields included are only used for identifying (and masking) low-lying areas under each sea level rise scenario.

- ***Shoreline Delineation:*** Solano_shoreline

  This polyline layer represents the line delineation along the high point of shoreline features. The dissolved shoreline is intended for visualization purposes.

- ***Overtopping Potential Depth and Shoreline by Type Information:*** Solano_overtopping_line_x
  - Overtopping Potential Depth: These lines depict the elevation of shoreline features relative to future water levels under each of the 10 sea level rise scenarios. The depth of overtopping is represented in the field ‘Overtopping Depth (ft).’ Null values indicate no overtopping.
  - Shoreline by Type: These lines also represent the shoreline by type classification completed by the San Francisco Estuary Institute (2016). The shoreline by type layer depicts the various shoreline categories as they relate to coastal flooding for a quick reference of natural and altered shorelines. The shoreline types depict natural shorelines, engineered structures or man-made shoreline alterations, and transportation structures. Features were digitized from a variety of sources including LiDAR, satellite, existing infrastructure layers and aerial imagery. For additional information on SFEI's methodology, see: http://www.sfei.org/content/flood-infrastructure-mapping-and-communication-project. Minor corrections to the original SFEI classifications were completed by AECOM as needed.

  For a full description of all attributes in the overtopping potential depth and shoreline by type, please see Table 1 below.

Table 1. Attribute Field Names and Descriptions for *Overtopping Potential* and *Shoreline by Type* Information in GIS Data Layers

Field in GIS layer	Source	Description	Attributes
Class	SFEI	A description of the feature being mapped.	‘Engineered Levee’, ‘Floodwall’, ‘Berm’, ’Shoreline Protection Structure’, ‘Embankment’, ’Transportation Structure’, ’Natural Shoreline’, ’Wetland’, ’Channel or Opening’, ’Water Control Structure’
Transportation Type	SFEI	Separated ‘Transportation Structure’ classification into two sub-classes, ‘Rail’ and ‘Major Road’ based on aerial imagery.	‘Major Road’ or ‘Rail’
Fortified	SFEI	If features were artificially hardened, indicated by the presence of concrete, riprap, or buttressing, than the ‘Fortified’ category was assigned a value of ‘Yes’. The best available aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Fortified field was assigned to all ten primary classification categories. Hardening of the mapped features could of been completed in an ad hoc manner or specifically designed to address wave erosion.	’Yes’ or ’No’

Field in GIS layer	Source	Description	Attributes
Frontage	SFEI	Along the Bay shore, frontage was assigned to features where there is either a 1) wetland, 2) beach, or 3) wetland and beach in front of a feature. Category is assigned as 'Wetland', 'Beach', or 'Wetland and Beach', accordingly. "None' designates Bay shore features with no wetland or beach frontage. A variety of aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Beaches were also identified from our partners at BCDC and were not explicitly mapped as features themselves.	'None', 'Wetland', 'Beach', or 'Beach and Wetland'
Bayshore Defense	SFEI	This field identifies the first line of features along the shoreline which would provide the 'first line of defense' to coastal flooding.	'First line of shoreline defense' or 'Not first line of shoreline defense' or 'Wetland on Bay shore'
Agency Designation	SFEI	Field is populated for all 'Engineered Levees' to show FEMA's designation (e.g., Ac- credited by FEMA, Formerly accredited by FEMA) as referenced from the FEMA MLI (2014) dataset or simply 'Engineered', if a feature was sourced as being engineered for flood management by an agency representative during dataset review meetings.	'Accredited by FEMA' or 'Formerly Ac- credited by FEMA' or 'Engineered' (if designated 'Engineered Levee' in Class field, or 'Engineered' if designated 'Floodwall' in Class field)
Agency Designation Source	SFEI	Source for attributing the 'Engineered Levee' classification.	(e.g., FEMA MLI (2014), CCCFCWCD, pro- vided by local stakeholders)

Field in GIS layer	Source	Description	Attributes
FEMA Accreditation Date	SFEI	The year a structure was accredited by FEMA, based on the FEMA MLI (2014) data- set. Only attributed for 'Engineered Levee' features.	(e.g., 1/15/1990)
Primary Map Source	SFEI	Refers to the primary DEM or other aerial imagery that was referenced for mapping.	(e.g., USGS 2010, NOAA/OPC 2010)
Geographic County	SFEI	The represented Bay Area county.	(e.g., Solano County)
Public/Private	SFEI	Features were assigned ownership (e.g., private, public) based on county parcel data- sets or individual county, city, and agency knowledge, when data was available. The California Protected Areas Dataset (Green Info Network, 2014) was also referenced. While effort has been made to attribute ownership accurately, limitations exist as some mapped features bordered two different parcels and assigning ownership could not be differentiated within the parcel dataset.	'Private' or 'Public'
Owner Details	SFEI	Specific names of owners, when data was available.	(e.g., NCFCWCD)
Maintained By	SFEI	Designates who is responsible for maintenance of a feature. Information was gathered from city, county, and agency representatives, where information was available. Only limited information on maintenance was readily available.	(e.g., USFWS)

Field in GIS layer	Source	Description	Attributes
Comments	SFEI	Additional comments for mapped features	(e.g., engineered levees that also have floodwalls)
Suppress Overtopping	AECOM	Field to designate whether the segment is shown on printed maps. Typical segments that are not shown include wetland segments that are within ~100 feet of primary shoreline, channel openings, or elevated transportation structures with openings.	Yes' or 'No'
Overtopping Depth (ft)	AECOM	Overtopping potential depth (in feet) per shoreline segment. Null values indicate no overtopping.	'Double' field type.

GIS DATABASE CATALOG – CONTRA COSTA COUNTY

Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project

This GIS database catalog describes all of the GIS datasets produced for the sea level rise and overtopping analysis for Contra Costa County, California. Metadata is included in FGDC CSDGM Metadata format within ‘ContraCosta_SLR_ART_2017’, which is viewable (and exportable) in ArcGIS.

COORDINATE SYSTEM: UTM ZONE 10N

- Horizontal Datum: North American Datum 1983 (NAD83) UTM Zone 10N - Meters
- Vertical Datum: North American Vertical Datum of 1988 (NAVD88) - Feet

The GIS data produced from this study are contained within a single folder titled “ContraCostaCo_OT_Inundation”. This folder contains all of the GIS products produced from the analysis as well as source files. These are described in more detail below:

/ContraCosta_lyr/

This folder contains two ArcGIS layer files (.lyr). These layers files can be added into ArcMap (.mxd) so that the inundation feature classes (found within the geodatabase) can be easily classified.

1. *symbology_inundation_raster.lyr*

   For visualizing the inundation rasters produced for each of the 10 total inundation scenarios.

2. *symbology_inundation_poly.lyr*

   For visualizing the inundation polygons produced for each of the 10 total inundation scenarios.

3. *symbology_lowlying.lyr*

   For visualizing the low-lying polygons produced for each of the 10 total inundation scenarios.

4. *symbology_overtopping.lyr*

   For visualizing the overtopping lines produced for each of the 10 total inundation scenarios.

5. *symbology_shoreline.lyr*

   For visualizing the shoreline placed under the overtopping layers.

/ContraCosta_SLR_ART_2017.gdb/

This geodatabase contains the SLR analysis and overtopping output for each of the ten scenarios. The sea level rise scenario is indicated by the number appended to the end of the filename. For example, the “landward_inundation_12” raster is the inundation layer for the MHHW + 12-inch scenario.

- ***Inundation Rasters:*** ContraCosta_inundation_rast_x

  These rasters contain extent and depth of land-only inundation (in feet) of the Contra Costa County bayside shoreline under various sea level rise scenarios. The sea level rise scenarios are described in terms of inches above the current conditions mean higher high water (MHHW) tidal datum. These scenarios include: 12”, 24”, 36”, 48”, “52”, “66”, 77”, “84”,”96” and 108” of water level above MHHW.

- ***Inundation Polygons:*** ContraCosta_inundation_poly_x

  These polygons were converted from raster (ContraCosta_inundation_rast_x). They are classified into seven features for each scenario based on the depth (in feet) of the water surface. The field 'DEPTH_FT' includes the following depths: "0 – 2", "2 – 4", "4 – 6", "6 – 8", "8 – 10", "10 – 12", "12+" feet.

- ***Lowlying Polygons:*** ContraCosta_lowlying_poly_x

  These polygons identify low-lying areas greater than one acre. They depict areas that are below the inundated water surface elevation, but are not hydraulically-connected to the inundated areas. The fields included are only used for identifying (and masking) low-lying areas under each sea level rise scenario.

- ***Shoreline Delineation:*** ContraCosta_shoreline

  This polyline layer represents the line delineation along the high point of shoreline features. The dissolved shoreline is intended for visualization purposes.

- ***Overtopping Potential Depth and Shoreline by Type Information:***
  ContraCosta_overtopping_line_x

  - Overtopping Potential Depth: These lines depict the elevation of shoreline features relative to future water levels under each of the 10 sea level rise scenarios. The depth of overtopping is represented in the field 'Overtopping Depth (ft).' Null values indicate no overtopping.
  - Shoreline by Type: These lines also represent the shoreline by type classification completed by the San Francisco Estuary Institute (2016). The shoreline by type layer depicts the various shoreline categories as they relate to coastal flooding for a quick reference of natural and altered shorelines. The shoreline types depict natural shorelines, engineered structures or man-made shoreline alterations, and transportation structures. Features were digitized from a variety of sources including LiDAR, satellite, existing infrastructure layers and aerial imagery. For additional information on SFEI's methodology, see: http://www.sfei.org/content/flood-infrastructure-mapping-and-communication-project. Minor corrections to the original SFEI classifications were completed by AECOM as needed.

  For a full description of all attributes in the overtopping potential depth and shoreline by type, please see Table 1 below.

Table 1. Attribute Field Names and Descriptions for *Overtopping Potential* and *Shoreline by Type* Information in GIS Data Layers

Field in GIS layer	Source	Description	Attributes
Class	SFEI	A description of the feature being mapped.	‘Engineered Levee’, ‘Floodwall’, ‘Berm’, ’Shoreline Protection Structure’, ‘Embankment’, ’Transportation Structure’, ’Natural Shoreline’, ’Wetland’, ’Channel or Opening’, ’Water Control Structure’
Transportation Type	SFEI	Separated ‘Transportation Structure’ classification into two sub-classes, ‘Rail’ and ‘Major Road’ based on aerial imagery.	‘Major Road’ or ‘Rail’
Fortified	SFEI	If features were artificially hardened, indicated by the presence of concrete, riprap, or buttressing, than the ‘Fortified’ category was assigned a value of ‘Yes’. The best available aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Fortified field was assigned to all ten primary classification categories. Hardening of the mapped features could of been completed in an ad hoc manner or specifically designed to address wave erosion.	’Yes’ or ’No’

Field in GIS layer	Source	Description	Attributes
Frontage	SFEI	Along the Bay shore, frontage was assigned to features where there is either a 1) wetland, 2) beach, or 3) wetland and beach in front of a feature. Category is assigned as 'Wetland', 'Beach', or 'Wetland and Beach', accordingly. "None' designates Bay shore features with no wetland or beach frontage. A variety of aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Beaches were also identified from our partners at BCDC and were not explicitly mapped as features themselves.	'None', 'Wetland', 'Beach', or 'Beach and Wetland'
Bayshore Defense	SFEI	This field identifies the first line of features along the shoreline which would provide the 'first line of defense' to coastal flooding.	'First line of shoreline defense' or 'Not first line of shoreline defense' or 'Wetland on Bay shore'
Agency Designation	SFEI	Field is populated for all 'Engineered Levees' to show FEMA's designation (e.g., Ac- credited by FEMA, Formerly accredited by FEMA) as referenced from the FEMA MLI (2014) dataset or simply 'Engineered', if a feature was sourced as being engineered for flood management by an agency representative during dataset review meetings.	'Accredited by FEMA' or 'Formerly Ac- credited by FEMA' or 'Engineered' (if designated 'Engineered Levee' in Class field, or 'Engineered' if designated 'Floodwall' in Class field)
Agency Designation Source	SFEI	Source for attributing the 'Engineered Levee' classification.	(e.g., FEMA MLI (2014), CCCFCWCD, pro- vided by local stakeholders)

Field in GIS layer	Source	Description	Attributes
FEMA Accreditation Date	SFEI	The year a structure was accredited by FEMA, based on the FEMA MLI (2014) data- set. Only attributed for 'Engineered Levee' features.	(e.g., 1/15/1990)
Primary Map Source	SFEI	Refers to the primary DEM or other aerial imagery that was referenced for mapping.	(e.g., USGS 2010, NOAA/OPC 2010)
Geographic County	SFEI	The represented Bay Area county.	(e.g., Contra Costa County)
Public/Private	SFEI	Features were assigned ownership (e.g., private, public) based on county parcel data- sets or individual county, city, and agency knowledge, when data was available. The California Protected Areas Dataset (Green Info Network, 2014) was also referenced. While effort has been made to attribute ownership accurately, limitations exist as some mapped features bordered two different parcels and assigning ownership could not be differentiated within the parcel dataset.	'Private' or 'Public'
Owner Details	SFEI	Specific names of owners, when data was available.	(e.g., NCFCWCD)
Maintained By	SFEI	Designates who is responsible for maintenance of a feature. Information was gathered from city, county, and agency representatives, where information was available. Only limited information on maintenance was readily available.	(e.g., USFWS)

Field in GIS layer	Source	Description	Attributes
Comments	SFEI	Additional comments for mapped features	(e.g., engineered levees that also have floodwalls)
Suppress Overtopping	AECOM	Field to designate whether the segment is shown on printed maps. Typical segments that are not shown include wetland segments that are within ~100 feet of primary shoreline, channel openings, or elevated transportation structures with openings.	Yes' or 'No'
Overtopping Depth (ft)	AECOM	Overtopping potential depth (in feet) per shoreline segment. Null values indicate no overtopping.	'Double' field type.

GIS DATABASE CATALOG – ALAMEDA COUNTY

Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project

This GIS database catalog describes all of the GIS datasets produced for the sea level rise and overtopping analysis for Alameda County, California. Metadata is included in FGDC CSDGM Metadata format within 'Alameda_SLR_ART_2017', which is viewable (and exportable) in ArcGIS.

COORDINATE SYSTEM: UTM ZONE 10N

- Horizontal Datum: North American Datum 1983 (NAD83) UTM Zone 10N - Meters
- Vertical Datum: North American Vertical Datum of 1988 (NAVD88) - Feet

The GIS data produced from this study are contained within a single folder titled "Alameda_OT_Inundation". This folder contains all of the GIS products produced from the analysis as well as source files. These are described in more detail below:

/Alameda_lyr/

This folder contains two ArcGIS layer files (.lyr). These layers files can be added into ArcMap (.mxd) so that the inundation feature classes (found within the geodatabase) can be easily classified.

1. *symbology_inundation_raster.lyr*

   For visualizing the inundation rasters produced for each of the 10 total inundation scenarios.

2. *symbology_inundation_poly.lyr*

   For visualizing the inundation polygons produced for each of the 10 total inundation scenarios.

3. *symbology_lowlying.lyr*

   For visualizing the low-lying polygons produced for each of the 10 total inundation scenarios.

4. *symbology_overtopping.lyr*

   For visualizing the overtopping lines produced for each of the 10 total inundation scenarios.

5. *symbology_shoreline.lyr*

   For visualizing the shoreline placed under the overtopping layers.

/Alameda_SLR_ART_2017.gdb/

This geodatabase contains the SLR analysis and overtopping output for each of the ten scenarios. The sea level rise scenario is indicated by the number appended to the end of the filename. For example, the "landward_inundation_12" raster is the inundation layer for the MHHW + 12-inch scenario.

- ***Inundation Rasters:*** Alameda_inundation_rast_x

  These rasters contain extent and depth of land-only inundation (in feet) of the Alameda County bayside shoreline under various sea level rise scenarios. The sea level rise scenarios are described in terms of inches above the current conditions mean higher high water (MHHW) tidal datum. These scenarios include: 12", 24", 36", 48", "52", "66", 77", "84","96" and 108" of water level above MHHW.

- ***Inundation Polygons:*** Alameda_inundation_poly_x

These polygons were converted from raster (Alameda_inundation_rast_x). They are classified into seven features for each scenario based on the depth (in feet) of the water surface. The field 'DEPTH_FT' includes the following depths: "0 – 2", "2 – 4", "4 – 6", "6 – 8", "8 – 10", "10 – 12", "12+" feet.

- ***Lowlying Polygons:*** Alameda_lowlying_poly_x

  These polygons identify low-lying areas greater than one acre. They depict areas that are below the inundated water surface elevation, but are not hydraulically-connected to the inundated areas. The fields included are only used for identifying (and masking) low-lying areas under each sea level rise scenario.

- ***Shoreline Delineation:*** Alameda_shoreline

  This polyline layer represents the line delineation along the high point of shoreline features. The dissolved shoreline is intended for visualization purposes.

- ***Overtopping Potential Depth and Shoreline by Type Information:*** Alameda_overtopping_line_x
  - Overtopping Potential Depth: These lines depict the elevation of shoreline features relative to future water levels under each of the 10 sea level rise scenarios. The depth of overtopping is represented in the field 'Overtopping Depth (ft).' Null values indicate no overtopping.
  - Shoreline by Type: These lines also represent the shoreline by type classification completed by the San Francisco Estuary Institute (2016). The shoreline by type layer depicts the various shoreline categories as they relate to coastal flooding for a quick reference of natural and altered shorelines. The shoreline types depict natural shorelines, engineered structures or man-made shoreline alterations, and transportation structures. Features were digitized from a variety of sources including LiDAR, satellite, existing infrastructure layers and aerial imagery. For additional information on SFEI's methodology, see: http://www.sfei.org/content/flood-infrastructure-mapping-and-communication-project. Minor corrections to the original SFEI classifications were completed by AECOM as needed.

  For a full description of all attributes in the overtopping potential depth and shoreline by type, please see Table 1 below.

Table 1. Attribute Field Names and Descriptions for *Overtopping Potential* and *Shoreline by Type* Information in GIS Data Layers

Field in GIS layer	Source	Description	Attributes
Class	SFEI	A description of the feature being mapped.	‘Engineered Levee’, ‘Floodwall’, ‘Berm’, ’Shoreline Protection Structure’, ‘Embankment’, ’Transportation Structure’, ’Natural Shoreline’, ’Wetland’, ’Channel or Opening’, ’Water Control Structure’
Transportation Type	SFEI	Separated ‘Transportation Structure’ classification into two sub-classes, ‘Rail’ and ‘Major Road’ based on aerial imagery.	‘Major Road’ or ‘Rail’
Fortified	SFEI	If features were artificially hardened, indicated by the presence of concrete, riprap, or buttressing, than the ‘Fortified’ category was assigned a value of ‘Yes’. The best available aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Fortified field was assigned to all ten primary classification categories. Hardening of the mapped features could of been completed in an ad hoc manner or specifically designed to address wave erosion.	’Yes’ or ’No’

Field in GIS layer	Source	Description	Attributes
Frontage	SFEI	Along the Bay shore, frontage was assigned to features where there is either a 1) wetland, 2) beach, or 3) wetland and beach in front of a feature. Category is assigned as ‘Wetland’, ‘Beach’, or ‘Wetland and Beach’, accordingly. “None’ designates Bay shore features with no wetland or beach frontage. A variety of aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Beaches were also identified from our partners at BCDC and were not explicitly mapped as features themselves.	‘None’, ‘Wetland’, ‘Beach’, or ‘Beach and Wetland’
Bayshore Defense	SFEI	This field identifies the first line of features along the shoreline which would provide the ‘first line of defense’ to coastal flooding.	‘First line of shoreline defense’ or ‘Not first line of shoreline defense’ or ‘Wetland on Bay shore’
Agency Designation	SFEI	Field is populated for all ‘Engineered Levees’ to show FEMA’s designation (e.g., Ac- credited by FEMA, Formerly accredited by FEMA) as referenced from the FEMA MLI (2014) dataset or simply ‘Engineered’, if a feature was sourced as being engineered for flood management by an agency representative during dataset review meetings.	‘Accredited by FEMA’ or ‘Formerly Ac- credited by FEMA’ or ‘Engineered’ (if designated ‘Engineered Levee’ in Class field, or ‘Engineered’ if designated ‘Floodwall’ in Class field)
Agency Designation Source	SFEI	Source for attributing the ‘Engineered Levee’ classification.	(e.g., FEMA MLI (2014), CCCFCWCD, pro- vided by local stakeholders)

Field in GIS layer	Source	Description	Attributes
FEMA Accreditation Date	SFEI	The year a structure was accredited by FEMA, based on the FEMA MLI (2014) data- set. Only attributed for 'Engineered Levee' features.	(e.g., 1/15/1990)
Primary Map Source	SFEI	Refers to the primary DEM or other aerial imagery that was referenced for mapping.	(e.g., USGS 2010, NOAA/OPC 2010)
Geographic County	SFEI	The represented Bay Area county.	(e.g., Alameda County)
Public/Private	SFEI	Features were assigned ownership (e.g., private, public) based on county parcel data- sets or individual county, city, and agency knowledge, when data was available. The California Protected Areas Dataset (Green Info Network, 2014) was also referenced. While effort has been made to attribute ownership accurately, limitations exist as some mapped features bordered two different parcels and assigning ownership could not be differentiated within the parcel dataset.	'Private' or 'Public'
Owner Details	SFEI	Specific names of owners, when data was available.	(e.g., NCFCWCD)
Maintained By	SFEI	Designates who is responsible for maintenance of a feature. Information was gathered from city, county, and agency representatives, where information was available. Only limited information on maintenance was readily available.	(e.g., USFWS)

Field in GIS layer	Source	Description	Attributes
Comments	SFEI	Additional comments for mapped features	(e.g., engineered levees that also have floodwalls)
Suppress Overtopping	AECOM	Field to designate whether the segment is shown on printed maps. Typical segments that are not shown include wetland segments that are within ~100 feet of primary shoreline, channel openings, or elevated transportation structures with openings.	Yes' or 'No'
Overtopping Depth (ft)	AECOM	Overtopping potential depth (in feet) per shoreline segment. Null values indicate no overtopping.	‘Double' field type.

GIS DATABASE CATALOG – SANTA CLARA COUNTY

Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project

This GIS database catalog describes all of the GIS datasets produced for the sea level rise and overtopping analysis for Santa Clara County, California. Metadata is included in FGDC CSDGM Metadata format within 'SantaClara_SLR_ART_2017', which is viewable (and exportable) in ArcGIS.

COORDINATE SYSTEM: UTM ZONE 10N

- Horizontal Datum: North American Datum 1983 (NAD83) UTM Zone 10N - Meters
- Vertical Datum: North American Vertical Datum of 1988 (NAVD88) - Feet

The GIS data produced from this study are contained within a single folder titled "SantaClaraCo_OT_Inundation". This folder contains all of the GIS products produced from the analysis as well as source files. These are described in more detail below:

/SantaClara_lyr/

This folder contains two ArcGIS layer files (.lyr). These layers files can be added into ArcMap (.mxd) so that the inundation feature classes (found within the geodatabase) can be easily classified.

1. *symbology_inundation_raster.lyr*

   For visualizing the inundation rasters produced for each of the 10 total inundation scenarios.

2. *symbology_inundation_poly.lyr*

   For visualizing the inundation polygons produced for each of the 10 total inundation scenarios.

3. *symbology_lowlying.lyr*

   For visualizing the low-lying polygons produced for each of the 10 total inundation scenarios.

4. *symbology_overtopping.lyr*

   For visualizing the overtopping lines produced for each of the 10 total inundation scenarios.

5. *symbology_shoreline.lyr*

   For visualizing the shoreline placed under the overtopping layers.

/SantaClara_SLR_ART_2017.gdb/

This geodatabase contains the SLR analysis and overtopping output for each of the ten scenarios. The sea level rise scenario is indicated by the number appended to the end of the filename. For example, the "landward_inundation_12" raster is the inundation layer for the MHHW + 12-inch scenario.

- ***Inundation Rasters:*** SantaClara_inundation_rast_x

  These rasters contain extent and depth of land-only inundation (in feet) of the Santa Clara County bayside shoreline under various sea level rise scenarios. The sea level rise scenarios are described in terms of inches above the current conditions mean higher high water (MHHW) tidal datum. These scenarios include: 12”, 24”, 36”, 48”, “52”, “66”, 77”, “84”,”96” and 108” of water level above MHHW.

- ***Inundation Polygons:*** SantaClara_inundation_poly_x

  These polygons were converted from raster (SantaClara_inundation_rast_x). They are classified into seven features for each scenario based on the depth (in feet) of the water surface. The field ‘DEPTH_FT’ includes the following depths: “0 – 2”, “2 – 4”, “4 – 6”, “6 – 8”, “8 – 10”, “10 – 12”, “12+” feet.

- ***Lowlying Polygons:*** SantaClara_lowlying_poly_x

  These polygons identify low-lying areas greater than one acre. They depict areas that are below the inundated water surface elevation, but are not hydraulically-connected to the inundated areas. The fields included are only used for identifying (and masking) low-lying areas under each sea level rise scenario.

- ***Shoreline Delineation:*** SantaClara_shoreline

  This polyline layer represents the line delineation along the high point of shoreline features. The dissolved shoreline is intended for visualization purposes.

- ***Overtopping Potential Depth and Shoreline by Type Information:*** SantaClara_overtopping_line_x
  - Overtopping Potential Depth: These lines depict the elevation of shoreline features relative to future water levels under each of the 10 sea level rise scenarios. The depth of overtopping is represented in the field ‘Overtopping Depth (ft).’ Null values indicate no overtopping.
  - Shoreline by Type: These lines also represent the shoreline by type classification completed by the San Francisco Estuary Institute (2016). The shoreline by type layer depicts the various shoreline categories as they relate to coastal flooding for a quick reference of natural and altered shorelines. The shoreline types depict natural shorelines, engineered structures or man-made shoreline alterations, and transportation structures. Features were digitized from a variety of sources including LiDAR, satellite, existing infrastructure layers and aerial imagery. For additional information on SFEI's methodology, see: http://www.sfei.org/content/flood-infrastructure-mapping-and-communication-project. Minor corrections to the original SFEI classifications were completed by AECOM as needed.

  For a full description of all attributes in the overtopping potential depth and shoreline by type, please see Table 1 below.

Table 1. Attribute Field Names and Descriptions for *Overtopping Potential* and *Shoreline by Type* Information in GIS Data Layers

Field in GIS layer	Source	Description	Attributes
Class	SFEI	A description of the feature being mapped.	‘Engineered Levee’, ‘Floodwall’, ‘Berm’, ’Shoreline Protection Structure’, ‘Embankment’, ’Transportation Structure’, ’Natural Shoreline’, ’Wetland’, ’Channel or Opening’, ’Water Control Structure’
Transportation Type	SFEI	Separated ‘Transportation Structure’ classification into two sub-classes, ‘Rail’ and ‘Major Road’ based on aerial imagery.	‘Major Road’ or ‘Rail’
Fortified	SFEI	If features were artificially hardened, indicated by the presence of concrete, riprap, or buttressing, than the ‘Fortified’ category was assigned a value of ‘Yes’. The best available aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Fortified field was assigned to all ten primary classification categories. Hardening of the mapped features could of been completed in an ad hoc manner or specifically designed to address wave erosion.	’Yes’ or ’No’

Field in GIS layer	Source	Description	Attributes
Frontage	SFEI	Along the Bay shore, frontage was assigned to features where there is either a 1) wetland, 2) beach, or 3) wetland and beach in front of a feature. Category is assigned as 'Wetland', 'Beach', or 'Wetland and Beach', accordingly. "None' designates Bay shore features with no wetland or beach frontage. A variety of aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Beaches were also identified from our partners at BCDC and were not explicitly mapped as features themselves.	'None', 'Wetland', 'Beach', or 'Beach and Wetland'
Bayshore Defense	SFEI	This field identifies the first line of features along the shoreline which would provide the 'first line of defense' to coastal flooding.	'First line of shoreline defense' or 'Not first line of shoreline defense' or 'Wetland on Bay shore'
Agency Designation	SFEI	Field is populated for all 'Engineered Levees' to show FEMA's designation (e.g., Ac- credited by FEMA, Formerly accredited by FEMA) as referenced from the FEMA MLI (2014) dataset or simply 'Engineered', if a feature was sourced as being engineered for flood management by an agency representative during dataset review meetings.	'Accredited by FEMA' or 'Formerly Ac- credited by FEMA' or 'Engineered' (if designated 'Engineered Levee' in Class field, or 'Engineered' if designated 'Floodwall' in Class field)
Agency Designation Source	SFEI	Source for attributing the 'Engineered Levee' classification.	(e.g., FEMA MLI (2014), CCCFCWCD, pro- vided by local stakeholders)

Field in GIS layer	Source	Description	Attributes
FEMA Accreditation Date	SFEI	The year a structure was accredited by FEMA, based on the FEMA MLI (2014) data- set. Only attributed for ‘Engineered Levee’ features.	(e.g., 1/15/1990)
Primary Map Source	SFEI	Refers to the primary DEM or other aerial imagery that was referenced for mapping.	(e.g., USGS 2010, NOAA/OPC 2010)
Geographic County	SFEI	The represented Bay Area county.	(e.g., Santa Clara County)
Public/Private	SFEI	Features were assigned ownership (e.g., private, public) based on county parcel data- sets or individual county, city, and agency knowledge, when data was available. The California Protected Areas Dataset (Green Info Network, 2014) was also referenced. While effort has been made to attribute ownership accurately, limitations exist as some mapped features bordered two different parcels and assigning ownership could not be differentiated within the parcel dataset.	‘Private’ or ‘Public’
Owner Details	SFEI	Specific names of owners, when data was available.	(e.g., NCFCWCD)
Maintained By	SFEI	Designates who is responsible for maintenance of a feature. Information was gathered from city, county, and agency representatives, where information was available. Only limited information on maintenance was readily available.	(e.g., USFWS)

Field in GIS layer	Source	Description	Attributes
Comments	SFEI	Additional comments for mapped features	(e.g., engineered levees that also have floodwalls)
Suppress Overtopping	AECOM	Field to designate whether the segment is shown on printed maps. Typical segments that are not shown include wetland segments that are within ~100 feet of primary shoreline, channel openings, or elevated transportation structures with openings.	Yes' or 'No'
Overtopping Depth (ft)	AECOM	Overtopping potential depth (in feet) per shoreline segment. Null values indicate no overtopping.	‘Double' field type.

GIS DATABASE CATALOG – SAN MATEO COUNTY

Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project

This GIS database catalog describes all of the GIS datasets produced for the sea level rise and overtopping analysis for San Mateo County, California. Metadata is included in FGDC CSDGM Metadata format within 'SanMateo_SLR_ART_2017', which is viewable (and exportable) in ArcGIS.

COORDINATE SYSTEM: UTM ZONE 10N

- Horizontal Datum: North American Datum 1983 (NAD83) UTM Zone 10N - Meters
- Vertical Datum: North American Vertical Datum of 1988 (NAVD88) - Feet

The GIS data produced from this study are contained within a single folder titled "SanMateoCo_OT_Inundation". This folder contains all of the GIS products produced from the analysis as well as source files. These are described in more detail below:

/SanMateo_lyr/

This folder contains two ArcGIS layer files (.lyr). These layers files can be added into ArcMap (.mxd) so that the inundation feature classes (found within the geodatabase) can be easily classified.

1. *symbology_inundation_raster.lyr*

   For visualizing the inundation rasters produced for each of the 10 total inundation scenarios.

2. *symbology_inundation_poly.lyr*

   For visualizing the inundation polygons produced for each of the 10 total inundation scenarios.

3. *symbology_lowlying.lyr*

   For visualizing the low-lying polygons produced for each of the 10 total inundation scenarios.

4. *symbology_overtopping.lyr*

   For visualizing the overtopping lines produced for each of the 10 total inundation scenarios.

5. *symbology_shoreline.lyr*

   For visualizing the shoreline placed under the overtopping layers.

/SanMateo_SLR_ART_2017.gdb/

This geodatabase contains the SLR analysis and overtopping output for each of the ten scenarios. The sea level rise scenario is indicated by the number appended to the end of the filename. For example, the "landward_inundation_12" raster is the inundation layer for the MHHW + 12-inch scenario.

- ***Inundation Rasters:*** SanMateo_inundation_rast_x

  These rasters contain extent and depth of land-only inundation (in feet) of the San Mateo County bayside shoreline under various sea level rise scenarios. The sea level rise scenarios are described in terms of inches above the current conditions mean higher high water (MHHW) tidal datum. These scenarios include: 12", 24", 36", 48", "52", "66", 77", "84","96" and 108" of water level above MHHW.

- ***Inundation Polygons:*** SanMateo_inundation_poly_x

  These polygons were converted from raster (SanMateo_inundation_rast_x). They are classified into seven features for each scenario based on the depth (in feet) of the water surface. The field 'DEPTH_FT' includes the following depths: "0 – 2", "2 – 4", "4 – 6", "6 – 8", "8 – 10", "10 – 12", "12+" feet.

- ***Lowlying Polygons:*** SanMateo_lowlying_poly_x

  These polygons identify low-lying areas greater than one acre. They depict areas that are below the inundated water surface elevation, but are not hydraulically-connected to the inundated areas. The fields included are only used for identifying (and masking) low-lying areas under each sea level rise scenario.

- ***Shoreline Delineation:*** SanMateo_shoreline

  This polyline layer represents the line delineation along the high point of shoreline features. The dissolved shoreline is intended for visualization purposes.

- ***Overtopping Potential Depth and Shoreline by Type Information:*** SanMateo_overtopping_line_x
  - Overtopping Potential Depth: These lines depict the elevation of shoreline features relative to future water levels under each of the 10 sea level rise scenarios. The depth of overtopping is represented in the field 'Overtopping Depth (ft).' Null values indicate no overtopping.
  - Shoreline by Type: These lines also represent the shoreline by type classification completed by the San Francisco Estuary Institute (2016). The shoreline by type layer depicts the various shoreline categories as they relate to coastal flooding for a quick reference of natural and altered shorelines. The shoreline types depict natural shorelines, engineered structures or man-made shoreline alterations, and transportation structures. Features were digitized from a variety of sources including LiDAR, satellite, existing infrastructure layers and aerial imagery. For additional information on SFEI's methodology, see: http://www.sfei.org/content/flood-infrastructure-mapping-and-communication-project. Minor corrections to the original SFEI classifications were completed by AECOM as needed.

  For a full description of all attributes in the overtopping potential depth and shoreline by type, please see Table 1 below.

Table 1. Attribute Field Names and Descriptions for *Overtopping Potential* and *Shoreline by Type* Information in GIS Data Layers

Field in GIS layer	Source	Description	Attributes
Class	SFEI	A description of the feature being mapped.	‘Engineered Levee’, ‘Floodwall’, ‘Berm’, ’Shoreline Protection Structure’, ‘Embankment’, ’Transportation Structure’, ’Natural Shoreline’, ’Wetland’, ’Channel or Opening’, ’Water Control Structure’
Transportation Type	SFEI	Separated ‘Transportation Structure’ classification into two sub-classes, ‘Rail’ and ‘Major Road’ based on aerial imagery.	‘Major Road’ or ‘Rail’
Fortified	SFEI	If features were artificially hardened, indicated by the presence of concrete, riprap, or buttressing, than the ‘Fortified’ category was assigned a value of ‘Yes’. The best available aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Fortified field was assigned to all ten primary classification categories. Hardening of the mapped features could of been completed in an ad hoc manner or specifically designed to address wave erosion.	’Yes’ or ’No’

Field in GIS layer	Source	Description	Attributes
Frontage	SFEI	Along the Bay shore, frontage was assigned to features where there is either a 1) wetland, 2) beach, or 3) wetland and beach in front of a feature. Category is assigned as ‘Wetland’, ‘Beach’, or ‘Wetland and Beach’, accordingly. “None’ designates Bay shore features with no wetland or beach frontage. A variety of aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Beaches were also identified from our partners at BCDC and were not explicitly mapped as features themselves.	‘None’, ‘Wetland’, ‘Beach’, or ‘Beach and Wetland’
Bayshore Defense	SFEI	This field identifies the first line of features along the shoreline which would provide the ‘first line of defense’ to coastal flooding.	‘First line of shoreline defense’ or ‘Not first line of shoreline defense’ or ‘Wetland on Bay shore’
Agency Designation	SFEI	Field is populated for all ‘Engineered Levees’ to show FEMA’s designation (e.g., Ac- credited by FEMA, Formerly accredited by FEMA) as referenced from the FEMA MLI (2014) dataset or simply ‘Engineered’, if a feature was sourced as being engineered for flood management by an agency representative during dataset review meetings.	‘Accredited by FEMA’ or ‘Formerly Ac- credited by FEMA’ or ‘Engineered’ (if designated ‘Engineered Levee’ in Class field, or ‘Engineered’ if designated ‘Floodwall’ in Class field)
Agency Designation Source	SFEI	Source for attributing the ‘Engineered Levee’ classification.	(e.g., FEMA MLI (2014), CCCFCWCD, pro- vided by local stakeholders)

Field in GIS layer	Source	Description	Attributes
FEMA Accreditation Date	SFEI	The year a structure was accredited by FEMA, based on the FEMA MLI (2014) data- set. Only attributed for ‘Engineered Levee’ features.	(e.g., 1/15/1990)
Primary Map Source	SFEI	Refers to the primary DEM or other aerial imagery that was referenced for mapping.	(e.g., USGS 2010, NOAA/OPC 2010)
Geographic County	SFEI	The represented Bay Area county.	(e.g., San Mateo County)
Public/Private	SFEI	Features were assigned ownership (e.g., private, public) based on county parcel data- sets or individual county, city, and agency knowledge, when data was available. The California Protected Areas Dataset (Green Info Network, 2014) was also referenced. While effort has been made to attribute ownership accurately, limitations exist as some mapped features bordered two different parcels and assigning ownership could not be differentiated within the parcel dataset.	‘Private’ or ‘Public’
Owner Details	SFEI	Specific names of owners, when data was available.	(e.g., NCFCWCD)
Maintained By	SFEI	Designates who is responsible for maintenance of a feature. Information was gathered from city, county, and agency representatives, where information was available. Only limited information on maintenance was readily available.	(e.g., USFWS)

Field in GIS layer	Source	Description	Attributes
Comments	SFEI	Additional comments for mapped features	(e.g., engineered levees that also have floodwalls)
Suppress Overtopping	AECOM	Field to designate whether the segment is shown on printed maps. Typical segments that are not shown include wetland segments that are within ~100 feet of primary shoreline, channel openings, or elevated transportation structures with openings.	Yes' or 'No'
Overtopping Depth (ft)	AECOM	Overtopping potential depth (in feet) per shoreline segment. Null values indicate no overtopping.	‘Double' field type.

GIS DATABASE CATALOG – CITY AND COUNTY OF SAN FRANCISCO

Adapting to Rising Tides Bay Area Sea Level Rise Analysis and Mapping Project

This GIS database catalog describes all of the GIS datasets produced for the sea level rise and overtopping analysis for the City and County of San Francisco, California. Metadata is included in FGDC CSDGM Metadata format within 'SanFrancisco_SLR_ART_2017', which is viewable (and exportable) in ArcGIS.

COORDINATE SYSTEM: UTM ZONE 10N

- Horizontal Datum: North American Datum 1983 (NAD83) UTM Zone 10N - Meters
- Vertical Datum: North American Vertical Datum of 1988 (NAVD88) - Feet

The GIS data produced from this study are contained within a single folder titled "SanFranciscoCo_OT_Inundation". This folder contains all of the GIS products produced from the analysis as well as source files. These are described in more detail below:

/SanFrancisco_lyr/

This folder contains two ArcGIS layer files (.lyr). These layers files can be added into ArcMap (.mxd) so that the inundation feature classes (found within the geodatabase) can be easily classified.

1. *symbology_inundation_raster.lyr*

   For visualizing the inundation rasters produced for each of the 10 total inundation scenarios.

2. *symbology_inundation_poly.lyr*

   For visualizing the inundation polygons produced for each of the 10 total inundation scenarios.

3. *symbology_lowlying.lyr*

   For visualizing the low-lying polygons produced for each of the 10 total inundation scenarios.

4. *symbology_overtopping.lyr*

   For visualizing the overtopping lines produced for each of the 10 total inundation scenarios.

5. *symbology_shoreline.lyr*

   For visualizing the shoreline placed under the overtopping layers.

/SanFrancisco_SLR_ART_2017.gdb/

This geodatabase contains the SLR analysis and overtopping output for each of the ten scenarios. The sea level rise scenario is indicated by the number appended to the end of the filename. For example, the "landward_inundation_12" raster is the inundation layer for the MHHW + 12-inch scenario.

- ***Inundation Rasters:*** SanFrancisco_inundation_rast_x

  These rasters contain extent and depth of land-only inundation (in feet) of the City and County of San Francisco bayside shoreline under various sea level rise scenarios. The sea level rise scenarios are described in terms of inches above the current conditions mean higher high water

(MHHW) tidal datum. These scenarios include: 12”, 24”, 36”, 48”, “52”, “66”, 77”, “84”,”96” and 108” of water level above MHHW.

- ***Inundation Polygons:*** SanFrancisco_inundation_poly_x

  These polygons were converted from raster (SanFrancisco_inundation_rast_x). They are classified into seven features for each scenario based on the depth (in feet) of the water surface. The field ‘DEPTH_FT’ includes the following depths: “0 – 2”, “2 – 4”, “4 – 6”, “6 – 8”, “8 – 10”, “10 – 12”, “12+” feet.

- ***Lowlying Polygons:*** SanFrancisco_lowlying_poly_x

  These polygons identify low-lying areas greater than one acre. They depict areas that are below the inundated water surface elevation, but are not hydraulically-connected to the inundated areas. The fields included are only used for identifying (and masking) low-lying areas under each sea level rise scenario.

- ***Shoreline Delineation:*** SanFrancisco_shoreline

  This polyline layer represents the line delineation along the high point of shoreline features. The dissolved shoreline is intended for visualization purposes.

- ***Overtopping Potential Depth and Shoreline by Type Information:*** SanFrancisco_overtopping_line_x
  - Overtopping Potential Depth: These lines depict the elevation of shoreline features relative to future water levels under each of the 10 sea level rise scenarios. The depth of overtopping is represented in the field ‘Overtopping Depth (ft).’ Null values indicate no overtopping.
  - Shoreline by Type: These lines also represent the shoreline by type classification completed by the San Francisco Estuary Institute (2016). The shoreline by type layer depicts the various shoreline categories as they relate to coastal flooding for a quick reference of natural and altered shorelines. The shoreline types depict natural shorelines, engineered structures or man-made shoreline alterations, and transportation structures. Features were digitized from a variety of sources including LiDAR, satellite, existing infrastructure layers and aerial imagery. For additional information on SFEI's methodology, see: http://www.sfei.org/content/flood-infrastructure-mapping-and-communication-project. Minor corrections to the original SFEI classifications were completed by AECOM as needed.

  For a full description of all attributes in the overtopping potential depth and shoreline by type, please see Table 1 below.

Table 1. Attribute Field Names and Descriptions for *Overtopping Potential* and *Shoreline by Type* Information in GIS Data Layers

Field in GIS layer	Source	Description	Attributes
Class	SFEI	A description of the feature being mapped.	‘Engineered Levee’, ‘Floodwall’, ‘Berm’, ’Shoreline Protection Structure’, ‘Embankment’, ’Transportation Structure’, ’Natural Shoreline’, ’Wetland’, ’Channel or Opening’, ’Water Control Structure’
Transportation Type	SFEI	Separated ‘Transportation Structure’ classification into two sub-classes, ‘Rail’ and ‘Major Road’ based on aerial imagery.	‘Major Road’ or ‘Rail’
Fortified	SFEI	If features were artificially hardened, indicated by the presence of concrete, riprap, or buttressing, than the ‘Fortified’ category was assigned a value of ‘Yes’. The best available aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Fortified field was assigned to all ten primary classification categories. Hardening of the mapped features could of been completed in an ad hoc manner or specifically designed to address wave erosion.	’Yes’ or ’No’

Field in GIS layer	Source	Description	Attributes
Frontage	SFEI	Along the Bay shore, frontage was assigned to features where there is either a 1) wetland, 2) beach, or 3) wetland and beach in front of a feature. Category is assigned as 'Wetland', 'Beach', or 'Wetland and Beach', accordingly. "None' designates Bay shore features with no wetland or beach frontage. A variety of aerial and satellite imagery (e.g., Bing Maps Aerial Imagery) was used to assign this field. Beaches were also identified from our partners at BCDC and were not explicitly mapped as features themselves.	'None', 'Wetland', 'Beach', or 'Beach and Wetland'
Bayshore Defense	SFEI	This field identifies the first line of features along the shoreline which would provide the 'first line of defense' to coastal flooding.	'First line of shoreline defense' or 'Not first line of shoreline defense' or 'Wetland on Bay shore'
Agency Designation	SFEI	Field is populated for all 'Engineered Levees' to show FEMA's designation (e.g., Ac- credited by FEMA, Formerly accredited by FEMA) as referenced from the FEMA MLI (2014) dataset or simply 'Engineered', if a feature was sourced as being engineered for flood management by an agency representative during dataset review meetings.	'Accredited by FEMA' or 'Formerly Ac- credited by FEMA' or 'Engineered' (if designated 'Engineered Levee' in Class field, or 'Engineered' if designated 'Floodwall' in Class field)
Agency Designation Source	SFEI	Source for attributing the 'Engineered Levee' classification.	(e.g., FEMA MLI (2014), CCCFCWCD, pro- vided by local stakeholders)

Field in GIS layer	Source	Description	Attributes
FEMA Accreditation Date	SFEI	The year a structure was accredited by FEMA, based on the FEMA MLI (2014) data- set. Only attributed for ‘Engineered Levee’ features.	(e.g., 1/15/1990)
Primary Map Source	SFEI	Refers to the primary DEM or other aerial imagery that was referenced for mapping.	(e.g., USGS 2010, NOAA/OPC 2010)
Geographic County	SFEI	The represented Bay Area county.	(e.g., The City and County of San Francisco)
Public/Private	SFEI	Features were assigned ownership (e.g., private, public) based on county parcel data- sets or individual county, city, and agency knowledge, when data was available. The California Protected Areas Dataset (Green Info Network, 2014) was also referenced. While effort has been made to attribute ownership accurately, limitations exist as some mapped features bordered two different parcels and assigning ownership could not be differentiated within the parcel dataset.	‘Private’ or ‘Public’
Owner Details	SFEI	Specific names of owners, when data was available.	(e.g., NCFCWCD)
Maintained By	SFEI	Designates who is responsible for maintenance of a feature. Information was gathered from city, county, and agency representatives, where information was available. Only limited information on maintenance was readily available.	(e.g., USFWS)

Field in GIS layer	Source	Description	Attributes
Comments	SFEI	Additional comments for mapped features	(e.g., engineered levees that also have floodwalls)
Suppress Overtopping	AECOM	Field to designate whether the segment is shown on printed maps. Typical segments that are not shown include wetland segments that are within ~100 feet of primary shoreline, channel openings, or elevated transportation structures with openings.	Yes' or 'No'
Overtopping Depth (ft)	AECOM	Overtopping potential depth (in feet) per shoreline segment. Null values indicate no overtopping.	'Double' field type.